USE OF MAIN CHANNEL AND SHALLOW-WATER HABITAT BY LARVAL FISHES IN THE LOWER MISSOURI RIVER

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by

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USE OF MAIN-CHANNEL AND SHALLOW-WATER HABITAT BY LARVAL FISHES IN THE LOWER MISSOURI RIVER

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ABSTRACT

The larval stage of a fish's life cycle is the most environmentally sensitive and loss of suitable habitat is a primary cause of increased mortality, yet the understanding of habitat requirements of larval fishes lags far behind other life stages. I developed a series of research objectives organized in a spatial hierarchy to characterize larval fish nursery habitat within the lower Missouri River. The larval fish assemblage, native carpsucker spp./buffalo spp. (*Carpiodes* spp./*Ictiobus* spp.) and invasive silver and bighead carp (*Hypophthalmichthys molitrix/nobilus*) catch-per-unit-effort (CPUE) differed significantly among three years (2002-2004) within the main channel, whereas native chub spp. (*Macrhybopsis* spp.) did not. Native carpsucker spp./buffalo spp. and chub spp. CPUE was significantly higher within sandbar aquatic terrestrial transition zone (ATTZ) than the main channel. Local-environmental factors accounted for the greatest proportion of variance in larval fish CPUE within sandbar ATTZ, followed by hydrologic and finally geomorphic factors at macro- and meso-habitat scales. At the microhabitat scale, the larval fish assemblage and carpsucker spp./buffalo spp. selected areas ≤10 cm deep with current velocities ≤5 cm/s. Silver/bighead carp exhibited no selection based on water depth or current velocity. Chub spp. selected depths between 20-50 cm and areas 2-3 m from the waters edge. The larval fish assemblage and several taxa exhibited a

significant nocturnal increase in CPUE within the primary channel and sandbar ATTZ at the macrohabitat scale in contrast to previous research indicating turbid rivers lacked a diel cycle in larval fish drift.

Chapter I

LARVAL FISH ECOLOGY AND HABITAT USE

There are five primary phases of a fish life cycle: 1) embryo, 2) larval, 3) juvenile, 4) adult, and 5) senescence (Figure 1). A few species have life cycles lacking a larval stage (termed direct development), emerging from the embryo with a similar body structure as adults. The vast majority of species exhibit indirect development as illustrated in Figure 1. The larval phase begins at emergence from the embryo and lasts until the full complement of adult fin rays are present and the larval finfold has been completely absorbed. Emerging larvae have reduced sensory ability (often having reduced or complete lack of visual ability and/or a lateral line system), and decreased motility due to size, lack of fin differentiation, incomplete neurological development, and in some cases lack of a swim bladder for buoyancy control. The larval phase, however, is the first phase a fish can interact with the environment, and actively, or passive/actively select habitat or environmental conditions (Pavlov 1994; Fuiman and Werner 2002).

Fishes are the most fecund vertebrate with individuals of some species producing 100,000 to over 1,000,000 embryos, however they suffer extremely high mortality during the environmentally sensitive larval stage (Fuiman and Werner 2002). The average mortality rate during the larval phase for freshwater fishes is 14.8% /day. The mean duration of the larval stage is 20.7 days resulting in 96.4% of emerging larvae not recruiting beyond the larval stage (Fuiman and Werner 2002). These numbers, however, were developed from unaltered systems. Survival through the larval stage is dependent on larvae reaching appropriate nursery habitat, but the quantity, quality, location, and

timing of availability of these habitats may be reduced or changed in rivers that have been altered. Two effects of river alteration that have been identified as having a major influence on larval fish recruitment are: changes in discharge (Scheidegger and Bain 1995; Humphries and Lake 2000; Humphries et al. 2002) and loss of nursery habitat (Holland 1986; Schiemer et al. 2001a). These alterations have resulted in the larval phase acting as a recruitment bottleneck for many fishes. These anthropogenic modifications have not affected all species similarly. Many fishes classified as habitat generalists have increased in number or expanded their range in altered systems while native rheophilic fishes have decreased in number, many becoming imperiled (Galat and Zweimüller 2001; Aarts et al. 2004).

Habitat rehabilitation projects have been initiated on many altered rivers with a stated goal of restoring the native fish fauna. Accurate knowledge of resource requirements throughout each species' life cycle must first be developed to maximize effectiveness of these attempts (Kurmayer et al. 1996; Schiemer et al. 2001b). Few research projects have been designed to assess effects of alteration of the annual hydrologic cycle on larval fishes. Scheidegger and Bain (1995), comparing a highly regulated and an unregulated Alabama stream, found that flow regulation reduced the abundance of larval fishes in nursery habitat, altered taxonomic composition, and disrupted microhabitat relations. Humphries and Lake (2000) and Humphries et al. (2002) found that an altered hydrograph didn't reduce spawning of several species in Australian rivers, but reduced recruitment through the larval stage. Considerable research has been initiated in rivers worldwide to define physical habitat requirements, or nursery habitat, for larval fishes (Table 1). Many of these projects attempt to compare habitat use among large physical

features within the environment such as islands, groyne (dike) fields, or types of shorelines (Baras et al. 1995; Gadomski and Barfoot 1998; Bartl and Keckeis 2004); whereas others attempt to characterize environmental conditions associated with larval fish presence at finer spatial scales (Copp 1990; Garner 1996; Kurmayer et al. 1996). However, it is likely that habitat selection at these varying scales is occurring in a hierarchical nature (Copp et al. 1994). Larger scale features such as bank slope and shoreline sinuosity may influence habitat selection to an area where appropriate environmental conditions are more common; whereas, the fish's position, or microhabitat, within the selected area is likely determined by finer scale conditions such as depth, current velocity or substrate type. Developing an understanding of discharge and nursery habitat conditions that are conducive to larval fish recruitment at multiple spatial scales could increase success for restoration of native fish faunas in altered rivers.

The lower Missouri River is a turbid, large floodplain river that has been dramatically altered to support navigation, flood control, agriculture, and recreation. Historically, the lower Missouri River had a bimodal annual flow pulse with an increase in discharge in March-April and a second, larger increase during June. Discharge decreased following the June rise and remained low for the remainder of the summer (Galat et al. 2005). Flow regulation has truncated the flow pulses and increased discharge during late summer resulting in a more stable annual hydrograph benefiting navigation (Galat and Lipkin 2000). Prior to bank stabilization and creation of a navigation channel, the Missouri River had a meandering, braided channel with diverse habitat owing to many sandbars, islands, secondary channels, and backwaters. It was characterized by continual bank erosion, and a tremendous sediment load making it one of the most turbid rivers in North

America (Pflieger and Grace 1987; Galat et al. 2005). Channelization of the lower Missouri River reduced surface area by 50%, reduced turbidity by 65%, and decreased the number of sandbars and islands by >90%, confining the river to a single, deep channel with swift current and little habitat complexity (Funk and Robinson 1974; Pflieger and Grace 1987).

Nursery habitat for larval fishes has been defined variously by researchers working in rivers around the world (Table 1). In general, these studies report larval riverine fishes use areas with low current velocity and shallow water. These areas provide increased water temperatures resulting in increased metabolism, and in conjunction with sufficient food supply can result in increased growth (Fuiman and Werner 2002). Shallow nursery area also provide refuge from many predators (Fuiman and Werner 2002). The success of habitat rehabilitation projects intent on increasing recruitment depends on accurately defining environmental conditions associated with habitat used by larval fishes within the range of shallow water available in the modern lower Missouri River or other large rivers. Junk et al. (1989) and Junk (2005) referred to the spatially and temporally dynamic, periodically inundated river floodplain as the aquatic terrestrial transition zone (ATTZ). In this study I will use the term ATTZ with a slightly different definition. I will use ATTZ to refer to inundated, littoral areas within the river channel, including the littoral area of instream sandbars and along the main-channel border (*Channel-margin ATTZ*). In the river-floodplain system the ATTZ changes with diel and seasonal variations in discharge. Channel-margin ATTZ (Figure 2) may be critical for larval fish in general that don't have access to floodplain ATTZ in altered rivers like the lower

Missouri River, and to rheophilic larval fishes in particular that may rarely use floodplain ATTZ even when available (Galat and Zweimüller 2001).

We developed a series of research objectives to define requirements for the riverine larval fish assemblage and selected taxa within a hierarchical spatial framework in the lower Missouri River that may be applicable to other channelized, large rivers. The hierarchical framework is a tool to aid in integration of results among research objectives. The following three chapters are written in a "stand alone format" using first person plural as they will be published as multi-author manuscripts. This format will result in some overlap in study site, methods, and references among chapters, but facilitate publication in peer-reviewed outlets.

There are three objectives for Chapter 2: (1) determine if larval fish catch-per-unit-effort (CPUE) differed among years (2002-2004) for the larval fish assemblage and selected taxa, and whether discharge and water temperature helped account for that difference within the main channel; (2) compare larval fish CPUE and water temperature between the main channel and sandbar ATTZ, and; (3) contrast the ability of geomorphic, local-environmental, and hydrologic conditions to account for variance in CPUE of the larval fish assemblage and selected taxa within sandbar ATTZ mesohabitats. The objective for Chapter 3 is to develop predictive models of habitat use by the larval fish assemblage and selected taxa within sandbar ATTZ, and evaluate the predictive ability of these models in sandbar and channel-border ATTZ at the microhabitat level. Chapter 4 examines diel changes in larval fish CPUE at the macrohabitat scale within the main channel, sandbar ATTZ, and off-channel scours for the larval fish assemblage and selected taxa; evaluating the hypothesis that turbid-water rivers lack a diel cycle of larval

fish drift. Chapter 5 integrates results from Chapters 2 through 4 and provides management implications.

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Table 1. Summary of nursery habitat for larval fishes from selected rivers. Data include taxa or group of research focus, river studied, nursery habitat classification, and article reference. "Assemblage" under species indicates project focused on many species within river, "rheophilic" indicates project focused on species requiring flowing water for one or all life stages, "generalist" indicates project focused on species not requiring flowing water for completion of any life stage. Nursery habitat contains a short description of where larval fishes were collected or observed. Studies are ordered alphabetically by author.

Taxa	**River**	**Nursery Habitat**	**Reference**
rheophilic cyprinids	River Ourthe, Belgium	channel margin along gravel bars	Baras et al. 1995
nase (*Chondrostoma nasus*)	River Wien, Austria	braided channel	Bartl and Keckeis 2004
roach (*Rulilus rutilus*)	upper Rhône River, France	early larvae – lentic areas 0.5-1.0 m deep dense vegetation, no current, silty substrate late larvae water depth <0.5 m, no current or vegetation	Copp 1990
assemblage	Columbia and Deschutes rivers, Oregon, USA	native taxa – channel introduced taxa – backwaters	Gadomski and Barfoot 1998
northern pikeminnow (*Ptychocheilus oregonensis*)	Columbia River, Oregon, USA	shallow, low-velocity shorelines of main-channel and backwaters with silt and sand substrate, with moderate to dense vegetation	Gadomski et al. 2001

Table 1. Continued.

Taxa	River	Nursery Habitat	Reference
roach (*Rutilus rutilus*) chub (*Leuciscus cephalous*)	River Great Ouse, England	water <1 m deep, near the bank, with emergent vegetation	Garner 1996
assemblage (rheophilic and generalist)	lower River Rhine, Netherlands	low current velocity, shallow water depths, and gently sloped shorelines	Grift et al. 2003
assemblage	upper Mississippi River, Minnesota, USA	backwaters, channel borders	Holland 1986
assemblage	River Morava, Czech Republic	rheophilic fishes selected sand/gravel beaches	Jurajda 1999
assemblage	Broken River, Australia	backwaters and channel margin	King 2004
perch (*Perca fluviatilis*)	Kyrönjoki River, Finland	shallow water (<0.5 m) with vegetation	Kjellman et al. 1996
rheophilic and generalist	River Danube, Austria	rheophilic – low water depth, heterogeneous substrate with shallow bank slope; eurytopic – greater depth, mud substrate or riprap	Kurmayer et al. 1996

Table 1. Continued

Taxa	River	Nursery Habitat	Reference
assemblage	Sinnamary River, French Guiana	sinuous shorelines, undercut banks, with vegetation and organic litter	Mérigoux and Ponton 1999
assemblage	Ohio River, Ohio, USA	margins along main channel and islands	Millard 1993
assemblage	Luxapalilia Creek, Mississippi, USA	high water temperatures, low current velocities, and shallow water depths	Peterson and VanderKooy 1995
Roanoke logperch (*Percina rex*)	Nottoway and Roanoke rivers, Virginia, USA	shallow, stagnant backwaters, secondary channels	Rosenberger and Angermeier 2003
assemblage	Tallapoosa and Cahaba rivers, Alabama, USA	depth <1.3 m, water velocity <8.4 cm/s (water velocity estimated)	Scheidegger and Bain 1995
assemblage	River Danube, Austria	gravel banks with low slopes and current velocity <50 cm/s	Schiemer et al. 1991
gizzard shad (*Dorosoma cepedianum*), sunfish (*Lepomis* spp.), emerald shiner (*Notropis atherinoides*)	Kanawha River, West Virginia, USA	*Lepomis* spp. – backwaters *Dorosoma cepedianum* and *Notropis atherinoides* – main channel border	Scott and Nielsen 1989

Table 1. Continued.

Taxa	River	Nursery Habitat	Reference
assemblage	upper Mississippi River, Iowa, USA	backwaters	Sheaffer and Nickum 1986
rheophilic species	lower River Rhine, Netherlands	unfixed (unstabilized) river banks with gentle shore slopes	Staas and Neumann 1996
rheophilic species	River Danube, Austria	rheophilic group A – lotic areas, coarse substrate, low water depth, medium to fast current velocities rheophilic group B – low current velocity	Wintersberger 1996

Figure 1. Illustration of a generalized life cycle of a fish from Fuiman and Werner 2002.

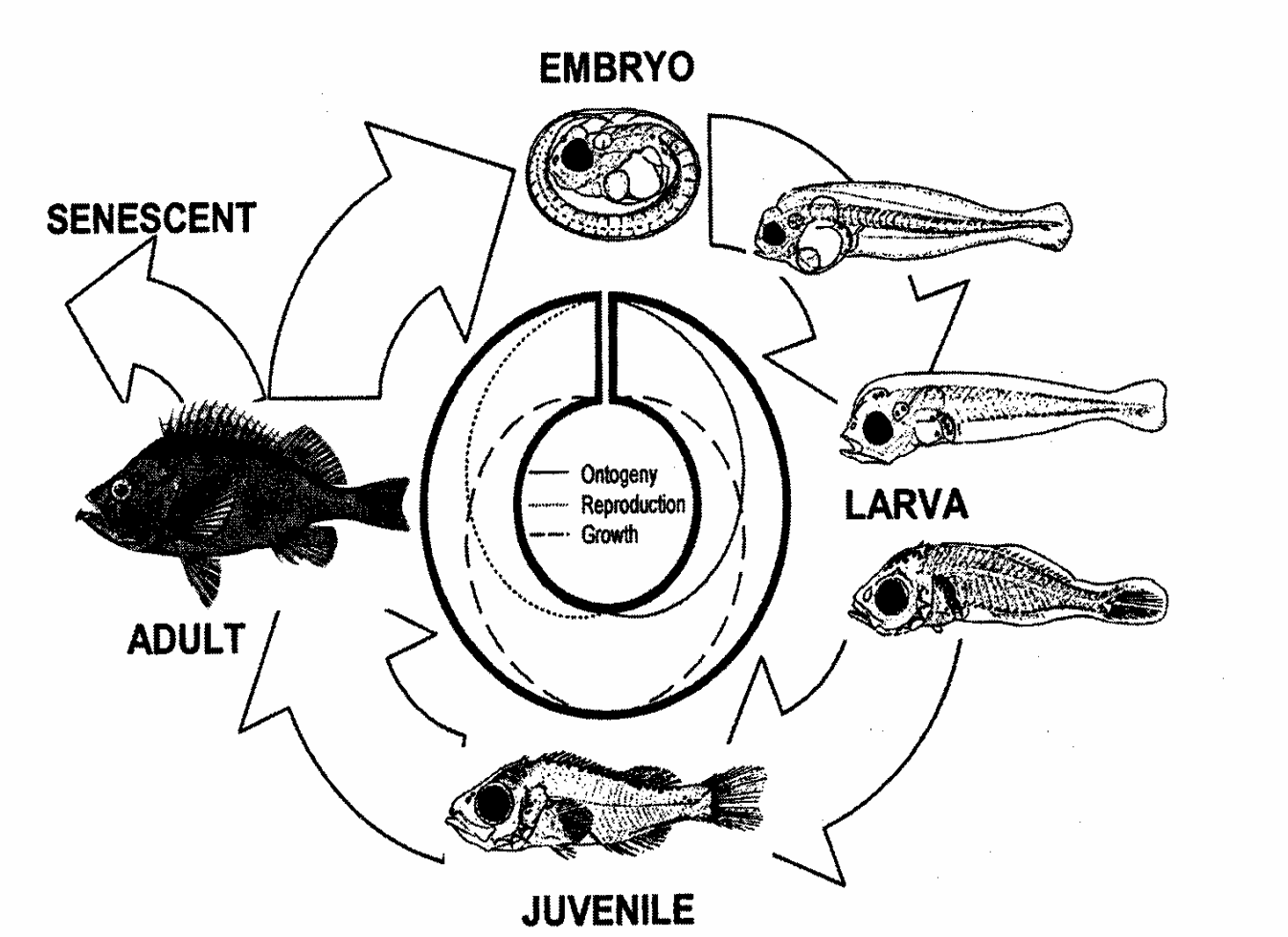
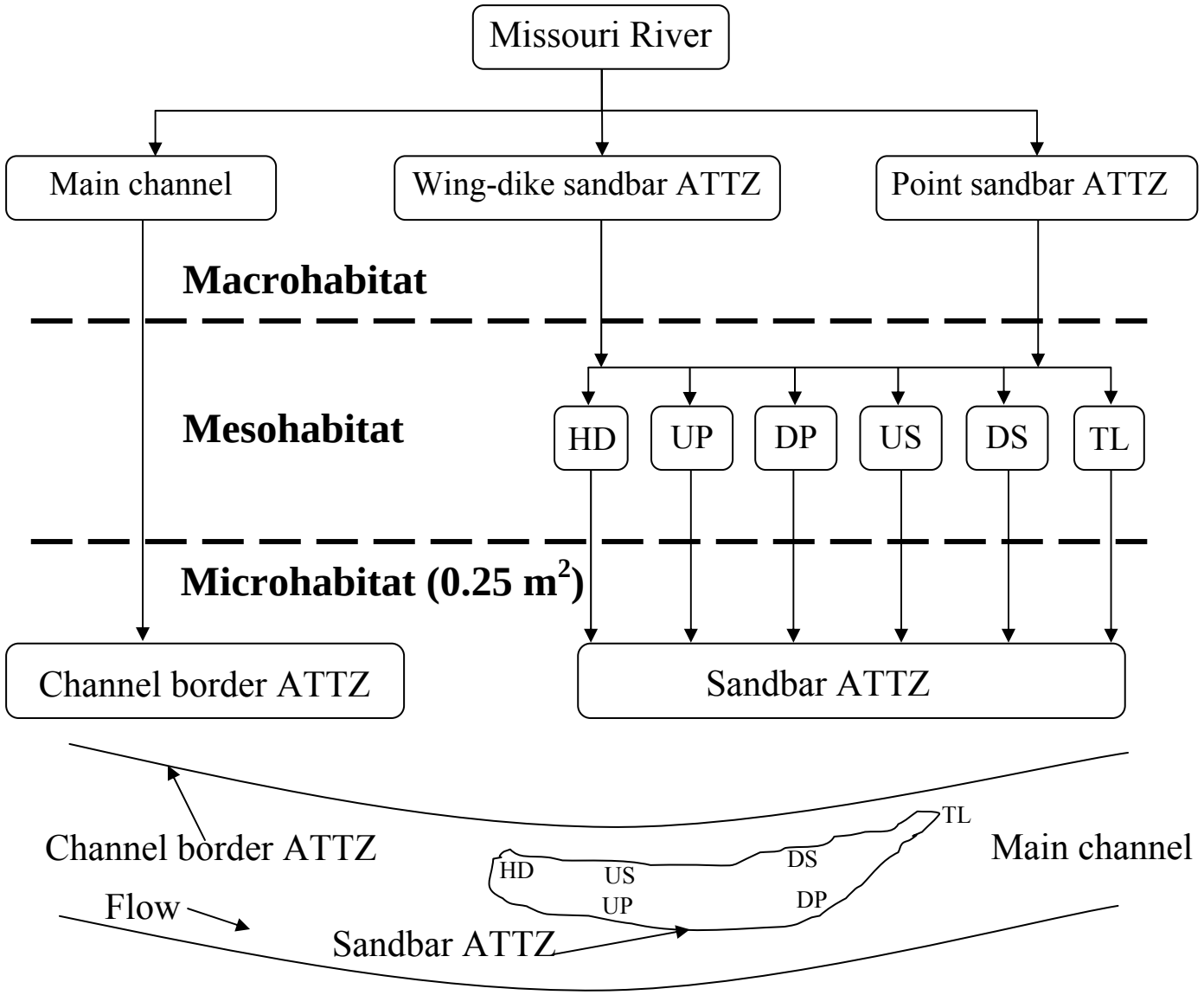


Figure 2. Flowchart illustrating the spatial hierarchy applied within the lower Missouri River. Macrohabitats included main channel (containing both primary and secondary channels when the latter were present), point sandbars (sandbars formed in the inside of a bend in the river), and wing-dike sandbars (sandbars formed behind wing-dikes). Mesohabitats included sandbar regions that were delineated based on channel orientation. Microhabitat was defined as the environmental conditions present within the water column at 0.25 m^2 sample collection locations within each sandbar and channel border aquatic terrestrial transition zone (ATTZ). The ATTZ was restricted to areas with water <1.0 m in depth. HD = most upstream point of sandbar, TL = most downstream point of sandbar, UP = sandbar mesohabitat halfway between sandbar midpoint and HD on primary channel side of sandbar, DP = mesohabitat halfway between sandbar midpoint and TL on primary channel side, UP = halfway between sandbar midpoint and HD on secondary channel side, DS = halfway between sandbar midpoint and TL on secondary side of sandbar.


Missouri River
Main channel
Wing-dike sandbar ATTZ
Point sandbar ATTZ
Macrohabitat
Mesohabitat
HD
UP
DP
US
DS
TL
Microhabitat (0.25 m2)
Channel border ATTZ
Sandbar ATTZ
Channel border ATTZ
HD
US
UP
DS
DP
TL
Main channel
Flow
Sandbar ATTZ

Chapter II

EFFECTS OF DISCHARGE, GEOMORPHIC, AND ENVIRONMENTAL CONDITIONS ON LARVAL FISHES IN THE LOWER MISSOURI RIVER

Abstract

We used a hierarchical research design to identify relations between abiotic conditions within the main channel, sandbar aquatic-terrestrial-transition-zone and catch-per-unit-effort (CPUE) for the larval fish assemblage and the native carpsucker and buffalo (*Carpiodes* spp./*Ictiobus* spp.) group, non-native silver and bighead carp (*Hypophthalmichthys molitrix/nobilis*) group, and native chub (*Macrhybopsis* spp.) group within the lower Missouri River. There were significant reductions in larval assemblage CPUE between 2002 vs. 2004 and 2003 vs. 2004, but not between 2002 vs. 2003 with discharge as a significant covariate. Native *Carpiodes* spp./*Ictiobus spp* exhibited significant reductions in CPUE between 2002 vs. 2003 and 2002 vs. 2004, but not 2003 vs. 2004 with discharge and water temperature as significant covariates. *Hypophthalmichthys* spp. CPUE was significantly higher during 2002 vs. 2004 and 2003 vs. 2004 but not 2002 vs. 2003 with discharge as a significant covariate. *Macrhybopsis* spp. did not differ significantly among years. *Carpiodes* spp./*Ictiobus* spp. and *Macrhybopsis* spp. were significantly more abundant in sandbar macrohabitats than within the main channel, whereas there was no significant difference in CPUE among macrohabitats for the invasive *Hypophthalmichthys* spp. Direct gradient analysis was then used to assess the amount of variance in larval fish CPUE within the ATTZ of instream sandbars was accounted for by four geomorphic (sandbar type, region, shoreline

slope, and sinuosity), three hydrologic (change in discharge over 1, 2, and 4 day means), and four local-environmental (current velocity, water depth, substrate type and temperature) factors. Local-environmental factors most strongly influenced larval fish CPUE within sandbar ATTZ, with current velocity accounting for the greatest proportion of variance. Hydrologic factors accounted for the second greatest proportion of variance and geomorphic factors accounted for the smallest proportion of variance in larval fish CPUE.

Introduction

Riverine ecosystems are among the most diverse, dynamic, and threatened on the planet (Junk and Wantzen 2003; Nilsson et al. 2005). The spatial component of these systems includes the river channel and its floodplain, but flowing water is the dynamic force driving these system and their inhabitants (Hynes 1975; Junk et al. 1989; Stanford et al. 1996; Humphries et al. 2002; Wiens 2002). Anthropogenic river modifications have resulted in separation of rivers from their floodplains, alteration of annual hydrographs, altered sediment transport, homogenization of in-stream habitat, detachment of discharge and water temperature patterns, change in disturbance regime, and decreased water quality (Ward and Stanford 1995; Stanford et al. 1996; Townsend et al. 1997; Galat and Lipkin 2000; Aarts et al. 2004; Nilsson et al. 2005).

Changing environmental conditions have lead to cascading changes in biological communities including decreases in diversity, increases in invasive species, and reduction in numbers or extirpation of many native fish species (Stanford et al. 1996; Rosenfeld 2003). Fishes requiring flowing water for completion of their life cycle including fluvial

specialist (species found almost exclusively in lotic waters) and fluvial dependant fishes (species found in lotic and lentic habitats, but requiring lotic waters for some part of their life cycle) have been most detrimentally affected. Fishes classified as macrohabitat generalist (fishes capable of completing their life cycle in either lotic or lentic environments) have increased in number or range (Galat and Zweimüller 2001; Aarts et al. 2004; Galat et al. 2005).

The life cycle of a species has specific windows in time that can act as bottlenecks for recruitment (Werner and Gilliam 1984). The larval stage often functions as a recruitment bottleneck for fishes due to decreased mobility and sensory ability, and increased vulnerability to anthropogenic environmental alteration (Scheidegger and Bain 1995; Humphries et al. 2002). Loss of habitat with environmental conditions conducive to growth and survival (i.e., nursery habitat) is a major contributor to decreased larval fish recruitment to the juvenile phase (Holland 1986). A second factor influencing spawning (Winemiller 1989; Humphries et al. 1999), transport of eggs and larvae (Baumgartner et al. 2004; Dudley 2004) and survival of larvae (Scheidegger and Bain 1995; Humphries et al. 2002) is alteration of the annual hydrograph.

Nursery habitat for larval fishes has been characterized in a variety of ways, and at a variety of spatial scales. It has been defined at macro- or mesohabitat scales (Pardo and Armitage 1997; Johnson and Jennings 1998) using geomorphic variables: margin of channel and sandbar (Millard 1993), river banks with gentle shoreline slope (Staas and Nuemann 1996), sand and gravel beaches (Jurajda 1999), and backwaters and channel margin (King 2004). Most commonly nursery habitat has been defined in terms of local environmental conditions such as current velocity, water depth, substrate type, and

presence of vegetation (Peterson and VanderKooy 1995; Scheidegger and Bain 1995; Wintersberger 1996; Gadomski et al. 2001). These local-environmental conditions would be expected to vary at meso- to microhabitat scales (Frissell 1986; Pardo and Armitage 1997). Only rarely have hydrologic variables such as changing discharge over time been evaluated (Arrington 2002; Galat et al. 2004b). In projects where nursery habitat is defined, the prevailing conditions in areas larval fish are most abundant are said to provide nursery habitat. Characteristics used to define these areas are typically from one or two of the before mentioned groups (i.e., geomorphic, local-environmental, or hydrologic), but there is rarely any attempt to provide specific comparisons of variables across all groups to determine how much of the variance in abundance each group of variables accounts.

The Missouri River is a highly altered large-floodplain river. The pre-regulation Missouri River had a broad, braided channel with many sandbars and islands. Diversity of habitat within its channel borders, as well as linkage between the Missouri River and its floodplain provided an abundance of aquatic terrestrial transition zone, ATTZ (Junk et al. 1989, Junk 2005). The current Missouri River has been separated from its floodplain by levees and channel armoring, its water restricted to a single deep channel, and the number and area of sandbars decreased by >90% (Funk and Robinson 1974; Pflieger and Grace 1987; Galat et al. 2005). The remaining sandbars are like "a string of beads" providing habitat heterogeneity in an otherwise homogeneous stream channel (Galat et al. 1998). The U.S. Army Corps of Engineers is responsible for protection and maintenance of existing sandbars and has initiated several restoration projects to increase the diversity

of shallow, slow-water areas through flow management and habitat creation (U.S. Army Corps of Engineers 2004).

Discharge is a key factor in larval fish dispersal in rivers, but few studies have evaluated the relationship between discharge and habitat use by larval fishes (Arrington 2002; Humphries et al. 2002; Galat et al. 2004b). We developed three objectives to evaluate the association of discharge, water temperature, and nursery habitat conditions on larval fishes in the lower Missouri River. These objectives were designed to better understand affects of discharge and temperature on larval fish abundance within the lower Missouri River in terms that can be applied to other large, impounded rivers. We also characterize the relationship between larval fishes and nursery habitat in geomorphic, local-environmental, and hydrologic terms to provide guidance for habitat rehabilitation projects within the lower Missouri River and other large rivers targeting creation of nursery habitat.

Our first objective is to determine if catch-per-unit-effort (CPUE) of the larval fish assemblage (all larval fishes collected during the study) and three selected taxa within the main channel of the lower Missouri River differed among three-years of study, and whether discharge and water temperature helped to explain that difference. We define Missouri River "main channel" as including mid-channel regions of both primary channel (navigation channel or thalweg) and secondary channels (separated from primary channel by an instream sandbar) combined. The main channel often functions as a pathway for larval dispersal, so comparisons of CPUE within the main channel (primary and secondary channels combined) may provide a method to separate effects of discharge and temperature on larval CPUE while excluding any confounding effects of shallow water.

Second, we compared differences in CPUE of the larval fish assemblage and selected taxa and water temperature between the main channel and sandbar ATTZ macrohabitats. We define sandbar ATTZ to extend from the waters edge to a depth of 1.0 m. Our final objective was to compare the ability of several abiotic factors to account for differences in larval fish CPUE at the assemblage level and for three selected taxa within the sandbar ATTZ during the entire period larval fish were present and during the longest period of stable discharge (change in daily discharge ≤5.0 %). Separating the longest period of stable discharge allows us to test a hypothesis supported by Arrington (2002) that larval fishes become more structured (meaning larval fishes are more tightly associated with nursery habitat during stable flow because the habitat is stationary within the environment, during fluctuating discharge nursery habitat is moving within the environment) in relation to the environment during periods of stable flow. Abiotic factors compared for our final objective included geomorphic [sandbar type (macrohabitat scale), and sandbar region, shoreline slope, and shoreline sinuosity (mesohabitat scale)], local-environmental [water temperature, depth, substrate type, and current velocity (each local-environmental factor was compared at the mesohabitat scale then mesohabitats were aggregated to compare macrohabitats)], and hydrologic [change in discharge over three time periods (discharge was evaluated with geomorphic and local-environmental factors to aid comparison of the influence on larval fish habitat use between the three classes of factors)]. Native carpsuckers and buffalos (*Carpiodes* spp./*Ictiobus* spp.), non-native silver and bighead carp (*Hypophthalmichthys molitrix/nobilis),* and native chubs (*Macrhybopsis* spp.) were selected as taxa for individual analyses because they represent different habitat-use guilds and abundance

trends. *Carpiodes* spp./*Ictiobus* spp. are predominantly habitat generalist species and have remained common in collections during river modification. *Hypophthalmichthys molitrix/nobilis* are non-native fluvial dependent species that have become abundant since their introduction in the 1970s, and *Macrhybopsis* spp. includes four native, predominantly fluvial specialist species that have decreased in abundance in collections since river modification (Galat et al. 2005). Larval fishes were compared at these taxonomic levels due to the inability to accurately identify many individuals to species level resulting from insufficient systematic information or damage to specimens during collection.

Methods

Site selection

Sandbars were identified for study by evaluating diversity of types present within the lower Missouri River. Digital orthophotos of the lower Missouri River collected by the U.S. Army Corps of Engineers between 26 February 2000 and 24 March 2000 were used to locate emergent sandbars between river kilometer 742 (mile 461) near Rulo, Nebraska and the confluence of the Missouri and Mississippi rivers. All emergent sandbars were classified into 1 of 3 categories based on their major formative process: point sandbar (formed on the depositional side of a bend in the river), wing-dike sandbar (formed in the eddy created downstream of a wing-dike), or tributary sandbar (formed directly downstream from the confluence of a tributary and the Missouri River). Point and wing-dike sandbars represented >98% of sandbars present, so these types were retained and tributary sandbars were excluded from further study. Five wing-dike and five point

sandbars, between river kilometers 253 and 351 (river miles 157 and 218) moving upstream from the confluence of the Missouri and Mississippi rivers, were selected based on the criteria that they would be emergent during the greatest portion of the season larval fishes were present.

Main-channel sites were selected in conjunction with each of the 10 sandbar sites to address our first objective, evaluating if discharge and water temperature contributed to differences in abundance of the larval fish assemblage and three selected taxa. Ten additional primary (navigation) channel sites were added to the study during 2004 in conjunction with a concurrent project (Reeves 2006, Chapter 3). These additional main-channel sites were interspersed with the original 10 main-channel sites and were within about 2 km of at least one sandbar macrohabitat, but were not adjacent to sandbars (Figure 1). Only main-channel sites selected in conjunction with sandbar macrohabitats (i.e., parallel to sandbars and approximately mid-channel) were used for the second objective, comparing abundance of the larval fish assemblage and three selected taxa between the main channel and sandbar macrohabitats.

Spatial scales

Differences in larval fish abundance within the lower Missouri River were assessed at two spatial scales: macrohabitat and mesohabitat (Figure 2). This hierarchy was not created to supplant previous spatial hierarchies, but to serve as a tool to assist in understanding and integration of research results. We use *Macrohabitat* to indicate distinct morphological units including main channel, composed of mid-channel regions of primary (navigation) and secondary channels (when the latter were present adjacent to

sandbars) and sandbar type (point and wing-dike sandbars). We use *Mesohabitat* to mean subunits (regions) of sandbar macrohabitats reflecting locations relative to the river channel and flow (Figure 3). Each sandbar macrohabitat ATTZ was divided into six mesohabitats based on channel aspect and sandbar morphology: 1) head (HD)– most upstream point of sandbar; 2) tail (TL)– most downstream point of sandbar; 3) upstream primary (UP)– about one-half of the distance between the sandbar midpoint and head region on the primary channel side of sandbar; 4) downstream primary (DP)– about one-half of the distance between the sandbar midpoint and the tail region; 5) upstream secondary (US)– about one-half of the distance between the sandbar midpoint and head region on the secondary channel side of sandbar; and 6) downstream secondary (DS)– about one-half of the distance between sandbar midpoint and tail region**.**

Temporal scale

Collection of larval fishes began 15 March 2002, 1 April 2003, and 1 April 2004, and continued through 30 September of each year. This sampling period was selected to ensure collection throughout the entire period larval fishes were anticipated to be present based on previous studies within the upper Mississippi and lower Missouri rivers (Holland 1986; Galat et al. 2004a, b). Lower Missouri River discharge is dynamic during this interval (Galat and Lipkin 2000) and we refer to it here after as *variable flow period* to contrast with larval fish collections when discharge was less variable (*stable flow period* – see below). Larval fishes were collected within the main channel two to three times per week to assess the relationship among annual differences in larval fish abundance and river discharge and water temperature over a three year period (objective

1). Larval fishes were collected within sandbar ATTZ on the same dates as main-channel samples during 2002 and on 10 randomly selected dates in 2003 for objective 2, comparing larval abundance between the main channel and sandbar ATTZ macrohabitats, and objective 3, comparing the ability of several abiotic factors to account for differences in abundance among sandbar mesohabitats. A reduced number of collections was made in sandbar ATTZs during 2003 to determine if the same factors accounted for the most variance in larval fish abundance, but not to make specific comparisons of the amount of variance accounted for by a single abiotic factor between years. An additional comparison within our third objective was to compare the ability of abiotic factors to account for variance during the entire time larval fishes were present (variable flow period) and during a period referred to as the stable flow period (longest continuous period larval fish were present and the change in daily mean discharge was ≤5.0 % per day during each of the two years of study). Research conducted on fish communities in tropical rivers has shown they become more organized in relation to their environment during periods of stable flow (Arrington 2002, Arrington and Winemiller 2003). If this pattern occurred in the lower Missouri River then models created to account for variance in larval fish abundance would be expected to perform better during periods of stable flow than during periods with more variable flow. Three groups of abiotic factors (i.e., geomorphic, local-environmental, and hydrologic) were included in the analysis of larval fish abundance within sandbar ATTZ (objective 3). The hydrologic group of factors was composed of three factors representing percent change in river discharge over three time periods: 1 day, 2 days, and 4 days. These factors were calculated using daily mean discharge for the lower Missouri River, recorded by the U.S. Geological Survey

Calculating hydrologic factors over several time periods allowed us to evaluate at what time scale larval fish abundance was most strongly influenced by changes in discharge.

Larval fish collection

Main-channel macrohabitat samples were collected mid-channel of the primary and secondary channels, from the upper 30 cm of the water column using paired, bow-mounted ichthyoplankton nets, 30-cm tall, 60-cm wide, and 1.4-m long, constructed of 500-μm Nytex nylon mesh (Colton et al. 1980, Pepin & Shears 1997). Samples were collected by traveling downstream approximately 1 m/s faster than the water current for about 300 m (Gallagher & Conner 1983, Brown 1989). Main channel sample volumes were calculated by measuring the distance nets travel using a General Oceanics model #2030R propeller-style flow meter suspended between the mouths of the nets and multiplying distance traveled by net area.

