

SCIENCE AND MANAGEMENT OF RIVER-FLOODPLAIN CONNECTIVITY FOR  
FISH MOVEMENT AND RECRUITMENT: A CASE STUDY OF A MANAGED  
WETLAND ON THE LOWER MISSOURI RIVER

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A Thesis

presented to

the Faculty of the Graduate School  
at the University of Missouri-Columbia

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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MAY 2016

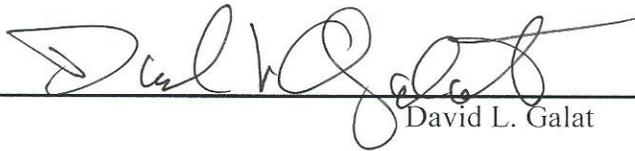
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SCIENCE AND MANAGEMENT OF RIVER-FLOODPLAIN CONNECTIVITY FOR  
FISH MOVEMENT AND RECRUITMENT: A CASE STUDY OF A MANAGED  
WETLAND ON THE LOWER MISSOURI RIVER

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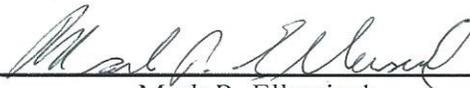
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**SCIENCE AND MANAGEMENT OF RIVER-FLOODPLAIN CONNECTIVITY  
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Dr. David L. Galat, Thesis Supervisor

**ABSTRACT**

Restoration projects along the lower Missouri River (LMOR), Missouri, are undertaken to mitigate past channelization and levee construction that severed river-floodplain connectivity and denied riverine fishes access to adjacent seasonally flooded wetlands. Two actively managed wetland pools were constructed for riverine fish spawning and nursery at Eagle Bluffs Conservation Area (EBCA) as part of the Missouri River Recovery Program. These pools were designed with water-control structures to enable controlled ingress and egress of riverine fishes. Lateral fish movements during temporary connectivity events between LMOR and these wetlands were investigated during two consecutive spring-summers. Objectives were to model river-floodplain connectivity, predict fish use of floodplain wetlands, and evaluate lateral fish movement to assess benefits and management options of lateral connectivity for fish recruitment. Connectivity events over the 1993-2008 modeled period typically were frequent (median: 7 events per year), in late spring (median: 1 June start date), and of short duration (median: 4 days). Thirty-eight species were predicted to access the wetland based on their distribution, habitat-use guilds, spawning temperature ranges, and river water temperature; the majority of those predicted species begin spawning between 10.0 to 21.2 °C, corresponding to 4 April to 1 June. Over 60 species used the wetlands during the two

study years, but only 12 taxa composed >1% of the export fish assemblage either year. Fish biomass exported from EBCA to LMOR was high (2007: 509 kg/h; 2008: 1458 kg/h) and dominant fish lengths <200 mm demonstrated substantial recruitment of young-of-year and juvenile fishes during wetland inundation and isolation. Fish assemblages associated with uncontrolled and controlled flooding of the wetland were moderately similar due to sharing 37 taxa, with 58 taxa present after uncontrolled, levee-topping connectivity in 2007 and 40 taxa present after controlled, backflooding connectivity in 2008. This is one of the few studies to quantify biomass export to a large river from a floodplain wetland and demonstrates the value of managed floodplain wetlands to annual recruitment of riverine fishes. Restoration and management that enables long duration, large magnitude river-floodplain connections in late spring followed by short-to-moderate duration wetland inundation and isolation fosters young-of-year fish recruitment of a rich variety of taxa on LMOR. These conditions, however, benefit both native and invasive fishes, particularly Asian carps. Proactive control strategies are recommended to reduce benefits to invasive Asian carps.

## INTRODUCTION

### Review of Background Literature

#### *Ecological Functions of River-Floodplain Systems and Importance of Floodplain*

##### *Wetlands for Fishes*

River-floodplain ecosystems contribute to biodiversity, perform numerous ecological and social functions, and require management for multiple objectives and benefits (Sparks 1995). Floodplain wetlands, such as those along the lower Missouri River serve a range of essential ecological and social functions, including fish and wildlife habitat, nutrient recycling with the main channel, flood control, and public outdoor activities (Middleton 1999; USACE 2003; Vaught and Bowmaster 1983). Effective management of a river-floodplain system to produce desired ecological benefits requires a conceptual understanding of how hydrologic and geomorphologic processes influence ecosystem processes and responses (Amoros and Bornette 2002; Jacobson and Galat 2008; Opperman et al. 2010). *River-floodplain connectivity* involves water-mediated transfer of energy, matter, and organisms between the main channel of the river and its associated floodplain (Pringle 2003). The biological inventory and ecosystem function of a given river-floodplain ecosystem are influenced by hierarchically arranged environmental filters, natural and anthropogenic drivers, and multiple stressors (e.g., climate, geology, hydrology, sediment regime, and water chemistry; Tockner et al. 2010). Consequently, the underlying flow regime and geomorphology affect the ability of species to use floodplain habitats for various life-history functions (Bunn and Arthington 2002; Opperman et al. 2010).

Floodplain wetlands provide important feeding spawning, nursery, and refuge habitats for riverine fishes (Junk et al. 1989; Poff et al. 1997; Welcomme 1985). Adults and juveniles of numerous species benefit from access to abundant floodplain food resources (Robertson et al. 2008; Welcomme 1985; Zeug et al. 2009). Adult fishes can also capitalize on optimal habitat conditions for reproduction (Welcomme 1985). Flooded wetland vegetation in particular provides plant-spawning fishes access to valuable spawning areas (Jurajda et al. 2004). Floodplain vegetation also benefits larval fish abundance with increased access to food and cover (Crain et al. 2004; Jurajda et al. 2004). Wetland habitats offer larval and juvenile fishes prospective exposure to warmer water temperatures that promote faster growth rates (Welcomme 1985). Growth of fishes on floodplain wetlands depends on several factors, including temperature (Schramm and Eggleton 2006) and food chain variables (Reid et al. 2012; Roach et al. 2009; Sommer et al. 2004). Wetland conditions that facilitate rapid growth rates may mitigate high predation losses of larval and juvenile fishes within the wetland (DeAngelis et al. 1997; Kushlan 1976) and where wetlands drain into the main channel (Ward and Stanford 1995). By providing ideal growing conditions, backwaters of river systems act as nursery environments and sources for age-0 fishes to the river (Csoboth and Garvey 2008).

Increased abundances and densities of flood-spawning fishes during and following lateral connectivity events indicate how spawning and nursery access can elevate fish assemblage productivity in river-floodplain systems (Rolls and Wilson 2010; Zeug and Winemiller 2008). However, the relationship between flow dynamics and movement of riverine fishes is complex, particularly how river-floodplain connectivity affects spawning and/or nursery by riverine fishes and thereby input of young-of-year

(YOY) and juvenile fish to the river (i.e., *fish recruitment*). Interactions between hydrologic processes and biological requirements affect the capacity of the floodplain to promote fish recruitment and thus impact fish assemblage composition, including the proportion of native versus invasive species using the floodplain (Crain et al. 2004). Varying degrees of surface connectivity combine with individual fish species' habitat preferences and tolerances to physiochemical parameters to influence lateral movements from the river into adjacent wetland habitats (Schramm and Eggleton 2006; Welcomme 1985). Life-history strategies of the regional fish assemblage determine how species respond to hydrologic and thermal cues (Csoboth and Garvey 2008; King et al. 2003; Zeug and Winemiller 2007) and influence the ability of species to use inundated areas for feeding, spawning, or nursery activities (King et al. 2003; Zeug and Winemiller 2008).

### ***Grouping Life-History Strategies of Fishes Using Ecological Guilds***

Life-history strategies vary across species, but ecological guilds were developed to group fish species that share similar life-history traits. Grouping species into guilds can facilitate discussion, assessment, and management of fishes based on similar functional or structural groups across geographic regions (Austen et al. 1994). Kinsolving and Bain (1993) grouped riverine fishes into habitat-use guilds according to prevalent use of lotic and lentic habitats during life-cycle stages: *fluvial specialists* use flowing water habitats for all stages; *fluvial dependents* occupy both habitat types but generally require flowing water for reproduction; *macrohabitat generalists* can complete all stages in lentic habitats. Simon (1999) updated reproductive guild classifications originally developed by Balon (1975) and categorized freshwater fish species by location or substrate used for

spawning, level of parental care, and key characteristics of early ontogeny. Such reproductive guilds reflect diverse life-history strategies for spawning within river-floodplain systems.

### ***Conceptual Models of Fish-Hydrology Relationships***

Although some fishes spawn in the main channel or its tributaries (Galat and Zweimüller 2001; Humphries et al. 1999), numerous species use inundated floodplains for spawning and/or nursery, and several conceptual models have been developed to describe the complex relations among flow regime, lateral connectivity, and riverine fish recruitment. The *Flood Pulse Concept* is defined by the pulsing of river discharge that initiates lateral connectivity between the main channel of a river and its associated floodplain, the nutrient recycling that occurs in the floodplain, and the effects of such on biological components of the system (Junk et al. 1989). Timing, duration, frequency, magnitude, and rate-of-change of the flood pulse are critical components of lateral connectivity that influence ecological processes (Galat et al. 2004b; Galat et al. 1998; Poff et al. 1997). As an extension of the Flood Pulse Concept, fish recruitment is assumed to be enhanced by exposure of larval fishes to increased food resources on the inundated floodplain (*Flood Recruitment Model*; Harris and Gehrke 1994) and positively correlated to area of floodplain inundation due to the river's flood pulse (*Flood Pulse Advantage*; Bayley 1991).

Building upon previous conceptual models, King et al. (2003) developed the *Optimal Environmental Conditions Model* (OEC Model) to describe five hydrologic

components of the flood pulse and river-floodplain connectivity that determine effective use of the inundated floodplain for spawning and nursery: (i) degree of coupling of temperature increases and flood pulses; (ii) predictability of the flood pulse; (iii) rate of hydrograph rises and falls; (iv) duration of floodplain inundation; and (v) proportion of the floodplain that is inundated. The OEC Model identified a range of potential flow and lateral connectivity dynamics and postulated a range of optimal conditions for YOY and juvenile fish recruitment on inundated floodplains (King et al. 2003). Since many riverine fishes have evolved to time spawning activities in relation to cues from increasing stage and temperature, more species can use lateral connections to spawning or nursery areas where the flow regime of a system is predictable and coupled with rises in temperature and stage (Bunn and Arthington 2002). River systems with predictable increases in flow and water temperatures contain fishes adapted to reproduce during lateral connectivity events and thereby provide offspring access to highly productive flooded areas (Junk et al. 1989; Poff et al. 1997; Zeug and Winemiller 2007).

### ***Spatiotemporal Context of Flow Regime, Lateral Connectivity and Fish Movement***

Consideration of interconnected patterns of scale, flow regime, river-floodplain connectivity, lateral fish movement, and recruitment of YOY and juvenile fishes is important for research and management (Amoros and Bornette 2002; Fullerton et al. 2010; Opperman et al. 2010). System-level processes and management actions influence site-level habitat characteristics and biotic responses (Amoros and Bornette 2002; Jacobson and Galat 2008; Rolls and Wilson 2010). Site-level knowledge of lateral fish movement onto floodplains and informed estimates of fish recruitment in relation to the

flow regime can improve understanding of ecological relationships and guide management actions at system and site levels (Ickes et al. 2005; King et al. 2010). Importantly, in systems with predictable flood pulses, geographic scale of the functioning floodplain and degree of access to suitable spawning and nursery areas determine magnitude of ecological benefits and whether fish recruitment is influential at the site or system level (Opperman et al. 2010).

Spatiotemporal gradients of lateral connectivity influence species composition and species relative abundance of the fish assemblage accessing the floodplain. Wetland sites with high spatial or temporal connectivity have a greater species richness (Galat et al. 1998; Lubinski et al. 2008; Miranda 2005), greater total fish assemblage abundance (Jurajda et al. 2004), increased abundance of flow-associated species (Galat et al. 2004b; Lasne et al. 2007; Miranda 2005), higher proportions of threatened or endangered species (Lasne et al. 2007), and more native species (Cucherousset et al. 2008; Lasne et al. 2007) than floodplains with lower spatiotemporal connectivity. Since spatiotemporal shifts in lateral connectivity influence population structure, it is important to understand how connectivity dynamics can affect an organism at each stage of its life cycle (Fullerton et al. 2010).

Tockner et al. (2000) highlighted the importance of distinguishing fish responses to *flow pulses* contained within the river mainstem from *flood pulses* that initiate lateral connectivity. Similarly, understanding fish movement and recruitment in response to a variety of representative floods (Opperman et al. 2010) and learning how to better manage flow regime components during connectivity events to encourage recruitment success (King et al. 2010) have been identified as important areas of information need.

Improved understanding of the flood pulse is achieved once it is broken down into types of representative floods. *Floodplain-maintenance floods* are flood pulses containing adequate energy to perform geomorphic work (such as depositing sediment on the floodplain) and having exceedance probabilities of approximately 5 to 75% (Opperman et al. 2010). *Floodplain-activation floods* are more frequent flood events of smaller magnitude that do not perform geomorphic work, but these representative floods can be further defined by their timing, frequency, and duration and linked to desired ecological outcomes such as providing spawning and nursery habitat to native fishes (Opperman et al. 2010). However, fish movement to, and recruitment within, periodically and continuously connected river-floodplain waterbodies has mostly been evaluated during flood versus non-flood years, with flood years characterized mainly by floodplain-activation events. Csoboth and Garvey (2008) showed stronger recruitment success of fluvial dependents in a year with a flood pulse than otherwise, indicated by fluvial dependents accounting for 90% of the larval drift entering a continuously connected floodplain lake during the flood year. Zeug et al. (2009) showed adult and juvenile gizzard shad (*Dorosoma cepedianum*) moved from the river into inundated oxbows for feeding and displayed greater movements into the more frequently connected oxbow.

### ***Anthropogenic Alterations of River-Floodplain Systems***

Anthropogenic modifications can alter the biological inventory and ecological function of a riverine floodplain (Tockner et al. 2010). Alterations of frequency, timing, or duration of flood events can affect species recruitment where movement of fishes between river and floodplain areas is essential to sustain populations (Amoros and Bornette 2002; Galat

and Lipkin 2000). Construction of lateral levees has reduced connectivity of many floodplains with the main channel and made these floodplains inaccessible to riverine fishes, thus diminishing or eliminating the natural benefits normally provided by the flood pulse (Sparks 1995).

### ***Restoration of River-Floodplain Systems and Ecosystem Management of Wetlands***

Restoration of river-floodplain connectivity and preservation of floodplain integrity are essential to stability and function of large river ecosystems (Gore and Shields Jr 1995). However, full restoration of highly regulated rivers to original or historical states is unlikely because multiple, and often competing, ecological and socioeconomic objectives and acceptable restoration designs cannot correct for all effects of anthropogenic modifications and disturbances (Middleton 1999; Sparks and Braden 2010; Sparks 1995). Even so, partial restoration or naturalization of a river-floodplain ecosystem can be achieved by restoring components of the flow regime and re-establishing dynamic connectivity events with its floodplain (Gore and Shields Jr 1995; Sparks and Braden 2010; Sparks et al. 1998). Restoration of flow and connectivity are equally important for promoting native species and biodiversity within a river-floodplain system (Bunn and Arthington 2002). Large-scale restoration and monitoring are needed to understand, restore, and maintain system processes that drive biotic actions, but it is also important to have small-scale mitigation and monitoring efforts to evaluate biotic responses to underlying processes and management actions (Jacobson and Galat 2008; King et al. 2003; King et al. 2009).

Re-establishing functional processes is imperative to creating a self-sustaining system (Palmer et al. 2005; Stanford et al. 1996; Tockner et al. 1998) and this can be achieved by restoring environmental flows (i.e., timing, quantity, and quality of water flows necessary to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them; Declaration 2007). Restoration and management scenarios that determine a target range of flow regime components, versus fixed endpoints, allow flexibility in managing a river segment for multiple ecological and socioeconomic objectives (King et al. 2010; King et al. 2009; Richter et al. 2006). An example scenario could be managing environmental flows that promote flow and connectivity dynamics falling within targeted ranges during at least 50% of years. Management flexibility is important because flow regime within the river mainstem influences lateral connectivity and inundation dynamics at the floodplain wetland. This type of cross-scale interaction is a critical component of ecosystem resilience to be understood and promoted when conducting ecosystem-based fisheries science and management actions (Francis et al. 2007).

Rebuilding structural components of the floodplain by developing managed wetlands provides an important mitigation step in restoring river-floodplain systems. In a *managed wetland*, water and habitat are manipulated (e.g., with respect to water levels, bottom contours, and vegetation composition) to address needs of targeted wildlife (Fredrickson and Taylor 1982). Water-control structures built into existing levees of a managed wetland can provide precise control of lateral exchange to allow management of connectivity and wetland inundation levels to be active, passive, or involve a combination of techniques. Understanding how management of lateral connectivity and inundation

dynamics can promote different objectives for fishes, moist-soil vegetation, waterfowl, shorebirds, and amphibians will help achieve multiple ecological benefits (Fredrickson and Taylor 1982; King et al. 2010; King et al. 2009). Lateral connectivity management for fisheries benefits needs to be evaluated through a comprehensive cost-benefit format because floodplain areas are used by numerous native and invasive fish species (Schultz et al. 2007). Effective management of lateral exchange pathways to maximize ecological benefits will require detailed knowledge of which species access floodplain wetlands and how life-history requirements and temporal dynamics of lateral connectivity mediate fish use of inundated areas (Ickes et al. 2005).

### **Research Goal and Objectives**

My goal is to model river-floodplain connectivity, predict fish use of floodplain wetlands, and evaluate lateral fish movement to assess benefits and management options of lateral connectivity for fish recruitment at a representative large-river-floodplain wetland.

Seven objectives were completed to realize this goal.

Two modeling objectives address underlying environmental and ecological components to understand river-floodplain connectivity and predict fish use of floodplain wetlands for recruitment.

- *Objective 1:* Model frequency, timing, duration, magnitude, rate-of-change, and water temperature of lateral connectivity between a river and an adjacent managed wetland.
  - *Contribution:* Characterizes how river flow regime and water temperature influence lateral connectivity dynamics at the wetland.

- *Objective 2:* Evaluate predicted and observed fish access to floodplain wetlands.
  - *Contribution:* Characterizes how fishes potentially use the lateral pathway during the spring-summer reproductive season and tests accuracy of fish-use predictions relative to observed wetland use by fishes.

The four targeted monitoring objectives involve quantification, evaluation, and comparison of lateral fish movement and associated ecological and environmental variables during multiple connectivity events between a river and managed wetland.

*Targeted monitoring* integrates focused monitoring within larger scientific investigations or active management efforts (Nichols and Williams 2006). It can produce estimates of system status to be compared against model-based predictions to improve understanding of the biological components of a system, thereby forming the basis for subsequent scientific and management actions (Nichols and Williams 2006); this is done here for the second half of Objective 2 by applying results of Objective 3. Monitoring fish use of floodplains should be designed to identify links between specific flood events and responses of fishes and to compare fish responses during years with different hydrologic conditions (King et al. 2010); this is done here with Objectives 4, 5, and 6.

- *Objective 3:* Estimate fish assemblage structure (composition, relative abundance, and relative structure), total abundance, and biomass for fishes that access and exit the wetland.
  - *Contribution:* Quantifies use of a floodplain wetland for recruitment and nursery by riverine fishes.
- *Objective 4:* Compare fish assemblages during uncontrolled and controlled flooding.

- *Contribution:* Describes how representative flood types influence lateral fish movement in periodically connected floodplain wetlands.
- *Objective 5:* Assess similarity of fish assemblages and size structure of selected taxa entering floodplain wetlands.
  - *Contribution:* Evaluates how ingress event timing (early or late spring) and other connectivity dynamics influence fish movement and use of the wetland for spawning and/or nursery by native versus invasive fishes.
- *Objective 6:* Assess similarity of fish assemblages and the size structure and growth rates of selected taxa exiting floodplain wetlands.
  - *Contribution:* Evaluates how early-to-mid-summer or late summer egress event timing influences fish movement and recruitment benefits of native versus invasive fishes.

The management recommendation objective uses results from previous objectives to assist site-level fisheries management of lateral connectivity and inundation dynamics.

- *Objective 7:* Propose integrated fish management options for actively managed wetlands to enhance YOY and juvenile native fish recruitment.
  - *Contribution:* Provides decision-support tools to help managers integrate competing ecological objectives to improve ecosystem management of river-floodplain wetlands.

## STUDY AREA

The Missouri River originates in southwest Montana and extends to its confluence with the Mississippi River near St. Louis, Missouri; this temperate, large river-floodplain system has been anthropogenically altered from its natural state (Galat et al. 2005a; NRC 2011). The lower one-third, or lower Missouri River (LMOR), is highly regulated by upstream impoundment, channelization, bank stabilization, and floodplain levees (Galat et al. 2005a; NRC 2011). These modifications altered sediment and flow dynamics and reduced lateral connectivity and adjacent wetland habitat (Galat et al. 1998; Hesse et al. 1988; Hesse et al. 1989), all vital aspects of the river's ecological integrity (Galat et al. 1998). However, the LMOR in central Missouri retains a seasonally predictable flood pulse (Galat and Lipkin 2000) that can connect the river to its floodplain, and it thereby provided an ideal study location at Eagle Bluffs Conservation Area (EBCA) – a managed floodplain wetland complex developed by the Missouri Department of Conservation (MDC). The river mainstem section associated with the EBCA wetland complex is the Boonville, MO reach of the LMOR (river kilometers [km] 254 to 325, river miles 158 to 202).

The EBCA wetland complex is bordered by Perche Creek to the northeast and by LMOR to the southwest. The portion used as the study site consists of two periodically connected wetland cells – pools 14 and 15 – located in the southeastern-most point of the complex near the Perche Creek-LMOR confluence at LMOR km 275 to 278 (river miles 171 to 173; Figure 1). Each wetland pool contains an identical water-control structure (fishway) constructed as part of the U.S. Army Corps of Engineer's LMOR Mitigation Program to allow fish passage into EBCA when LMOR stage is high enough to connect

with the pools via Perche Creek (USACE 2003). The EBCA wetland complex includes a canal (approximately 0.01 km<sup>2</sup> [2.7 acres]) connecting pools 14 and 15 to Perche Creek by way of a concrete spillway (13.7 m [45 ft] long and 3.1 m [10 ft] wide) that acts as the floodplain-access point (located approximately 725 m [0.5 mile] from the Perche Creek-LMOR confluence), directs water movement, and provides an area of gradual transition from the higher elevation of the canal to the lower elevation of Perche Creek. This system enables fish ingress to the pools from LMOR at high river stages and their subsequent egress to LMOR when either pool is drained through its fishway. Flooding of these wetland pools can be controlled by raising or lowering the fishway's two gates (located on either side of the levee) during periods of connectivity (Figure 2, a, b); the lateral exchange pathway can also be managed more passively by keeping fishway gates open and allowing the river to flood and drain from the wetland without further intervention.

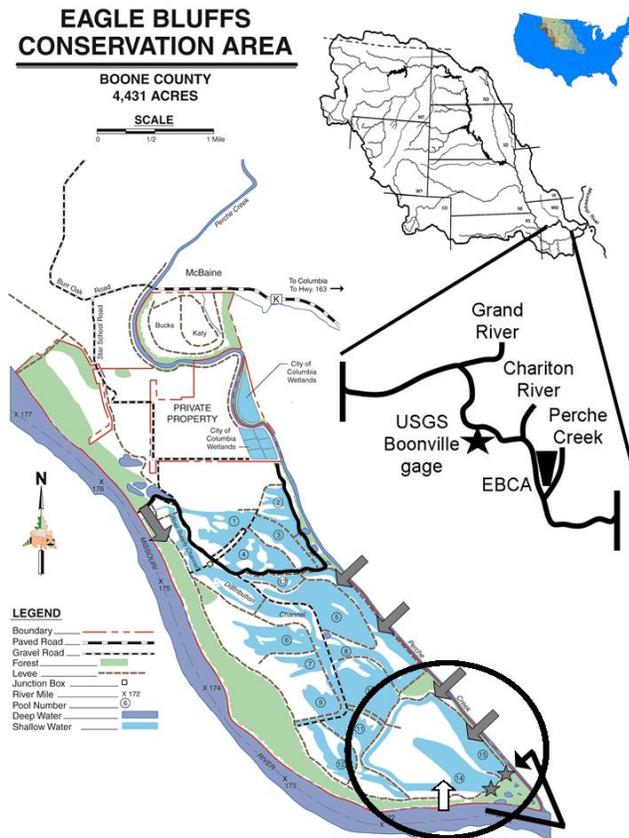


Figure 1. Hierarchical locations of study area. Top right figure shows location of Missouri River watershed within the United States. Next, the Boonville, MO, reach of the lower Missouri River (LMOR) segment is shown as an offset of the Missouri River watershed map. Locations of Eagle Bluffs Conservation Area (EBCA, triangle) and of United States Geological Survey (USGS) Boonville gage station (black star) within the Boonville, MO reach of the LMOR are indicated on the offset map. Next, EBCA is shown in the bottom left figure. Circle indicates the study location -- wetland pools 14 and 15; grey stars indicate the fish passage water-control structure (i.e., fishway) of each pool. Black arrow indicates designed backflooding incursion route from LMOR to pools when LMOR stage rises above fishway base elevation. Inundation of the majority of EBCA occurs when LMOR stage rises above elevation of exterior levees. Grey arrows indicate water ingress points during the levee-topping event; white arrow indicates location of the levee breach, and area south of the black line was the portion of EBCA inundated by the LMOR. Base figure of EBCA: Missouri Department of Conservation.



Figure 2. Fish passage water-control structure (i.e., fishway) at Eagle Bluffs Conservation Area wetland pool 15 and fyke net used to sample lateral fish movement. (a) Riverside view of fishway with riverside gate raised from bottom. (b) Poolside view of fishway with poolside gate completely closed at bottom and almost completely raised at top. Riverside gate is visible through the fishway with its bottom gate raised and its top gate slightly lowered. Grating across top of levee is evidenced by the shadow against the concrete raceway between the fishway's two gates. (c) Fyke net used to sample fishes entering or exiting fishways; see text for net dimensions.

Operation of a pool's fishway – alone or in concert with water-control structures connecting the pool to EBCA interior – allows area managers to manipulate wetland pool inundation dynamics. *Full-pool level* (maximum water level allowed by managers from a moist-soil management standpoint) for pool 14 is reached when the staff gage reading in the fishway's poolside water-control structure is 171.91 m amsl (564.0 ft amsl or 1.1 m [3.5 ft] above the fishway base); this reading corresponds to a surface area of 17.0 hectare (ha; 42 acres) of inundated wetland habitat. Full-pool level for pool 15 is 172.21 m amsl (565.0 ft amsl or 1.4 m [4.5 ft] above the fishway base), corresponding to a wetland inundation surface area of 23.5 ha (58 acres).

## RESEARCH DESIGN

Flow dynamics and lateral connectivity were evaluated for the LMOR to determine their relationships to fish movement and recruitment patterns of adult, juvenile, and YOY fishes. Fish seasonal movements through managed fishways during temporary lateral connectivity events between the LMOR and EBCA wetland pools were investigated during two consecutive spring-summer periods characterized by different flood types. Importantly, infrequent disturbance events offer opportunities to conduct natural or manipulative experiments (King et al. 2010; Sparks et al. 1998). Natural experiments in response to catastrophic events can improve understanding of how fish communities work and can sometimes provoke new hypotheses or explanations about system functions and patterns of species responses and associations (Crowder 1990). The representative flood types during the study years provided such opportunities for informative natural experiments.

In the context of this study, *lateral connectivity* refers to exchanges that occur through the fishways between LMOR and EBCA wetland pools (those modeled in Objective 1 and those targeted for monitoring in Objectives 3 to 6) as well as to a levee-topping event between LMOR and the EBCA wetland complex (evaluated in Objective 4). A *connectivity event* is defined as the surface connection pathway between the LMOR and EBCA wetland pools; *connectivity event variables* refer to the flood pulse and lateral connectivity characteristics of an individual event (e.g., water temperature, duration, stage magnitude). However, the specific definition of a connectivity event, and thus the identification and calculation of its connectivity event variables, varies between modeled and monitored events. Connectivity events modeled in Objective 1 are defined

relative to an unmanaged pulse and connection, which occurs from time water rises above the connection stage until it falls again. In contrast, connectivity events targeted for monitoring of fish movement in Objectives 3 to 6 are defined relative to events actively controlled via fishway gate manipulations. Additionally, elevations of the top of EBCA levees (175.26 m amsl; 575.0 ft amsl) and the base of the fishways (170.84 m amsl; 560.5 ft amsl) serve as reference elevations for characterizing and distinguishing between a *floodplain-maintenance event* (i.e., topflooding over levees) and a *floodplain-activation event* (i.e., backflooding via fishways). A floodplain-maintenance flood at EBCA is defined as a flood that exceeds the elevation of the levees surrounding EBCA. A floodplain-activation flood at EBCA is defined as a flood instigating an ingress connectivity event via the fishway by reaching or exceeding the fishway's base elevation for  $\geq 1$  day. A floodplain-activation flood is typically defined as an event of longer duration (e.g.,  $\geq 1$  week) presumably needed to provide ecological benefits for native fishes (Opperman et al. 2010). However, a shorter time frame was used here to define EBCA floodplain-activation floods to reflect the inherently flashy dynamics of the LMOR which might still offer recruitment benefits to native species. Fishes accessing or exiting the wetlands were sampled during multiple lateral connectivity events. Fish ingress and egress were identified by controlled water intake or release from the wetland to the LMOR via the fishway.

The research design blended a quasi-experimental approach (Cook et al. 1979) with case study tactics (Yin 2009) because of variable hydrologic and lateral connectivity dynamics during the two study years, limited control over study variables, lack of replication opportunity, and the contextual nature of the goal and objectives. System

constraints (e.g., flood pulse dynamics) during individual ingress connectivity events did not allow randomization of independent variables (e.g., timing or stage magnitude of connectivity). However, active manipulation of fishway gates enabled partial experimental control over connectivity events. Quasi-experimental control allowed traditional statistical analyses after accounting for certain data assumptions and restrictions. Due to lack of environmental control and replication, case study tactics such as pattern matching, explanation building, and time-series analysis (Yin 2009) were used to analyze connectivity events.

## **METHODS**

Long-term river stage and water temperature data collected in the river mainstem were used for the two modeling objectives. Datasets for the four targeted monitoring objectives were composed of hydrologic, water temperature, and fish data collected at the two floodplain wetlands (particularly at their fishways). Objectives 1 and 2 are presented separately from the collection and processing of data for Objectives 3 to 6. Next, I describe the main data adjustments necessary to conduct the research; I then explain data analyses associated with Objectives 1 to 7. Details presented in the technical report (Montgomery and Galat 2014) are referenced to reduce space and simplify concepts as necessary.

## **Data Collection and Processing for Modeling Objectives**

### ***River Stage Data for Objective 1***

The U. S. Geological Survey Boonville, MO gage station (USGS 06909000) is the closest gage upriver of EBCA with no major intervening tributaries. It provided the primary dataset to determine mainstem river connection stage with EBCA wetland pools and model LMOR-EBCA connectivity event dynamics (USGS 2008).

Stage data at USGS Boonville gage (collected at 15-minute intervals) and at EBCA wetland pools (recorded at various times throughout the day) from 2002 to 2008 were used to determine minimum mainstem river stage necessary for lateral connection with the wetland pools. This period included LMOR-EBCA connectivity events that occurred since construction of pools in 2001. Stage readings recorded at the USGS Boonville gage were directly matched with readings at EBCA fishways or time interpolated where necessary (Montgomery and Galat 2014, Appendix B).

Daily LMOR stage data (recorded at 08:00) from 1993 to 2008 at the USGS Boonville gage were used to calibrate, estimate, validate, and update the model parameters. River stage (and water temperature) data were used to identify and model hypothetical connectivity events (occurring before construction of EBCA pools) and estimates of actual connectivity events after construction of EBCA pools (when fishway gates were open). The period from 1993 to 2008 was used to model LMOR-EBCA lateral connectivity events because it included record high (e.g., 1993 and 1997) and low (e.g., 2003 and 2006) flows.

### ***Water Temperature Data for Objectives 1 and 2***

Long-term daily water temperature data (recorded at 08:00) from the Boonville Water Treatment Plant (BWTP) intake (Baslee 2008) in the river mainstem were used as the primary dataset for both modeling objectives. Water temperature data collected at the floodplain-access point within Perche Creek and daily *in situ* river mainstem water temperature data from USGS Boonville gage (section: *supplemental water temperature data*) were also used to test certain assumptions of the BWTP dataset. Water temperatures upriver at Boonville, MO were shown to accurately represent water temperatures at the floodplain-access point during prospective LMOR-EBCA connectivity events (Montgomery and Galat 2014). Water temperatures at the BWTP intake were also representative, from an ecological standpoint, of *in situ* mainstem river water temperatures at the USGS Boonville gage for connecting water temperatures to calendar dates (Montgomery and Galat 2014).

### **Data Collection and Processing for Targeted Monitoring Objectives**

#### ***Hydrologic Conditions and Connectivity Event Sampling Designs during Field Seasons***

The flood-pulse type initiating lateral connectivity with the floodplain differed between study years. Two small pulses in 2007 preceded a major spring flood pulse that overtopped and breached the levee surrounding the pools and inundated a large proportion of EBCA (ca. 10 May 2007; Figure 1). Multiple spring flood pulses of smaller magnitude and duration in 2008 connected the pool via the fishway; a larger summer flood pulse followed, but gate manipulations permitted only its leading edge to connect with the wetland (Figure 3).

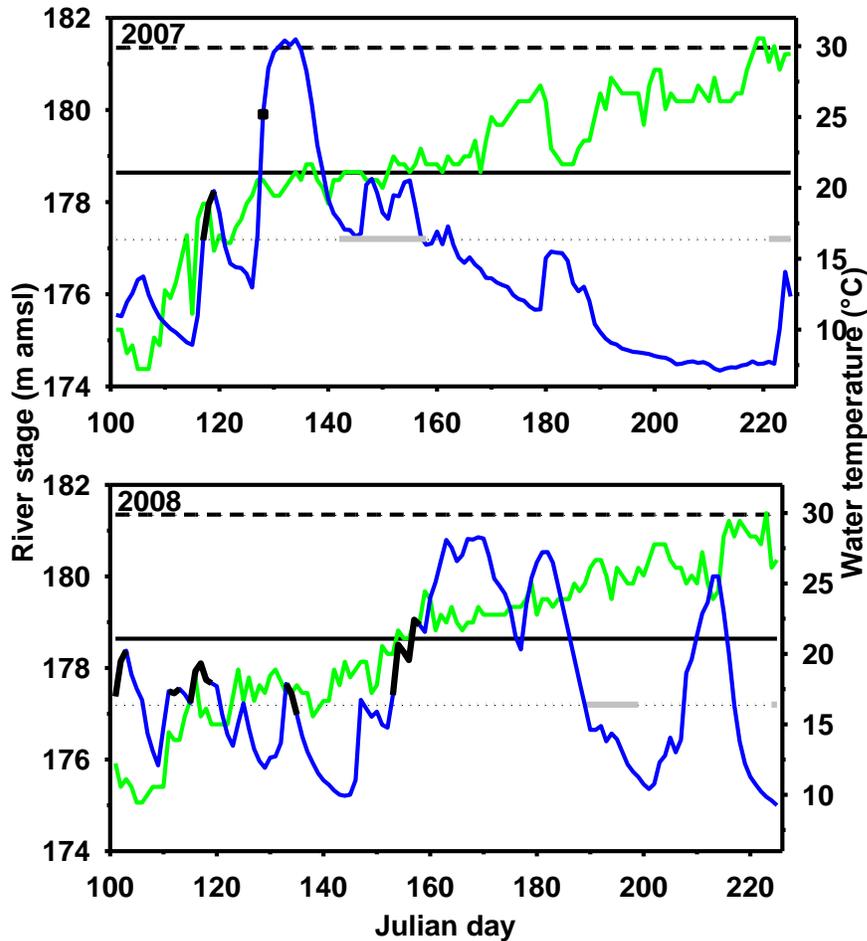


Figure 3. Lower Missouri River (LMOR) daily stage height (blue line) and water temperature (green line) for 2007 and 2008 field seasons, and overlay of the timing and duration of ingress events (bold black lines) and egress events (grey horizontal lines) between LMOR and Eagle Bluffs Conservation Area (EBCA) wetland pools 14 and 15. Stage and water temperature were recorded at U. S. Geological Survey (USGS) Boonville gage station and Boonville Water Treatment Plant, respectively. Horizontal dotted line indicates minimum stage of connection (177.20 m amsl) between LMOR and EBCA. Horizontal solid line indicates full-pool level (178.64 m amsl) of pool 15. Horizontal dashed line indicates maximum stage threshold (181.35 m amsl) at which overtopping of levees and inundation of EBCA occurs.

Fish sampling of fishways with a fyke net (section: *fyke-net design*) was conducted during 2007 and 2008 spring-summer connectivity events. Connection and disconnection of the lateral pathway during each event occurred through manipulation of

fishway gates. Field seasons (28 April to 12 August 2007 [JD 119 to 225] and 10 April to 12 August 2008 [JD 101 to 225]) were designated by first ingress event and final egress event sampled each year. Seven controlled ingress events were sampled during the field seasons (two in 2007; five in 2008). Initiation and termination of fyke-net sampling of ingress events depended on the specific nature of the LMOR flood pulse as well as relative water levels in the river and wetland (Table 1, Figure 3). Four managed egress events (an early-season and late-season event each year) were also sampled; fishway gate manipulations controlled timing and duration of those events in relation to pre-existing pool conditions (e.g., wetland inundation levels) and sampling procedure restrictions (Table 1). Research and management decisions about water releases during early-season egress events of both years reflected the shared circumstances that full-pool level had been exceeded and water needed to be drained off the area – even though the manner by which the wetland had been overfilled differed between levee overtopping and levee seepage. Sampling designs used during targeted monitoring efforts of these early-season egress events also differed (Table 1). Early-season egress events concluded when water in the wetland was reduced to full-pool level; at that point, fishway gates were closed, and remaining water and fishes were retained in pool 15 until late-season egress events. During those late-season egress events, fishway gates remained open to allow fishes to exit to LMOR until pool water level dropped to a height where fishes could no longer exit; gates were then closed and fish sampling was completed. In 2007, the late-season egress event was initiated after 63 days of wetland inundation and isolation following the early-season egress event; in 2008, the two egress events were initiated 31 and 66 days after closure of fishway gates following the final ingress event.

Table 1. Connectivity events sampled during 2007 and 2008 including water movement, pool location, sampling design and dates, gate operation, and fyke-net sampling breakdown. Event identification codes are a string of numbers and a letter indicating event sampling order for that year (1, 2, ..., 7); whether it was an ingress (I) or egress (E) event; which pools' fishway was used (14 or 15); and the study year (07 = 2007 or 08 = 2008). The two egress events of each year are also referred to as early-season and late-season egress events (early = *3E1407*, *6E1508*; late = *4E1507*, *7E1508*). Egress event *3E1407* is italicized to highlight its close association with the levee-topping connectivity event. Data collection details are in footnotes.

Connectivity event	Water movement	Pool	Sampling design	Sampling dates		Pool staff gage reading (m amsl)		Gate operation in relation to event <sup>a</sup>		Gate position and number of net samples		Number of net samples <sup>b</sup>	
				Start	End	Start	End	Opened	Closed	Top	Bottom	Day	Night
1I1407	Ingress	14	Entire event	27-Apr-2007	29-Apr-2007	170.96	171.85	Base <sup>c</sup>	Peak	n/a	3	1	2
2I1407	Ingress	14	Entire event	8-May-2007	8-May-2007	171.88	171.88	Equal	Full	n/a	1	1	n/a
<i>3E1407</i>	Egress	14	Entire event <sup>d</sup>	21-May-2007	6-Jun-2007	173.31	171.91	Access	Drop	16 <sup>e</sup>	14	15	15 <sup>f</sup>
4E1507	Egress	15	Stratified random	8-Aug-2007	12-Aug-2007	172.23	170.93	n/a	End	n/a	27	14	13
1I1508	Ingress	15	Entire event	10-Apr-2008	12-Apr-2008	171.27	172.15	Equal	Peak	n/a	4	2	2
2I1508	Ingress	15	Entire event	21-Apr-2008	22-Apr-2008	170.93	171.04	Equal	Peak	n/a	3	2	1
3I1508	Ingress	15	Entire event	24-Apr-2008	28-Apr-2008	170.84	171.40	Base	2nd peak	n/a	9	5	4
4I1508	Ingress	15	Entire event	13-May-2008	14-May-2008	171.15	170.89	Equal	Disconnect	n/a	3	1	2
5I1508	Ingress	15	Entire event	2-Jun-2008	6-Jun-2008	171.21	172.39	Equal	Full	n/a	11	6	5
6E1508 <sup>g</sup>	Egress	15	Simple random	7-Jul-2008	17-Jul-2008	172.82	172.30	n/a	Drop	8	8	16	n/a

Table 1 (continued)

Connectivity event	Water movement	Pool	Sampling design	Sampling dates		Pool staff gage reading (m amsl)		Gate operation in relation to event <sup>a</sup>		Gate position and number of net samples		Number of net samples <sup>b</sup>	
				Start	End	Start	End	Opened	Closed	Top	Bottom	Day	Night
7E1508 <sup>g</sup>	Egress	15	Stratified random	11-Aug-2008	12-Aug-2008	172.18	170.95	n/a	End	n/a	13	10	3

<sup>a</sup> Base: river water level reached base elevation of fishway; Equal: equalization of pool and river water levels; Access: river water level dropped, allowing access to fishway for net installation; Peak: peak of flood pulse; Full: full pool water level reached, river flood pulse still rising; Drop: once pool water level dropped to level of full pool; End: end of draining water from the pool; Disconnect: disconnection of waterbodies because river water level fell below base elevation of fishway.

<sup>b</sup> Day samples were taken within the time period from approximately 07:00-17:00, and night samples from approximately 17:00-07:00.

<sup>c</sup> Pool 14 was empty at start of event although staff gage did not read 170.84 m amsl due to local precipitation.

<sup>d</sup> Entire event sampled with fyke net except for final day, in which a simple random subsample was performed.

<sup>e</sup> Gate was not open from top position; instead, water was spilling over top of gate until 30 May 2007 when bottom gate was then opened because of reduced water discharge through the fishway.

<sup>f</sup> Night period includes one extended sample that encompassed two nights and one day period.

<sup>g</sup> All events except 6E1508 and 7E1508 had gate opening heights of 30 cm; for these two events, gate opening height was 15 cm due to strain on net from increased fish and debris load.

Fyke-net samples for each event were divided into day and night periods. Net sample duration within these periods depended on the amount of fishes and debris entering or exiting the pool. Conditions allowed virtually continuous sampling of ingress events from time of connection to disconnection by using long-duration (~10 to 14 h) net sets. This type of sampling design was not always possible for egress events because the amount of water, fishes, and debris exiting the wetland sometimes limited sampling to using short-duration (~15 to 60 min) net sets. See Table 1 and Montgomery and Galat (2014) for sampling design details of individual events.

Individual connectivity events are identified by a code consisting of a string of numbers and a letter indicating (i) event sampling order for that year (e.g., 1, 2, ..., 7); (ii) whether it was an ingress (I) or egress (E) event; (iii) which pools' fishway was used (i.e., 14, 15); and (iv) study year (07 = 2007 or 08 = 2008). For example, identification code *3E1407* signifies the third egress event at pool 14 in 2007. Only *3E1407* is italicized to identify its close association with the levee-topping event. The combined 2007 egress event data represent the *floodplain-maintenance event*, whereas the combined 2008 ingress and egress event data represent *floodplain-activation events*. The two egress events of each year are distinguished as *early-season* and *late-season egress events* (early = *3E1407*, *6E1508*; late = *4E1507*, *7E1508*) to emphasize the extended length of time that elapsed between them.

### ***Supplemental Water Temperature Data***

Water temperature readings for the 2007 and 2008 field seasons were taken at three locations in the river-floodplain section: river mainstem, floodplain-access point, and wetland pools. Water temperatures were acquired from the USGS Boonville gage (April-August, at 15 min intervals; USGS 2008) to characterize river mainstem water temperatures. Water temperatures at the floodplain-access point were taken at the Perche Creek connection to the mitigation site. Temperatures recorded in EBCA poolside raceways 14 and 15 characterized water temperatures in the wetland pools. HOBO Pro v2<sup>1</sup> water temperature loggers recorded data for each field season at the floodplain-access point and wetland pools every four hours in 2007 and once per hour in 2008. Pool 14 had a logger only in 2007, the sole year the pool was used. Data from the USGS Boonville gage and the Perche Creek logger were used to supplement BWTP water temperature data (section: *water temperature data for Objectives 1 and 2*). Data from all three locations were used to characterize water temperatures fishes generally encountered when moving laterally between the river and floodplain; the methods and results of this evaluation are in the technical report Montgomery and Galat (2014). Finally, to evaluate fish movement relative to water temperatures of the 11 monitored connectivity events, data from the Perche Creek logger were used for ingress events and data from the pools' loggers were used for egress events. Temperature characterizations for individual connections were derived from those locations because it was assumed fishes originating from those locations were primarily responding to local water temperatures.

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<sup>1</sup> The use of trade, product, industry or firm names or products or software or models, whether commercially available or not, is for informative purposes only and does not constitute an endorsement by the U.S. Government or the US Geological Survey.

### *Connectivity Event Variables of Monitored Connectivity Events*

Connectivity events targeted for monitoring of fish movement are defined differently than modeled connectivity events because fishway gate manipulations occurred during monitored events. Ten variables were used to characterize connectivity events and relate event characteristics to sampled fish movements: mean photoperiod, mean water temperature, duration (summed net samples and total event), mean fishway stage magnitude, water exchange (mean discharge and total volume of water), type of water-level fluctuation, and rate-of-change (rise or fall; Table 2). Calculations of connectivity event variables are performed relative to the time period between the opening and closing of fishway gates or to the individual fyke-net samples collected during an event, and they are presented in Table 2. It is important, however, to note a few points. Two types of duration were calculated for each event to demonstrate the proportion of each event sampled with the fyke net. Two types of water exchange were calculated for each event to better understand water movement and volume of water exchanged between the river and wetland pools. The water-level fluctuation variable characterized LMOR hydrograph shape during an event and type of water-level fluctuations at the fishway. Rate-of-rise and rate-of-fall were calculated for ingress and egress events, respectively.

Table 2. Definitions and calculations of the connectivity event variables used to characterize the hydrothermal dynamics of connectivity events modeled in Objective 1 and targeted for monitoring of fish movement in Objectives 3-6.

Connectivity event variable (unit of measurement)	Definition and calculation
Modeling objective <sup>a</sup>	
Event frequency (n)	Number of times LMOR stage at USGS Boonville gage was $\geq 177.20$ m amsl within each interval (calendar year, spawning window, and monthly).
Timing of event start date (Julian day)	Start date designated as first Julian day (JD) of each event when LMOR stage at USGS Boonville gage was $\geq 177.20$ m amsl.
Duration (day)	Number of consecutive days stage was $\geq 177.20$ m amsl.
Mean river stage magnitude (m amsl)	Averaged stage values at USGS Boonville gage for each day of event.
Mean fishway stage magnitude (m)	Minimum stage of connection subtracted from mean river stage magnitude.
Rate-of-rise (m/day)	Stage recorded on first day of connectivity subtracted from peak in stage during the event and then divided by number of days between the two readings. When there were multiple peaks during an event, the first peak was used; when there were two days in a row with the same stage value, the first day was used for calculations.
Rate-of-fall (m/day)	Calculated comparably to rate-of-rise, but using last day of connectivity.
Mean water temperature (°C)	Averaged temperature values for each day of event.
Targeted monitoring objectives <sup>b</sup>	
Event duration (h)	Total elapsed time from opening to closing of fishway gates.
Sampling duration (h)	Summed duration of individual net samples.
Mean fishway stage magnitude (m)	Averaged water depths recorded throughout the event.
Water-level fluctuation (n/a)	Expressed as (i) rising river stage resulting in net water movement into the wetland; (ii) stable water levels stemming from a peak or trough in the river's hydrograph resulting in zero or near zero velocity readings at the fishway; (iii) falling river stage resulting in net water movement out of the wetland; or, (iv) a managed water release from the wetland not associated with river stage.
Mean discharge (m <sup>3</sup> /s)	Net-sample mean water velocity (m/s; averaged across readings taken with a flow meter) was multiplied against area (m <sup>2</sup> ) of the fishway underwater to produce the mean discharge of each net sample, which were then averaged to produce the final mean discharge of the event.
Total volume (m <sup>3</sup> )	Multiplied event mean discharge (m <sup>3</sup> /s) against event duration (s).
Rate-of-rise (m/day)	Stage recorded at the beginning of connectivity subtracted from stage at end of the ingress event and then divided by event duration (days or fractions thereof).
Rate-of-fall (m/day)	Stage at the end of the egress event subtracted from stage at beginning and then divided by event duration (days or fractions thereof).
Mean water temperature (°C)	Temperature readings recorded during the time frames of individual fyke-net samples were averaged to produce the mean temperature of each net sample, which were then averaged to produce the final mean temperature of the event.
Mean photoperiod (h/day)	Averaged daylight hours of each event.

<sup>a</sup>Modeled connectivity events were defined by the number of days LMOR stage at USGS Boonville gage was consistently above the minimum stage of connection ( $\geq 177.20$  m amsl). Stage data from USGS Boonville gage and water temperature data from Boonville Water Treatment Plant were used to model connectivity dynamics.

<sup>b</sup>Connectivity events targeted for monitoring were defined relative to fishway gate manipulations for each event (see Table 1). Stage and velocity data recorded at wetlands, water temperature data collected at floodplain-access point and wetlands, and photoperiod data obtained from U.S. Naval Observatory website ([http://aa.usno.navy.mil/data/docs/RS\\_OneYear.php](http://aa.usno.navy.mil/data/docs/RS_OneYear.php)) were used to characterize connectivity dynamics of events targeted for monitoring fish movement.

### ***Fyke-Net Design***

Fish assemblages using the fishways during connectivity events were sampled with a fyke net designed by Innovative Net Systems<sup>1</sup> (Figure 2, c). Dimensions of the heavy duty 12 mm (0.5 in) mesh fyke-net opening (1.8 m x 1.8 m [6 ft x 6 ft] square frame) spanned the entire width of the fishway's concrete raceway and the net-opening height equaled the maximum potential depth of water moving through the fishway gates thereby sampling the entire water column during a connectivity event. Fyke-net total length was 16.5 m (54 ft), with its dimensions gradually reduced in size so the cod-end section of the net containing the fish catch was maneuverable by technicians. The cod-end section (5.5 m [18 ft] in length) had three mesh funnels to trap and separate fishes according to size (30 cm [12 in], 15 cm [6 in], and 5 cm [2 in]) and was attached to the net with a zipper to allow removal to empty the catch and clean out debris. Nearly continuous fish sampling (when possible) was accomplished by using two identical cod-end sections, removing the first to empty and process fishes then immediately attaching the second. The net was placed in the poolside raceway during ingress events and in the riverside raceway during egress events to capture fishes as they entered or exited the pool through the fishway.

### ***Fyke-Net Fish Sampling of Monitored Connectivity Events***

All sampled large-bodied fishes and a moderate proportion of small-bodied fishes were identified to species, enumerated, measured for total length (mm) and weight (g) in the field, and then released into the waterbody they were entering. Selected species (varying by event) with >100 specimens were subsampled; all individuals were enumerated and length and weight measurements were taken on every 5<sup>th</sup> or 10<sup>th</sup> randomly selected

specimen. Remaining small-bodied fishes were preserved in a 10% solution of formalin and then comparably processed in the laboratory. Subsampling occurred for some events with high numbers of preserved specimens. Laboratory subsampling techniques for net samples with >100 specimens generally followed those used in the field except for 3E1407 where preserved numbers were very large. For that event, subsampling was based on sample splitting procedures used for high numbers of aquatic invertebrates (Cuffney et al. 1993), and additional gross sub-sampling techniques were applied to a small portion of its net samples.

Not all specimens could be identified to species due to their small size and/or poor preservation and those were identified to either genus or family. Where inadequate preservation caused identification and measurement difficulties, length and weight measurements were not recorded to avoid inaccurate readings. Specimens identified only to family were labeled Unidentified *family* (e.g. Unidentified *Cyprinidae*); those identified only to genus were labeled *Genus* spp. (e.g. *Hypophthalmichthys* spp.). Four taxa groups were created grouping specimens identified as specific species together with specimens identified only to genus (section: *adjustment of fish data*).

### ***Larval-Net Fish Sampling of Monitored Connectivity Events***

Eggs and larvae moving through the fishway during each connection were taken at the beginning of each fyke-net sample using a 500- $\mu$ m mesh plankton net (1.0 m [40 inches] in length with a 0.5 m x 0.3 m [18 inches x 12 inches] opening). Larval fishes collected with the plankton net were preserved in the field in 10% formalin and taken to the laboratory for identification, enumeration, and length measurement. Specimens were

identified to the lowest possible taxonomic level (species, genus, or family) using Holland-Bartels et al. (1990). Larval-net data were subsequently used only to provide mean total length estimates for taxon-specific instantaneous growth rate calculations in Objective 6. (See Montgomery and Galat 2014 for detailed methods.)

### **Adjustment of Fish Data**

Adjustment and standardization steps were performed using the specimen-identity data format before conducting data analyses because variations in specimen processing during the four egress events meant not all specimens could be identified to species. Specimen-identity data format refers to the level of taxonomic identification of specimens within the dataset, specifically for four taxonomic groups of fishes. Taxa groups combined data collected on specimens identified to species with specimens identified to genus to facilitate description and comparison of fish assemblages of individual and combined connectivity events and to enable comparison of egress with ingress events. Related specimens identified to varying taxonomic levels for each connectivity event were combined and classified under one of four taxa group labels: Asian carps, Buffalofishes, Redhorses, and Shiners.

*Asian carps* contained the largest number of specimens, including bighead carp (*Hypophthalmichthys nobilis*), silver carp (*H. molitrix*), hybrid bighead-silver carp (*H. nobilis* x *H. molitrix*), and specimens identified only to *Hypophthalmichthys* spp. Common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) are also commonly recognized as Asian carps, but these two species are referred to by their

common names since all were identified to species. Introduced bighead carp and silver carp, as well as common carp and grass carp, were further identified as *invasive species* because of their well-documented adverse effects on aquatic ecosystems (Dibble and Kovalenko 2009; Kolar et al. 2007; Miller and Crowl 2006). Other non-native fishes (i.e., western mosquitofish [*Gambusia affinis*], striped bass [*Morone saxatilis*] and goldfish [*Carassius auratus*]) are referred to as *introduced species*.

The *Buffalofishes* taxa group involved bigmouth buffalo (*Ictiobus cyprinellus*), smallmouth buffalo (*I. bubalus*), black buffalo (*I. niger*), and specimens identified to *Ictiobus* spp. contained the second largest number of specimens. *Redhorses* consisted of black redhorse (*Moxostoma duquesnii*), golden redhorse (*M. erythrurum*), shorthead redhorse (*M. macrolepidotum*), and specimens identified just to *Moxostoma* spp. *Shiners* included river shiner (*Notropis blennius*), sand shiner (*N. stramineus*), bigmouth shiner (*Hybopsis dorsalis*), or specimens identified only to *Notropis* spp.

Fish data expressed in terms of taxa groups are referred to as *collapsed groups*, whereas fish data of varying identification levels within taxa groups are referred to as *expanded groups*. Importantly, the difference between these two specimen-identity formats reflects how the individual data were processed. For example, in the expanded groups format, data for bigmouth buffalo, smallmouth buffalo, black buffalo, and specimens identified to *Ictiobus* were presented separately; but, in the collapsed groups format, data for those taxa were combined and presented as a whole for the *Buffalofishes* taxa group. Hybrids and taxa identified to either genus or family not associated with the four recognized taxa groups were retained as identified in datasets of both specimen-identity formats. Varied application of the two specimen-identity data formats to

objectives permitted flexibility in analyzing fish data collected during connectivity events while also accommodating data restrictions.

Finally, a preliminary standardization was performed before applying data to individual-fish level analyses of Objective 5 (size structures during ingress events) and Objective 6 (size structures during egress events and growth rates during inundation periods). This standardization step adjusted species-specific, or taxon-specific, weight-length data by identifying and excluding major bivariate outliers (i.e., outliers in x- and y-dimensions in regression plots of weight against length from combined data across all 11 events). See Montgomery and Galat (2014) for figures.

## **Data Analysis**

### ***Objective 1: Connectivity Event Prediction Model***

The stage-level relationship between a river mainstem and its floodplain wetland was determined and then used to delineate discrete lateral connectivity events; the flow and temperature dynamics of events predicted by this *Connectivity Event Prediction Model* were then described.

#### *Calculation of Minimum Stage of Lateral Connection*

A least-squares regression analysis was performed to determine the minimum stage necessary at the USGS Boonville gage for connectivity at EBCA (termed *minimum stage of connection*). Predictions were calculated slightly outside of the observed data range to

determine the minimum stage of connection because readings of LMOR stage at EBCA fishways were recorded only after river stage was above the minimum stage of connection and the exact stage elevations were unknown as to when river water levels in the canal were below the level of the fishway's staff gage. Lower Missouri River stage at the USGS Boonville gage was regressed separately against LMOR stage at EBCA for each pool. The base elevation of the EBCA fishway (170.84 m amsl) was substituted for "x" in the equation of the line to calculate minimum stage of connection. Also, LMOR stage at the USGS Boonville gage corresponding to the *maximum stage threshold* of the levees surrounding EBCA was determined by substituting the elevation of the top of the levees (175.26 m amsl) for "x" in the equation of the line. Plots of residuals against predicted values confirmed no influential outliers and equal distribution about the error line, indicating assumptions of homoscedasticity and linearity were met (Montgomery and Galat 2014, Figures 2.4 and 2.5).

*Identification and Delineation of Predicted Connectivity Events and Initial Estimation of Connectivity Event Prediction Model*

Data from 1993 to 2008 were used to delineate an event by determining points of connection and disconnection between the river and wetland. For the Connectivity Event Prediction Model, initiation of a connectivity event at EBCA was defined as the day when LMOR stage at the USGS Boonville gage was  $\geq 177.20$  m amsl (derived in above section) and disconnection was defined as the day when LMOR stage fell below 177.20 m amsl. Connectivity events were identified at the three time intervals: calendar year (wet or dry flood year), spawning window (ecologically relevant; Objective 2), and

monthly (research and management relevant). A connectivity event was counted as occurring at any of these intervals if the interval had  $\geq 1$  day(s) with stage at the USGS Boonville gage  $\geq 177.20$  m amsl.

Eight connectivity event variables were calculated to characterize dynamics for each identified connectivity event from 1993 to 2008: event frequency, event timing, duration, mean river stage magnitude, mean fishway stage magnitude, rate-of-rise, rate-of-fall, and mean water temperature (Table 2). The LMOR stage and water temperature data were used to initially model connectivity event variables for predicted connections from 1993 to 2006 as percentiles at the calendar year and spawning window intervals. Additionally, a histogram illustrated connectivity event frequency per month.

#### *Validation of Connectivity Event Prediction Model using 2007 & 2008 Stage and Water Temperature Data*

Model validation is the process for demonstrating that a model accords with current knowledge and scientifically accepted data, and is thus appropriate for its intended purpose (Rykiel 1996). This study employed *historical validation*, or *data-splitting*, which uses part of the data to build the model and a different subset to test whether the model behaves as the system does (Rykiel 1996). Historical validation can also be used to forecast system behavior and allows comparisons for determining whether the model's predictions and the system's behavior are the same (Rykiel 1996). In this study, validity of model estimates for all eight connectivity event variables developed from 1993 to 2006 stage and water temperature data (hereafter *predicted*) was evaluated by comparing

initial model estimates to predictions from 2007 and 2008 data (hereafter *observed*) at calendar year, spawning window, and monthly scales.

Model validation was performed differently for connectivity event frequency than for other variables because 2007 and 2008 connection frequency at all scales was a single value (number of events per interval) that could not be averaged. A standardized z-test was used to evaluate frequency estimates. Mean connectivity event frequency predicted at the calendar year, month, and spawning window scales was compared, separately for each year and interval, to the observed connection frequencies. The null hypothesis ( $H_0$ ) tested at each scale was “no difference in number of events between predicted mean and observed value.” The alternative hypothesis ( $H_a$ ) tested was two-sided for each scale of analysis: “the mean number of events predicted was different from the number of observed events.” Comparison of observed connectivity event frequency with the predicted mean connectivity event frequency required the values at each scale for 2007 and 2008 be standardized by calculating their z-score. The z-score ( $Z$ ) was calculated using standard error of model predictions (SE) because the mean ( $\mu$ ) used in Equation 1 was the calculated mean from the model (Zar 2010). The value “X” in Equation 1 was the observed number of events for each time interval for 2007 and 2008.

$$Z = (X-\mu)/SE \quad \text{(Equation 1)}$$

Once the z-score was calculated for each scale the corresponding probability value was determined from the table of standard normal probabilities (Table A, p 652; Moore 2004). Absolute value of the z-score was used when determining probability value from

Table A in Moore (2004) since  $H_a$  was a two-sided hypothesis. For each test, p-values were determined by inserting the probability value for “ $p$ ” into Equation 2.

$$\text{p-value} = 2(1-p) \quad (\text{Equation 2})$$

The probability function was multiplied by 2 to correct p-values for the two-sided alternative hypothesis. Null hypothesis of no difference was rejected if the p-value  $< 0.05$  for each of the calendar year, spawning window, and monthly comparisons for 2007 and 2008. At the month scale, z-scores were not calculated for January because from 1993 to 2008 there were no connectivity events during that month.

A nonparametric Kruskal-Wallis test performed for model validation compared medians of the remaining seven connectivity event variables predicted from the model against observed data at the calendar year and spawning window scales. A Kruskal-Wallis test was used because data distributions were non-normal.

Predicted stage and water temperature were evaluated with observed data in three additional ways not limited to discrete connectivity events (like the rest of the model validation); these evaluations compared data independently of whether there was a connectivity event. First, daily stage and water temperature readings for LMOR were plotted together for 2007 and 2008, over a plot of mean daily stage and mean daily water temperature (with  $\pm 95\%$  confidence intervals [CIs]) from 1993 to 2006 and with minimum stage of connection and maximum stage threshold included as reference lines, to illustrate general trends between stage and temperature for the entire year. Next, general trends in rising water temperatures during the entire spawning season were analyzed by comparing dates from model predictions when mean water temperatures first

reached 5, 10, 12, 14, 16, 18, 20, 22, 25, and 27.7 °C ( $\pm 95\%$  CI surrounding the date) with dates those temperatures were first observed in 2007 and 2008. The entire spawning season was considered from 2.2 °C (lowest spawning temperature reported in Objective 2) to 30.0 °C (highest daily water temperature common to 2007 and 2008). Finally, differences in slope of daily river water temperature increases during the entire spawning season among three time periods (1993-2006 means, 2007, and 2008) were tested by performing an analysis of covariance (ANCOVA) with Julian day as the covariate to account for variations in temperature due to time of year.

#### *Update of Connectivity Event Prediction Model*

The initial model was updated by adding data from 2007 and 2008 into the dataset and recalculating percentiles for the eight connectivity event variables to include as much data as possible to improve future uses.

Next, two additional measures of connectivity probability, frequency, and duration were calculated at the month scale to help describe LMOR-EBCA lateral connectivity dynamics. *Connectivity event probability* is the likelihood of an occurrence of an event per month. The cumulative number of days connected per month defined *monthly connectivity duration*. A panel graph of three histograms illustrates monthly data with associated 95% CI's for connectivity event probability, mean monthly connectivity duration, and mean number of discrete connectivity events using the entire dataset of the updated model (1993 to 2008).

Finally, a flood frequency analysis using standard methods for the Log-Pearson Type III distribution technique (OSU 2013) was performed using river stage data from

1993 to 2008 to describe representative flood types at EBCA. First, river stages associated with various return intervals (i.e., 1.01, 2, 5, 10, 25, 50, 100, and 200 years) were predicted. Exceedance probabilities were then determined for minimum stage of connection (a floodplain-activation flood) and for maximum stage threshold (a floodplain-maintenance flood) by evaluating results of the flood frequency analysis.

### ***Objective 2: Predicted and Observed Fish Access to Floodplain Wetlands***

Fish species accessing floodplain wetlands were predicted based on their distribution, habitat-use guilds, spawning temperature ranges, and river water temperature. The predicted fish assemblage was compared with the assemblage observed using the EBCA wetland during controlled, backflooding connectivity events via the fishway in 2008.

#### *Development of Fish-Use Predictions*

Three lists of Missouri River fish species were created by incorporating multiple species-specific factors to describe and predict species accessing EBCA wetlands: a master list of all Missouri River fishes; a regional species list of fishes found within the LMOR; and a list of fishes predicted to enter EBCA for spawning, nursery, or both.

#### *Missouri River fish species*

The *master list* of mainstem Missouri River fish species was modified from Galat et al. (2005b) to include generic distribution and abundance of all 136 Missouri River fishes by freshwater ecoregion, drainage unit, and physiographic province as well as species-

specific habitat distribution and classification in habitat-use and reproductive guilds. Habitat-use guild classifications used in the master list included fluvial specialist, fluvial dependent, and macrohabitat generalist (Kinsolving and Bain 1993). Status of each species (native or introduced) and habitat-use guild classifications (Galat et al. 2005b) were retained, except freshwater drum (*Aplodinotus grunniens*) was changed from macrohabitat generalist to fluvial dependent based on a re-classification of this species (Csoboth and Garvey 2008). Reproductive guilds used in the master list reflected the classification scheme developed by Balon (1975) and modified by Simon (1999).

#### *Criteria for revising Missouri River fishes*

Distribution criteria were applied to revise the master list of 136 Missouri River fish species to a *regional species list*. The first criterion for inclusion in the regional species list was that a species must be routinely collected within LMOR drainage units (i.e., Nishnabotna-Chariton [river km 957 to 384] and Lower Missouri [river km 384 to 0]; see Galat et al. 2005b for explanation of drainage units). Incidental species were removed from the list, as were fishes with relative abundances classified as marginal (M) or sporadic (S) for the Central Lowland or Ozark plateaus (see Galat et al. 2005b for explanation of physiographic provinces). However, selected species (e.g., western mosquitofish) were retained despite a previous relative abundance classification of marginal or sporadic following a supplementary literature review (MDC 2012; Pflieger and Smith 1997). For the second criterion, a species was retained in the regional species list if its habitat distribution included the main channel or floodplain; reservoir fishes and waifs, likely washed in from reservoirs or tributaries were excluded.

Finally, an exclusion criterion based on habitat-use guild classifications was applied to the regional species list to identify species predicted to enter the wetland pool (termed *predicted EBCA-use fishes*). Fishes classified as fluvial specialists were removed from the regional list because they do not routinely spawn in or use floodplain wetlands.

#### *Spawning Temperature Ranges of Missouri River Fishes*

Spawning temperature range and peak spawning temperature ranges for Missouri River fishes were determined from a literature review. The spawning temperature range, derived from lowest to highest reported spawning temperatures for each species in the predicted EBCA-use fishes list, was abstracted from the master list. *Peak spawning temperature* was the most frequently reported temperature of spawning activity. See Appendix C in Montgomery and Galat (2014) for master list, regional species list, spawning temperatures, and spawning temperatures report criteria.

#### *Spawning Date Ranges of Missouri River Fishes*

Literature-based species-specific spawning temperatures were compared with daily water temperature data from the BWTP (1937 to 2008) to predict when LMOR fishes would spawn. First, mean daily water temperature and associated 95% CIs were calculated and depicted as dates when temperatures of 5, 10, 12, 14, 16, 18, 20, 22, 25, and 26.7 °C were first reached. Second, calendar dates when lower and upper spawning temperature values were reached for each species were estimated by determining the corresponding day a specific mean daily water temperature value was reached. Third, a frequency histogram

illustrated the number of predicted EBCA-use fishes that would begin spawning at different water temperatures. Next, calendar dates were determined for the *spawning window* used in Objective 1 during which nearly all (85%) of the species on the list of predicted EBCA-use fishes begin spawning. Appearance of a natural break at 85% in the data reflected that two species start spawning at much colder temperatures than the rest of the predicted fish assemblage.

Fine-scale timing of lateral connectivity events most beneficial for native fish spawning and nursery use of the floodplain was addressed by dividing the predicted assemblage into *early-spring* and *late-spring* spawning groups, using the modal water temperature at which fishes begin spawning as the cut-off between these groups. Designations of early-spring and late-spring spawning groups facilitated evaluation of patterns (e.g., timing and range) in spawning temperatures of individual species (and ecological guilds) to develop tools and strategies for ecosystem-based fisheries management of native versus invasive species in Objective 7.

#### *Comparing Predicted and Observed Fish Assemblages*

Accuracy of fish-use predictions was tested through case-study techniques comparing predicted and empirically based patterns; specifically, the predicted EBCA-use fishes list was compared to data collected during the 2008 field season using the Jaccard similarity coefficient in two testing rounds. This similarity index was selected because it is based on incidence data rather than abundance data and fish-use predictions were based on presence or absence of specific species. The Jaccard index differentiates species shared

between two assemblages from those unique to each assemblage to determine their similarity: a value of “0” means there are no common species, whereas a value of “1” indicates identical species composition (Kwak and Peterson 2007). Statistical inferences cannot be made about the Jaccard index, but values  $<0.60$  indicate that “considerable differences” were found in the species compositions of those fish assemblages (Gauch 1982; Lohr and Fausch 1997; Rahel 1990). In applying the Jaccard index, fish assemblages with values  $<0.60$  were *considerably different*, those with values from 0.60 to 0.80 were *moderately similar*, and those  $>0.80$  were *highly similar*. The expanded groups data format (with specimens not identified to species removed) was used to evaluate fish-use predictions since predictions were based on specific species.

Testing of fish-use predictions addressed species with different habitat-use and reproductive guilds that could access the wetland; such testing had to be done in two rounds because some common fluvial dependents (e.g., pelagophil reproductive guild) could have entered floodplains as eggs or larvae and would not have been sampled with the fyke net during ingress events even though they might have used the wetland as a nursery and been sampled during egress events. In the first round, predictions were compared to incidence data gathered from the five ingress events. The compiled list was updated to include data from both egress events and then compared to the list of predicted EBCA-use fishes in the second round of testing. This later round required use of fyke-net egress data; larval-net data collected during the five 2008 ingress events could not be used because the majority of larval specimens could not be identified to species.

Values for the predicted and observed assemblages in each testing round were incorporated into Equation 3 to calculate the Jaccard similarity coefficient:

$$C_{1,2} = p/(p+m+r), \quad (\text{Equation 3})$$

where  $p$  = number of species present in both assemblages,  $m$  = number of species present in Assemblage 1 but not in Assemblage 2, and  $r$  = number of species present in Assemblage 2 but not Assemblage 1 (Kwak and Peterson 2007). The list of predicted EBCA-use fishes formed the Predicted Assemblage for the first and second rounds of testing. Observed Assemblage 1 was created by combining incidence data from events 1I1508 through 5I1508 for the first round. Observed Assemblage 1 species list was updated with additional species sampled during egress events 6E1508 and 7E1508 (then identified as Observed Assemblage 2), and the latter was used to determine whether the similarity index value would improve during the second round of testing.

For each additional species in Observed Assemblage 2, a species-specific cut-off value representing maximum length at age-0 (determined from a literature review; Appendix A: Table A1) was applied to the smallest specimen of that species collected during the two 2008 egress events to distinguish residual 2007 fishes that overwintered in the pool from 2008 age-0 fishes. Only specimens with a total length measurement below the cut-off value were included in Observed Assemblage 2.

Finally, a qualitative comparison of specific species, habitat-use guilds, reproductive guilds, native versus introduced status, and spawning groups (early or late spring) was performed to clarify results.

***Objective 3: Fish Assemblage Structure, Total Abundance, and Biomass during Connectivity Events***

*Fish Assemblage Structure*

Five metrics described fish assemblages using the fishway between the river and EBCA:

(i) relative *species (or taxa) richness* (number of species or taxa); (ii) *species (or taxa) composition* (incidence of species or taxa); (iii) *species (or taxa) relative abundance* (number of individuals collected per species or taxa); (iv) *species (or taxa) relative structure* (percent ratio of taxa relative abundance to total number of individuals across all taxa); and (v) *fish assemblage relative abundance* (total number of collected individuals summed across all species or taxa). These metrics were organized under two categories: individual connectivity event (7 ingress events and 4 egress events) and yearly total ingress and egress (*ingress 2007, ingress 2008, egress 2007, and egress 2008*).

Metrics were calculated for both specimen-identity data formats.

Species richness was measured relative to the regional species list. Fishes identified only to genus or family were not included in species richness estimates developed from the expanded groups dataset; however, they were included in taxa richness estimates since they were reported in datasets of the expanded groups and collapsed groups formats. Additionally, information about status (native or introduced) and ecological guild membership (habitat-use and reproductive) of fishes sampled with the fyke net was summarized at the individual connectivity event and yearly total ingress and egress levels as well as at the *EBCA total* level (i.e., across all 11 events).

Datasets were standardized by sampling effort for each connectivity event to account for various event duration and sampling methods. Taxa raw relative abundance

was standardized to taxa catch-per-unit-effort (CPUE) relative abundance by dividing raw count by net sample duration; CPUE values from each net sample were then averaged to produce mean CPUE (fish/h) of an event. Mean CPUE and its standard error were calculated using formulae for simple random sampling for all events except 4E1507 and 7E1508 where formulae for stratified random sampling were used (Hansen et al. 2007). Fish assemblage CPUE relative abundance was calculated by summing across species (or taxa) mean CPUE relative abundances to develop species (or taxa) relative structure estimates that sum to 100% for yearly total ingress and egress fish assemblages.

### *Total Abundance*

Fish assemblage total abundance, taxa total abundance, and taxa relative structure of fish assemblages egressing to the river for events and years were calculated using the collapsed groups data format. *Total abundance* is the actual number of individuals in a population; whereas relative abundance is an estimate of population size based on data related to the total population size. Three methods were used across egress events to estimate export total abundance (using raw relative abundance data as input) reflecting differences in sample designs among events. Simple extrapolation techniques were used for the 2007 early-season egress event as fish sampling used uninterrupted draining and long duration net sets (with one subsample). A multi-step extrapolation procedure was used for the 2008 early-season egress event because fish sampling used interrupted draining and short duration net sets (Montgomery and Galat 2014). A SAS code interpolation procedure was applied to both late-season egress events because fish

sampling used uninterrupted draining and varying duration net sets (Montgomery and Galat 2014).

Event-level estimations of total abundances (fish assemblage and taxa) were summed for each year, and taxa relative structures were calculated for fish assemblages (four individual egress events and two year totals). Next, fish assemblage total abundance for each event and year was standardized using three formats (duration, volume, and area). Event duration and water exchange volume were used for event-specific standardizations. Total duration of fishway gate operation and total volume of water released from EBCA were calculated for year-level standardizations by summing values for the two events each year. Hourly fish export from the fishway (fish/h) was estimated by dividing fish assemblage total abundance by duration of fishway gate operation. Volumetric export (fish/m<sup>3</sup>) from the fishway was determined by dividing fish assemblage total abundance by water exchanged through the fishway. Areal fish export (fish/ha) from the inundated wetland was estimated by dividing fish assemblage total abundance by surface area of wetland pool 15 (23.5 ha, 58 acres).

### *Biomass*

Fish assemblage and taxa gross biomass import from LMOR to EBCA and gross biomass export to LMOR in 2007 and 2008 were estimated by summing biomass for individual ingress and egress events. Event-level biomass (“ $\hat{B}$ ”; g) was calculated as:

$$\hat{B} = \hat{N} \times \bar{w}, \quad (\text{Equation 4})$$

where “ $\hat{N}$ ” was the estimated total abundance and “ $\bar{w}$ ” was the median weight (g) of the fish sampled during a connectivity event (Hayes et al. 2007). Total abundance estimates used in biomass calculations were produced differently for ingress and egress events due to different sampling designs. Raw relative abundance was used to characterize total abundance for the seven ingress events because sampling involved continuous fyke net use. In contrast, estimated total abundance values were used for the four egress events because they involved non-continuous fyke net sampling. Taxon-specific median weights, plus the 25<sup>th</sup>- and 75<sup>th</sup>-percentile of weights forming the interquartile range (IQR) of weights, were calculated for each connectivity event and then multiplied by total abundance of each taxon to estimate unstandardized biomass (g) and its attendant variability (i.e., IQR of biomass). Fish assemblage biomass and its IQR for each connectivity event were computed by summing unstandardized taxa biomasses. Although Hayes et al. (2007) recommended using mean weight to indirectly calculate biomass via Equation 4, median weight was used here because of data collection restrictions: e.g., data were grouped across life stages because field and laboratory subsampling prevented accurate separation of the entire dataset into adult and juvenile specimens. The majority of individuals in the assemblage were small, lighter YOY or juveniles, but mean weights were occasionally strongly influenced by large, heavier adult specimens. Median weights (and attendant IQR) thus provided a more informative characterization of the weight of the overall fish population sampled during a connectivity event and avoided inflated biomass estimates overly influenced by larger adults representing a small proportion of the population. Unfortunately, weight

measurements were not collected on selected specimens during various events, so biomass for a few taxa was knowingly underestimated.

Event-specific biomass estimates were standardized by duration (g/h) and volume ( $\text{g}/\text{m}^3$ , as above in *total abundance* section): two event-specific standardizations were used to offset difficulties encountered in quantifying amount of water exchanged during some events. Next, event-specific estimates for the fish assemblage and taxa (unstandardized and standardized) were summed together for each year to produce gross import and gross export biomass estimates (unstandardized and standardized). Finally, gross import and gross export per year were standardized by area (g/ha, as above). Only gross import and gross export for each year (using collapsed groups data format) are presented in Objective 3 Results; fish assemblage biomass is displayed in all formats, but taxa biomass is displayed only as biomass per hour. See Montgomery and Galat (2014) for other formats.

Net export biomass of the total fish assemblage was calculated for 2008 because movements between the river and wetland were constrained to the fishway. However, net biomass export could not be estimated in 2007 because the overtopping event prevented complete estimation of gross import from LMOR and fish sampling could not account for bilateral fish movement during that time. The wetland pool was drained immediately before each ingress event in 2008, and fish sampling was not conducted during those draining periods. However, water was only briefly retained in the wetland before these pre-draining periods, so it was assumed these ingress and egress biomasses would be equivalent. Also, since draining before 1I1508 to 4I1508 allowed fishes entering the wetland during ingress events an opportunity to return to the river, it was

assumed the last event (5I1508) was the primary source of fishes that reproduced in the wetland or used it for nursery. Two estimates for calculating net export biomass of the total fish assemblage served to mitigate collection and standardization issues: gross import biomass was subtracted from gross export biomass, and import biomass for 5I1508 was subtracted from gross export biomass.

***Objective 4: Fish Assemblages during Uncontrolled and Controlled Flooding***

Similarity of lateral fish movements between uncontrolled and controlled floodplain access was evaluated by comparing taxa composition of the combined fish assemblage from the two 2007 egress events against assemblage data from the five ingress events and two egress events in 2008. The Jaccard Index (Equation 3 in Objective 2 Methods) was used to compare similarity of the uncontrolled and controlled floodplain-access assemblages after conducting various data management steps because the 2007 levee-topping event prohibited quantitative sampling of fishes during all instances of ingress. Data in the collapsed groups format were transformed into binary relative abundance to analyze similarity in taxa compositions between assemblages.

Assemblages were compared in two testing rounds because species belonging to different habitat-use and reproductive guilds could access the wetland during controlled ingress events. Some fluvial dependent species in the pelagophil reproductive guild could enter floodplains as eggs or larvae and would not have been sampled with the fyke net during the 2008 ingress events even though they might have used the wetland as nursery and been sampled during subsequent egress events. Combined incidence data

from the two 2007 egress events (Uncontrolled Flooding Assemblage) were compared in the first testing round to combined incidence data from the five 2008 ingress events (Controlled Flooding Assemblage 1). Next, the list of sampled fishes associated with controlled wetland flooding in the first round was updated to include data from the two 2008 egress events, and this revised list (Controlled Flooding Assemblage 2) was compared to the Uncontrolled Flooding Assemblage in the second testing round. Before applying the Jaccard Index in the second testing round, a species-specific cut-off value representing literature determined maximum length at age-0 fishes (Appendix A: Table A1) was applied to the smallest specimen of each additional species collected during the two 2008 egress events. This enabled distinguishing residual 2007 fishes that overwintered in the pool from 2008 age-0 fishes present in the Controlled Flooding Assemblage 2. Only specimens with a total length measurement below the age-0 cut-off value were included in the Controlled Flooding Assemblage 2.

Finally, a qualitative comparison was performed between the Uncontrolled Flooding Assemblage and Controlled Flooding Assemblage 2 in respect to specific habitat-use and reproductive guilds.

### ***Objective 5: Fish Assemblage Similarity and Size Structures of Selected Species***

#### ***Entering Floodplain Wetlands***

##### *Similarity of Fish Assemblages*

Data in the expanded groups format (with specimens not identified to species removed) and in the CPUE relative abundance format were used to evaluate similarity of fish

assemblages accessing EBCA wetland pools during 111407 and each of the five 2008 ingress events. Comparable sampling designs for the six ingress events allowed use of a similarity index employing quantitative abundance data rather than using an incidence data index as was done for Objectives 2, 4, and 6. Fish assemblage percent similarity was compared among the six events and between each event and the total assemblage averaged across events. Calculation of percent similarity followed Kwak and Peterson (2007) and used species relative structure. Percent similarity varies from 0 to 100%, with “0” indicating no species in common and “100%” signifying identical species composition and species relative structure (Kwak and Peterson 2007).

#### *Species-Specific Size Structures*

Length data collected during all seven ingress events were used to evaluate size structures of selected fishes entering the wetland. Six numerically dominant species were selected: common carp, shortnose gar (*Lepisosteus platostomus*), bigmouth buffalo, gizzard shad, western mosquitofish, and orangespotted sunfish (*Lepomis humilis*). A relative length-frequency histogram was created for each species using the entire length range of collected specimens and stacking data by event. Species-specific cut-off values representing maximum length at age-0 and minimum length at sexual maturity (Appendix A: Table A1) were indicated on histograms to evaluate patterns in life stages using the fishway.

***Objective 6: Similarity of Fish Assemblages and the Size Structure and Growth Rates of Selected Taxa Exiting Floodplain Wetlands***

*Similarity of Fish Assemblages*

Similarity of taxa composition of fish assemblages sampled during early-season (3E1407, 6E1508) and late-season (4E1507, 7E1508) egress events were compared, separately for each year, by applying the Jaccard similarity coefficient (Equation 3 in Objective 2 Methods) to presence/absence transformed data in the collapsed groups format. Before applying the Jaccard Index to the 2008 egress events, a taxon-specific cut-off value representing maximum length at age-0 (Appendix A: Table A1) was applied to the smallest specimen of each taxon collected during those events to distinguish residual 2007 fishes that overwintered in the pool from 2008 age-0 fishes. Specific habitat-use and reproductive guilds were also evaluated for each year's early-season and late-season egress events.

*Taxon-Specific Size Structures*

Size structures of selected taxa during early-season (3E1407, 6E1508) and late-season (4E1507, 7E1508) egress events were characterized using length data from fyke-net samples. Eleven taxa (six large-bodied [maximum size = >300 mm] and five small-bodied [maximum size = <300 mm]) were selected. Invasive large-bodied taxa were Asian carps, common carp, and grass carp; native large-bodied species were gizzard shad, freshwater drum, and shortnose gar. Native small-bodied taxa were orangespotted sunfish, green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), and Shiners,

whereas western mosquitofish were the only introduced small-bodied species. Bluegill and Shiners were used only for the 2007 characterization; other taxa were used for both years. A relative length-frequency histogram was created for each taxon and egress event (using the entire length range of collected specimens), and cut-off values representing maximum length at age-0 and minimum length at sexual maturity (Appendix A: Table A1) were used to evaluate patterns in life stages exiting the wetland. The reported length (200 mm) when gizzard shad exceed gape-limits of most predators (DiCenzo et al. 1996; Pope et al. 2010) was used to evaluate sizes of exiting large-bodied taxa.

### *Taxon-Specific Growth Rates*

#### *Overview*

Mean instantaneous growth rates during managed wetland inundation periods each year were calculated for the eleven taxa using length data from multiple connectivity events. Instantaneous growth rates characterized fish growth because overall time frame was <1 year (Isely and Grabowski 2007). Instantaneous growth rate (GI, mm/day) is defined as:

$$GI = \frac{(\ln(TL_1) - \ln(TL_0))}{(time_1 - time_0)}, \quad (\text{Equation 5})$$

where  $\ln(TL_0)$  and  $\ln(TL_1)$  correspond to natural logs of mean total lengths (mm) of a sampled cohort at  $time_0$  and  $time_1$  (Isely and Grabowski 2007). Taxon-specific data collected with larval and fyke nets provided input values of mean lengths at different times each year. Larval-net data supplied one input value, but number of values from fyke-net data varied with taxa and events because multiple cohorts were collected for each taxon. Taxon-specific cohort mean lengths (from fyke net, larval net, or both gears)

were identified, refined, and linked between two reference times in 2007 (early-season [ $time_0$ ] and late-season [ $time_1$ ] egress events) and among three times in 2008 (final ingress event [ $time_0$ ], early-season egress event [ $time_1$ ], and late-season egress event [ $time_2$ ]) to calculate growth rates during each inundation period and year via Equation 5.

### *Data standardization*

Data from multiple events and fish-sampling gears represented different length ranges across taxa and events requiring standardization that treated large-bodied and small-bodied taxa differently. Sexually mature adult cut-off values (Appendix A: Table A1) were applied to length data of common carp, Asian carps, grass carp, gizzard shad, freshwater drum, and shortnose gar to remove adult specimens from the dataset before conducting growth rate analyses. However, cut-off values were not applied to the five small-bodied taxa because length frequencies of small-bodied fishes tend to be unimodal and normally distributed, making it hard to separate juveniles and adults.

Larval-net and fyke-net data used to calculate growth rates for the various taxa, cohorts, and time frames are reported in Appendix B, as are the details for designation of reference times and wetland inundation durations and for development of growth rate calculation groups. Mean total lengths of taxa collected with the larval net during 3E1407 and 5I1508 provided  $time_0$  values for respective years; the identified and refined cohort-specific mean total lengths of taxa collected with the fyke net during the four egress events were used for  $time_0$  and  $time_1$  values in 2007 and for  $time_1$  and  $time_2$  values in 2008. Three groups of growth rates were calculated for 2007 (referred to as *fyke-net*

*only*, *larval-net only*, and *combination* to distinguish  $time_0$  data sources) and for 2008 (referred to as  $time_{0-1}$ ,  $time_{0-2}$ , and  $time_{1-2}$  to reflect evaluated inundation periods).

Taxon-specific cohort mean lengths representative of YOY and juvenile recruitment patterns were identified and refined from fyke-net sampling of early-season and late-season events each year, and then mean lengths of individual cohorts were linked between reference times. Center and spread of length distributions of numerous taxa during one or multiple egress events indicated protracted and asynchronous recruitment patterns making characterization of growth using overall mean, median, or modal length in Equation 5 problematic. Accordingly, the three step modal progression analysis routine of the FiSAT II<sup>1</sup> programming package (Gayaniilo et al. 2006) was used to discriminate taxon-specific cohorts sampled during each egress event. That analysis routine has been used successfully to identify individual cohorts and determine length values for calculating growth and other population dynamics (Casale et al. 2011; Close et al. 2010; Scalici et al. 2010). Details of each step are reported in Appendix B.

#### *Taxon-specific mean instantaneous growth rate calculations and evaluations*

Because the number of taxon-specific cohort mean lengths and number of reference times used for growth rate calculations varied each year (due to hydrologic conditions, connectivity event sampling designs, and available sources of length data), taxon-specific growth rates were averaged to produce one final mean instantaneous growth rate (and standard deviation) for each inundation period and year. Percent differences in taxon-specific growth rates between years (2007 fyke-net only and 2008  $time_{1-2}$  groups) and

between 2008 inundation periods (groups  $\text{time}_{0-1}$  and  $\text{time}_{0-2}$ ) were calculated to evaluate and compare mean growth rates among taxa.

***Objective 7: Recommendations for Site-Level Wetland Management of Lateral Connectivity, Inundation, and Native Fish Recruitment***

Results from Objectives 1 to 6 were used to propose integrated fish management options to enhance native YOY and juvenile fish recruitment on actively managed large river-floodplain wetlands (Table 3). Six decision-support tools were designed to guide management strategies and actions by describing environmental and ecological filters for lateral connectivity and fish movement, presenting options for timing of inflow connectivity events and of water releases to the river in a cost-benefit framework to enhance wetland use by native versus invasive fishes, and offering a framework to guide decisions for operating fishway gates that control the lateral exchange pathway.

Table 3. Decision-support tools to help manage river-floodplain lateral connectivity, inundation, and native fish recruitment. Information for each tool includes its description, purpose, methods, and the objectives that contributed to its development.