Larval fishes were collected from each of the six mesohabitats within point and wing-dike sandbar ATTZs (results from mesohabitat sample collection were aggregated for macrohabitat comparisons). We first delineated a 50-m transect at the approximate midpoint of each sandbar mesohabitat. In cases where mesohabitats were <50 m in length the transect length was reduced so the distance between adjacent transects was greater than or equal to transect length. Two larval fish samples were collected within each of the six mesohabitats using a hand-operated push-cart outfitted with paired ichthyoplankton nets (Colton et al. 1980, Pepin & Shears 1997). Push-cart ichthyoplankton nets were of the same construction as bow-mounted nets, 30-cm tall, 60-cm wide, and 1.4-m long with 500-μm Nytex nylon mesh. The push-cart had a skid

below the nets allowing it to slide over the substrate in water <30-cm deep, and float with the top of the net at the water surface in water >30-cm deep. Ten centimeters was selected as the minimum sample depth within the sandbar ATTZ prior to the sampling season by evaluating the nets ability to collect small buoyant objects. The 10-cm sample depth was marked at 5-m increments within each mesohabitat before sampling larval fishes to demarcate the inshore ATTZ boundary of the sample collection path. It was necessary to mark the sample path prior to collection because some areas had uneven substrate or sinuous shoreline causing the distance between the waters edge and the 10-cm water depth to vary. A shoreward sandbar ATTZ sample was collected by traveling downstream approximately 1 m/s faster than the water current (Gallagher & Conner 1983, Brown 1989) with the shoreward side of the sample cart traveling along a pre-established 10-cm depth line**.** The second ATTZ sample was collected in the same manner along a contiguous path, riverward of the shoreward sample. Sampling order for sandbar ATTZ mesohabitats and samples within each mesohabitat was selected randomly.

Sandbar ATTZ sample volumes were calculated by multiplying net area by transect length in areas where water depth was greater than 30 cm. Sample volume was adjusted in areas where water depth was insufficient for complete net submersion by measuring water depth (cm) every 10 m on both sides of the push-cart path. The mean of these two depths was multiplied by transect length to calculate an adjusted sample volume. Sandbar mesohabitats on the secondary-channel side of sandbars were occasionally de-watered during periods of low flow and could not be sampled. Sandbars were overtopped during each year of study, and larval fishes could not be collected within the sandbar

ATTZ while sandbars were submerged. This sampling design resulted in collecting larval fishes at exposed sandbar ATTZs from the entire water column at depths between 10 and ≤30 cm and from the top 30 cm of the water column at depths from >30 cm to 1 m.

Larval fish handling and identification

Net contents were fixed in the field using 10% neutrally buffered formalin, and stored for 24 hours. Samples were then transferred to 80% ethanol, and stored until identification. Larval fishes were separated in the laboratory from detritus using combined methods of staining larval fishes with eosin Y, and floatation using sucrose solution (Anderson 1959; Pask and Costa 1971; Hall et al., 1996). All larval fishes were identified to the lowest reliable taxonomic level using keys developed by May and Gassaway (1967), Auer (1982), Fuiman et al. (1983), Holland-Bartels et al. (1990), Wallus et al. (1990), and Kay et al. (1994). The developmental stage of each larval fish was then noted as proto- meso- or meta-larvae based on work by Snyder (1976). The taxonomic level individual larval fish could be identified to was influenced by physical condition and developmental stage of the specimen. In some cases fishes could be identified to genus or species, but some individuals could only be reliably identified to family. For example two groups of cyprinids could not be reliably separated and had to be grouped into Cyprinid A (*Hybognathus argyritis, H. hankinsoni, H. placitus,* and *Notemigonus crysoleucus*) and Cyprinid B (*Cyprinella spiloptera, Lythrurus umbratilis, Notropis blennius, N. buchanani, N. shumarki, N. stramineus, N. wickliffi,* and

Phenacobius mirabilis). Verification of identification for selected taxa including all larval sturgeon was conducted by Darrel E. Snyder at the Colorado State larval fish laboratory.

Abiotic variables

Daily mean river discharge was collected by the U.S. Geological Survey gauge at Boonville, MO (gauge number 6909000) at river km 317. Main-channel mean water temperatures for each larval fish collection were calculated by averaging water temperature measured to the nearest 0.1 °C using an electronic thermistor at the upstream and downstream ends of each 300-m mid-channel collection path. Daily mean discharge and main-channel mean temperature were used for objective one, evaluating the relationship between discharge, water temperature, and abundance of larval fishes in the main channel, and objective two, comparing the abundance of larval fishes and water temperature between sandbar and main-channel macrohabitats.

The first step in objective three, comparing the ability of several geomorphic, local-environmental, and hydrologic factors ability to account for variance in larval fish abundance within sandbar ATTZ, was to compare those factors between sandbar macrohabitats and among sandbar mesohabitats. Geomorphic factors included sandbar macrohabitat (type), sandbar mesohabitat (region), shoreline slope, and shoreline sinuosity. Shoreline slope was calculated by dividing the change in water depth between the 10-cm shoreward collection boundary and the depth measured 3.0 m riverward (where 3.0 m = the width of the two contiguous collection paths) at 10-m increments within each sandbar mesohabitat. This provided five slope values for each mesohabitat. The mean of these values was calculated to provide a single slope value for each sandbar

mesohabitat on a given day. The six mesohabitat mean shoreline slope values were then used to calculate a sandbar macrohabitat mean shoreline slope.

Shoreline sinuosity was calculated by first measuring the linear distance of the shoreline edge between the upstream and downstream ends of the marked sample path to the nearest 1.0 cm. Shoreline sinuosity within each mesohabitat was then calculated by dividing shoreline length by the straight-line distance of the marked sample path (generally 50 m). This method provided a single measure of shoreline sinuosity for each mesohabitat on a given day. Sandbar macrohabitat mean shoreline sinuosity was then derived by calculating the mean of sandbar mesohabitat values.

Local-environmental variables (water temperature, water depth, substrate type, and current velocity) within sandbar mesohabitats were recorded at 10-m increments on the shoreward and riverward side of each collection path immediately after larval fish collection. Water temperature was measured to the nearest 0.1 ºC using a digital thermistor. This value was subtracted from the temperature recorded within the primary channel on the same day to remove inherent seasonal changes in water temperature. Water depth was measured to the nearest 1.0 cm with a graduated meter stick. The dominant substrate type was recorded as silt, sand, or gravel and assigned a particle size value from the Wentworth (1922) scale: silt = 0.0156 mm, sand = 0.037 mm, and gravel = 4.0 mm. Current velocity was measured to the nearest 1 cm/s using a Marsh McBirney model 2000 portable flow meter at 60% of water depth measured from the surface. Mesohabitat means were calculated for each of the local environmental variables on each day for comparisons among mesohabitats. Macrohabitat means were calculated for each local-environmental variable by calculating the mean of mesohabitat values calculated for

the sandbar ATTZ on a given day. For example, current velocity was recorded on the inside and outside of each collection path at 10-m increments within each mesohabitat, that provided 20 measures of current velocity within each mesohabitat on a given day. The mean of these values was calculated providing a single current velocity mean for each mesohabitat on each date to be used for comparison among sandbar mesohabitats. Macrohabitat mean current velocity for comparison between sandbar macrohabitats was derived by averaging all mesohabitat mean current velocity values within each sandbar type .

We calculated three values representing change in daily mean discharge to determine if rising or falling discharge affects larval abundance, and whether larval abundance is more influenced by short term changes in discharge or those over a longer time scale. The first was percent change in discharge between day x and day x-1 (referred to as 1-d). The second was percent change in discharge between day x and the mean of day x-1 and day x-2 (referred to as 2-d). The final was percent change in discharge between day x and the mean of days x-1, x-2, x-3, and x-4 (referred to as 4-d). Hydrologic factors were not compared between macro- or among meso-habitats as they were calculated from a single daily mean discharge value, and as such, were independent of the spatial scales included in this study.

Data analysis

Comparisons of larval fish abundance between macro- or meso-habitats were made using larval fish catch-per-unit-effort (CPUE – number of larval fishes/ m^3). Larval fish CPUE was calculated by dividing the number of larval fishes within an individual sample

by the volume of water sampled. Two samples were collected within each sandbar mesohabitat. The total number of larval fishes from each sample was divided by the volume of water filtered for that sample; the mean of the two resulting values was then calculated to represent the mesohabitat mean CPUE. A sandbar macrohabitat mean CPUE was derived by averaging all mesohabitat means within the sandbar macrohabitat. Main-channel mean macrohabitat CPUE was calculated by dividing the number of larval fishes collected within each of two primary-channel and two secondary-channel samples by the volume of water filtered within each sample, then calculating the mean of these four values. Water temperatures were measured at multiple locations along the inside and outside of the sample collection paths within each sandbar mesohabitat. The mean of these values was calculated to represent the mesohabitat mean water temperature. Sandbar macrohabitat mean water temperature was derived by averaging the six sandbar mesohabitat water temperatures.

Our first objective was to determine if there were significant relationships between CPUE of larval fishes within the main channel of the lower Missouri River and daily mean discharge and water temperature. We used an analysis of covariance (ANCOVA) with CPUE as the dependent variable, year as the independent variable, and discharge and water temperature as covariates to determine if CPUE differed significantly among years and if there was a significant relationship between either or both covariates and CPUE for the larval fish assemblage, *Carpiodes* spp./*Ictiobus* spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp. Both groups of *Macrhybopsis aestivalis/storeriana,* and *gelida/meeki* had to be combined for this objective due to low numbers collected in the main channel. We tested assumptions associated with normality prior to analysis using a

Shapiro-Wilks test, and homogeneity of variance using a Fligner-Killeen test. CPUE failed assumption testing and were $\log_{10}$ transformed and re-tested. Interaction terms were created using covariate X year and were tested to ensure responses were parallel. We also used LS means tests for pairwise comparisons of CPUE among years to determine which years were significantly different for the assemblage and each selected taxa.

The second objective was to determine if larval assemblage and selected taxa abundance differed among the main channel and point and wing-dike sandbar ATTZ macrohabitats. We used an ANCOVA with CPUE as the dependent variable, macrohabitat as the independent variable and water temperature as the covariate. A mean water temperature was derived for each sandbar macrohabitat by averaging all water temperatures recorded within the sandbar ATTZ on a given day. We followed the same assumption testing procedures detailed for the first objective.

The first step in our final objective, comparing the ability of geomorphic, local environmental, and hydrologic factors to account for variance in larval fish abundance among sandbar ATTZ mesohabitats, was to understand how the geomorphic and local environmental factors differed among the six mesohabitats of each sandbar macrohabitat. Hydrologic factors 1-d, 2-d, and 4-d were based on daily mean discharge measurements and were determined for the entire river segment, therefore, they did not differ between sandbar macrohabitats or among mesohabitats. We used a three-factor analysis of variance (ANOVA) to determine if each geomorphic (N = 2) or local-environmental variable (N = 4) differed significantly between sandbar macrohabitats (N = 2), among mesohabitats (N = 6), or between years (N = 2) . Due to the number of comparisons, the

level of significance was adjusted to α=0.00714 [0.05/7; where 7 = the three main effects (macrohabitat, mesohabitat, and year) + the four interaction terms created from the main effects] (Toothacker 1993). Geomorphic factors included shoreline slope and shoreline sinuosity. Local environmental conditions tested included difference in water temperature between sandbar mesohabitat and primary channel, water depth, dominant substrate particle size, and current velocity.

Detrended correspondence analysis (DCA) is an indirect gradient analysis (Hill and Gauch 1980) that used a habitat-by-species data matrix to search for underlying associations among sample sites (in this case sandbar macro and mesohabitats) based on species composition (ter Braak 1995). Species, or taxa, that are shown near a habitat type were collected in greater numbers at that site, and sites that are near one another had similar species composition. The DCA analysis determined: (1) which of the direct gradient analyses (CCA or RDA) should be used to determine the contribution of each of the geomorphic, local environmental, and hydrologic factors to differences in larval fish abundance, (2) if there were associations between particular species and sandbar macro- or mesohabitats, and if (3) larval fishes classified within the same habitat-use guild (Galat and Zweimüller 2001; Aarts et al. 2004; Galat et al. 2005) were associated with particular habitats. DCA gradients <4.0 standard deviations indicate the species response to environmental gradients are short and linear and redundancy analysis (RDA) is appropriate. DCA gradients >4.0 standard deviations indicate species responses are unimodal and canonical correspondence analysis (CCA) is appropriate (ter Braak 1986; ter Braak 1995; Legendre and Legendre 1998). Separate DCAs were performed on 2002 and 2003 larval fish frequency of occurrence. Each DCA included the larval fish

assemblage and all taxa present in ≥5.0% of samples (13 taxa in 2002, and seven in 2003). Species present in <5.0% of samples were excluded due to distorting effects rare species can have on multivariate analyses (Gauch 1982; ter Braak and Šmilauer 2002). CANOCO 4.5 was used to perform the DCA using default settings (ter Braak and Šmilauer 2002).

The final step in our second objective was to use RDA, a multivariate statistical technique that combines aspects of ordination and multiple regression to describe patterns in species distributions using matrices of macro-mesohabitat by species and macro-mesohabitat by environmental data (geomorphic, local-environmental, and hydrologic factors) (ter Braak 1995). Redundancy analysis performs multiple regressions of all species simultaneously creating linear combinations of environmental variables (ter Braak and Šmilauer 2002). We used RDA analysis because it allowed us to evaluate the response of CPUE for many species, some of which we may not have been able to analyze individually due to low collection numbers, to multiple environmental variables simultaneously. We included geomorphic factors (sandbar macrohabitat, sandbar mesohabitat, shoreline slope, and shoreline sinuosity), local-environmental factors (water temperature, depth, substrate type, and current velocity), and hydrologic factors (1-d , 2-d, and 4-d).

We performed separate RDA analyses and partial RDA (pRDA) analyses for the variable flow period during 2002 and 2003, and during the stable flow period using default settings provided in CANOCO 4.5. A pRDA is an analysis containing a subset of the explanatory variables. Partial RDAs can be used to determine how much total variance an individual explanatory variable accounts for, and how much variance it

accounts for that no other explanatory variable accounts for (unique variance). For example, two variables that are highly correlated would be expected to account for much of the same variance, but two variables that are not correlated at all would be expected not to explain any of the same variance. We used the forward selection feature in CANOCO 4.5 to apply a Monte Carlo permutation test (N=9999) relating environmental variables to the larval fish assemblage. The Monte Carlo permutation test screens each environmental variable to determine the significance of the relationship between the environmental variable and the larval fish assemblage with a Bonferroni adjusted α of 0.05/number of environmental variables, $\alpha \leq 0.0125$ (ter Braak 1995).

Results

Larval fish occurrence and abundance

We collected a total of 30 larval taxa (taxa includes species or groups of species that could not be separated) during this three year study. Twenty-nine larval taxa were collected during 2002, 17 in 2003, and 14 in 2004 (Table 1). Twenty-seven larval taxa were collected from point sandbars (PB), twenty-seven from wing-dike sandbars (WD), and twenty-four from the main-channel (MC) macrohabitats. Twenty-two larval taxa were collected in all three macrohabitats (main channel and both sandbar types) during the study. Macrohabitat generalist taxa were most common (16 taxa), followed by fluvial dependent (9 taxa) and fluvial specialist (7 taxa). Taxa containing species that belonged to more than one guild were considered to belong to all guilds represented by the species contained. Shortnose gar *Lepisosteus platostomus* and bluntnose minnow *Pimephales notatus* were not collected in the main channel. Sturgeon spp. *Scaphirhynchus* spp.,

mooneye *Hiodon tergisus*, and creekchub *Semotilus atromaculatus* were not collected at point sandbars. Largemouth bass *Micropterus salmoides* and crappie spp. *Pomoxis* spp. were not collected at wing-dike sandbars.

The calendar date when larval fishes were first collected was consistent among years: 24 April 2002, 26 April 2003, and 25 April 2004. However, the date when larval fishes were last collected was earlier each year of study: 29 September 2002, 17 September 2003, and 9 September 2004. Sixty-two percent of larval taxa were first collected during increasing discharge in 2002, 38% during decreasing discharge, and no taxa were first collected during stable discharge (this includes data from main channel and sandbar macrohabitats). First collection was only noted in the main channel during 2003 and 2004, due to decreased sample effort in sandbar macrohabitats, with 39% appearing during increasing discharge, 48% during decreasing discharge, and 13% during stable discharge during 2003, and 38%, 56%, and 6% occurring during 2004, respectively (Table 2).

Fifty-four percent of larval taxa were collected in the main channel prior to being collected from sandbar ATTZ, whereas 39% were collected in sandbar ATTZ prior to being collected in the main channel, and only 7% (gizzard shad *Dorosoma cepedianum*, and threadfin shad *Dorosoma petenense*) were first collected in the main channel and sandbar ATTZ on the same date during 2002 (Table 2). This comparison could not be made during 2003 because larvae were not sampled in sandbar ATTZ on each date they were sampled within the main channel. Carpsucker/buffalo spp., white sucker *Catostomus commersoni*, and blue sucker *Cycleptus elongates* were collected for the first time between 25 April and 2 May of each of the three years across macrohabitats. All

first collections of these taxa occurred during an increase in discharge except for the first collection of blue sucker in 2004 that occurred during a decreasing discharge (Table 2). There was not a consistent pattern in date, water temperature, or discharge trend for first collection of silver/bighead carp. There also was no consistent pattern in date or water temperature associated with first collection of silver/speckled chub or sturgeon/sicklefin chub, but all first collections across macrohabitats and years were during periods of stable or falling discharge. First collections of longnose gar *Lepisosteus osseus* and shortnose gar occurred within eight days between 2002 and 2003, with all first collections occurring during decreasing discharge.

The order of first collection of larval fishes based on water temperature (date) for the ten most abundant taxa (present in all three years of study) across macrohabitats and years were (water temperature shown is the water temperature of the sample the larval fish was collected in): Cyprinid group B – 13.5 ˚C (24 April 2002), Carpsucker spp./Buffalo spp. – 13.5 ˚C (24 April 2002), Cyprinidae – 13.5 ˚C (24 April 2002), silver/bighead carp – 13.7 ˚C (29 April 2002), gizzard shad – 15.1 ˚C (1 May 2002), grass carp (*Ctenopharyngodon idella*) – 16.1 ˚C (1 May 2002), sturgeon/sicklefin chub – 16.1 ˚C (1 May 2002), goldeye (*Hiodon alosoides*) – 17.5 ˚C (2 May 2003), Cyprinid group A – 17.7 ˚C (29 April 2003), and silver/speckled chub – 22.6 ˚C (28 May 2003). The ten most abundant taxa first appeared in main-channel samples on average 1 day later and at 1.4 ˚C warmer water temperature in 2003 than 2002. The difference was greater between 2004 and 2002 with the ten most abundant taxa first appearing 24 days later and at 4.9 ˚C warmer water temperature on average during 2004.

Total mean CPUE for 2002 and 2003 combined was 757/100m^3 at wing-dike bars, 567/100m^3 in the main channel, and 494/100m^3 at point bars (Table 1). Larval fish were about ten times more abundant in main-channel samples during 2002 and 2003 than in 2004 (Table 1). Seventeen taxa were most abundant within the head (HD), upstream primary (UP) and upstream secondary (US) mesohabitats within wing-dike sandbar ATTZ [longnose gar, Clupeidae spp., *Alosa* spp., gizzard shad, threadfin shad, goldeye, common carp *Cyprinus carpio,* Cyprinid group B, sicklefin/sturgeon chub, emerald shiner *Notropis atherinoides,* bluntnose minnow, carpsucker spp./buffalo spp., Catostomidae spp., white sucker, mosquito fish *Gambusia affinis,* sunfish *Lepomis* spp., and *Sander* spp.]. Nine taxa were most abundant within downstream primary (DP) downstream secondary (DS) and tail (TL) mesohabitats in 2002 [shortnose gar, mooneye, grass carp, Cyprinidae spp., Cyprinid group A, silver/bighead carp, blue sucker, and freshwater drum *Aplodinotus grunniens*]. Twenty-two taxa were most abundant within the HD, US, and TL mesohabitats of point sandbars (shortnose gar, longnose gar, *Alosa* spp. gizzard shad, threadfin shad, grass carp, common carp, Cyprinidae spp., Cyprinid group A, Cyprinid group B, silver/bighead carp, silver/speckled chubs, sicklefin/sturgeon chubs, emerald shiner, Catostomidae spp., white sucker, blue sucker, sunfish spp., largemouth bass, crappie spp., *Sander* spp., and freshwater drum) and two within the remaining UP, DP, and DS mesohabitats (Clupidae spp., carpsucker/buffalo spp.) (Table 3; see Figure 3 for sandbar mesohabitat illustration).

Only 11 taxa were collected within wing-dike mesohabitats in 2003 (common carp, Cyprinidae spp., Cyprinid A, Cyprinid B, silver/speckled chubs, sicklefin/sturgeon chubs, emerald shiner, bluntnose minnow, carpsucker/buffalo spp., mosquito fish, and sunfish

spp.), and twelve taxa within point sandbar mesohabitats, (gizzard shad, goldeye, Cyprinid group A, Cyprinid group B, silver/bighead carp, silver/speckled chub, sicklefin/sturgeon chub, emerald shiner, bluntnose minnow, carpsucker/buffalo spp., mosquito fish, and sunfish spp.). The lower number of taxa collected in sandbar mesohabitats in 2003 was likely due to the reduced sampling effort.

Total length of larval carpsucker spp./buffalo spp., silver/bighead carp, silver/speckled chubs, and sicklefin/sturgeon chubs on the last date they were collected show that protolarvae of each taxa were present until September 2002. Protolarvae for carpsucker spp./buffalo spp. and silver/bighead carp were also present during September of 2003 and 2004. Sicklefin/sturgeon chub protolarvae were present until September of 2003, but the last collection of any sicklefin/sturgeon chub larvae occurred during August of 2004. Silver/speckled chub larvae were present until August 2003, but these were metalarvae (based on total length), and silver/speckled chub larvae were only collected on 12 August 2004.

Discharge, temperature, and larval fish abundance in the main channel

Water temperatures were warmer during April and May of 2004 than during the same period in 2002 or 2003 (Figure 4). The greatest discharge recorded during the three year study periods occurred during mid May 2002, with an increase from about 1490 cms to 6450 cms during a 10 day period. The lowest discharge (883 cms) recorded during the three study periods occurred in August 2002. There were five increases in discharge of 25% or more within a 24-hour period during 2002, three during 2003, and seven during 2004. Discharge in 2003 was lower during spring (01 April to 21 June) than during 2002.

The first flow pulse occurred in early May of 2003, increasing from approximately 1750 to 3000 cms, and a second smaller pulse occurred during mid June. Summer (22 June through 30 September) flow was slightly higher during 2003 than 2002. The first flow pulse occurred in late March of 2004 (not shown), earlier than the previous two years. Discharge remained more variable during the remainder of the spring and summer than the previous two years (Figure 4).

Catch per unit effort within the main channel differed significantly among years for the larval fish assemblage and for two of the three selected taxa (Carpsucker spp./Buffalo spp. and silver/bighead carp; Table 4). Carpsucker spp./buffalo spp. and *Macrhybopsis* spp. were most abundant in 2002, and decreased each year thereafter, though this difference was not significant for *Macrhybopsis* spp. (Table 1). Silver/bighead carp were most abundant in 2003, followed by 2002 (Table 1). All three taxa were least abundant in 2004. Discharge significantly improved model fit for the larval fish assemblage, carpsucker spp./buffalo spp., and silver/bighead carp CPUE (Table 4). Water temperature also contributed significantly to the carpsucker spp./buffalo spp. model. Sampling effort differed among years, decreasing by ~39% between 2002 and 2003; however, total CPUE decreased by only ~6%. Sampling effort decreased by ~11% between 2003 and 2004, but total CPUE decreased by ~93%.

Larval fish abundance and water temperature between macrohabitats

Larval fish assemblage and carpsucker spp./buffalo spp. CPUE were highest within wing-dike sandbar ATTZ followed by point-sandbar ATTZ, and lowest within the main channel during 2002 (Table 1). Silver/bighead carp were most abundant in the main

channel, followed by wing-dike, and then point sandbar ATTZ. Silver/speckled chubs and sturgeon/sicklefin chubs had to be combined to have a sufficient sample size for comparison between sandbar and main-channel macrohaitats. Both taxa were least abundant in the main channel, with silver/speckled chubs most abundant within wing-dike sandbar ATTZ and sturgeon/sicklefin chubs most abundant within point sandbar ATTZ.

There was no significant statistical difference in CPUE among macrohabitats (main channel, point, or wing-dike sandbars) for the larval fish assemblage (f=2.6, df=2, p=0.079) or silver/bighead carps (f=2.2, df=2 , p=0.117);(Table 5). Carpsucker spp./buffalo spp. did differ significantly among macrohabitats (f=3.89, df=2, p=0.023) as did *Macrhybopsis* spp. (f=9.25, df=2, p=0.0002). Pairwise comparisons using LS means showed Carpsucker spp./buffalo spp. had significantly higher CPUE within point-sandbar ATTZ than main channel habitat (f=2.56, df=1, p=0.03), though differences between wing-dike and point sandbars and wing-dike and main channel were not significant. *Macrhybopsis* spp. had significantly lower mean CPUE within the main channel than at wing-dikes sandbars (f=4.22, df=1, p=0.0001); differences in CPUE were not significant between point and wing-dike sandbars or point and main channel (Table 5). Water temperature helped to explain a significant portion of the variation in assemblage CPUE among macrohabitats, but did not help to explain a significant portion of the variation in CPUE within the three selected taxa (Table 5). Mean water temperatures (mean of all daily measurements) recorded at point sandbars during the 2002 study period were approximately 0.4 ˚C greater than at wing-dike sandbars, and approximately 1.4 ˚C greater than mean main-channel temperatures (Figure 5).

Abiotic conditions within sandbar ATTZ

Comparison of abiotic factors among sandbar macro- and meso-habitats showed shoreline slope differed significantly at the macro- ($f = 24.74$, df=1, $p<0.0001$) and meso-habitat ($f=4.81$, df=6, $p<0.0001$) scales. Mean wing-dike shoreline slope was 16.0 º, whereas mean point sandbar shoreline slope was 6.6 º (Table 6). The point sandbar head (HD) mesohabitat had the lowest slope (3.3 º), whereas the wing-dike upstream primary channel (DP) mesohabitat had the highest slope (17.6 º; Figure 6A). Shoreline sinuosity (Figure 6B) and water temperature (Figure 6C) did not differ significantly at macro- or mesohabitat levels. The area sampled (sandbar ATTZ riverward of the 10-cm depth line) was significantly deeper within wing-dike macro- ($f=21.93$, df=1, $p<0.0001$) and mesohabitats ($f=5.21$, df=1, $p<0.0001$) than at point sandbar macro- or mesohabitats. Mean water depth of samples within wing-dike sandbar macrohabitats was 36.4 cm versus 23.9 cm within point sandbar macrohabitats. The downstream primary channel (DP) mesohabitat had the greatest depth within point sandbars (30.4 cm) while the head (HD) had the lowest (19.1 cm). The tail (TL) mesohabitat was the deepest within wing-dike sandbars (39.7 cm) while head was the shallowest (33.1 cm) (Figure 6D; Table 6).

Substrate particle size differed significantly between macrohabitats ($f=106.5$, df=1, $p<0.0001$), but not among mesohabitats (Figure 6E). Mean point sandbar substrate particle size was 0.48 mm (medium to coarse sand) and mean wing-dike sandbar substrate particle size was 0.08 mm (very fine sand; Wentworth 1922).

Current velocity differed significantly at the macrohabitat level ($f=16.92$, df=1, $p<0.0001$), but not at the mesohabitat level between sandbar types. Mean current velocity was 64.6 cm/s within point sandbar macrohabitats and 32.3 cm/s within wing-

dike sandbar macrohabitats. Highest mean current velocity was within the point bar DP (85.4 cm/s) mesohabitat and lowest was within wing-dike sandbar US (17.5 cm/s) (Figure 6F; Table 6). None of the geomorphic or local-environmental factors differed significantly between years within sandbar macro- or mesohabitats.

Abiotic factors and larval fish abundance

Detrended correspondence analysis (DCA) of frequency of occurrence of larval taxa by habitat showed a separation of sandbar mesohabitats along the first axis and sandbar macrohabitats along the second axis (Figure 7). There was limited separation of larval fish taxa along either axis. Freshwater drum separated most strongly along Axis 1 grouping more closely with point sandbar head regions and point and wing-dike sandbar tail regions. The remaining taxa were clustered near the origin (meaning there was not a strong pattern in the frequency of use of these species among macro- or mesohabitats). Taxa separation within the DCA was about 1.5 standard deviations (SD) indicating species response to environmental gradients were short and linear and therefore redundancy analysis (RDA) was the appropriate direct gradient analysis to compare individual geomorphic, local-environmental, and hydrologic factors ability to account for variance in larval fish CPUE.

Redundancy analyses were conducted using 2002 and 2003 $\log_{10}$ transformed CPUE data across sandbar macro- and mesohabitats for the entire sample season and for the stable flow period The global model (including all geomorphic, local-environmental, and hydrologic factors) explained 13.2% of the variance in total larval fish CPUE between sandbar macro- and mesohabitats for the variable flow period (Table 8). The

amount of variance in larval CPUE explained by the global model increased to 25.1% for the stable flow period. The global model accounted for a significant portion of the variance in larval CPUE among mesohabitats for both time periods (p<0.0020 for all of 2002, and p<0.0001 for stable flow period), however a large portion of the variance was unaccounted for by our global model (Table 8). The global model accounted for 29.9% of the variance for the entire 2003 sample season and 33.2 for the stable flow period. Global models contained the same geomorphic, local-environmental, and hydrologic factors in both years, but the 2003 analysis was conducted using larvae collected from approximately $1/10^{th}$ the volume of water sampled and 7 of the 13 taxa from the 2002 data set.

The partial RDA analyses of the entire 2002 sampling season showed local-environmental factors explained a greater proportion of the variance (8.9%, p<0.0001) than hydrologic (2.9%, p=0.0025) or geomorphic factors (2.1%, p=0.0471; Table 7). Current velocity explained the greatest proportion of variance of all individual factors (6.9%, p=0.001), and was the only local-environmental factor that accounted for a significant portion of the total variance explained by the global model for the entire sample season. The change in discharge on a given day from the mean of the discharges for the four previous days (4-d factor) explained the greatest proportion of total variance of the hydrologic factors, and the second greatest of all individual factors (2.1%, p=0.002) during 2002. The 2-d factor was also explained a significant portion of the variance (1.1%, p=0.002), but the 2-d and 4-d factors were highly correlated due to the nature of their calculation, meaning they accounted for much of the same variance. The 4-d factor explained the greatest proportion of variance in abundance not explained by

the other hydrologic factors (unique variance). For example the 4-d factor accounted for 2.1% of the total variance in larval fish CPUE. It explained 1.3% of the total variance in larval fish CPUE that no other factor included in the analysis accounted for, meaning that the other 0.8% of variance the 4-d factor helped to explain was also accounted for by another factor in the analysis (Table 7). Geomorphic factors explained the smallest proportion of the variance in CPUE (2.1%; Table 7). None of the geomorphic factors accounted for a significant portion of the variance, but sandbar macrohabitat did account for the greatest proportion of variance by geomorphic factors (0.7%, p=0.520).

Comparison of the RDA and partial RDA results between the entire 2002 sample season and the period of stable flow showed that current velocity continued to account for the greatest proportion of variance, but shoreline slope and shoreline sinuosity accounted for more variance than sandbar macrohabitat. The 4-d factor also continued to account for the greatest proportion of variance within the hydrologic factors.

The technique of serially running partial RDA's to compare ability of specific factors to account for variance in CPUE of larval taxa by macro- and mesohabitats was repeated for the entire 2003 sample season, and period of stable flow. Local-environmental factors again accounted for the greatest proportion of variance (17.3%) followed by geomorphic factors (9.3%) and hydrologic factors (3.3%) (Table 7). Current velocity again accounted for the greatest proportion of variance explained by the global model (10.6%). The 4-d factor accounted for the greatest proportion of variance within the hydrologic factors (2.0%). Shoreline sinuosity accounted for a greater proportion of variance (5.0%) than sandbar macrohabitat (2.2%) within the geomorphic variables. During the 2003 stable flow analysis sandbar mesohabitat explained a greater proportion

of variance (5.9%) than shoreline sinuosity (4.8%). During both periods sandbar mesohabitat accounted for a greater proportion of unique variance (variance not accounted for by the inclusion of all other variables into the model) than shoreline sinuosity.

Biplots were created subsequent to the RDA analyses illustrating the association between larval fishes collected in sandbar ATTZ during 2002 (Figure 8A) and 2003 (Figure 9A) and abiotic factors (i.e., geomorphic, local-environmental and hydrologic). Biplots project larval fish CPUE and abiotic factors along arrows with axes representing gradients in both taxa and abiotic factors. The angle between arrows in biplots indicates the correlation sign between taxa or abiotic factor. Angles <90 º have a positive correlation, angles >90 º have a negative correlation, and angles near 90 º have no correlation. Arrow length is a measure of the amount of variance of larval fish abundance an abiotic factor accounts for (longer arrows explain a greater proportion of variance than shorter arrows) or taxa separation (taxa with longer arrows separate to a greater degree than taxa with short arrows).

Current velocity had the longest arrows in 2002 and 2003, meaning it accounted for the greatest proportion of variance in larval fish CPUE. The 2-d and 1-d factors were highly correlated with the 4-d factor, and thus, point in nearly the same direction. Cyprinid group A and B, and emerald shiners grouped near one another in one cluster, and silver/bighead carp and grass carp grouped in another (Figure 8A). The 2003 biplot showed cyprinid groups A and B forming one group and silver/bighead carp, gizzard shad and emerald shiners forming a second group (Figure 9A).

The specific effects of a single abiotic factor on CPUE of larval fishes are best interpreted using t-plots, that use Van Dobben circles to illustrate the amount of variance accounted for by a single abiotic factor and its association with larval fish taxa (Figures 8B-D, and 9B-D). The size of the circle is related to the amount of variance the abiotic factor accounts for; factors with larger circles account for more variance than factors with small circles. Taxa associated with low values of an abiotic factor point in the direction of the clear circle; those associated with higher values point in the direction of the shaded circle in Figures 8B, C and 9 B, C. Taxa with arrowheads enclosed within Van Dobben circle are those that show a significant relationship with the abiotic factor based on multiple regression. The macrohabitat factor is dichotomous with wing-dike sandbars represented by the shaded circle, and point sandbars represented by the clear circle in Figures 8D and 9D.

Current velocity (CV) explained the greatest proportion of variance in 2002 and 2003. *Cyprinidae* spp., cyprinid A and B, carpsucker spp./buffalo spp., emerald shiners, sunfish, and total larval CPUE were significantly related to lower values of current velocity in 2002 (Figure 9A). Only total CPUE was significantly related to lower current velocity in 2003. Silver/bighead carp were at a nearly right angle to the current velocity circles during 2002 and 2003, indicating current velocity accounted for little or no variance in their CPUE. Freshwater drum were also at a right angle to CV in 2002, but were not collected in sufficient numbers for inclusion in the 2003 analysis. Grass carp were the only taxa that showed an association with higher current velocities in 2002.

The 4-d factor (difference in discharge between day x and the mean of the four previous days) accounted for the greatest amount of variance within the hydrologic

factors during 2002 and 2003. Silver/speckled chubs, Cyprinidae, goldeye, freshwater drum, silver/bighead carp, and grass carp were associated with decreasing values in 2002, meaning discharge was falling compared to the four day mean (Figure 8C). Cyprinid group A and emerald shiners were associated with increasing 4-d values. The relationship between 4-d and silver/bighead carp, grass carp, goldeye, cyprinid group A, and emerald shiners was significant during 2002. Carpsuckers spp./buffalo spp. were associated with increasing 4-d values in 2003 (Figure 9C). Gizzard shad and silver/bighead carp were significantly related to decreasing discharge in 2003. Emerald shiner and silver/speckled chubs were associated with decreasing discharge; however, this association was non-significant (Figure 9C).

Macrohabitat explained the largest amount of variance of the geomorphic factors, and the third greatest amount of variance of all factors in 2002, although it explained less in 2003. The relationship between larval taxa and macrohabitat was nearly identical to the 4-d variable in 2002 (Figures 8C and D) and very similar in 2003 (Figures 9C and D). There was a significant relationship between silver/bighead carp and grass carp with wing-dike sandbars in 2002 (Figure 8D), however, that relationship reversed for silver/bighead carp in 2003 (Figure 9D). Freshwater drum and goldeye were associated with wing-dike sandbars in 2002, but neither taxa were included in the 2003 analysis. Carpsucker spp./buffalo spp. showed little association to sandbar macrohabitat in 2002, but was associated to wing-dike sandbars during 2003 (Figure 9D).

The submerged ATTZ sampled at point sandbars differed in general from wing-dike sandbars by being shallower with more gentle slopes, exhibited higher water velocities, and had coarser substrate. The submerged ATTZ sampled at wing-dike sandbars was

generally more homogeneous than point sandbars. The distribution of larval fishes was more homogeneous within wing-dike sandbars than point sandbars (Table 3). The greatest number of taxa was collected within the tail (TL) mesohabitat of point bars during 2002 and 2003.

Discussion

Fish populations have been dramatically altered through regulation of rivers worldwide (Galat and Zweimüller 2001; Aarts et al. 2004). An important first step in rehabilitation of regulated rivers and their fisheries is to understand how variability within the river affects critical periods of a fish's life cycle, and what factors influence fish habitat use. Our research showed that discharge and water temperature dynamics were significantly associated with patterns of larval fish CPUE among years in the lower Missouri River, and that larval fishes were significantly more abundant in sandbar macrohabitats than in surface waters of the main channel. Our research also showed that larval fish habitat use within the upper 30 cm of the water column within the sandbar ATTZ (between the waters edge and a depth of 1 m) is most strongly influenced by the local-environmental factor current velocity, followed by the hydrologic factor change in flow from the four day mean, and finally the geomorphic factor macrohabitat.

The 2004 Missouri River hydrograph was more variable (seven changes in discharge of ≥25% in a 24-hour period) during the study period than 2002 (five changes) or 2003 (three changes). The water temperature profile also differed in 2004 from 2002 and 2003 by reaching 15 ˚C (the threshold at which many larval Missouri River fishes are expected to be present (Galat et al. 2004b)), at least two weeks earlier (Figure 4). During 2004 the

water temperature in the main channel reached 15 ˚C prior to April 01. Main channel temperatures didn't reach that temperature until approximately May 01 in 2002 or 2003. The 2002 and 2003 dates match those reported by Galat et al. (2004b) for 1996 and 1997. Fewer taxa were collected during 2004 across main-channel and sandbar macrohabitats. Taxa appeared 24 days later on average, and the duration they were present was nearly three weeks shorter in 2004 than 2002. Total volume of water sampled did differ between years (Table 1) due to accrual of small differences in sample volume over long periods of time, but differences in catch-per-unit-effort (CPUE) did not follow differences in volume sampled, and the scale of the difference in abundance was an order of magnitude greater than the difference in volume sampled.

Our analysis of larval fish habitat use between sandbar and main-channel macrohabitats illustrates the importance of shallow-water ATTZ as nursery habitat for some larval fishes. Many research projects have illustrated the importance of nursery habitat for larval fishes, or the importance of the environmental conditions found within this habitat (see Table 1, Chapter 1). Most research projects, including this one, use larval CPUE as an indicator of the "importance" of a habitat type for larval fishes. However, Doisy et al. (in review) reports daily growth increments for gizzard shad *Dorosoma cepedianum* larvae were higher in the sandbar ATTZ than the main channel of the lower Missouri River. Instead of assuming higher CPUE was associated with better growth conditions, Doisy et al. (in review) was able to show that larvae within sandbar ATTZ grew more rapidly. This means they would likely progress through the larval bottleneck more rapidly and be subject to the high mortality rates of the larval period for

a shorter period of time. This research supports our findings and illustrating the physiological response associated with the increased CPUE.

Relations between larval fishes and environmental conditions within the sandbar ATTZ are complex. Current velocity, change in discharge from previous four day mean, and sandbar macrohabitat each contributed to explaining differences in larval fish CPUE, and each represents a different class of abiotic variables: local-environmental, hydrologic, and geomorphic, respectively. That each class of variables accounted for significant portions of differences in larval fish CPUE, points to potential shortcomings in definitions of nursery habitat that address only one class of variables (Sheaffer and Nickum 1986; Scott and Nielsen 1989; Millard 1993; Peterson and VanderKooy 1995; Rosenberger and Angermeier 2003). The relationship of larval fish composition and abundance with their environment is clearly not one-dimensional. Each taxa included in our analyses exhibited unique associations with abiotic factors. The complex nature of the relationship between an individual taxon and the environment, as well as differences among taxa, should be considered in defining nursery habitat.

The amount of variance in larval fish CPUE within sandbar ATTZ remaining unexplained by the abiotic factors included in our analyses was large. Our global model, including all geomorphic, local-environmental, and hydrologic factors, accounted for ~13 % of the total variance in larval fish CPUE in 2002 and ~30 % in 2003. Limiting the analysis to a period of stable flow nearly doubled the variance accounted for by the global model in 2002 and slightly increased it in 2003. The ability of the global model to account for a greater portion of the variance in larval CPUE during a period of stable flow in both years supports the hypothesis that larval fish communities become more

structured during periods of stable flow, as noted by Arrington (2002) in tropical rivers. By "structured" we mean that during periods of rapid change in discharge the location of nursery habitat is moving within the environment, but during periods of stable flow nursery habitat is fixed within the environment. Larval fishes are better able to locate and remain within nursery habitat when it is fixed as opposed to moving. Also, during periods of variable flow larvae may be flushed from nursery habitat into the main channel. This may mean that projects correlating larval fish CPUE and habitat use may find differing results within the same system if conducted during periods of stable or changing discharge.

The difference in variance explained by our global models between the two years of study may be related to the decreased number of taxa included in the 2003 analysis. We were able to include 13 taxa in our 2002 redundancy analysis, but due to the decreased sample effort during 2003 (about 10% of 2002) only seven taxa met the collection requirement to be included in the analysis. There are a number of potential reasons why our global models did not explain a greater percent of the variance in larval fish abundance. Models attempting to explain differences in abundance at the assemblage level would be expected to perform poorly if individual larval taxa have unique habitat use strategies operating at the macro- or mesohabitat scales. Research comparing habitat use by different species of larval fishes within the same river has shown a segregation along environmental gradients (Scott and Nielsen 1989; Kurmayer et al. 1996; Wintersberger 1996; Gadomski and Barfoot 1998; Jurajda 1999), and research on individual species has shown segregation among habitats by larval developmental stage (Copp 1990; Galat et al. 2004b). The inter- and intra-specific differences in habitat use

may have led to decreased model efficiency. Also, if habitat selection is occurring at a finer spatial scale (e.g., microhabitat) then models functioning at a coarser scale (macro- or meso-habitat) may not be able to detect it.

Research defining larval fish habitat use at multiple scales should optimally be integrated to create a more complete understanding of what constitutes effective nursery habitat. In a concurrent study, we evaluated microhabitat selection at the assemblage level and for carpsucker spp./buffalo spp., silver/bighead carps, and chub spp. showing each did exhibit unique habitat selection strategies at the microhabitat scale in the lower Missouri River (Reeves 2006). Specifically we showed the larval fish assemblage and carpsucker spp./buffalo spp. selected areas with current velocities ≤5 cm/s and water depth ≤10 cm while chub spp. selected areas with water depth from 30 to 50 cm that were ≥2 m from the waters edge (Reeves 2006). Integrating these microhabitat results with our findings here at macro- and meso-habitat scales show that primary larval fish nursery habitat is not all areas with water depth <1.0 m composing the ATTZ around sandbars in the lower Missouri River. Rather, larval fishes are using habitat based on the environmental conditions present within that habitat. Thus, if providing nursery habitat is a management priority then strategies that emphasize providing the greatest amount of this shallow (≤10 cm), low-current velocity (≤5 cm/s) area either through habitat rehabilitation, flow regulation, or a combination thereof will likely achieve the greatest success.

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Table 1. Mean catch-per-unit-effort (CPUE) for larval fishes collected from 2002 through 2004 from point (PB) and wing-dike (WD) sandbars and main channel (MC) macrohabitats of the lower Missouri River. Means represent number of larval fishes collected /100 m^3 in each habitat between the dates of first and last collection for each taxa. Fishes were identified to the lowest reliable level; in some cases family, genus, species, or group of species. Habitat-use guild (s = fluvial specialist, d = fluvial dependant, and g = macrohabitat generalist) from Galat et al. (2005). Genus CPUE includes all species listed beneath it. CPUE is reported to nearest 0.1 larvae/100 m^3. Taxa with an asterisk were present, but densities were <0.10 larvae/100 m^3. Code is the acronym used for each taxon in figures.

			CPUE (number larvae/100m^3)						
			2002			**2003**			**2004**
Taxa	**Code**	**Guild**	**PB**	**WD**	**MC**	**PB**	**WD**	**CH**	**MC**
Scaphirhynchus spp.	SCP		0.0	0.2	0.0*	0.0	0.0	0.0	0.0
S. albus		s							
S. platorynchus		s							
Lepisosteus osseus	LNG	d	0.1	0.2	0.2	0.0	0.0	1.4	0.0
Lepisosteus platostomus	SNG	d	0.3	0.2	0.1	0.0	0.0	0.0	0.0
Clupeidae spp.	CLP		0.9	1.2	0.2	0.0	0.0	0.0	0.0
Alosa spp.	ALS		0.7	0.7	0.3	0.0	0.0	0.0	0.0
A. alabamae		d							
A. chrysochloris		d							
Dorosoma cepedianum [1,2]	GZS	g	3.6	7.0	3.6	7.7	0.0	4.8	1.7
Dorosoma petenense	TFS	g	0.4	0.1	0.3	0.0	0.0	0.0	0

Table 1. Continued.

			CPUE (number larvae/100m^3)						
			2002			2003			2004
Taxa	**Code**	**Guild**	**PB**	**WD**	**CH**	**PB**	**WD**	**CH**	**CH**
Hiodon alosoides	GLD	d	2.4	8.5	1.9	0.6	0.0	12.7	0.7
Hiodon tergisus	MUN	d	0.0	1.1	0.0*	0.0	0.0	2.0	0.0
Ctenopharyngodon idella [1]	GRC	d	2.5	4.8	5.8	0.0	0.0	34.0	5.9
Cyprinus carpio	CCP	g	0.2	1.4	1.9	0.0	3.2	0.5	0.2
Cyprinidae spp. [1]	CYP		5.2	19.4	23.0	0.0	13.5	3.4	0.1
Cyprinid A [1,2]	CYA		217.8	107.2	1.9	11.1	43.8	2.5	0.4
Hybognathus argyritis		d							
H. hankinsoni		g							
H. placitus		d							
Notemigonus crysoleucas		g							
Cyprinid B [1,2]	CYB		16.3	14.7	16.2	40.8	231.4	7.0	0.3
Cyprinella spiloptera		s							
Lythrurus umbratilis		s							
Notropis blennius		s							
N. buchanani		s							
N. shumardi		s							
N. stramineus		s							
N. wickliffi		s							
Phenacobius mirabilis		s							

Table 1. Continued.

			CPUE (number larvae/100m^3)						
			2002			2003			2004
Taxa	**Code**	**Guild**	**PB**	**WD**	**CH**	**PB**	**WD**	**CH**	**CH**
Hypophthalmichthys spp. [1,2]	HYP		5.5	62.0	156.0	4.2	0.0	264.6	9.9
H. molitrix		d							
H. nobilis		d							
Macrhybopsis A [1,2]	MAA		8.8	28.2	0.8	2.3	5.7	0.4	0.1
M. aestivalis		s							
M. storeriana		g							
Macrhybopsis B [1]	MAB		16.3	4.9	0.4	0.3	0.7	0.1	0.3
M. gelida		s							
M. meeki		s							
Notropis atherinoides [1,2]	EMS	g	52.4	63.5	63.9	53.1	16.2	2.7	0.4
Pimephales notatus	BNM	g	0.0	0.1	0.0	0.6	3.4	0.0*	0.0*
Semotilus atromaculatus	CRK	g	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Carpiodes/Ictiobus spp. [1,2]	CI		71.3	109.5	17.9	8.4	49.2	7.1	3.4
C. carpio		g							
C. cyprinus		g							
C. velifer		s							
I. bubalus		g							
I. cyprinellus		g							
I. niger		g							
Catostomidae spp.	CAT		0.2	0.3	0.1	0.0	0.0	0.0*	0.0

Table 1. Continued.

			CPUE (number larvae/100m^3)						
			2002			2003			2004
Taxa	**Code**	**Guild**	**PB**	**WD**	**CH**	**PB**	**WD**	**CH**	**CH**
Catostomus commersoni	WHT	d	4.7	1.2	4.2	0.0	0.0	0.5	1.0
Cycleptus elongatus	BLU	s	0.6	1.0	0.6	0.0	0.0	0.5	0.4
Gambusia affinis	MOS	g	0.1	0.1	0.0*	0.1	0.3	0.0*	0.0
Lepomis spp. [1]	LEP		1.5	1.7	1.2	0.3	0.3	0.1	0.2
L. cyanellus		g							
L. humilis		g							
L. macrochirus		g							
L. megalotis		g							
Micropterus salmoides	LMB	g	0.1	0.0	0.0*	0.0	0.0	0.1	0.0
Pomoxis spp.	POM		0.2	0.0	0.1	0.0	0.0	0.0*	0.0
P. annularis		g							
P. nigromaculatus		g							
Sander spp.	SND		1.3	1.8	1.3	0.1	1.1	0.5	1.0
S. canadense		g							
S. vitreum		g							
Aplodinotus grunniens [1]	FWD	g	0.4	0.5	4.9	0.0	0.0	3.8	1.1
Unknown	UNK		4.2	8.8	4.4	0.1	0.0	0.9	0.5
Total number taxa			26	27	23	13	12	24	17
Total CPUE by location [1,2]			369.5	388.8	291.9	124.5	367.7	275.1	20.3
Total volume sampled by location m^3			5890	3010	15239	800	190	9233	8305

[1] Taxa present in ≥5.0% of samples in 2002; used for Redundancy Analyses
[1, 2] Taxa present in ≥5.0% of samples in 2002 and 2003; used for Redundancy Analyses

Table 2. Dates, fish mean total length (TL, mm), water temperature (T, ºC), and discharge trend when larval fish taxa were first and last collected in the main-channel and sandbar aquatic-terrestrial transition zone (ATTZ) during 2002, and the main channel only during 2003 and 2004. Four day trends in discharge (Q), where - indicates decreasing discharge, + indicates increasing discharge, and 0 indicates discharge changed by less than 5%. NA under first occurrence indicates larvae were not collected; NA under last occurrence indicates larvae were collected only on one date.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Scaphirhynchus spp.	2002 PC	27-May	16.1	18.3	+	3-Jul	16.6	29.0	+
	2002 SB	21-Jun	41.0	26.2	-	NA			
	2003 PC	NA				NA			
	2004 PC	NA				NA			
Lepisosteus osseus	2002 PC	10-Jun	34.2	26.0	-	26-Jun	16.2	29.2	-
	2002 SB	17-Jun	27.8	25.2	-	26-Jun	27.8	30.8	-
	2003 PC	18-Jun	36.0	25.7	-	NA			
	2004 PC	NA				NA			
Lepisosteus platostomus	2002 PC	10-Jun	21.2	26.0	-	24-Jun	24.3	27.5	-
	2002 SB	11-Jun	24.4	26.4	-	15-Jul	40.5	29.2	0
	2003 PC	NA				NA			
	2004 PC	NA				NA			
Clupeidae spp.	2002 PC	21-May	3.0	17.8	-	7-Aug	3.3	29.4	-
	2002 SB	5-Jun	5.2	25.4	-	26-Jun	7.5	31.0	-
	2003 PC	NA				NA			
	2004 PC	NA				NA			

Table 2. Continued.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Alosa spp.	2002 PC	29-Apr	8.5	13.7	+	15-Jul	15.1	28.9	0
	2002 SB	21-May	7.1	18.4	-	22-Jul	6.3	30.8	-
	2003 PC	NA				NA			
	2004 PC	NA				NA			
Dorosoma cepedianum	2002 PC	1-May	12.4	15.1	+	16-Jul	18.2	28.2	0
	2002 SB	1-May	11.6	16.1	+	28-Aug	14.1	26.8	+
	2003 PC	9-May	6.7	18.7	+	29-Jul	16.8	30.0	-
	2004 PC	10-Jun	11.8	24.0	+	19-Jul	7.0	28.0	-
Dorosoma petenense	2002 PC	10-Jun	17.2	26.0	-	15-Jul	14.5	28.5	0
	2002 SB	10-Jun	18.6	26.1	-	16-Jul	17.5	28.8	0
	2003 PC	NA				NA			
	2004 PC	NA				NA			
Hiodon alosoides	2002 PC	24-May	11.6	19.1	-	28-Jun	14.4	28.8	-
	2002 SB	3-May	12.5	18.6	-	29-Jul	18.2	30.7	0
	2003 PC	9-May	5.9	18.7	+	3-Jul	11.8	29.0	+
	2004 PC	2-May	12.4	17.5	-	29-Jun	10.6	24.6	+
Hiodon tergisus	2002 PC	29-Apr	11.5	13.7	+	3-Mar	10.9	16.2	-
	2002 SB	17-Jun	11.8	26.4	-	27-Jun	15.6	29.4	-
	2003 PC	19-Jun	14.5	26.5	-	1-Jul	20.5	27.5	+
	2004 PC	NA				NA			
Ctenopharyngodon idella	2002 PC	20-May	5.7	19.6	-	30-Aug	7.3	26.1	0
	2002 SB	1-May	8.9	16.1	+	30-Aug	7.3	26.5	0
	2003 PC	20-May	6.5	19.6	-	16-Sep	7.2	24.3	+
	2004 PC	15-May	6.6	21.7	-	2-Sep	6.9	24.6	+

Table 2. Continued.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Cyprinus carpio	2002 PC	20-May	8.0	17.5	-	23-Jul	3.7	30.5	0
	2002 SB	21-May	7.5	18.1	-	30-Aug	9.3	26.5	0
	2003 PC	13-May	6.6	18.0	0	27-Aug	8.9	31.0	+
	2004 PC	20-May	8.1	22.1	-	2-Sep	5.7	24.6	+
Cyprinidae spp.	2002 PC	29-Apr	7.5	13.7	+	13-Sep	4.9	25.5	0
	2002 SB	24-Apr	6.5	13.5	+	25-Sep	10.6	21.1	-
	2003 PC	13-May	3.7	17.9	-	8-Jun	4.5	29.9	0
	2004 PC	22-Jun	3.8	24.5	-	19-Jul	6.8	28.0	-
Cyprinid A	2002 PC	28-May	3.5	19.2	+	30-Aug	5.2	26.1	0
	2002 SB	21-May	5.3	18.2	-	23-Sep	11.3	21.7	0
	2003 PC	29-Apr	9.3	17.7	+	3-Sep	5.5	25.7	+
	2004 PC	10-Jun	5.4	24.0	+	28-Jun	4.6	24.2	-
Cyrpind B	2002 PC	1-May	8.7	15.1	+	6-Sep	9.8	26.2	0
	2002 SB	24-Apr	6.8	13.5	+	29-Sep	15.9	22.0	0
	2003 PC	13-May	3.3	18.0	0	3-Sep	6.2	25.7	+
	2004 PC	16-Jun	5.1	25.0	+	5-Aug	4.2	26.3	0
Hypophthalmichthys spp.	2002 PC	29-Apr	7.2	13.7	+	7-Sep	10.3	27.7	0
	2002 SB	1-May	8.7	16.1	+	29-Sep	7.7	22.1	0
	2003 PC	27-May	7.7	21.8	-	16-Sep	8.3	24.3	+
	2004 PC	20-May	8.3	22.1	-	2-Sep	7.6	24.6	+
Macrhybopsis A	2002 PC	10-Jun	6.7	26.0	-	7-Sep	5.3	27.7	0
	2002 SB	3-Jun	6.0	26.8	-	6-Sep	6.8	26.2	0
	2003 PC	28-May	7.4	22.6	-	14-Aug	19.1	29.5	0
	2004 PC	12-Aug	5.2	25.7	0	NA			

Table 2. Continued.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Macrhybopsis B	2002 PC	8-Jun	5.9	25.6	-	6-Sep	5.7	26.9	0
	2002 SB	1-May	7.2	16.1	-	22-Aug	14.7	27.5	+
	2003 PC	9-Jun	5.9	22.3	0	3-Sep	6.8	23.0	+
	2004 PC	19-Jul	6.4	28.0	-	12-Aug	6.4	25.7	0
Notropis atherinoides	2002 PC	27-May	8.7	18.3	+	21-Aug	8.4	27.2	+
	2002 SB	1-May	7.1	16.1	-	25-Sep	8.2	21.2	-
	2003 PC	28-May	5.0	18.2	-	3-Sep	4.4	23.0	+
	2004 PC	NA				NA			
Pimephales notatus	2002 PC	NA				NA			
	2002 SB	NA				NA			
	2003 PC	9-Jun	7.0	23.7	0	14-Aug	4.2	29.5	0
	2004 PC	20-May	5.8	22.1	-	6-Aug	12.6	25.7	0
Semotilus atromaculatus	2002 PC	29-Apr	9.8	13.7	+	NA			
	2002 SB	NA				NA			
	2003 PC	NA				NA			
	2004 PC	NA				NA			
Carpiodes spp./*Ictiobus* spp.	2002 PC	29-Apr	9.5	13.7	+	15-Jul	16.7	28.9	0
	2002 SB	24-Apr	7.1	13.5	+	29-Sep	7.7	22.1	0
	2003 PC	29-Apr	7.2	17.7	+	16-Sep	11.9	24.3	+
	2004 PC	25-Apr	6.1	17.3	+	2-Sep	4.0	24.6	+
Catostomidae spp.	2002 PC	20-May	6.8	17.5	-	12-Aug	3.1	28.6	+
	2002 SB	3-Jun	5.0	29.9	-	23-Jul	9.9	29.4	0
	2003 PC	26-Apr	6.1	17.6	+	NA			
	2004 PC	NA				NA			

Table 2. Continued.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Catostomus commersoni	2002 PC	29-Apr	10.3	13.7	+	20-May	10.5	19.6	-
	2002 SB	24-Apr	8.2	13.5	+	17-Jul	19.7	29.5	-
	2003 PC	26-Apr	9.1	17.6	+	18-Jun	22.9	25.7	-
	2004 PC	25.Apr	11.2	17.3	+	15-May	12.4	21.7	-
Cycleptus elongatus	2002 PC	29-Apr	10.9	13.7	+	3-May		16.2	-
	2002 SB	1-May	11.5	16.1	+	3-May		16.1	-
	2003 PC	29-Apr	9.3	17.7	+	NA			
	2004 PC	2-May	12.4	17.5	-	NA			
Gambusia affinis	2002 PC	13-Jun	9.7	24.8	+	NA			
	2002 SB	28-Aug	9.2	28.6	+	30-Aug	8.5	26.7	0
	2003 PC	18-Jun	10.8	25.7	-	NA			
	2004 PC	NA				NA			
Lepomis spp.	2002 PC	29-Apr	5.4	13.7	+	21-Aug	11.0	27.2	+
	2002 SB	1-May	6.5	16.1	+	30-Aug	11.1	26.6	0
	2003 PC	29-Apr	7.8	17.7	+	3-Sep	13.7	23.0	+
	2004 PC	28-Jun	14.8	24.1	+	20-Jul	6.5	28.4	-
Micropterus salmoides	2002 PC	29-Apr	7.2	13.7	+	16-Jul	8.2	28.2	0
	2002 SB	24-Jun	6.9	27.8	-	14-Aug	6.8	27.3	0
	2003 PC	14-May	10.8	18.2	-	NA			
	2004 PC	NA				NA			
Pomoxis spp.	2002 PC	27-May	5.1	18.3	+	14-Jun	15.2	24.9	+
	2002 SB	16-Jul	13.9	29.1	0	28-Aug	6.9	26.8	+
	2003 PC	29-May	9.3	29.3	-	NA			
	2004 PC	NA				NA			

Table 2. Continued.

		First collection				Last collection			
Taxa	Year	Date	TL	T	Q	Date	TL	T	Q
Sander spp.	2002 PC	29-Apr	6.3	13.7	+	13-Jun	6.8	24.8	+
	2002 SB	24-Apr	7.5	13.5	+	5-Jun	13.5	25.1	-
	2003 PC	26-Apr	8.5	17.6	+	18-Jun	29.9	25.7	-
	2004 PC	NA				NA			
Aplodinotus grunniens	2002 PC	27-May	6.4	18.3	+	15-Jul	4.1	27.3	+
	2002 SB	3-Jun	4.0	26.7	-	26-Aug	4.4	26.6	0
	2003 PC	20-May	5.2	20.1	-	3-Sep	6.0	23.0	+
	2004 PC	15-May	4.7	21.7	-	9-Sep	4.9	25.0	-

Table 3. Mean catch-per-unit-effort (CPUE) for larval fishes collected in 2002 and 2003 from point and wing-dike sandbar mesohabitats in the lower Missouri River. CPUE is shown to nearest 0.1 larvae/100m^3. Taxa codes are shown in Table 1.

	2002 CPUE (number larvae/100m^3)											
	Point						Wing-Dike					
Taxa	**HD**	**UP**	**US**	**DP**	**DS**	**TL**	**HD**	**UP**	**US**	**DP**	**DS**	**TL**
Scaphirhynchus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Lepisosteus osseus	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.8	0.0	0.0	0.0
Lepisosteus platostomus	0.9	0.0	0.0	0.0	0.0	1.1	0.0	0.7	0.0	0.0	0.8	0.0
Clupeidae spp.	0.0	0.0	0.0	3.5	2.0	0.0	1.5	3.4	0.0	1.5	0.0	0.0
Alosa spp.	0.0	0.0	1.6	1.3	0.8	1.0	0.3	2.6	0.0	1.4	0.0	0.0
Dorosoma cepedianum	10.3	1.5	0.7	2.8	0.2	5.1	4.7	13.7	8.2	9.5	3.3	0.6
Dorosoma petenense	0.0	0.3	0.0	0.0	0.0	2.6	0.0	0.4	0.0	0.0	0.0	0.0
Hiodon alosoides	0.3	5.9	2.2	0.0	0.0	5.9	15.8	3.5	21.3	0.9	6.4	4.1
Hiodon tergisus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	3.7	1.9
Ctenopharyngodon idella	4.4	3.5	1.1	0.0	0.0	5.1	5.1	1.3	3.7	3.1	6.5	10.3
Cyprinus carpio	0.0	0.0	0..3	0.1	0.2	0.6	0.5	0.0	1.7	1.1	1.2	1.5
Cyprinidae spp.	1.0	1.4	17.6	2.7	3.6	6.9	18.4	33.8	3.8	5.0	67.2	3.0
Cyprinid A	222.1	99.8	271.7	16.9	267.7	521.3	150.0	147.7	49.1	156.1	45.1	19.4
Cyprinid B	14.2	11.8	51.7	6.1	8.6	15.4	15.2	30.1	12.2	15.3	6.8	11.7
Hypophthalmichthys spp.	11.8	6.2	4.4	0.3	0.7	7.7	35.6	28.6	72.6	34.3	275.1	14.8
Macrhybopsis A	0.5	5.6	23.2	5.4	2.7	17.6	37.7	30.3	33.7	9.5	76.9	2.7
Macrhybopsis B	54.3	16.1	20.1	0.8	0.0	1.9	0.8	11.5	11.0	0.9	4.0	1.0
Notropis atherinoides	49.9	38.8	96.0	19.5	13.8	56.1	130.0	31.4	153.4	32.5	11.7	4.0

Table 3. Continued.

	2002 CPUE (number larvae/100m^3)											
	Point						Wing-Dike					
Taxa	**HD**	**UP**	**US**	**DP**	**DS**	**TL**	**HD**	**UP**	**US**	**DP**	**DS**	**TL**
Pimephales notatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Semotilus atromaculatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carpiodes/Ictiobus spp.	103.5	83.7	75.1	12.3	164.2	59.1	125.5	7.5	563.4	15.7	166.1	13.2
Catostomidae spp.	0.0	0.0	0.3	0.4	0.0	0.5	0.9	0.0	0.0	0.3	0.0	0.4
Catostomus commersoni	0.0	0.0	2.3	1.7	0	10.1	3.4	0.0	0.0	0.0	0.0	2.6
Cycleptus elongatus	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0
Gambusia affinis	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Lepomis spp.	4.8	0.1	0.4	0.8	0.3	2.0	1.2	1.1	4.8	1.8	1.7	0.7
Micropterus salmoides	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Pomoxis spp.	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sander spp.	0.0	0.0	0.9	0.0	0.0	8.0	0.0	0.9	6.3	0.0	1.5	1.8
Aplodinotus grunniens	1.3	0.3	0.4	0.0	0.0	0.3	0.0	0.4	0.8	0.0	0.0	1.8
Unknown	4.4	1.3	5.8	2.8	2.1	7.1	7.9	7.4	4.3	6.2	18.1	7.2
Total number taxa	16	14	18	15	12	22	18	18	19	17	16	18
Total CPUE by location	403	235	506	63.1	411	643	470	295	787	252	613	83.5
Total volume (m^3) sampled by location	955	1118	871	1097	731	1118	607	634	371	568	316	514

Table 3. Continued.

	2003 CPUE (number larvae/100m^3)											
	Point						Wing-Dike					
Taxa	**HD**	**UP**	**US**	**DP**	**DS**	**TL**	**HD**	**UP**	**US**	**DP**	**DS**	**TL**
Scaphirhynchus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lepisosteus osseus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lepisosteus platostomus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clupeidae spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alosa spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dorosoma cepedianum	4.1	15.2	0.0	16.1	3.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Dorosoma petenense	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hiodon alosoides	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hiodon tergisus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ctenopharyngodon idella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprinus carpio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	59.2	0.0
Cyprinidae spp.	0.0	0.0	0.0	0.0	0.0	0.0	59.2	9.2	0.0	0.0	0.0	0.0
Cyprinid A	40.1	2.8	3.8	14.0	1.6	8.8	62.9	53.3	47.5	37.3	78.9	10.7
Cyprinid B	103.5	0.0	146.2	0.0	22.6	6.1	808.5	151.5	295.2	30.8	0.0	31.0
Hypophthalmichthys spp.	3.1	13.6	0.0	0.0	3.1	4.4	0.0	0.0	0.0	0.0	0.0	0.0
Macrhybopsis A	1.9	2.9	0.0	5.9	1.6	0.7	1.7	10.0	31.5	0.0	0.0	0.0
Macrhybopsis B	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	7.0	0.0	0.0	0.0
Notropis atherinoides	25.5	2.3	112.3	1.8	9.1	173.8	7.0	10.2	7.3	46.6	0.0	3.6
Pimephales notatus	0.0	0.0	0.0	1.3	0.0	2.2	12.3	4.3	0.0	0.0	0.0	0.0
Semotilus atromaculatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. Continued.

	2003 CPUE (number larvae/100m^3)											
	Point						Wing-Dike					
Taxa	**HD**	**UP**	**US**	**DP**	**DS**	**TL**	**HD**	**UP**	**US**	**DP**	**DS**	**TL**
Carpiodes/Ictiobus spp.	5.1	6.9	15.9	1.8	18.7	3.1	4.4	54.9	17.5	15.3	0.0	157.5
Catostomidae spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catostomus commersoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cycleptus elongatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gambusia affinis	0.0	0.0	0.0	0.0	0.0	0.6	0.0	1.4	0.0	0.0	0.0	0.0
Lepomis spp.	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	1.4	0.0	0.0
Micropterus salmoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pomoxis spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sander spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aplodinotus grunniens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unknown	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Total number taxa	8	6	4	6	7	11	7	9	6	5	2	4
Total CPUE by location	182.4	34.6	278.1	31.3	58.0	204.9	955.8	296.2	405.9	131.4	138.1	202.9
Total volume (m^3) sampled by location	98	130	120	162	130	162	30	47	7	47	5	39

Table 4. Analysis of covariance results of larval fish catch-per-unit-effort (number larval fishes /1 m^3) among years, accounting for differences in lower Missouri River discharge and main-channel water temperature, for the larval fish assemblage and individual taxa (*Carpiodes* spp./*Ictiobus* spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp.). Between year comparisons were made using least squared means. Larvae were collected within the lower Missouri River main channel between 01 April and 30 September, 2002 – 2004.

	Year		Discharge		Temperature	
	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value
Assemblage	9.99	<0.0001	11.13	0.0011	2.79	0.0969
2002 –vs- 2003		0.7738				
2002 –vs- 2004		<0.0001				
2003 –vs- 2004		0.0014				
Carpiodes spp./*Ictiobus* spp.	9.16	0.0002	11.60	0.0009	4.18	0.0428
2002 –vs- 2003		0.0442				
2002 –vs- 2004		0.0001				
2003 –vs- 2004		0.1239				
Hypophthalmichthys spp.	5.40	0.0055	7.05	0.0088	1.15	0.2861
2002 –vs- 2003		0.9995				
2002 –vs- 2004		0.0090				
2003 –vs- 2004		0.0127				
Macrhybopsis spp.	2.43	0.0913	0.01	0.9177	4.23	0.0416
2002 –vs- 2003		0.1936				
2002 –vs- 2004		0.1264				
2003 –vs- 2004		0.9270				

Table 5. Analysis of covariance results of larval fish catch per unit effort (number larval fishes /1 m^3) among macrohabitats (main channel, point sandbar, and wing-dike sandbar), accounting for water temperature, for the larval fish assemblage and individual taxa (*Carpiodes* spp./*Ictiobus* spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp.). Between habitat comparisons were made using least squared means. Larvae were collected within the lower Missouri River main channel and sandbar macrohabitats between 01 April and 30 September 2002.

	Macrohabitat		Temperature	
	F-value	*p*-value	F-value	*p*-value
Assemblage	2.6	0.0789	6.58	0.0117
CH –vs- WD		0.3128		
CH –vs- PB		0.0865		
PB –vs- WD		0.8271		
Carpiodes spp./*Ictiobus* spp.	3.89	0.0234	3.07	0.0828
CH –vs- WD		0.1424		
CH –vs- PB		0.0318		
PB –vs- WD		0.8388		
Hypophthalmichthys spp.	2.19	0.1165	0.03	0.8593
CH –vs- WD		0.6076		
CH –vs- PB		0.0995		
PB –vs- WD		0.0594		
Macrhybopsis spp.	9.25	0.0002	1.61	0.2072
CH –vs- WD		0.0001		
CH –vs- PB		0.0768		
PB –vs- WD		0.1893		

Table 6. Mean and standard deviation for each sandbar macrohabitat (point and wing-dike) and each mesohabitat HD = head, most upstream point of sandbar; TL = tail, most downstream point of sandbar; UP = upstream primary channel, mesohabitat halfway between sandbar midpoint and HD on primary channel side; DP = downstream primary channel, mesohabitat halfway between midpoint and TL on primary channel side; US = upstream secondary channel, halfway between midpoint and HD on secondary channel side, DS = downstream secondary channel, halfway between midpoint and TL on secondary channel. Abiotic factors CV = current velocity (cm/s), Depth = water depth (cm), Substrate = substrate particle size (mm), Temp. = temperature difference between sandbar meso or macro habitat and primary channel (C˚), Slope = shoreline slope(˚), Sinuosity = shoreline sinuosity (distance of waters edge (m)/straight line distance (m)

	CV		**Depth**		**Substrate**		**Temp.**		**Slope**		**Sinuosity**	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Point bar	64.6	42.3	23.9	7.3	0.48	0.52	0.48	1.13	6.6	5.3	1.1249	0.2095
Head	64.9	44.0	19.1	5.1	0.76	0.90	-0.15	0.72	3.3	3.2	1.2183	0.2212
UP	79.4	43.9	24.8	6.8	0.42	0.29	0.52	0.93	7.2	5.1	1.0795	0.1054
US	36.6	36.2	22.3	6.1	0.46	0.47	0.90	1.53	5.4	4.1	1.1142	0.1816
DP	85.4	38.4	30.4	8.8	0.52	0.50	0.39	0.97	11.8	6.4	1.0506	0.0517
DS	63.6	42.6	20.5	4.0	0.35	0.08	0.68	1.33	4.2	2.2	1.1061	0.1168
Tail	57.9	32.1	26.5	5.3	0.39	0.33	0.51	1.12	7.8	4.1	1.1804	0.3721
Wing-Dike	32.3	29.6	36.4	11.6	0.08	0.20	-0.03	0.59	16.0	8.0	1.0530	0.0877
Head	31.3	22.1	33.1	9.6	0.11	0.37	-0.04	0.58	14.3	6.7	1.1163	0.1739
UP	27.8	23.9	37.9	9.2	0.08	0.14	-0.04	0.61	17.6	7.3	1.0406	0.0425
US	17.5	16.9	36.6	10.1	0.06	0.12	0.09	0.66	15.9	7.2	1.0384	0.0355
DP	33.3	36.8	37.9	11.6	0.07	0.13	0.04	0.57	17.5	6.7	1.0387	0.0253
DS	22.1	23.4	33.2	8.2	0.05	0.11	-0.07	0.56	14.1	6.0	1.0302	0.0187
Tail	61.6	37.2	39.7	17.4	0.12	0.17	-0.16	0.57	16.8	11.0	1.0538	0.0394

Table 7. Redundancy analyses of larval fish abundance within sandbar macrohabitat ATTZ during 2002 and 2003. Analyses were conducted for the entire sampling period each year (variable period) and the period when discharge varied by <5.0% during a 24-hour period (stable period). Results show amount of variance accounted for by the global model (all factors combined) and for each sub-set of factors (i.e., geomorphic, local-environmental, and hydrologic), and for individual factors (e.g., depth). Total = the percent variance in abundance accounted for by a factor or set of factors, and Unique = amount of variance accounted for by a factor or set of factors that is not accounted for by any other factor or set of factors. 1-d = the percent change in daily mean discharge between day x and the previous day, 2-d = the percent change between day x and the mean of the two previous days, 4-d = percent change between day x and the mean of the four previous days. The *p*-value is the significance of the factor or set of factors resulting from a Monte Carlo permutation test.

		2002				2003			
		Entire Season		Stable		Entire Season		Stable	
		Total	Unique	Total	Unique	Total	Unique	Total	Unique
Global		13.2		25.1		29.9		33.2	
	p	0.0020		0.0001		0.1439		0.3042	
Geomorphic		2.1	1.0	3.1	1.0	9.3	8.4	13.4	8.7
	p	0.0471		0.1134		0.1396		0.2425	
Sandbar macrohabitat		0.7	0.4	0.5	0.2	2.2	2.0	2.9	1.0
	p	0.520		0.3732		0.3349		0.3462	
Sandbar mesohabitat		0.1	0.1	0.4	0.3	3.8	4.2	5.9	3.8
	p	0.6420		0.4195		0.1146		0.0893	

Table 7. Continued.

	2002				2003			
	Entire Season		Stable		Entire Season		Stable	
	Total	Unique	Total	Unique	Total	Unique	Total	Unique
Geomorphic (continued)								
Slope	0.5	0.2	1.5	0.2	1.8	1.5	1.7	0.9
p	0.1420		0.0385		0.0398		0.5712	
Sinuosity	0.5	0.1	0.8	0.3	5.0	0.9	4.8	1.2
p	0.1480		0.1483		0.0896		0.1262	
Environmental	8.9	7.9	19.2	16.5	17.3	13.9	17.1	14.5
p	0.0001		0.0001		0.0329		0.1146	
Current velocity	6.9	7.5	13.5	14.8	10.6	7.5	6.6	4.7
p	0.0010		0.0001		0.0025		0.0662	
Water depth	0.4	0.2	1.4	0.2	1.0	4.5	1.3	2.6
p	0.2110		0.0451		0.5669		0.5744	
Temperature	0.1	0.3	0.9	0.2	0.4	0.9	0.6	0.2.4
p	0.8900		0.1493		0.8852		0.8606	
Substrate	0.3	0.6	0.3	1.6	2.3	1.1	2.5	1.0
p	0.2260		0.4892		0..3336		0.4147	
Hydrologic	2.9	3.2	5.7	4.3	3.3	6.1	6.1	7.7
p	0.0025		0.0010		0.7928		0.6309	
1d	0.7	0.9	0.9	0.9	1.1	3.7	0.6	1.5
p	0.066		0.1394		0.6142		0.3097	
2d	1.1	0.7	0.8	1.7	1.2	3.7	1.0	1.6
p	0.0020		0.1463		0.5713		0.7648	
4d	2.1	1.3	1.2	3.1	2.0	2.6	2.8	4.2
p	0.0020		0.0676		0.3731		0.3444	

Figure 1. Lower Missouri River study section between river kilometer 253 and 351 (river mile 157 and 218) traveling upstream from the confluence of the Missouri and Mississippi rivers. Point sandbars sampled are represented by octagons, wing-dike sandbars sampled are represented by triangles, and additional primary-channel sample sites are represented by rectangles.