Decision-support tool	Objectives
<p>1. Target range of flow and temperature dynamics during connectivity events.  <i>Why:</i> To guide LMOR site-level management strategies for lateral connectivity via water-control structures that encourage connectivity event dynamics within a targeted range of flows and temperatures.  <i>How:</i> Applied the flow targets approach to Connectivity Event Prediction Model; range of values of derived summary statistics that fall between the 25th- and 75th-percentiles for each variable in the model identified as the core 50%, or target range, of values.</p>	1
<p>2. Synoptic visualization of connectivity event timing, duration, and frequency in relation to species-specific spawning temperature ranges.  <i>Why:</i> To communicate how overlapping hydrologic, thermal, and ecological filters influence river-floodplain connectivity and fish recruitment to help determine beneficial timing for a lateral connection within the spring-summer reproductive season to promote native fish use of the wetland for spawning and nursery.  <i>How:</i> Created a figure showing the timing, frequency, and duration of predicted connectivity events and the timing of species-specific spawning temperature ranges relative to the overall spawning window and its sub-grouping of early- and late-spring spawners.</p>	1, 2
<p>3. Cost-benefit assessment of ingress event timing (early or late spring) in relation to wetland use by native versus invasive fish species.  <i>Why:</i> To guide actions controlling lateral connectivity that influence riverine fish spawning and/or nursery by helping decide whether to allow an ingress event.  <i>How:</i> Developed a table showing how fine-scale timing of connectivity events within the spawning window influences wetland use; evaluations were made relative to native versus invasive fishes, macrohabitat generalists versus fluvial dependents, and species-specific spawning temperature ranges.</p>	2, 3, 5
<p>4. Cost-benefit assessment of egress event timing (early-to-mid-summer or late summer) in relation to recruitment benefits of native versus invasive fish taxa.  <i>Why:</i> To guide actions controlling wetland inundation duration that influence YOY and juvenile fish recruitment benefits by helping decide when to allow an egress event.  <i>How:</i> Developed a table showing how egress event timing in the summer influences wetland use; evaluations were made relative to native versus invasive fishes.</p>	6
<p>5. Decision tree for management of river-floodplain connectivity and wetland inundation.  <i>Why:</i> To help select actions to manage connectivity and inundation dynamics during the spring-summer season.  <i>How:</i> Developed a figure showing the hydrology, possible management actions in response to that hydrology, and alternative ecological goals and their associated management actions to be considered.</p>	1 to 6
<p>6. Summarized visualization of management considerations, proposed ecological benefits, and evaluation of management actions to be addressed when controlling river-floodplain connectivity and wetland inundation.  <i>Why:</i> To help weigh multiple questions, actions, and potential outcomes when selecting actions to manage connectivity and inundation dynamics.  <i>How:</i> Developed a figure showing the questions and actions within the three decision-support components to be considered.</p>	1 to 6

## RESULTS

### **Objective 1: Connectivity Event Prediction Model**

#### *Minimum Stage of Connection and Maximum Stage Threshold*

Predicted minimum stage at the USGS Boonville gage for LMOR to connect with EBCA fishways was 177.20 m amsl (581.4 ft amsl, 4.87 m, 16.0 ft) with a high coefficient of determination (Appendix C: Figure C1, Table C1). Maximum LMOR stage threshold when EBCA levees were overtopped was 181.35 m amsl (595.0 ft amsl, 9.02 m, 30.6 ft) at the USGS Boonville gage.

#### *Predicted Connectivity Events*

Seventy-seven potential LMOR-EBCA connectivity events were estimated between 1993 and 2006, 34% (26) occurred within the 4 April to 1 June (JD 95 to 153) spawning window. Connectivity event predicted frequency was 7.4 connections per calendar year and 2.1 connections per spawning window. Highest monthly connection frequencies occurred from March to August with a maximum of 1.3 connections in June (Figure 4). Mean connection frequencies per month had wide CIs due to the range (0-4 connections) of event frequencies across years.

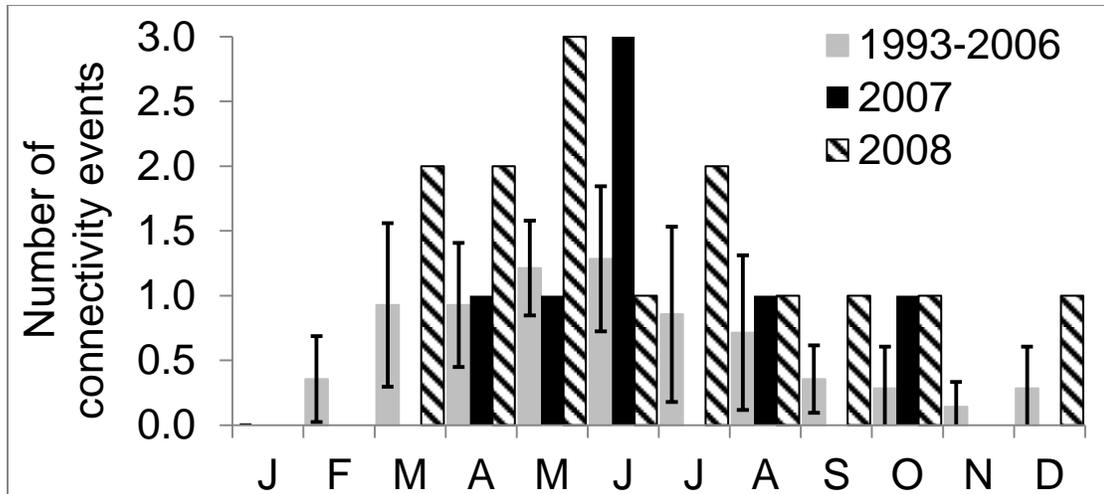


Figure 4. Frequency (number of events per month)  $\pm$ 95% confidence intervals of lateral connections between lower Missouri River and Eagle Bluffs Conservation Area wetland pools for the 1993-2006 model and 2007 and 2008 study years.

Remaining 1993 to 2006 modeled hydrologic variables are reported at the calendar year scale; however, percentile statistics were similar at the spawning window scale for most variables, except duration (Table 4). Start date timing of the *core 50%* (range between 25<sup>th</sup>- and 75<sup>th</sup>-percentiles) of predicted connectivity events encompassed the 4 April to 1 June (JD 95 to 153) spawning window and occurred between 11 April and 6 August (JD 102 and JD 219). Duration of connections varied greatly (coefficient of variation [CV] = 204%), with only a few >23 days and the majority <10 days. Mean water stage magnitude at the fishway was moderately predictable for a given connectivity event (CV = 83%) with 80% of connections having a mean depth between 0.13 m and 1.74 m (0.4 ft and 5.7 ft). Almost 90% of fishway connections had an estimated rate-of-rise <1.0 m/day and all connections had an estimated rate-of-fall  $\leq$ 0.90 m/day. Rate-of-fall was slower than rate-of-rise; the core 50% of predicted connections' rate-of-rise ranged from 0.19 to 0.73 m/day and a rate-of-fall ranged from 0.16 to 0.47 m/day.

Table 4. Percentile statistics for eight lateral connectivity event variables between lower Missouri River and wetland pools at Eagle Bluffs Conservation Area from 1993-2006 model and 2007 and 2008 study years. Statistics reported at two scales: calendar year (Julian day 1 to 366) and spawning window (when a majority of fishes predicted to enter the wetland begin spawning: 4 April to 1 June, Julian day 95 to 153). For connectivity events at the year scale, there are 77 observations for the model, 7 for 2007, and 14 for 2008; for events at the spawning window scale, there are 26 observations for the model, 2 for 2007, and 6 for 2008. Connectivity event frequencies for 2007 and 2008 are observed values, not derived summary statistics.

Connectivity event variable (unit of measurement)	Group	Percentile						
		5	10	25	50	75	90	95
Scale: calendar year								
Event frequency (n)	Model	0	1	3	7	11	17	.
	2007				7			
	2008				14			
Timing of event start date (Julian day)	Model	54	66	102	153	219	293	337
	2007	119	119	125.75	162	253	.	.
	2008	64	68.5	103.5	140	245.5	344.5	.
Duration (day)	Model	1	1	2	4	11	23	64
	2007	1	1	1	3	10	.	.
	2008	1	1	2	4	9	28	.
Mean river stage magnitude (m amsl)	Model	177.28	177.33	177.46	177.82	178.35	178.94	179.42
	2007	177.36	177.36	177.40	177.65	178.22	.	.
	2008	177.23	177.25	177.44	177.73	178.77	179.54	.
Mean fishway stage magnitude (m)	Model	0.08	0.13	0.26	0.62	1.15	1.74	2.22
	2007	0.16	0.16	0.20	0.45	1.02	.	.
	2008	0.03	0.05	0.24	0.53	1.57	2.34	.
Rate-of-rise (m/day)	Model	0.07	0.10	0.19	0.41	0.73	1.06	1.26
	2007	0.16	0.16	0.20	0.25	0.37	.	.
	2008	0.03	0.03	0.10	0.36	0.52	0.84	.
Rate-of-fall (m/day)	Model	0.06	0.09	0.16	0.31	0.47	0.72	0.76
	2007	0.03	0.03	0.13	0.30	0.51	.	.
	2008	0.03	0.05	0.17	0.29	0.52	0.79	.
Mean water temperature (°C)	Model	3.5	5.7	10.1	17.8	23.3	25.6	26.5
	2007	16.1	16.1	16.9	21.0	22.6	.	.
	2008	5.3	5.4	7.6	16.1	20.7	25.1	.
Scale: spawning window								
Event frequency (n)	Model	0	0	1	3	3	4	.
	2007				2			
	2008				6			
Timing of event start date (Julian day)	Model	90	96	106	124	143	150	153
	2007	119	119	119	124	.	.	.
	2008	101	101	109	129	149	.	.

Table 4 (continued)

Connectivity event variable (unit of measurement)	Group	Percentile						
		5	10	25	50	75	90	95
Scale: spawning window								
Duration (day)	Model	1	1	2	6	25	71	133
	2007	3	3	3	17	.	.	.
	2008	1	1	1	4	17	.	.
Mean river stage magnitude (m amsl)	Model	177.28	177.32	177.48	178.00	178.86	179.43	179.68
	2007	177.99	177.99	177.99	178.46	.	.	.
	2008	177.23	177.23	177.28	177.59	178.23	.	.
Mean fishway stage magnitude (m)	Model	0.08	0.12	0.28	0.80	1.66	2.23	2.48
	2007	0.79	0.79	0.79	1.26	.	.	.
	2008	0.03	0.03	0.08	0.39	1.03	.	.
Rate-of-rise (m/day)	Model	0.08	0.12	0.21	0.50	0.79	1.10	1.23
	2007	0.29	0.29	0.29	0.45	.	.	.
	2008	0.03	0.03	0.08	0.16	0.46	.	.
Rate-of-fall (m/day)	Model	0.06	0.08	0.14	0.30	0.40	0.67	0.76
	2007	0.47	0.47	0.47	0.55	.	.	.
	2008	0.03	0.03	0.08	0.19	0.39	.	.
Mean water temperature (°C)	Model	10.0	11.5	13.9	17.4	20.1	22.2	22.9
	2007	16.1	16.1	16.1	18.5	.	.	.
	2008	10.6	10.6	14.2	16.9	20.3	.	.

The 2.9 to 28.0 °C range of mean water temperatures during the 77 predicted connectivity events coincided with the overall spawning temperature range for 36 of the 38 fish species predicted to enter EBCA (2.2 to 35.0 °C; Objective 2 Results). The core 50% of predicted yearly connections occurred from 11 April to 6 August (JD 102 to 219) when mean water temperatures ranged from 10.1 to 23.3 °C (Table 4) and variability was low (CV = 46%), overlapping the 10.0 to 21.2 °C spawning window of predicted fishes (Objective 2 Results).

### *Validity of Initial Connectivity Event Prediction Model Estimates*

Predictions for seven of eight connectivity event variables from the 1993 to 2006 model (hereafter just model) and the 2007 and 2008 connectivity events at calendar year ( $n = 6$  and  $n = 12$ , respectively) and spawning window ( $n = 2$  and  $n = 6$ , respectively) scales were not significantly different (Kruskal-Wallis test; Appendix C: Table C2,  $p \geq 0.11$ ). Only connectivity event frequency was significantly different between study years and the model and depended on the study year (2007 or 2008) and the interval assessed (year, spawning window, or month; Z-test; Appendix C: Table C3).

Connectivity event frequency was more similar to model predictions in 2007 than 2008. Event frequency in 2007 was accurately predicted by the model at both year and spawning window scales (Appendix C: Table C3). However, model frequency predictions at the month scale were only 45% accurate, with six months in 2007 significantly different than predicted (Appendix C: Table C4). In contrast, connectivity event frequency in 2008 was significantly different from the model at all three scales, and only three months had connection frequencies not significantly different from the model (Appendix C: Tables C3, C4). Months with the largest differences in connection frequency were June 2007 and May 2008. The number of events observed was more than double that predicted; although duration was just one day for two of the three connections for respective months.

Whereas within year stage of the LMOR is highly variable, water temperature is highly predictable. Patterns in 2007 and 2008 daily stage and water temperatures generally followed trends depicted by 1993-2006 mean stage and mean water temperature and their associated 95% CIs (Figure 5). Rises in LMOR stage initiating

lateral connectivity with EBCA pools typically occurred during rising water temperatures, but also at times of peak river temperatures (Figure 5). Two-thousand seven was a warmer year than 1993-2006, with 80% of temperature values reached at an earlier date than model means and 95% CIs, and water temperatures during 2008 fell within model predictions, with 90% of temperature values occurring within the 95% CIs (Appendix C: Table C5). Even though 2007 was warmer than a modelled year and 2008, rates of temperature rise during the spring-summer reproductive season were not significantly different among the 1993-2006 means, 2007, and 2008 (ANCOVA;  $n = 519$ ,  $F\text{-value} = 2.24$ ,  $p = 0.11$ ).

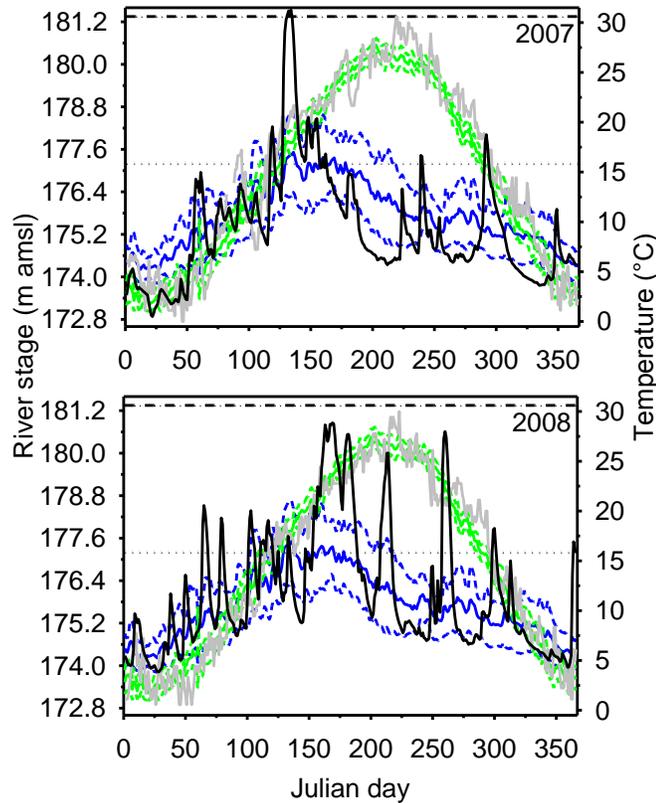


Figure 5. Lower Missouri River (LMOR) daily stage (black line) and water temperature (grey line) for 2007 and 2008 overlaid on LMOR mean daily stage (blue line), mean daily water temperature (green line), and their associated  $\pm 95\%$  confidence intervals (dashed blue and green lines) for 1993 to 2006. Horizontal dotted line indicates minimum stage of connection (177.20 m amsl) between LMOR and Eagle Bluffs Conservation Area (EBCA). Horizontal dashed-dotted line indicates EBCA maximum stage threshold (181.35 m amsl) at which overtopping of levees and inundation of EBCA occurs.

### ***Final Connectivity Event Prediction Model***

Given the minor differences reported above, values of the eight originally modeled connectivity event variables were similar for the original 1993-2006 model and the updated 1993 to 2008 model (Figures 4, 6; Tables 4, 5). Additional measures of connectivity probability, frequency, and duration described below augmented the slightly less accurate measure (relative to the other originally modeled variables) of connectivity

event frequency. Connectivity event probability was highest in May (88%) and June (81%; Figure 6, c). Similarly, connectivity event frequency and monthly connectivity duration showed the strongest likelihood of lateral connectivity in May and June (Figure 6, a, b). The EBCA wetland pools routinely connected with the LMOR; peak river stage at the 2-year return interval (180.33 m amsl, 591.26 ft amsl) translated to a fishway connectivity event stage magnitude of 3.13 m (10 ft; Table 6). The minimum stage of fishway connection for an EBCA floodplain-activation flood (LMOR stage = 177.20 m amsl, 581.4 ft amsl) had an exceedance probability of 88% and a 1.1-year return interval. Maximum stage threshold of EBCA levees (LMOR stage = 181.35 m amsl, 595.0 ft amsl) had an exceedance probability of 35% and a 2.8-year return interval for a floodplain-maintenance flood.

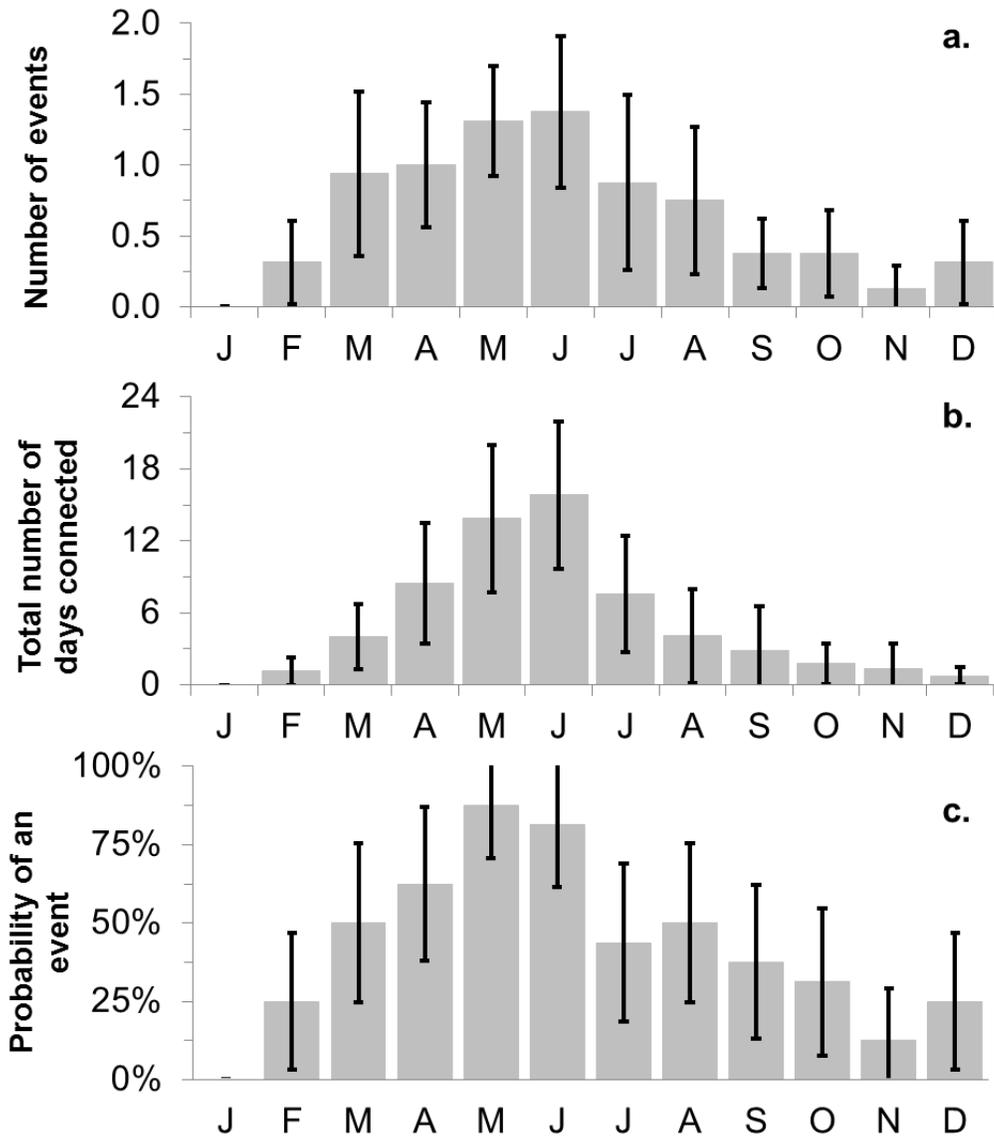


Figure 6. Descriptors of lateral connection between lower Missouri River (LMOR) and Eagle Bluffs Conservation Area (EBCA) wetland pools per month, 1993 to 2008: (a) predicted mean event frequency (number of discrete events), (b) predicted mean monthly connectivity duration (cumulative number of days), and (c) predicted probability of a connectivity event occurring (yes or no). Vertical bars represent  $\pm 95\%$  confidence intervals associated with predictions.

Table 5. Percentile statistics for eight lateral connectivity event variables between lower Missouri River and wetland pools at Eagle Bluffs Conservation Area from 1993-2008 model. Statistics reported at two scales: calendar year (Julian day 1 to 366; 95 observations) and spawning window (when a majority of fishes predicted to enter the wetland begin spawning: 4 April to 1 June, Julian day 95 to 153; 34 observations).

Connectivity event variable (unit of measurement)	Percentile						
	5	10	25	50	75	90	95
Scale: calendar year							
Event frequency (n)	0	1	3	7	11	16	.
Timing of event start date (Julian day)	56	68	107	153	222	295	337
Duration (day)	1	1	2	4	9	23	51
Mean river stage magnitude (m amsl)	177.28	177.33	177.44	177.80	178.34	178.95	179.44
Mean fishway stage magnitude (m)	0.08	0.13	0.24	0.60	1.14	1.75	2.24
Rate-of-rise (m/day)	0.05	0.09	0.18	0.35	0.66	1.01	1.20
Rate-of-fall (m/day)	0.06	0.09	0.16	0.31	0.47	0.69	0.76
Mean water temperature (°C)	3.7	5.7	10.6	17.4	23.0	25.6	26.4
Scale: spawning window							
Event frequency (n)	0	0	1	3	4	5	.
Timing of event start date (Julian day)	91	99	110	126	143	151	153
Duration (day)	1	1	2	6	25	66	100
Mean river stage magnitude (m amsl)	177.27	177.29	177.48	177.98	178.86	179.44	179.64
Mean fishway stage magnitude (m)	0.07	0.09	0.28	0.78	1.66	2.24	2.44
Rate-of-rise (m/day)	0.07	0.09	0.17	0.44	0.73	1.06	1.20
Rate-of-fall (m/day)	0.05	0.08	0.14	0.30	0.42	0.63	0.76
Mean water temperature (°C)	10.2	11.3	14.9	17.2	20.1	22.4	22.9

Table 6. Flood frequency as return intervals performed using Log-Pearson Type III distribution analysis on lower Missouri River stage data from U. S. Geological Survey Boonville gage for calendar years 1993 to 2008. Predicted river stage at return intervals is presented in meters above mean sea level (m amsl) and feet above mean sea level (ft amsl) along with skew coefficients.

Return period (years)	Skew coefficient k(-0.4626)	River stage	
		(m amsl)	(ft amsl)
1.01	-2.40	175.83	576.87
2	0.02	180.33	591.64
5	0.85	181.90	596.79
10	1.27	182.71	599.45
25	1.72	183.57	602.25
50	2.00	184.11	604.04
100	2.25	184.60	605.64
200	2.48	185.04	607.10

## **Objective 2: Predicted and Observed Fish Access to Floodplain Wetlands**

### ***LMOR Water Temperatures Corresponding to Calendar Dates***

There was little variation in the date a specific water temperature was predicted during the spring-summer reproductive season. For example, the 95% CI when 16 °C was reached spanned six days in early May (Appendix D: Table D1).

### ***Fish-Use Predictions and Representation of Ecological Guilds***

The 136 species master list for the Missouri River, was reduced to a 52 species LMOR regional species list (Montgomery and Galat 2014, Appendix C, Tables C.1, C.2).

Thirty-eight fish species were predicted to access the floodplain for spawning or nursery during a lateral connectivity event (Table 7). Macrohabitat generalist species composed 74% of predicted EBCA-use fishes and 26% were fluvial dependents. Seven (18%) of the 38 predicted EBCA-use fishes were introduced species and most were fluvial dependents except goldfish, common carp, and western mosquitofish. Four reproductive guilds dominated the 38 species predicted to enter the wetland: lithopelagophil (32%, 12 species), speleophil (18%, 7 species), phytophil (16%, 6 species), and pelagophils (13%, 5 species; Table 7).

Table 7. Spawning temperature range estimates for 36 of 38 lower Missouri River (LMOR) fish species predicted to enter Eagle Bluffs Conservation Area wetland pools during a connectivity event. Additional species information includes habitat-use guild (macrohabitat generalist [MG] and fluvial dependent [FD]), reproductive guild, and estimated spawning calendar and Julian date ranges for LMOR. Species are ordered by increasing spawning temperature ranges. Silver carp and species listed below it are designated as late-spring spawners, whereas species listed before are considered early-spring spawners. Species with no ending spawning date range exhibit an upper temperature limit for spawning above the peak mean water temperature observed in LMOR. Introduced species are indicated with an asterisk and invasive species with two asterisks. See Introduction for definitions of ecological guilds.

Scientific name	Common name	Habitat-use guild	Reproductive guild	Spawning temperature range (°C)	Spawning date range	
					Calendar dates	Julian dates
<i>Sander vitreus</i>	walleye	MG	Lithopelagophil	2.2-24.0	18 February - 21 June	49-173
<i>Sander canadensis</i>	sauger	MG	Lithopelagophil	3.9-11.7	5 March - 16 April	65-107
<i>Hiodon alosoides</i>	goldeye	FD	Lithopelagophil	10.0-21.7	4 April - 5 June	95-157
<i>Dorosoma cepedianum</i>	gizzard shad	MG	Lithopelagophil	10.0-29.0	4 April -	95-
<i>Ictiobus cyprinellus</i>	bigmouth buffalo	MG	Lithopelagophil	13.3-27.0	22 April -	113-
<i>Polyodon spathula</i>	paddlefish	FD	Lithopelagophil	13.3-20.6	22 April - 31 May	113-152
<i>Cyprinus carpio</i> **	common carp	MG	Phytolithophil	13.9-28.0	24 April -	115-
<i>Micropterus salmoides</i>	largemouth bass	MG	Polyphil	13.9-26.7	24 April - 2 August	115-215
<i>Pomoxis nigromaculatus</i>	black crappie	MG	Phytophil	14.0-23.9	24 April - 20 June	115-172
<i>Pomoxis annularis</i>	white crappie	MG	Phytophil	14.0-23.9	24 April - 20 June	115-172
<i>Morone saxatilis</i> *	striped bass	FD	Phytolithophil	14.4-23.9	25 April - 20 June	116-172
<i>Pimephales promelas</i>	fathead minnow	MG	Speleophil	14.4-29.4	25 April -	116-
<i>Notemigonus crysoleucas</i>	golden shiner	MG	Phytophil	15.0-27.0	30 April -	121-
<i>Carassius auratus</i> *	goldfish	MG	Phytophil	15.0-29.8	30 April -	121-
<i>Lepisosteus osseus</i>	longnose gar	FD	Phytolithophil	15.0-30.0	30 April -	121-
<i>Hypophthalmichthys molitrix</i> **	silver carp	FD	Pelagophil	15.5-26.9	2 May -	123-
<i>Aplodinotus grunniens</i>	freshwater drum	FD	Pelagophil	15.5-28.5	2 May -	123-
<i>Gambusia affinis</i> *	western mosquitofish	MG	Viviparous	15.6-18.0	3 May - 16 May	124-137
<i>Ictiobus bubalus</i>	smallmouth buffalo	MG	Lithopelagophil	15.6-18.3	3 May - 17 May	124-138
<i>Cyprinella lutrensis</i>	red shiner	MG	Speleophil	15.6-31.7	3 May -	124-

Table 7 (continued)

Scientific name	Common name	Habitat-use guild	Reproductive guild	Spawning temperature range (°C)	Spawning date range	
					Calendar dates	Julian dates
<i>Ameiurus natalis</i>	yellow bullhead	MG	Speleophil	15.6-23.9	3 May - 20 June	124-172
<i>Hybognathus hankinsoni</i>	brassy minnow	MG	Phytophil	16.0-27.0	4 May -	125-
<i>Lepisosteus platostomus</i>	shortnose gar	MG	Phytophil	16.5-24.0	6 May - 21 June	127-173
<i>Lepomis macrochirus</i>	bluegill	MG	Polyphil	17.0-32.2	10 May -	131-
<i>Ctenopharyngodon idella</i> **	grass carp	FD	Pelagophil	17.6-30.6	14 May -	135-
<i>Hypophthalmichthys nobilis</i> **	bighead carp	FD	Pelagophil	18.0-30.0	16 May -	137-
<i>Lepomis humilis</i>	orangespotted sunfish	MG	Lithophil	18.0-31.7	16 May -	137-
<i>Carpionodes carpio</i>	river carpsucker	MG	Lithopelagophil	18.3-24.0	17 May - 21 June	138-173
<i>Ictalurus punctatus</i>	channel catfish	MG	Speleophil	18.9-29.5	21 May -	142-
<i>Macrhybopsis storeriana</i>	silver chub	MG	Lithopelagophil	18.9-18.9	21 May - 22 May	142-143
<i>Pylodictis olivaris</i>	flathead catfish	FD	Speleophil	19.0-29.0	21 May -	142-
<i>Carpionodes cyprinus</i>	quillback	MG	Lithopelagophil	19.0-28.0	21 May -	142-
<i>Lepomis cyanellus</i>	green sunfish	MG	Polyphil	19.0-35.0	21 May -	142-
<i>Pimephales notatus</i>	bluntnose minnow	MG	Speleophil	20.0-26.1	27 May - 13 July	148-195
<i>Ameiurus melas</i>	black bullhead	MG	Speleophil	21.0-30.0	1 June -	153-
<i>Notropis atherinoides</i>	emerald shiner	MG	Pelagophil	22.2-24.0	8 June - 21 June	160-173
<i>Hybognathus argyritis</i>	western silvery minnow	FD	Lithopelagophil			
<i>Ictiobus niger</i>	black buffalo	MG	Lithopelagophil			

### ***Species-Specific Spawning Water Temperature and Spawning Date Ranges***

Spawning temperature ranges and corresponding calendar dates were found in the literature for 36 of the 38 species (Table 7). Approximated spawning temperature range for the 36 fish species was 2.2 to 35.0 °C and spawning date range was 19 February to approximately 2 August (LMOR peak mean daily water temperature of 26.7 °C; Table 7).

Mean daily water temperature when all 36 species were predicted to have begun spawning was 15.4 °C (Mode: 15.6 °C; Appendix D: Figure D1). The spawning window when 85% were estimated to begin spawning was 10.0 to 21.2 °C, corresponding to 4 April to 1 June (JD 95 to 153). Forty-seven percent (17 species) of the 36 fish species were predicted to begin spawning before 15.6 °C, 11% (4 species) at 15.6 °C, 42% (15 species) after 15.6 °C, and 61% (22 species) remained spawning at 25.0°C (Table 7; Appendix D: Figure D1). The modal value for the minimum water temperature necessary for spawning was rounded up to 16 °C (mean = 4 May; 95% CI = 2 to 7 May) and separated early- and late-spring spawning groups (Table 7; Appendix D: Figure D1).

Spawning temperature range of 9 fluvial dependent species predicted to access the floodplain was 10.0 to 30.6 °C, or 4 April to 2 August when LMOR water temperature peaked. Total spawning temperature range was relatively wide (20.6 °C) for these species and spawning range for individual species followed a similar trend with an average individual range of 11.4 °C. Native paddlefish (*Polyodon spathula*) had the narrowest spawning temperature range (7.3 °C), estimated to start on 22 April and extend over 40 days in LMOR. In contrast, fluvial dependent species such as invasive Asian carps (*Hypophthalmichthys* spp.) had a spawning temperature range twice as wide (14.5 °C) as paddlefish, or about 93 days beginning 2 May. Paddlefish were grouped into both

early- and late-spring spawning groups since they begin spawning at lower water temperatures than Asian carps (~13 °C versus ~16 to 18 °C). Silver carp, and especially bighead carp, were designated as late-spring spawners (Table 7).

Estimated range of spawning temperatures of 27 macrohabitat generalist species was also wide, ranging from 2.2 to 35.0 °C (18 February to 2 August). Invasive common carp had a protracted spawning range width of 14.1 °C, or about 101 days during the spawning season. In contrast, native shortnose gar showed a spawning range half as wide (7.5 °C) or approximately 47 days. Common carp were characterized as early- and late-spring spawners, whereas shortnose gar belonged only to the late-spring spawning group (Table 7).

### ***Predicted and Observed Fish Assemblages***

A higher number of species accessed the wetland during 2008 than predicted; macrohabitat generalists (69%) and lithopelagophils (26%) were dominant. A 0.60 Jaccard similarity coefficient indicated assemblages were “moderately similar” since slightly over half of all species were present in predicted and observed assemblages. Thirty-eight species were predicted to enter the area during a connectivity event, but 31 species were sampled entering during the five ingress events with 26 on the list of predicted EBCA-use fishes (Table 8). Forty-two percent of the 12 species predicted to enter the wetland, but not sampled, were fluvial dependents and 50% were lithopelagophils, which can enter floodplains as larvae.

Table 8. Similarity (Jaccard similarity coefficient) in taxa compositions (presence = 1; absence = 0) of fish assemblages using Eagle Bluffs Conservation Area wetland pools: predicted (P) versus observed (O1 and O2) assemblages (Objective 2), uncontrolled flooding (UF) versus controlled flooding (CF1 and CF2) assemblages (Objective 4), and early-season (early) versus late-season (late) egress event assemblages of each year (Objective 6). Assemblages in Objectives 2 and 4 are evaluated with data during two testing rounds (Ingress Only and All Connections) due to different habitat-use and reproductive requirements of floodplain-using fish assemblages. Assemblage-level information includes taxa richness, number of taxa shared between assemblages, and number of taxa unique to each assemblage. Taxon-specific information, where available, includes common name, ecological guild (habitat-use and reproductive [Repro]), and incidence data for each assemblage. See footnotes for assemblage data details, definitions of ecological guild acronyms, and explanation of the use of “n/a.”

Common name <sup>a</sup>	Ecological guild		Objective 2 <sup>d</sup>			Objective 4 <sup>e</sup>			Objective 6 <sup>f</sup>			
	Habitat-use <sup>b</sup>	Repro <sup>c</sup>	P	O1	O2	UF	CF1	CF2	2007		2008	
									Early	Late	Early	Late
chestnut lamprey	FD	LPH	0	1	1	1	1	1	1	0	0	0
paddlefish	FD	LPP	1	0	1	1	0	1	1	0	0	1
spotted gar	MG	PHP	0	0	0	1	0	0	1	0	0	0
longnose gar	FD	PHL	1	0	0	1	0	0	1	0	0	0
shortnose gar	MG	PHP	1	1	1	1	1	1	1	1	1	1
skipjack herring	FD	PHL	0	0	1	1	0	1	1	0	1	0
gizzard shad	MG	LPP	1	1	1	1	1	1	1	1	1	1
goldeye	FD	LPP	1	0	1	1	0	1	1	1	1	1
central stoneroller	FS	LPH	0	0	0	1	0	0	1	0	0	0
goldfish	MG	PHP	1	1	1	1	1	1	1	1	1	1
grass carp	FD	PEP	1	1	1	1	1	1	1	1	1	1
red shiner <sup>g</sup>	MG	SEP	1	0	0 <sup>h</sup>	1	0	0 <sup>h</sup>	1	1	0 <sup>h</sup>	0
common carp	MG	PHL	1	1	1	1	1	1	1	1	1	1
western silvery minnow	FD	LPP	1	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
brassy minnow	MG	PHP	1	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
silver carp <sup>h</sup>	FD	PEP	1	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bighead carp <sup>h</sup>	FD	PEP	1	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bighead carp x silver carp hybrid <sup>h</sup>	FD	PEP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
unidentified Asian carp <sup>h</sup>	FD	PEP	n/a	n/a	n/a	1	1	1	1	1	1	1

Table 8 (continued)

Common name <sup>a</sup>	Ecological guild		Objective 2 <sup>d</sup>			Objective 4 <sup>e</sup>			Objective 6 <sup>f</sup>			
	Habitat-use <sup>b</sup>	Repro <sup>c</sup>	P	O1	O2	UF	CF1	CF2	2007		2008	
									Early	Late	Early	Late
common shiner	FD	LPH	0	0	0	1	0	0	0	1	0	0
redfin shiner	FS	LPH	0	0	0	1	0	0	1	0	0	0
speckled chub	FS	LPP	0	0	0	1	0	0	1	0	0	0
silver chub	MG	LPP	1	0	1	1	0	1	1	0	1	0
golden shiner	MG	PHP	1	1	1	1	1	1	1	0	1	0
rudd		PHL	0	0	0	1	0	0	1	0	0	0
emerald shiner	MG	PEP	1	1	1	1	1	1	1	1	1	1
river shiner <sup>k</sup>	FS	LPP	0	0	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bigmouth shiner <sup>k</sup>	FS	PEP	0	0	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
sand shiner <sup>k</sup>	FS	LPP	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
unidentified shiner <sup>k</sup>	FS		n/a	n/a	n/a	1	0	1	1	1	1	0
unidentified minnow			n/a	n/a	n/a	1	1	1	1	1	0	0
bluntnose minnow	MG	SEP	1	1	1	1	1	1	1	0	0	0
fathead minnow	MG	SEP	1	0	0	1	0	0	1	0	0	0
bullhead minnow	MG	SEP	0	1	1	1	1	1	1	1	1	0
creek chub	MG	LPH	0	1	1	1	1	1	1	0	0	0
river carpsucker	MG	LPP	1	1	1	1	1	1	1	1	1	0
quillback	MG	LPP	1	1	1	1	1	1	1	1	1	0
blue sucker	FS	LPP				1	0	0	1	0	0	0
smallmouth buffalo <sup>j</sup>	MG	LPP	1	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bigmouth buffalo <sup>j</sup>	MG	LPP	1	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
black buffalo <sup>j</sup>	MG	LPP	1	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
unidentified buffalo <sup>j</sup>	MG	LPP	n/a	n/a	n/a	1	1	1	1	1	1	1
golden redborse <sup>i</sup>	FD	LPH	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
shorthead redborse <sup>i</sup>	FD	LPH	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
black redborse <sup>i</sup>	FS	LPH	0	0	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
unidentified redborse <sup>i</sup>		LPH	n/a	n/a	n/a	1	0	1	1	0	1	0
black bullhead	MG	SEP	1	1	1	1	1	1	1	1	1	0

Table 8 (continued)

Common name <sup>a</sup>	Ecological guild		Objective 2 <sup>d</sup>			Objective 4 <sup>e</sup>			Objective 6 <sup>f</sup>			
	Habitat-use <sup>b</sup>	Repro <sup>c</sup>	P	O1	O2	UF	CF1	CF2	2007		2008	
									Early	Late	Early	Late
yellow bullhead	MG	SEP	1	1	1	1	1	1	1	1	1	1
channel catfish <sup>g</sup>	MG	SEP	1	1	1	1	1	1	1	1	0 <sup>h</sup>	0
flathead catfish	FD	SEP	1	0	0	1	0	0	1	0	0	0
starhead topminnow	MG	PHL	0	0	0	1	0	0	1	0	0	0
western mosquitofish	MG	VIV	1	1	1	1	1	1	1	1	1	1
brook silverside	MG	PHL	0	0	0	1	0	0	1	0	0	0
white bass	FD	PHL	0	1	1	1	1	1	0	1	0	1
striped bass	FD	PHL	1	1	1	1	1	1	1	0	1	1
green sunfish	MG	POP	1	1	1	1	1	1	1	1	1	1
warmouth	MG	LPH	0	0	0	1	0	0	1	0	0	0
orangespotted sunfish	MG	LPH	1	1	1	1	1	1	1	1	1	1
green sunfish x orangespotted sunfish hybrid	MG		n/a	n/a	n/a	1	1	1	1	0	0	1
bluegill	MG	POP	1	1	1	1	1	1	1	1	1	1
longear sunfish	MG	POP	0	0	0	1	0	0	1	0	0	0
redeer sunfish	MG	POP	0	0	0	1	0	0	1	0	0	0
unidentified Lepomis	MG		n/a	n/a	n/a	1	0	0	1	1	0	0
smallmouth bass	MG	POP	0	0	1	0	0	1	0	0	1	0
spotted bass	MG	POP	0	1	1	1	1	1	1	0	1	1
largemouth bass	MG	POP	1	0	0	1	0	0	1	0	0	0
unidentified Micropterus spp.	MG	POP	n/a	n/a	n/a	1	0	0	1	0	0	0
white crappie	MG	PHP	1	1	1	1	1	1	1	1	1	1
black crappie	MG	PHP	1	1	1	1	1	1	1	0	1	0
unidentified sunfish	MG		n/a	n/a	n/a	1	0	0	0	1	0	0
johnny darter	MG	SEP	0	0	1	0	0	1	0	0	1	0
logperch	MG	LPH	0	0	1	0	0	1	0	0	1	0
blackside darter	FS	LPH	0	0	0	1	0	0	1	0	0	0
sauger	MG	LPP	1	0	1	1	0	1	1	0	1	0
walleye	MG	LPP	1	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 8 (continued)

Common name <sup>a</sup>	Ecological guild		Objective 2 <sup>d</sup>			Objective 4 <sup>e</sup>			Objective 6 <sup>f</sup>			
	Habitat-use <sup>b</sup>	Repro <sup>c</sup>							2007		2008	
			P	O1	O2	UF	CF1	CF2	Early	Late	Early	Late
freshwater drum	FD	PEP	1	1	1	1	1	1	1	1	1	1
Round one (Ingress Only)		Total taxa	38	31		58	30					
		Shared taxa	26	26		30	30					
		Unique taxa	12	5		28	0					
Round two (All Connections)		Total taxa	38		42	58		40	55	28	34	21
		Shared taxa	30		30	37		37	25	25	18	18
		Unique taxa	8		12	21		3	30	3	16	3
Jaccard similarity coefficient				0.60	0.60		0.52	0.61		0.43		0.49

<sup>a</sup> Two specimen-identity data formats used: expanded groups and collapsed groups. Expanded groups format identifies all specimens to the lowest possible taxonomic level (species, genus or family) and data for four groups of taxa (indicated by superscripts i-l) not combined into genus-level groups. Collapsed groups format provides data associated with each of those four taxa groups combined into one genus-level group.

<sup>b</sup> Habitat-use guilds: fluvial specialist (FS), fluvial dependent (FD), and macrohabitat generalist (MG).

<sup>c</sup> LPP = Lithopelagophil; LPH = Lithophil; PEP = Pelagophil; PHL = Phytolithophil; PHP = Phytophil; POP = Polyphil; SEP = Speleophil; VIV = Viviparous.

<sup>d</sup> P = Predicted assemblage = list of predicted fishes from Table 7; O1 = Observed Assemblage 1 = 2008 ingress; O2 = Observed Assemblage 2 = 2008 total; Expanded groups data format used with specimens not identified to species removed from dataset (indicated by a "n/a").

<sup>e</sup> UF = Uncontrolled Flooding Assemblage = 2007 Egress; CF1 = Controlled Flooding Assemblage 1 = 2008 ingress; CF2 = Controlled Flooding Assemblage 2 = 2008 total; Collapsed groups data format was used.

<sup>f</sup> Early-season egress events = 3E1407 in 2007 and 6E1508 in 2008; Late-season egress events = 4E1507 in 2007 and 7E1508 in 2008; Collapsed groups data format was used.

<sup>g</sup> Collected specimen not included because it failed to pass the minimum total length requirement; see text for details.

<sup>h</sup> Expanded groups: bighead carp, silver carp, bighead-silver carp hybrid, unidentified Asian carp. Collapsed groups: Asian carps.

<sup>i</sup> Expanded groups: black redhorse, golden redhorse, shorthead redhorse, unidentified redhorse. Collapsed groups: Redhorses.

<sup>j</sup> Expanded groups: bigmouth buffalo, smallmouth buffalo, black buffalo, unidentified buffalofish. Collapsed groups: Buffalofishes.

<sup>k</sup> Expanded groups: river shiner, sand shiner, bigmouth shiner, unidentified shiner. Collapsed groups: Shiners.

n/a = represents (i) reconciliation of using expanded groups and collapsed groups specimen-identity data formats in the same table in relation to the 4 taxa groups identified with superscripts h-k; (ii) species predicted but not observed in any connectivity event; and (iii) additional specimens not identified down to species level and, if sampled, not used in Objective 2.

Five of the 12 species predicted to enter, but not sampled during ingress events, were sampled subsequently during egress events. All except red shiner (*Cyprinella lutrensis*) had specimens below the maximum age-0 length cut-off values and were lithopelagophils. The smallest red shiner specimen collected exiting EBCA was 40 mm

total length, indicating it was likely an age-1 residual 2007 fish. Since there were seven additional species sampled during egress events that were not predicted to enter EBCA, the Jaccard similarity coefficient did not increase after including data from egress events despite the increase in species shared between predicted and observed assemblages (Table 8). Twelve species were collected across 2008 ingress and egress events (Observed Assemblage 2; Table 8), but 10 did not pass the two distribution criteria. Either they were considered rarely collected or were identified as primarily reservoir or tributary species. Fewer than eight individuals of each species were sampled across all seven connectivity events (using raw count data), except for spotted bass (*Micropterus punctulatus*), chestnut lamprey (*Ichthyomyzon castaneus*), and skipjack herring (*Alosa chrysochloris*). River shiner and bigmouth shiner were collected during egress events, although not predicted because of their fluvial specialist habitat-use. However, both had specimens smaller than age-0 length cut-off values (32 mm and 31 mm, respectively) and thus remained in the Observed Assemblage 2 species list.

### **Connectivity Event Variables of Monitored Connectivity Events and Wetland**

#### **Inundation Durations (used in Objectives 3, 5, and 6)**

Ingress events showed a wide range in duration and stage magnitude (Table 9), which was displayed for six of the seven ingress events as a matrix depicting ingress event types with an overlay of flood-pulse water level, photoperiod, and water temperature as secondary filters (Figure 7); event 2I1407 was not classified due to its extremely short duration. Variations in water exchanged during ingress events exhibited long duration and large magnitude (5I1508), long duration and medium magnitude (3I1508), medium

duration and large magnitude (1I1508), short duration and medium magnitude (1I1407), and short duration and low mean stage magnitude (2I1508 and 4I1508; Figure 7). Event 1I1407 was also flashy due to its fast rate-of-rise combined with observed duration and magnitude. Mean water temperatures during the seven ingress events ranged from 11.7 to 22.1 °C; temperatures during 1I1407 were between 2I1508 and 3I1508 which occurred at similar dates the following spring (Table 9). Accordingly, events 1I1407, 2I1508 and 3I1508 were designated as mid-spring events rather than early- or late-spring events because of their thermal characteristics (Figure 7).

Table 9. Measured and calculated variables (ranges) describing connectivity events between lower Missouri River (LMOR) and Eagle Bluffs Conservation Area (EBCA) wetland pools. Event identification codes are a string of numbers and a letter indicating event sampling order for that year (1, 2, ..., 7); whether it was an ingress (I) or egress (E) event; which pools' fishway was used (14 or 15); and study year (07 = 2007 or 08 = 2008). The two egress events of each year are also referred to as early-season and late-season egress events (early = *3E1407*, *6E1508*; late = *4E1507*, *7E1508*). Egress event *3E1407* is italicized to highlight its close association with the levee-topping connectivity event. Rate-of-rise was calculated for ingress events where water was entering EBCA from LMOR, and rate-of-fall was calculated for egress events where water was exiting EBCA to LMOR. For additional explanation of calculations of variables, see Methods section: *connectivity event variables of monitored connectivity events*.

Connectivity event	Mean temperature (°C)	Mean photoperiod (h/day)	Event duration (h)	Sampling duration (h)	Mean fishway stage magnitude (m)	Water level fluctuation	Water exchange <sup>a</sup>		Rate-of-rise (m/day) <sup>b</sup>	Rate-of-fall (m/day)
							Mean discharge (m <sup>3</sup> /s)	Total volume (m <sup>3</sup> )		
1I1407	14.4 (14.2-14.7)	13.73 (13.72-13.75)	35.88	35.88	0.69 (0.12-1.01)	rising	0.03 (0.02-0.04)	3961	0.59	
2I1407	19.7 n/a	14.07 n/a	0.25	0.25	1.04 n/a	rising	1.08 n/a	972	n/a	
<i>3E1407</i>	23.7 (20.5-28.8)	14.62 (14.45-14.77)	375.50	366.00	1.91 (1.07-2.47)	managed	0.87 (0.12-1.80)	1 170 733		0.09
4E1507	30.4 (26.6-34.2)	13.88 (13.82-13.95)	96.50	29.75	0.28 (0.09-1.39)	managed	0.17 (<0.01-1.47)	58 630		0.32
1I1508	11.7 (10.7-12.5)	13.08 (13.03-13.12)	44.75	43.25	1.10 (0.43-1.40)	rising	0.22 (-0.04-0.67)	35 899	0.47	
2I1508	13.4 (13.3-13.6)	13.49 (13.47-13.52)	35.75	35.00	0.17 (0.09-0.21)	stable	0.00 (<-0.01 - <0.01)	0	0.07	
3I1508	17.5 (15.7-20.5)	13.66 (13.58-13.73)	103.75	99.83	0.56 (0.00-0.85)	stable	0.01 (<-0.01 - 0.04)	2347	0.50 (0.14-0.85)	

Table 9 (continued)

Connectivity event	Mean temperature (°C)	Mean photoperiod (h/day)	Event duration (h)	Sampling duration (h)	Mean fishway stage magnitude (m)	Water level fluctuation	Water exchange <sup>a</sup>		Rate-of-rise (m/day) <sup>b</sup>	Rate-of-fall (m/day)
							Mean discharge (m <sup>3</sup> /s)	Total volume (m <sup>3</sup> )		
4I1508	14.2 (13.5-14.6)	14.27 (14.25-14.28)	36.00	34.17	0.14 (0.05-0.30)	falling	0.00 (-0.01 - <0.01)	0	-0.17	
5I1508	22.1 (21.6-22.9)	14.77 (14.73-14.8)	114.50	108.58	1.09 (0.37-1.55)	rising	0.54 (-0.01-1.53)	224 491	0.43 (<0.01-0.85)	
6E1508	28.4 (24.7-30.8)	14.69 (14.60-14.77)	35.08	5.50	1.70 (1.49-1.98)	managed	0.59 (0.13-1.15)	74 232		0.35
7E1508	27.2 (25.8-29.6)	13.80 (13.78-13.82)	31.02	5.40	0.87 (0.11-1.34)	managed	0.21 (0.01-0.75)	23 009		0.96

<sup>a</sup> Fine-scale water-level fluctuations resulted in overall very small negative discharge readings for events 2I1508 and 4I1508 ( $\leq -0.002$  m<sup>3</sup>/s) despite overall river stage being stable for 2I1508 and decreasing for 4I1508. Discharge readings were replaced with zeros to reflect these circumstances and more accurately depict the water movement situation occurring during these events. The negative readings for volume of water exchanged during 2I1508 (-42 m<sup>3</sup>) and 4I1508 (-250 m<sup>3</sup>) were also replaced with zeros; however, the negative readings, after transformation to absolute values, were used to standardize biomass by area in Objective 3.

<sup>b</sup> Two water-level peaks were sampled during events 3I1508 and 5I1508, and mean rate-of-rise was determined for each event by averaging the two rates.

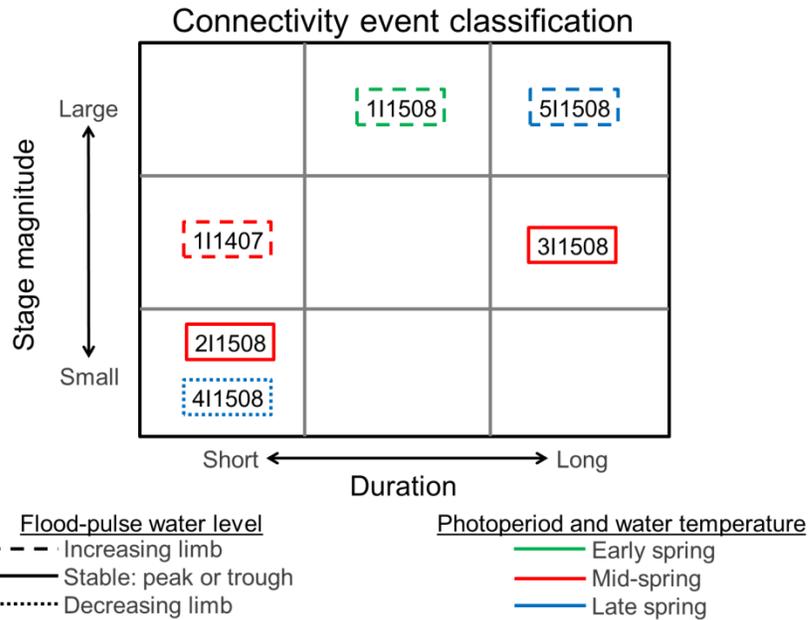


Figure 7. Duration and stage magnitude matrix depicting ingress event types that occurred via fishways of wetland pools 14 and 15 at Eagle Bluffs Conservation Area on the lower Missouri River. Flood-pulse water level, photoperiod, and water temperature are secondary modifying filters that influence what riverine fish species enter the wetland during an ingress event and what activities these fishes perform in the wetland.

Hydrothermal dynamics during early-season egress event *3E1407* were generally different from the other three egress events due to the levee-topping event preceding it and subsequent inundation of most of EBCA. Event *3E1407* occurred earlier in the spring-summer period than the other egress events and had the lowest mean water temperature (23.7 °C [ $\pm 1.7$  °C SD]) compared to the range of 27.2 °C [ $\pm 1.1$  °C SD] to 30.4 °C [ $\pm 2.3$  °C SD] for other egress events; Table 9). Also, event *3E1407* had a larger total volume of water released (by a range of 1 096 500 to 1 147 724 m<sup>3</sup>) over a longer duration (by a range of 279 to 344 h) than the other egress events. Even so, mean photoperiods were similar between the two early early-season egress events (14.62 h/day [ $\pm 0.10$  h/day SD] in *3E1407* and 14.69 h/day [ $\pm 0.07$  h/day SD] in *6E1508*) and between

the two late-season egress events (13.88 h/day [ $\pm 0.05$  h/day SD] in 4E1507 and 13.80 h/day [ $\pm 0.02$  h/day SD] in 7E1508; Table 9).

Early-season egress events occurred from 21 May to 6 June (JD 142 to 158) in 2007 and from 7 July to 17 July (JD 189 to 199) in 2008 (Table 1). Late-season egress events occurred from 8 August to 12 August (JD 221 to 225) in 2007 and from 11 August to 12 August (JD 224 to 225) in 2008. The start of the 2008 early-season egress event was 47 days later than in 2007, but the 2008 late-season egress event was only 3 days later than in 2007. The 2007 early-season egress began 11 days after the assumed beginning of the levee over-topping on 10 May (JD 131), and the 2008 early-season egress started 31 days after the conclusion of the final ingress event 5I1508 on 6 June (JD 158). The 2007 late-season egress event began 79 days after the start of the early-season egress, whereas 35 days transpired between starts of the 2008 early- and late-season egress events.

### **Objective 3: Fish Assemblage Structure, Total Abundance, and Biomass during Connectivity Events**

#### ***Fish Assemblage Structure***

Sixty-three species, two hybrids, and eight taxa groups were sampled across the eleven connectivity events and composed the EBCA Total fish assemblage (Table 10)<sup>2</sup>.

Dominant habitat-use guilds were macrohabitat generalist (60%, 38 species) and fluvial

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<sup>2</sup> The CPUE data for the collapsed groups format is presented here; species-specific ecological guild information is in Objective 2 Results; and, CPUE data for the expanded groups format is in Appendix E.

dependent (24%, 15 species); the 8 reproductive guilds (except for viviparous) were represented rather evenly, with each constituting 8 to 19% (6 to 14 species; Tables 8, 11). Combined relative species richness across all 11 connectivity events was high, 41 of the 52 species from the regional species list were sampled moving through the fishway; species richness for individual events ranged from 5 to 57. A mean of 15 species was sampled per ingress event (range = 5 to 27 species; Table 11). A mean of 36 species (range = 21 to 57 species) was sampled per egress event, with early-season events (3E1407, 6E1508) exhibiting almost twice as many species as late-season events (4E1507, 7E1508; Table 11).

Table 10. Taxa relative abundance, taxa relative structure, and fish assemblage relative abundance for fish assemblages sampled during 10 connectivity events between lower Missouri River and Eagle Bluffs Conservation Area wetland pools during spring-summer 2007 and 2008. Categories are individual connectivity event (6 ingress and 4 egress) and yearly total ingress and egress (Ingress 2007, Ingress 2008, Egress 2007, and Egress 2008). Collapsed groups data format identifies specimens to lowest possible taxonomic level (species, genus, or family) and combines data for four groups of taxa into genus-level groups reflecting varying identification levels across events (Asian carps, Buffalofishes, Shiners, and Redhorses). Taxa relative abundance ( $\pm 1$  standard error) is raw count data standardized by catch-per-unit-effort (CPUE) to mean number of fish collected per hour (fish/h). Taxa relative structure (% in italics) is the percent ratio of taxa relative abundance to total number of individuals across all taxa. Fish assemblage relative abundance is summed taxa relative abundance estimates. See Table 9 for connectivity event code explanation. Fish assemblage data for event 2I1407 were excluded because only one 15-minute fyke-net sample was taken and count data were not extrapolated to one hour to calculate mean CPUE and its standard error.

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
	1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008
chestnut lamprey	0.27 (0.13)	0.61 (0.28)		0.02 (0.01)		0.04 (0.03)	0.02 (0.02)				0.27 n/a	0.22 (0.19)	0.02 n/a	
paddlefish	<i>0.51</i>	<i>3.03</i>		<i>0.45</i>		<i>0.11</i>	<i>&lt;0.01</i>				<i>0.51</i>	<i>1.31</i>	<i>&lt;0.01</i>	
spotted gar							0.07 (0.03)			0.80 (0.80)			0.07 n/a	(0.80) n/a
longnose gar							<i>&lt;0.01</i>			<i>0.01</i>			<i>&lt;0.01</i>	<i>0.01</i>
shortnose gar	0.90 (0.51)	0.55 (0.30)		0.49 (0.24)	0.32 (0.19)	19.40 (8.30)	10.70 (6.86)	118.53 (62.44)	203.06 (42.95)	290.35 (131.73)	0.90 n/a	5.19 (4.74)	64.61 (53.91)	246.71 (43.64)
	<i>1.73</i>	<i>2.72</i>		<i>11.06</i>	<i>16.07</i>	<i>50.68</i>	<i>0.19</i>	<i>7.14</i>	<i>2.03</i>	<i>4.97</i>	<i>1.73</i>	<i>30.44</i>	<i>1.75</i>	<i>3.10</i>

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress					Egress				Ingress		Egress		
	1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008
skipjack							1.96		4.88				1.96	4.88
herring							(1.60)		(3.39)				n/a	n/a
							0.03		0.05				0.05	0.06
gizzard	0.21	1.18		1.13	0.28	3.57	79.03	883.49	3963.44	819.58	0.21	1.54	481.26	2391.51
shad	(0.21)	(0.59)		(0.35)	(0.28)	(1.09)	(59.16)	(480.11)	(3254.98)	(419.70)	n/a	(0.71)	(402.23)	(1571.93)
	0.39	5.85		25.56	14.13	9.33	1.38	53.23	39.54	14.02	0.39	9.03	13.02	30.06
goldeye							6.12	1.41	309.44	0.67			3.77	155.05
							(2.27)	(1.30)	(203.00)	(0.62)			(2.36)	(154.38)
							0.11	0.08	3.09	0.01			0.10	1.95
central stoneroller							0.14						0.14	
							(0.09)						n/a	
							<0.01						<0.01	
goldfish	19.56	0.38		0.10		0.10	6.78	6.27	0.81	9.00	19.56	0.19	6.52	4.91
	(6.38)	(0.17)		(0.06)		(0.06)	(5.03)	(2.23)	(0.75)	(7.13)	n/a	(0.09)	(0.26)	(4.09)
	37.33	1.87		2.16		0.27	0.12	0.38	0.01	0.15	37.33	1.13	0.18	0.06
grass carp						0.01	43.94	12.68	857.44	84.77		0.01	28.31	471.10
						(0.01)	(18.12)	(7.25)	(297.32)	(40.57)		n/a	(15.63)	(386.34)
						0.02	0.77	0.76	8.55	1.45		0.05	0.77	5.92
red shiner							51.93	1.00	6.69				26.46	6.69
							(14.39)	(1.00)	(3.82)				(25.46)	n/a
							0.91	0.06	0.07				0.72	0.08
common carp	6.39	7.80		0.99	0.06	11.46	4854.38	66.37	85.94	413.22	6.39	5.08	2460.38	249.58
	(3.73)	(3.56)		(0.64)	(0.06)	(4.14)	(4630.15)	(34.44)	(48.81)	(199.62)	n/a	(2.74)	(2394.01)	(163.64)
	12.19	38.73		22.37	2.83	29.94	84.95	4.00	0.86	7.07	12.19	29.78	66.58	3.14

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
Asian carps	0.07		0.02		0.09	445.36	212.01	3421.19	576.52		0.06	328.68	1998.85	
	(0.04)		(0.01)		(0.04)	(219.07)	(57.60)	(1930.67)	(429.94)		(0.02)	(116.67)	(1422.33)	
	0.33		0.44		0.23	7.79	12.77	34.13	9.86		0.34	8.89	25.12	
common shiner							2.00					2.00		
							(2.00)					n/a		
							0.12					0.05		
redfin shiner						0.01						0.01		
						(<0.01)						n/a		
						<0.01						<0.01		
speckled chub						<0.01						<0.01		
						(<0.01)						n/a		
						<0.01						<0.01		
silver chub						0.05		1.56				0.05	1.56	
						(0.02)		(0.92)				n/a	n/a	
						<0.01		0.02				<0.01	0.02	
golden shiner	0.10	0.05	0.01	0.03	0.19	0.27		6.13		12.00	0.08	0.27	6.13	
	(0.05)	(0.05)	(0.01)	(0.03)	(0.08)	(0.08)		(2.78)		n/a	(0.03)	n/a	n/a	
	0.52	1.64	0.23	1.41	0.51	<0.01		0.06		4.16	0.46	0.01	0.08	
rudd						<0.01						<0.01		
						(<0.01)						n/a		
						<0.01						<0.01		
emerald shiner			0.01		0.02	16.92	0.47	13.31	1.40		0.02	8.70	7.36	
			(0.01)		(0.02)	(7.34)	(0.01)	(11.14)	(0.87)		(0.01)	(8.22)	(5.96)	
			0.23		0.06	0.30	0.03	0.13	0.02		0.09	0.24	0.09	

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
Shiners						0.58 (0.27)	2.92 (1.77)	0.69 (0.42)				1.75 (1.17)	0.69 n/a	
						0.01	0.18	0.01				0.05	0.01	
unidentified minnow				0.03 (0.03)		0.58 (0.37)	5.82 (4.62)				0.03 n/a	3.20 (2.62)		
				1.41		0.01	0.35				0.16	0.09		
bluntnose minnow			0.01 (0.01)			0.29 (0.11)					0.01 n/a	0.29 n/a		
			0.20			0.01					0.05	0.01		
fathead minnow						<0.01 (<0.01)						<0.01 n/a		
						<0.01						<0.01		
bullhead minnow	0.02 (0.02)				0.02 (0.02)	12.44 (4.01)	1.00 (1.00)	0.19 (0.19)			0.02 (<0.01)	6.72 (5.72)	0.19 n/a	
	0.10				0.04	0.22	0.06	<0.01			0.10	0.18	<0.01	
creek chub	0.02 (0.02)					0.15 (0.06)					0.02 n/a	0.15 n/a		
	0.10					<0.01					0.12	<0.01		
river carpsucker			0.03 (0.03)	0.03 (0.03)	0.03 (0.03)	0.51 (0.28)	0.41 (0.34)	0.69 (0.33)			0.03 (<0.01)	0.46 (0.05)	0.69 n/a	
			0.70	1.41	0.08	0.01	0.02	0.01			0.18	0.01	0.01	
quillback			0.03 (0.02)		0.02 (0.01)	0.01 (0.01)	0.15 (0.15)	1.25 (0.77)			0.03 (<0.01)	0.08 (0.07)	1.25 n/a	
			0.66		0.06	<0.01	0.01	0.01			0.15	<0.01	0.02	

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
blue sucker						5.33 (3.72) 0.09							5.33 n/a 0.14	
Buffalofishes	0.14 (0.14) 0.26	4.71 (1.44)		0.61 (0.33) 13.79	0.03 (0.03) 1.41	1.24 (0.62) 3.24	146.43 (78.53) 2.56	1.10 (0.64) 0.07	17.50 (4.23) 0.17	0.80 (0.80) 0.01	0.14 n/a 0.26	1.65 (1.05) 9.66	73.76 (72.67) 2.00	9.15 (8.35) 0.12
Redhorses						0.48 (0.23) 0.01							0.48 n/a 0.01	0.38 n/a <0.01
black bullhead	0.03 (0.03) 0.06			0.01 (0.01) 0.21			0.01 (<0.01) <0.01	2.49 (2.21) 0.15	0.06 (0.06) <0.01		0.03 n/a 0.06	0.01 n/a 0.05	1.25 (1.24) 0.03	0.06 n/a <0.01
yellow bullhead					0.02 (0.01) 0.05	<0.01 (<0.01) <0.01	1.60 (0.98) 0.10	0.06 (0.06) <0.01	1.00 (1.00) 0.02			0.02 n/a 0.05	0.80 (0.80) 0.02	0.53 (0.47) 0.01
channel catfish		0.02 (0.02) 0.10				0.18 (0.11) 0.48	2.07 (0.86) 0.04	0.07 (0.04) <0.01	0.38 (0.38) <0.01			0.10 (0.08) 0.59	1.07 (1.00) 0.03	0.38 n/a <0.01
flathead catfish						0.24 (0.10) <0.01							0.24 n/a 0.01	
starhead topminnow						<0.01 (<0.01) <0.01							<0.01 n/a <0.01	

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
western mosquitofish	2.57 (1.13)	0.90 (0.61)	3.01 (1.83)	0.48 (0.11)	0.41 (0.08)	0.10 (0.05)	0.67 (0.14)	41.63 (16.92)	71.19 (13.13)	1194.20 (509.94)	2.57 n/a	0.98 (0.52)	21.15 (20.48)	632.69 (561.51)
brook silverside	4.91	4.46	92.88	10.83	20.85	0.25	0.01 (0.02)	2.51	0.71	20.42	4.91	5.75	0.57	7.95
white bass						0.01 (0.01)		4.00 (4.00)		2.48 (1.93)		0.01 n/a	4.00 n/a	2.48 n/a
striped bass						0.02 (0.01)		0.24		0.04 (0.04)		0.04 n/a	0.11 n/a	0.03 (1.70)
green sunfish	8.35 (5.22)	1.03 (0.43)	0.03 (0.03)	0.07 (0.04)	0.03 (0.03)	0.09 (0.05)	0.19 (0.04)	41.12 (11.16)	195.00 (71.22)	306.56 (207.09)	8.35 n/a	0.25 (0.20)	20.66 (20.46)	250.78 (55.78)
warmouth	15.93	5.13	0.86	1.65	1.41	0.24	<0.01 (0.01)	2.48	1.95	5.24	15.93	1.47	0.56	3.15
orangespotted sunfish	13.20 (6.70)	2.68 (1.15)	0.12 (0.04)	0.24 (0.11)	0.21 (0.06)	0.61 (0.38)	4.36 (1.48)	118.29 (32.87)	737.94 (193.37)	2110.76 (1248.00)	13.20 n/a	0.77 (0.48)	61.33 (56.96)	1424.35 (686.41)
green sunfish x orangespotted sunfish hybrid	25.20	13.29	3.64	5.40	10.48	1.60	0.08 (0.01)	7.13	7.36	36.10 (0.43)	25.20	4.52 n/a	1.66 n/a	17.90 n/a
							<0.01		0.01	0.50		0.03	0.01	0.50
							<0.01			0.01		0.16	<0.01	0.01

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
bluegill	0.76	0.04	0.03	0.09	0.53	0.18	6.72	116.85	22.19	2.38	0.76	0.17	61.78	12.28
	(0.48)	(0.04)	(0.03)	(0.04)	(0.11)	(0.05)	(1.50)	(50.26)	(9.11)	(1.14)	n/a	(0.09)	(55.06)	(9.90)
	<i>1.45</i>	<i>0.19</i>	<i>0.98</i>	<i>1.99</i>	<i>27.16</i>	<i>0.46</i>	<i>0.12</i>	<i>7.04</i>	<i>0.22</i>	<i>0.04</i>	<i>1.45</i>	<i>1.02</i>	<i>1.67</i>	<i>0.15</i>
longear sunfish							<0.01						<0.01	
							(<0.01)						n/a	
							<0.01						<0.01	
redeer sunfish							0.01						<0.01	
							(0.01)						n/a	
							<0.01						<0.01	
unidentified Lepomis							0.01	3.23					1.62	
							(<0.01)	(1.59)					(1.61)	
							<0.01	<i>0.19</i>					<i>0.04</i>	
smallmouth bass									0.75					0.75
									(0.75)					n/a
									<i>0.01</i>					<i>0.01</i>
spotted bass						0.02	0.10		59.06	0.60		0.02	0.10	29.83
						(0.02)	(0.03)		(29.86)	(0.60)		n/a	n/a	(29.23)
						<i>0.06</i>	<0.01		<i>0.59</i>	<i>0.01</i>		<i>0.13</i>	<0.01	<i>0.37</i>
largemouth bass	0.03						0.08				0.03		0.08	
	(0.03)						(0.04)				n/a		n/a	
	<i>0.06</i>						<0.01				<i>0.06</i>		<0.01	
unidentified Micropterus spp.							<0.01						<0.01	
							(<0.01)						n/a	
							<0.01						<0.01	

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008	
white crappie	0.04 (0.03)	0.01 (0.01)	0.02 (0.01)	0.02 (0.01)	0.35 (0.27)	2.29 (1.19)	2.75 (1.62)	0.40 (0.28)		0.02 (0.01)	1.32 (0.97)	1.58 (1.18)		
black crappie	0.21	0.24	0.06	0.07 (0.04)	0.03 (0.01)	0.14	0.03 (9.85)	0.01		0.15 n/a	0.04 n/a	0.02 n/a		
unidentified sunfish		1.60			<0.01		0.44 (0.35)			0.41	<0.01	0.16		
johnny darter							0.44 (0.35)		0.06 (0.06)				0.06 n/a	
logperch									0.31 (0.22)				0.31 n/a	
blackside darter									<0.01			<0.01		
sauger									0.32 (0.11)	0.13 (0.09)		0.32 n/a	0.13 n/a	
									0.01	<0.01		0.01	<0.01	

Table 10 (continued)

Common name (CG)	Taxa mean CPUE relative abundance (fish/h)													
	(Standard error of taxa mean CPUE relative abundance) <sup>a</sup>													
	<i>Taxa relative structure (%)</i>													
	Ingress						Egress				Ingress		Egress	
	1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	3E1407	4E1507	6E1508	7E1508	2007 <sup>b</sup>	2008	2007	2008
freshwater drum				0.01 (0.01) 0.22	0.84 (0.42) 2.19		14.74 (7.58) 0.26	12.07 (7.84) 0.73	21.75 (9.55) 0.22	21.78 (8.93) 0.37		0.42 (0.41) 2.49	13.41 (1.34) 0.36	21.76 (0.01) 0.27
Fish assemblage CPUE relative abundance (fish/h)	52.40	20.14	3.24	4.42	1.97	38.28	5714.52	1659.69	10 024.81	5847.17	52.40	17.05	3695.16	7956.26
Taxa richness	12	16	5	20	12	24	55	28	34	21	12	30	58	37

<sup>a</sup> The standard error associated with the mean relative abundance estimate of a given species (or taxa) is displayed as “n/a” at the yearly total ingress and egress level when that species (or taxa) was sampled during only one corresponding connectivity event; standard error is displayed with the mean relative abundance data at the individual connectivity event level.

<sup>b</sup> Species (or taxa) and fish assemblage relative abundances for event 1I1407 and for Ingress 2007 are identical because raw count data from 2I1407 were not standardized to CPUE.

Table 11. Native, introduced, and total species richness and number of species in two ecological guilds (habitat-use and reproductive) for fish assemblages sampled during 11 connectivity events between lower Missouri River and Eagle Bluffs Conservation Area (EBCA) wetland pools during spring-summer 2007 and 2008. Guild representation shown for individual connectivity event (ingress or egress), yearly total ingress and egress, and EBCA total.

Ecological guild	Individual connectivity events											Ingress		Egress		EBCA total
	Ingress						Egress					2007	2008	2007	2008	
	1I1407	2I1407	1I508	2I508	3I508	4I508	5I508	3E1407	4E1507	6E1508	7E1508					
Habitat-use																
Macrohabitat generalist	11	10	15	5	18	10	20	35	19	27	13	13	24	35	27	38
Fluvial dependent	1	0	2	0	4	0	7	13	7	7	8	1	7	15	9	15
Fluvial specialist	0	0	0	0	0	0	0	8	2	3	0	0	0	8	3	9
Blank	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1
Reproductive																
Phytolithophil	1	1	1	0	1	1	3	7	2	3	3	1	3	8	4	8
Lithopelagophil	2	1	3	0	5	3	6	14	8	9	4	2	6	14	10	14
Phytophil	2	3	4	1	5	2	4	6	3	5	3	3	5	6	5	6
Pelagophil	0	0	1	0	4	0	5	6	5	6	5	0	5	6	6	6
Speleophil	1	0	2	0	2	0	3	8	5	6	1	1	5	8	6	9
Lithophil	2	2	3	1	2	1	2	9	2	3	1	3	3	10	3	12
Polyphil	3	2	2	2	2	2	3	6	2	4	3	3	3	6	4	7
Viviparous	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Native species richness	9	7	13	4	17	8	19	48	22	29	13	11	23	50	31	54
Introduced species richness	3	3	4	1	5	2	8	9	6	8	8	3	8	9	8	9
Species richness	12	10	17	5	22	10	27	57	28	37	21	14	31	59	39	63

Analysis of the CPUE relative abundance data format (which excluded data from 2I1407) showed fish assemblage relative abundance was considerably larger during egress than ingress events. It also indicated fewer fishes were produced in the wetland in 2007 even though more fishes entered that year. Total ingress and egress calculations for

2007 revealed 52 fish/h entered the wetland and 3695 fish/h exited to the river; whereas, for 2008, only 17 fish/h entered but 7956 fish/h exited (Table 10).

Taxa relative structures of fish assemblages both years were influenced by the extremely high relative abundance estimates of a few taxa (Table 10). Goldfish, orangespotted sunfish, and green sunfish composed 78% (41 fish/h) of taxa relative structure entering the wetland in 2007; whereas, dominant taxa entering the wetland in 2008 were common carp, shortnose gar, Buffalofishes, and gizzard shad (79%, 13 fish/h). The fish assemblage exiting to the river in 2007 was dominated by common carp (67%, 2460 fish/h), followed by gizzard shad and Asian carps (22%, 810 fish/h). The assemblage exiting in 2008 was dominated by gizzard shad and Asian carps (55%, 4390 fish/h), followed by orangespotted sunfish and western mosquitofish (26%, 2057 fish/h). Five additional species composed >1% of the fish assemblage during either egress 2007 or egress 2008: grass carp, goldeye (*Hiodon alosoides*), Buffalofishes, bluegill, and red shiner.

### ***Total Abundance***

Estimated raw, unstandardized total abundances of the total export fish assemblages moving from EBCA wetland pools to the LMOR in 2007 and 2008 were approximately 3.0 and 3.3 million fishes, respectively (Table 12). Taxa relative structure estimates calculated using taxa total abundance were similar to taxa relative structure estimates calculated using taxa relative abundance, with three to four dominant taxa for the total export assemblage each year. In order of decreasing taxa relative structure, the exported

fish assemblage was dominated by common carp, gizzard shad, and Asian carps in 2007 (79%) and by orangespotted sunfish, gizzard shad, Asian carps, and western mosquitofish in 2008 (79%; Table 12). Export fish assemblage total abundance occurred over 19.7 days while about 1.23 hm<sup>3</sup> (325 million gallons) of water was released from EBCA during 2007 and over 2.8 days while about 0.01 hm<sup>3</sup> (26 million gallons) of water was released during 2008. Total export fish assemblage standardized by duration in 2007 was approximately 6450 fish/h; but in 2008, it was 49 379 fish/h, despite the lateral exchange pathway having been open for 151% less time in 2008 than in 2007. Total export fish assemblage standardized by volume was approximately 3 fish/m<sup>3</sup> in 2007, but it was 34 fish/m<sup>3</sup> in 2008 despite 170% less water volume exported that year than in 2007. The total export fish assemblage standardized by area (relative to full-pool water level) was approximately 130 000 fish/ha (52 000 fish/acre) in 2007 and approximately 139 000 fish/ha (56 000 fish/acre) in 2008.

Table 12. Estimates of fish assemblage total abundance, taxa total abundance, and taxa relative structure of fish assemblages sampled during four egress events in spring-summer 2007 and 2008 where water and fishes exited Eagle Bluffs Conservation Area wetland pools to the lower Missouri River via a managed water release through the fishway. Fish assemblage total abundance was also standardized to fish export by duration of fishway gate operation (fish/h), fish export by amount of water exchanged (fish/m<sup>3</sup>), and fish export by inundated wetland surface area (fish/ha). Collapsed groups (CG) data format is used here (see Table 10 for explanation).

Common name (CG)	Taxa total abundance (fish) (Taxa relative structure [%])					
	Individual egress events				2007 total	2008 total
	2007		2008			
Early	Late	Early	Late			
chestnut lamprey	7 (<0.01)				7 (<0.01)	
paddlefish	29 (<0.01)			289 (0.01)	29 (<0.01)	289 (0.01)
spotted gar	4 (<0.01)				4 (<0.01)	
longnose gar	5 (<0.01)				5 (<0.01)	
shortnose gar	3203 (0.20)	95 004 (6.53)	9385 (1.41)	168 048 (6.47)	98 207 (3.23)	177 433 (5.44)
skipjack herring	531 (0.03)		350 (0.05)		531 (0.02)	350 (0.01)
gizzard shad	21 637 (1.36)	674 330 (46.33)	306 802 (45.95)	335 612 (12.93)	695 967 (22.86)	642 414 (19.68)
goldeye	1901 (0.12)	444 (0.03)	19 289 (2.89)	346 (0.01)	2345 (0.08)	19 635 (0.60)
central stoneroller	44 (<0.01)				44 (<0.01)	
goldfish	1950 (0.12)	3647 (0.25)	65 (0.01)	4053 (0.16)	5597 (0.18)	4118 (0.13)
grass carp	14 070 (0.89)	8306 (0.57)	43 525 (6.52)	37 377 (1.44)	22 376 (0.74)	80 902 (2.48)
red shiner	16 696 (1.05)	396 (0.03)	275 (0.04)		17 092 (0.56)	275 (0.01)
common carp	1 318 632 (83.00)	62 111 (4.27)	5837 (0.87)	210 614 (8.11)	1 380 743 (45.36)	216 450 (6.63)
Asian carps	143 579 (9.04)	182 414 (12.53)	230 536 (34.52)	243 843 (9.39)	325 993 (10.71)	474 379 (14.53)
common shiner		885 (0.06)			885 (0.03)	

Table 12 (continued)

Common name (CG)	Taxa total abundance (fish)					
	(Taxa relative structure [%])					
	Individual egress events				2007 total	2008 total
	2007		2008			
Early	Late	Early	Late			
redfin shiner	2				2	
	(<0.01)				(<0.01)	
speckled chub	2				2	
	(<0.01)				(<0.01)	
silver chub	17		39		17	39
	(<0.01)		(0.01)		(<0.01)	(<0.01)
golden shiner	89		271		89	271
	(0.01)		(0.04)		(<0.01)	(0.01)
rudd	1				1	
	(<0.01)				(<0.01)	
emerald shiner	5039	96	1041	525	5135	1566
	(0.32)	(0.01)	(0.16)	(0.02)	(0.17)	(0.05)
Shiners	191	2461	40		2652	40
	(0.01)	(0.17)	(0.01)		(0.09)	(<0.01)
unidentified minnow	226	6270			6496	
	(0.01)	(0.43)			(0.21)	
bluntnose minnow	93				93	
	(0.01)				(<0.01)	
fathead minnow	1				1	
	(<0.01)				(<0.01)	
bullhead minnow	3730	443	5		4172	5
	(0.23)	(0.03)	(<0.01)		(0.14)	(<0.01)
creek chub	49				49	
	(<0.01)				(<0.01)	
river carpsucker	153	246	22		399	22
	(0.01)	(0.02)	(<0.01)		(0.01)	(<0.01)
quillback	5	35	67		40	67
	(<0.01)	(<0.01)	(0.01)		(<0.01)	(<0.01)
blue sucker	1593				1593	
	(0.10)				(0.05)	
Buffalofishes	45 121	1246	602	289	46 367	891
	(2.84)	(0.09)	(0.09)	(0.01)	(1.52)	(0.03)
Redhorses	144		32		144	32
	(0.01)		(<0.01)		(<0.01)	(<0.01)
black bullhead	3	1427	1		1430	1
	(<0.01)	(0.10)	(<0.01)		(0.05)	(<0.01)
yellow bullhead	1	353	1	0	354	1
	(<0.01)	(0.02)	(<0.01)	(<0.01)	(0.01)	(<0.01)
channel catfish	719	45	32		764	32
	(0.05)	(<0.01)	(<0.01)		(0.03)	(<0.01)

Table 12 (continued)

Common name (CG)	Taxa total abundance (fish)					
	(Taxa relative structure [%])					
	Individual egress events				2007 total	2008 total
	2007		2008			
Early	Late	Early	Late			
flathead catfish	90 (0.01)				90 (<0.01)	
starhead topminnow	1 (<0.01)				1 (<0.01)	
western mosquitofish	214 (0.01)	66 802 (4.59)	2693 (0.40)	432 684 (16.67)	67 016 (2.20)	435 377 (13.34)
brook silverside	7 (<0.01)				7 (<0.01)	
white bass		1279 (0.09)		1075 (0.04)	1279 (0.04)	1075 (0.03)
striped bass	2 (<0.01)		434 (0.06)	3569 (0.14)	2 (<0.01)	4003 (0.12)
green sunfish	61 (<0.01)	64 973 (4.46)	10 577 (1.58)	145 050 (5.59)	65 034 (2.14)	155 627 (4.77)
warmouth	6 (<0.01)				6 (<0.01)	
orangespotted sunfish	1227 (0.08)	158 245 (10.87)	29 883 (4.48)	1 000 030 (38.52)	159 472 (5.24)	1 029 914 (31.55)
green sunfish x orangespotted sunfish hybrid	2 (<0.01)			235 (0.01)	2 (<0.01)	235 (0.01)
bluegill	2129 (0.13)	109 213 (7.50)	933 (0.14)	580 (0.02)	111 343 (3.66)	1514 (0.05)
longear sunfish	1 (<0.01)				1 (<0.01)	
redeer sunfish	4 (<0.01)				4 (<0.01)	
unidentified Lepomis	2 (<0.01)	2582 (0.18)			2584 (0.08)	
smallmouth bass			16 (<0.01)			16 (<0.01)
spotted bass	30 (<0.01)		3095 (0.46)	229 (0.01)	30 (<0.01)	3324 (0.10)
largemouth bass	24 (<0.01)				24 (<0.01)	
unidentified Micropterus spp.	1 (<0.01)				1 (<0.01)	
white crappie	102 (0.01)	2530 (0.17)	96 (0.01)	56 (<0.01)	2632 (0.09)	152 (<0.01)

Table 12 (continued)

Common name (CG)	Taxa total abundance (fish) (Taxa relative structure [%])					
	Individual egress events				2007 total	2008 total
	2007		2008			
	Early	Late	Early	Late		
black crappie	12 (<0.01)		878 (0.13)		12 (<0.01)	878 (0.03)
unidentified sunfish		343 (0.02)			343 (0.01)	
johnny darter			1 (<0.01)			1 (<0.01)
logperch			5 (<0.01)			5 (<0.01)
blackside darter	1 (<0.01)				1 (<0.01)	
sauger	109 (0.01)		2 (<0.01)		109 (<0.01)	2 (<0.01)
freshwater drum	5257 (0.33)	9386 (0.64)	924 (0.14)	11 677 (0.45)	14 643 (0.48)	12 601 (0.39)
Fish assemblage total abundance (fish)	1 588 749	1 455 509	667 752	2 596 182	3 044 258	3 263 934
Fish export (fish/h)	4231	15 083	19 035	83 694	6450	49 379
Fish export (fish/m <sup>3</sup> )	1.4	24.8	9.0	112.8	2.5	33.6
Fish export (fish/ha)	67 688	62 011	28 449	110 609	129 699	139 058
Duration of water movement (h)	376	97	35	31	472	66
Amount of water exchanged (m <sup>3</sup> )	1 170 733	58 630	74 232	23 009	1 229 363	97 241

## ***Biomass***

### *Fish Assemblage Export Biomass*

Unstandardized gross export biomass of the total fish assemblage was greater in 2007 (53 997 kg, 60 US tons) than 2008 (45 578 kg, 50 US tons; Table 13). However, fish assemblage gross export biomass standardized by duration was 2.9 times greater in 2008 (1457 kg/h) than in 2007 (509.2 kg/h) despite the lateral exchange pathway being open for 151% less time in 2008. Similarly, fish assemblage gross export biomass standardized by volume was 2.3 times greater in 2008 (1.89 kg/m<sup>3</sup>) than in 2007 (0.81 kg/m<sup>3</sup>) despite 170% less water volume exported in 2008. Conversely, biomass standardized by area showed relatively equal gross export biomass (1.2 times greater in 2007) between 2007 (2301 kg/ha) and 2008 (1942 kg/ha). In English units more familiar to managers, fish assemblage gross export biomass was 0.6 US tons/h, 0.05 lbs/cfs, or 1.0 US tons/acre in 2007 and it was 1.6 US tons/h, 0.12 lbs/cfs, or 0.9 US tons/acre in 2008.

Table 13. Gross import and export of standardized biomass (g/h), 25<sup>th</sup> - 75<sup>th</sup> interquartile range (IQR, in parentheses) of standardized biomass, and taxa biomass relative structure (% , in italics) for each taxon and the entire fish assemblage collected during connectivity events between lower Missouri River (LMOR) and Eagle Bluffs Conservation Area (EBCA) wetland pools in spring-summer 2007 and 2008. Gross import to EBCA represents annual combined ingress event data; gross export to LMOR expresses annual combined egress event data. Fish assemblage biomass (and associated IQR) is also reported for the unstandardized format (g), for the standardized by amount of water exchanged format (g/m<sup>3</sup>), and for the standardized by area of inundated wetland format (g/ha). Entry of “n/a” indicates a taxon was sampled, but weight measurements were not recorded and standardized biomass estimate was not calculated; a blank entry indicates a taxon was not sampled that year. Superscript “a” indicates where maximum and minimum values for weight were used to calculate IQR of standardized biomass instead of the 25<sup>th</sup> - and 75<sup>th</sup> -percentiles because of sample size restrictions. Collapsed groups (CG) data format is used here (explanation in Table 10).