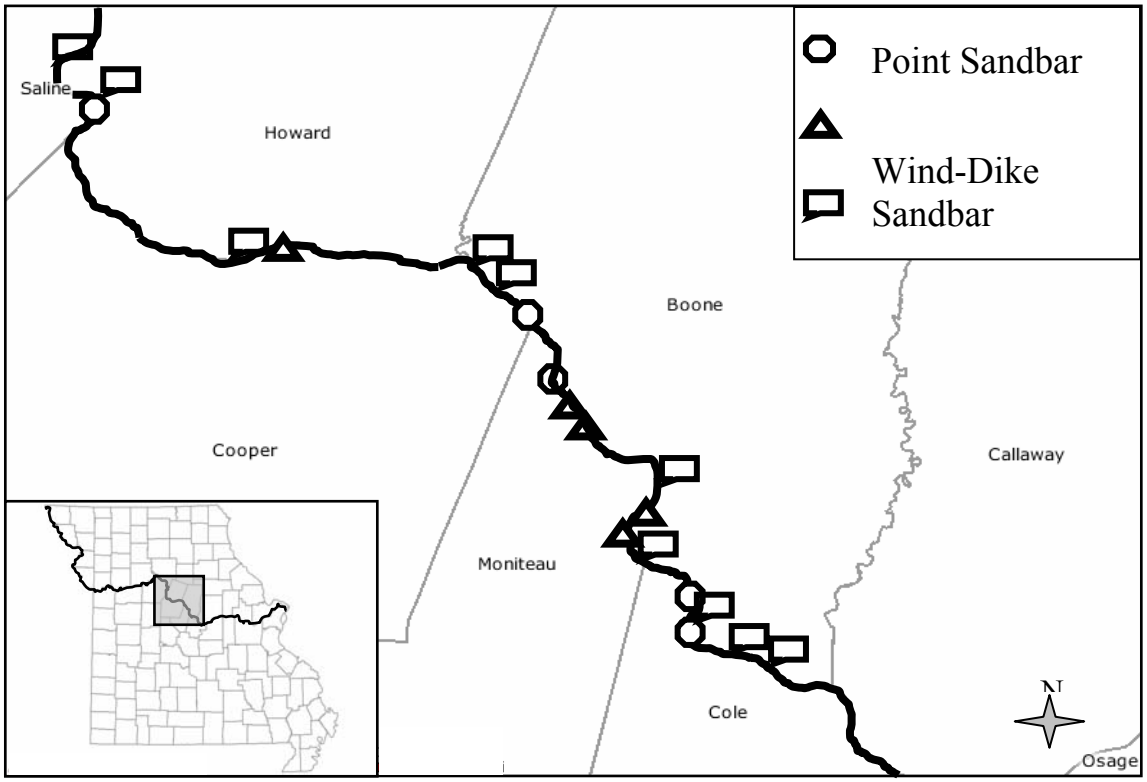


Figure 2. Flowchart illustrating the spatial hierarchy applied within the lower Missouri River. Macrohabitats included main channel (containing both primary and secondary channels when secondary channels were present), point sandbars (sandbars formed in the inside of a bend in the river), and wing-dike sandbars (sandbars formed behind wing-dikes). Mesohabitats included sandbar regions which were delineated based on channel orientation. Microhabitat was defined as environmental conditions present within the water column at 0.25 m^2 sample collection locations within each sandbar and channel-border aquatic-terrestrial-transition-zone (ATTZ). The ATTZ was restricted to areas with water <1.0 m in depth. HD = head, most upstream point of sandbar; TL = tail, most downstream point of sandbar; UP = upstream primary channel, sandbar mesohabitat halfway between sandbar midpoint and HD on primary channel side of sandbar; DP = downstream primary channel, mesohabitat halfway between sandbar midpoint and TL on primary channel side; US = upstream secondary channel, halfway between sandbar midpoint and HD on secondary channel side, DS = downstream secondary channel, halfway between sandbar midpoint and TL on secondary side of sandbar

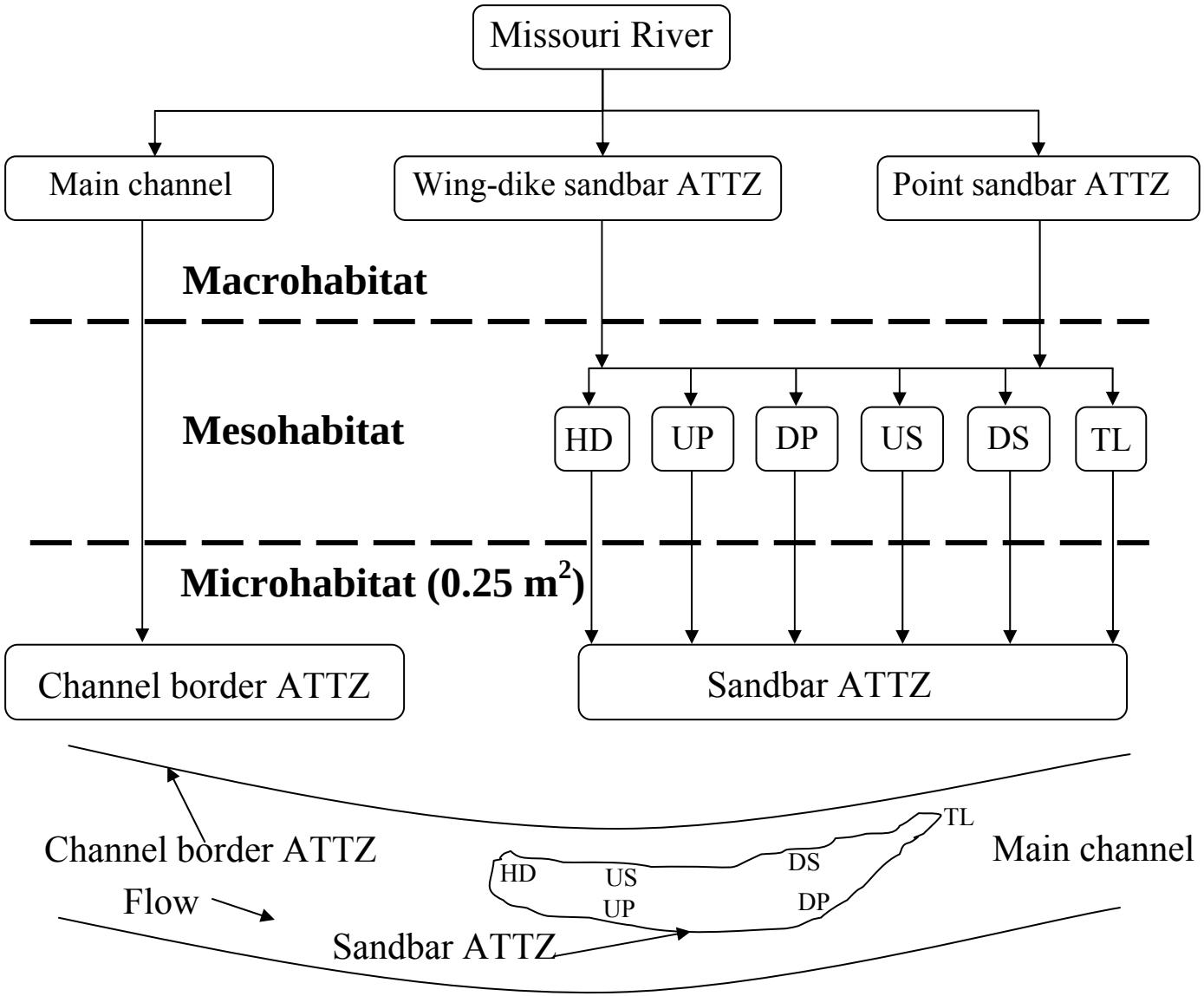

Missouri River
Main channel
Wing-dike sandbar ATTZ
Point sandbar ATTZ
Macrohabitat
Mesohabitat
HD
UP
DP
US
DS
TL
Microhabitat (0.25 m2)
Channel border ATTZ
Sandbar ATTZ
Channel border ATTZ
Flow
Sandbar ATTZ
Main channel
HD
US
UP
DP
DS
TL

Figure 3. Aerial view of Missouri River study section illustrating primary (PC) and secondary (SC) channels (combined into a main channel macrohabitat when secondary channels were present), and point (top) and wing-dike (bottom) sandbar macrohabitats. Sandbar mesohabitats include: Head = HD, Upstream Primary = UP, Downstream Primary = DP, Upstream Secondary = US, Downstream Secondary = DS, Tail = TL. Arrow signifies direction of flow. Photos made by U.S. Army Corps of Engineers between 26 February 2000 and 24 March 2000.

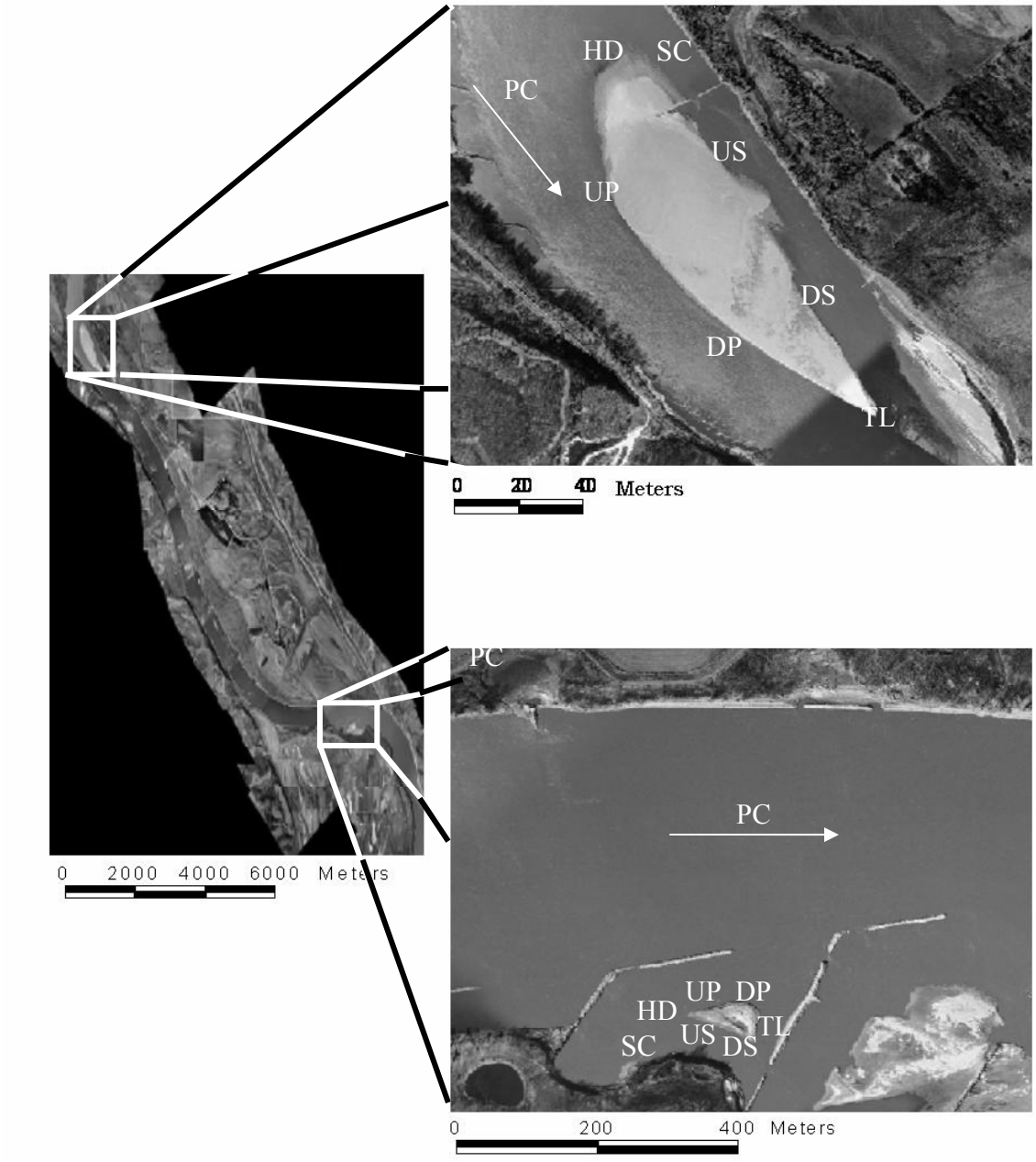

HD
SC
PC
US
UP
DS
DP
TL
0 200 400 Meters
0 2000 4000 6000 Meters
PC
PC
UP
DP
HD
TL
US
SC
DS
0 200 400 Meters

Figure 4. Graphs showing water temperature, discharge, and larval fish catch-per-unit-effort (CPUE) within the main channel of the lower Missouri River from 2002-2004. Water temperature shown with diamonds, measured in C° with units on the far left axis, discharge shown with a continuous line measured in cubic meters per second (CMS) with units on the inside left axis, and log10 transformed larval fish CPUE shown using bars with units on the right axis. Discharge measured for the lower Missouri River between 01 April and 30 September, 2002-2004. Discharge data are from U. S. Geological Survey, Boonville, MO gage (#6909000).

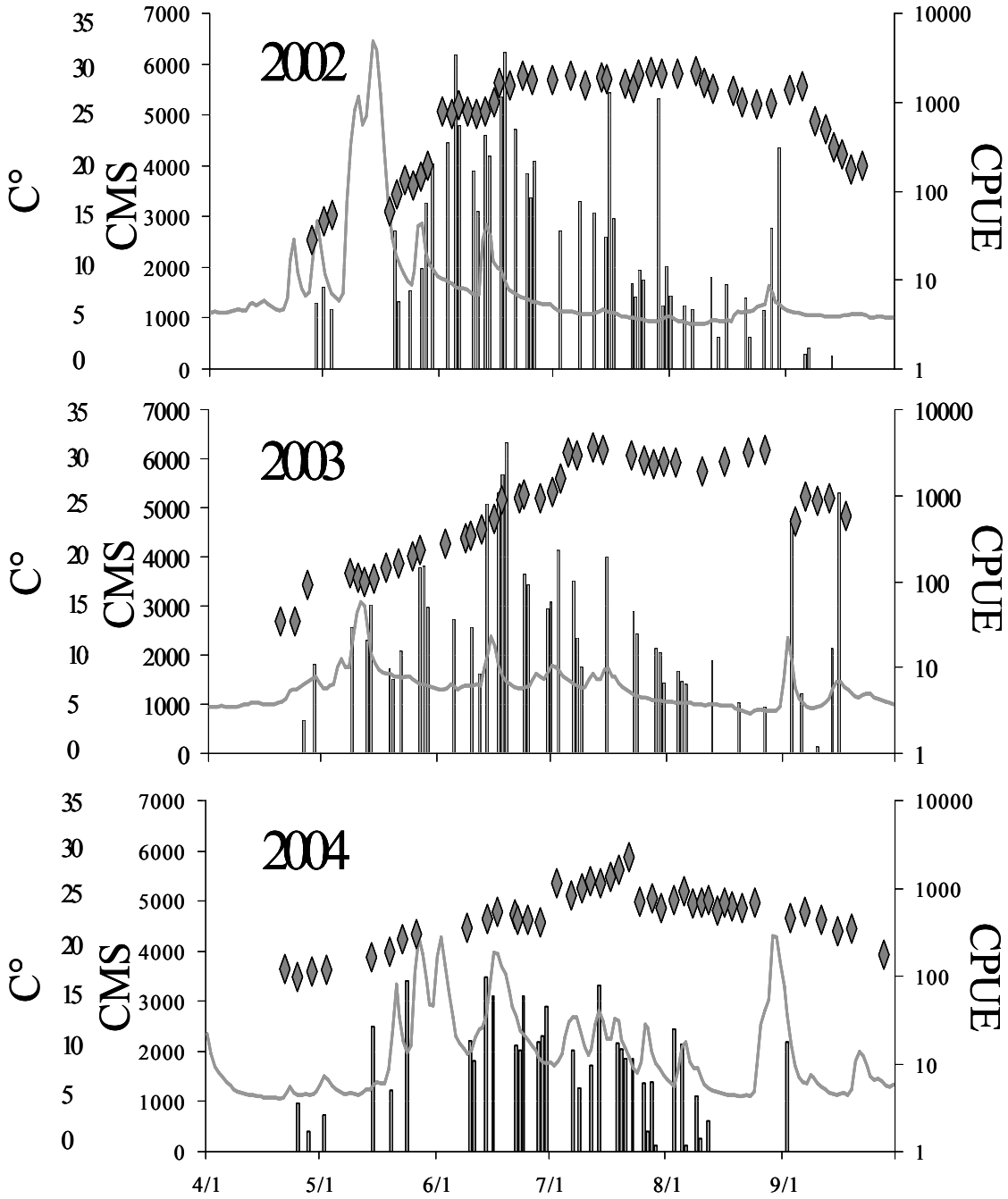

2002
2003
2004
C°
CMS
CPUE
35
30
25
20
15
10
5
0
7000
6000
5000
4000
3000
2000
1000
0
10000
1000
100
10
1
4/1
5/1
6/1
7/1
8/1
9/1

Figure 5. Illustration of the results from the analysis of covariance (ANCOVA) comparing catch per unit effort (CPUE) between macrohabitat types: MC = main channel, PB = point sandbar, and WD = wing-dike sandbar. A horizontal line signifies no significant difference among macrohabitat types (p>0.05), an arrow pointing down indicates larval fish CPUE was significantly lower than within the macrohabitat type with the arrow pointing up.

	Assemblage	*Carpiodes* spp./ *Ictiobus* spp.	*Hypophthalmichthys* spp.	*Macrhybopsis* spp.
MC	—	↓	—	↓
PB	—	↑	—	—
WD	—	—	—	↑

Figure 6. Histograms of mean $\pm$ 1 standard error of six local-environmental variables at point (grey bar) and wing-dike (black bar) sandbar macrohabitats and the six mesohabitats within each during 01 April to 30 September of 2002 and 2003. See text for significance tests. Water temperature is the difference between sandbar mesohabitat and primary channel . Mesohabitat abbreviations: HD – most upstream point of sandbar, TL – most downstream point of sandbar, UP – approximately one-half the distance between sandbar midpoint and HD on primary channel side of sandbar, DP – approximately one-half the distance between sandbar midpoint and TL, US – approximately one-half the distance between sandbar midpoint and HD on secondary channel side of sandbar, and DS – approximately one-half the distance between sandbar midpoint and TL**.**

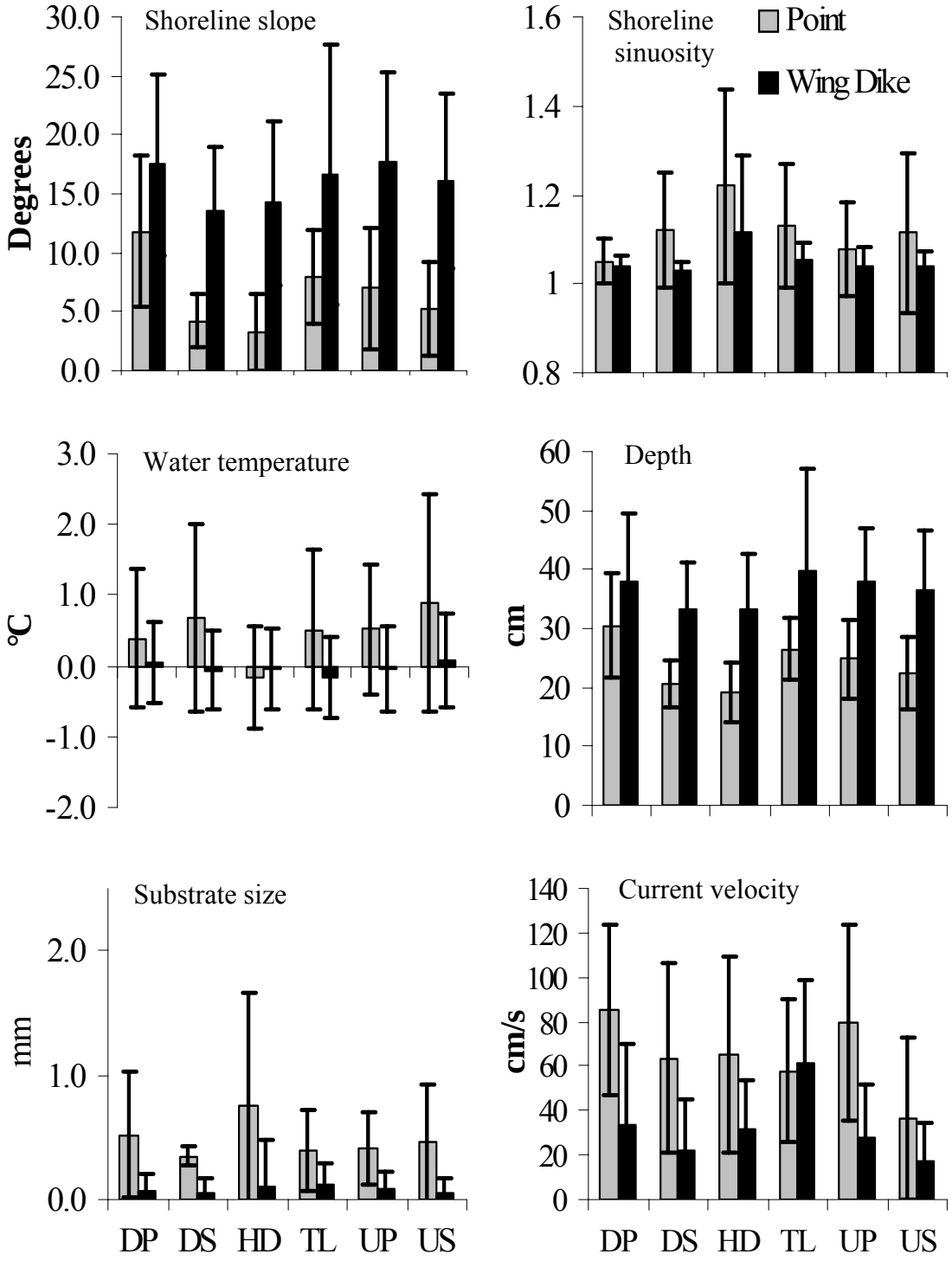

Shoreline slope
Degrees
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Shoreline sinuosity
Point
Wing Dike
1.6
1.4
1.2
1
0.8
Water temperature
°C
3.0
2.0
1.0
0.0
-1.0
-2.0
Depth
cm
60
50
40
30
20
10
0
Substrate size
mm
2.0
1.0
0.0
Current velocity
cm/s
140
120
100
80
60
40
20
0
DP DS HD TL UP US
DP DS HD TL UP US

Figure 7. Detrended correspondence analysis (DCA) scatter plot of taxa frequency of occurrence within sandbar ATTZ of the lower Missouri River in 2002. See Table 1 for taxa abbreviations. Open circles represent sandbar mesohabitats, closed triangles represent fluvial specialist, diamonds represent fluvial dependent, and squares represent macrohabitat generalist from Galat et al. (2005). Mesohabitats near one another have many species in common within collections. Species occurring near one another commonly occur in the same sandbar macro- and mesohabitats.

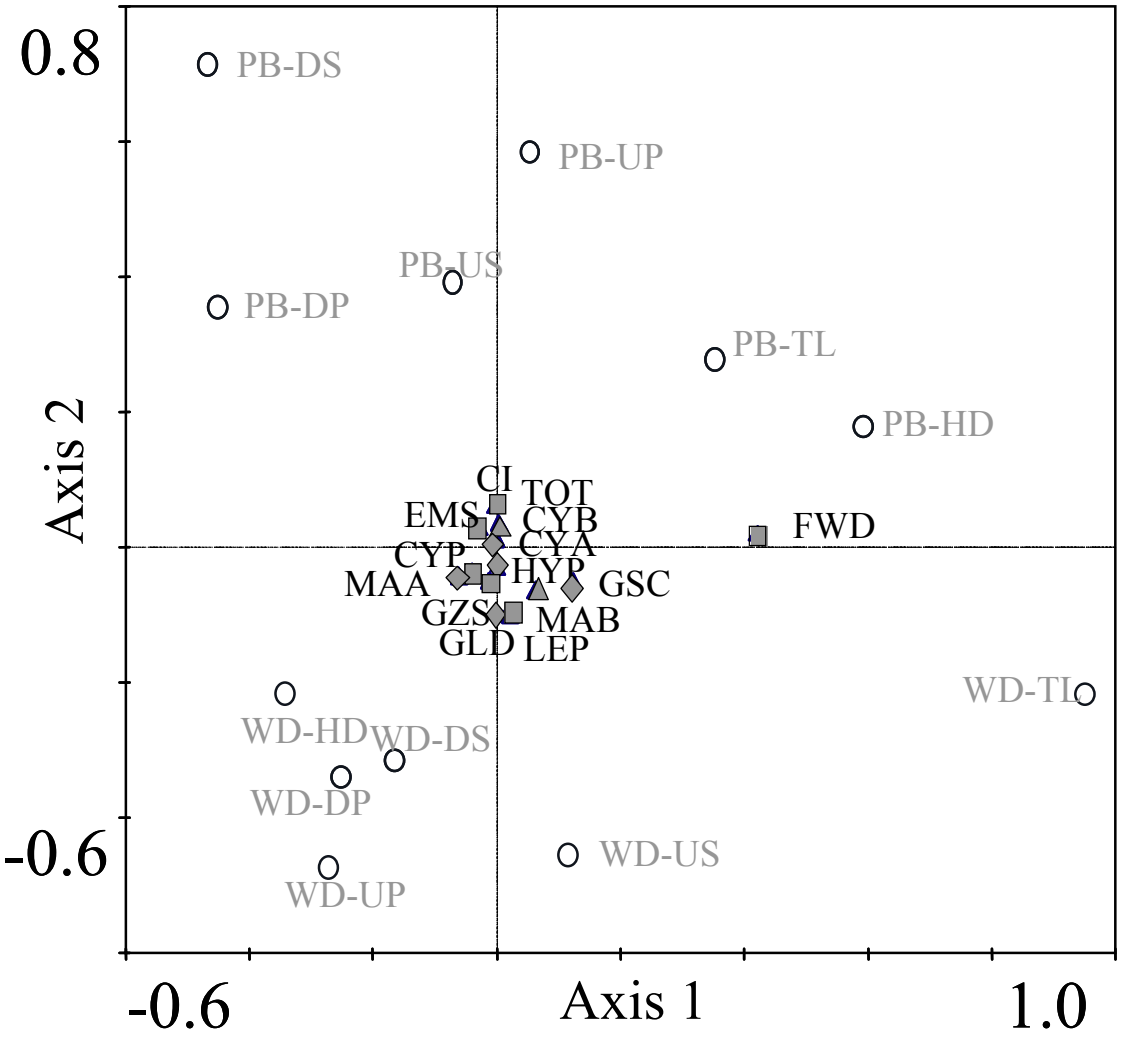


Figure 8. Biplots illustrating redundancy analysis for larval fishes collected in sandbar ATTZ during 2002 and associated abiotic (geomorphic, local-environmental and hydrologic) factors. (A) scatter plot projecting larval fish abundance and abiotic factors. T-plots with Van Dobben circles for the three most significant explanatory factors: (B) cv – current velocity, (C) 4-d – difference in flow between day x and mean of previous four days, (D) mac = sandbar macrohabitat [clear circle = point sandbar (PB), shaded circle = wing-dike sandbar (WD)]. See Results for explanation of arrows and circles and Table 1 for species abbreviations. Dpth – water depth, meso – sandbar mesohabitat, slp – shoreline slope, sin – shoreline sinuosity, tmp – temperature, 1-d – difference in flow between day x and day x-1, 2-d – difference in flow between day x and mean of previous 2 days, 4-d – difference in flow between day x and mean of 4 previous days.

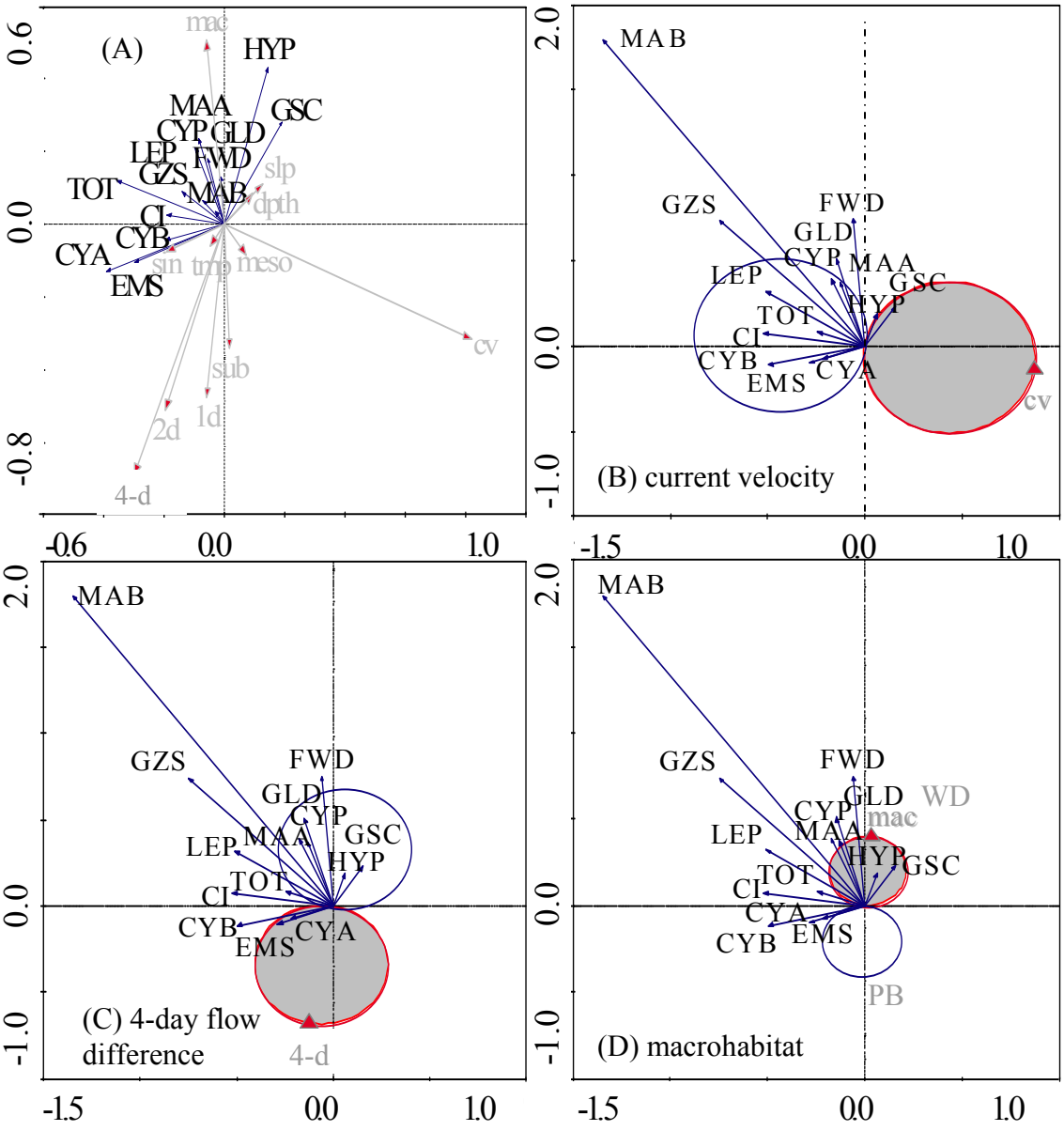
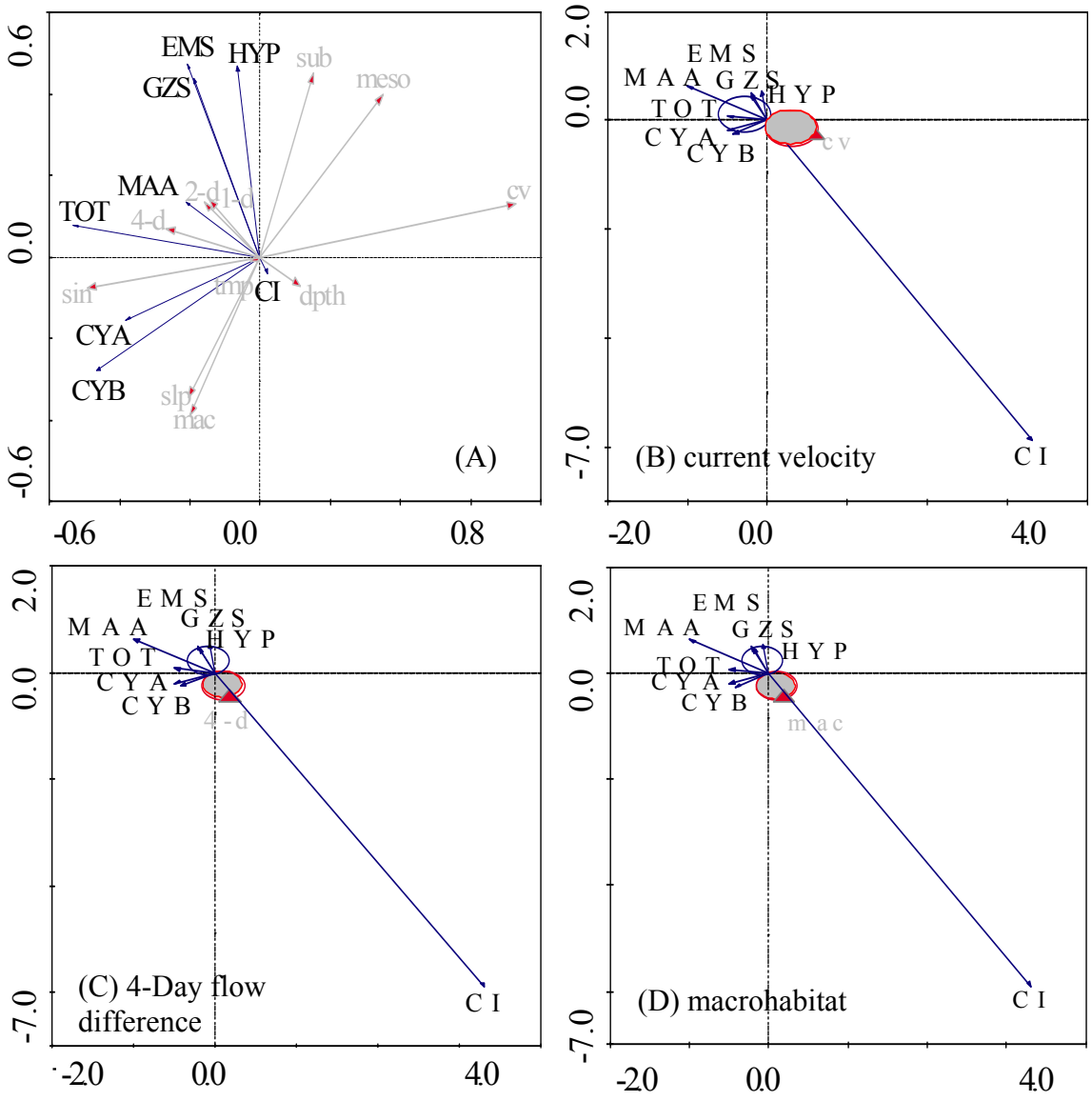

(A)
mac
HYP
MAA
GSC
CYP
GLD
LEP
FWD
GZS
slp
TOT
MAB
dpth
CI
CYB
CYA
sin
tmp
meso
EMS
cv
sub
1d
2d
4-d
0.6
0.0
-0.8
-0.6
0.0
1.0
(B) current velocity
MAB
GZS
FWD
GLD
CYP
MAA
LEP
GSC
HYP
TOT
CI
CYB
CYA
EMS
cv
2.0
0.0
-1.0
-1.5
0.0
1.0
(C) 4-day flow difference
4-d
(D) macrohabitat
WD
PB

Figure 9. Biplots illustrating redundancy analysis for larval fishes collected in sandbar ATTZ during 2003 and associated abiotic (geomorphic, local-environmental and hydrologic) factors. (A) scatter plot projecting larval fish abundance and abiotic factors. (B-D) t-plots with Van Dobben circles for the three most significant explanatory factors: (B) cv – current velocity, (C) 4-d – difference in flow between day x and mean of previous four days, (D) mac = sandbar macrohabitat [clear circle = point sandbar (PB), shaded circle = wing-dike sandbar (WD)]. See Results for explanation of arrows and circles and Table 1 for species abbreviations. Dpth – water depth, meso – sandbar mesohabitat, slp – shoreline slope, sin – shoreline sinuosity, tmp – temperature, 1-d – difference in flow between day x and day x-1, 2-d – difference in flow between day x and mean of previous 2 days, 4-d – difference in flow between day x and mean of 4 previous days.


EMS
HYP
sub
meso
GZS
MAA
2-d
1-d
cv
TOT
4-d
sin
imp
CI
dpth
CYA
CYB
slp
mac
(A)
0.6
0.0
-0.6
-0.6
0.0
0.8
(B) current velocity
C I
2.0
0.0
-7.0
-2.0
0.0
4.0
(C) 4-Day flow difference
(D) macrohabitat

Chapter III

NURSERY HABITAT FOR RHEOPHILIC LARVAL FISHES IN THE CHANNEL MARGIN OF A REGULATED, LARGE FLOODPLAIN RIVER, LOWER MISSOURI RIVER

Abstract

The larval stage of a fish life cycle is often a recruitment bottleneck in regulated rivers due to loss of nursery habitat, with nursery habitat being defined herein as areas with appropriate environmental conditions for ontogeny. Definitions of nursery habitat are often too coarse to be effective targets for river rehabilitation projects. We characterized microhabitat (0.25 m^2) use and associated environmental variables along the aquatic-terrestrial-transition-zone (ATTZ) of primary-channel margin (0 to 1-m depth) in the channelized lower Missouri River, Missouri, for the larval fish assemblage and for selected taxa. Two components of the channel-margin ATTZ were evaluated, sandbar and primary-channel-border ATTZ. Information theoretic analyses were used to identify environmental variables including water depth, distance from shore, substrate type, temperature, current velocity, and presence of vegetation that best predicted larval fish presence-absence at the assemblage level and for native carpsuckers (*Carpiodes* spp.), non-native bighead and silver carps (*Hypophthalmichthys nobilus* and *H. molitix*), and native chubs (*Macrhybopsis* spp.). Microhabitat selection analysis was used to determine the range of each predictive environmental variable selected for at the assemblage level and for selected taxa. The larval fish assemblage and *Carpiodes* spp. selected areas ≤10 cm deep with with current velocity ≤5 cm/s. *Hypophthalmichthys nobilus/ molitix*

showed no selection based on water depth or current velocity, but selected for areas with water temperatures near or ≤2.0 C˚ below main channel temperatures. *Macrhybopsis* spp. selected depths between 21 and 40 cm, that were >2 m from the waters edge. Refining existing definitions of nursery habitat within channel margin ATTZ will increase success of shallow-water habitat rehabilitation projects targeting rheophilic larval fishes.

Introduction

Many large rivers in the industrialized world have been modified for recreation, navigation, hydroelectricity, and/or agriculture (Obeng 1981; Welcomme 1985; Nilsson et al. 2005; Sparks 1995). These anthropogenic modifications have altered riverine ecosystems resulting in the imperilment of many riverine fishes. Rheophilic species (those requiring flowing water for the completion of their life cycle) in particular have been severely impacted, many being listed as imperiled. However, native and non-native habitat generalists (fish capable of completing their life cycle in lentic waters) have expanded their ranges or increased in abundance (Galat and Zweimüller 2001; Aarts et al. 2004). One of the primary factors resulting in the imperilment of rheophilic fishes has been loss of in-channel habitat with appropriate environmental conditions for larval fish development (Holland 1986; Keckeis et al. 1996; Wintersberger 1996). Loss of this nursery habitat can dramatically impact recruitment as the larval stage is the most environmentally sensitive of a fish's life cycle (Fuiman and Werner 2002).

Habitat restoration projects are under way to rehabilitate, or re-create habitat for the benefit of fishes negatively impacted through development. Many of these projects,

especially in large rivers, take place where conflicting interests among a diverse array of stakeholders persist (Hayes 2002; Dokulil 2005). Success of these habitat rehabilitation projects depend in part on their ability to provide ecologically appropriate environmental conditions for fishes to complete their life cycles without negatively affecting other uses (Rosenfeld 2003). The first step in this process is to develop practical definitions of ecologically relevant habitat based on accurate knowledge of each species' habitat requirements throughout their life cycle (Kurmayer et al. 1996; Schiemer et al. 2001).

Several research projects have characterized environmental conditions associated with larval fish habitat use within the borders of the river channel. Scheidegger and Bain (1995) used estimated maximum sustained swimming speed for many larval fishes to define nursery habitat in terms of current velocity in two streams in Alabama. Kurmayer et al. (1996) found that larvae of rheophilic species were associated with gravel banks and banks with a low slope in the River Danube. King (2004) determined littoral areas and backwaters were important for larval fish development in an Australian lowland river.

Shallow-water, channel-margin areas are spatially and temporally dynamic, changing elevation and location as water levels varied with diel and seasonal changes in river discharge. Thus, they represent the in-channel fraction of the aquatic terrestrial transition zone or ATTZ (Junk et al. 1989; Junk 2005) used by many rheophilic fishes as shallow-water nursery. This channel-margin ATTZ portion of the total river-floodplain ATTZ may be critical for successful recruitment of rheophilic fishes in many of the world's regulated large rivers that are channelized and disconnected from their floodplain.

The Missouri River of the central United States exemplifies a regulated large river with a rich rheophilic ichthyofauna (Galat et al. 2005). The pre-regulation Missouri River had a broad, braided channel with many sandbars and islands (Hesse et al. 1988; Galat et al. 2005). The channel-margin ATTZ of braided rivers thus includes both the moving littoral along the border of the primary channel and the moving littoral associated with islands and sandbars (i.e., islands with no or permanent terrestrial vegetation). We define the *channel-margin ATTZ* for this study as extending from the water's edge to a water depth of 1.0 m. Larval fish habitat use was determined within two major components of the channel-margin ATTZ, along sandbars (hereafter *sandbar ATTZ*) and along the perimeter of the river's primary channel, (hereafter *channel-border ATTZ*). Previous research has illustrated the importance of shallow-water, in-channel areas for larval-fish development (Carter et al. 1986; Copp 1990; Scheidegger and Bain 1995; Kurmayer et al.1996; Wintersberger 1996; Baras and Nindaba 1999; King 2004; Reichard et al. 2004), and the channel-margin ATTZ provides much of the in-channel, shallow-water habitat available to larval fishes within the channelized lower Missouri River.

Previous research on habitat use by rheophilic larval fishes was conducted at different levels of spatial resolution; however, environmental conditions that made these areas valuable as nursery habitat may have been similar (Scheidegger and Bain 1995; Kurmayer et al. 1996; King 2004). Copp et al. (1994) point out the importance of the hierarchical nature of habitat use when evaluating relationships between species and their environment. Larger-scale factors such as bank slope and shoreline sinuosity may influence habitat selection to an area where appropriate environmental conditions are more common; whereas, the fish's position, or microhabitat, within the selected area is

likely determined by finer-scale factors such as depth, current velocity, or substrate type. Our objectives were to develop statistical models characterizing environmental variables associated with larval fish microhabitat use within the ATTZ of sandbars in 2003, evaluate the predictive ability of these models along sandbar and channel-border ATTZs in 2004, and compare environmental conditions within sandbar and channel margin ATTZ in 2003 and 2004. Evaluating model predictive ability in sandbar and channel-border ATTZs separately allowed us to determine if the environmental variables associated with habitat use predict larval fish presence similarly in different shallow-water ATTZ types. We characterized larval fish microhabitat use at the assemblage level (for all taxa of larval fishes collected within the channel-margin ATTZs), and for native carpsuckers (*Carpiodes* spp.), non-native bighead and silver carps (*Hypophthalmichthys* spp.), and native big river chubs (*Macrhybopsis* spp.).

Study Area

The historic Missouri River had a meandering, braided channel with diverse habitat owing to the many sandbars, islands, secondary channels, and backwaters. It was characterized by continual bank erosion, and a high sediment load making it one of the most turbid rivers in North America (Pflieger and Grace 1987; Galat et al. 2005). The contemporary Missouri River is divided into three sections nearly equal in length reflecting anthropogenic alterations. The upper Missouri is largely free flowing from the headwaters ending above the influence of Fort Peck Dam. The middle Missouri consists of six large impoundments extending from Fort Peck Dam to Gavins Point Dam near Souix City, Iowa. The lower Missouri River extends from Gavins Point Dam to the

confluence with the Mississippi River near Saint Louis, MO. The lower Missouri River has been leveed, channelized, and its flow regulated for flood control and navigation (Hesse et al. 1988). Channelization of the lower Missouri River reduced surface area by 50%, reduced turbidity by 65%, and decreased the number of sandbars and islands by >90%, confining the river to a single, deep channel with swift current and little habitat complexity (Funk and Robinson 1974; Pflieger and Grace 1987).

The lower Missouri River study section for this project was between river kilometers 253 and 351 (river mile 157 and 218) moving upstream from the confluence of the Missouri and Mississippi rivers near St. Louis, Missouri (Figure 1). Ten sandbars were selected for study in 2003 and 2004 from the two dominant types of sandbars present: (1) five formed on the inside bend of the river (point sandbar) and (2) five formed behind rock wing-dikes or groins (wing-dike sandbar). Ten additional sites along the channel-border ATTZ were included in 2004. Each channel-border site was outside of the thalweg either on the inside of a river bend or along a straight run (Figures 1 and 2).

Methods

Digital orthophotos of the lower Missouri River collected by the U.S. Army Corps of Engineers between 26 February 2000 and 24 March 2000 were used to locate emergent sandbars between river kilometer 742 (mile 461) near Rulo, Nebraska and the confluence of the Missouri and Mississippi rivers. All emergent sandbars were classified into one of three categories based on their major formative process: point sandbar, wing-dike sandbar, or tributary sandbar (formed directly downstream from the confluence of a tributary and the Missouri River). Point and wing-dike sandbars composed >98% of

sandbars present, so tributary sandbars were excluded from further study. Wing-dike and point sandbar study sites were selected in 2003 based on their elevation, to maximize their emergence when larval fish were present. Channel-border ATTZ sites were selected in 2004 to compare larval fish habitat use between channel-border and sandbar ATTZ sites. Channel-border sites were selected based on bank slope (visual inspection at low water), absence of shoreline rock armament (natural substrate), and were interspersed within sandbar sampling locations (Figures 1 and 2). Bank slope was used as a selection feature because channel-border areas with low bank slope would reach a depth of 1 m more gradually than areas with a higher slope, potentially providing a greater diversity of depths and current velocities. Mean daily river discharge was collected by the U.S. Geological Survey gauge at Boonville, MO (river km 317).

Spatiotemporal scales

Larval fish habitat use in the channel-margin ATTZ was addressed by first partitioning the ATTZ into three levels of spatial resolution. The coarsest scale was *macrohabitat*, defined as sandbar type and channel border. *Mesohabitat* composed the next lower spatial scale and was practically defined as sandbar regions for this study, but are generally considered features 10 to 100 meters in length. *Mesohabitat* features include bank slope, shoreline sinuosity, and channel aspect. Differential larval fish use of macro- and mesohabitats are reported elsewhere (Reeves 2006). The finest level of spatial resolution, *microhabitat,* was defined by the gear deployed to sample larval fishes as 0.25 m^2 and was the scale we applied here to measure nursery habitat use by larval fishes and associated environmental variables. Whereas "microhabitat" is generally

defined as the location of an individual fish (Frissell et al. 1986; Minshall 1988; Mattingly 1999), it is currently not possible to achieve this level of spatial resolution for semi-transparent larval fishes in a large turbid river like the lower Missouri River.

Research was conducted in 2003 and 2004, with 2003 devoted to developing statistical models of larval fish habitat use and evaluating the predictive ability of these models during 2004 (model building and evaluation are detailed in statistical section). Larval fish collection began on 1 April and continued through 30 September of 2003 and 2004 which included the entire period larval fishes were anticipated to be present based on previous studies (Holland 1986; Galat et al. 2004a, b). This was done to ensure collection of the broadest portion of lower Missouri River fish fauna, including larvae of early and late spawning species.

Sandbar sampling order was random with approximately two sandbars sampled per week in 2003. Both channel-border and sandbar sampling order were random in 2004, with a goal of creating separate sandbar and channel-border model validation data sets with about one third the number of samples collected in 2003. The goal of establishing separate data sets for model validation approximately one-third the size of our 2003 "training" data set is based on Huberty (1994). To this end, one sandbar and six channel-border sites were sampled per week in 2004.

Each sandbar (macrohabitat) ATTZ was divided into 6 regions (mesohabitats) based on channel aspect and sandbar morphology: 1) head – most upstream point of sandbar, 2) tail – most downstream point of sandbar, 3) upstream primary – approximately one-half of the distance between the sandbar midpoint and head region on the primary channel side of sandbar, 4) downstream primary – approximately one-half of the distance between

the sandbar midpoint and the tail region, 5) upstream secondary – approximately one-half of the distance between the sandbar midpoint and head region on the secondary channel side of sandbar, and 6) downstream secondary – approximately one-half of the distance between sandbar midpoint and tail region**.** These regions were selected to represent the diversity of ATTZ habitats surrounding sandbars for a concurrent study comparing larval fish habitat use at broader spatial scales (chapter 2 Reeves 2006). Channel-border sites with natural substrate were smaller in area than sandbars due to the frequency of shoreline armoring. As a result, channel-border sites could only contain one 50-m long sampling area.

Environmental variables and fish sampling

Environmental variables used to characterize microhabitat and relate with larval fish use of the channel-margin ATTZ included: water depth, current velocity, water temperature, substrate type, distance from shoreline, and presence/absence of vegetation. A 50-m cable marked at 10-m increments was first positioned along the sandbar or channel-border waterline. Three of the 10-m increments were randomly selected for sampling. Transects perpendicular to the shoreline were then created at each of the three selected increments by suspending a second cable above the water, marked in 1-m increments. The second cable was anchored at the water's edge and at the point where the water depth equaled 1.0 m. A maximum of 10 larval fish samples were collected along each transect. If total transect distance to the 1.0 m depth was <10 m, samples were collected at 1-m intervals. If the transect distance to 1.0 m depth was >10 m, samples were collected at equidistant points (e.g., if the distance was 18m, samples were

collected at the waters edge, 2 m, 4 m, 6 m, 8 m, 10 m, 12 m, 14 m 16 m, and 18 m). Transect sampling order and order of sample collection within each transect was random. Each transect was approached from downstream to reduce larval fish disturbance. A one-minute interval between samples was allowed for larval fishes to return to normal distribution (La Bolle et al. 1984).

Environmental variables were measured at each collection site and used as model parameters. Current velocity was measured to the nearest 1 cm/s in the middle of the sample area using a Marsh McBirney model 2000 portable flow meter at 60% of water depth measured from the surface. Distance from shoreline was measured to the nearest 1 m from the collection site to the waters edge. The dominant substrate type was recorded as gravel, sand, or silt. Water temperature was measured using a digital thermometer to the nearest 0.1 ^{o}C. Water depth was measured to the nearest 1 cm in the middle of the collection site. Finally, presence or absence of any vegetation within a sample was recorded.

Larval fishes were collected using a drop net with 0.5-m length, 0.5-m width, 1.0-m height, and constructed of 500 μm Nytex mesh. Two 1.25-m handles were attached to the net to minimize larval fish disturbance as the sampler approached. The net frame was open at the top and bottom, and had a billow on the downstream side with a detachable collection cup. After the net was dropped the contents were swept into the billow using a sweep net previously positioned on the upstream side of the net. The sweep net was of the same width and height as the drop net and constructed of 500 μm Nytex kept rigid using metal brackets at the top and bottom. This design allowed the net contents to be pushed into the net billow and then washed into the collection cup. We selected drop

nets for sampling larval fishes because they collect fishes throughout the water column and at the substrate; they functioned well in all three substrates sampled (gravel, sand, and silt), and in vegetated areas. The use of an internal sweep net allowed us to push the net contents into the billow with a single sweep using similar effort regardless of sample depth. Drop nets also provided the ability to associate larval fish presence to environmental variables at a fine spatial scale. We believe this approach to be a superior alternative to point electofishing within the channel-margin ATTZ (Copp and Peňáz 1988; Copp 1989; Copp 1990; Copp 1993). Electofishing effectiveness varies by species, it can be negatively affected by current velocity (high current velocity can sweep larvae out of the sample area), depth (effectiveness of electrofishing decreases as distance from electrodes increase), shoreline slope (less efficient in areas with steep shorelines due to rapid increase in depth), turbidity (makes fishes less visible for net collection), and substrate type (silt substrate may pull electric field down and limit effective range) (Kolz et al. 1998).

Larval fish handling and Identification

Net contents were fixed in the field in a 10% solution of neutrally buffered formalin. Samples were transferred to 70% ethanol in the laboratory after fixing for 24 hours and were stored until identification. Larval fishes were separated from detritus using combined methods of staining with eosin Y, and sucrose flotation (Anderson 1959; Pask and Costa 1971; Hall et al. 1996). All larval fishes were identified to the lowest reliable taxonomic level using keys developed by May and Gassaway (1967), Auer (1982), Fuiman et al. (1983), Holland-Bartels et al. (1990), Wallus et al. (1990), and Kay et al.

(1994). Identifications for selected taxa, including all larval sturgeon, were verified by Darrel E. Snyder at the Colorado State University Larval Fish Laboratory.

Statistical analysis

The first step in the statistical analysis was to determine what environmental variables or combination of environmental variables we measured (i.e., water depth, current velocity, water temperature, substrate type, distance from shoreline, and presence/absence of vegetation) most accurately predicted presence/absence of larval fishes. To accomplish this we first developed a set of candidate models based on a review of larval fish literature (Copp 1990; Schiemer et al. 1991; Baras et al 1995; Peterson and VanderKooy 1995; Mérigoux and Ponton 1999; Gadomski et al. 2001). The candidate models were evaluated using Akiaki's Information Theoretic (AIC) analysis. Prior to analysis all independent variables were regressed against one another to test for multicollinearity. The resulting R^2's were within the tolerance ($1-R^2$) >0.20 so multicollinearity was not considered problematic (Garson 2005).

We used a k-fold partitioning strategy for model training and validation (Fielding and Bell 1997; Boyce et al. 2002). This process involved splitting data from 2003 into three groups (A, B, and C) nearly equal in size using a random number generator. Model training was performed using logistic regression with each model from the *a priori* list of candidate models on two of the three 2003 data sets, then validated using the third data set. This meant each model would be trained and validated three times with the 2003 data set: 1) training set A + B, validation C, 2) training set A + C, validation B, 3) training set B + C validation A. The above process was applied to the assemblage and

Carpiodes spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp. genera analyses. *Carpiodes* spp. included *C. carpio, C. □ollock□,* and *C. velifer*; *Hypophthalmichthys* spp. contained *H. molitrix* and *H. nobilus*; and *Macrhybopsis* spp. were represented by *M. aestivalis*, *M. gelida, M. meeki,* and *M. storeriana*. *Carpiodes* were selected because they are a group of native riverine macrohabitat generalists and were common in our samples. *Hypophthalmichthys* were included because they are the dominant invasive fluvial dependent fishes in the lower Missouri River and were also common in our collections. *Macrhybopsis* were selected because they are archetypical native "big river" fluvial specialists and all but *M. aestivalis* are listed as imperiled by one or more states along the Missouri River (Galat et al. 2005).

Models at the assemblage level were also validated against the 2004 sandbar ATTZ and the 2004 channel-border ATTZ data sets separately. Validating models against the sandbar and channel-border data sets separately allowed comparison of model predictive ability between ATTZ types. It also enabled us to determine if the environmental variables we measured had a similar ability to predict larval fish presence in both ATTZ types. Percent concordance was used as a measure of a model's ability to accurately predict larval fish presence. Model validation for individual taxa followed the same format as assemblage level analyses with the 2003 data set, but the sandbar and channel-border ATTZ data sets had to be combined due to decreased catches in 2004 samples (Table 1). Combining the two data sets prevented us from comparing model predictive ability between ATTZ types for individual taxa.

The -2 log likelihood was recorded during model training and used to calculate the QAIC, which is the AIC value with an adjustment for over-dispersion (common in count

data). The ΔQAIC (min QAIC – model QAIC) and Akaike weights were then calculated for each model. Model weights are the "likelihood of the model given the data" and enable comparisons of model support (e.g., a model with a weight of 0.2 would be twice as likely as a model with a weight of 0.1 given the data (Burnham and Anderson 1998)). Burnham and Anderson (1998) suggest when evaluating models using QAIC, that models with ΔQAIC values <2 are considered to have substantial support, models with ΔQAIC values between 2 and 7 have considerably less support and models with ΔQAIC values >10 have essentially no support. We only considered models with ΔQAIC values <2. Models with ΔQAIC values <2 were averaged for the assemblage and each of the selected taxa to improve model fit by weighting parameter estimates using AIC model weights. The resulting averaged model was then evaluated against the 2003 and 2004 data sets.

Capen et al. (1986) noted that in presence/absence analyses there is an assumption that all suitable habitat is used. In cases where suitable habitat is unused due to low abundance it may be misclassified as used and lower the model's perceived predictive ability. We attempted to avoid the problem by only using dates where larval fishes appeared in ≥10% of samples for analysis at the assemblage level. This analysis was then repeated using only dates where larval fishes appeared in ≥20% of samples. Results of the two analyses were similar so only those of the ≥10% analyses will be presented. This process could not be repeated for analyses of genera, due to the lack of dates when they were present in ≥20% of samples.

Larval fish habitat selection

Microhabitat availability and use within the sandbar ATTZs (i.e., channel-margin ATTZ) were compared for each of the environmental variables present in the most supported models from the AIC analyses. The model selection step determined which environmental parameters were predictive of larval fish microhabitat use; comparing microhabitat availability and use illustrated the range of each environmental variable larval fish used within the sandbar ATTZ. To accomplish this, catch-per-unit-effort (CPUE) was calculated for the assemblage level analysis and for *Carpiodes* spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp. by dividing the total number of larvae (assemblage level), or the total number of larva from each of the three selected genera within an individual sample by the volume of water sampled. Volume sampled was calculated by multiplying the area of the net (0.5 m width X 0.5 m length) by the water depth measured at the middle of the sample. CPUE was standardized and reported as a number of larvae per 1.0 m^3 rounded to the nearest 0.1.

Microhabitat availability was calculated by organizing all samples collected between the first and last day of larval fish presence by each environmental variable for each of the 10 sandbars sampled in 2003. For example if depth were selected as an important predictor of larval fish presence, all samples would be ordered from shallowest to greatest depth within a single sandbar. Samples were then divided into classes (i.e., 1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, and >80 cm depth). This process occurred for each of the predictive environmental variables. Current velocity was divided into 5 cm/s classes (i.e., 0-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35, 36-40, and >40 cm/s). Temperature classes were normalized by first subtracting the mean primary channel

temperature for a given day from the temperature within each sample collected on that day. Samples with a negative value had water temperatures less than the mean primary channel temperature and samples with positive values had water temperatures above the average primary channel temperature. This was done to remove inherent seasonal changes in water temperature and focus on daily temperature difference between primary channel and sandbar ATTZ. Classes were then created by dividing samples into nine groups (i.e., ≤-2.0, ≤-1.5, ≤-1.0, ≤-0.5, -0.4, to 0.4, ≥ 0.5, ≥ 1.0, ≥ 1.5, ≥ 2.0). Finally, samples for substrate type were grouped as silt, sand, or gravel, and vegetation was noted as present or absent.

Habitat availability for each sandbar was calculated by dividing the number of samples collected within an environmental variable class by the total number of samples collected within the individual sandbar ATTZ. Microhabitat use within each environmental variable class was then calculated by dividing the larval fish CPUE collected within each habitat class by the total CPUE collected within the sandbar ATTZ. Microhabitat selection was determined using compositional analysis (Aebischer et al., 1993) comparing log-ratio transformed use and availability data for each sandbar with a likelihood ratio test. If the omnibus test showed there were significant differences in habitat use from random then the analysis performed pairwise comparisons between habitat classes to determine which classes differed significantly ($p < 0.05$) from one another. Histograms of microhabitat availability and use were prepared for each environmental variable to illustrate selection or avoidance among habitat classes.

Results

Larval fishes were collected from a total of 4,427 microhabitat samples taken between 01 April 2003 and 30 September 2003 and 03 April 2004 through 30 September 2004. We collected 2,558 larval fishes in sandbar ATTZs during 2003 representing 20 species, six genera containing several species, and four groups of species likely from multiple genera that couldn't be separated further (Table 1). During 2003, 370 larval fishes were collected within sandbar ATTZs representing 15 species, three genera, and four groups of species. In 2004, 261 larval fishes were collected within channel-border ATTZs representing 15 species, three genera, and four groups of species (Table 1). We collected 1,185 microhabitat samples along sandbars and 843 microhabitat samples along channel borders in 2004; both values were in excess of the approximately 800 samples (1/3 of the 2003 total) we had set as a goal within each ATTZ type for model validation. Larval fishes were present in collections from 29 April to 17 September with a maximum CPUE on 17 June in 2003 and from 15 May to 16 August with a maximum CPUE on 15 June 2004 (Table 2). There was a total CPUE of 11.3 larvae/m^3 between the first and last day of larval fish presence in sandbar ATTZs during 2003. In 2004 there was a total CPUE of 2.8 larvae/m^3 in sandbar ATTZs and 3.2 larvae/m^3 in channel-border ATTZs. Sampling procedures and equipment were identical in 2003 and 2004; however, only 79.2% of the number of samples collected in 2003 were collected in 2004. The percent of samples collected per week was relatively consistent during the entire sampling period. The reduction in sample collection would not appear to account for the large decrease in larval fish CPUE between 2003 and 2004, or the shortened period larval fish were present.

Discharge was higher and more variable during the 2004 sampling season than 2003 (Figure 3). The first flood pulse of 2003 occurred during mid-May, and the second occurred during mid-June. Two smaller increases in discharge occurred during late-June and early-July. Discharge decreased slowly until September. The earliest pulse occurred during late-March of 2004. The second pulse did not occur until mid-June. Discharge repeatedly spiked during the remainder of the 2004 sampling season.

Model selection

Information theoretic models containing depth, current velocity, substrate type, and temperature were most strongly supported at the assemblage level (i.e., ΔQAIC values <2), but no single model or variable was consistently most supported (Table 3). However, the model composed of depth, current velocity, and an interaction between the two was selected as most supported in two of the three analyses. This model had a mean percent concordance, or accurately predicted larval fish presence during model validation 60.2% of the time using the 2003 data sets, a mean of 52.3% using the 2004 sandbar data, and a mean of 49.6% using the 2004 channel border data. Model averaging improved percent concordance within the 2003 data set to 62.4%, 52.8% using 2004 sandbar data, and 50.5% using 2004 channel border data (model shown below).

Y=-0.0128 - 0.0145*current velocity - 0.0093*depth – 0.0011*substrate –
0.003*temperature – 0.0001*distance from shoreline – 0.0011*julian date
+ 0.0004*current velocity*depth – 0.0001*depth*temperature –
0.0003*current velocity*temperature + 0.000005*depth*substrate

The model composed of current velocity, depth, and an interaction between the two had the lowest ΔQAIC value in two of three analyses for *Carpiodes* spp. (Table 4). This model had a mean percent concordance of 66.8% using the 2003 data sets for model validation and a mean of 53.6% using the 2004 combined sandbar and channel border data sets. Models composed solely of depth or current velocity were ranked first or second most supported in each of the three sets of analyses. Temperature and substrate type also appeared in models with ΔQAIC <2. Model averaging improved percent concordance within the 2003 data set to 68.5%, but percent concordance within the 2004 combined data sets remained at 53.6% (model shown below).

Y= -0.7594 – 0.01186*current velocity – 0.01168*depth – 0.00087*substrate – 0.0043*temperature – 0.0041*distance from shoreline +0.000069*julian date -0.0000042*depth*temperature + 0.0000753*current velocity*temperature

The model consisting solely of temperature was the most supported for *Hypophthalmichthys* spp. in two of three analyses with depth and temperature being selected in the third analysis (Table 5). The temperature model had a mean percent concordance of 67.9% within the 2003 data sets, and a mean of 51.9% using the combined 2004 data sets. Models including depth, current velocity, and date were also in models for *Hypophthalmichthys* spp. habitat use with ΔQAIC<2. Model averaging improved percent concordance within the 2003 data set to 74.7%, and within the 2004 combined data sets to 61.3% (model shown below).

Y= 8.1965 – 0.017*current velocity – 0.0096*depth – 0.00222*substrate – 0.2063*temperature – 0.0017*distance from shoreline +0.02005*julian date -0.0000071*current velocity*depth + 0.000079*depth*temperature – 0.00012*current velocity*temperature +0.0872*depth*substrate

Macrhybopsis spp. habitat use was best represented by the model consisting solely of current velocity in two of three analyses with the substrate only model selected in the third analysis. Depth, distance from shore, and date also appeared in models for *Macrhybopsis* spp. habitat use with ΔQAIC<2 (Table 6). The current velocity model had a mean percent concordance of 44.0% in the two analyses with ΔQAIC<2 in the 2003 data set, and a mean of 50.8% using the 2004 combined data set. Model averaging improved percent concordance within the 2003 data set to 49.8% but this model did not have a higher percent concordance within the 2004 combined data sets (47.5%; model shown below).

Y= -3.01317 – 0.01398*current velocity – 0.0011*depth + 0.003481*substrate + 0.00101*temperature + 0.00037*distance from shoreline + 0.0000098*julian date - 0.0000514*current velocity*depth + 0.0000366*current velocity* temperature – 0.00000*depth*substrate

Mean and standard deviation for each environmental variable measured in all samples containing larval fish (assemblage) or for samples containing one of the three taxonomic groups in 2003 and 2004 were compared to help explain differences in predictive ability of models between sample years (Table 7). Mean water depth for samples containing larval fish (assemblage), *Carpiodes* spp, and *Hypophthalmichthys* spp. increased from

2003 to 2004, whereas mean water depth decreased for *Macrhybopsis* spp. (Table 7). Mean current velocity increased for assemblage, and *Carpiodes* spp., but decreased for *Hypophthalmichthys* spp. and was nearly halved for *Macrhybopsis* spp. between 2003 and 2004. The mean distance from sample site to waters edge decreased for each group between years. Mean water temperature decreased for assemblage, *Carpiodes* spp. and *Macrhybopsis* spp., but increased slightly for *Hypophthalmichthys* spp. The percent of samples collected in areas with gravel or sand substrate decreased, while it increased in areas with silt substrate at the assemblage level. The opposite trend was present for *Carpiodes* spp. with an increased percent of samples containing *Carpiodes* spp. collected in areas with gravel or sand substrate, and a corresponding decrease in areas with silt substrate. The percent of samples containing *Hypophthalmichthys* spp. increased in areas with gravel and silt substrate in 2004, and decreased in areas with sand substrate. *Macrhybopsis* spp. showed yet another trend with increased collections in areas with silt substrate and decreased in areas with gravel or sand.

Microhabitat availability and selection

The assemblage level compositional analysis of microhabitat availability and use for all samples collected in the 0 to 1.0 m sandbar ATTZ during 2003 showed significant selection based on water depth ($X^2 = 74.88$, df = 8, $p < 0.0001$). Larval fishes selected water ≤10 cm deep with 70% of CPUE occurred within this depth class although it composed only 15% of sampled available habitat. Larval fishes also selected for areas with current velocity ≤5 cm/s with 71% of CPUE though it composed 41% of sampled available habitat ($X^2 = 25.91$, df = 8, $p < 0.05$). Larval fishes also exhibited significant

habitat selection based on water temperature (X^2 = 20.08, df = 8, p <0.05), but the only significant pairwise comparison was between areas with water temperatures ≤-2.0 C° below main channel temperatures and areas with water temperatures ±0.4 C° of the main channel temperature. There was not significant selection based on substrate type (X^2 = 0.35, df = 8, p = 0.839; Figure 4).

Carpiodes spp. showed significant habitat selection based on water depth with nearly 80% of. CPUE in water ≤10 cm in depth, whereas these depths represented only 15% of sampled available habitat in the 0.0 to 1.0 m range (X^2 = 36.39, df = 8, p <0.0001; Figure 5). *Carpiodes* spp. also exhibited significant selection based on current velocity with 86% of CPUE collected in water with current velocities ≤10 cm/s though these areas composed only 56% of available habitat (X^2 = 21.68, df = 8, p <0.05). *Carpiodes* spp. also exhibited significant habitat selection based on water temperature (X^2 = 19.41, df = 8, p <0.05), though none of the pairwise comparisons showed significant selection for a habitat class. There was not significant selection based on substrate type (X^2 = 1.56, df = 8, p = 0.458; Figure 5).

Hypophthalmichthys spp. did not show significant habitat selection based on water depth (X^2 = 12.44, df = 8, p=0.133) or current velocity (X^2 = 9.47, df = 8, p=0.304). *Hypophthalmichthys* spp. did exhibit significant habitat selection based on differences in water temperature between the habitat and the main channel (X^2 = 23.01, df = 8, p<0.05). The pattern of habitat selection was not consistent with *Hypophthalmichthys* spp. selecting for areas with water temperatures ≤-2.0 C° below main-channel temperatures and within ±0.4 C° of main-channel temperatures, though these areas were only

significantly different than areas with water temperatures falling between these two classes (Figure 6).

Macrhybopsis spp. showed significant habitat selection based on water depth (X^2 = 29.68, df = 8, p<0.001), with 69% of CPUE within areas with water depth within the 30 cm and 40 cm depth classes though these areas only represented 24% of sampled available habitat. There was no selection based on current velocity (X^2 = 11.61, df = 8, p =0.17) or substrate type (X^2 = 0.51, df = 8, p =0.78), though distance from shoreline was significant for *Macrhybopsis* spp. (X^2 = 38.62, df = 8, p<0.0001). Fourty-seven percent of *Macrhybopsis* spp. CPUE was collected 2 to 3 meters from the shoreline though these classes only represented 24% of sampled available habitat (Figure 7).

Environmental variables

Environmental variables were compared between the 2003 and 2004 data sets to determine if there were significant differences in conditions that might help explain differences in predictive ability of habitat use models between years. Mean current velocities (mean of all current velocity measurements collected within the given habitat type) were higher along sandbars in 2004 than 2003 (18.5 cm/s and 15.9 cm/s, respectively), but mean current velocity were nearly twice as high along sandbars in 2003 than along the channel borders in 2004 (9.5 cm/s). Differences in current velocity within sandbar ATTZ between 2003 and 2004 were not significant (X^2=2.54, df=9, p=0.98) and between 2003 sandbar and 2004 channel borders were not significant (X^2=15.80, df=9, p=0.071). Samples collected along sandbars in 2003 had a slightly greater mean depth than 2004 (39.8 cm and 36.3 cm, respectively), but this difference was not significant

(X^2=1.27, df=9, p=0.99). Channel-border samples had the greatest mean depth (44.1 cm), but differences in sample depths between channel border and the 2003 sandbar data were not significant (X^2=6.64, df=9, p=0.68). The mean distance between the point a sample was collected and the waters edge was lowest at channel-border sites (2.5 m), followed by sandbars in 2004 (5.4 m), and greatest along sandbars in 2003 (5.7 m). Distance between sample location and waters edge was not significantly different between 2003 and 2004 sandbar ATTZs (X^2=0.85, df=9, p>0.99), but the difference between 2003 sandbar and 2004 channel-border ATTZs was significant (X^2=25.48, df=9, p=0.002). The mean difference in water temperature between the sample location and the primary channel was greatest at sample sites in sandbar ATTZs in 2003, with samples having a mean water temperature 0.4 C˚ above primary channel temperatures. In 2004, mean sandbar ATTZ samples were 0.3 C˚ above primary-channel temperatures, and mean channel-border temperatures were approximately 0.1 C˚ above primary-channel temperatures. There were not significant differences in shallow-water warming between 2003 and 2004 sandbar ATTZ (X^2=8.27, df=9, p=0.51) but there were between 2003 sandbar and 2004 channel-border ATTZ (X^2=17.08, df=9, p>0.047). Substrate particle sizes were more heterogeneous along sandbars than along the channel borde sites. In 2003 5.0% of samples were collected in areas with gravel substrate, 49.4% had sand substrate, and 45.7% had silt substrate in the sandbar ATTZ. In 2004 results were 11.8% gravel, 63.9% sand, and 24.3% silt along sandbars, and 0.0% gravel, 4.0% sand, and 96.0% silt along channel borders. Differences in substrate composition were not significant between 2003 and 2004 sandbar ATTZ (X^2=6.07, df=2, p=0.48), but were significant between 2003 sandbar and 2004 channel-border ATTZ (X^2=61.50, df=2,

$p<0.0001$). Vegetation was only found in areas with silt substrate. In 2003 vegetation was present in 1.8% of sample locations along sandbars. In 2004 it was present in 1.6% of sandbar sample locations and 9.9% of channel border sample locations.

Discussion

Our analysis of larval fish microhabitat use within the lower Missouri River channel-margin ATTZ led us to three conclusions: 1) riverine larval fishes appear to select nursery microhabitat, 2) predictive models of microhabitat selection developed within sandbar ATTZs more accurately predicted larval fish presence within sandbar ATTZs than channel-border ATTZs, and 3) different larval fish genera exhibit unique microhabitat selection strategies. The assemblage-level analyses clearly illustrated riverine larval fishes selected the portion of the defined ATTZ with the shallowest depth and elevated water temperatures. These results support findings by other researchers (Schiemer et al. 1991; Scheidegger and Bain 1995; Kurmayer et al. 1996; Grift et al. 2003); though their research was conducted at broader spatial scales.

The habitat-use models we evaluated consistently performed more poorly in channel-margins than sandbar ATTZs. This may be due to differences in the environmental conditions present in the two ATTZ types. The difference between larval fish CPUE collected in 2003 and 2004 presented a complication when we attempted to compare habitat use models between sandbar and channel-border ATTZs. This study was originally designed to allow comparisons for each of the selected genera, but this was not possible due to reduced CPUE. Sampling equipment, study design, and staff were similar or identical between years. The total number of samples was reduced by approximately

20%, but the densities of larval fish were approximately 65% lower in 2004. Concurrent research projects (see chapter 2, Reeves 2006) found reduced larval fish CPUE within the main channel of the lower Missouri River during 2004 as well. The similar pattern found by concurrent projects leads us to believe that reduced CPUE was a result of conditions beyond the scope of this project and not the result of collection effort.

Each of the three genera present in sufficient numbers for individual analyses exhibited a unique habitat use strategy within channel-margin ATTZs. These strategies can be visualized spatially with *Carpiodes* spp. using a narrow shoreline-margin-band where water depths were shallowest. *Macrhybopsis* spp. used a second riverward band with deeper water. Finally, *Hypophthalmichthys* spp. showed a broad use of depth and current velocity classes. Presence of *Hypophthalmichthys* spp. across multiple depths and current velocities, and high abundance in primary and secondary channels in a concurrent study (Reeves 2006) indicates they may continue drifting within the water column during their larval stage and would be more transient through channel-margin ATTZ areas identified as nursery habitat for larval *Carpiodes* spp. and *Macrhybopsis* spp.