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])		<i>Taxa biomass relative structure (%)</i>	
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
chestnut	3.43	0.44	5.68	
lamprey	(3.09 - 4.63)	(0.34 - 0.59)	(4.21 - 6.76)	
	<i>0.01</i>	<i>&lt;0.01</i>	<i>0.01</i>	
paddlefish		0.17		214.00
		(0.09 - 0.24)		(214.00 - 214.00)
		<i>&lt;0.01</i>		<i>0.01</i>
spotted gar		6.04		
		(2.57 - 7.47)		
		<i>&lt;0.01</i>		
longnose gar		14.34		
		(8.02 - 16.70)		
		<i>&lt;0.01</i>		
shortnose gar	6932.60	245 152.07	10 461.74	440 850.69
	(5948.80 - 7739.42)	(188 571.89 - 336 658.01)	(8504.19 - 13 108.93)	(203 208.40 - 641 269.94)
	<i>29.00</i>	<i>48.15</i>	<i>20.76</i>	<i>30.24</i>
skipjack herring		641.43		6.58
		(641.43 - 641.43)		(5.49 - 13.37)
		<i>0.13</i>		<i>&lt;0.01</i>
gizzard shad	3373.89	140 142.51	627.52	112 791.91
	(1623.16 - 6286.83)	(54 439.88 - 211 764.01)	(317.78 - 1136.66)	(65 270.52 - 218 506.71)
	<i>14.11</i>	<i>27.52</i>	<i>1.25</i>	<i>7.74</i>

Table 13 (continued)

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])			
	<i>Taxa biomass relative structure (%)</i>			
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
goldeye		24.58 (21.21 - 28.18)		1332.18 (1104.04 - 1642.80)
		<0.01		0.09
central stoneroller		0.04 (0.04 - 0.06)		
		<0.01		
goldfish	2797.67 (1864.67 - 3730.66)	1458.84 (1155.54 - 1954.70)	40.63 (23.75 - 73.21)	1259.80 (953.00 - 1728.56)
	11.70	0.29	0.08	0.09
grass carp		6511.98 (3893.46 - 7979.86)	88.65 (88.65 - 88.65)	49 588.02 (35 803.98 - 66 360.35)
		1.28	0.18	3.40
red shiner		44.46 (33.35 - 60.92)		14.19 (9.41 - 22.05)
		0.01		<0.01
common carp	10 564.94 (7309.76 - 16 218.83)	9989.84 (7158.09 - 29 224.72)	25 611.38 (18 787.70 - 35 406.13)	230 295.86 (144 084.90 - 307 271.37)
	44.19	1.96	50.83	15.80
Asian carps		101 424.27 (86 652.94 - 116 086.01)	237.34 (40.03 - 334.60)	596 964.87 (510 894.04 - 693 159.76)
		19.92	0.47	40.95
common shiner		2.38 (2.38 - 2.38)		
		<0.01		
redfin shiner		0.01 (<0.01 - 0.01)		
		<0.01		
speckled chub		<0.01 (<0.01 - <0.01)		
		<0.01		
silver chub		0.26 (0.20 - 0.38)		0.34 (0.28 - 0.44)
		<0.01		<0.01
golden shiner	n/a	1.16 (0.88 - 1.81)	1.31 (1.15 - 2.46)	6.53 (4.69 - 8.46)
	n/a	<0.01	<0.01	<0.01

Table 13 (continued)

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])			
	<i>Taxa biomass relative structure (%)</i>			
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
rudd		0.02 (0.02 - 0.02) <0.01		
emerald shiner		30.18 (24.95 - 35.14) 0.01	0.06 (0.01 - 0.06) <0.01	12.33 (10.92 - 43.12) <0.01
Shiners		3.80 (2.65 - 4.54) <0.01		0.31 (0.31 - 0.31) <0.01
unidentified minnow		9.75 (7.80 - 11.70) <0.01	0.02 (0.02 - 0.02) <0.01	
bluntnose minnow		0.35 (0.24 - 0.43) <0.01	<0.01 (<0.01 - <0.01) <0.01	
fathead minnow		0.01 (0.01 - 0.01) <0.01		
bullhead minnow		12.71 (8.84 - 17.98) <0.01	0.03 (0.02 - 0.04) <0.01	0.02 (0.02 - 0.02) <0.01
creek chub		0.06 (0.05 - 0.08) <0.01	0.03 (0.03 - 0.03) <0.01	
river carpsucker		28.34 (22.90 - 37.24) 0.01	2.87 (1.23 - 3.96) 0.01	0.82 (0.66 - 1.07) <0.01
quillback		3.90 (2.58 - 5.71) <0.01	1.38 (1.11 - 2.67) <0.01	2.32 (2.23 - 7.13) <0.01
blue sucker		2.86 (2.17 - 3.67) <0.01		
Buffalofishes	128.00 (92.44 - 263.11)	213.64 (63.80 - 255.11)	13 160.43 (9843.63 - 16 660.30)	9.57 (7.59 - 14.97)
Redhorses	0.54	0.04 0.13 (0.10 - 0.17) <0.01	26.12	<0.01 n/a n/a n/a

Table 13 (continued)

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])			
	<i>Taxa biomass relative structure (%)</i>			
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
black bullhead	0.79 (0.79 - 0.79) <0.01	35.68 (4.76 - 62.54) 0.01	0.46 (0.46 - 0.46) <0.01	0.01 (0.01 - 0.01) <0.01
yellow bullhead		11.63 (8.82 - 14.45) <0.01	2.62 (2.62 - 2.62) 0.01	0.02 (0.02 - 0.02) <0.01
channel catfish		77.21 (28.30 - 207.48) 0.02	74.26 (48.06 - 122.29) 0.15	n/a n/a n/a
flathead catfish		40.77 (27.18 - 50.96) 0.01		
starhead topminnow		<0.01 (<0.01 - <0.01) <0.01		
western mosquitofish	n/a n/a n/a	117.85 (83.17 - 207.99) 0.02	2.84 (2.10 - 3.61) 0.01	4898.12 (3215.84 - 7009.59) 0.34
brook silverside		0.02 (0.02 - 0.03) <0.01		
white bass		301.60 (200.76 - 441.53) 0.06	0.28 (0.28 - 0.28) <0.01	746.15 (545.62 - 935.59) 0.05
striped bass		0.55 (0.49 - 0.60) <0.01	1.52 (1.52 - 1.52) <0.01	2103.63 (1725.68 - 2297.37) 0.14
green sunfish	n/a n/a	512.84 (377.42 - 808.53) 0.10	5.76 (3.37 - 8.83) 0.01	3562.77 (2436.77 - 5934.68) 0.24
warmouth	n/a 4.08 (4.08 - 4.08) 0.02	0.07 (0.05 - 0.10) <0.01		
orangespotted sunfish	n/a n/a	747.67 (514.24 - 1114.44) 0.15	7.78 (4.85 - 11.21) 0.02	10 181.26 (4963.52 - 18 936.70) 0.70
green sunfish x orangespotted sunfish hybrid	n/a	0.18 (0.07 - 0.30) <0.01	0.19 (0.19 - 0.19) <0.01	117.58 (3.57 - 231.59) 0.01

Table 13 (continued)

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])			
	<i>Taxa biomass relative structure (%)</i>			
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
bluegill	92.44 (92.44 - 92.44) 0.39	449.71 (326.34 - 661.26) 0.09	3.81 (1.14 - 10.50) 0.01	58.31 (21.43 - 115.62) <0.01
longear sunfish		0.02 (0.02 - 0.02) <0.01		
redeer sunfish		0.02 (0.02 - 0.02) <0.01		
unidentified Lepomis		1.10 (0.83 - 1.10) <0.01		
smallmouth bass				1.14 (1.14 - 1.14) <0.01
spotted bass		0.04 (0.03 - 0.06) <0.01	5.30 (3.62 - 6.99) 0.01	122.34 (90.59 - 207.03) 0.01
largemouth bass	9.48 (9.48 - 9.48) 0.04	0.03 (0.03 - 0.10) <0.01		
unidentified Micropterus spp.		n/a n/a n/a		
white crappie		37.47 (26.42 - 188.64) 0.01	14.03 (10.89 - 17.16) 0.03	7.05 (5.76 - 8.61) <0.01
black crappie		0.20 (0.01 - 5.89) <0.01	18.13 (3.33 - 26.99) 0.04	41.05 (27.03 - 60.44) <0.01
unidentified sunfish		n/a n/a n/a		
johnny darter				<0.01 (<0.01 - <0.01) <0.01
logperch				0.14 (0.08 - 0.17) <0.01
blackside darter		n/a n/a n/a		

Table 13 (continued)

Common names (CG)	Taxa standardized biomass (g/h)			
	(IQR of taxa standardized biomass [g/h])			
	<i>Taxa biomass relative structure (%)</i>			
	2007		2008	
	Gross import	Gross export	Gross import	Gross export
sauger		0.26 (0.20 - 0.34)		0.23 (0.22 - 0.23)
		<0.01		<0.01
freshwater drum		1091.32 (366.98 - 1923.08)	9.04 (6.57 - 13.37)	2475.05 (1636.91 - 3452.51)
		0.21	0.02	0.17
Fish assemblage standardized biomass (g/h)	23 907.32	509 146.83	50 385.09	1 457 665.19
(IQR [g/h])	(16 948.71 - 34 350.27)	(344 684.57 - 710 488.75)	(37 702.51 - 67 050.51)	(976 248.66 - 1 969 455.74)
Duration of water movement (h)	36.13	472.00	334.75	66.10
Amount of water exchanged (m <sup>3</sup> )	4932.66	1 229 363.00	262 737.45	97 241.38
Fish assemblage unstandardized biomass (g)	431 397.78	53 997 486.87	4 094 082.10	45 578 137.69
(IQR [g])	(296 884.51 - 648 506.44)	(35 091 338.03 - 75 850 091.16)	(3 051 143.40 - 5 492 997.45)	(30 465 857.56 - 61 597 174.09)
Fish assemblage standardized biomass (g/m <sup>3</sup> )	111.24	814.90	230.07	1887.25
(IQR [g/m <sup>3</sup> ])	(76.65 - 166.92)	(558.63 - 1134.78)	(170.63 - 298.07)	(1276.77 - 2546.33)
Fish assemblage standardized biomass (g/ha)	18 379.43	2 300 529.24	174 425.81	1 941 828.12
(IQR [g/ha])	(12 648.58 - 27 629.21)	(1 495 044.56 - 3 231 545.81)	(129 992.06 - 234 025.73)	(1 297 978.85 - 2 624 309.17)

1

Estimates of 2008 net export biomass of the entire fish assemblage revealed total import biomass was small relative to export biomass in 2008 and any shortcomings associated with calculation of net export were minimal. Gross export biomass was so large in 2008 that the difference between gross export (509.2 kg/h) and net export (485.2 kg/h) was small (approximately 4%). Similarly, difference between gross and net export was also very small (approximately 2%) when data for four of the 2008 ingress events were removed from the calculation and only import biomass from the final ingress event (511508) was used to calculate 2008 fish assemblage net export biomass (1434 kg/h).

#### *Taxa Export Biomass*

Larger gross export biomass in 2008 than in 2007 was also evident for numerous species and taxa, with export >1 kg/h recorded for 7 taxa in 2007 and for 12 taxa in 2008, and largest biomass exported each year in descending order was from shortnose gar, Asian carps, gizzard shad, common carp, and grass carp (Table 13). Gross export biomass of shortnose gar in 2008 (2<sup>nd</sup> largest) was 1.8 times larger than in 2007 (largest). Asian carps gross biomass exported in 2008 (largest) was 5.9 times greater than in 2007 (3<sup>rd</sup> largest). Gizzard shad gross biomass exported was similar in 2007 (2<sup>nd</sup> largest) and 2008 (4<sup>th</sup>). Common carp gross biomass exported in 2008 (3<sup>rd</sup> largest) was 23.1 times greater than in 2007 (4<sup>th</sup>). Grass carp gross export biomass (5<sup>th</sup> largest each year) was 7.6 times higher in 2008 than in 2007.

Seven additional taxa exported large biomasses, with freshwater drum and goldfish export >1 kg/h both years (Table 13). Freshwater drum gross biomass exported was similar in 2007 (7<sup>th</sup> largest) and 2008 (9<sup>th</sup>), as was goldfish gross biomass exported in

2007 (6<sup>th</sup>) and 2008 (12<sup>th</sup>). Biomasses >1 kg/h were exported only in 2008 for orangespotted sunfish (6<sup>th</sup> largest), western mosquitofish (7<sup>th</sup>), green sunfish (8<sup>th</sup>), striped bass (10<sup>th</sup>) and goldeye (11<sup>th</sup>).

#### **Objective 4: Fish Assemblages during Uncontrolled and Controlled Flooding**

Taxa composition of fish assemblages accessing EBCA wetland pools via uncontrolled and controlled flooding were “moderately similar” (Jaccard coefficient = 0.61; Table 8), sharing 37 taxa when controlled access was characterized by conjoining the presence/absence data from the two 2008 egress events and the five 2008 ingress events (Controlled Flooding Assemblage 2). Fifty-eight taxa entered EBCA from the 2007 levee-topping, floodplain-maintenance event (Uncontrolled Flooding Assemblage; presence/absence data from the two 2007 egress events), whereas of 40 taxa accessed the wetland through the fishway during backflooding, floodplain-activation events (Controlled Flooding Assemblage 2). Assemblage similarity increased from “considerably different” to “moderately similar” after 2008 egress data were included within Controlled Flooding Assemblage 2. The Jaccard similarity index was recalculated because 11 taxa not sampled during 2008 ingress events were sampled during egress events and (except for a residual 2007 red shiner) those taxa (all lithopelagophils) had specimens below maximum age-0 length cut-off values.

Coarse-scale totals of habitat-use and reproductive guilds were very similar for fish assemblages accessing the wetland via uncontrolled and controlled flooding (Table 8). Macrohabitat generalists were the dominant habitat-use guild ( $\geq 64\%$ , 37 of 58 taxa in

Uncontrolled Flooding Assemblage and 28 of 40 taxa in Controlled Flooding Assemblage 2) and fluvial dependents composed approximately 20% of each assemblage (12 taxa in Uncontrolled Flooding Assemblage and 9 taxa in Controlled Flooding Assemblage 2). Only one fluvial specialist specimen was present in Controlled Flooding Assemblage 2, but fluvial specialists made up 10% of Uncontrolled Flooding Assemblage with six taxa. Eight reproductive guilds were present in each assemblage: all guilds except for viviparous were rather evenly represented, each constituting 7 to 20% of the assemblage. Lithopelagophil was the dominant reproductive guild of both assemblages, with 21% (11 of 53 taxa with membership information) in Uncontrolled Flooding Assemblage and 22% (8 of 37 taxa with membership information) in Controlled Flooding Assemblage 2.

## **Objective 5: Fish Assemblage Similarity and Size Structures of Selected Species**

### **Entering Floodplain Wetlands**

#### *Similarity of Fish Assemblages*

Five of six ingress events had fish assemblages moderately similar in structure (44 to 62%) to the averaged total fish assemblage entering EBCA wetlands (Table 14; Appendix E: Table E1). The short duration, low magnitude event in mid-spring (2I1508) was least similar to the averaged total fish assemblage (percent similarity = 11%). Fish assemblages of the three medium-to-long duration, medium-to-large magnitude events (1I1508, 3I1508, and 5I1508) were moderately similar to each other (45 to 59%), but no other clear pattern emerged between similarity of fish assemblages and either timing or size (duration and magnitude) of connectivity events.

Table 14. Percent similarity index values (%) comparing floodplain-accessing fish assemblages for six ingress events and for the averaged, total assemblage across those events (Ingress total). A “0.0” indicates no species in common and “100.0” indicates identical fish assemblage structure. Ingress events are lateral connectivity periods where fish enter Eagle Bluffs Conservation Area wetland pools from the lower Missouri River. Event identification codes are a string of numbers and a letter indicating event sampling order for that year (1, 2, ..., 5); that it was an ingress (I); which pools’ fishway was used (14 or 15); and study year (07 = 2007 or 08 = 2008).

Ingress event	Percent similarity (%)						Ingress total
	1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	
1I1407	.	40.0	10.4	30.6	23.6	17.5	59.3
1I1508	40.0	.	9.7	58.8	30.3	45.3	60.9
2I1508	10.4	9.7	.	16.5	28.4	3.1	10.8
3I1508	30.6	58.8	16.5	.	50.6	49.9	61.7
4I1508	23.6	30.3	28.4	50.6	.	32.2	43.9
5I1508	17.5	45.3	3.1	49.9	32.2	.	53.3
Ingress total	59.3	60.9	10.8	61.7	43.9	53.3	.

### *Species-Specific Size Structures*

A broad range of selected species size classes were sampled during the seven ingress events (Figure 8). Native gizzard shad ranged from 46 to 452 mm with a bimodal distribution of juvenile and adult specimens. In contrast, unimodal distributions dominated by adults were displayed for invasive common carp (27 to 790 mm), native shortnose gar (415 to 785 mm), and native bigmouth buffalo (39 to 643 mm). Small-bodied species showed unimodal distributions, with introduced western mosquitofish (26 to 55 mm) dominated by adults and native orangespotted sunfish (27 to 88 mm) dominated by juveniles.

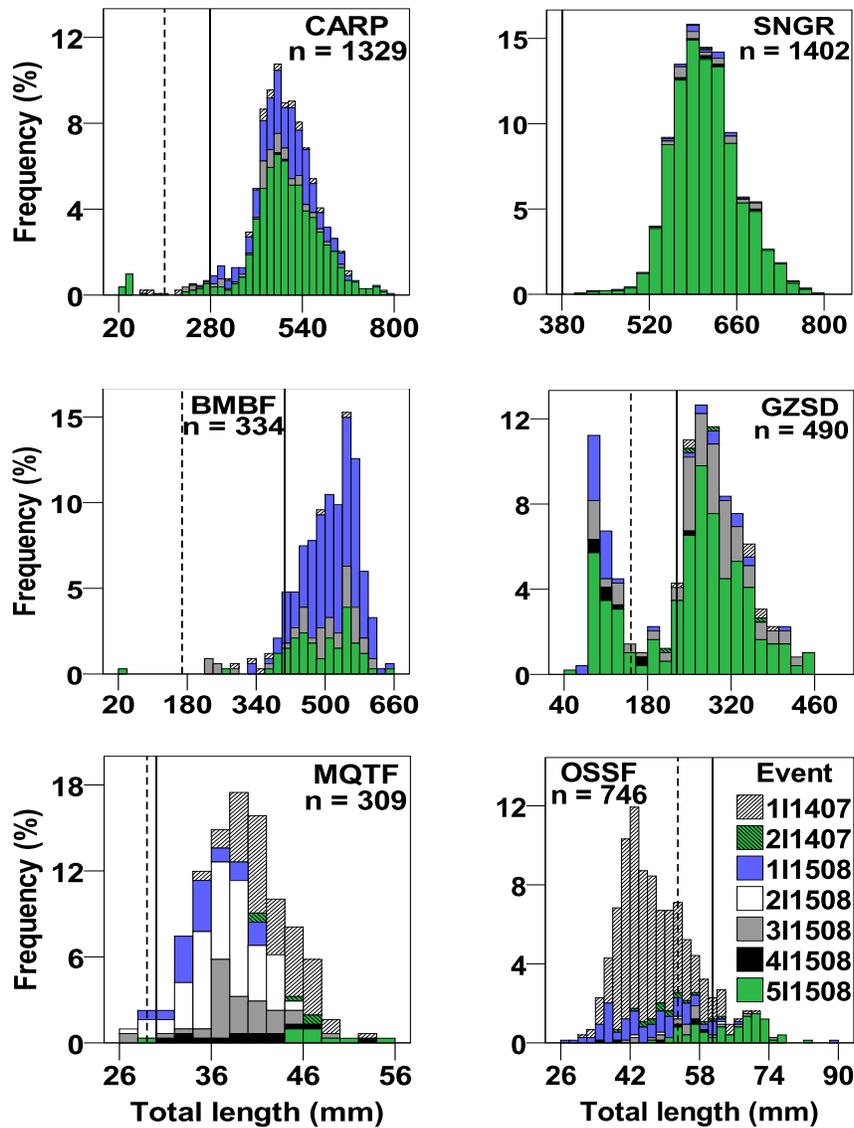


Figure 8. Relative length-frequency histograms of six fish species sampled during lower Missouri River controlled fishway ingress events at Eagle Bluffs Conservation Area during spring-summer 2007 and 2008: common carp (*Cyprinus carpio*, CARP), shortnose gar (*Lepisosteus platostomus*, SNGR), bigmouth buffalo (*Ictiobus cyprinellus*, BMBF), gizzard shad (*Dorosoma cepedianum*, GZSD), western mosquitofish (MQTF, *Gambusia affinis*) and orangespotted sunfish (OSSF, *Lepomis humilis*). Histogram bin widths are 20 mm for the four large-bodied species and 2 mm for MQTF and OSSF. Vertical dashed line indicates approximate maximum total length for age-0 juveniles, and vertical solid line indicates cut-off between juveniles and sexually mature adults (Appendix A, Table A1). Note different axis scales. For the connectivity event identification code, first number refers to the overall sampling order of events of that year and final number refers to the year (see Table 14 for further explanation).

## **Objective 6: Similarity of Fish Assemblages and the Size Structure and Growth Rates of Selected Taxa Exiting Floodplain Wetlands**

### ***Similarity of Fish Assemblages***

Taxa compositions of fish assemblages were “considerably different” between early-season and late-season egress events during both flood year types (Jaccard coefficient = 0.43 in 2007 and 0.46 in 2008; Table 8). Approximately half the taxa sampled during the early-season egress event each year were not sampled during the late-season event, although >85% of taxa sampled during the late-season event had been sampled during the early-season event. Assemblages of the 2007 early-season (3E1407) and late-season (4E1507) egress events contained 55 and 28 taxa, respectively; and, assemblages of the 2008 early-season (6E1508) and late-season (7E1508) egress events had 34 and 21 taxa, respectively. All taxa in 2008 events had specimens below maximum age-0 length cut-off values except red shiner and channel catfish (*Ictalurus punctatus*) whose lengths indicated they were age-1 or older and likely residual 2007 fishes. Early-season and late-season egress events of both flood year types showed similar proportions of habitat-use guilds, with macrohabitat generalist dominant (65 to 75%, 14 to 36 taxa), fluvial dependent second most abundant (18 to 33%, 6 to 10 taxa), and fluvial specialist comprising a small percentage (0 to 11%, 0 to 6 taxa) of the assemblage.

Lithopelagophils were the dominant reproductive guild (20%, 10 taxa) during the 2007 early-season egress event, but lithopelagophils and speleophils were co-dominant (21% each, with 5 taxa) during the late-season egress event. Lithopelagophils were again dominant (23%, 7 taxa) during the 2008 early-season egress event, but pelagophils were dominant (22%, 4 taxa) during the late-season egress event.

### *Taxon-Specific Size Structures*

A broad range of size classes was sampled for eleven taxa during 2007 egress events and nine taxa during 2008 events (Figures 9, 10). A wider range of lengths was collected during the 2007 early-season egress event (3E1407) than during the other three events, showing an increased presence of adults and large juveniles of all taxa and smaller YOY specimens (10 to 20 mm) of some large-bodied taxa (e.g., common carp, freshwater drum, and shortnose gar). Application of taxon-specific sexually mature cut-off values generally distinguished YOY and juvenile specimens from adults for five of the large-bodied taxa; however for shortnose gar, the sexually mature cut-off value (381 mm) split the composite length distribution in the 2007 late-season egress event.

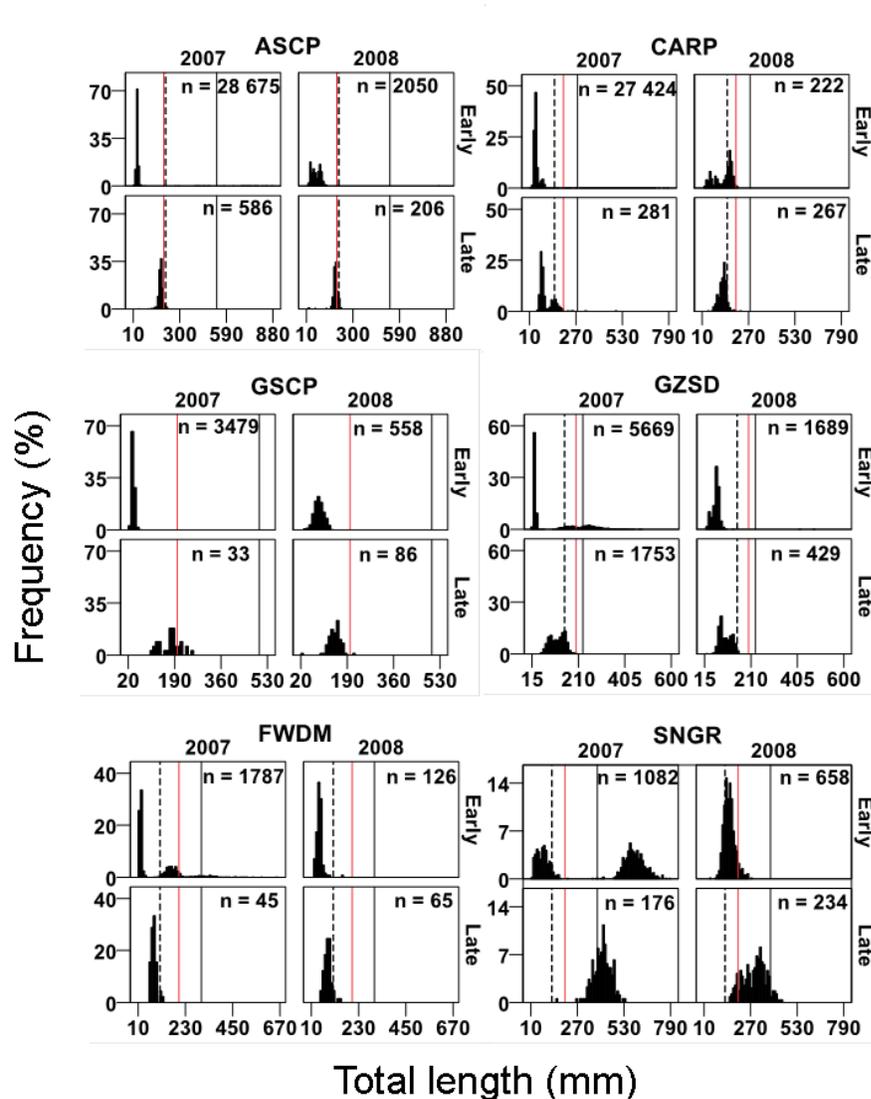


Figure 9. Relative length-frequency histograms for six large-bodied fish taxa sampled during 2007 and 2008 early- and late-season egress events: Asian carps taxa group (*Hypophthalmichthys* spp., ASCP), common carp (*Cyprinus carpio*, CARP), grass carp (*Ctenopharyngodon idella*, GSCP), gizzard shad (*Dorosoma cepedianum*, GZSD), freshwater drum (*Aplodinotus grunniens*, FWDM), and shortnose gar (*Lepisosteus platostomus*, SNGR). Histogram bin widths are 10 mm. Vertical dashed line indicates approximate maximum total length for age-0 juveniles, and vertical solid line indicates cut-off between juveniles and sexually mature adults (Appendix A, Table A1; grass carp data not available). Vertical red line is the total length (200 mm) at which fishes begin exceeding gape-limits of most riverine predators. Asian carps taxa group consisted of bighead carp (*Hypophthalmichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*), hybrid bighead-silver carp (*H. nobilis* x *H. molitrix*), and specimens identified only to *Hypophthalmichthys* genus level (i.e., *Hypophthalmichthys* spp.). Note the different axis scales.

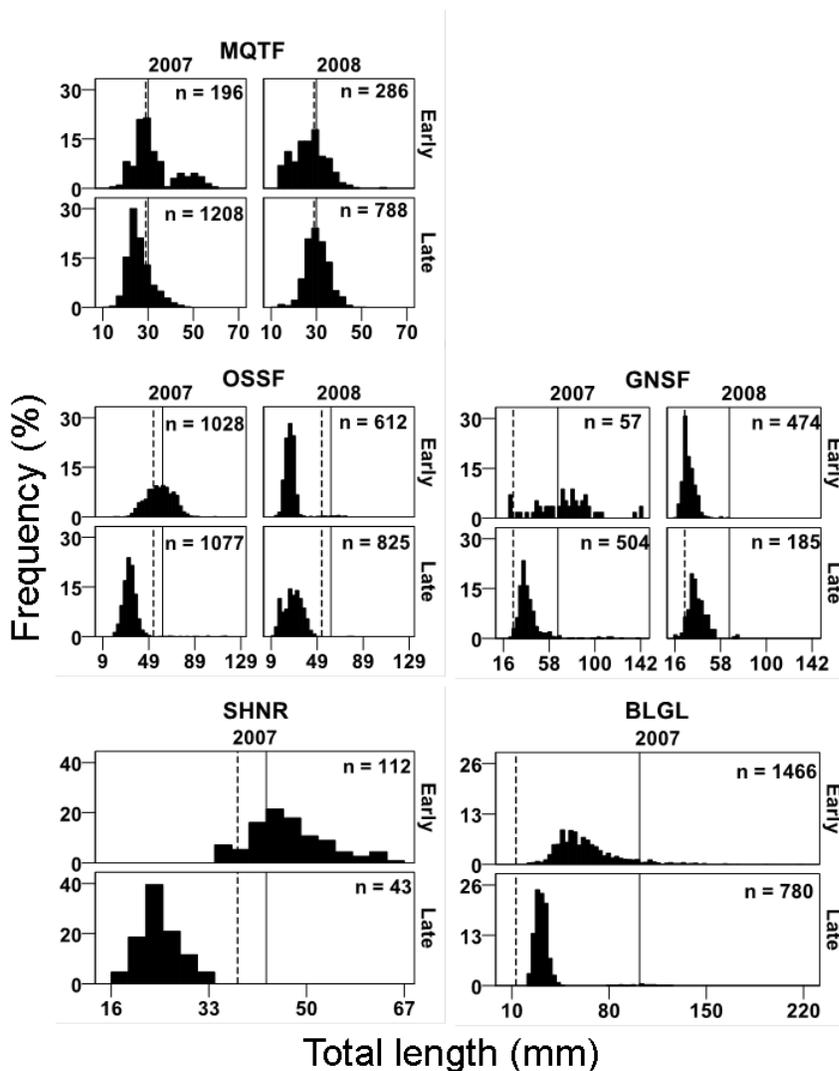


Figure 10. Relative length-frequency histograms for five small-bodied fish taxa sampled during 2007 and 2008 early- and late-season egress events: western mosquitofish (*Gambusia affinis*, MQTF), orangespotted sunfish (*Lepomis humilis*, OSSF), green sunfish (*Lepomis cyanellus*, GNSF), Shiners taxa group (*Notropis* spp., SHNR), and bluegill (*Lepomis macrochirus* BLGL). Histogram bin widths are 3 mm. Vertical dashed line indicates approximate maximum total length for age-0 juveniles, and vertical solid line indicates cut-off between juveniles and sexually mature adults (Appendix A, Table A1). Shiners taxa group consisted of specimens identified as river shiner (*Notropis blennioides*), sand shiner (*Notropis stramineus*), bigmouth shiner (*Hybopsis dorsalis*), or specimens identified to the level of *Notropis* genus (*Notropis* spp.). Note the different axis scales.

Relative center of length distributions (mean, median, and/or mode) differed between large-bodied and small-bodied taxa. Larger specimens (large juveniles and adults) were sampled during the 2007 early-season egress event for all eleven taxa; but, opposite trends in representation of small YOY specimens during early-season versus late season egress events were shown for large-bodied and small-bodied taxa. Small YOY specimens of large-bodied taxa were generally larger during late-season events each year (Figure 9); but, YOY specimens of small-bodied taxa were either similar in size between early-season and late-season events or smaller in the later event (Figure 10).

Maximum size of specimens exiting EBCA to LMOR during 2007 and 2008 late-season events varied among large-bodied taxa, but was similar among small-bodied taxa (Figures 9, 10). Large-bodied invasive taxa were generally larger than native taxa and much nearer to the general gape-limit of riverine predators (i.e. 200 mm), except for shortnose gar – the largest species – which showed maximum sizes widely distributed around approximately 300 to 400 mm. The order of largest-to-smallest lengths for the five remaining large-bodied taxa was Asian carps, grass carp, common carp, gizzard shad, and freshwater drum. Invasive Asian carps lengths were narrowly distributed around approximately 190 mm; native freshwater drum lengths were narrowly distributed around approximately 80 mm. Maximum sizes of the five small-bodied taxa were widely distributed around approximately 30 mm.

### ***Taxon-Specific Growth Rates***

Four trends were identified from the three groups of mean instantaneous growth rates calculated each year. First, large-bodied taxa generally had faster growth rates than small-bodied taxa both years (Tables 15, 16); although, only shortnose gar and Asian carps consistently displayed faster growth rates than those of small-bodied taxa in 2007 (i.e., displayed non-overlapping individual growth rate values or non-overlapping standard deviations of mean growth rates). Second, large-bodied fluvial dependents Asian carps and grass carp had faster instantaneous growth rates than large-bodied macrohabitat generalists in the 2007 larval-net only group, as shown by non-overlapping standard deviations of mean growth rates or non-overlapping individual growth rate values (Table 15). Third, the degree to which growth rates differed between 2007 and 2008 varied among large-bodied taxa, demonstrated by the range of taxon-specific percent differences (9 to 61%) between growth rates of 2007 fyke-net only and 2008 time<sub>1-2</sub> calculation groups (Tables 15, 16). Fourth, five of the nine taxa evaluated in 2008 showed large percent differences (33 to 64%) in growth rates between time<sub>0-1</sub> and time<sub>0-2</sub> calculation groups: in descending order, orangespotted sunfish, common carp, shortnose gar, green sunfish, and grass carp (Table 16). See Appendix B for details of these trends.

Table 15. Mean instantaneous growth rates, and their standard deviations (SD), calculated between early-season egress event 3E1407 (time<sub>0</sub>) and late-season egress event 4E1507 (time<sub>1</sub>) for eleven taxa in 2007. Length data for time<sub>0</sub> used to calculate growth rates between time<sub>0</sub> and time<sub>1</sub> are from larval-net only, fyke-net only, or both gears combined. Additional information includes total sample size of individuals collected with the fyke net and number of links of cohort mean lengths used to calculate growth rates. Length values used for individual calculations within the three groups are found in Table B2 in Appendix B.

Taxa	Fyke net total sample size (N)		Data source for time <sub>0</sub> <sup>a</sup>								
			Larval-net only <sup>b</sup>			Combination <sup>c</sup>			Fyke-net only <sup>d</sup>		
	3E1407	4E1507	Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)	
			Mean	SD		Mean	SD		Mean	SD	
Asian carps	28 630	586	1	0.038	n/a	2	0.031	0.010	1	0.025	n/a
common carp	27 191	279	2	0.031	0.007	5	0.020	0.011	3	0.013	0.005
grass carp	3478	33	2	0.044	0.005	4	0.032	0.014	2	0.021	0.005
gizzard shad	4635	1749	2	0.030	0.005	5	0.021	0.012	3	0.015	0.012
freshwater drum	1688	45	1	0.032	n/a	2	0.026	0.008	1	0.020	n/a
shortnose gar	452	48	*	n/a	n/a	2	0.028	0.008	2	0.028	0.008
western mosquitofish	196	1208	1	0.015	n/a	1	0.015	n/a	**	n/a	n/a
orangespotted sunfish	1028	1077	1	0.024	n/a	1	0.024	n/a	**	n/a	n/a
green sunfish	57	504	1	0.025	n/a	5	0.011	0.008	4	0.008	0.004
bluegill	1466	780	1	0.022	n/a	11	0.007	0.007	10	0.006	0.006
Shiners	112	43	1	0.017	n/a	1	0.017	n/a	**	n/a	n/a

<sup>a</sup> Wetland inundation duration between time<sub>0</sub> and time<sub>1</sub> was 67 days.

<sup>b</sup> Larval-net only; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using larval-net only data from 3E1407 and fyke-net only data from 4E1507. <sup>c</sup> Combination; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using both larval-net and fyke-net data from 3E1407 and fyke-net only data from 4E1507. <sup>d</sup> Fyke-net only; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using fyke-net only data from both events.

\*all links of cohort mean lengths from larval-net only data provided unrealistic values for instantaneous growth rates.

\*\*fyke-net only data gave negative values for instantaneous growth rates.

Table 16. Mean instantaneous growth rates, and their standard deviations (SD), for nine taxa calculated among three 2008 events: ingress event 5I1508 (time<sub>0</sub>), early-season egress event 6E1508 (time<sub>1</sub>), and late-season egress event 7E1508 (time<sub>2</sub>). Lengths used to calculate growth rates between reference times are from larval-net only data (time<sub>0</sub>) or fyke-net only data (time<sub>1</sub>, time<sub>2</sub>). Additional information includes total sample size of individuals collected with the fyke net and number of links of cohort mean lengths used to calculate growth rates. Length values used for individual calculations within the three groups are found in Table B3 in Appendix B.

Taxa	Fyke net total sample size (N)		Inundation period								
			Time <sub>0-1</sub> <sup>a</sup>			Time <sub>0-2</sub> <sup>b</sup>			Time <sub>1-2</sub> <sup>c</sup>		
	6E1508	7E1508	Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)	
				Mean	SD		Mean	SD		Mean	SD
Asian carps	2049	206	2	0.047	0.012	1	0.044	n/a	2	0.039	0.018
common carp	222	267	3	0.064	0.015	2	0.041	0.004	3	0.023	0.012
grass carp	558	86	1	0.063	n/a	1	0.045	n/a	1	0.019	n/a
gizzard shad	1687	429	2	0.034	0.010	3	0.031	0.004	6	0.028	0.014
freshwater drum	126	65	1	0.032	n/a	1	0.028	n/a	1	0.022	n/a
shortnose gar	658	220	3	0.068	0.007	3	0.046	0.002	11	0.019	0.011
western mosquitofish	286	788	2	0.022	0.010	1	0.018	n/a	2	0.013	0.014
orangespotted sunfish	612	825	1	0.034	n/a	2	0.017	0.006	1	0.004	n/a
green sunfish	474	185	1	0.036	n/a	3	0.025	0.010	2	0.022	0.019

<sup>a</sup> Time<sub>0-1</sub>; time<sub>0</sub> was 5I1508, time<sub>1</sub> was 6E1508, and growth rates were calculated using larval-net only data from 5I1508 and fyke-net only data from 6E1508. Wetland inundation duration for time<sub>0-1</sub> was 40 days.

<sup>b</sup> Time<sub>0-2</sub>; time<sub>0</sub> was 5I1508, time<sub>2</sub> was 7E1508, and growth rates were calculated using larval-net only data from 5I1508 and fyke-net only data from 7E1508. Wetland inundation duration for time<sub>0-2</sub> was 67 days.

<sup>c</sup> Time<sub>1-2</sub>; time<sub>1</sub> was 6E1508, time<sub>2</sub> was 7E1508, and growth rates were calculated using fyke-net only data from both events. Wetland inundation duration for time<sub>1-2</sub> was 27 days.

## **Objective 7: Recommendations for Site-Level Management of Lateral Connectivity, Wetland Inundation, and Native Fish Recruitment**

### ***Environmental and Ecological Filters***

Characterizing a target range of flow and temperature dynamics for individual connectivity events at annual and spawning window scales (Table 5) combined with describing connectivity event timing, frequency, and duration relative to timing of species-specific spawning temperatures (Figure 11) yields a framework that can aid managers promoting fish recruitment in actively managed floodplain wetlands.

Percentile statistics calculated for the eight connectivity event variables in Table 5 provide managers with the typical value (median) and core 50% range of values (25<sup>th</sup>- and 75<sup>th</sup>-percentiles) to be expected during a normative connectivity event and the rare, and more extreme, values that can occur (5<sup>th</sup>-, 10<sup>th</sup>-, 90<sup>th</sup>-, and 95<sup>th</sup>-percentiles); these estimates reduce the level of uncertainty involved in anticipating environmental conditions for a prospective connectivity event.

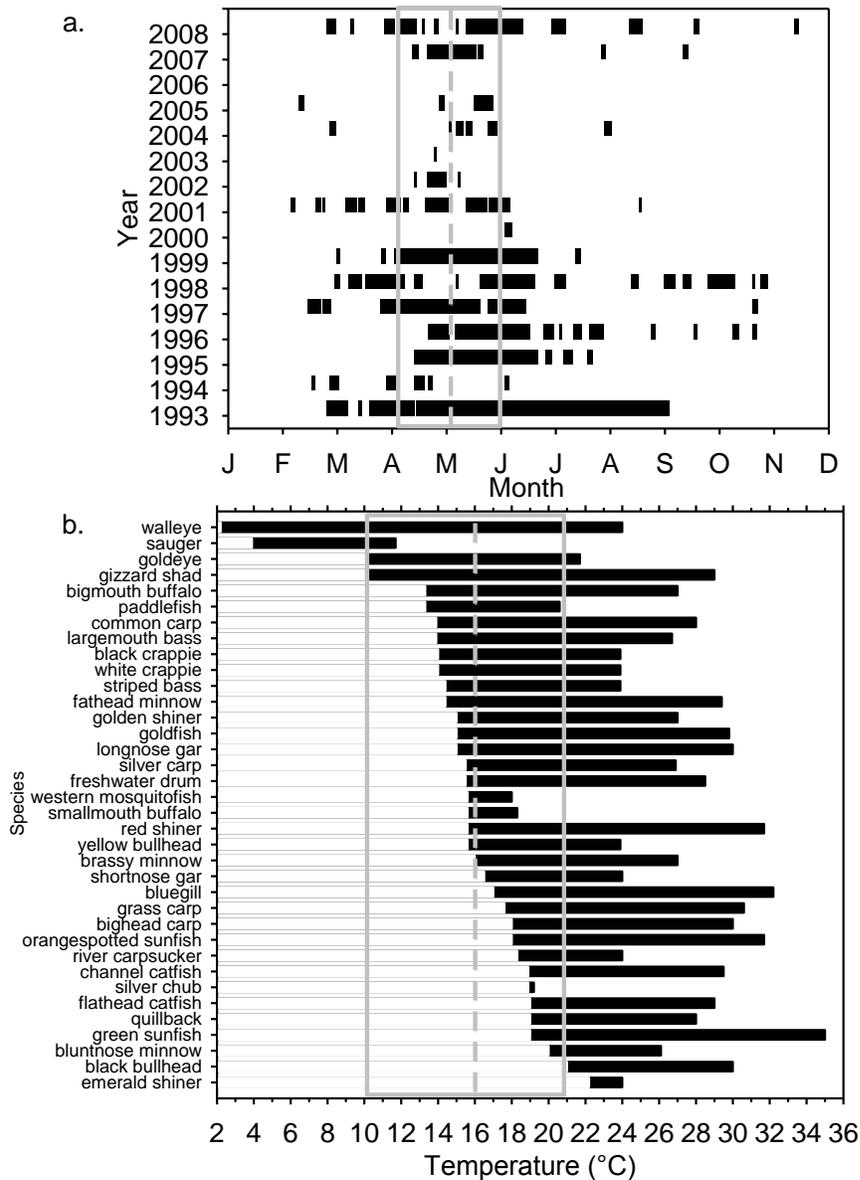


Figure 11. Synoptic visualization of lateral connectivity dynamics in relation to species-specific spawning temperature ranges. (a) Timing, frequency, and duration of predicted connectivity events between the lower Missouri River (LMOR) and Eagle Bluffs Conservation Area, 1993-2008. (b) Spawning temperature ranges for 36 of the 38 fish species predicted to enter wetland pools during a LMOR-EBCA connectivity event. Grey boxes depict date range (4 April to 1 June, Julian days 95 to 153) when 85% of LMOR fishes are predicted to begin spawning; grey dotted lines mark 16 °C (4 May, Julian day 125), which separate early-spring and late-spring spawning fishes. The grey box in (a) corresponds with that in (b); however, see Table D1 in Appendix D for exact predicted calendar dates (Julian dates)  $\pm$ 95% confidence intervals when various lower Missouri River mean water temperatures are first reached.

The target range of flow and temperature dynamics at the annual scale indicates environmental conditions associated with a normative LMOR-EBCA connectivity event via the fishway that could be controlled via gate manipulations. Flood pulses of short duration, moderate stage magnitude, and fast rate-of-change characterize the majority of EBCA connections (Table 5), and annual timing of connections overlaps the biologically relevant spawning interval for the majority of LMOR fishes (i.e., the spawning window; Figure 11). These conditions permit species with a variety of life-history strategies to access floodplain wetlands within the LMOR Boonville, MO reach for spawning or nursery. Management actions that establish lateral connectivity via the fishway when river flooding occurs during the spawning window can benefit fish recruitment even though timing of connectivity events probably has less effect on fish use of wetlands for feeding or refuge.

Duration of individual connectivity events and their timing within the spawning window may be more important for fluvial dependents than for macrohabitat generalists due to their different reproductive requirements. The majority of macrohabitat generalists can spawn in floodplain wetlands. However, most fluvial dependents spawn in the river mainstem and produce either buoyant eggs (pelagophils) or pelagic larvae (lithopelagophils), so lateral connectivity with the floodplain must occur immediately following spawning or hatching for eggs or larvae to drift into the wetland. Managers can use results of this study (explained below) to make more informed decisions on when to let water into the wetland relative to species or guild spawning times.

## ***Cost-Benefit Assessment of Ecological Responses***

### *Timing of Early- or Late-spring Ingress Events Relative to Fish Use of the Wetland for Spawning or Nursery*

Timing of lateral connections before or after river temperatures of 16 °C influences the assemblage that accesses EBCA and LMOR wetlands and impacts the life stage and activities of floodplain-accessing fishes (Table 17). Managers may be able to manipulate the fish assemblage structure that accesses the floodplain for recruitment by controlling the fine-scale timing of connectivity events within the spawning window (i.e., early or late spring).

Table 17. Cost-benefit evaluation of ingress event timing before (early spring) or after (late spring) lower Missouri River water temperatures reached 16 °C near Eagle Bluffs Conservation Area. Costs and benefits are evaluated in relation to native versus invasive riverine fishes, macrohabitat generalist versus fluvial dependent habitat-use guilds, and species-specific spawning temperature ranges. See Introduction for definition of habitat-use guilds. See Table 7 for spawning temperature ranges of fishes predicted to use floodplain wetlands and Tables 8 and 10 for observed fishes.

Ingress event timing	Outcome of associations between ingress event timing and species-specific spawning temperature ranges and life-history requirements	
	Benefit	Cost
Early spring	<ol style="list-style-type: none"> <li>1. Early spawning native macrohabitat generalists (e.g., gizzard shad and bigmouth buffalo) are within spawning temperature ranges and can access wetland for spawning and/or nursery.</li> <li>2. Native fluvial dependents paddlefish and goldeye are within spawning temperature range. Probability is moderate for eggs (goldeye) or larvae (both) to drift into the wetland.</li> <li>3. Striped bass, an introduced fluvial dependent promoted as a game species, are within spawning temperature range. Probability is moderate for eggs or larvae to drift into the wetland.</li> <li>4. Invasive fluvial dependents silver carp, bighead carp, and grass carp are not within spawning temperature ranges. Probability is low for eggs or larvae drifting into wetland.</li> </ol>	<ol style="list-style-type: none"> <li>1. Native fluvial dependents freshwater drum and longnose gar are barely within spawning temperature ranges. Probability is low for eggs (drum) or larvae (both) to drift into the wetland.</li> <li>2. Numerous native species are not within spawning temperature ranges and can only benefit from wetland use for feeding or refuge.</li> <li>3. Invasive common carp and introduced goldfish (both early spawning macrohabitat generalists) are within spawning temperature ranges and can access wetland for spawning and/or nursery.</li> </ol>
Late spring	<ol style="list-style-type: none"> <li>1. Early spawning native macrohabitat generalists remain within spawning temperature ranges (e.g., gizzard shad and bigmouth buffalo) and can access wetland for spawning and/or nursery.</li> <li>2. Late spawning native macrohabitat generalists are within spawning temperature ranges (e.g., shortnose gar, emerald shiner, orangespotted sunfish, and channel catfish) and can access wetland for spawning and/or nursery.</li> <li>3. All native fluvial dependents (paddlefish, goldeye, freshwater drum, and longnose gar) and introduced striped bass are within spawning temperature ranges. Probability is high for eggs or larvae to drift into the wetland.</li> </ol>	<ol style="list-style-type: none"> <li>1. All invasive and/or introduced macrohabitat generalists (early spawning common carp and goldfish and late spawning western mosquitofish) are within spawning temperature ranges and can access wetland for spawning and/or nursery.</li> <li>2. All invasive fluvial dependents (silver carp, bighead carp, and grass carp) are within spawning temperature ranges. Probability is high for eggs or larvae to drift into the wetland.</li> </ol>

Connectivity events that occur before 16 °C (4 May, JD 125) exhibit fewer invasive fishes entering wetlands for immediate spawning or nursery, but these circumstances also enable fewer native species to similarly use the area, especially fluvial dependents (Figure 11, Table 17). This prediction is based on the finding that 4 versus 8 invasives and 13 versus 19 natives entered the wetland in early-spring event 1I1508 as opposed to late-spring event 5I1508 (Table 11). When connectivity events occur after LMOR water temperatures reach 10 °C, but before temperatures reach 16 °C, almost half of the fish assemblage can capitalize on the available habitat (47%, based on their spawning temperature requirements; Figure 11). However, those early-spring spawners will be mostly (73%) macrohabitat generalist species, such as native gizzard shad and invasive common carp (Table 17). The combination of spawning temperature requirements and spawning location requirements for the majority of fluvial dependent species indicates that only a few fluvial dependents capitalize on connections with the floodplain for nursery-area access before 4 May (Table 17, early spring benefit # 2). Low presence of fluvial dependents during 1I1508 in early spring corroborates this prediction (Table 11).

When connectivity occurs after LMOR water temperatures reach between 16 °C and 21 °C (4 May to 1 June, JD 125 to 124), numerous native and invasive species belonging to both habitat-use guilds capitalize on the floodplain connection for recruitment because approximately 94% of the fish assemblage spawns here (Figure 11). This was evident in the increased presence of both habitat-use guilds during the late-spring event 5I1508 (Table 11). Several early-spawning macrohabitat generalists can spawn after 16 °C and can therefore enter the floodplain for recruitment during the

majority of spring connectivity events (Table 17, late spring benefit # 1 and cost # 3).

Additionally, since all predicted fluvial dependents spawn between 16 °C and 21 °C, eggs or larvae of these fishes may drift into the floodplain for nursery during late spring events (Table 17, late spring cost # 2 and benefit # 3).

*Timing of Early- or Late-Season Egress Events Relative to Fish Recruitment Benefits*

Timing of water release and size of fishes exported to the river influence subsequent food chain dynamics relative to riverine fishes that prey on newly imported YOY fishes and to fishes that compete for food with newly imported YOY fishes (specifically plankton).

Managers can influence the magnitude of recruitment benefits gained by different members of floodplain-using fish assemblage by controlling the fine-scale timing of water releases for early- or late-season summer egress events (Table 18).

Table 18. Cost-benefit evaluation of egress event timing (early-to-mid-summer or late summer) when water and fish are released from managed wetlands at Eagle Bluffs Conservation Area (EBCA). Costs and benefits are described in relation to management interests that promote native species and reduce invasive species. When a management action benefits both natives and invasives, the ecological response is displayed as a benefit for natives, but as a cost for invasives. Conclusions apply only to the eleven taxa evaluated under Objectives 5 and 6, unless otherwise stated. See footnotes “a” and “b” for derivation of benchmark values approximating timing and durations of managed wetland inundation and isolation. See Introduction for definitions of habitat-use guilds.

Egress event timing	Outcome of associations between egress event timing and taxon-specific recruitment benefits	
	Benefit	Cost
Early-to-mid-summer <sup>a</sup>	<ol style="list-style-type: none"> <li>All 5 evaluated native species have faster growth rates during moderate than long inundation durations; e.g., shortnose gar, orangespotted sunfish, and green sunfish displayed ~30 to 60% faster growth rates.</li> <li>Native species that might use floodplains as recruitment sites in a more transient manner (e.g., goldeye, a fluvial dependent) may have higher export total abundances during moderate than long inundation durations.</li> <li>Large-bodied invasive taxa are unable to grow to sizes close to the general gape-limit of riverine predators (200 mm) when inundation duration is short-to-moderate; e.g., total lengths of YOY exported ranged from ~25 to 150 mm indicating a high probability being eaten in the river mainstem.</li> </ol>	<ol style="list-style-type: none"> <li>All 4 evaluated invasive taxa have faster growth rates during moderate than long inundation durations; e.g., common carp and grass carp displayed ~40% faster growth rates.</li> <li>Shortnose gar are unable to use the wetland to its full potential as a recruitment site when inundation duration is short-to-moderate; e.g., this native macrohabitat generalist attained the largest maximum size and greatest export biomass of the ~30 to 60 species composing the floodplain-using fish assemblage.</li> <li>Large-bodied native species are exposed to greater risks than invasive taxa in early-to-mid-summer benefit # 3; e.g., total lengths of YOY exported ranged from ~25 to 100 mm.</li> <li>Short-to-moderate inundation durations provide fishes with a less productive recruitment site; e.g., taxa export biomasses were generally lower with shorter residence times in the wetland.</li> </ol>
Late summer <sup>b</sup>	<ol style="list-style-type: none"> <li>Freshwater drum and gizzard shad growth rates benefit from any duration of wetland inundation; e.g., these native species experienced fairly continuous fast growth rates for an extended period of time.</li> </ol>	<ol style="list-style-type: none"> <li>Asian carps and western mosquitofish growth rates benefit from any duration of wetland inundation; e.g., these highly invasive taxa experienced fairly continuous fast growth rates for an extended period of time.</li> </ol>

Table 18 (continued)

Egress event timing	Outcome of associations between egress event timing and taxon-specific recruitment benefits	
	Benefit	Cost
Late summer <sup>b</sup>	<p>2. Large-bodied native species are able to grow to sizes closer to the general gape-limit of riverine predators when inundation duration is long as opposed to short; e.g., exported YOY were ~50 to 150 mm, providing slightly greater protection against predation in the river.</p> <p>3. Shortnose gar are able to use the wetland to its full potential as a recruitment site when inundation duration is long; e.g., they attained the largest maximum size and greatest export biomass of the ~30 to 60 species composing the floodplain-using fish assemblage.</p> <p>4. Moderate-to-long inundation durations provide fishes with a more productive recruitment site; e.g., taxa export biomasses were generally larger with longer wetland residence times.</p>	<p>2. Native species that might use floodplains as recruitment sites in a more transient manner (e.g., goldeye) may have lower export total abundances during longer than shorter inundation durations.</p> <p>3. Large-bodied invasive taxa gain greater protection than native species in late-summer benefit # 2; e.g., exported YOY were ~100 to 200 mm.</p>

<sup>a</sup> A short-to-moderate duration of wetland inundation and isolation associated with an early-to-mid-summer egress event is defined relative to (i) the approximately 11 days that elapsed between the levee-topping connectivity event and early-season egress event during the 2007 floodplain-maintenance flood year, and (ii) the 40 days that elapsed between the final ingress event and early-season egress event during the 2008 floodplain-activation flood year. Start of the early-season egress event was 47 days earlier in 2007 (21 May) than in 2008 (7 July).

<sup>b</sup> A long duration of wetland inundation and isolation associated with a late-summer egress event is defined relative to (i) the 67 days that elapsed between the early-season and late-season egress events during the 2007 floodplain-maintenance flood year, and (ii) the 67 days that elapsed between the final ingress event and late-season egress event during the 2008 floodplain-activation flood year. Start of the late-season egress event was only 3 days earlier in 2007 (8 August) than in 2008 (11 August).

Both native and invasive large-bodied species released to the river will be well below the generalized gape-limit of riverine predators (i.e., 200 mm) when an early-season summer egress event occurs rather than a late-season re-connection (Figure 9). Export sizes below the generalized gape-limit is a cost for native species such as gizzard shad and a benefit to invasive species such as common carp (Table 18, early-to-mid-summer cost # 3 and benefit # 3). A late-season egress event provides the benefit of

releasing native large-bodied species to the river when they are closer to reaching the gape-limit of riverine predators and allows shortnose gar to attain greater maximum size and export biomass (Table 18, late-summer benefit #s 2 and 3). However, costs of a late-season egress event include faster growth rates for invasive Asian carps and the release of all large-bodied invasive taxa to the river when they are very close to exceeding the gape-limit of riverine predators (Table 18, late-summer cost #s 1 and 3).

### ***Guiding Framework for the Decision-Making Process***

The decision tree (Figure 12) and its associated considerations (Figure 13) can help managers decide whether an ingress connection event should be allowed to occur, how to manage the lateral exchange during the connectivity event, and when to permit an egress event to reconnect the wetland to the river. Such lateral connectivity events can be managed by opening and closing the fishway gates. When a spring flood pulse occurs, managers have several options once they decide to open fishway gates and enable connectivity (Figure 12). One alternative is to allow the lateral exchange pathway to remain open during the entire flood pulse: river water would then enter and drain the wetland relative to the rise and fall of river stage. Alternatively, managers could close the fishway gates either at the flood pulse peak or on the receding limb of the pulse. These latter strategies retain river water within the wetland, extending inundation duration and thereby promoting fisheries-based objectives. A fourth alternative is to close fishway gates at a specific river stage relevant to a targeted water depth for moist-soil vegetation inundation to primarily benefit waterfowl. By artificially controlling

wetland inundation, managers can produce outcomes modeled after pre-existing reference conditions or designed to attain a desired ecological or socioeconomic goal.

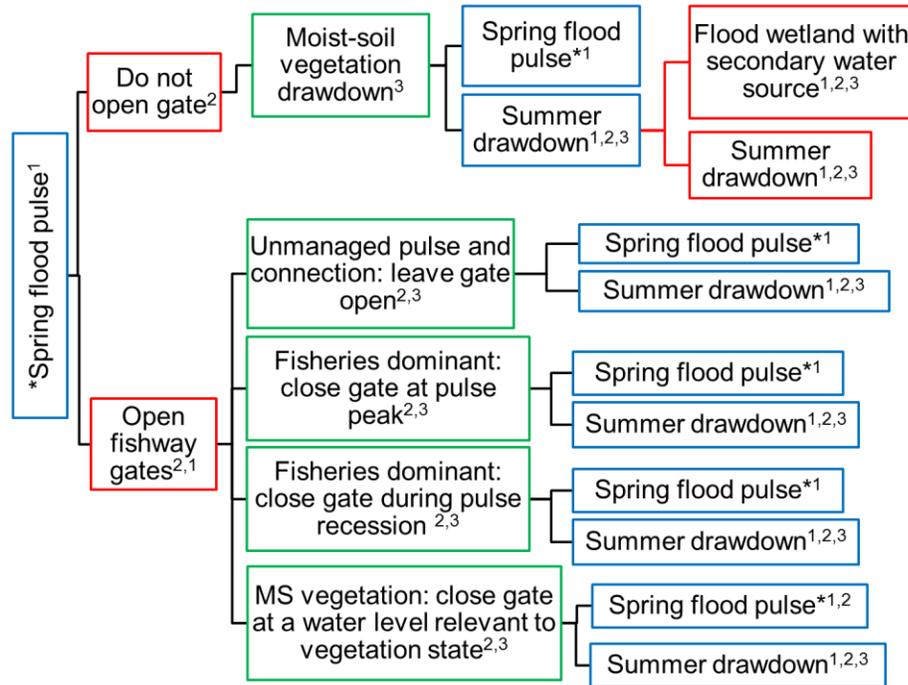


Figure 12. Decision tree to support site-level management of lateral connectivity and inundation dynamics during spring flood pulses enabling fish ingress to a managed floodplain wetland. Blue boxes indicate the hydrology to be considered; red boxes indicate possible management actions; green boxes indicate alternative ecological goals and their associated management actions. Superscripts within boxes refer reader to Figure 13 for management considerations, proposed ecological benefits, and evaluation of management actions. Boxes with superscript “1” describe the current situation requiring a management decision. Boxes with superscript “2” provide management decision options. Boxes with superscript “3” indicate the system state from which different situations may subsequently occur. Boxes with multiple superscripts require the reader to concurrently address several decision-support components. Asterisks indicate reader should return to beginning of decision tree. Branched red-line fragments indicate the two red-box management actions at the top right of diagram are appropriate responses to every “summer drawdown” situation. The “MS vegetation” in the final green box refers to the ecological goal of promoting growth of moist-soil vegetation to achieve waterfowl objectives.

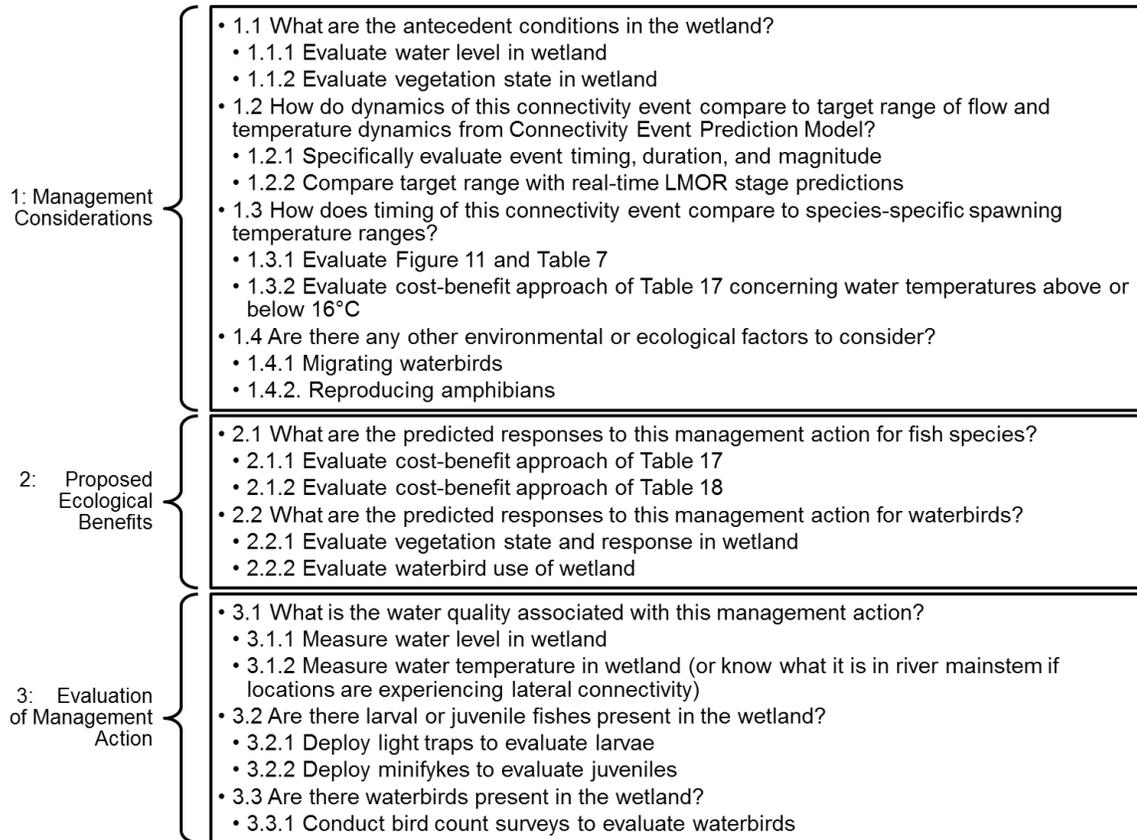


Figure 13. Three components of decision-support tool footnotes 1-3 in Figure 12 for site-level management of lateral connectivity and wetland inundation for fish movement and recruitment. Boxes include questions and actions within each component.

Information organized in Table 5, Figure 11, Table 17, and Table 18 can help managers identify considerations and ecological outcomes relevant to wetland management decisions. In particular, decisions concerning spring flood pulses depicted in Figure 12 can be addressed through the questions and associated actions presented as points 1.1 to 3.1 in Figure 13. Managers can evaluate abiotic and biotic responses to their actions by conducting real-time monitoring of water quality and of wetland use by fishes and waterbirds during wetland inundation duration, and thereby determine when to release water and fish to the river (Figure 13, points 3.1 to 3.3).

## DISCUSSION

### **Main Conclusion and Primary Management Implication**

River-floodplain connectivity in the spring-summer reproductive season benefits YOY fish recruitment of numerous LMOR fishes, and active management strategies can promote environmental conditions that foster native fish spawning and nursery on floodplain wetlands. Management actions within the range of connectivity event environmental and ecological conditions that promote large magnitude, long duration ingress events in late spring will benefit the most native fishes (Table 5, Figure 11). Specifically, beneficial conditions are connectivity events that are of medium-to-large stage magnitudes ( $\geq 0.56$  to 1.10 m [1.8 to 3.6 ft] at the fishway), of medium-to-long durations ( $\geq 45$  to 115 h), occur from 4 April to 1 June, but preferably after 4 May ( $> 16$  °C), and are followed by moderate durations ( $\sim 40$  days) of wetland inundation and isolation. These conditions allow spawning and nursery of numerous LMOR fishes to yield high species richness, total abundance, and large biomass exported when water is released to the river. However, these conditions also benefit invasive bighead carp, silver carp, common carp, and grass carp. Combining management strategies that promote wetland use by native fishes with appropriately selected control methods to reduce benefits to invasive Asian carps could advance multiple ecological and socioeconomic goals at the wetland and within the Boonville, MO reach of the LMOR.

## Research Conclusions

### *Environmental and Ecological Filters of Connectivity Events*

Developing and implementing successful management schemes for individual floodplain wetlands require a solid conceptual understanding of key processes in river-floodplain systems and of their effects on a diverse biota (Tockner et al. 1998). The interaction between flow regime and geomorphology of natural or created floodplain wetland sites – specifically minimum stage of connection – dictates the lateral connectivity dynamics at that site. The calculated river stage for LMOR-EBCA connection at the fishway is 1.53 m (5.0 ft) below the designated LMOR “flood stage” at the USGS Boonville gage (178.73 m amsl, 586.4 ft amsl). *Flood stage* is defined as the river stage beyond which rising water levels become a hazard to lives or property (Jacobson and Galat 2008; NWS 2012). This difference in elevation reflects that the mitigation area was constructed to enable connectivity before hazardous inundation of the floodplain. Fortuitously, the occurrence of an uncontrolled floodplain-maintenance flood and several controlled floodplain-activation floods enabled us to evaluate connectivity dynamics across a range of flood magnitudes and their ecological outcomes.

### *Representative Floods*

Comparing flow regime patterns of the study years against the initial Connectivity Event Prediction Model helped identify and reduce structural uncertainties about connection types at EBCA and their predicted return intervals. This aids evaluation and management of fish-hydrology relationships relative to representative flood types. Although 2007 was

generally similar to model predictions regarding overall shape of the flood pulse, it was a floodplain-maintenance event because the pulse overtopped and breached the EBCA levee and deposited sediment. The return interval of the 2007 flood pulse (5.7 years) and of flood pulses reaching the top of the EBCA levee (2.8 years) indicated floodplain-maintenance floods are frequent at EBCA. However, what qualifies as a floodplain-maintenance flood at EBCA may not be one at other locations along LMOR because this designation involves a site-specific return interval. The return interval of this representative flood reflects factors such as river gradient, differences between main channel and floodplain elevations, and sediment supply (Florsheim and Mount 2002; Opperman et al. 2010). Two-thousand-eight was also a high flood year, but exhibited multiple floodplain-activation flood pulses of shorter and varying duration that connected the river and wetland via the fishway and did not substantially alter floodplain geomorphology. This 2008 pattern was similar to that observed during other modeled years (e.g., 1993, 1998, and 2004), but exceeded model predictions for event frequency. Natural spring and summer rises occurred in May and June 2008 due to runoff from localized precipitation events and tributary inputs (USACE 2008), producing the cross-scale effect of the multiple connectivity events at EBCA. Importantly, conclusions about river-floodplain connectivity dynamics and associated fish-use of the wetland could be developed from the two study years and used to make additional management recommendations (beyond those in Objective 7 Results) because the two flood year types studied were characteristic of the hydrologic conditions depicted by the initial Connectivity Event Prediction Model. Furthermore, the 16 years of data used to develop the updated model (i.e., 1993-2008) and describe river-floodplain connectivity provides

managers with strong, reliable predictions of the connectivity dynamics that can occur at EBCA because that time frame included record high (e.g., 1993 and 1997) and low (e.g., 2003 and 2006) flows.

The two representative study-year floods produced dissimilar periodic lateral connections that differentially affected the floodplain. First, incursion route of river water was fundamentally different for the two flood types: topflooding over the levee versus backflooding through the fishway (Figure 1). Second, magnitude of water inflow was considerably larger during the levee-topping event due to the higher stage of connection than during individual backflooding events. Third, size and number of lateral exchange pathways onto the floodplain were greater during the levee-topping event because there were multiple incursion points with varying widths and exchange rates; whereas during backflooding events, the cross-sectional area of the single exchange pathway was constrained to the dimensions of the fishway. Fourth, there was greater likelihood of two-way fish movement during the levee-topping event than through the fishway because following complete inundation of the floodplain, but before flood recession, the lateral exchange pathway exhibited a smaller head differential and a lower velocity than if the water entered and exited via the fishway. Fifth, since levee-topping event dynamics were un-managed it was a quasi-natural connection event, whereas connectivity dynamics were altered through gate manipulations during backflooding events.

The two connection pathways also permitted different types of lateral fish movement. The uncontrolled levee-topping connection likely transported fish onto the floodplain via a mixture of passive and active movements, with all life stages passively

carried by the extensive water currents dominating. Combined fish assemblage of the 2007 egress events represented mainstem fish activity occurring during the overtopping event in addition to fishes that typically access the floodplain during backflooding lateral connections. Lateral fish movements during controlled connectivity events through the fishway were also likely a mixture of active (adults and juveniles seeking out the fishway channel) and passive (e.g., drifting eggs and larvae) movements, but with active movements dominating. Consequently, the observed fish assemblage of 2008 ingress and egress events largely represented lateral movements of fishes that typically access floodplains during backflooding.

#### *Predicted Connectivity Dynamics*

Evaluating the final Connectivity Event Prediction Model within the framework of King et al.'s (2003) Optimal Environmental Conditions (OEC) Model helped to determine suitability of the wetland as a spawning and nursery habitat for riverine fishes by highlighting factors potentially falling outside proposed optimal ranges (Figure 14). However, the OEC Model depicts a conceptualized river with an idealized flow regime distinguished by predictable, slow-to-moderately rising and falling flood pulses of long duration. This type of flood pulse is typical for flow regimes associated with snowmelt river-floodplain systems or systems with both snowmelt and rain influences (Poff and Ward 1989). However, using the conceptual model developed by Poff and Ward (1989) to classify streamflow variability and predictability, the LMOR can be described as a perennial flashy river with both snowmelt and rain influences. Inter-annual predictability of the timing of the flood pulse is high due to the hydroclimatic regime of the entire

Missouri River basin, but rates-of-change of intra-annual flood pulses are naturally fast due to influences of localized precipitation and tributary inputs (Galat and Lipkin 2000). Therefore, evaluating the LMOR flow regime within the optimal ranges of the OEC Model will highlight its present and potential suitability for fish recruitment via river-floodplain connectivity.

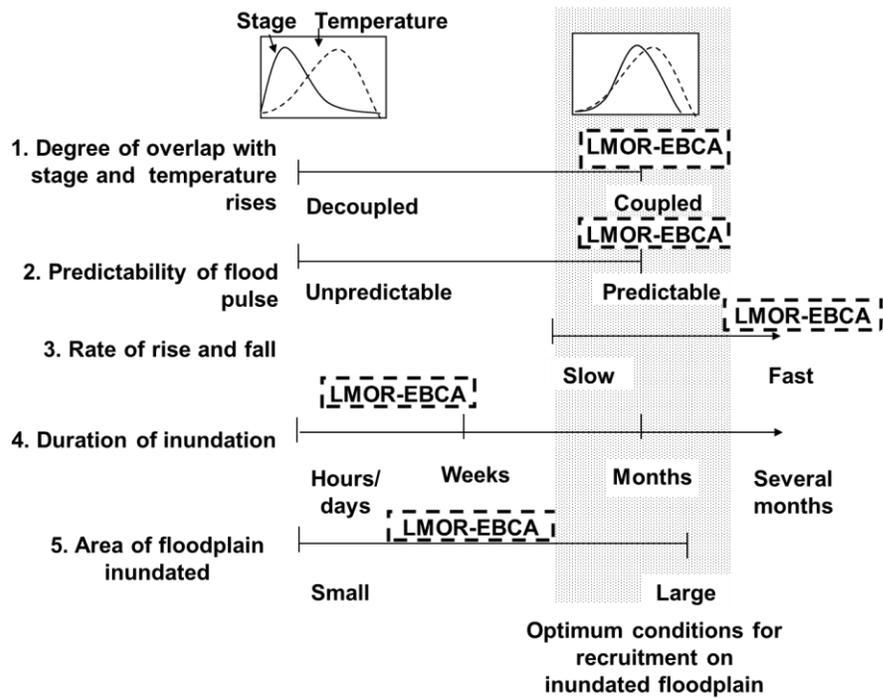


Figure 14. Five factors of the Optimal Environmental Conditions (OEC) Model used to describe the suitability of river-floodplain connectivity to promote access to spawning and nursery areas of the floodplain by riverine fishes; dashed boxes indicate locations along each factor’s continuum for lateral connectivity events between the lower Missouri River (LMOR) and Eagle Bluffs Conservation Area (EBCA) modeled in Objective 1. Base figure of OEC Model modified from King et al. 2003.

Connectivity events between the LMOR and EBCA currently fall within the designated optimal range of conditions for degree of coupling between temperature increases and flood pulses (OEC factor 1) and flood pulse predictability (OEC factor 2;

Figure 14). The Connectivity Event Prediction Model showed event frequency is predictable at inter- and intra-annual scales: a connectivity event occurs in most years, and in most years the core 50% of events occurs from 16 April to 9 August (JD 107 to 222). However, event frequency is not as predictable at the intra-seasonal scale. Although connectivity events typically occurred during one or more of the spring-summer months (usually in May or June), there was higher uncertainty about event frequency and duration than the model implied. Accordingly, although researchers and managers can use the information in Table 5 to anticipate values of connectivity event variables, the model is not as robust at predicting when, and how many, events will occur within the spring-summer reproductive season. Nevertheless, the model's prediction of highest frequency of LMOR-EBCA connections in May and June reflected that the LMOR hydrologic regime is driven by snowmelt in the watershed and high regional and local spring precipitation modified by reservoir water releases (Galat et al. 2005b; Galat and Lipkin 2000; Jacobson and Galat 2008). Unless climate change reduces Missouri River basin water yields by the approximately 10 to 20% predicted (Stone et al. 2001), and thereby reduces the inter- and intra-annual timing and predictability of floodplain-connecting flood pulses, subsequent research and management actions on the LMOR can focus on other aspects of connectivity requiring attention, such as rate-of-change and duration.

Rate-of-rise and rate-of-fall of LMOR-EBCA connectivity events were moderate to fast, and thus fall outside the OEC Model's designated optimal range (OEC factor 3; Figure 14). However, those rate-of-change dynamics correspond to spikes on LMOR hydrographs and follow closely the overall rate-of-change dynamics within the main

channel modeled by Galat and Lipkin (2000). The natural flow regime of the Missouri River was inherently flashy, and rates-of-rise and rates-of-fall have only slightly increased in the Boonville, MO reach of the LMOR since river regulation (Galat and Lipkin 2000).

Duration of floodplain inundation from LMOR-EBCA connectivity events also falls outside the OEC Model's optimal range (OEC factor 4; Figure 14). Duration of contemporary LMOR flood pulses translates to LMOR-EBCA connectivity events lasting just several days to weeks (Figure 11). This is generally considered shorter than the optimal time period needed by fish species using floodplain areas for recruitment. Numerous studies of temperate river systems demonstrate that periods of floodplain inundation need to last several weeks to months to maximize benefits of the area as a spawning and nursery environment (Galat et al. 1998; King et al. 2003; Sparks et al. 1998). However, the intersection of functional (i.e., short, but highly variable durations of intra-annual LMOR flood pulses) and structural (i.e., size and complexity of historical floodplain) processes in the Missouri River implies the pre-regulation floodplain may have provided more satisfactory environmental conditions for fish spawning and nursery despite the flow regime not completely matching the ideal flow regime for fish recruitment discussed in the Flood Pulse Concept and OEC Model. Despite the floodplain not being connected for long, uninterrupted periods, connection frequency at EBCA is high (Figure 11), and this enables riverine fishes to gain access to the inundated floodplain's abundant resources for recruitment within this river reach. Furthermore, event duration from the Connectivity Event Prediction Model matches the present (and past) flow regime, indicating long duration events still occur on the LMOR at EBCA

(annual scale 90<sup>th</sup>-percentile = 23 days) and supporting the findings of Galat and Lipkin (2000) that the variability in high flows has decreased within the Boonville, MO reach of the LMOR. Long duration (and high magnitude) events still happen, but they are much less frequent than historical dynamics. Importantly, duration of river-floodplain connectivity within the spawning window increases to a core 50% range of 2 to 25 days over a core 50% range of 2 to 9 days at the annual scale. This reduces duration uncertainty at the inter-seasonal scale at the same time uncertainty about event frequency increases. Results show a lower likelihood of short events (1 to 2 day) and an increased chance of a very long event (>25 days).

The OEC model was designed to depict an idealized, optimal river-floodplain system and offers a generalized reference for how a river's floodplain can provide conditions that promote fish recruitment. However, this model should not be viewed as a pedestal of optimal conditions that managers of all river-floodplain systems should strive to achieve. As indicated in Figure 14, the LMOR meets some but not all of the OEC criteria for an idealized river-floodplain system. Importantly, although the LMOR does not completely fit this idealized model, the present river system does a good job of promoting fish recruitment via river-floodplain connectivity – as indicated by the high species richness and biomass exported during this study – despite the upriver flow regulation, channelization, and levee construction that has occurred. Furthermore, the potential suitability of LMOR floodplain habitat to promote fish recruitment, relative to the proportion of the floodplain inundated (OEC factor 5), would be further increased by continued support of mitigation efforts of the current Missouri River Recovery Program (see section: *selection and management of LMOR floodplain wetland mitigation sites*).

### ***Importance of Floodplain Wetlands for Fish Recruitment to the River***

Lateral connectivity at EBCA promotes fish assemblage diversity, as indicated by the majority of the 38 predicted EBCA-use fishes found entering the wetland via the fishway during normative, backflooding connectivity events and by additional species using the wetland following the levee-topping connectivity event. Spawning and nursery of many fishes that entered EBCA during these two connection types yielded high richness, total abundance, and gross biomass export during subsequent water releases to the river, indicating lateral connectivity at EBCA contributes to substantial annual recruitment of YOY and juvenile riverine fishes. Flow regime plays a fundamental role in determining the life-history composition of the fish assemblage within a river system (Mims and Olden 2012). Flow dynamics were probably the primary factors influencing species relative structure of the fish assemblage accessing EBCA wetland pools, as opposed to water temperature or photoperiod, since evaluated connectivity events occurred within the spawning window. Life-history patterns of individual species (or of an ecological guild) influence the flow dynamics and lateral connectivity characteristics that are optimal for recruitment (Górski et al. 2011; King et al. 2003; Zeug and Winemiller 2008). Accordingly, the variety of flood pulses that occur in LMOR allows a range of connectivity event types that support different fish movement and recruitment strategies.

Native fish recruitment benefits at the assemblage level were high in terms of richness, but recruitment benefits from using the EBCA wetland varied at the taxon-specific level. Results suggest gizzard shad, common carp, and Asian carps gain higher benefits than other taxa as shown by their large relative abundances during ingress and

egress events, fast growth rates during periods of wetland inundation and isolation, and large export biomass during egress events. Gizzard shad size structures during ingress events of medium-to-large magnitude and medium-to-long duration at EBCA mirrored fish-use findings for an inundated floodplain lake on the Illinois River in which multi-modal size distributions of gizzard shad accessing the floodplain during the spring showed the area is used by juveniles and adults (Schultz et al. 2007). Benefits by multiple life stages of gizzard shad revealed herein were also shown in the Brazos River, Texas where gizzard shad exhibited the greatest reproductive activity in the spring during the rising limb of the flood pulse (Zeug and Winemiller 2007) and both juveniles and adults used inundated oxbows to access food resources (Zeug et al. 2009). Floodplain use by adult common carp and benefits gained by YOY common carp in this study also mirrored results from other studies. Large numbers of adult common carp move onto floodplain areas in spring to spawn and feed (Schultz et al. 2007; Stuart and Jones 2006). Common carp larval abundances on the floodplain also increase after connectivity events (King et al. 2003). The successful use of EBCA wetland pools for YOY recruitment by Asian carps was similar to their routine use of periodically connected wetlands on the lower Mississippi River floodplain (Varble et al. 2007).

### ***Levee-Topping versus Backflooding Connections and Fish Movement and Recruitment***

Several conclusions emerged about fish movement and representation of ecological guilds when the uncontrolled levee-topping connectivity event was compared to controlled backflooding events. Magnitude and incursion route of the two connection types influence how benefits of wetland access are expressed by the floodplain-using fish

assemblage. The fish assemblage during the 2007 levee-topping year showed higher species richness than in 2008 with multiple backflooding events, but 2007 also yielded lower export biomass because fish assemblage total abundance was higher in 2008. This finding underscores the importance of understanding how spatiotemporal degree of lateral connectivity of a given floodplain waterbody influences its use by LMOR fishes. It also suggests (i) periodically connected wetlands that backflood like the designed connectivity dynamics at EBCA affect native fish recruitment through biomass input to the river; and (ii) floodplain waterbodies with higher spatiotemporal degrees of connectivity than EBCA contribute to fish assemblage diversity by promoting recruitment of native flow-associated species on the LMOR, particularly fluvial specialists, but also fluvial dependents and generalist species.

The EBCA fish assemblage was characterized by higher native species richness in the levee-topping year (50 species) than the backflooding year (31 species), showing that many fishes are adapted to capitalize on larger, infrequent, floodplain-maintenance flood events along LMOR. Similarly, Galat et al. (2004b) found a trend of increasing species richness (largely fluvial dependents and fluvial specialists) with increasing degrees of connectivity in LMOR scours demonstrating varying spatiotemporal connectivity. Importantly, except for the higher species richness exhibited during early-season egress event 3E1407 (57 species), individual ingress and egress events at EBCA during the study years demonstrated values (5 to 37 species) generally similar to those found in four other river-floodplain fish-use studies on the LMOR (i.e., 21 to 40 species or taxa) (Chapman et al. 2003; Galat et al. 2004a; Galat et al. 2004b; Whitley et al. 2005). Similarly, 41 species were sampled in 2013 in the Lower Little Sioux Bend (Deer Island)

of the Missouri River (river km 1080, river mile 671) as part of the Habitat Assessment and Monitoring Program of the Missouri River Recovery Program (MRRP) (MRRP 2015). The five dominant taxa sampled at Lower Little Sioux Bend in 2013 – *Cyprinella* spp., which included spotfin shiners, red shiners, and unidentified YOY shiners, (40% of catch), freshwater drum (14%), emerald shiner (*Notropis atherinoides*; 11%), channel catfish (10%), and silver chub (*Macrhybopsis storeriana*; 5%) (MRRP 2015) – showed low (Shiners, channel catfish, and silver chub) or moderate (freshwater drum, emerald shiner, and red shiner) abundances at EBCA following the levee-topping event, but were overshadowed by the dominance of common carp (Table 10). Furthermore, low gross export biomass in 2007 for Shiners indicated YOY recruitment of this fluvial specialist benefited from floodplain access, even if those benefits were not accrued at higher levels similar to the more numerically abundant taxa. These collective findings suggest the designed connectivity dynamics of EBCA provide inundated habitat similar to other natural and managed waterbodies on the LMOR floodplain, but floodplain waterbodies with overtopping or flow-thru incursion routes are important for a subset of LMOR fishes.

Although fluvial specialists do not typically use floodplain waterbodies, they have been found using floodplain resources for nursery benefits, as suggested by a larger proportion of that guild in the fish assemblage exiting the wetland after the levee-topping event and by fish-use findings of other studies. This has been noted in waterbodies with higher degrees of lateral connectivity, particularly on different floodplain sections of the LMOR through collection of larval and/or juvenile specimens of blue sucker (*Cycleptus elongatus*), sand shiner, and speckled chub (*Macrhybopsis aestivalis*) in continuously and

periodically connected natural scours (Galat et al. 2004a; Galat et al. 2004b; Whitley et al. 2005). Those three fluvial specialists were found at EBCA after the levee-topping event and also in constructed wetlands with continuous or periodic lateral connections with the LMOR (Chapman et al. 2003). Larger, less frequent, flood events along the LMOR allow greater exchange of organisms between the river and floodplain, but considerable variation is displayed in how fishes respond to the opportunities presented. Fluvial specialists that accessed the wetland during the levee-topping connectivity event were either rarely (e.g., blackside darter [*Percina maculata*]) or infrequently (e.g., blue sucker) collected during 3E1407, indicating their access to the floodplain likely resulted from one or two mechanisms. First, the rarer species may have been flushed out of a tributary and deposited in the wetland due to increased flows. Blackside darter is present in the LMOR, but mostly associated with riffle or pool habitats within streams (MDC 2012). Displacement of species out of tributaries has also been shown to influence species richness and fish assemblage structure on Mississippi River floodplains (Barko et al. 2006). Second, more abundant species that typically use the river main channel border or continuously connected backwaters may have entered when above average flows deposited them (as YOY) onto the EBCA floodplain. Larval blue sucker use slackwater shorelines provided by off-channel islands as nursery habitat (Adams et al. 2006). Additionally, wetland proximity to the river mainstem (a migration distance factor) influences the ability of age-0 blue sucker to use the inundated floodplain (Fisher and Willis 2000). The presence of blue sucker on the EBCA floodplain after the levee-topping event was likely due to the increased flows and extended duration of connectivity combined with the close spatial proximity of the wetland pools to the confluence of the

LMOR and Perche Creek. Presence of YOY blue sucker at EBCA in relation to the levee-topping event, but not the backflooding events, parallels the work of Fisher and Willis (2000) who found age-0 blue suckers in a “confluence backwater” site highly connected to the Missouri River in North Dakota, but not in a larger backwater site located 0.5 km (0.3 mile) off the main channel that is seasonally connected by inlet and outlet channels.

Fluvial dependents exhibited different degrees of waterbody use with lotic versus lentic characteristics. Some fluvial dependents (e.g., longnose gar [*Lepisosteus osseus*], flathead catfish [*Pylodictis olivaris*], Redhorses, and paddlefish) may be more adapted to lotic conditions and thus largely or completely restricted to using EBCA wetlands during larger flood pulses that connect with the wetlands via top-flooding; other fluvial dependents (e.g., freshwater drum, Asian carps, grass carp, and goldeye) benefit additionally from access to the inundated floodplain during a subset of floodplain-activation flood events. This difference in the ability of fluvial dependents to use inundated floodplain waterbodies was indicated by the restricted presence of the first group in 3E1407 while the second group showed appreciable relative abundances during 2008 egress events. My findings generally parallel those of Miyazono (2008), who discovered stronger use of floodplain waterbodies with higher rather than lower spatiotemporal degrees of connectivity by different fluvial dependents in floodplain lakes within the Yazoo River Basin (lower Mississippi Alluvial Valley). Miyazono (2008) found longnose gar and flathead catfish mostly in connected floodplain lakes, whereas freshwater drum were able to inhabit lakes with lower connectivity potentials. Connectivity potential is based on horizontal distance between lakes and rivers, area of

neighboring water bodies, and number of inlets/outlets (Miyazono 2008). By extension, connectivity potential of the EBCA wetland was higher in 2007 than 2008 because of the larger number of inlet and outlet points associated with the levee-topping connectivity event in 2007 compared to the single point of entry and exit via the fishway in 2008 (Figure 1). Higher connectivity potential of EBCA in 2007 permitted opportunistic use of the wetland by numerous flow-associated species. Similarly, in a meandering lowland river-floodplain system in Texas, most of the sampled longnose gar were from the river mainstem and spotted gar (*Lepisosteus oculatus*) were found in oxbow habitats, but during the wet year relative to dry year, longnose gar abundance significantly increased in oxbows (Robertson et al. 2008). Floodplain-use patterns from that gar study combined with my finding that adult longnose gar were present at EBCA only in low relative abundances during 3E1407 suggest longnose gar might benefit from access to inundated floodplain waterbodies on the LMOR that have higher spatiotemporal degrees of connectivity than the designed connectivity situation at EBCA. Furthermore, low relative abundance of flathead catfish during 3E1407, with the majority of specimens older juveniles (event mean = 250 mm  $\pm$ 41 mm SD), corroborates habitat-use patterns found in previous LMOR studies. Although flathead catfish use shallow, low-velocity areas downstream of wing- and L-dike structures on LMOR to complete their spawning cycle (Garrett 2010), they also increase their movements into tributaries during flood conditions within the spawning season (Garrett and Rabeni 2011). Moreover, their increased growth rates reflect their increased foraging success on the inundation floodplain during flooding periods (Jones and Noltie 2007). Recruitment benefits for YOY flathead catfish were not observed at EBCA; but my findings, combined with

previous LMOR studies, suggest use of LMOR floodplain wetlands by flathead catfish may mostly be opportunistic by larger juveniles to access increased food resources available during floodplain-maintenance events.

### ***Timing, Duration, and Magnitude of Backflooding Connections and Fish Movement***

Intra-seasonal connection timing influences whether certain fishes can use the wetland only for foraging and refuge or also for spawning and nursery, and my results indicated events occurring from 4 April to 1 June, but preferably after 4 May ( $>16^{\circ}\text{C}$ ), allow the most native fishes to use EBCA wetlands for spawning and nursery (Figure 11, Table 17). My results also suggested the combined effect of duration and magnitude of inflow acts as an additional environmental filter influencing fish movement. However, results about connectivity event size on fish movements came from only two years of data collection, whereas event timing and spawning temperature results presented in Figure 11 and Table 17 were drawn from 16 years of hydrologic data collection, coupling of river water temperatures and calendar dates from 72 years of data collection, and information about spawning temperatures from peer-reviewed literature. Conclusions about the influence of event timing are therefore more robust, whereas conclusions presented below about the influence of event size will need to be corroborated by future research.

Depending on the combination of values for duration, magnitude, and rate-of-change, ranges in connectivity event variables can translate into small, medium, or large amounts of water exchanged between the river and floodplain during a given event (Figure 7). Duration and magnitude of an inflow connectivity event at the fishway and its timing within the spring-summer reproductive season relative to water temperature,

photoperiod, and species-specific spawning temperature ranges collectively influenced the species and ecological guilds that accessed the wetland and the life stages represented by those floodplain-accessing fishes. Specific combinations of traits (strategies) will be favored in a given population under a certain set of environmental selective forces (Mims et al. 2010). Species composition (presence-absence of a species) may change with ingress event magnitude, duration, and timing in early or late spring, but the relative structure of ecological guilds represented will be somewhat constant. The specific environmental filters of a given event may influence species composition, as shown by the number and identity of the dominant species across events. However, relatively constant structure of the ecological guilds represented during an event was also indicated because macrohabitat generalists dominated the fish assemblage during all ingress events, while fluvial dependents showed much lower representation and were present only in events of medium-to-large magnitude and medium-to-long duration (Table 11). These findings are similar to what Górski et al. (2011) reported for the Volga River: viz., that even though recruitment success varies among fish species, the composition of life-history strategies within the floodplain-using fish assemblage remains stable between years – unless unpredictable environmental conditions develop that promote opportunistic strategists. Opportunistic strategists are species such as western mosquitofish that have small body size, low longevity, early maturity, and low fecundity, and they are adapted to stochastic environmental conditions associated with high levels of disturbance intensity and frequency (Winemiller 2005).

The pattern of relatively constant structure of life-history strategists during connectivity events occurring in the spring-summer reproductive season, but varying

dominant species identity relative to event duration, magnitude, and intra-seasonal timing was supported by patterns in the presence and relative abundance of eight macrohabitat generalists during the five 2008 ingress events. Small-bodied western mosquitofish, orangespotted sunfish, green sunfish, bluegill, and golden shiner (*Notemigonus crysoleucas*) as well as large-bodied common carp, gizzard shad, and shortnose gar can be considered part of the baseline fish assemblage during any given event. However, during events of short duration and low magnitude, small-bodied baseline species become dominant members of the floodplain-accessing fish assemblage and timing of those events influences whether large-bodied baseline species are absent (early-to-mid-spring events) or less abundant (late spring events). The overwhelming dominance of western mosquitofish during 2008 supported the finding of Górski et al. (2011) that unpredictable environmental conditions promote opportunistic strategists; such conditions occur at EBCA when flashy flood dynamics in mid-spring produce a small magnitude, short duration event that most large-bodied fishes might not use. Opportunistic strategists have an advantage as they reproduce in a variety of habitats and environmental conditions (Zeug and Winemiller 2007). Additionally, reproductive activity of western mosquitofish and bluegill coincides with peak flows, as opposed to the ascending limb of the hydrograph, so these species may be able to use inundated habitat for reproduction during low flows (Zeug and Winemiller 2007). Accordingly, ingress events at EBCA with smaller amounts of water exchanged may allow these two species access to shallowly inundated habitat that most large-bodied fishes may be unable to use. Other small-bodied baseline species probably benefit in similar ways.