A question raised by these findings is why there was a lack of selection by *Hypophthalmichthys* spp. and *Macrhybopsis* spp. for areas with current velocities less than the 8.4 cm/s estimated maximum sustained swimming speed of many larval fishes (Scheidegger and Bain 1995), as higher velocities would seem to be less energetically efficient. Two potential answers are: 1) larval fishes were using the zone just a few centimeters above the substrate with lower current velocities than where we measured, or 2) larval fishes were actively/passively drifting through the areas sampled. Without

vertical stratification of samples it is impossible to determine if either or both of these options were occurring.

Hypophthalmichthys spp. spawn in the open channel on the rising limb of the hydrograph relying on water current to transport larvae to off-channel areas for development (Yi et al. 1991). Scours connected to the lower Missouri River have been shown to have significantly greater abundance of larval and juvenile fishes, including *Hypophthalmichthys* spp., than the primary channel (Tibbs and Galat 1997; Galat et al. 2004b). In highly regulated rivers, where off-channel areas seldom connect during flow pulses, larval *Hypophthalmichthys* spp. may continue drifting in the channel as off-channel areas are inaccessible. This may explain why *Hypophthalmichthys* spp. were present across a variety of depths with relatively high current velocity in this project, and why they show high recruitment during years with very high water levels, and thus access to more off-channel areas for larval development (Schrank and Guy 2002). The relationship between success of *Hypophthalmichthys* spp. recruitment and flood-pulse magnitude may have important implications in current debates regarding management of the lower Missouri River.

Less information exists regarding the spawning behavior and larval habitat use of *Macrhybopsis* spp. Johnston (1999) proposed congenerics generally share the same spawning mode and *M. aestivalis* is a broadcast spawner with non-adhesive, semi-buoyant eggs that remain in suspension with water current (Botrell et al. 1964; Platania and Altenback 1998; Johnston 1999; Rahel and Thel 2004). Juvenile and adult *Macrhybopsis gelida* and *meeki* are archetypical big river fishes using areas with high current velocities and depths (Dieterman 2000; Berry et al. 2004), but *M. aestivalis* is a

common resident of pools and backwaters (Pflieger 1997). We were able to distinguish *M. gelida* and *M. meeki* from *M. aestivalis* and *M. storeriana*, but the low numbers collected during 2004 made model validation impossible at this level. Results from this analysis should be considered a basis for further *Macrhybopsis* spp. microhabitat studies.

Determining "how" larval fish were using microhabitat highlights the issue of sampling resolution. Optimally a fish's exact location in three-dimensional space would be used to define its microhabitat, but this is often unrealistic, especially for larval fish. We defined "microhabitat" by the volume of our sampling gear, or 0.25 m^2 multiplied by the depth of the water column. This level of resolution was accepted as a compromise between the need to sample a sufficient volume of water to ensure larval fish collection, a desire to associate larval fish presence to the smallest point in space possible, and the environmental constraints associated with sampling in the channel-margin ATTZ of a large, turbid river.

Characterizing channel-margin ATTZ larval fish nursery at a microhabitat scale illustrates the environmental variables larval fish experience at the approximate point in space where they reside. However, habitat selection is also influenced by environmental factors operating at higher spatial scales (Kurmayer et al. 1996; Mérigoux and Ponton 1999; Grift et al. 2003). In this study we focused on proximate variables such as depth, current velocity, substrate type, water temperature, etc. but the presence and magnitude of these variables are controlled in a spatial hierarchy. The nature of larger scale features such as sandbar type, bank slope, or shoreline sinuosity may make particular environmental condition more or less likely to occur. Projects considering only macrohabitat features, however, lack the resolution to determine what it is about these

features that make them important as nursery habitat to larval fishes. Microhabitat results such as ours could most beneficially be used to refine larger-scale habitat use models such as those presented by Reeves (chapter 2, 2006) reporting that larval fishes abundance within sandbar ATTZ of the lower Missouri River was most influenced by proximate environmental conditions (such as those of this project), discharge patterns (flow stability), and to a lesser extent spatial features (such as sandbar type). Multi-scale habitat-use models could then be used to increase efficacy of river rehabilitation projects that require clearly defined objectives to be ecologically successful (Kondolf and Micheli 1995; Kauffman et al. 1997; Roni et al. 2002, Palmer et al. 2005). Habitats selectively used must then be available to larval fishes at the appropriate time during ontogeny if they are to successfully recruit to juveniles. Identifying particularly vulnerable periods within a species' life cycle that function as recruitment bottlenecks and then targeting rehabilitation efforts to reduce these restrictions is an effective component of a comprehensive strategy for benefiting population recovery of native fishes. It is important to note, however, this project was conducted in river during daylight hours, and even less information exists detailing habitat use by larval fishes during the night.

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Table 1. Mean catch-per-unit-effort (CPUE) for larval fishes collected in 2003 and 2004 from lower Missouri River sandbar and channel-border ATTZs. Taxa CPUE represents all species listed under it. CPUE is presented to the nearest 0.1 larvae/m^3. Taxa with an asterisk were present but densities were <0.10 larvae/m^3. Habitat use guild is from Galat et al. (2005); (s = fluvial specialist, d = fluvial dependant, and g = macrohabitat generalist).

	CPUE (number larvae/m^3)			
	2003	2004		
Taxa	**Sandbar**	**Channel Border**	**Sandbar**	**Guild**
Scaphirhynchus spp.	0.1	0.0	0.0	
S. albus				s
S. platorynchus				s
Lepisosteus osseus	0.1	0.0	0.0	D
Dorosoma cepedianum	0.0 *	0.2	0.0 *	g
Hiodon alosoides	0.1	0.8	0.2	D
Ctenopharyngodon idella	1.6	0.4	0.1	D
Cyprinella lutrensis	0.3	0.0 *	0.0 *	g
Cyprinus carpio	0.1	0.4	0.0	g
Cyprinidae spp.	0.0 *	0.0	0.0	
Cyprinid A	0.2	0.2	0.0 *	
Hybognathus argyritis				D
H. hankinsoni				g
H. placitus				D
Notemigonus crysoleucas				g

Table 1. Continued.

Taxa	CPUE (number larvae/m^3) 2003 Sandbar	2004 Channel Border	2004 Sandbar	Guild
Cyprinid B	0.5	0.2	0.1	
Cyprinella spiloptera				s
Lythrurus umbratilis				s
Notropis blennius				s
N. buchanani				s
N. shumardi				s
N. stramineus				s
N. wickliffi				s
Phenacobius mirabilis				s
Hypophthalmichthys spp	3.7	1.0	0.4	D
H. molitrix				
H. nobilis				
Luxilus cornutus	0.2	0.0	0.1	D
Macrhybopsis spp.	0.4	0.6	0.3	
M. aestivalis				s
M. gelida				s
M. meeki				s
M. storeriana				g
Notropis atherinoides	0.3	0.1	0.0 *	g
Pimephales notatus	0.1	0.2	0.1	g
Pimephales promelas	0.1	0.1	0.0	g
Semotilus atromaculatus	1.1	0.0	0.1	g

Table 1. Continued.

Taxa	CPUE (number larvae/m^3) 2003 Sandbar	2004 Channel Border	2004 Sandbar	Guild
Carpiodes spp.	6.7	0.5	2.1	
C. carpio				g
C. cyprinus				g
C. velifer				s
Catostomus commersoni	0.1	0.0	0.0	d
Ictiobus spp.	0.2	0.4	0.0	
I. bubalus				g
I. cyprinellus				g
I. niger				g
Lepomis spp.	0.1	0.0 *	0.0	
L. cyanellus				g
L. humilis				g
L. macrochirus				g
L. megalotis				g
Sander spp.	0.2	0.0	0.4	
S. canadense				g
S. vitreum				g
Aplodinotus grunniens	0.0 *	0.0 *	0.1	g
Unknown	0.3	0.0 *	0.1	
Total	11.3	3.2	2.8	

Table 2. Total catch-per-unit-effort (CPUE) for larval fishes collected in the lower Missouri River channel-margin ATTZ, 2003. Dates are first and last collection, maximum CPUE, mean water temperature, and mean and range of larvae total lengths on those dates.

	Total	**First collected**		**Max CPUE**			**Last collected**		**Total length (mm)**	
	CPUE			CPUE						
2003	(#/m^3)	Date	Temp °C	(#/m^3)	Date	Temp °C	Date	Temp °C	Mean	Range
Assemblage	11.3	29-Apr	18.4	44.2	17-Jun	26.2	17-Sep	23.2	9.3	23.7
Hypophthalmichthys spp.	3.7	28-May	22.0	27.2	17-Jun	26.2	23-Jul	30.2	8.1	6.6
Macrhybopsis spp.	0.4	12-Jun	23.7	1.9	30-Jun	27.9	12-Aug	29.3	9.8	17.2
Carpiodes spp.	6.7	22-May	19.7	22.4	10-Jun	23.6	14-Sep	24.3	10	22.8
2004										
Assemblage	3.2	15-May	22.7	27.8	15-Jun	25	16-Aug	25.5	7.8	18.7
Hypophthalmichthys spp.	0.7	20-May	22.6	18.5	15-Jun	25	27-Jul	24.2	8.6	4.4
Macrhybopsis spp.	0.4	20-May	22.6	1.6	6-Aug	25.8	12-Aug	25.8	8.4	13.0
Carpiodes spp.	1.5	15-May	22.7	9.8	30-Jun	24.9	16-Aug	25.5	7.2	12.3

Table 3. Results of information theoretic analyses for Missouri River larval fish assemblage habitat selection models with ΔQAIC <2, QAIC = Akaike Information Theoretic value with adjustment for over-dispersion, ΔQAIC = difference between minimum QAIC for the set of candidate models and the individual model QAIC. Model weight is likelihood of the model given the data normalized to 1.0. Percent concordance is accuracy for prediction of larval fish presence for each model. Validation includes the results from model validation for the k-fold cross validation using the three subsets from the 2003 data set (A, B, C) and the 2004 sandbar and shoreline data sets. Model parameters are: dpth=water depth, cv=current velocity, jul=julian date, sub=substrate type, tmp=water temperature.

				Validation		
Training sets A and B				2003 set C	2004 sandbar	2004 shoreline
Model	QAIC	ΔQAIC	weight	% concordance	% concordance	% concordance
cv + dpth + cv*dpth	274.47	0.00	13.7	60.2	52.7	49.4
dpth + jul	274.96	0.49	10.7	57.5	50.5	56.4
jul	275.01	0.55	10.4	49.9	43.6	53.8
dpth + tmp	275.60	1.14	7.8	58.4	49.9	52.3
tmp	275.98	1.51	6.4	51.4	50.5	50.7

Table 3. Continued.

				Validation		
Training sets A and C				2003 set B	2004 sandbar	2004 shoreline
Model	QAIC	ΔQAIC	weight	% concordance	% concordance	% concordance
dpth	197.27	0.00	11.7	53.2	48.8	50.3
dpth + sub	197.28	0.01	11.6	51.4	46.1	50.5
dpth + jul	197.55	0.29	10.1	55.9	49.6	55.5
dpth + tmp	198.00	0.73	8.1	55.6	49.9	51.7
sub	198.29	1.02	7.0	26.4	18.3	3.4
cv + dpth + cv*dpth	198.52	1.25	6.3	59.8	52.0	49.9
cv	198.55	1.29	6.1	50.7	48.6	49.2
jul	198.66	1.39	5.8	53.9	43.6	53.6
cv + dpth	199.04	1.77	4.8	54.0	49.3	50.6
dpth + sub + cv	199.24	1.97	4.4	51.1	45.5	50.7

Table 3. Continued.

				Validation		
Training sets A and C				2003 set B	2004 sandbar	2004 shoreline
Model	QAIC	ΔQAIC	weight	% concordance	% concordance	% concordance
tmp	199.25	1.99	4.3	55.2	50.0	49.9
dpth + sub + dpth*sub	199.26	2.00	4.3	51.3	46.0	50.5
Training sets B and C				2003 set A	2004 sandbar	2004 shoreline
cv + dpth + cv*dpth	419.53	0.00	48.8	60.7	52.3	49.4

Table 4. Results of information theoretic analyses for Missouri River larval *Carpiodes* spp. habitat selection models with ΔQAIC <2, QAIC = Akaike Information Theoretic value with adjustment for over-dispersion, ΔQAIC = difference between minimum QAIC for the set of candidate models and individual model QAIC. Model weight is likelihood of the model given the data normalized to 1.0. Percent concordance is accuracy for prediction of larval fish presence for each model. Validation includes results from model validation for k-fold cross validation using the three subsets from the 2003 data set (A, B, C) and the 2004 sandbar and shoreline data sets. Model parameters are: dpth=water depth, cv=current velocity, jul=julian date, sub=substrate type, tmp=water temperature.

				Validation	
Training sets A and B				2003 set C	2004
Model	QAIC	ΔQAIC	Weight	% concordance	% concordance
dpth	93.60	0.00	18.90	61.9	55.7
cv	94.12	0.52	14.60	58.5	55.2
cv + dpth +cv*dpth	94.64	1.04	11.23	63.7	55.9
cv + dpth	94.83	1.23	10.21	61.5	57.9
dpth + tmp	95.56	1.96	7.10	62.2	56.0
dpth + jul	95.60	1.99	6.98	62.3	55.7
Training sets A and C				2003 set B	2004
cv + dpth +cv*dpth	146.66	0.00	29.68	64.7	52.4
dpth	147.68	1.02	17.78	62.1	52.2

Table 4. Continued.

				Validation	
Training sets B and C				2003 set A	2004
Model	QAIC	ΔQAIC	Weight	% concordance	% concordance
cv + dpth +cv*dpth	149.83	0.00	19.02	70.8	52.4
cv	150.09	0.27	16.64	65.7	20.8
dpth	150.92	1.10	10.99	71.8	52.0
sub	151.03	1.20	10.42	19.5	22.6
cv + dpth	151.77	1.94	7.20	71.7	51.7

Table 5. Results of information theoretic analyses for Missouri River larval *Hypophthalmichthys* spp. habitat selection models with ΔQAIC <2, QAIC = Akaike Information Theoretic value with adjustment for over-dispersion, ΔQAIC = difference between minimum QAIC for the set of candidate models and individual model QAIC. Model weight is likelihood of the model given the data normalized to 1.0. Percent concordance is accuracy for prediction of larval fish presence for each model. Validation includes results from model validation for k-fold cross validation using three subsets from the 2003 data set (A, B, C) and 2004 sandbar and shoreline data sets. Model parameters are: dpth=water depth, cv=current velocity, jul=julian date, sub=substrate type, tmp=water temperature.

				Validation	
Training sets A and B				2003 set C	2004
Model	QAIC	ΔQAIC	Weight	% concordance	% concordance
tmp	30.43	0.00	0.16	67.7	48.5
cv	30.66	0.23	0.14	67.9	38.9
dpth + tmp	31.44	1.01	0.09	70.3	45.1
jul	31.80	1.37	0.08	51.1	39.2
dpth + jul	31.92	1.49	0.07	69.3	40.4
cv+jul	32.10	1.67	0.07	71.4	40.2
dpth	32.10	1.67	0.07	56.5	42.9
cv + dpth	32.42	1.99	0.06	69.4	40.8

Table 5. Continued.

				Validation	
Training sets A and C				2003 set B	2004
Model	QAIC	ΔQAIC	Weight	% concordance	% concordance
dpth + tmp	27.50	0.00	0.18	67.2	58.1
tmp	27.59	0.09	0.17	65.3	53.6
cv + tmp +cv*tmp	29.17	1.68	0.08	73.0	54.0
dpth+tmp + dpth*tmp	29.30	1.81	0.07	71.2	57.4
jul	29.42	1.92	0.07	49.2	55.9
Training sets B and C				2003 set A	2004
tmp	32.84	0.00	0.14	69.1	53.6
cv	32.99	0.15	0.13	70.2	32.6
jul	33.64	0.80	0.10	40.2	55.9
dpth + jul	33.87	1.03	0.09	66.8	60.6
dpth + tmp	33.94	1.09	0.08	71.3	60.2
cv+jul	33.95	1.11	0.08	68.0	56.9
cv + dpth	34.77	1.93	0.06	69.1	66.6

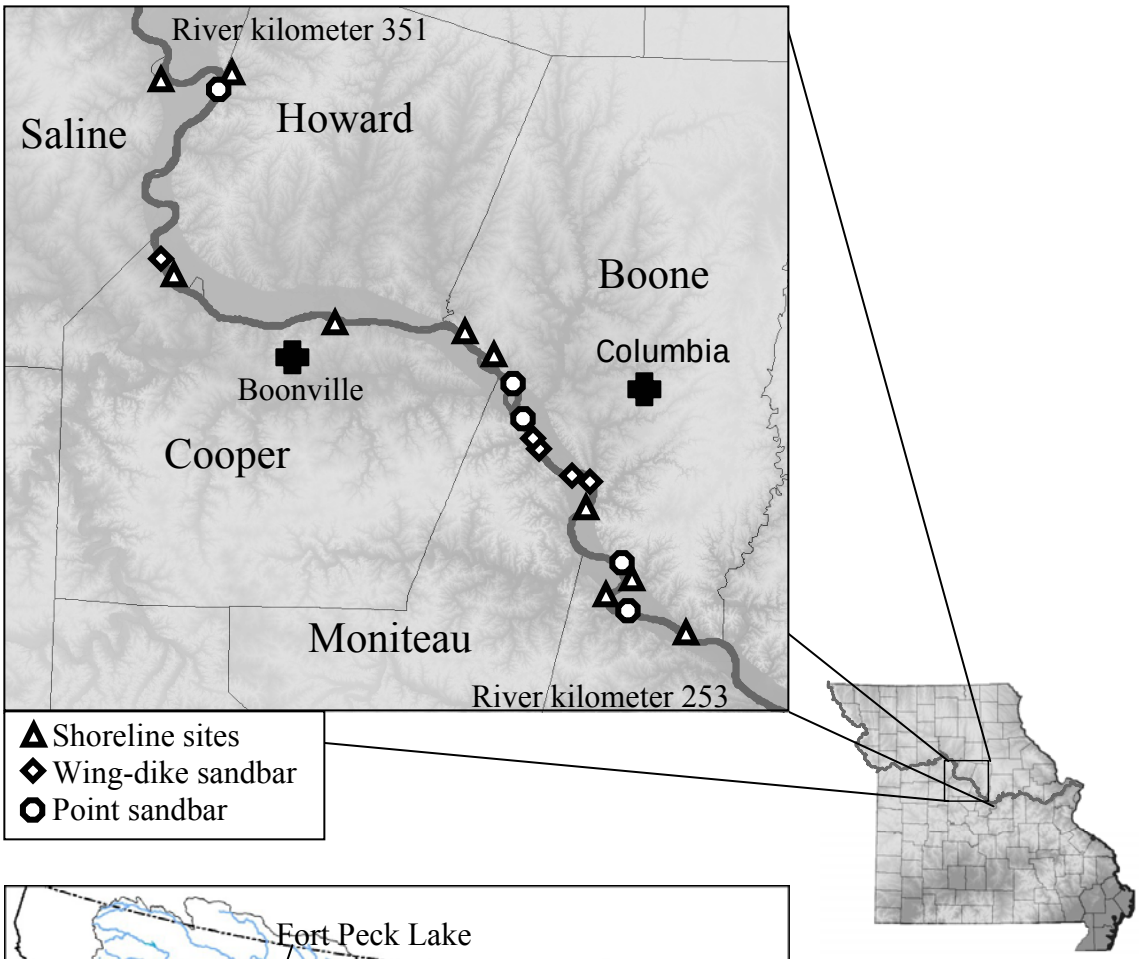
Table 6. Results of information theoretic analyses for Missouri River *Macrhybopsis* spp. habitat selection models with ΔQAIC <2, QAIC = Akaike Information Theoretic value with adjustment for over-dispersion, ΔQAIC = difference between minimum QAIC for the set of candidate models and individual model QAIC. Model weight is likelihood of the model given the data normalized to 1.0. Percent concordance is accuracy for prediction of larval fish presence for each model. Validation includes results from model validation for the k-fold cross validation using the three subsets from the 2003 data set (A, B, C) and the 2004 sandbar and shoreline data sets. Model parameters are: dpth=water depth, cv=current velocity, jul=julian date, sub=substrate type, tmp=water temperature.

				Validation	
Training sets A and B				2003 set C	2004
Model	QAIC	ΔQAIC	Weight	% concordance	% concordance
cv	341.05	0.00	0.27	40.9	52.7
cv + dpth	342.96	1.91	0.10	43.3	55
Training sets A and C				2003 set B	2004
cv	503.35	0.00	0.22	47.1	48.9
dist	503.73	0.38	0.18	39	43.2
jul	504.94	1.59	0.10	28.4	32.3
cv + dpth	505.21	1.87	0.08	48	49.7
Training sets B and C				2003 set A	2004
sub	829.26	0.00	0.31	27.5	2.3
dpth + sub + dpth*sub	830.70	1.44	0.15	49.4	50.7
dpth + sub	831.24	1.98	0.11	34.2	2.3

Table 7. Mean (m) ± standard deviation (sd) for environmental variables including: water depth, current velocity, distance from shore (distance), and water temperature, as well as percent of microhabitat samples collected along sandbars and channel margins with gravel, sand, or silt substrate within the lower Missouri River in 2003 and 2004 containing larval fishes (Assemblage), *Carpiodes* spp., *Hypophthalmichthys* spp., and *Macrhybopsis* spp.

	Water Depth	**Current Velocity**	**Distance**	**Temperature**	**Substrate**		
	cm	cm/s	m	°C			
2003	m ± sd	m ± sd	m ± sd	m ± sd	% gravel	% sand	% silt
Assemblage	34.5 ± 26.4	15.3 ± 17.3	5.9 ± 9.94	27.5 ± 2.8	4.6	45.5	49.9
Hypophthalmichthys spp.	48.2 ± 25.5	24.1 ± 20.0	7.8 ± 11.9	25.9 ± 1.4	0	48.2	51.8
Macrhybopsis spp.	39.7 ± 19.1	13.8 ± 16.0	6.2 ± 8.0	27.9 ± 1.8	2.5	62.5	35
Carpiodes spp.	28.1 ± 26.8	14.2 ± 16.2	5.3 ± 8.3	28.3 ± 3.0	0	49.1	50.9
2004							
Assemblage	40.5 ± 24.4	14.0 ± 14.7	4.0 ± 5.2	26.3 ± 2.0	3.7	41.9	54.4
Hypophthalmichthys spp.	53.1 ± 24.0	22.1 ± 17.0	4.5 ± 5.7	26.1 ± 1.9	9.3	33.3	57.4
Macrhybopsis spp.	37.5 ± 18.8	6.4 ± 5.9	2.3 ± 3.1	26.8 ± 1.6	1.4	25.7	72.9
Carpiodes spp.	36.5 ± 24.5	16.0 ± 15.2	4.8 ± 5.9	26.2 ± 2.2	4.3	61.5	34.2

Figure 1. Map of the Missouri River drainage basin showing upper, middle, and lower Missouri River reaches and a map of the research area from river kilometer 253 (mile 157) to river kilometer 351 (mile 218). Wing-dike sandbar study sites sampled in 2003 and 2004 are marked by diamonds, point sandbars are marked by circles, and shoreline study sites sampled in 2004 are marked by triangles.


River kilometer 351
Saline
Howard
Boone
Columbia
Boonville
Cooper
Moniteau
River kilometer 253
Shoreline sites
Wing-dike sandbar
Point sandbar

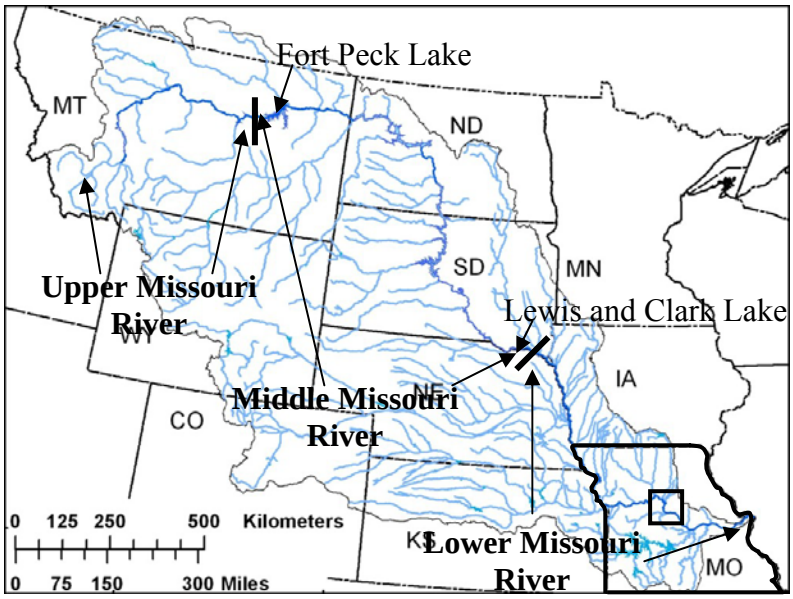

Fort Peck Lake
MT
ND
SD
MN
Upper Missouri River
Lewis and Clark Lake
WY
IA
NE
Middle Missouri River
CO
0 125 250 500 Kilometers
0 75 150 300 Miles
KS
Lower Missouri River
MO

Figure 2. Aerial view of Missouri River study section illustrating channel border, point sandbar, and wing-dike sandbar study sites. Photos made by U.S. Army Corps of Engineers between 26 February 2000 and 24 March 2000.

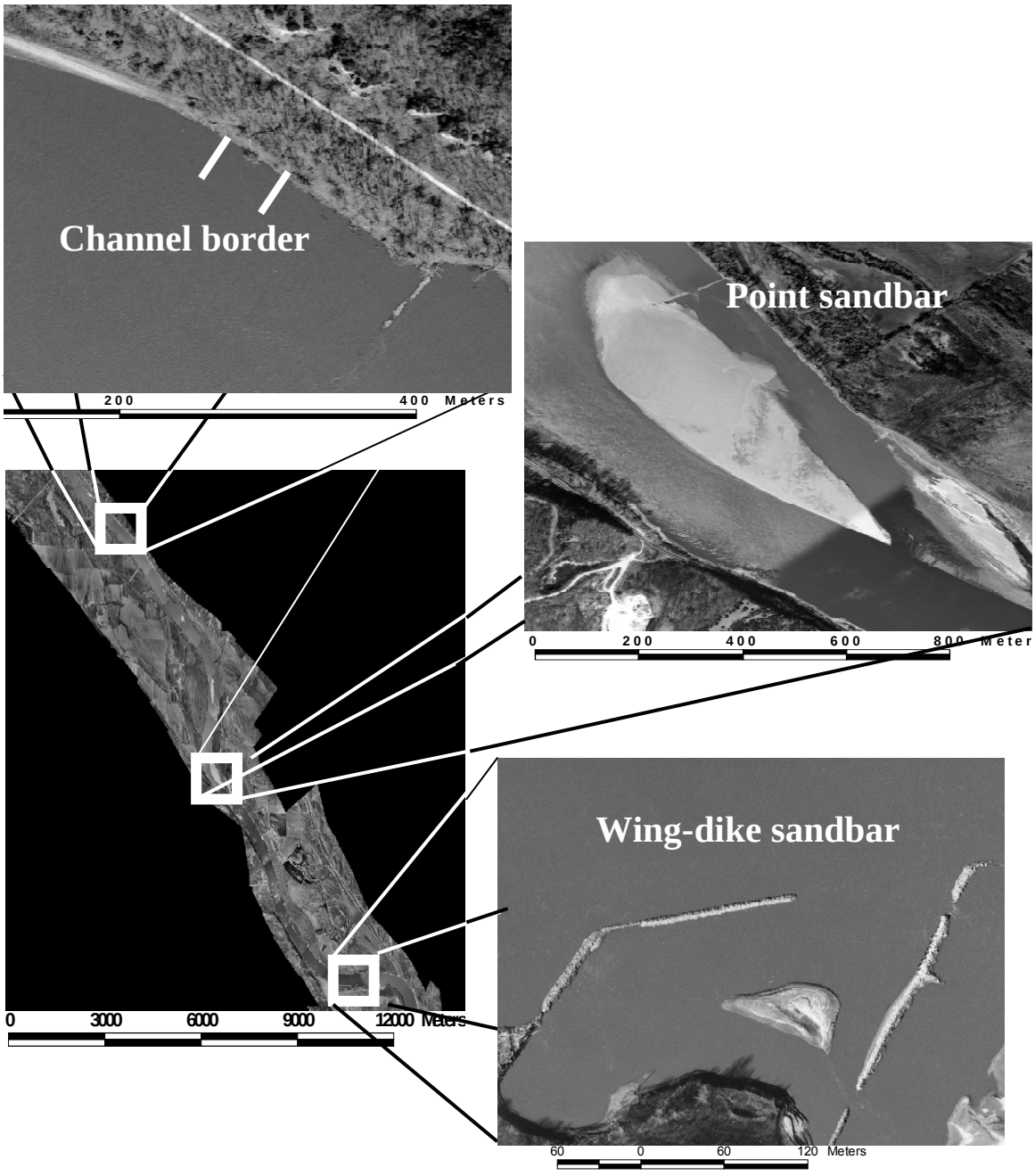


Figure 3. Missouri River daily mean discharge recorded between 15 March and 30 September of 2003 and 2004 at the USGS gauging station near Boonville, MO (gauge number 6909000).

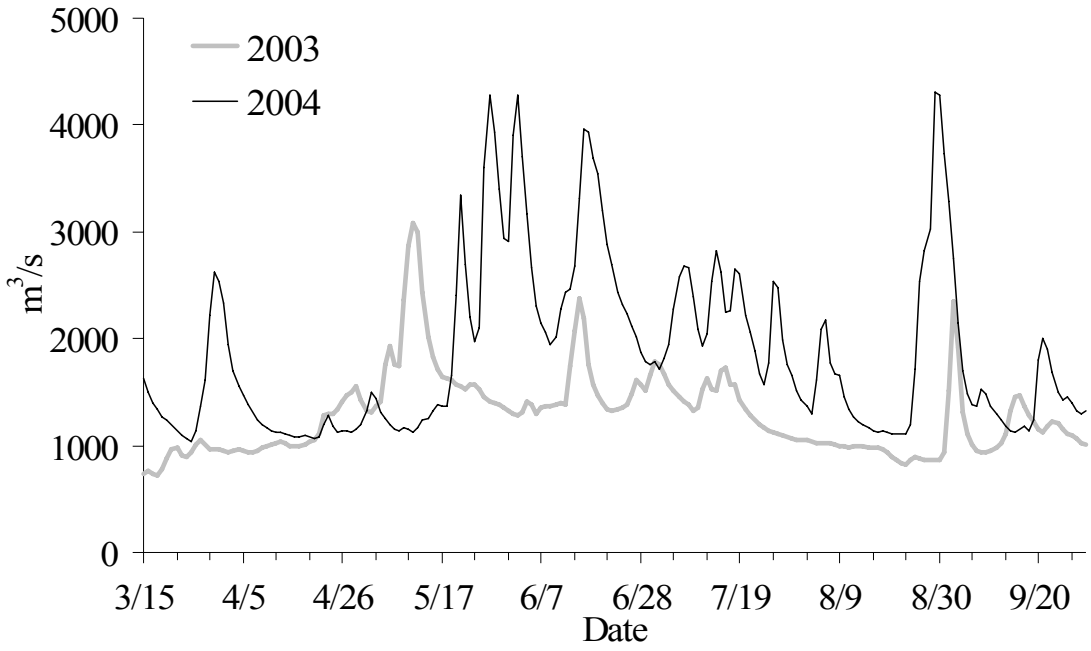


Figure 4. Histograms of use and availability of depth, current velocity, water temperature, and substrate type, with level of significance and Chi square (χ^2) from compositional analysis for the larval fish assemblage from microhabitat samples collected in the ATTZ of the lower Missouri River from April to September 2003. Habitat classes with asterisks are significantly ($p<0.05$) different than non-asterisked classes

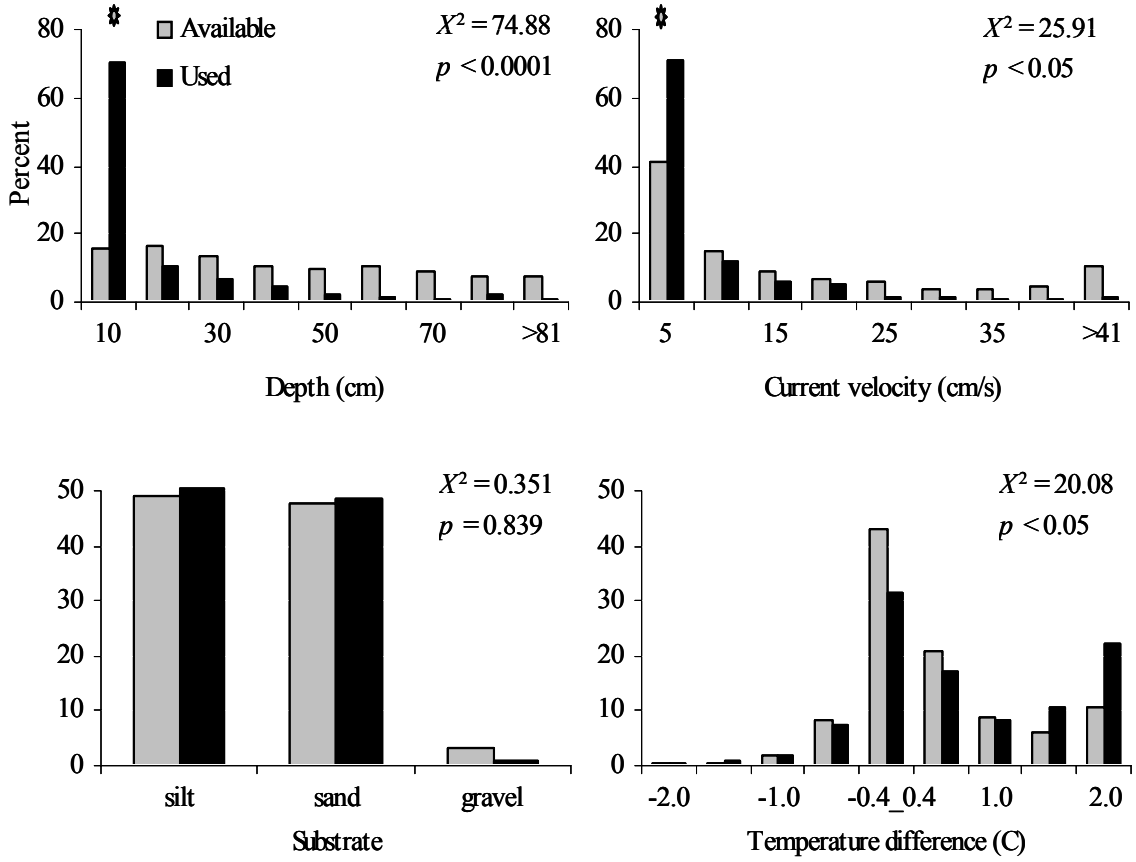


Figure 5. Histograms of use and availability of depth, current velocity, water temperature, and substrate type, with level of significance and Chi square (χ^2) from compositional analysis for larval *Carpiodes* spp. from microhabitat samples collected in the ATTZ of the lower Missouri River from April to September 2003. Habitat classes with asterisks are significantly ($p<0.05$) different than non-asterisked classes

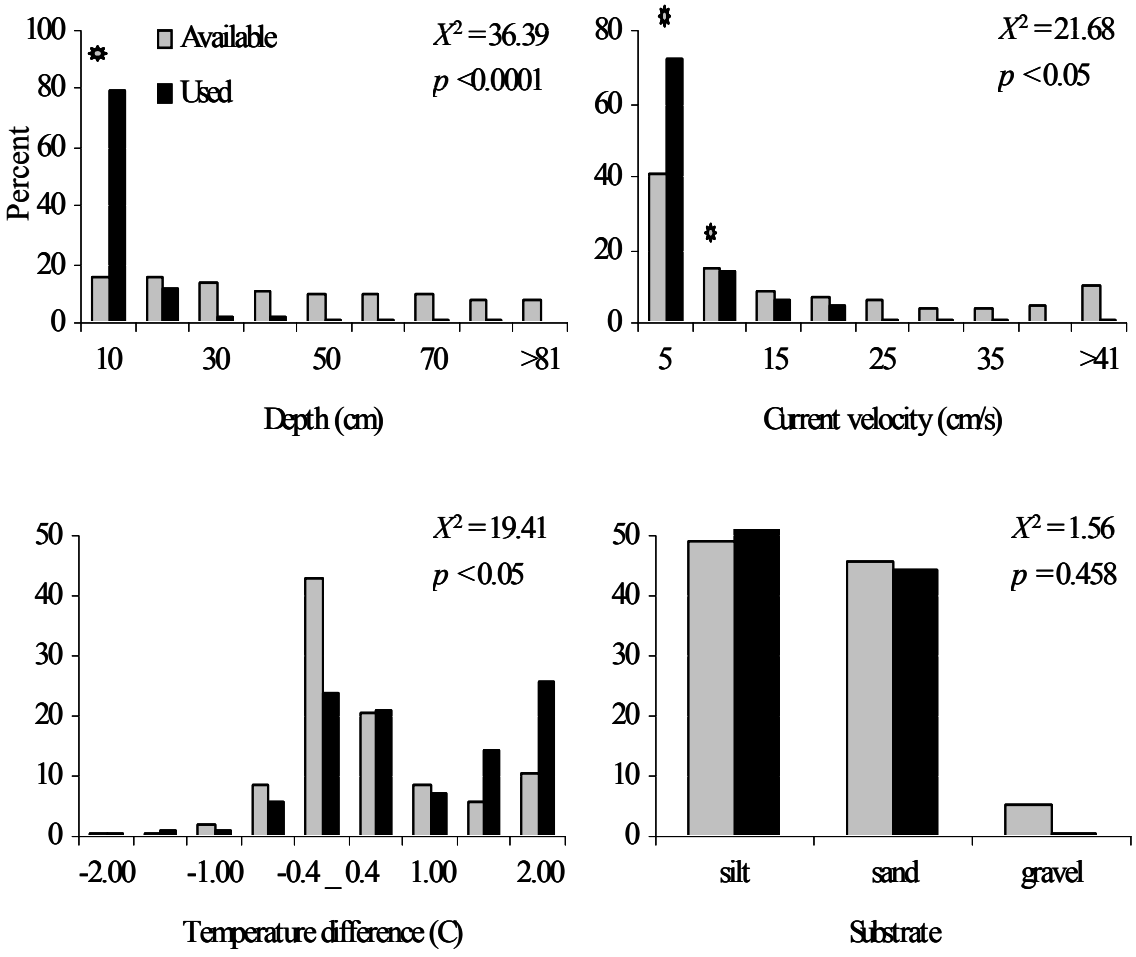


Figure 6. Histograms of use and availability of depth, current velocity, and water temperature with level of significance and Chi square (χ^2) from compositional analysis for larval *Hypophthalmichthys* spp. from microhabitat samples collected in the ATTZ of the lower Missouri River from April to September 2003. Habitat classes with asterisks are significantly ($p<0.05$) different than non-asterisked classes