Large-bodied baseline species dominate assemblages during events of longer duration and/or larger magnitude, although identity of the dominant species varies, (probably relative to event timing and species spawning temperature ranges). Common carp and gizzard shad are baseline species able to capitalize on a wide range of larger-sized events for access to floodplain spawning habitats because of their early and protracted spawning temperature ranges combined with their dominance in events throughout the spring. Shortnose gar could be considered a baseline species that can capitalize only on a narrow range of larger-sized events in late spring for access to spawning habitat. This is suggested because they are late-spring spawners with a more constricted range and they dominated only during 5I1508.

Timing of ingress events determines whether floodplain-accessing macrohabitat generalists can immediately spawn or only use the EBCA wetland for other activities (Table 17). However, as was the case for the baseline species, amount of water exchanged also appears to influence the movement patterns of certain macrohabitat generalists. Inflows of medium-to-large magnitude and medium-to-long duration at EBCA were associated with higher species composition and relative abundance of macrohabitat generalists such as bigmouth buffalo, smallmouth buffalo, and white crappie (*Pomoxis annularis*). Floodplain waterbodies are important for white crappie because they may not be able to reproduce in the main channel due to fast velocities of high flow pulses disrupting their reproductive activity, specifically their successful building and guarding of nests (Zeug and Winemiller 2007). Accordingly, the high predictability (almost yearly) of flood pulses that create medium or large amounts of water exchanged through the fishway probably permits development of habitat conditions

during the subsequent inundation and isolation period that are stable long enough for white crappie to use the wetland for reproduction.

Movement to floodplain habitats from the river mainstem is necessary for completing certain life-history stages for many riverine fishes (Csoboth and Garvey 2008; Galat et al. 2005b); and, late spring ingress events through the fishway are particularly important for fluvial dependent Asian carps, grass carp, freshwater drum, and goldeye because connection timing allows their eggs and/or larvae to drift into the wetland (Table 17, late spring benefit # 3 and cost # 2). Incidence patterns of those fluvial dependents during the 2008 ingress events suggested event duration and magnitude serve as additional environmental filters on fish movement and recruitment by interacting with event timing to influence the life stage using the wetland. My findings indicated ingress events with medium or large amounts of water exchanged that occur in early and mid-spring provide access to food and refuge only for adults and  $\geq$  age-1 juveniles of Asian carps and freshwater drum; whereas similar-sized inflow events in late spring allow Asian carps, grass carp, freshwater drum, and goldeye to use the wetland as a nursery. The importance of large magnitude, long duration inflows in late spring for YOY and juvenile recruitment of these species was indicated by the presence of adult Asian carps, grass carp, freshwater drum and of larval specimens of all four fluvial dependents during 5I1508 combined with the moderate or large gross export biomasses and size structures dominated by YOY during subsequent egress events for all four species.

### ***Inundation Dynamics, Timing of Water Releases, and Fish Recruitment Benefits***

Fast growth rates during wetland inundation, high gross biomass exported, and size structures dominated by age-0 specimens during egress events indicated recruitment of native and invasive taxa benefit from use of the inundated wetland during both flood year types. These findings corroborate the Flood Recruitment Model that proposes fish recruitment is enhanced through exposure of larval fishes to increased food resources on the inundated floodplain (Harris and Gehrke 1994). Patterns observed for gizzard shad and freshwater drum during ingress and egress events correspond with those of Csoboth and Garvey (2008) who showed larvae gizzard shad and freshwater drum that drifted onto the floodplain were able to grow and make an ontogenetic habitat shift before returning to the river in high numbers as juveniles. However, additional mechanisms beyond duration and magnitude of flooding and favorable temperatures potentially influence recruitment success on the floodplain (Górski et al. 2011). During inundation that extends into late summer, both abiotic (e.g., anoxia and desiccation) and biotic (competition and predation) processes may influence, or slightly mask, the effect of successful spawning (Górski et al. 2011). Accordingly, the overriding influence of some intra-wetland driver (such as competition) could explain why Buffalofishes had appreciably smaller gross export biomasses than the dominant taxa even though adult Buffalofishes entered the wetland during ingress events in numbers similar to gizzard shad. Longer residence within the EBCA wetland generally translates to higher biomass and larger size at export, but longer residence may also increase stress and survival risks (depending on the species). Higher water temperatures accompanied lower dissolved oxygen levels during inundation (Montgomery and Galat 2014, Appendix O), and

declining water quality as inundation duration extended may have provoked this switching effect from promoting fast growth rates to negatively influencing population dynamics.

Floodplain wetlands may also be important locations for certain species to make ontogenetic diet shifts that could influence intra-wetland trophic dynamics by either reducing or increasing competition for resources. Shortnose gar make an ontogenetic shift to piscivory after reaching ~30 mm TL (MNHP 2013). This diet shift occurs while shortnose gar are still in the larval stage (Appendix A: Table A1, larval cut-off value: 50 mm). This early shift to higher energy density food items could explain why shortnose gar displayed one of the fastest growth rates of all evaluated taxa and exported biomasses that were the largest of all taxa in 2007 and 2<sup>nd</sup> largest in 2008. On the other hand, grass carp are not herbivorous as larvae and juveniles, and instead these life stages feed on zooplankton and other organisms (e.g. insect larvae) and can potentially compete with native fishes for food and alter trophic dynamics (Dibble and Kovalenko 2009).

Accordingly, investigations to better understand the ecosystem impacts of all life stages of grass carp should occur in systems where reproduction of naturalized populations has been confirmed (Dibble and Kovalenko 2009). My findings of fast growth rates and large biomass export of YOY and juvenile grass carp combined with larger export sizes of grass carp than gizzard shad and freshwater drum suggested two conclusions about grass carp. The LMOR Boonville reach contains a reproductively active grass carp population; and, EBCA wetlands could be good locations to investigate the possible competitive influence of larval and juvenile grass carp on the floodplain-using fish assemblage.

Early- versus late-season egress events result in tradeoffs to the fish assemblage. Numerous fish taxa (e.g., Asian carps, and gizzard shad) showed considerably higher export biomasses and had grown much closer in size to the generalized gape-limit of riverine predators (200 mm) during late-season egress. However, insofar as Asian carps, common carp, and grass carp displayed larger size structures and larger export biomasses than most native taxa (except for shortnose gar), they realized greater overall benefits to YOY recruitment than most native taxa as residence time within the wetland was extended into late summer. Additionally, as wetland inundation and isolation over the summer extended from approximately 11 days towards a duration of 67 days during the levee-topping year, Shiners displayed slow instantaneous growth rates (Table 15) and decreasing body conditions (Montgomery and Galat 2014); these patterns indicate Shiners (and other fluvial specialists) may need shorter inundation and isolation durations in levee-topping than backflooding years. Growth rates of all evaluated taxa slowed between early- and late-season egress events in 2008 (Table 16), suggesting moderate durations (~40 days) during backflooding years allow native species adequate time to use the floodplain as a nursery before physiochemical conditions begin to stress fishes and negatively impact growth and survival. Diminishing returns of fisheries production with extended duration of floodplain inundation has also been indicated for gizzard shad (as a constantly decreasing trend) and for black and white crappies and possibly Buffalofishes after a threshold has been reached (Alford and Walker 2013). Furthermore, considerably different fish assemblages between early- and late-season egress events suggested that when two egress events occur during a given summer, the fish assemblage using the wetland will not be the same between events because some species may leave completely

(e.g. skipjack herring, Redhorses) or mostly (e.g., Buffalofishes, goldeye) and lentic-adapted species such as western mosquitofish and orangespotted sunfish will remain and become dominant. Floodplain waterbodies characterized along a connectivity continuum by lower connection frequencies and longer periods of isolation show transitioning from diverse assemblages with species compositions similar to what is in the river to assemblages dominated by smaller-bodied, more lentic-adapted fishes such as centrarchids and clupeids (Galat et al. 2004b; Lubinski et al. 2008; Miranda 2005).

The increased YOY and juvenile recruitment success of Asian carps at EBCA relative to gizzard shad and other natives was probably due to their greater ability to capitalize on available resources on the newly inundated floodplain. The fast growth rates of Asian carps while exposed to warm water temperatures during inundation periods (~28 °C; Montgomery and Galat 2014, Appendix O) corroborates Chapman and George's (2011) laboratory findings that silver and bighead carps developed faster under warmer water temperature conditions (~22 °C versus ~20 °C). Fast growth rates of Asian carps at EBCA probably allowed them to quickly begin feeding on larger-sized prey, thereby improving their survival chances when exported to the river. Since Asian carps can compete with native taxa for food resources (Schrank et al. 2003), determining productivity in EBCA wetlands during future studies could clarify whether food resources are limiting and whether this affects recruitment success of Asian carps or certain native species during managed wetland inundation. This information is especially important since the flexible diets of bighead and silver carps allow them to adapt to variable environmental conditions (Sampson et al. 2009). This behavioral adaptation

may provide a feeding advantage during inundation and isolation periods regardless of the physiochemical profiles associated with different flood year types.

## **Management Implications**

### ***Contingency Plans for Site-Level Management of Lateral Connectivity, Wetland Inundation, and Native Fish Recruitment***

Research and management of river-floodplain connectivity and fish recruitment are complicated by the interaction of fishes' multifaceted life-history strategies with fluctuating spatiotemporal dynamics of lateral connectivity (Fullerton et al. 2010).

Adaptive management of lateral connectivity and inundated floodplain wetlands therefore requires adjusting for spatiotemporal variability in system structure and functions by developing management scenarios that include multiple contingency plans (Sparks et al. 1998). Information in Table 5 characterizes the cross-scale influence of reach-level flow dynamics on site-level lateral connectivity, thereby facilitating determination and maintenance of ecosystem resilience needed to promote ecosystem-based fisheries management (Francis et al. 2007). The Connectivity Event Prediction Model helps identify opportunities to capitalize on lateral connectivity and anticipate values of connectivity event variables. This enables EBCA managers to incorporate connectivity events with the river as an additional water source when planning how to manipulate inundation depth and duration in the wetland. The Connectivity Event Prediction Model also provides a foundation for developing contingency plans for management actions at EBCA and similar wetlands to address connectivity dynamics during different types of

high flood years in relation to ecosystem-based management goals. In the face of uncertainties that might otherwise prompt inaction (or delay) by managers, development of potential future scenarios promotes provisional management actions subject to further refinement (Carpenter 2002; Francis et al. 2007).

Management actions concerning inundation dynamics and timing of water releases at the wetland should differ in response to levee-topping versus backflooding events because native fish assemblage recruitment benefits differ between these two connection types. Floodplain-maintenance events that overtop EBCA levees are not as frequent as floodplain-activation events via the fishway that do not rise above the wetland's full-pool water level (return interval of 1.1 to 1.3 years); nevertheless, floodplain-maintenance events are still fairly frequent (minimum return interval of 2.8 to 5.7 years). Accordingly, development of contingency plans for levee-topping events can help managers adjust strategies for adapting to levee-topping events that present very different circumstances than designed backflooding events.

Contingency planning should incorporate decision thresholds into management plans to adaptively manage flood pulses that laterally connect with the floodplain (Sparks et al. 1998). For instance, advance management priorities might be set so that after a spring flood pulse has inundated the floodplain for a specified length of time, priorities would shift toward promoting fish recruitment over moist-soil plant production (Sparks et al. 1998). Incorporating this type of duration-based threshold into contingency plans for backflooding events may also serve management interests to favor native versus invasive fish recruitment (see below paragraphs). Area managers might be further well-served by incorporating magnitude-based decision thresholds for shifting management priorities.

One such decision threshold occurs when EBCA levees are overtopped, although additional thresholds relevant to objectives for other wetland species could be designated at lower flood magnitudes. All such contingency plans at EBCA for levee-topping connectivity events that temporally and spatially inundate the wetland will need to be continually refined based on further analyses. My findings, however, suggest some appropriate starting points. For example, when the river overtops the levee and then quickly recedes, it is important to drain some water off the area at the first opportunity. Alternatively, when the river overtops the levee, but then slowly recedes and remains high for an extended duration, it is important to allow a lateral exchange pathway to remain open via the fishway. These management actions would promote spawning and nursery of flow-associated taxa (e.g., Shiners) and allow fishes temporary access to floodplain resources and then quick return to the river (Table 18, early-to-mid summer benefit # 2).

The decision tree depicted in Figure 12 can help managers decide their course of action in response to a normative, backflooding connectivity event by preparing them for the type of connectivity dynamics they will encounter and the decision options available for responding to those dynamics. Since event duration is relatively short at the spawning window scale (75% of events <25 days; Table 5), planned manipulations of fishway gates on actively managed wetlands could extend the length of time water is on the floodplain for fishery-based goals as well as for promoting other management objectives. Importantly, managers can capture and retain water for longer durations following backflooding than levee-topping events. This action would promote spawning

and nursery of several key native and invasive taxa, but would require addressing additional management considerations (Figure 13).

Furthermore, managers can use conclusions about the combined influence of event magnitude and duration on fish movement summarized here (and detailed in the *timing, duration, and magnitude of backflooding connections and fish movement* section) to tailor objectives and actions to the anticipated fish assemblage structure. The eight macrohabitat generalists comprising the baseline fish assemblage will likely be present during the majority of event types managers will encounter; managers can use this knowledge to design actions to allow native species use of the wetland while controlling simultaneous use by Asian carps. When managers have opportunities to manipulate prospective connectivity events to promote native fish recruitment, they can reasonably ascertain in advance whether to expect just baseline invasive species – i.e., common carp and western mosquitofish that would likely be present during any event – or the full suite of invasive species typically present during events of medium-to-large magnitude and medium-to-long duration. However, when that larger-sized event occurs in late spring, Asian carps and grass carp can use it for recruitment, so additional Asian carp control methods may be needed (see next subsection). But importantly, management actions at EBCA that allow connectivity events to occur in spring – especially long duration, large magnitude events in late spring – would encourage native fish recruitment.

Management actions at the wetland site concerning inundation dynamics and timing of water releases in early versus late summer will need to consider recruitment benefits for native versus invasive fishes (summarized here and detailed in Table 18 and the *inundation dynamics, timing of water release, and fish recruitment benefits* section).

Young-of-the-year and juveniles of all large-bodied taxa would return to the river well-below the general gape-limit of predators during early-season egress events (Table 18). This implies a greater cost for natives than invasives because natives would be more likely to suffer high predation losses due to smaller sizes upon export to the river while still ill-equipped to compete for food and survive the upcoming fall and winter; conversely, small size of fishes exporting to the river is a benefit to riverine piscivorous fishes like recreationally important catfishes and sauger. Furthermore, since fish-use patterns at EBCA generally indicated moderate durations (~40 days) of inundation are better overall than long durations (~67 days), the safest management option to encourage native fish recruitment and the largest variety of fish species to survive is to develop contingency plans that permit egress events in early-to-mid-summer.

### ***Invasive Fish Taxa***

The national Asian carp management and control plan advises biological information be provided to the USACE concerning habitat restoration sites within the Missouri River Mitigation Project and how those sites benefit native species as well as Asian carps and grass carp (Conover et al. 2007). The high species richness and biomass exported to the LMOR during this study showed the EBCA mitigation site promotes spawning and nursery of native species. This finding suggests if multiple, similar mitigation sites were present, the biomass collectively exported from them could provide substantial population-scale benefits to the native fish assemblage. Unfortunately however, as more mitigation sites are created, so too are more nursery habitats for Asian carps and (to a

lesser extent) grass carp since these invasive taxa respond to the same movement cues as numerous native fishes.

Extirpation of Asian carps and grass carp in the wild is the goal of the national Asian Carp management and control plan (Conover et al. 2007). However, when an introduced species has become established and achieved nuisance levels, management options become limited and more difficult and may need to be focused on containment and control instead of eradication (Kolar et al. 2010). Prevention tactics such as barriers using acoustics, bubble curtains, and electricity may be effective at the northern edge of the Asian carp invasion; but, within the LMOR where the fish are already well established, it may be more beneficial to revise our perceptions of, and responses to, these invasive taxa. Society's perceptions of nuisance fish change over time and management goals and actions do not remain static (Kolar et al. 2010), so perhaps control and containment efforts on the LMOR could be adjusted for Asian carps as society's perception of them as a value-added item begins to shift.

Increased commercial and recreational fishing for Asian carps and promotion of their socioeconomic use could offset management costs associated with control and removal efforts. Commercial harvest of Asian carps in Missouri has increased over the past decade, and they were the third most harvested fish group in 2012 at 23 616 kg (26 US tons), which was 15% of the total harvest (Tripp et al. 2013). The current market for Asian carps is mostly found in Asia: 239 496 771 kg (264 000 US tons) of beheaded, dressed, and frozen Asian carps were shipped overseas in 2014 from the Two Rivers Fisheries processing plant in Kentucky (Downs 2015). However, the United States market could be further developed if our society's perception of the fish changes. Results

from a recent survey on the willingness of Americans to taste and then purchase Asian carps as a food product were promising, with >70% willing to try a free sample and their willingness to buy highest for fillets at 68% and lowest for fish cakes at 59% (Varble and Secchi 2013). However, since there is currently higher market appeal for adult bighead carp, there may be a risk that harvest efforts would become size-selective or species-selective and undermine efforts to effectively collapse Asian carp populations through fishing methods (Tsehaye et al. 2013). Economic incentives may be required to encourage commercial fishing of juvenile Asian carps for use in value-added items such as fish-oil products, organic fertilizer, or aquaculture fish meal (Tsehaye et al. 2013).

Proactive management and control strategies at multiple spatial scales aimed at removing Asian carps will remain important for the next ten to twenty years regardless of whether it is a flood or drought year on the LMOR. Longevity data suggest Asian carps can have maximum life spans of 7 to 16 years (Kolar et al. 2005; Tsehaye et al. 2013; Williamson and Garvey 2005); and fecundity of Asian carps increases with age and body size (Kolar et al. 2005). Many of the Asian carps that benefited from use of EBCA wetlands as recruitment sites during 2007 and 2008 – then as age-0 and age-1 individuals – are now sexually mature, long-lived individuals. Even now as they may be nearing the end of their life span, female Asian carps produced at EBCA during the study years may display fecundities of approximately 770 000 eggs, as suggested by Schrank and Guy (2002). These collective results indicate strong year classes were recruited into the LMOR from EBCA during 2007 and 2008, and comparably strong year classes were likely also recruited at other LMOR floodplain sites during those two flood years. Hydrologic conditions on the LMOR continued to be flood years from 2009 to 2015,

except 2012 and 2013 ([http://waterdata.usgs.gov/mo/nwis/uv?site\\_no=06909000](http://waterdata.usgs.gov/mo/nwis/uv?site_no=06909000)), so strong year classes of Asian carps have likely been produced in the LMOR system almost every year since this study. A comparable series of strong year classes for Asian carp recruitment was also found on the Illinois River in 2004 and 2009 by Phelps and Willis (2013); their findings combined with the biomass and size structure patterns of Asian carps found exiting EBCA in this study indicate Asian carps are very successful at adding new cohorts to their populations. Increased abundances of Asian carps may pose a major impediment for expanding use of actively managed floodplain wetlands like EBCA to benefit recruitment of native fishes to the Missouri River unless proactive management and control strategies are used. However, unless it can be shown that Asian carps are outcompeting and thus having a deleterious effect upon native species (as opposed to just out-performing them), there is no need to be unduly alarmed and deny Missouri River fishes access to floodplain wetlands.

This study showed a rich and diverse fish assemblage used EBCA and large numbers and biomass were exported – all despite the abundant Asian carps that also used EBCA. Asian carps are well-established in the LMOR, but native fishes remain abundant and are doing well. The information presented in Tables 17 and 18 can help managers of floodplain wetlands weigh the costs and benefits of fish use when promoting inflow and outflow connectivity events. Preventing inflow to EBCA when water temperatures are within spawning ranges of Asian carps could serve as a control measure, but the cost of reducing ingress of native fishes might outweigh benefits to reducing Asian carps. Similarly, preventing water releases to the river in the summer could serve as a control measure, but this option would also deny prospective benefits to native fish recruitment.

A compromise could allow late-spring ingress events (~after 16 °C, 4 May) followed by egress events in early-to-mid-summer after moderate durations of inundation and isolation (~40 days). Such management actions would provide native fishes adequate time to access the floodplain in the spring and use it as a nursery in the summer before physiochemical conditions begin to stress fishes and negatively impact growth and survival; such actions would also allow invasive fishes to be exported while they are still below the gape-limit of riverine predators.

### ***Selection and Management of LMOR Floodplain Wetland Mitigation Sites***

The proportion of the LMOR floodplain inundated by the flood pulse that can promote fish recruitment (Figure 14, factor 5) is addressed by MRRP land acquisition through mitigation. The functional surface area of a floodplain is extremely important because it influences whether ecological benefits are just local, as with a limited amount of available floodplain habitat, or whether benefits translate to the population or system-level, as with a spatially extensive floodplain (Opperman et al. 2010). A large proportion of the historical floodplain of the Missouri River was lost due to structural and functional modifications, including a 50% reduction of river-floodplain surface area in Missouri (Funk and Robinson 1974). The MRRP has taken and continues to take actions to identify and restore approximately 675 km<sup>2</sup> (166 750 acres) of land at over 50 individual sites throughout the LMOR floodplain (MRRP 2012). My research demonstrated that LMOR stage and temperature rises are coupled despite the highly altered system (Figure 5) and that highest frequency and predictability of river-floodplain connectivity events occurs during the temperature window at which a majority of riverine fishes begin

spawning (Figures 6, 11). These findings indicate the LMOR Boonville, MO reach provides a relatively large area and an optimal focal location for MRRP to acquire and maintain floodplain mitigation sites and pathways for lateral fish movement. Similar connectivity dynamics and fish assemblages can be expected where relative spatiotemporal locations of existing or potential mitigation sites are similar to those at EBCA. Furthermore, Jacobson et al. (2015) identified several reaches of the LMOR (river km 40-122 [river mile 25-76], 363-474 [227-296], 602-662 [376-414], and 816-907 [510-567]) where 50% of the floodplain is within reach of high-frequency floods and thus would be promising locations to promote connectivity opportunities and ecological restoration. Mitigation sites built within those identified reaches could expect to have fish assemblages similar to this study.

Floodplain sites demonstrating lower degrees of lateral connectivity typically contain fish assemblages dominated by species with generalist life-history requirements, such as gizzard shad or centrarchids (Galat et al. 2004a). Fish assemblage results of Objectives 5 and 6 corroborated this fish-use pattern, specifically assemblages of the small magnitude, short duration ingress events and the late-season egress event being dominated by western mosquitofish and orangespotted sunfish. Management goals for mitigation sites at higher elevations than EBCA might therefore put a stronger focus on waterbirds than riverine fishes since timing of lateral connectivity is not as important for the macrohabitat generalists that would use those wetlands (compared to fluvial dependents that would use wetlands with higher spatiotemporal connectivity dynamics).

My findings for the levee-topping event suggested that an inundated floodplain with complex spatial and temporal connectivity dynamics promotes high quality

recruitment conditions for LMOR fishes that typically use channel borders or continuously connected wetlands as nursery sites. Production of YOY native fluvial specialists (e.g., Shiners and blue sucker) and promotion of refuge and feeding habitat for strongly flow-associated native fluvial dependents (e.g., longnose gar, flathead catfish, and paddlefish) would benefit from construction of appropriately designed mitigation sites. Appropriately designed sites include those built along channel borders to mimic the braided, shifting channel of the natural river system by having a continuous or nearly continuous lateral exchange pathway and those built to allow direct river water incursion routes (such as the flow-through sites, or chutes, currently being constructed as part of MRRP). Such constructions would provide greater recruitment benefits for flow-associated fishes than backflooded mitigation sites located at distances greater than >0.8 km (>0.5 miles) from the mainstem. Additionally, Sterner et al. (2009) recommends longer chutes (similar to those at Tate Island and Lisbon Bottom) that permit floodplain connectivity while also encouraging natural river processes to develop habitat diversity – specifically a combination of shallow water and backwater areas – because this promotes high species richness and benefits juveniles of many native species, particularly flow-associated species. Continuously connected sites would also benefit other fluvial dependents able to use the floodplain as a nursery, specifically Asian carps, grass carp, freshwater drum, and goldeye, because the increased duration of connectivity and range of water temperatures improve the likelihood that eggs or larvae of these taxa will access the floodplain. This is an important ecological point to consider when evaluating ecosystem-based management strategies for continuously connected, or frequently connected, sites at lower elevations and the information in Table 17 can help managers

address this point. The increased likelihood of the presence of key fluvial dependents at these mitigation sites should increase concerns about native versus invasive fish recruitment.

## **Summary of Research Value to River Fish Management and River-Floodplain**

### **Connectivity**

1. Incursion route of river water onto the floodplain is an important physical feature that influences fish assemblage composition using the inundated habitat. Some fluvial dependents (and select fluvial specialists) capitalize only on topflooding connectivity events at EBCA because of their specific, flow-related habitat-use requirements, but other fluvial dependents also gain recruitment benefits from accessing the inundated wetland during a subset of backflooding events via the fishway. Macrohabitat generalists capitalize on nearly the full range of connectivity event types at EBCA. These findings at EBCA might translate to continuously connected wetlands (or chutes) versus periodically connected wetlands elsewhere on the LMOR.
2. Adequate fish access to the wetland requires more than just a backflooding connectivity event via the EBCA fishway. The duration, magnitude, and intra-seasonal timing of a given event will also influence fish assemblage structure accessing the wetland and whether individual species can use it for spawning and/or nursery in addition to feeding and refuge.
3. Monitoring the exchange pathway during individual connections showed riverine fishes use the wetland for spawning and/or nursery and they successfully recruit to the river in substantial numbers. Larger-scale studies that monitor floodplain

waterbodies before or after flooding – but not during – may considerably underestimate the degree of use these areas receive, especially since some species may use the floodplain in a highly transient manner when there is a pathway allowing quick return to the river. Notably, when Hogberg and Pegg (2015) investigated fish use of a portion of the Missouri River floodplain during an atypical large magnitude, long duration flood, they found a high number of species (42) using the floodplain, but also highlighted the importance of identifying relevant habitat features to help improve our understanding of factors fish are keying onto when responding to extreme flood events.

4. This study indicates the contemporary LMOR hydrology and extensive floodplain (due in part to recent mitigation and recovery efforts) enables frequent channel-floodplain connections of sufficient magnitude and duration for wetlands to provide a functional and highly productive spawning and nursery area for many species of native Missouri River fishes. Benefits of high species richness and high export biomass from wetlands to the LMOR occur despite the long history of flow and habitat alterations on the Missouri River and even though Asian carps also benefit from these wetlands. Since Asian carps are well-established in the LMOR and their eradication is highly unlikely, and since successful commercial enterprises have been developed using harvested Asian carps, perhaps we should adapt to the reality of their presence and develop further uses for these invasive taxa while we continue to promote native fish recruitment on the LMOR.

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## APPENDICES

### Appendix A: Literature-Derived Species-Specific and Taxon-Specific Total Length Cut-Off Values for Fishes Collected at Eagle Bluffs Conservation Area

Table A1. Species-specific or taxon-specific total length (TL, mm) cut-off values from the literature for two categories: life stage-based and age-based. Species- or taxon-specific total length cut-off values are used for completion of various objectives. Information includes identification code, common name, scientific name, maximum larval TL, minimum sexually mature adult TL, maximum age-0 TL, and maximum age-1 TL. References are listed at bottom of table.

Scientific name	Common name	Fish code	Life stage-based total length cut-off value (mm)		Age-based total length cut-off value (mm)	
			Larval <sup>a</sup>	Sexually mature adult <sup>b</sup>	Age-0 <sup>c</sup>	Age-1 <sup>c</sup>
<i>Ichthyomyzon castaneus</i>	chestnut lamprey	CNLP	152 <sup>d</sup>	254 <sup>d</sup>		
<i>Polyodon spathula</i>	paddlefish	PDFH	20	1067	295	551
<i>Lepisosteus oculatus</i>	spotted gar	STGR			264	
<i>Lepisosteus osseus</i>	longnose gar	LNGR	41	500	279	475
<i>Lepisosteus platostomus</i>	shortnose gar	SNGR	50	381 <sup>d</sup>	127	417
<i>Lepisosteus</i> spp.	unidentified gar	UGR	50			
<i>Alosa chrysochloris</i>	skipjack herring	SJHR	21	305 <sup>d</sup>	127 <sup>d</sup>	
<i>Dorosoma cepedianum</i>	gizzard shad	GZSD	24	229 <sup>d</sup>	152	315
Unidentified <i>Clupeidae</i>	unidentified herring	UHR	24			
<i>Hiodon alosoides</i>	goldeye	GDEY	33	355 <sup>d</sup>	130	196
<i>Campostoma anomalum</i>	central stoneroller	CLSR			99	130
<i>Carassius auratus</i>	goldfish	GDFH		109 <sup>d</sup>	64	89
<i>Ctenopharyngodon idella</i>	grass carp	GSCP	14	500 <sup>e</sup>		
<i>Cyprinella lutrensis</i>	red shiner	RDSN	16	46 <sup>d</sup>	36	48
<i>Cyprinus carpio</i>	common carp	CARP	17	279	150	366
<i>Hypophthalmichthys molitrix</i>	silver carp	SVCP		530 <sup>f</sup>		
<i>Hypophthalmichthys nobilis</i>	bighead carp	BHCP	15	700	212	
<i>Hypophthalmichthys nobilis</i> x <i>H. molitrix</i>	bighead carp x silver carp hybrid	BHSV	15	530 <sup>f</sup>	212	
<i>Hypophthalmichthys</i> spp.	unidentified Asian carp	UAC	15	530 <sup>f</sup>	212	
<i>Luxilus cornutus</i>	common shiner	CMSN			79	96
<i>Lythrurus umbratilis</i>	redfin shiner	RFSN		38		56

Table A1 (continued)

Scientific name	Common name	Fish code	Life stage-based total length cut-off value (mm)		Age-based total length cut-off value (mm)	
			Larval <sup>a</sup>	Sexually mature adult <sup>b</sup>	Age-0 <sup>c</sup>	Age-1 <sup>c</sup>
<i>Macrhybopsis aestivalis</i>	speckled chub	SKCB	12	46 <sup>d</sup>		49
<i>Macrhybopsis storeriana</i>	silver chub	SVCB	21		60	145
<i>Notemigonus crysoleucas</i>	golden shiner	GDSN	21	76 <sup>d</sup>	58	71
<i>Scardinius erythrophthalmus</i>	rudd	RUDD		203 <sup>d</sup>		
<i>Notropis atherinoides</i>	emerald shiner	ERSN	14	63 <sup>d</sup>	66 <sup>d</sup>	83 <sup>d</sup>
<i>Notropis blennioides</i>	river shiner	RVSN	6	51	56	64
<i>Hybopsis dorsalis</i>	bigmouth shiner	BMSN	5		36	56
<i>Notropis stramineus</i>	sand shiner	SNSN	12	43 <sup>d</sup>	38	48
<i>Notropis</i> spp.	unidentified shiner	UNO	10	43 <sup>g</sup>	38	48
Unidentified <i>Cyprinidae</i>	unidentified minnow	UCY	10	41 <sup>g</sup>		
<i>Pimephales notatus</i>	bluntnose minnow	BNMW	16	50.5	48	58
<i>Pimephales promelas</i>	fathead minnow	FHMW	17	48	58	61
<i>Pimephales vigilax</i>	bullhead minnow	BHMW	8		51	64
<i>Semotilus atromaculatus</i>	creek chub	CKCB		76	71	104
<i>Carpionides carpio</i>	river carpsucker	RVCS	17	240	132	213
<i>Carpionides cyprinus</i>	quillback	QLBK	15	305 <sup>d</sup>	38	246
<i>Cycleptus elongatus</i>	blue sucker	BUSK	31 <sup>h</sup>	610	50	
<i>Ictiobus bubalus</i>	smallmouth buffalo	SMBF	24	374	122	241
<i>Ictiobus cyprinellus</i>	bigmouth buffalo	BMBF	30	406	168	279
<i>Ictiobus niger</i>	black buffalo	BKBF	25			310
<i>Ictiobus</i> spp.	unidentified buffalo	UBF	24	374	122	241
<i>Moxostoma erythrurum</i>	golden redbreast	GDRH	16	290	99	218
<i>Moxostoma macrolepidotum</i>	shorthead redbreast	SHRH	27	330		
<i>Moxostoma duquesnii</i>	black redbreast	BKRH		233		
<i>Moxostoma</i> spp.	unidentified redbreast	URH	16	290	99	218
<i>Ameiurus melas</i>	black bullhead	BKBH	13	254	51	168
<i>Ameiurus natalis</i>	yellow bullhead	YLBH		140	74	178
<i>Ictalurus punctatus</i>	channel catfish	CNCF	15	304 <sup>d</sup>	94	190
<i>Pylodictis olivaris</i>	flathead catfish	FHCF	15	457 <sup>d</sup>	104	249
<i>Fundulus dispar</i>	starhead topminnow	SHTM		46 <sup>d</sup>		

Table A1 (continued)

Scientific name	Common name	Fish code	Life stage-based total length cut-off value (mm)		Age-based total length cut-off value (mm)	
			Larval <sup>a</sup>	Sexually mature adult <sup>b</sup>	Age-0 <sup>c</sup>	Age-1 <sup>c</sup>
<i>Gambusia affinis</i>	western mosquitofish	MQTF		30	29	31
<i>Labidesthes sicculus</i>	brook silverside	BKSS	15			
<i>Morone chrysops</i>	white bass	WTBS	20	254	254	354
<i>Morone saxatilis</i>	striped bass	SDBS		633	122	
<i>Lepomis cyanellus</i>	green sunfish	GNSF	15	66	25 <sup>b</sup>	165
<i>Lepomis gulosus</i>	warmouth	WRMH		79	81	128
<i>Lepomis humilis</i>	orangespotted sunfish	OSSF	11	61	53	55
<i>Lepomis cyanellus x L. humilis</i>	green sunfish x orangespotted sunfish hybrid	GSOS	15	66	86	165
<i>Lepomis macrochirus</i>	bluegill	BLGL	15	102 <sup>b</sup>	13 <sup>b</sup>	119
<i>Lepomis megalotis</i>	longear sunfish	LESF		56	51	74
<i>Lepomis microlophus</i>	reardear sunfish	RESF		134	76	132
<i>Lepomis</i> spp.	unidentified <i>Lepomis</i>	ULP	15	66	86	165
<i>Micropterus dolomieu</i>	smallmouth bass	SMBS	27	292	190	292
<i>Micropterus punctulatus</i>	spotted bass	STBS		216	127	236
<i>Micropterus salmoides</i>	largemouth bass	LMBS	16	250	145	226
<i>Micropterus</i> spp.	unidentified <i>Micropterus</i> spp.	UMC	16	216	145	226
<i>Pomoxis annularis</i>	white crappie	WTCP	16	150	124	208
<i>Pomoxis nigromaculatus</i>	black crappie	BKCP	18	140	119	196
Unidentified	unidentified	UCN	14	66	86	165
<i>Centrarchidae</i>	sunfish					
<i>Etheostoma nigrum</i>	johnny darter	JYDR	10	42.5	51	70
<i>Percina caprodes</i>	logperch	LGPH	14	71.5	81	121
<i>Percina maculata</i>	blackside darter	BSDR		52	60	68
<i>Sander canadensis</i>	sauger	SGER	15	318	216	371
<i>Aplodinotus grunniens</i>	freshwater drum	FWDM	15	304 <sup>d</sup>	112 <sup>d</sup>	206 <sup>d</sup>

<sup>a</sup> Holland-Bartels et al. (1990) or Sargent (1996).

<sup>b</sup> O'Hara et al. (2007).

<sup>c</sup> Carlander (1969; 1977; 1997).

<sup>d</sup> MDC (2012).

<sup>e</sup> Cudmore and Mandrak (2004).

<sup>f</sup> Williamson and Garvey (2005).

<sup>g</sup> Sargent (1996).

<sup>h</sup> Adams et al. (2006).

## **Appendix B: Growth Rates of Selected Fish Taxa during Varying Durations of Managed Wetland Inundation and Isolation (Objective 6)**

### **Methods**

#### *Reference Time Designations and Growth Rate Calculation Groups*

The final day of sampling a connectivity event, when fishway gates were closed, was input for  $time_0$ ,  $time_1$ , or  $time_2$  in Equation 5. In 2007,  $time_0$  was the final day of early-season egress event *3E1407* (6 June [JD 158]) and  $time_1$  was the end of late-season egress event *4E1507* (12 August [JD 225]); wetland inundation duration between those reference times was 67 days. In 2008,  $time_0$  was the final day of ingress event *5I1508* (6 June [JD 158]). Closure of fishway gates at the end of *5I1508* retained river water and fishes in the wetland until the subsequent water releases that year, early-season egress event *6E1508* ( $time_1$ ; 16 July [JD 198]) and late-season egress event *7E1508* ( $time_2$ ; 12 August [JD 225]).  $Time_1$  served as the endpoint reference time for the managed inundation period that lasted 40 days from  $time_0$  to  $time_1$ , and it served as the initial reference time for the 27 day inundation period lasting from  $time_1$  to  $time_2$ . Total inundation duration for 2008 was 67 days from  $time_0$  to  $time_2$  (this period encompassed two individual periods of inundation and isolation [ $time_{0-1}$  and  $time_{1-2}$ ]).

Taxon-specific growth rate calculations used larval-net data collected during *3E1407* and *5I1508* and fyke-net data from the four egress events. Use of larval-net data assumed that larval fishes collected during the 2007 early-season egress event (*3E1407*) and the final 2008 ingress event (*5I1508*) were members of cohorts sampled during later egress event(s) of each year. Data inputs for cohort mean length at  $time_0$  (*3E1407*) for the single 2007 inundation period were drawn from fyke-net data, larval-net data, and combined data from the two gears; fyke-net data were used to characterize cohort mean

lengths at time<sub>1</sub> (4E1507). Cohort mean lengths from each time<sub>0</sub> data source were compared with cohort mean lengths at time<sub>1</sub> to calculate three groups of growth rates to distinguish time<sub>0</sub> data sources: *fyke-net only*, *larval-net only*, and *combination*. Three groups of growth rates (referred to as *time<sub>0-1</sub>*, *time<sub>0-2</sub>*, and *time<sub>1-2</sub>* to reflect evaluated inundation periods) were calculated for 2008. Cohort mean lengths derived from larval-net data at time<sub>0</sub> (5I1508) were compared first to cohort mean lengths derived from fyke-net data at time<sub>1</sub> (6E1508), and then to those from time<sub>2</sub> (7E1508); then, time<sub>1</sub> and time<sub>2</sub> cohort mean lengths were compared directly.

Growth rates calculated for the 2007 fyke-net only group permitted comparison with 2008 time<sub>1-2</sub> calculations due to similar data sources (fyke net only) and reference times (early-season to late-season egress events). The other two groups of growth rate calculations provided a more complete understanding of fish growth during inundation periods each year. Larval-net data from 2007 provided length additions needed to contrast with the wide range of lengths collected with the fyke net. Inclusion of 2008 larval-net data from the ingress event that preceded the early-season egress event permitted evaluation of the entire summer inundation period. Final input values for taxon-specific cohort mean lengths from larval-net and fyke-net data each year were identified and refined before calculating instantaneous growth rates.

#### *Taxon-Specific Time<sub>0</sub> Mean Total Lengths from Larval-Net Data*

Mean total lengths of taxa collected with the larval net during 3E1407 and 5I1508

provided time<sub>0</sub> values for respective years. Mean lengths of larval specimens sampled in 3E1407 and 5I1508 and identified to species, genus, or family were matched to specific taxa because taxonomic level of identification varied among and within connectivity

events. The only larval specimens identified to species-level were freshwater drum (both years) and common carp (2007). Data for other taxa required using values for larval specimens identified to a coarser taxonomic scale or a literature-derived value. Mean length data from five taxonomic groups of specimens collected during 3E1407 were applied to eight of eleven taxa in 2007: (i) *Hypophthalmichthys* spp. to Asian carps; (ii) unidentified *Cyprinidae* to grass carp and Shiners; (iii) unidentified herring to gizzard shad; (iv) *Lepisosteus* spp. to shortnose gar; and (v) unidentified *Centrarchidae* to green sunfish, orangespotted sunfish, and bluegill. Mean length data from four taxonomic groups of specimens collected during 5I1508 were applied to five of nine taxa in 2008: (i) *Hypophthalmichthys* spp. to Asian carps; (ii) unidentified *Cyprinidae* to grass carp and common carp; (iii) unidentified herring to gizzard shad; and (iv) *Lepisosteus* spp. to shortnose gar. No larval data were collected for green sunfish or orangespotted sunfish during 5I1508, so the mean total length of unidentified *Centrarchidae* from sampling of 3E1407 was used for 2008 time<sub>0</sub> values for these two species. Literature-derived length-at-birth information (9 mm) was used for western mosquitofish (Haynes and Cashiner 1995) for both years because no specimens were sampled during 3E1407 or 5I1508.

#### *Use of Three Step Modal Progression Analysis to Discriminate Cohorts*

The three step modal progression analysis routine of the FiSAT II programming package (Gayani et al. 2006) was used to discriminate taxon-specific cohorts sampled during each egress event. The first step involved decomposing length-frequency histograms constructed using conservative bin widths (10 mm for large-bodied taxa and 3 mm for small bodied taxa) into initial estimates of their Gaussian component length cohorts using

Bhattacharya's method (Bhattacharya 1967) by subtracting sequentially identified length cohorts from the remainder of the length distribution through iterative computations of regression lines (Gayaniilo et al. 2006). In the second step, initial estimates for mean lengths of identified cohorts were refined with the maximum likelihood procedure (NORMSEP) within the FiSAT II program that separates normally distributed length distributions for each identified cohort. Individual cohorts were retained where the calculated separation index (SI) was greater than two, i.e., the difference between successive means divided by the difference between their estimated standard deviation (Gayaniilo et al. 2006). In the third step, final values for mean length and standard deviation of each identified cohort were compiled for time<sub>0</sub>, time<sub>1</sub>, and time<sub>2</sub> along with estimates of mean length from larval-net data, and cohort-specific mean lengths were linked between reference times each year for Equation 5. Initially, only links between mean lengths indicating positive growth were included in calculations. However, to reduce potential errors from linking values promoting unrealistic growth rates, the reliability of links between cohort mean lengths calculated for each egress event by modal progression analysis (or between larval-data mean lengths and cohort mean lengths) was evaluated using literature-derived information on taxon-specific lengths at age-0 and age-1. Links between mean lengths were excluded for some taxa where the change in length between two values seemed unlikely for the time difference between connectivity events, such as between larval-net data estimates and the largest cohort mean lengths of fyke-net data that were most likely representative of > age-1 fish.

### ***Results***

Mean total lengths of specimens sampled with the larval net during the time<sub>0</sub> connectivity event of each year (3E1407 and 5I1508) ranged from 7 to 15 mm for the 11 taxa in 2007 and 9 taxa in 2008 (Table B1). The number of distinct fyke-net cohorts (SI >2.0) within a length-frequency distribution varied from 1 to 7 depending on taxa and egress event, with generally more taxon-specific cohorts sampled during 3E1407 (mean of 2.7 cohorts per event) than during the other three egress events (means of 1.6 to 2.0 cohorts per event; Tables B2, B3).

Table B1. Mean total lengths (mm) of larval fishes collected during connectivity events between lower Missouri River and Eagle Bluffs Conservation Area wetland pools during spring-summer 2007 and 2008. Only events where fishes were collected are shown. Specimens were identified to lowest possible taxonomic level; those labeled “unidentified” could not be positively identified at any level. Taxon-specific information includes scientific name, mean total length, (sample size [n], and range of lengths collected). See Table 1 for explanation of event codes.

Taxa	Mean total length (mm) (n: range)					
	Ingress events		Egress events			
	2I1407	5I1508	3E1407	4E1507	6E1508	7E1508
<i>Lepisosteus</i> spp.		10 (4: 7-12)	15 (1:15)			
Unidentified herring <sup>a</sup>		13 (1:13)	15 (474: 6-24)		7 (1:7)	
<i>Hiodon alosoides</i>		12 (1:12)				
<i>Cyprinus carpio</i>			14 (1:14)			
<i>Hypophthalmichthys</i> spp.		10 (4: 9-11)	14 (59: 10-15)			9 (4: 6-10)
<i>Ictiobus</i> spp.			20 (14: 13-24)		19 (7: 15-23)	
Unidentified <i>Cyprinidae</i>	9 (2: 8-9)	7 (112: 5-9)	8 (2: 6-8)			
<i>Gambusia affinis</i>				14 (16: 7-21)	21 (11: 15-22)	18 (106: 9-24)
<i>Micropterus</i> spp.			10 (5: 9-11)			
Unidentified <i>Centrarchidae</i> <sup>b</sup>			7 (68: 4-12)	13 (6: 10-15)	7 (230: 4-15)	11 (470: 6-15)
<i>Aplodinotus grunniens</i>		13 (1:13)	10 (10: 4-15)			
Unidentified			5 (31: 3-8)		5 (22: 4-6)	
Total	9 (2: 8-9)	7 (123: 5-13)	14 (667: 3-24)	14 (22: 7-21)	8 (272: 4-23)	12 (580: 6-24)

<sup>a</sup> *Dorosoma cepedianum* or *Alosa chrysochloris*.