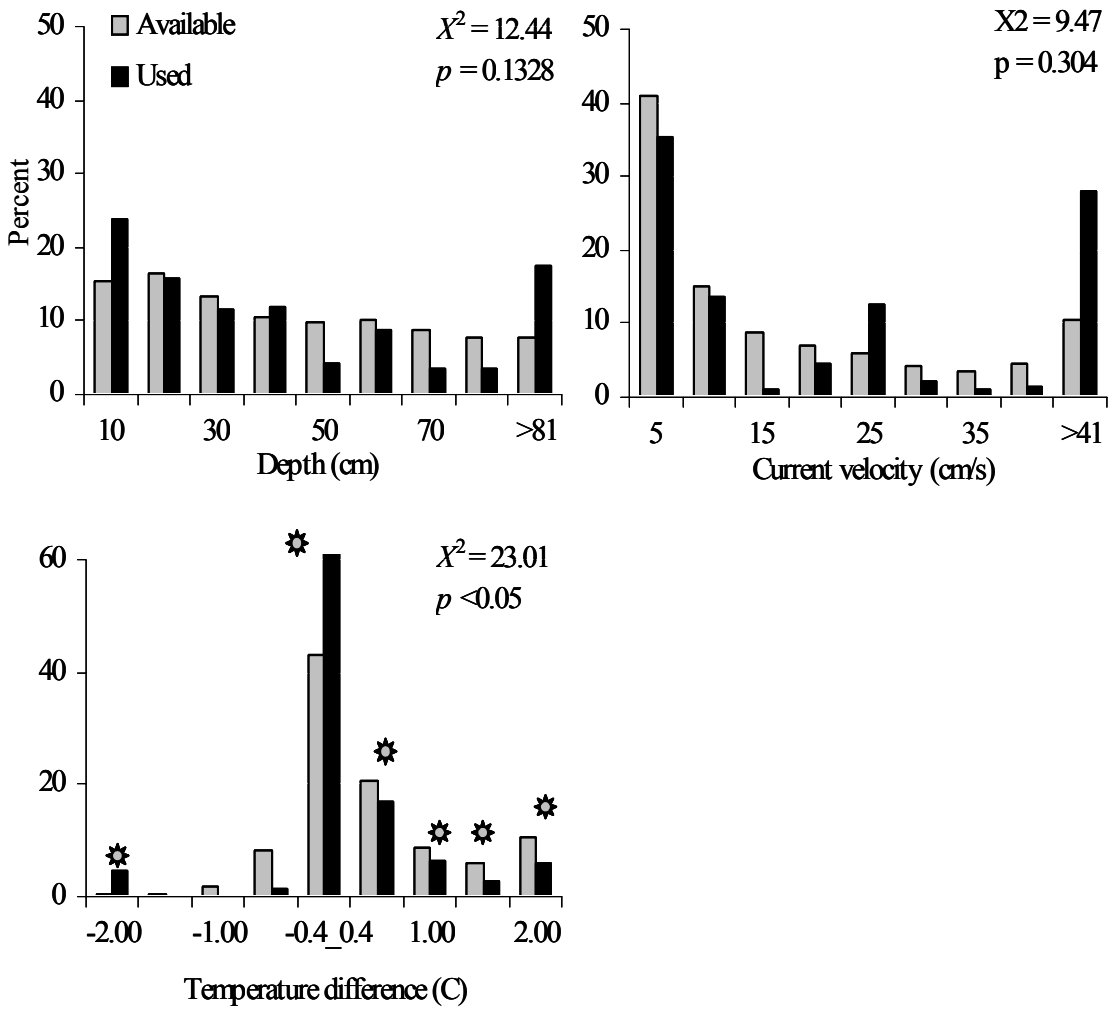
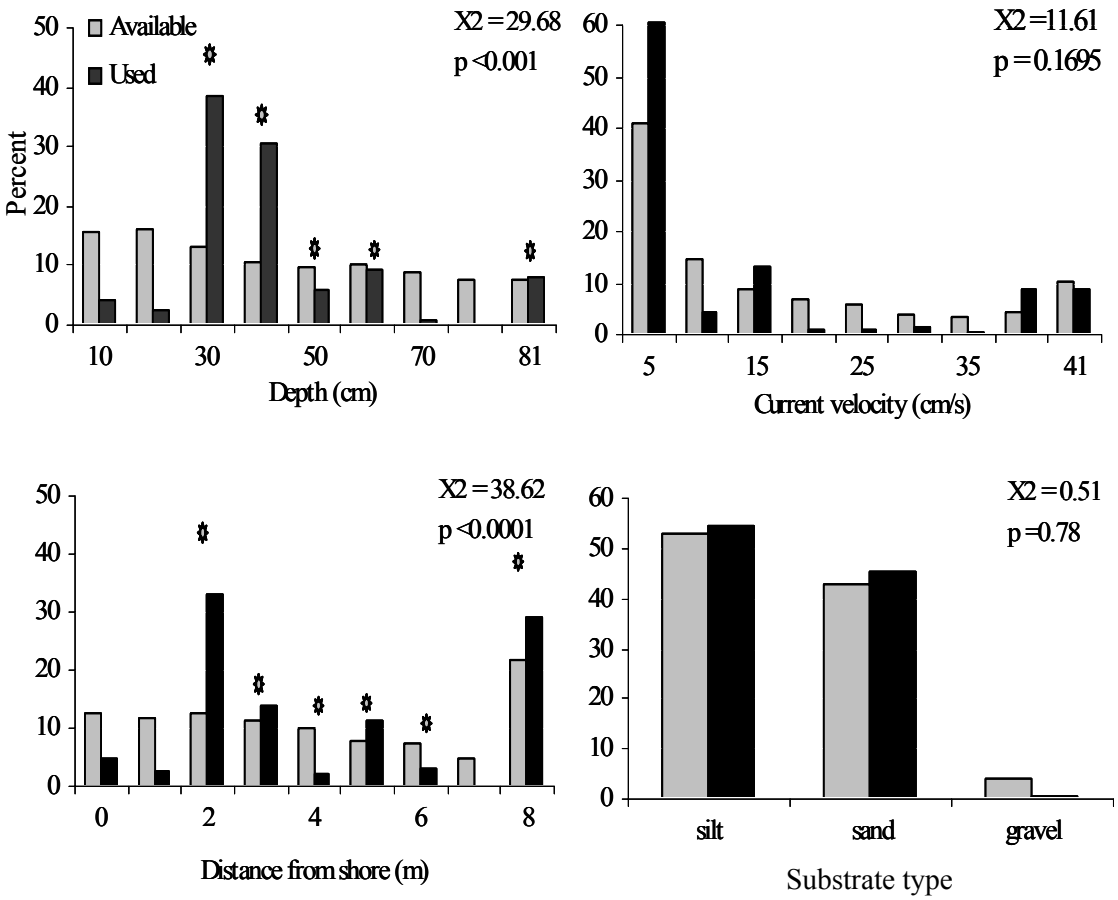


Figure 7. Histograms of use and availability of depth, current velocity, distance from shore, and substrate type, with level of significance and Chi square (χ^2) from compositional analysis for larval *Macrhybopsis* spp. from microhabitat samples collected in the ATTZ of the lower Missouri River from April to September 2003. Habitat classes with asterisks are significantly ($p<0.05$) different than non-asterisked classes



Chapter IV

TEMPORAL SHIFT IN HABITAT USE BY LARVAL FISHES IN A LARGE, TURBID RIVER, MISSOURI RIVER, MISSOURI

Abstract

We collected larval fishes in the lower Missouri River, Missouri, a large, turbid-water river to evaluate the suggestion by previous research that rivers with water transparency <30 cm lack a nocturnal shift in habitat use. Larval fishes were collected every six hours per 24-hour period in two floodplain waterbodies (one continuously connected and one periodically connected to the Missouri River) in summer 1996 (26 June and 3 July) and summer 1997 (3 July and 10 July). Larval fishes were also collected every four hours per 24-hour period along in-channel sandbar margins and within primary and secondary channels on seven occasions during summer 2002 (30 May, 6, 19, 27 June, 17 July, 1 and 8 August). There were no significant increases in catch-per-unit-effort (CPUE) for all taxa combined at night within floodplain waterbodies (mean Secchi <30 cm on 3 of 4 occasions). There was a significant increase from day to night in CPUE for all taxa combined along in-channel sandbars and primary and secondary channels. This pattern was evident though mean Secchi depth was 12 cm during the study period. Several taxa exhibited significantly higher nocturnal CPUE within floodplain waterbodies and along in-channel sandbars including: *Carpiodes*/*Ictiobus* spp., *Ctenopharyngodon idella,* and a group of Cyprinids. We propose the effect of water transparency is species specific, and ability to detect significant increases in larval fish abundance may be determined by

resolution of data analysis. Species-specific drift patterns of abundant taxa may mask patterns of rare taxa when analyzed at the assemblage level.

Introduction

The life cycle of many fishes is punctuated by three major migrations: 1) migration of adults to spawning grounds, 2) migration (hereafter referred to as drift) of eggs and larvae from spawning sites to nursery habitat, and 3) migration of pre-adults to adult habitats (Fuiman and Werner 2002). Each of these migrations can represent a period when the individual is at increased vulnerability to physiological stress and predation (Lucan and Baras 2001). Understanding patterns of larval fish drift in rivers is complicated by the ephemeral presence of many species, difficulty of working in lotic systems at night, complexity of habitats, and difficulty of sampling fish larvae similarly among habitat types. Due to these factors, many research projects focus specifically on larval drift only near the shore (Scott and Nielsen 1989, Baras and Nindaba 1999, Reichard et al. 2001) or only in the primary channel (Clark and Pearson 1980, Johnston et al. 1995). While these projects provide valuable information, research integrating lateral (shoreline, anabranches, and primary channel) (Brown and Armstrong 1985, Robinson et al. 1998), or vertical components of larval fish drift (streambed, mid-depth, and surface) (Corbett and Powles 1986, Pavlov 1995, de Graaf et al. 1999**)**, or both (Carter et al. 1986, Reichard et al. 2004), provide a more thorough picture of larval fishes drift pattern.

One component of larval fish drift receiving increasing attention has been the diel pattern of drift in rivers. A vertical diel migration is well documented for many marine fishes (Brodeur and Rugen 1994, Fuiman and Werner 2002) as well as in many

freshwater lakes or reservoirs (Thayer et al. 1983, Wurtsbaugh and Neverman 1988, Gehrke 1992, Sammons and Bettoli 2002). Increased larval abundance in drift samples collected at night has been detected in some rivers (Brown and Armstrong 1985, Carter et al. 1986, Næsje et al. 1986, Gadomski and Barfoot 1998, Oesmann 2003); however, no nocturnal increase in larval fish drift has also been reported (Pavlov et al. 1977, Sager 1987; Savenkova and Asanov 1988, Bogdanov et al. 1991). Pavlov et al. (1995) noted that presence or absence of a diel pattern in abundance of drifting larval fishes in the upper Amazon River system was related to turbidity. Rivers with water transparency >30 cm had this daily rhythm, whereas rivers with transparencies <30 cm did not.

We tested the hypothesis that rivers with water transparencies <30 cm lacked a diel pattern in larval fish abundance at the assemblage level, and for individual taxa in the lower Missouri River, a large, turbid-water river (Galat et al. 2005a). Water transparency within the lower Missouri River is consistently <30 cm during summer months (Table 1). We also reviewed literature on the presence-absence of a diel shift in larval drift in other rivers to determine if the lower Missouri River follows a pattern consistent to other turbid-water rivers. Developing an understanding of mechanisms driving larval drift is vital for locating and protecting required spawning habitat for imperiled or commercially valuable species, projects intending on restoring nursery habitat, adequately estimating year-class strength or stock assessment, and preserving conditions conducive for dispersal of larval fishes from spawning grounds to nursery habitat.

Study area

The Missouri River is the longest river in the U.S., flowing 3768 km, and draining $1/6^{th}$ of the continental U.S. (Galat et al. 2005b). Headwaters of the Missouri River are in the Rocky Mountains, it then flows through the Great Plains, Central Lowlands, and Interior Highlands before joining the Mississippi River near St. Louis, Missouri. The lower Missouri River was historically a broad, meandering river with many side-channels and sandbars prior to European settlement. It was nicknamed "Big Muddy" as it was one of the most turbid large rivers in North America (Galat et al. 2005b). Development projects during the early and mid 1900's have effectively divided the Missouri River into three distinct segments, nearly equal in length (Hesse et al. 1988). The lower one-third was channelized through installation of wing-dikes, shoreline armoring, and levee construction. This decreased surface area by 50%, reducing sandbar number by >90%, and confined much of its flow to a single deep, swift channel (Funk and Robinson 1974). A series of six large reservoirs compose the middle one-third of the river. The upper third remains predominantly free flowing (Hesse et al. 1988). Installation of six dams, and their associated reservoirs, has altered the flow regime and dramatically decreased turbidity of the lower Missouri River. Annual mean turbidity measurements at St. Louis, Missouri ranged between 1200 and 2700 JTU's prior to impoundment. Turbidity was decreased by about two-thirds to between 400 and 700 JTU's after completion of the final dam (Pflieger and Grace 1987).

The study section of lower Missouri River was between river kilometers 283 and 421, measured moving upstream from the confluence with the Mississippi River (Figure 1). Four study sites were selected; two floodplain waterbodies and two sandbars within the

main-stem Missouri River. The floodplain waterbodies, or scours where formed when floodwaters overtopped or breeched a levee and excavated a basin during the "Great Midwest Flood" of 1993 (Galat et al. 1997). One scour remained continuously connected to the Missouri River and one was connected to the river periodically during seasonal high-flows. Each sandbar represented one of the two dominant classes of sandbars in the lower Missouri River, those formed: 1) on the inside of a river bend, and 2) behind rock wing dikes.

Methods

Larval fishes were collected from scours twice in 1996 (26 June and 3 July) and twice in 1997 (3 July and 10 July) at 6:00, 12:00, 18:00 and 24:00 hours. They were collected using a larval sled net (25-cm tall, 54-cm wide, 1.4-m long, with 500-µm Nytex nylon mesh) based on designs by Topp (1967) and Yocum and Tesar (1980). The sled was designed to float in the upper 0.5 m of the water column in areas >0.5-m deep. Runners on the bottom of the sled's frame allowed the sled to slide over the substrate in water <0.5-m deep. This facilitated use of the same sampling device in both near-shore and open-water areas (Galat et al. 2004).

Scours were divided into six habitat categories based on proximity to shore and presence or absence of current. Three habitat categories with no detectable current were present in both scours and were chosen for sampling. Near-shore shallow (NSS) areas were defined as <0.6-m deep and <30 m from shore. Near-shore deep (NSD) areas were >0.6-m deep and <30 m from shore. Finally, open water (OW) habitats were >0.6-m deep and >30 m from shore (Galat et al. 2004).

For most samples, the sled was towed at the surface 30 m behind a boat at a speed of approximately 1 m/s. A General Oceanics model #2030R flow meter was suspended in the mouth of the net to determine the distance of each tow. In water too shallow for boat operation, the net was pulled 60 m by hand at a speed of approximately 1m/s. Tow volume was calculated by multiplying the area of the net opening by length of the tow. Volume of water filtered for boat and hand-towed NSS samples were adjusted for portions of the tow the entire net opening was not submerged (Galat et al. 2004).

Larval fishes were collected in 2002 on 30 May, 6, 19, and 27 June, 17 July, and 1 and 8 August around sandbars and within adjacent primary and secondary channels at 2:00, 6:00, 10:00, 14:00, 18:00 and 22:00 hours. Collectively these will be referred to as "sandbar" samples to distinguish from "scour' samples previously described. Primary and secondary channel samples were collected using paired, bow-mounted ichthyoplankton nets (30-cm tall, 60-cm wide, 1.4-m in length, with 500-µm Nytex nylon mesh) (Colton et al. 1980, Pepin and Shears 1997). Larval fishes were collected along sandbar margins using a hand-operated push-cart with paired □ollock□a□nkton nets of the same construction as bow-mounted nets. The push-cart had a skid allowing it to slide over the substrate in water <30-cm deep, and float with the top of the net at the water surface in water >30-cm deep. Both gears sample the upper 30 cm of the water column, and collections were made by traveling downstream approximately 1 m/s faster than the water current (Gallagher and Conner 1983, Brown 1989).

Two 50-m transects were sampled along sandbar margins; one on the primary and one on the secondary channel facing sides, along the downstream one-half of the sandbar. Two parallel samples were collected within each transect. The shoreward sample was

collected by traveling downstream with the shoreward side of the sample cart traveling along the aquatic-terrestrial transition zone (ATTZ). The riverward sample was collected in the same manner along a contiguous path, riverward of the first. Two primary and two secondary channel samples were collected mid-channel by traveling downstream approximately 350 m.

Collection distance was measured for boat samples using a General Oceanics model #2030R propeller-style flow meter suspended between mouths of the nets. Sample volumes were calculated for boat and push-cart samples by multiplying net area by distance traveled. Sample volume was adjusted in areas where water depth was insufficient for complete net submersion (i.e., <30 cm), by measuring water depth in cm every 10 m on both sides of the push-cart path. The mean of these two depths was used to calculate an adjusted net area.

Water transparency

Turbidity, using a Hach ratio turbidimeter measured in NTU's, and light absorbance, at 440 nm in a 5 cm light path X 1000, were measured approximately monthly from March 1994 through September 2002 for a concurrent study. Only light absorbance was collected beginning in June 2002, due to the high correlation between the two measures (Knowlton unpublished data). Galat et al. (2004) related Secchi depths to turbidity using the following equation:

$$\text{Log NTU} = 3.199 - 1.259 \log \text{Secchi depth (cm)}; r^2 = 0.79, p<0.0001$$

The Galat et al. (2004) equation was derived for turbidity (NTU) measures so light absorbance (ABS) data had to first be converted to NTUs using the following equation

derived from 31 paired turbidity and absorbance values collected between May and August from the Knowlton data set:

$$NTU = 0.2749*ABS + 0.5272;\ r^2 = 0.99,\ p<0.0001$$

Turbidity and absorbance data were converted to Secchi depth to be more easily compared with other diel larval fish studies (Table 2) that used Secchi depth as their measure of water transparency.

Larval fish handling and identification

Net contents were fixed in the field in 10% neutrally buffered formalin, and stored for 24 hours. Samples were then transferred to 70% ethanol and stored until identification. Larval fishes were separated in the laboratory from detritus using combined methods of staining larval fishes with eosin Y, and flotation using sucrose solution (Anderson 1959, Pask and Costa 1971, Hall et al. 1996). All larval fishes were identified to the lowest reliable taxonomic level using keys developed by May and Gassaway (1967), Auer (1982), Fuiman et al. (1983), Holland-Bartels et al. (1990), Wallus et al. (1990), and Kay et al. (1994). Verification of identification for selected taxa including larval sturgeon was conducted by Darrel E. Snyder at the Colorado State University Larval Fish Laboratory.

Statistical analysis

Abundance of larval fishes was reported and analyzed as catch per unit effort (CPUE = number of fish / 100 m^3 water). Prior to analysis, assumptions of normality and homogeneity of variance of CPUE data were tested using Shapiro-Wilks and Fligner-Killeen tests, respectively. Raw CPUE data failed to meet the required assumptions.

Common data transformations were performed according to Tabachnick and Fiddell (2001) and assumptions re-tested. Transformed CPUE data continued to fail to meet assumptions, so a rank transformation of CPUE data was used (Conover 1980, Schabetsberger et al. 2000) for all subsequent analyses.

Samples from all habitat types collected over a single 24-hour period were grouped and ranked by CPUE. Due to the long collection period for sandbar data (30 May through 8 August), ephemeral presence of many larval fishes, and changing hydrograph of the lower Missouri River, the 2002 summer was divided into two periods for analysis (Figure 3). During the spring sample period (30 May – 27 June) there were four sampling trips. The point sandbar and the wing-dike sandbar were each sampled twice on alternating trips. During summer (17 July – 8 August) only the point sandbar was sampled. This was due to low water levels that were insufficient to maintain a secondary channel at the wing-dike sandbar. Larval fishes were only collected on two occasions per year in the floodplain scours; these were within about one week of each other, so these data were not separated for analysis.

During analysis the 06:00 sample repeatedly appeared as an anomalous night sample with CPUE more similar or often lower than day samples. Sunrise and sunset times were then reviewed from the NOAA website (http://www.srrb.noaa.gov/highlights/sunrise /sunrise.html), and it was found that the 06:00 sample was collected within one hour of sunrise on several occasions. Due to concerns the 06:00 sample may represent a crepuscular effect and obscure differences between day and night, a separate data set was created repeating the above described methods, but excluding the 06:00 sample. Sunset

was greater than one hour after collection of the 18:00 sample on all dates so this sample was not excluded from analysis.

Ranked CPUE data were analyzed using a split-split-plot in time ANOVA. Habitat category (NSS, NSD, and OW for scours, or shoreward, riverward, and channel for sandbar) was the main plot, day/night and interactions with habitat category were sub plots, and time of sample collection and interactions with habitat category and day/night were sub-sub plots. Least significant means tests were used when a significant F-test occurred. This analysis was repeated two times for floodplain scour collections: 1) all collection dates and all samples, and 2) all collection dates excluding 06:00 samples, and six times for in-channel sandbar collections: 1) all collection dates and all samples, 2) all collection dates excluding the 06:00 samples, 3) spring collection dates all samples, 4) spring collection dates excluding 06:00 samples, 5) summer collection dates all samples, and 6) summer collection dates excluding 06:00 samples. Individual analyses were conducted as described above with any taxonomic group present in at least 50% of the samples collected within two, 24-hour periods. Probability levels were adjusted for repeated analyses using a Bonferoni correction to $\alpha = 0.025$ (.05/2) for floodplain scour analyses, and $\alpha = 0.0083$ (.05/6) for in-channel sandbar analyses.

Results

A total of 75,347 larval fishes representing 22 taxonomic groups was collected along the two in-channel sandbars and within the primary and secondary channels in 2002. Ten taxonomic groups were present in at least 50% of sandbar samples collected within 2, 24-hour periods and were analyzed individually. Fewer larvae were collected within the

floodplain scours, a total of 9,379 larval fishes representing 14 taxonomic groups. Four taxonomic groups were present in at least 50% of scour samples collected within two, 24-hour periods and were analyzed individually (Table 3).

Five taxonomic groups were only present during the spring sampling period for in-channel sandbars: grass carp (*Ctenopharyngodon idella*), gizzard shad (*Dorosoma cepedianum*), goldeye (*Hiodon alosoides*), bighead/silver carps (*Hypophthalmichthys molitrix/nobilis*), and sicklefin/sturgeon (*Macrhybopsis meeki/gelida*) chubs. Seventeen paddlefish (*Polyodon spathula*) were collected during the study; sixteen were collected at night. More sunfish (*Lepomis* spp.) were collected in floodplain scours (2,259) than along in-channel sandbars and primary and secondary channels (108). Although sunfish composed 24.1% of the total catch within floodplain scours, they were only present on one date, and thus, were not analyzed separately.

Results of the split-split-plot ANOVA of total CPUE for the entire 2002 collection period revealed significantly higher CPUE at night with the 06:00 sample excluded, but total CPUE was not significantly different with inclusion of the 06:00 sample. The carpsuckers/buffalo (*Carpiodes* spp./*Ictiobus* spp.) group had significantly higher CPUE at night for the total 2002 collection period excluding the 06:00 sample and during the spring sample period excluding the 06:00 sample, however, these differences were not significant with the 06:00 sample included. Grass carp had significantly higher CPUE at night with and without the 06:00 sample included (Table 4). Three taxonomic groups (gizzard shad, sicklefin/sturgeon chub, and emerald shiner (*Notropis atherinoides*)) had higher CPUE during the day, but none of these differences were significant. Only one

taxonomic group, Cyprinid B, had significantly higher CPUE at night during the summer sampling period.

Total CPUE was not significantly different between night and day for the floodplain scours with or without the inclusion of the 06:00 sample; however differences in CPUE approached significance with the 06:00 sample excluded $p=0.0267$. No taxonomic group had significant differences between day and night CPUE with inclusion of the 06:00 sample, but both carpsuckers spp./buffalo spp. and cyprinid B had significantly higher CPUE at night with the exclusion of the 06:00 sample.

Discussion

Contrary to our hypothesis, initial analysis of total catch-per-unit-effort (CPUE) of larval fishes in floodplain scours and within the mainstem Missouri River did not show a significant increase in larval fish CPUE at night. These initial results were in agreement with Pavlov et al. (1995), who suggested rivers with Secchi depths <30 cm would lack a diel larval fish drift pattern. With the exclusion of a dawn sample, that had previously been misclassified as a night sample, we found significantly higher total CPUE at night at our in-channel sample locations. Analyses for taxa specific patterns associated with season and the Missouri River hydrograph (Figure 3) showed that several of our taxonomic groups also displayed significantly increased CPUE at night during part or all of the sampling season.

Many rivers with Secchi depths <30 cm lack a nocturnal increase in larval fish CPUE within the drift (Table 4, Pavlov et al. 1977, Savenkova and Asanov 1988, Pavlov 1994, Araujo-Lima et al. 2001). The lower Missouri River channel and scours had a mean

Secchi depth < 30 cm throughout this study. Our assemblage and taxa-level analyses of total CPUE for the entire summer (including 06:00 sample) at our in-channel sample locations failed to detect a nocturnal increase because: 1) samples collected at or near dawn were included as part of the night period, and 2) samples collected over 4 months were included in a single analysis.

About 63% of the 32 papers only presented results for comparison of day/night, or diel larval fish drift at the assemblage level (Table 2). This level of analysis is an important first step, but as we have shown, the effect of decreased water transparency on larval fishes is likely a species specific phenomenon. Such species specific differences in day/night drift patterns might help explain contradictory findings within individual rivers (e.g., Pavlov et al. 1995, Araujo-Lima et al. 2001).

Research projects that only consider larval drift at the assemblage level may effectively "wash out" taxa-specific patterns by aggregating their data. Non-significant findings could have been a result of low replication (such as our floodplain scour study), inclusion of a misclassified sample (06:00 or dawn sample), or analyzing at too coarse a scale (too long a period of study or assemblage level only). Projects that detect significant, assemblage level differences between day and night larval drift may owe their result to one or two dominant taxa within collections, but this can't be determined without analysis at a more refined level of taxonomic resolution.

Species-specific patterns of drift may become especially important when considering effects of environmental change. Turbidity of the lower Missouri River has been decreased by two-thirds following construction of six upstream, mainstem dams (Pflieger and Grace 1987). Galat et al. (2005a) summarized main channel, fluvial fishes [i.e.,

Pflieger's (1997) 'big river' fishes] for the mainstem Missouri River. Few of these species were present in sufficient numbers for analysis, but of those that were goldeye, silver/speckled chubs, and sicklefin/sturgeon chubs did not exhibit significant increases in nocturnal drift. Over 90% of paddlefish larvae were collected at night, grass carp, a non-native, macrohabitat generalist exhibited significantly higher larval fish drift at night.

It has been hypothesized that larval fish drift at night to avoid sight-feeding predators (Blaxter 1986, Pavlov et al. 1995). Some fishes that evolved in highly turbid rivers may lack this nocturnal larval drift pattern and subsequently may be more vulnerable to diurnal, sight-feeding piscivores downriver from mainstem impoundments (e.g., rainbow smelt (*Osmerus mordax*) and white perch (*Morone □ollock□a*). This may give non-native macrohabitat generalist fishes with largely nocturnal drift a competitive advantage.

When designing a research project we are forced to make decisions that will inevitably bias results. How, where, and when fishes are sampled as well as how we choose to analyze data can strongly influence the perceived results. Realizing that the physical character of a river may influence the diel cycle of larval fish habitat use will allow researchers, and managers to more accurately estimate stock recruitment, reproductive success, and location of spawning grounds.

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Table 1. Secchi depth on dates larval fishes were collected within the lower Missouri River floodplain waterbodies in 1996 and 1997, estimated Secchi depths for lower Missouri River in-channel sample location for the 2002 period of study, and 9 year (1994-2002) Secchi depth descriptive statistics. See text for how Secchi depths were estimated in 2002.

Date of larval fish collection	Date of water transparency	Secchi depth (cm)
Scours		
1996		
26-Jun	26-Jun	16
3-Jul	3-Jul	15
1997		
3-Jul	3-Jul	61[a]
10-Jul	10-Jul	14
In-Channel		
2002		
30-May	20-May	4
6-Jun		
19-Jun		
27-Jun	25-Jun	9
17-Jul	22-Jul	25
1-Aug		
8-Aug	20-Aug	10
2002 mean ± standard error		12 ± 4.7, n=4
9 year mean ± standard error		10 ± 1.1, n=34,
9 year min and max		min=2, max=25

[a] The periodically connected scour was disconnected from the Missouri River due to low water levels.

Table 2. Larval fish diel drift from selected rivers. Data include the river studied, country, latitude, and fish taxa, "night" under results indicates significantly more larval fishes were collected drifting at night, "day" indicates significantly more were collected during the day, "none" indicates no significant difference detected between night and day. Studies are grouped based on day-night results and by country.

River	Country	Latitude	Taxa	Results	Reference
Great Ouse River	England	51N	all taxa	day	Garner 1996
Lower Mississippi River	USA	33N	Gizzard Shad	day	Gallagher and Conner 1983
Amazon and	Brazil	5S	all taxa	day in Amazon, secchi <30cm	Araujo-Lima et. al. 2001
Rio Negro rivers				night in Rio Negro, secchi >2m	
River Lohajang	Bangladesh	24N	all taxa	night	de Graff et. al. 1999
River Ourth	Belgium	51N	cyprinids	night	Baras and Nindaba 1999
Danube River	Bulgaria		all taxa	night	Vassilev 1994
St. Mary's River	Canada	45N	all taxa	night	Winnell and Jude 1991
Valley River	Canada	50N	all taxa	night	Johnston et. al. 1995

Table 2. Continued.

River	Country	Latitude	Taxa	Results	Reference
Apsley, Redmond creeks	Canada	47N	White sucker & Walleye	night	Corbett and Powles 1986
Rivers Morava, Kyjovka	Czech Rep.	49N	all taxa	night	Reichard et. al. 2001
River Dyje	Czech Rep.	49N	all taxa	night	Reichard et. al. 2004
River Morava	Czech Rep.	48N	Roach and Bitterling	night, secchi 8-40cm	Jurajda 1998
Elbe River	Germany	50N	all taxa	night	Oesmann 2003
River Sieg	Germany	51N	Barbel	night, secchi >60cm	Bischoff and Scholten 1996
Maraoué, Bandama, N'zi, and Léraba	Ivory Coast	5N	all taxa	night	Elouard and Lévêque 1977
Mina, Tateishi, Omo-dani	Japan	33N	Gobies	night	Iguchi and Mizuno 1990
Gudbrandsolalslogen	Norway	61N	Whitefish and Ciscoes	night	Næsje and Jonsson 1986
Putah Creek	USA	34N	all taxa	night	Marchetti and Moyle 2000
Sturgeon River	USA	44N	Lake sturgeon	night	Auer and Baker 2002
Columbia, Deschutes	USA	45N	all taxa	night	Gadomski and Barfoot 1998

Table 2. Continued.

River	Country	Latitude	Taxa	Results	Reference
Illinois River	USA	35N	Channel catfish	night	Armstrong and Brown 1983
Illinois River	USA	35N	all taxa	night	Brown and Armstrong 1985
Ohio River	USA	39N	all taxa	night	Clark and Pearson 1980
Cape Fear River	USA	35N	all taxa	night	Sager 1987
upper Colorado River	USA	40N	cyprinids	night	Carter et. al. 1986
Rhone River	France	45N	all taxa	night, larger larvae during day	Peñáz et. al. 1992
Amazon, Samiriya,	Peru	5S	Siluriformes and	night with secchi depth >30cm	Pavlov et. al. 1995
and Nanay			Characiformes	none with secchi depth <30cm	
Ili River	Russia	45N	all taxa	night in high water clarity	Nezdoliy 1984
				none in low water clarity	
Man'ya River	Russia	52N	native taxa	none	Bogdanov et. al. 1991
River Atrek	Russia	37N	all taxa	none, secchi depth 12-25cm	Savenkova and Asanov 1988
River Kuban	Russia	45N	all taxa	none, secchi depth 4-10cm	Pavlov et al. 1977

Table 2. Continued.

River	Country	Latitude	Taxa	Results	Reference
Broken River	Australia	33S	Murray cod	none	Humphries 2005
Cape Fear River	USA	35N	Gizzard shad	none	Sager 1987

Table 3. Number of larval fishes collected within each habitat category: shoreward, riverward, and channel or NSS (near-shore shallow) NSD (near-shore deep) and OW (open water) by species for the spring (A) and summer (B) collection periods in 2002 at in-channel sample locations and in 1996-1997 in floodplain scours. The percent each species represented of the total catch for the spring and summer collection periods (%) at in-channel and floodplain scour locations is presented. Taxonomic groups in bold were present in sufficient quantity and duration for individual analysis.

		2002 In-channel Sandbar and Channel								1996-1997 Floodplain scour			
		Shoreward		Riverward		Channel		%		NSS	NSD	OW	%
Scientific Name	Common Name	A	B	A	B	A	B	A	B				
Alosa alabamae/chrysochloris	Alabama shad/skipjack herring	2	NP	0	NP	8	NP	0.01	NP	0	0	0	0
Aplodinotus grunniens	freshwater drum	15	0	16	3	260	27	0.42	0.48	44	54	23	1.29
Carpoides/Ictiobus spp.	carpsuckers/buffalo	1557	74	1162	162	1084	58	5.5	4.73	1134	111	43	13.73
Ctenopharyngodon idella	grass carp	236	NP	174	NP	3295	NP	5.36	NP	91	143	42	2.94
Cyprinidae		485	9	36	5	12009	12	18.12	0.42	186	20	5	2.25
Cyprinidae A – *Cyprinella lutrensus*	red shiner												
and *Notropis stramineus*	sand shiner	33	2281	12	1186	52	72	0.14	56.94	265	29	1	3.15
Cyprinidae B[a] – *Luxilus cornutus*	common shiner												
Hybognathus argyritis/placitus	western silvery/plains minnows	20	150	25	97	1354	11	2.02	4.15	1590	420	392	25.61
Cyprinus carpio	common carp	21	0	1	2	77	1	0.14	0.05	3	1	3	0.07
Dorosoma cepedianum	gizzard shad	54	NP	36	NP	60	NP	0.22	NP	277	1180	20	15.75

Table 3. Continued.

		2002 In-channel Sandbar and Channel								1996-1997 Floodplain scour			
		Shoreward		Riverward		Channel		%		NSS	NSD	OW	%
Hiodon alosoides	goldeye	84	NP	79	NP	132	NP	0.43	NP	1	2	4	0.07
Hypophthalmichthys militrix/nobilus	silver/bighead carp	1980	NP	1865	NP	34529	NP	55.51	NP	211	141	50	4.29
Ictalurus furcatus/punctatus	blue/channel catfish	1	NP	0	NP	2	NP	0	NP	0	0	0	0
Lepisosteus ooculatus	shortnose gar	3	NP	2	NP	1	NP	0.01	NP	0	0	0	0
Lepomis spp.	sunfish	14	0	12	0	48	34	0.11	0.55	513	1707	39	24.09
Macrhybopsis aestivalis/storeriana	silver/speckled chub	923	272	934	220	86	33	2.81	8.45	98	2	3	1.1
Macrhybopsis gelida/meeki	sicklefin/sturgeon chub	328	NP	610	NP	50	NP	1.43	NP	183	29	26	2.54
Micropterus salmoides	largemouth bass	2	0	3	0	0	5	0.01	0.08	0	0	0	0
Notropis atherinoides	emerald shiner	130	173	62	402	72	19	0.38	9.56	0	0	0	0
Platygobio gracilis	flathead chub	0	NP	71	NP	0	NP	0.1	NP	0	0	0	0
Polyodon spathula	paddlefish	0	NP	2	NP	16	NP	0.03	NP	0	0	0	0
Pomoxis annularis/nigromaculatus	black/white crappie	0	NP	4	NP	8	NP	0.02	NP	66	214	13	3.12
Scaphirhynchus albus/platorynchus	pallid/shovelnose sturgeon	0	NP	0	NP	1	NP	0	NP	0	0	0	0
Unidentifiable		907	583	1155	42	2932	282	7.22	14.59	0	0	0	0

[a] Cyprinid B may contain emerald shiners for the floodplain scour data set which were identified separately within in-channel samples.

Table 4. Results of split-split-plot ANOVA with F-statistic and p-value for Total (entire sample period), Spring (samples from 30 May – 27 June), Summer (17 July – 8 August) for Total CPUE and taxonomic groups present in ≥50% of samples on at least 2, 24-hour sampling trips for in-channel areas and floodplain scours (df=1 for all analyses). Species with NP in the summer sample period were not present so only an analysis of spring CPUE data could be preformed. Results in bold signify significant results (p>0.0083 for in-channel locations and p>0.025 for floodplain scours).