<sup>b</sup> Sixteen specimens in 3E1407 and all specimens in 4E1507, 6E1508, and 7E1508 identified to *Lepomis* spp.

Table B2. Mean total lengths (mm) from two connectivity events and two fish-sampling gears were identified, refined, and used to calculate instantaneous growth rates of eleven taxa in 2007. Mean lengths were from early-season egress event 3E1407 (larval-net and fyke-net data) and late-season egress event 4E1507 (fyke-net data only). Mean lengths from larval-net data were raw, overall mean length values; see Table B1. Multiple cohorts were represented with taxon-specific length-frequency distributions produced from fyke-net data, so cohort mean lengths were identified and refined using modal progression analysis (Gayanilo et al. 2006). Individual cohorts were retained where the calculated separation index (SI) was > “2.” An SI of “0” was listed for analyses that identified only one cohort and an “n/a” for the first cohort of analyses that identified multiple cohorts. For each taxon and cohort group, information includes connectivity event and sampling gear, computed mean total length (or overall mean for larval-net data), standard deviation of mean total length, sample size, and SI value (if provided or applicable).

Connectivity event: sampling gear	Cohort group	Computed mean total length (mm)	Standard deviation	Sample size	SI
<i>Asian carps (Hypophthalmichthys spp.)</i>					
3E1407: larval net	1	14	1	59	n/a
3E1407: fyke net	1	35	6	28 630	0
4E1507: fyke net	1	181	14	586	0
<i>Common carp (Cyprinus carpio)</i>					
3E1407: larval net	1	14	n/a	1	n/a
3E1407: fyke net	1	42	7	23 699	0
3E1407: fyke net	2	79	11	3447	4
3E1407: fyke net	3	166	30	36	4
4E1507: fyke net	1	79	9	186	0
4E1507: fyke net	2	151	30	93	4
<i>Grass carp (Ctenopharyngodon idella)</i>					
3E1407: larval net	1	8	3	2	n/a
3E1407: fyke net	1	38	5	3478	0
4E1507: fyke net	1	121	10	8	0
4E1507: fyke net	2	191	27	25	4
<i>Gizzard shad (Dorosoma cepedianum)</i>					
3E1407: larval net	1	15	4	474	n/a
3E1407: fyke net	1	26	5	3793	0
3E1407: fyke net	2	132	6	56	19
3E1407: fyke net	3	178	27	786	3
4E1507: fyke net	1	92	17	765	0
4E1507: fyke net	2	145	18	984	3
<i>Freshwater drum (Aplodinotus grunniens)</i>					
3E1407: larval net	1	10	4	10	n/a
3E1407: fyke net	1	22	6	1118	0
3E1407: fyke net	2	164	27	523	9
3E1407: fyke net	3	275	19	48	5
4E1507: fyke net	1	82	14	45	0

Table B2 (continued)

Connectivity event: sampling gear	Cohort group	Computed mean total length (mm)	Standard deviation	Sample size	SI
<i>Shortnose gar (Lepisosteus platostomus)</i>					
3E1407: larval net	1	15	n/a	1	n/a
3E1407: fyke net	1	36	10	113	0
3E1407: fyke net	2	78	21	241	3
4E1507: fyke net	1	344	37	48	0
<i>Western mosquitofish (Gambusia affinis)</i>					
3E1407: larval net	1	9	n/a	n/a	n/a
3E1407: fyke net	1	28	5	154	0
3E1407: fyke net	2	48	5	42	4
4E1507: fyke net	1	24	3	761	0
<i>Orangespotted sunfish (Lepomis humilis)</i>					
3E1407: larval net	1	7	2	68	n/a
3E1407: fyke net	1	44	5	112	0
3E1407: fyke net	2	60	11	916	2
4E1507: fyke net	1	33	10	1077	0
<i>Green sunfish (Lepomis cyanellus)</i>					
3E1407: larval net	1	7	2	68	n/a
3E1407: fyke net	1	23	2	5	0
3E1407: fyke net	2	46	7	9	5
3E1407: fyke net	3	59	2	3	3
3E1407: fyke net	4	81	12	36	3
3E1407: fyke net	5	141	2	3	8
4E1507: fyke net	1	35	5	404	0
4E1507: fyke net	2	103	18	15	4
<i>Bluegill (Lepomis macrochirus)</i>					
3E1407: larval net	1	7	2	68	n/a
3E1407: fyke net	1	26	3	17	0
3E1407: fyke net	2	49	8	759	4
3E1407: fyke net	3	66	7	400	2
3E1407: fyke net	4	86	9	190	2
3E1407: fyke net	5	101	2	18	3
3E1407: fyke net	6	111	3	32	4
3E1407: fyke net	7	133	10	31	3
4E1507: fyke net	1	30	4	660	0
4E1507: fyke net	2	90	8	9	10
4E1507: fyke net	3	111	7	14	3
<i>Shiners (Notropis spp.)</i>					
3E1407: larval net	1	8	3	2	n/a
3E1407: fyke net	1	47	7	112	0
4E1507: fyke net	1	24	4	43	0

Table B3. Mean total lengths (mm) from three connectivity events and two fish-sampling gears were identified, refined, and used to calculate instantaneous growth rates of nine taxa in 2008. Mean lengths from larval-net data determined for ingress event 5I1508 were raw, overall mean length values; see Table B1. Mean lengths from fyke-net data were determined for early-season (6E1508) and late-season (7E1508) egress events. Multiple cohorts were represented with taxon-specific length-frequency distributions produced with fyke-net data, so cohort mean lengths were identified and refined using modal progression analysis (Gayanilo et al. 2006). Individual cohorts were retained where the calculated separation index (SI) was > “2.” An SI of “0” was listed for analyses that identified only one cohort and an “n/a” for the first cohort of analyses that identified multiple cohorts. For each taxon and cohort group, information includes connectivity event and sampling gear, computed mean total length (or overall mean for larval-net data), standard deviation of mean total length, sample size, and SI value (if provided or applicable).

Connectivity event: sampling gear	Cohort group	Computed mean total length (mm)	Standard deviation	Sample size	SI
<i>Asian carps (Hypophthalmichthys spp.)</i>					
5I1508: larval net	1	10	1	4	n/a
6E1508: fyke net	1	46	12	1039	0
6E1508: fyke net	2	94	14	1010	4
7E1508: fyke net	1	190	23	206	0
<i>Common carp (Cyprinus carpio)</i>					
5I1508: larval net	1	7	1	112	n/a
6E1508: fyke net	1	50	12	46	0
6E1508: fyke net	2	92	12	35	4
6E1508: fyke net	3	162	17	141	5
7E1508: fyke net	1	87	14	20	0
7E1508: fyke net	2	128	21	247	2
<i>Grass carp (Ctenopharyngodon idella)</i>					
5I1508: larval net	1	7	1	112	n/a
6E1508: fyke net	1	87	18	558	0
7E1508: fyke net	1	144	24	86	0
<i>Gizzard shad (Dorosoma cepedianum)</i>					
5I1508: larval net	1	13	n/a	1	n/a
6E1508: fyke net	1	37	6	258	0
6E1508: fyke net	2	67	10	1429	4
7E1508: fyke net	1	83	12	243	0
7E1508: fyke net	2	111	6	55	3
7E1508: fyke net	3	134	11	131	3
<i>Freshwater drum (Aplodinotus grunniens)</i>					
5I1508: larval net	1	13	n/a	1	n/a
6E1508: fyke net	1	47	15	126	0
7E1508: fyke net	1	85	17	65	0

Table B3 (continued)

Connectivity event: sampling gear	Cohort group	Computed mean total length (mm)	Standard deviation	Sample size	SI
<i>Shortnose gar (Lepisosteus platostomus)</i>					
5I1508: larval net	1	10	2	4	n/a
6E1508: fyke net	1	117	5	26	0
6E1508: fyke net	2	147	25	573	2
6E1508: fyke net	3	210	29	59	2
7E1508: fyke net	1	188	16	32	0
7E1508: fyke net	2	222	8	21	3
7E1508: fyke net	3	254	10	28	4
7E1508: fyke net	4	322	31	138	3
<i>Western mosquitofish (Gambusia affinis)</i>					
5I1508: larval net	1	9	n/a	n/a	n/a
6E1508: fyke net	1	16	2	36	0
6E1508: fyke net	2	28	7	250	3
7E1508: fyke net	1	30	5	788	0
<i>Orangespotted sunfish (Lepomis humilis)</i>					
5I1508: larval net	1	7	2	68	n/a
6E1508: fyke net	1	26	7	612	0
7E1508: fyke net	1	16	2	84	0
7E1508: fyke net	2	29	8	720	3
<i>Green sunfish (Lepomis cyanellus)</i>					
5I1508: larval net	1	7	2	68	n/a
6E1508: fyke net	1	28	5	456	0
7E1508: fyke net	1	19	2	2	0
7E1508: fyke net	2	36	7	180	4
7E1508: fyke net	3	74	2	3	9

The connection between cohort mean length values associated with reference times contrasted within a given taxon-specific growth rate calculation group is referred to as a *link*. The number of links between mean total lengths associated with each cohort and reference time<sup>3</sup> used to calculate individual instantaneous growth rates varied from one to eleven links across the three groups of growth rate calculations each year<sup>4</sup> (Figures B1, B2). Mean lengths of individual cohorts identified in the four egress events were

<sup>3</sup> 2007: time<sub>0</sub> = 3E1407, time<sub>1</sub> = 4E1507; 2008: time<sub>0</sub> = 5I1508, time<sub>1</sub> = 6E1508, and time<sub>2</sub> = 7E1508.

<sup>4</sup> 2007 groups: fyke-net only, larval-net only, and combination; 2008 groups: time<sub>0-1</sub>, time<sub>0-2</sub>, and time<sub>1-2</sub>.

generally smaller than literature-derived taxon-specific cut-off values for age-0 or age-1 fish. Most links between cohort mean lengths for the two connectivity events compared were considered realistic for calculating growth for a time period <4 months. However, for three species certain links were considered unrealistic and were not used in growth rate calculations. Unincorporated links for 2007 were between the smaller mean lengths of time<sub>0</sub> (larval-net or fyke-net data) and the largest cohort mean lengths of time<sub>1</sub> for shortnose gar, green sunfish, and bluegill (Figures B1, B2). The link not used for shortnose gar in 2008 was between the mean length of time<sub>0</sub> (larval-net data) and the largest cohort mean length of time<sub>2</sub> (Figure B1). Specimens comprising the largest cohorts of time<sub>1</sub> in 2007 and time<sub>2</sub> in 2008 were >age-0 (Tables B2, B3) and would have confounded growth rate estimates; therefore they were not included in calculations for those three species in 2007 and 2008.

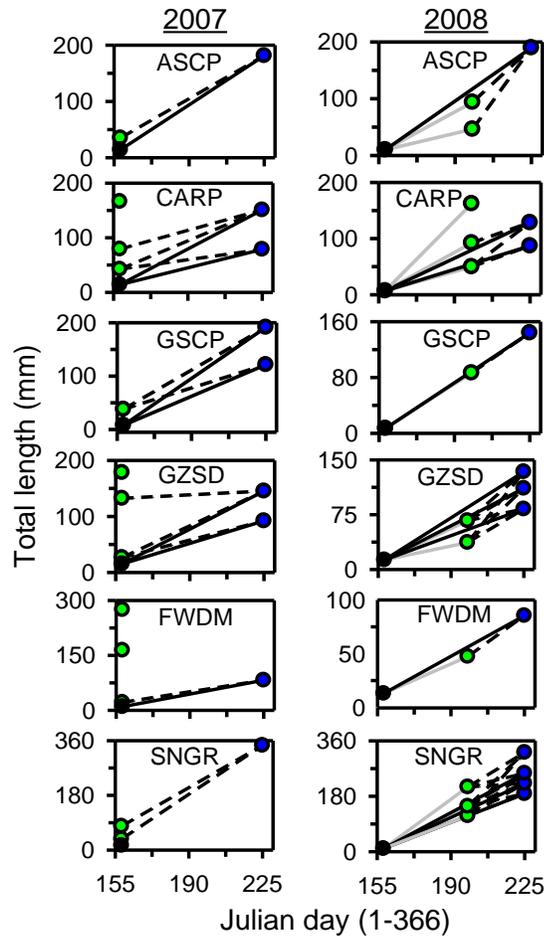


Figure B1. Mean total lengths (mm) of individual cohorts for six large-bodied taxa linked among connectivity events and data sources to estimate instantaneous growth rates during various periods of managed wetland inundation: Asian carps taxa group (*Hypophthalmichthys* spp., ASCP), common carp (*Cyprinus carpio*, CARP), grass carp (*Ctenopharyngodon idella*, GSCP), gizzard shad (*Dorosoma cepedianum*, GZSD), freshwater drum (*Aplodinotus grunniens*, FWDM), and shortnose gar (*Lepisosteus platostomus*, SNGR). Connectivity events (ingress and egress) occurred between lower Missouri River and Eagle Bluffs Conservation Area wetland pools during spring-summer 2007 and 2008 via controlled water movement through a fishway. Green circles represent cohort-specific mean lengths for fyke-net data during early-season egress events (3E1407 and 6E1508), and blue circles represent cohort-specific mean lengths during late-season egress events (4E1507 and 7E1508). Black circles represent larval-net data cohort-specific mean lengths during 3E1407 and 5I1508. Black solid lines represent links between the larval-net cohorts of 3E1407 or 5I1508 and the fyke-net cohorts of each year's late-season egress event. Black dashed lines represent links between fyke-net cohorts of early-season and late-season egress events both years. Grey solid lines represent links between the larval-net cohort in 5I1508 and fyke-net cohorts in 6E1508 in 2008. Note the different y-axis scales.

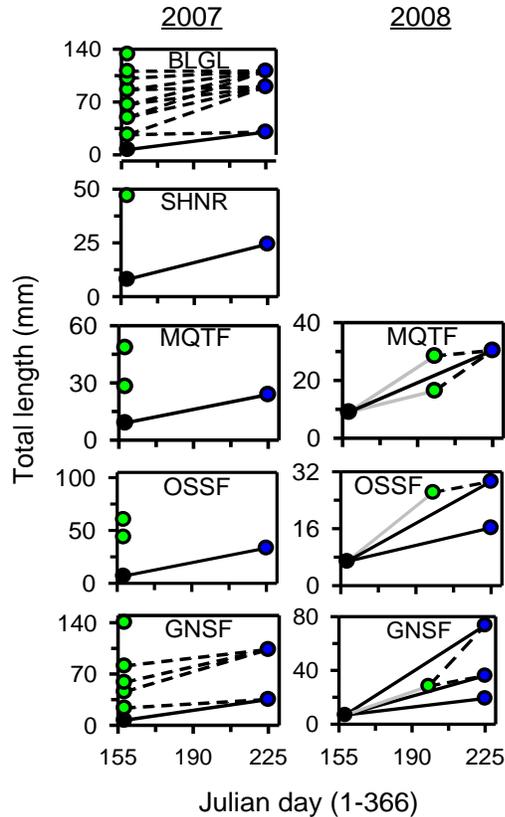


Figure B2. Mean total lengths (mm) of individual cohorts for five small-bodied taxa were linked among connectivity events and data sources to estimate instantaneous growth rates during various periods of managed wetland inundation: bluegill (*Lepomis macrochirus*, BLGL), Shiners taxa group (*Notropis* spp., SHNR), western mosquitofish (*Gambusia affinis*, MQTF), orangespotted sunfish (*Lepomis humilis*, OSSF), and green sunfish (*Lepomis cyanellus*, GNSF). Connectivity events (ingress and egress) occurred between lower Missouri River and Eagle Bluffs Conservation Area wetland pools during spring-summer 2007 and 2008 via controlled water movement through a fishway. Green circles represent cohort-specific mean lengths for fyke-net data during early-season egress events (3E1407 and 6E1508), and blue circles represent cohort-specific mean lengths during late-season egress events (4E1507 and 7E1508). Black circles represent larval-net data cohort-specific mean lengths during 3E1407 and 5I1508. Black solid lines represent links between the larval-net cohorts of 3E1407 or 5I1508 and the fyke-net cohorts of each year's late-season egress event. Black dashed lines represent links between fyke-net cohorts of early-season and late-season egress events both years. Grey solid lines represent 2008 links between the larval-net cohort in 5I1508 and fyke-net cohorts in 6E1508. Note the different y-axis scales.

Four trends were identified from the three groups of mean instantaneous growth rates calculated each year. First, large-bodied taxa generally had faster growth rates than small-bodied taxa both years (Tables B4, B5); although, only shortnose gar and Asian carps consistently displayed faster growth rates than those of small-bodied taxa in 2007 (i.e., displayed non-overlapping individual growth rate values or non-overlapping standard deviations of mean growth rates). Second, large-bodied fluvial dependents Asian carps and grass carp had faster instantaneous growth rates than large-bodied macrohabitat generalists in the 2007 larval-net only group, as shown by non-overlapping standard deviations of mean growth rates or non-overlapping individual growth rate values (Table B4). Third, the degree to which growth rates differed between 2007 and 2008 varied among large-bodied taxa, demonstrated by the range of taxon-specific percent differences (9 to 61%) between growth rates of 2007 fyke-net only and 2008 time<sub>1-2</sub> calculation groups (Tables B4, B5). Fourth, five of the nine taxa evaluated in 2008 showed large percent differences (33 to 64%) in growth rates between time<sub>0-1</sub> and time<sub>0-2</sub> calculation groups: in descending order, orangespotted sunfish, common carp, shortnose gar, green sunfish, and grass carp (Table B5). Details indicating these trends are provided below.

Table B4. Mean instantaneous growth rates, and their standard deviations (SD), calculated between early-season egress event 3E1407 (time<sub>0</sub>) and late-season egress event 4E1507 (time<sub>1</sub>) for eleven taxa in 2007. Length data for time<sub>0</sub> used to calculate growth rates between time<sub>0</sub> and time<sub>1</sub> are from larval-net only, fyke-net only, or both gears combined. Additional information includes total sample size of individuals collected with the fyke net and number of links of cohort mean lengths used to calculate growth rates. Length values used for individual calculations within the three groups are found in Table B2.

Taxa	Fyke net total sample size (N)		Data source for time <sub>0</sub> <sup>a</sup>								
			Larval-net only <sup>b</sup>			Combination <sup>c</sup>			Fyke-net only <sup>d</sup>		
	3E1407	4E1507	Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)	
			Mean	SD		Mean	SD		Mean	SD	
Asian carps	28 630	586	1	0.038	n/a	2	0.031	0.010	1	0.025	n/a
common carp	27 191	279	2	0.031	0.007	5	0.020	0.011	3	0.013	0.005
grass carp	3478	33	2	0.044	0.005	4	0.032	0.014	2	0.021	0.005
gizzard shad	4635	1749	2	0.030	0.005	5	0.021	0.012	3	0.015	0.012
freshwater drum	1688	45	1	0.032	n/a	2	0.026	0.008	1	0.020	n/a
shortnose gar	452	48	*	n/a	n/a	2	0.028	0.008	2	0.028	0.008
western mosquitofish	196	1208	1	0.015	n/a	1	0.015	n/a	**	n/a	n/a
orangespotted sunfish	1028	1077	1	0.024	n/a	1	0.024	n/a	**	n/a	n/a
green sunfish	57	504	1	0.025	n/a	5	0.011	0.008	4	0.008	0.004
bluegill	1466	780	1	0.022	n/a	11	0.007	0.007	10	0.006	0.006
Shiners	112	43	1	0.017	n/a	1	0.017	n/a	**	n/a	n/a

<sup>a</sup> Wetland inundation duration between time<sub>0</sub> and time<sub>1</sub> was 67 days.

<sup>b</sup> Larval-net only; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using larval-net only data from 3E1407 and fyke-net only data from 4E1507. <sup>c</sup> Combination; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using both larval-net and fyke-net data from 3E1407 and fyke-net only data from 4E1507. <sup>d</sup> Fyke-net only; time<sub>0</sub> was 3E1407, time<sub>1</sub> was 4E1507, and growth rates were calculated using fyke-net only data from both events.

\*all links of cohort mean lengths from larval-net only data provided unrealistic values for instantaneous growth rates.

\*\*fyke-net only data gave negative values for instantaneous growth rates.

Table B5. Mean instantaneous growth rates, and their standard deviations (SD), for nine taxa calculated among three 2008 events: ingress event 5I1508 (time<sub>0</sub>), early-season egress event 6E1508 (time<sub>1</sub>), and late-season egress event 7E1508 (time<sub>2</sub>). Lengths used to calculate growth rates between reference times are from larval-net only data (time<sub>0</sub>) or fyke-net only data (time<sub>1</sub>, time<sub>2</sub>). Additional information includes total sample size of individuals collected with the fyke net and number of links of cohort mean lengths used to calculate growth rates. Length values used for individual calculations within the three groups are found in Table B3.

Taxa	Fyke net total sample size (N)		Inundation period								
			Time <sub>0-1</sub> <sup>a</sup>			Time <sub>0-2</sub> <sup>b</sup>			Time <sub>1-2</sub> <sup>c</sup>		
	6E1508	7E1508	Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)		Links of cohort mean lengths (N)	Instantaneous growth rate (mm/day)	
				Mean	SD		Mean	SD		Mean	SD
Asian carps	2049	206	2	0.047	0.012	1	0.044	n/a	2	0.039	0.018
common carp	222	267	3	0.064	0.015	2	0.041	0.004	3	0.023	0.012
grass carp	558	86	1	0.063	n/a	1	0.045	n/a	1	0.019	n/a
gizzard shad	1687	429	2	0.034	0.010	3	0.031	0.004	6	0.028	0.014
freshwater drum	126	65	1	0.032	n/a	1	0.028	n/a	1	0.022	n/a
shortnose gar	658	220	3	0.068	0.007	3	0.046	0.002	11	0.019	0.011
western mosquitofish	286	788	2	0.022	0.010	1	0.018	n/a	2	0.013	0.014
orangespotted sunfish	612	825	1	0.034	n/a	2	0.017	0.006	1	0.004	n/a
green sunfish	474	185	1	0.036	n/a	3	0.025	0.010	2	0.022	0.019

<sup>a</sup> Time<sub>0-1</sub>; time<sub>0</sub> was 5I1508, time<sub>1</sub> was 6E1508, and growth rates were calculated using larval-net only data from 5I1508 and fyke-net only data from 6E1508. Wetland inundation duration for time<sub>0-1</sub> was 40 days.

<sup>b</sup> Time<sub>0-2</sub>; time<sub>0</sub> was 5I1508, time<sub>2</sub> was 7E1508, and growth rates were calculated using larval-net only data from 5I1508 and fyke-net only data from 7E1508. Wetland inundation duration for time<sub>0-2</sub> was 67 days.

<sup>c</sup> Time<sub>1-2</sub>; time<sub>1</sub> was 6E1508, time<sub>2</sub> was 7E1508, and growth rates were calculated using fyke-net only data from both events. Wetland inundation duration for time<sub>1-2</sub> was 27 days.

Large-bodied taxa generally had faster instantaneous growth rates than small-bodied taxa. This outcome held when results were compared among taxa for the 2007 fyke-net only calculation group and the 2008 time<sub>1-2</sub> group, although there was a clearer distinction among taxa in 2007 than 2008 (Tables B4, B5). Specifically, large-bodied shortnose gar, Asian carps, grass carp, and freshwater drum displayed standard deviations of mean growth rates (or individual growth rate values) that did not overlap with those of small-bodied taxa in 2007, but in 2008 all taxa displayed overlapping standard deviations of mean growth rates (or overlapping individual growth rate values). In presenting these result patterns, overlap in growth rates among taxa was evaluated using standard deviations of mean growth rates where possible, otherwise overlap was evaluated using individual growth rate values.

Growth rates for small-bodied taxa were still slower than for large-bodied taxa when larval data were used to account for the addition of small YOY specimens that dominated size structures of small-bodied taxa during late-season egress events each year. Growth rates from the 2007 larval-net only calculation group ranged from 0.030 to 0.044 mm/day for five of the six large-bodied taxa and from 0.015 to 0.025 mm/day for the five small-bodied taxa (Table B4). No growth rate was calculated for shortnose gar for the larval-net only group because the link between cohort mean lengths provided an unrealistic value. Only large-bodied common carp showed a standard deviation of its mean growth rate that overlapped the individual growth rate values of small-bodied green sunfish and orangespotted sunfish in the 2007 larval-net only group. Growth rates were faster for all other large-bodied taxa and slower for all other small-bodied taxa (i.e., they displayed non-overlapping individual growth rate values or non-overlapping standard

deviations of mean growth rates). The trend of faster growth rates for large-bodied taxa than for small-bodied taxa was still evident, although less pronounced, when data from both larval-net and fyke-net samplings of 3E1407 were used for time<sub>0</sub> lengths in the 2007 combination calculation group, despite the exception of orangespotted sunfish (Table B4). However, only large-bodied Asian carps and shortnose gar had standard deviations that did not overlap the individual growth rate values (or standard deviations of mean growth rates) of small-bodied taxa – excluding orangespotted sunfish. Large-bodied grass carp and freshwater drum had standard deviations of mean growth rates that overlapped values for small-bodied orangespotted sunfish and green sunfish; but, large-bodied gizzard shad and common carp had standard deviations of mean growth rates that overlapped values for all small-bodied taxa. In 2008, growth rates in the time<sub>0-1</sub> calculation group (i.e., 5I1508 to 6E1508) ranged from 0.032 to 0.068 mm/day for the six large-bodied taxa and from 0.022 to 0.036 mm/day for the three small-bodied species (Table B5). Only large-bodied shortnose gar, common carp, and grass carp displayed standard deviations of mean growth rates (or individual growth rate values) that did not overlap those of small-bodied taxa. Growth rates in the 2008 time<sub>0-2</sub> calculation group (i.e., 5I1508 to 7E1508) also showed similar trends to those of the time<sub>0-1</sub> group: growth rates ranged from 0.028 to 0.046 mm/day for large-bodied taxa and from 0.017 to 0.025 mm/day for small-bodied species (Table B5). Shortnose gar, grass carp, Asian carps, and common carp were the large-bodied taxa that displayed non-overlapping standard deviations of mean growth rates (or non-overlapping individual growth rate values) with those of small-bodied green sunfish, western mosquitofish, and orangespotted sunfish. Large-bodied gizzard shad and freshwater drum had growth rates similar to green

sunfish, but western mosquitofish and orangespotted sunfish grew more slowly than those two large-bodied species (i.e., had non-overlapping individual growth rate values or non-overlapping standard deviations of mean growth rates).

Large-bodied fluvial dependents Asian carps and grass carp had faster instantaneous growth rates than large-bodied macrohabitat generalists in the 2007 larval-net only group, as shown by non-overlapping standard deviations of mean growth rates or non-overlapping individual growth rate values (Table B4). Asian carps also displayed a faster growth rate than common carp in the 2007 fyke-net only group, indicated by the fluvial dependent's individual growth rate value falling outside of the standard deviation of the macrohabitat generalist's mean growth rate. Otherwise in 2007, all large-bodied taxa showed similar growth rates (i.e., overlapping standard deviations of mean growth rates or overlapping individual growth rate values).

Patterns in instantaneous growth rates of individual large-bodied taxa ranged from consistently fast growth rates across the six calculation groups to varying growth rates according to data source and inundation period. Patterns in growth rates for native shortnose gar and invasive grass carp were consistently fast for the majority of calculation groups (range = means of 0.021 mm/day [ $\pm 0.005$  standard deviation] to 0.068 mm/day [ $\pm 0.007$  standard deviation]), but showed slow growth rates for the 2008 time<sub>1-2</sub> group (shortnose gar = mean of 0.019 mm/day [ $\pm 0.011$  standard deviation], grass carp = value of 0.019 mm/day; Tables B4, B5). Invasive Asian carps displayed consistently fast growth rates across the six calculation groups (range = value of 0.025 mm/day to mean of 0.047 mm/day [ $\pm 0.012$  standard deviation]; Tables B4, B5). The degree to which growth rates differed between 2007 and 2008 varied among large-bodied taxa, as demonstrated

by a range of taxon-specific percent differences between growth rates of 2007 fyke-net only and 2008 time<sub>1-2</sub> groups (percent differences were calculated between mean growth rates where possible, otherwise they were between individual growth rate values). Four taxa displayed large percent differences between years: gizzard shad, common carp, and Asian carps had faster growth rates in 2008 (61%, 57%, and 46%, respectively), and shortnose gar had faster growth rates in 2007 (39%; Tables B4, B5). Generally similar growth rates between years were shown by grass carp (10% faster in 2007) and freshwater drum (9% faster in 2008; Tables B4, B5). Also, growth rates for all large-bodied taxa in 2008 were faster in the first, shorter inundation period (i.e., time<sub>0-1</sub>) than in the second, extended inundation period (i.e., time<sub>0-2</sub>), with the largest percent differences shown for common carp (45%), shortnose gar (39%), and grass carp (33%; Table B5). Percent differences between time<sub>0-1</sub> and time<sub>0-2</sub> growth rates were smaller for freshwater drum (14%), Asian carps (7%), and gizzard shad (6%).

Patterns in instantaneous growth rates also varied according to data source and inundation period for small-bodied taxa. Growth rates in the 2007 larval-net only group were similar among orangespotted sunfish (0.024 mm/day), green sunfish (0.025 mm/day), and bluegill (0.022 mm/day; Table B4). Growth rates were also similar between Shiners (0.017 mm/day) and western mosquitofish (0.015 mm/day), which were the slowest for all taxa in the 2007 larval-net only group (Table B4). No growth rates could be calculated for western mosquitofish, orangespotted sunfish, and Shiners in the 2007 fyke-net only group due to lack of links between available mean lengths needed to generate positive growth estimates (Figure B2). For the three small-bodied species evaluated in 2008, growth rates were faster in time<sub>0-1</sub> than in time<sub>0-2</sub> (Table B5). Notably,

orangespotted sunfish showed the largest percent difference (64%) of all taxa evaluated in 2008 (Table B5). Green sunfish also demonstrated a large percent difference (34%) between time<sub>0-1</sub> and time<sub>0-2</sub> growth rates, whereas western mosquitofish displayed a small percent difference (19%).

**Appendix C: Connectivity Event Prediction Model (Objective 1)**

Table C1. Statistics for ordinary least squares regression of lower Missouri River (LMOR) stage readings at U. S. Geological Survey Boonville gage against LMOR stage readings at Eagle Bluffs Conservation Area wetland pools 15 and 14.

Location	R	R square	Adjusted R squared	Standard error	Observations
Pool 15	0.983	0.966	0.966	0.193	74
Pool 14	0.986	0.972	0.972	0.184	67
		Coefficient	Standard error	T statistic	P-value
Pool 15	Intercept	1.977	3.866	0.511	0.611
	Pool 15 reading	1.026	0.022	45.878	<0.001
Pool 14	Intercept	-1.320	3.775	-0.350	0.728
	Pool 14 reading	1.045	0.022	47.808	<0.001

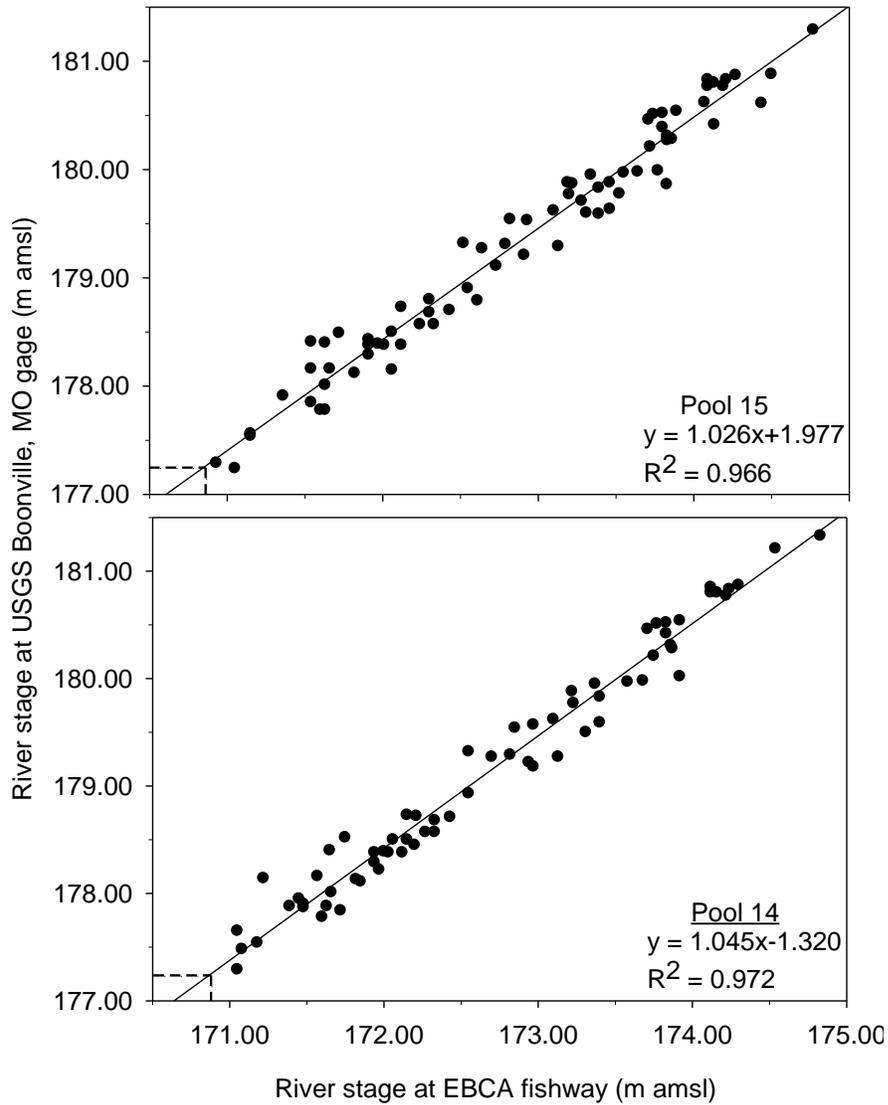


Figure C1. Results of ordinary least squares regression between lower Missouri River (LMOR) stage at U. S. Geological Survey (USGS) Boonville gage and LMOR stage at Eagle Bluffs Conservation Area (EBCA) pool's fishways. The relation was used to determine LMOR stage necessary to initiate lateral connectivity with fishways at each of pools 14 and 15. Minimum stage of connection (dotted line) calculated by substituting fishway base elevation (170.84 m amsl) for "x" in the equation for the lines.

Table C2. Kruskal-Wallis (K-W) test comparing medians among the 1993 to 2006 model, 2007, and 2008 for seven connectivity event variables calendar year and spawning window scales. Statistics include test statistic, degrees of freedom (DF), K-W p-value, sample size (n), and medians.

Connectivity event variable (unit of measurement)	Calendar year (n = 95)			Spawning window (n = 34)		
	Test statistic	DF	P-value	Test statistic	DF	P-value
Timing of event start date (Julian day)	0.46	2	0.79	0.35	2	0.84
Duration (day)	1.95	2	0.38	0.90	2	0.64
Mean river stage magnitude (m amsl)	0.28	2	0.87	2.31	2	0.32
Mean fishway stage magnitude (m)	0.28	2	0.87	2.31	2	0.32
Rate-of-rise (m/day)	2.56	2	0.28	4.34	2	0.11
Rate-of-fall (m/day)	0.03	2	0.98	3.97	2	0.14
Mean water temperature (°C)	1.98	2	0.37	0.23	2	0.89

Connectivity event variable (unit of measurement)	Calendar year			Spawning window		
	Model median (n = 77)	2007 median (n = 6)	2008 median (n = 12)	Model median (n = 26)	2007 median (n = 2)	2008 median (n = 6)
Timing of event start date (Julian day)	153	162	140	124	124	129
Duration (day)	4	2.5	4	6	17	4
Mean river stage magnitude (m amsl)	177.82	177.65	177.73	178.00	178.46	177.59
Mean fishway stage magnitude (m)	0.62	0.45	0.53	0.80	1.26	0.39
Rate-of-rise (m/day)	0.41	0.25	0.36	0.50	0.45	0.16
Rate-of-fall (m/day)	0.31	0.30	0.29	0.30	0.55	0.19
Mean water temperature (°C)	17.8	21.0	16.1	17.4	18.5	16.9

Table C3. Standardized z-statistics comparing predicted connection frequency from 1993-2006 model with observed frequency from 2007 and 2008 study years at two scales: number of events per calendar year and per spawning window. Statistics include model mean and standard error (SE) for number of events per year and per spawning window, number of events per year and per spawning window during the two study years, z-statistic, probability value, and p-value. Significant p-values ( $\leq 0.05$ ) are presented in boldface font.

Scale of analysis	Group	Mean	SE	Number of events	Z-statistic	Probability value	P-value
Calendar year	Model	7.4	1.5				
	2007			7			
	2008			14			
	2007 vs. Model				-0.24	0.59	0.8104
	2008 vs. Model				4.42	1.00	<b>0.0004</b>
Spawning window	Model	2.1	0.3				
	2007			2			
	2008			6			
	2007 vs. Model				-0.41	0.66	0.6818
	2008 vs. Model				11.17	1.00	<b>0.0004</b>

Table C4. Standardized z-statistics comparing predicted number of events per month from 1993 to 2006 model with observed number of events per month from 2007 and 2008 study years. Statistics include model mean and standard error (SE) of number of events per month, values for two sample years of the number of events per month, z-statistic, probability value, and p-value. Z-scores were not calculated for January because from 1993 to 2008 there were zero connectivity events during that month. Significant p-values ( $\leq 0.05$ ) are presented in boldface font.

Group	Metric	J	F	M	A	M	J	J	A	S	O	N	D
Model	Mean	0	0.4	0.9	0.9	1.2	1.3	0.9	0.7	0.4	0.3	0.1	0.3
	SE	0	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.1	0.2	0.1	0.2
2007	Value	0	0	0	1	1	3	0	1	0	1	0	0
2008	Value	0	0	2	2	3	1	2	1	1	1	0	1
2007	Z-statistic		-2.11	-2.88	0.29	-1.15	6.00	-2.48	0.94	-2.69	4.37	-1.47	-1.75
vs.	Probability value		0.98	1.00	0.61	0.87	1.00	0.99	0.82	1.00	1.00	0.93	0.96
Model	P-value		<b>0.0358</b>	<b>0.0042</b>	0.7718	0.2542	<b>0.0004</b>	<b>0.0132</b>	0.3524	<b>0.0074</b>	<b>0.0004</b>	0.1416	0.0818
2008	Z-statistic		-2.11	3.32	4.37	9.55	-1.00	3.31	0.94	4.84	4.37	-1.47	4.37
vs.	Probability value		0.98	1.00	1.00	1.00	0.84	1.00	0.82	1.00	1.00	0.93	1.00
Model	P-value		<b>0.0358</b>	<b>0.0010</b>	<b>0.0004</b>	<b>0.0004</b>	0.3174	<b>0.0010</b>	0.3524	<b>0.0004</b>	<b>0.0004</b>	0.1416	<b>0.0004</b>

Table C5. Mean calendar and Julian dates,  $\pm 95\%$  confidence intervals (CI), when water temperatures are predicted to be reached based on the 1993 to 2006 model, and dates when water temperatures were first observed during 2007 and 2008 study years.

Water temperature (°C)	1993 – 2006		2007		2008	
	Mean calendar start date (95% CI)	Mean Julian day start date (95% CI)	Calendar start date	Julian day start date	Calendar start date	Julian day start date
5.0	21-February (11-Feb – 11-Mar)	52 (42 – 71)	24-February	55	3-March	63
10.0	29-March (24-Mar – 2-Apr)	89 (84 – 93)	13-March	73	25-March	85
12.0	7-April (2-Apr – 19-Apr)	98 (93 – 110)	22-March	82	10-April	101
14.0	19-April (8-Apr – 2-May)	110 (99 – 123)	29-March	89	20-April	111
16.0	5-May (19-Apr – 8-May)	126 (110 – 129)	31-March	91	24-April	115
18.0	15-May (8-May – 17-May)	136 (129 – 138)	26-April	117	25-April	116
20.0	23-May (17-May – 2-Jun)	144 (138 – 154)	6-May	127	30-May	151
22.0	10-June (30-May – 12-Jun)	162 (151 – 164)	31-May	152	5-June	157
25.0	28-June (20-Jun – 9-Jul)	180 (172 – 191)	18-June	170	27-June	179
27.7	21-July (17-Jul – 10-Aug)	203 (199 – 223)	10-July	192	20-July	202

**Appendix D: Predicted and Observed Fish Access to Floodplain Wetlands  
(Objective 2)**

Table D1. Predicted calendar dates (Julian dates)  $\pm$ 95% confidence intervals when lower Missouri River mean water temperatures were first reached. Water temperature data are from Boonville water treatment plant for 1937 to 2008.

Temperature (°C)	Calendar start date		
	Mean	95% Confidence interval	
		Lower	Upper
5.0	11-March (71)	6-March (66)	15-March (75)
10.0	4-April (95)	1-April (92)	8-April (99)
12.0	17-April (108)	15-April (106)	19-April (110)
14.0	24-April (115)	22-April (113)	26-April (117)
16.0	4-May (125)	2-May (123)	7-May (128)
18.0	16-May (137)	14-May (135)	19-May (140)
20.0	27-May (148)	22-May (143)	30-May (151)
22.0	7-June (159)	5-June (157)	10-June (162)
25.0	2-July (184)	26-June (178)	6-July (188)
26.7	2-August (215)	18-July (200)	11-August (224)

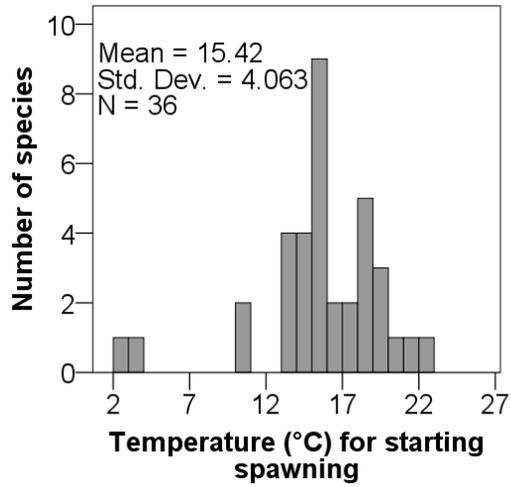


Figure D1. Water temperature at which spawning is first reported for 36 fish species predicted to enter Eagle Bluffs Conservation Area wetland pools during a lateral connectivity event with the lower Missouri River; and, number of species estimated to begin spawning at each temperature value.

**Appendix E: Species and Fish Assemblage Relative Abundance during Ingress Events (Objective 5)**

Table E1. Species mean catch-per-unit-effort (CPUE, fish/h) relative abundance and fish assemblage CPUE relative abundance for six ingress events and for the averaged, total assemblage across those events (Ingress total). Ingress events are lateral connectivity periods where fish enter Eagle Bluffs Conservation Area wetland pools from the lower Missouri River. Event identification codes are a string of numbers and a letter indicating event sampling order for that year (1, 2, ..., 5); that it was an ingress (I); which pools' fishway was used (14 or 15); and study year (07 = 2007 or 08 = 2008).

Common name	Species mean CPUE relative abundance (fish/h)						Ingress total
	Ingress event						
	1I1407	1I1508	2I1508	3I1508	4I1508	5I1508	
chestnut lamprey	0.27	0.61		0.02		0.04	0.23
shortnose gar	0.90	0.55		0.49	0.32	19.40	4.33
gizzard shad	0.21	1.18		1.13	0.28	3.57	1.27
goldfish	19.56	0.38		0.10		0.10	5.03
grass carp						0.01	0.01
common carp	6.39	7.80		0.99	0.06	11.46	5.34
silver carp		0.07		0.01		0.06	0.04
bighead carp				0.01		0.03	0.02
golden shiner		0.10	0.05	0.01	0.03	0.19	0.08
emerald shiner				0.01		0.02	0.02
bluntnose minnow				0.01			0.01
bullhead minnow		0.02				0.02	0.02
creek chub		0.02					0.02
river carpsucker				0.03	0.03	0.03	0.03
quillback				0.03		0.02	0.03
smallmouth buffalo		0.33		0.10	0.03	0.09	0.14
bigmouth buffalo	0.14	4.38		0.51		1.15	1.54
black buffalo						0.01	0.01
black bullhead	0.03			0.01			0.02
yellow bullhead						0.02	0.02
channel catfish		0.02				0.18	0.10
western mosquitofish	2.57	0.90	3.01	0.48	0.41	0.10	1.24
white bass						0.01	0.01
striped bass						0.01	0.01
green sunfish	8.35	1.03	0.03	0.07	0.03	0.09	1.60
orangespotted sunfish	13.20	2.68	0.12	0.24	0.21	0.61	2.84
bluegill	0.76	0.04	0.03	0.09	0.53	0.18	0.27
spotted bass						0.02	0.02
largemouth bass	0.03						0.03
white crappie		0.04		0.01		0.02	0.02
black crappie				0.07			0.07
freshwater drum				0.01		0.84	0.42
Fish assemblage CPUE relative abundance (fish/h)	52.40	20.14	3.24	4.42	1.91	38.28	24.85

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