Location	Scientific Name	Common Name	Total				Spring				Summer			
			with 06:00		without 06:00		with 06:00		without 06:00		with 06:00		without 06:00	
			F	p	F	p	F	p	F	p	F	p	F	p
Sandbar	Total CPUE		4.21	0.043	**12.09**	**9E-04**	1.4	0.243	6.36	0.016	3.85	0.057	6.09	0.02
	Carpoides/Ictiobus spp.	carpsuckers/buffalo	2.07	0.155	**8.73**	**0.005**	4.42	0.041	**13.84**	**7E-04**	0.32	0.578	0.01	0.926
	Ctenopharyngodon idella	grass carp					**11.23**	**0.003**	**19.86**	**3E-04**	NP	NP	NP	NP
	Cyprinidae		0.37	0.548	0.01	0.933	1	0.336	0.86	0.378	0	0.967	0.78	0.399
	Cyprinidae B – *Luxilus cornutus*	common shiner, western-												
	Hybognathus argyritis/placitus	silvery/plains minnows	2.65	0.109	2.28	0.138	0.07	0.787	0.19	0.671	**7.88**	**0.008**	7.83	0.009
	Dorosoma cepedianum	gizzard shad					1.56	0.224	3.58	0.075	NP	NP	NP	NP
	Hiodon alosoides	goldeye					1.2	0.281	3.6	0.069	NP	NP	NP	NP

Table 4. Continued.

Location	Scientific Name	Common Name	Total				Spring				Summer			
			with 06:00		without 06:00		with 06:00		without 06:00		with 06:00		without 06:00	
			F	p	F	p	F	p	F	p	F	p	F	p
Sandbar	*Hypophthalmichthys militrix/nobilus*	silver/bighead carp					1.75	0.192	4.72	0.036	NP	NP	NP	NP
	Macrhybopsis aestivalis/storeriana	silver/speckled chub	8.05	0.007	7.23	0.011	0.41	0.527	1.21	0.285	10.78	0	6.89	0.017
	Macrhybopsis gelida/meeki	sicklefin/sturgeon chub					0.62	0.437	0.45	0.511	NP	NP	NP	NP
	Notropis atherinoides	emerald shiner	1.29	0.263	3.53	0.071	0.78	0.395	0.07	0.797	4.05	0.055	6.72	0.018
Scour	Total CPUE		1.04	0.318	6.37	0.027								
	Carpoides/Ictiobus spp.	carpsuckers/buffalo	5.37	0.032	**76.87**	**<0.0001**								
	Cyprinidae B – *Luxilus cornutus*	common shiner, western-												
	Hybognathus argyritis/placitus	silvery/plains minnows	2.61	0.123	**12.88**	**0.006**								
	Dorosoma cepedianum	gizzard shad	3.72	0.07	6.45	0.032								
	Hypophthalmichthys militrix/nobilus	silver/bighead carp	0.38	0.544	4.01	0.076								

Figure 1. Map of the research area. Study sites are marked by map characters. PC Scour is the periodically connected floodplain waterbody, and CC Scour is continuously connected floodplain waterbody; both sampled in 1996 and 1997. WD Sandbar is the wing-dike sandbar, and PT Sandbar is the point sandbar; both sampled in 2002.

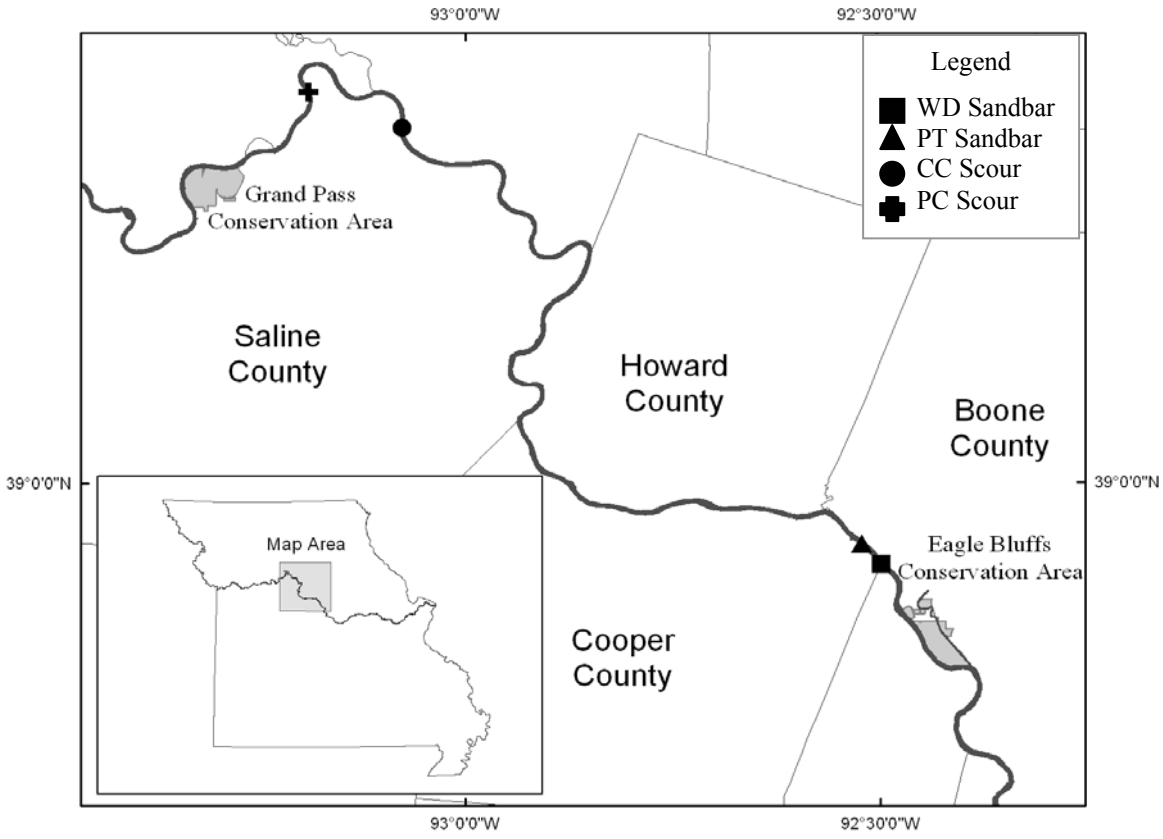
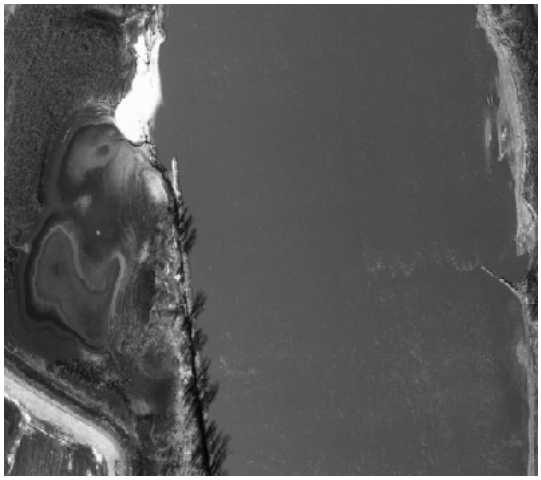


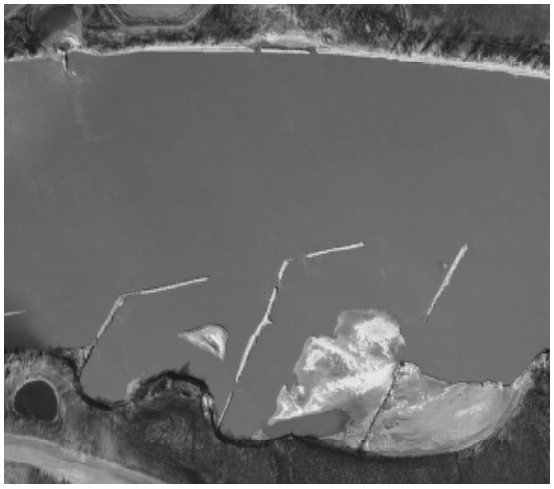
Figure 2. Aerial photographs of the lower Missouri River collected by the US Army Corps of Engineers between 26 February 2000 and 24 March 2000 showing a continuously-connected (CC) scour (top left), a periodically-connected (PC) scour (top right), a wing-dike (WD) sandbar (lower left), and an point (PT) sandbar (lower right). The CC site was continuously connected during spring and summer flows, but was disconnected at the time of photo due to winter low flows.

Continuously-connected



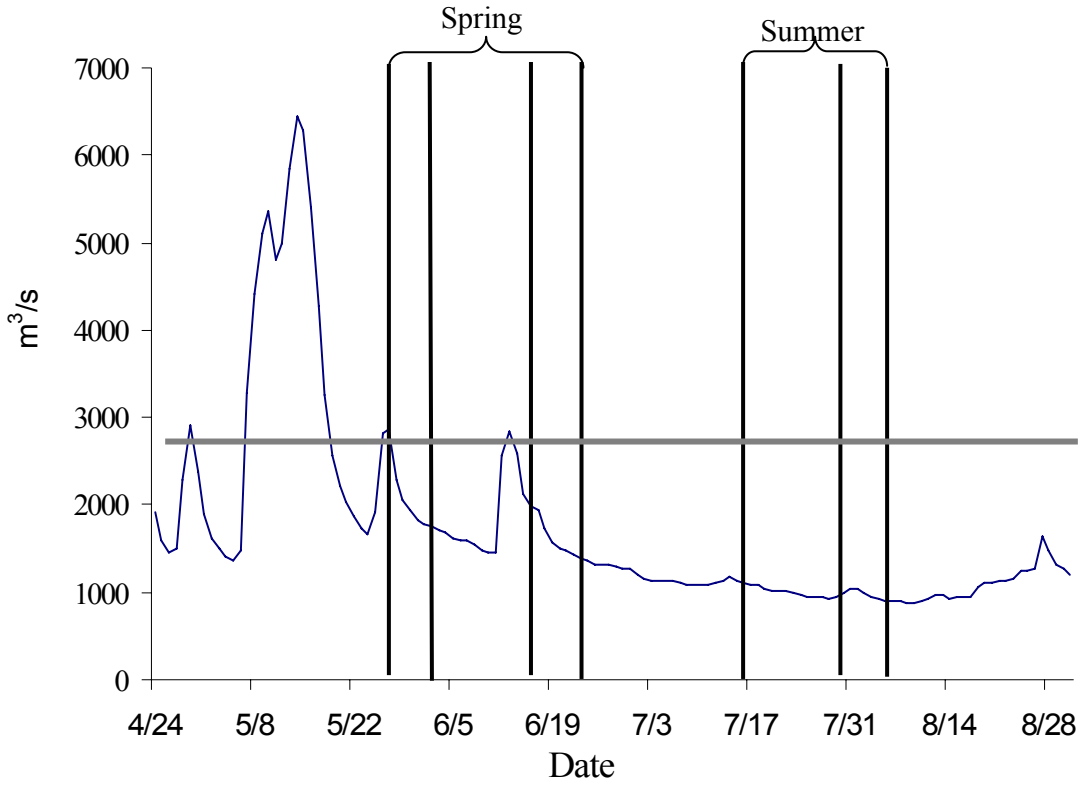
Periodically-connected

Wing-dike



Point sandbar

Figure 3. Missouri River hydrograph for 24 May – 15 August 2002 from the United States Geological Survey gauging station at Boonville, MO. Vertical bars represent dates of larval fish collection. Horizontal bar represents the estimated point at which all sandbars were inundated.



Chapter V

SUMMARY AND MANAGEMENT IMPLICATIONS

Introduction

Our research goal was to determine habitat or environmental conditions associated with larval fish nursery habitat in the lower Missouri River. An understanding of the conditions characterizing nursery habitat could be used to improve recruitment through the environmentally sensitive larval stage. Research objectives were designed to characterize requirements for the riverine larval fish assemblage and selected taxa within a spatial hierarchy. The hierarchical framework we developed (Table 1) was to aid in integration of results among research objectives. Our broadest scale was macrohabitat which included main-channel conditions (discharge and water temperature) and type of sandbar (point or wing-dike). We used two finer spatial scales (meso- and micro-habitat) to refine our understanding of the relationship between environmental conditions and larval fish habitat use within sandbar macrohabitats. Mesohabitat referred to sandbar regions that were designated based on channel orientation. Microhabitat conditions were those associated with larval fish collection at the 0.25 m^2 level.

Summary

The objectives of this research project were designed to work together so each would refine the understanding of nursery habitat for larval fishes gained from the previous objective. Comparisons of larval fish catch-per-unit-effort (CPUE) among the main channel and two sandbar (point and wing-dike) macrohabitats for native (carpsucker

spp./buffalo spp. and chub spp.) and introduced (silver/bighead carp) taxa demonstrated native taxa used sandbar ATTZ to a greater extent than the main channel while there was no significant difference among macrohabitats for the introduced taxa (Table 2).

The next set of objectives were designed to determine what conditions within the sandbar ATTZ make it larval fish nursery habitat. Local-environmental (current velocity, water depth, substrate type, and water temperature), geomorphic (sandbar macrohabitat, sandbar mesohabitat, shoreline slope, and shoreline sinuosity) and hydrologic (change in discharge between the day of sample collection and the previous day, mean of the two previous days, and mean of four previous days) factors were compared to determine what factors explained the greatest portion of variance in larval fish CPUE. This analysis showed the local-environental variables were most influential (Table 2); with current velocity accounting for the greatest amount of variance of any single factor.

Macrohabitat comparisons show native larval fishes use sandbar ATTZ as nursery habitat, and mesohabitat comparisons show local-environmental factors within the sandbar ATTZ influence larval fish CPUE to a greater extent than geomorphic or hydrologic factors. The next step in our research was to determine what environemental conditions could be used to predict larval fish presence at a microhabitat level (0.25 m^2), and what range within each environmental condition did larval fish select. We found the larval fish assemblage and carpsucker spp./buffalo spp. selected areas with water depth ≤10 cm and water velocity ≤5 cm/s. Silver/bighead carp used habitat across depth and current velocities indicating they may be drifting through sandbar ATTZ. This would be consistent with the higher silver/bighead carp CPUE observed within the main channel, and previous research demonstrating larval silver/bighead carp remain in the drift until

transported to off-channel scours (Yi et al. 1991). Chub spp. selected areas with water depths between 20 cm and 50 cm, and areas that were ≥2 m from the waters edge (Table 2; Figure 1).

Implications

The description of nursery habitat for the larval assemblage within the lower Missouri River, from the above analysis is water ≤10 cm deep with current velocity ≤5 cm/s. This description does not contain habitat classifiers such as point or wing-dike sandbar. This means habitat rehabilitation projects or river management plans with the goal of providing nursery habitat should consider options that maximize presence of areas meeting this description whether these areas are associated with point or wing-dike sandbars.

Using this nursery habitat description in management of the lower Missouri River, or other regulated river, requires an understanding of the relations among depth, current velocity, discharge and channel form. The relations between depth, discharge, and channel form are much easier to understand and model than that of current velocity so depth alone will be used to represent nursery habitat from this point. Tracy-Smith (2006) mapped the sandbars used for this study at a variety of discharges and modeled the relationship between discharge and area surrounding sandbars within three depth classes (0 - 0.5 m, 0.51 – 1.0 m, and 1.01 to 1.5 m). The relationship between discharge and habitat availability of these classes roughly resembled a bell-shaped curve, meaning a range of discharges exist that can maximize the quantity of water 0 – 0.5 m (category is broader than habitat described as nursery for larval assemblage, but does incorporate

assemblage, carpsucker spp./buffalo spp., and chub spp. nursery habitats) in depth. Tracey-Smith (2006) found that nursery habitat (0 – 0.5 m) was maximized at about 1300 m^3/s along point sandbars and about 600 m^3/s and 1400 m^3/s along wing-dike sandbars. The results of this research and that of Tracy-Smith (2006) together provide both a description of nursery habitat conditions and the range of discharge that can be used to maximize nursery habitat availability within the current lower Missouri River.

References

Tracy-Smith, E. 2006. Relation of Missouri River flows to sandbar morphology with implications for selected biota. Masters thesis. University of Missouri, Columbia, Missouri, USA.

Yi, B., Z. Yu, Z. Liang, and S. Shen. 1991. Distribution, natural conditions and breeding production of the spawning grounds of four famous freshwater fishes on the main stream of the Changiiang River. Proceedings of the fourth Chinese oceanological and limnological science conference. Science Press. Beijing, China. Pp.181-190.

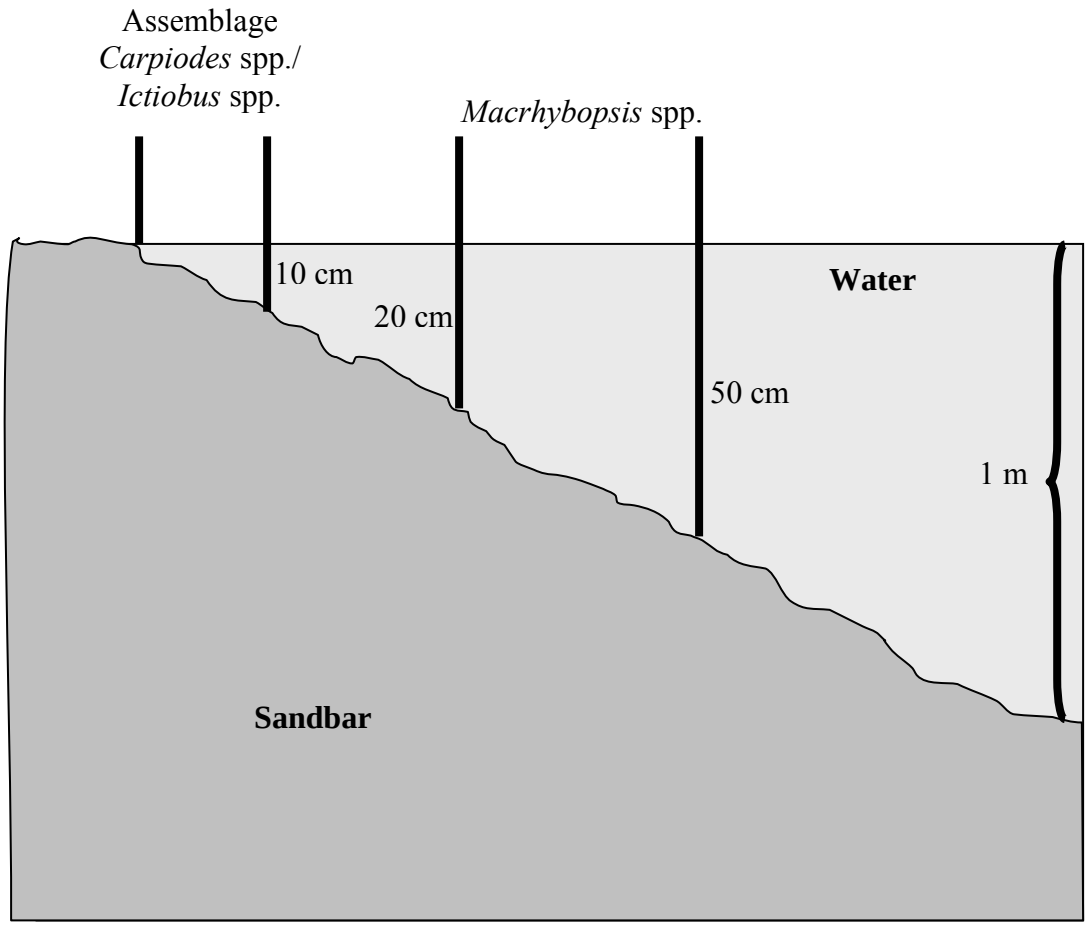
Table 1. Research spatial hierarchy with the habitat units associated with each spatial scale, physical feature at which larval fish collection took place within the lower Missouri River, and the response variable used to compare habitat units. ATTZ = aquatic-terrestrial-transition-zone, CPUE = catch-per-unit-effort, primary = primary channel, secondary = secondary channel.

Spatial scale	Habitat unit	Feature	Response
Macrohabitat	Main channel	Primary channel	Effects of discharge and water
		Secondary channel	temperature on larval fish CPUE
	Sandbar ATTZ	Point sandbar	Comparison of larval fish CPUE
		Wing-dike sandbar	among main-channel, point, and
			wing-dike sandbar macrohabitats
Mesohabitat	Sandbar region	Head	Comparison of geomorphic (sandbar
		Upstream primary	type, sandbar region, shoreline slope
		Upstream secondary	and sinuosity), local-environmental
		Downstream primary	(velocity, water depth, temperature,
		Downstream secondary	and substrate type), and hydrologic
		Tail	(change in discharge from 1, 2, and
			4-day means) factors ability to account
			for variance in larval fish CPUE.
Microhabitat	Channel margin ATTZ	Sandbar 0.25m^2	Comparison of use versus
		Channel border 0.25m^2	availability of local-environmental
			conditions (current velocity, water
			depth, temperature, substrate type,
			and aquatic vegetation) within
			sandbar and channel-border
			ATTZ by larval fishes

Table 2. Habitat use results for the larval fish assemblage and selected taxa at macrohabitat, mesohabitat, and microhabitat scales; no difference indicates there was no difference in habitat use found at that scale. Point or wing-dike sandbar indicate larval fish catch per unit effort was significantly greater within this macrohabitat.

	Macrohabitat	Mesohabitat	Microhabitat
assemblage	no difference	Local-environmental factors (current velocity, water depth, substrate type, and water temperature)	≤10 cm deep ≤5cm/s current velocity
Carpsucker spp./ Buffalo spp.	point sandbar ATTZ		≤10 cm deep ≤5cm/s current velocity
Silver/bighead carp	no difference		No selection based on depth or current velocity
Chub spp.	wing-dike sandbar ATTZ		20 cm – 50 cm deep ≥2 m from waters edge

Figure 1. Illustration of nursery habitat selected by the larval fish assemblage, *Carpiodes* spp./*Ictiobus* spp., and *Machrybopsis* spp. within the 0-1 m aquatic terrestrial transition zone of a sandbar.



Appendix A

Tables of macro- and meso-habitat CPUE by taxa

Table A-1. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error of total larval fish collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Channel	187.8 ± 65.8	581.3 ± 225.7	369.5 ± 65.8	388.8 ± 71.8	212.9 ± 86.9	322.5 ± 177.8	124.5 ± 40.7	367.7 ± 151.1	19.1 ± 4.4	33.0 ± 20.4
HD			403.1 ± 18.8	470.1 ± 106.5			182.4 ± 105.1	955.8 ± 752.8		
UP			234.5 ± 90.0	295.4 ± 106.5			34.6 ± 28.6	296.2 ± 165.8		
US			505.8 ± 177.6	786.8 ± 366.0			278.1 ± 137.6	405.9 ± 224.1		
DP			63.1 ± 15.7	252 ± 105.4			31.3 ± 17.3	131.4 ± 59.3		
DS			411.3 ± 208.6	612.6 ± 300.4			58.0 ± 22.4	138.1 ± 138.1		
TL			643.2 ± 227.6	83.5 ± 22.8			204.9 ± 175.4	202.9 ± 133.6		

Table A-2. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be identified beyond genus *Alosa* spp. collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Channel	0.2 ± 0.1	0.4 ± 0.3	0.7 ± 0.2	0.7 ± 0.4	0.0	0.0	0.0	0.0	0.0	0.0
HD			0.0	0.3 ± 0.3			0.0	0.0		
UP			0.0	2.6 ± 1.9			0.0	0.0		
US			1.6 ± 1.2	0.0			0.0	0.0		
DP			1.3 ± 0.6	1.4 ± 1.4			0.0	0.0		
DS			0.8 ± 0.6	0.0			0.0	0.0		
TL			1.0 ± 0.6	0.0			0.0	0.0		

Table A-3. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for freshwater drum (*Aplodinotus grunniens*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. . HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Channel	5.5 ± 1.4	3.1 ± 1.4	0.4 ± 0.2	0.5 ± 0.2	3.6 ± 1.2	4.2 ± 2.0	0.0	0.0	0.9 ± 0.3	2.0 ± 2.0
HD			1.3 ± 0.8	0.0			0.0	0.0		
UP			0.3 ± 0.2	0.4 ± 0.3			0.0	0.0		
US			0.4 ± 0.3	0.8 ± 0.8			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.3 ± 0.2	1.8 ± 1.0			0.0	0.0		

Table A-4. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be identified beyond family Catostomidae collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0.0	0.0*	0.0	0.0	0.0	0.0
HD			0.0	0.9 ± 0.7			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.3 ± 0.3	0.0			0.0	0.0		
DP			0.4 ± 0.4	0.3 ± 0.3			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.5 ± 0.3	0.4 ± 0.4			0.0	0.0		

Table A-5. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for carpsuckers and buffalo (*Carpiodes* spp./*Ictiobus* spp.) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	18.1 ± 3.4	4.3 ± 1.4	71.3 ± 22.8	109.5 ± 49.9	6.7 ± 1.7	8.0 ± 2.8	8.4 ± 2.5	49.2 ± 29.5	4.0 ± 1.2	3.4 ± 0.4
HD			103.5 ± 77.8	125.5 ± 66.4			5.1 ± 3.9	4.4. ± 4.4		
UP			83.7 ± 58.7	7.5 ± 2.4			6.9 ± 4.3	54.9 ± 49.7		
US			75.1 ± 29.3	563.4 ± 387.3			15.9 ± 9.8	17.5 ± 17.5		
DP			12.3 ± 7.8	15.7 ± 5.8			1.8 ± 1.8	15.3 ± 12.0		
DS			164.2 ± 125.7	166.1 ± 119.9			18.7 ± 9.4	0.0		
TL			59.1 ± 29.4	13.2 ± 4.8			3.1 ± 3.1	157.5 ± 143.6		

Table A-6. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for white sucker (*Catostomus commersoni*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.0 ± 0.4	9.8 ± 9.1	4.7 ± 3.2	1.2 ± 0.8	0.4 ± 0.2	0.6 ± 0.4	0.0	0.0	1.2 ± 0.3	0.0
HD			0.0	3.4 ± 3.4			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			2.3 ± 2.3	0.0			0.0	0.0		
DP			1.7 ± 1.7	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
T			10.1 ± 10.1	2.6 ± 2.6			0.0	0.0		

Table A-7. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be identified beyond family Clupidae. collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.2 ± 0.1	0.4 ± 0.3	0.9 ± 0.6	1.2 ± 0.7	0.0	0.0	0.0	0.0	0.0	0.0
HD			0.0	1.5 ± 1.5			0.0	0.0		
UP			0.0	3.4 ± 3.1			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			3.5 ± 3.1	1.5 ± 0.9			0.0	0.0		
DS			2.0 ± 2.0	0.0			0.0	0.0		
TL			0.0	0.0			0.0	0.0		

Table A-8. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for grass carp (*Ctenopharyngodon idella*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	6.0 ± 3.1	3.2 ± 1.5	2.5 ± 1.0	4.8 ± 1.5	14.3 ± 6.7	39.5 ± 21.9	0.0	0.0	5.8 ± 2.1	5.4 ± 2.9
HD			4.4 ± 2.2	5.1 ± 2.7			0.0	0.0		
UP			3.5 ± 2.2	1.3 ± 0.8			0.0	0.0		
US			1.1 ± 0.6	3.7 ± 2.6			0.0	0.0		
DP			0.0	3.1 ± 1.7			0.0	0.0		
DS			0.0	6.5 ± 5.3			0.0	0.0		
TL			5.1 ± 4.5	10.3 ± 7.2			0.0	0.0		

Table A-9. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for blue sucker (*Cycleptus elongatus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.7 ± 0.5	0.7 ± 0.7	0.6 ± 0.6	1.0 ± 1.0	0.0	0.7 ± 0.7	0.0	0.0	0.0	0.0
Hd			3.8 ± 3.8	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	6.0 ± 6.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.0	0.0			0.0	0.0		

Table A-10. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be identified beyond family Cyprinidae. collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	34.9 ± 15.5	4.9 ± 2.9	5.2 ± 1.8	19.4 ± 8.2	6.0 ± 4.5	0.1 ± 0.1	0.0	13.5 ± 11.4	0.0*	0.0
HD			1.0 ± 0.5	18.4 ± 13.3			0.0	59.2 ± 59.2		
UP			1.4 ± 1.1	33.8 ± 19.8			0.0	9.2 ± 9.2		
US			17.6 ± 10.9	3.8 ± 2.2			0.0	0.0		
DP			2.7 ± 1.7	5.0 ± 2.1			0.0	0.0		
DS			3.6 ± 1.6	67.2 ± 60.9			0.0	0.0		
TL			6.9 ± 3.7	3.0 ± 1.3			0.0	0.0		

Table A-11. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be separated beyond cyprinid group A (*Hybognathus argyritis, H. hankinsoni, H. placitus*, and *Notemigonus crysoleucas*)collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.0 ± 0.2	3.8 ± 1.8	217.8 ± 53.6	107.2 ± 33.5	0.2 ± 0.1	5.7 ± 5.3	11.1 ± 4.8	43.8 ± 10.0	0.0	0.2 ± 0.2
HD			222.1 ± 108.3	150.0 ± 58.7			40.1 ± 25.5	62.9 ± 37.2		
UP			99.8 ± 56.7	147.7 ± 109.6			2.8 ± 1.7	53.3 ± 19.8		
US			271.7 ± 137.5	49.1 ± 16.3			3.8 ± 2.2	47.5 ± 40.5		
DP			16.9 ± 5.2	156.1 ± 109.8			14.0 ± 12.6	37.3 ± 17.4		
DS			267.7 ± 165.3	45.1 ± 18.4			1.6 ± 1.6	78.9 ± 78.9		
TL			521.3 ± 237.2	19.4 ± 9.1			8.8 ± 8.8	10.7 ± 4.5		

Table A-12. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for fishes that could not be separated beyond cyprinid group B (*Cyprinella spiloptera, Lythrurus umbratilis, Notropis blennius, N. buchanani, N. shumardi, N. stramineus, N. wickliffi,* and *Phenacobius mirabilis*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.0 ± 0.3	50.9 ± 45.7	16.3 ± 6.5	14.7 ± 2.6	1.1 ± 0.8	0.4 ± 0.2	40.8 ± 22.8	231.4 ± 153.0	0.3 ± 0.2	0.0
HD			14.2 ± 5.6	15.2 ± 6.5			103.5 ± 66.3	808.5 ± 796.8		
UP			11.8 ± 4.7	30.1 ± 9.8			0.0	151.5 ± 123.3		
US			51.7 ± 45.7	12.2 ± 7.2			146.2 ± 142.7	295.2 ± 232.3		
DP			6.1 ± 1.9	15.3 ± 6.0			0.0	30.8 ± 20.6		
DS			8.6 ± 6.2	6.8 ± 2.4			22.6 ± 22.6	0.0		
TL			15.4 ± 5.7	11.7 ± 4.7			6.1 ± 6.1	31.0 ± 21.9		

Table A-13. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for common carp (*Cyprinus carpio*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.1 ± 0.4	0.9 ± 0.5	0.2 ± 0.2	1.35 ± 0.6	0.03 ± 0.02	0.8 ± 0.4	0.0	3.2 ± 2.8	0.2 ± 0.1	0.0
HD			0.0	0.5 ± 0.4			0.0	0.0		
UP			0.0	0.0			0.0	1.4 ± 1.4		
US			0.3 ± 0.2	1.7 ± 1.7			0.0	0.0		
DP			0.1 ± 0.1	1.1 ± 1.1			0.0	0.0		
DS			0.2 ± 0.2	1.2 ± 1.0			0.0	59.2 ± 59.2		
TL			0.6 ± 0.4	1.5 ± 1.0			0.0	0.0		

Table A-14. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for gizzard shad (*Dorosoma cepedianum*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.4 ± 0.5	7.7 ± 3.0	3.6 ± 1.7	7.0 ± 1.9	0.8 ± 0.4	11.0 ± 4.8	7.7 ± 3.6	0.0	0.7 ± 0.5	6.6 ± 6.5
HD			10.3 ± 9.0	4.7 ± 2.9			4.1 ± 0.01	0.0		
UP			1.5 ± 0.6	13.7 ± 7.8			15.2 ± 15.2	0.0		
US			0.7 ± 0.4	8.2 ± 4.4			0.0	0.0		
DP			2.8 ± 1.7	9.5 ± 4.0			16.1 ± 16.1	0.0		
DS			0.2 ± 0.2	3.3 ± 1.5			3.9 ± 3.9	0.0		
TL			5.1 ± 1.9	0.6 ± 0.6			3.3 ± 0.4	0.0		

Table A-15. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for mosquito fish (*Gambusia affinis)* collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.0	0.0	0.1 ± 0.1	0.1 ± 0.1	0.0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.3	0.0	0.0
HD			0.0	0.3 ± 0.3			0.0	0.0		
UP			0.0	0.0			0.0	1.4 ± 1.4		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.3 ± 0.3	0.0			0.6 ± 0.6	0.0		

Table A-16. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for goldeye (*Hiodon alosoides*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	3.9 ± 1.6	1.3 ± 0.6	2.4 ± 1.3	8.5 ± 3.2	5.5 ± 2.9	24.0 ± 13.7	0.59 ± 0.59	0.0	0.6 ± 0.2	0.5 ± 0.5
HD			0.3 ± 0.3	15.8 ± 14.0			4.1 ± 4.1	0.0		
UP			5.9 ± 5.1	3.5 ± 2.7			0.0	0.0		
US			2.2 ± 1.2	21.3 ± 11.6			0.0	0.0		
DP			0.0	0.9 ± 0.9			0.0	0.0		
DS			0.0	6.4 ± 4.4			0.0	0.0		
TL			5.9 ± 5.2	4.1 ± 4.1			0.0	0.0		

Table A-17. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for mooneye (*Hiodon tergisus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.01 ± 0.01	0.0	0.0	1.1 ± 0.7	0.0	0.0	0.0	0.0	0.0	0.0
HD				0.0			0.0	0.0		
UP				0.0			0.0	0.0		
US				0.9 ± 0.9			0.0	0.0		
DP				0.0			0.0	0.0		
DS				3.7 ± 3.7			0.0	0.0		
TL				1.9 ± 1.9			0.0	0.0		

Table A-18. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for bighead and silver carps (*Hypophthalmichthys molitrix/nobilus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	107.2 ± 53.7	277.2 ± 127.5	5.5 ± 1.7	62.0 ± 29..3	220.9 ± 102.5	269.0 ± 179.9	4.2 ± 2.5	0.0	8.7 ± 2.9	20.6 ± 12.8
HD			11.8 ± 5.7	35.6 ± 14.4			3.1 ± 3.1	0.0		
UP			6.2 ± 3.8	28.6 ± 16.9			13.6 ± 13.6	0.0		
US			4.4 ± 2.3	72.6 ± 49.3			0.0	0.0		
DP			0.3 ± 0.2	34.3 ± 22.5			0.0	0.0		
DS			0.7 ± 0.5	275.1 ± 253.4			3.1 ± 3.1	0.0		
TL			7.7 ± 6.3	14.8 ± 8.2			4.4 ± 2.9	0.0		

Table A-19. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for longnose gar (*Lepisosteus osseus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.0	0.5 ± 0.5	0.0	0.0	0.0	0.0
HD			0.0	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.8 ± 0.8			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.6 ± 0.6	0.0			0.0	0.0		

Table A-20. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for shortnose gar (*Lepisosteus platostomus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.0*	0.3 ± 0.1	0.3 ± 0.2	0.2 ± 0.2	0.0	0.0	0.0	0.0	0.0	0.0
HD			0.9 ± 0.9	0.0			0.0	0.0		
UP			0.0	0.7 ± 0.7			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.8 ± 0.8			0.0	0.0		
Tail			1.1 ± 0.7	0.0			0.0	0.0		

Table A-21. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for sunfishes (*Lepomis cyanellus, L. humilis, L. macrochirus, and L. megalotis*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.8 ± 0.3	0.9 ± 0.4	1.5 ± 0.6	1.7 ± 0.4	0.1 ± 0.1	0.0*	0.3 ± 0.3	0.3 ± 0.3	0.0*	0.3 ± 0.3
HD			4.8 ± 2.9	1.2 ± 0.5			0.0	0.0		
UP			0.1 ± 0.1	1.1 ± 0.5			0.0	0.0		
US			0.4 ± 0.4	4.8 ± 2.3			0.0	0.0		
DP			0.8 ± 0.4	1.8 ± 0.9			0.0	1.4 ± 1.4		
DS			0.3 ± 0.3	1.7 ± 1.1			0.0	0.0		
TL			2.0 ± 0.8	0.7 ± 0.6			1.8 ± 1.8	0.0		

Table A-22. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for speckled and silver chubs (*Macrhybopsis aestivalis/storeriana*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.8 ± 0.4	0.9 ± 0.6	8.8 ± 2.5	28.2 ± 7.6	0.1 ± 0.1	0.7 ± 0.5	2.3 ± 1.1	5.7 ± 3.7	0.0*	0.1 ± 0.1
HD			0.5 ± 0.2	37.7 ± 21.3			1.9 ± 1.9	1.7 ± 1.7		
UP			5.6 ± 2.5	30.3 ± 13.4			2.9 ± 2.2	10.0 ± 10.0		
US			23.2 ± 13.3	33.7 ± 23.3			0.0	31.5 ± 31.5		
DP			5.4 ± 2.5	9.5 ± 3.4			5.9 ± 5.2	0.0		
DS			2.7 ± 1.2	76.9 ± 46.4			1.6 ± 1.6	0.0		
TL			17.6 ± 8.0	2.7 ± 1.4			0.7 ± 0.7	0.0		

Table A-23. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for sturgeon and sicklefin chubs (*Macrhybopsis gelida/meeki*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.2 ± 0.1	0.7 ± 0.4	16.3 ± 10.4	4.9 ± 2.5	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.3	0.7 ± 0.7	0.1 ± 0.1	0.5 ± 0.5
HD			54.3 ± 54.3	0.8 ± 0.5			0.0	0.0		
UP			16.1 ± 11.3	11.5 ± 10.9			0.0	0.0		
US			20.1 ± 14.6	11.0 ± 7.2			0.0	7.0 ± 7.0		
DP			0.8 ± 0.7	0.9 ± 0.7			0.0	0.0		
DS			0.0	4.0 ± 3.4			0.0	0.0		
TL			1.9 ± 1.0	1.0 ± 0.5			1.5 ± 1.5	0.0		

Table A-24. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for largemouth bass (*Micropterous salmoides*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.0*	0.0	0.1 ± 0.1	0.0	0.0*	0.0	0.0	0.0	0.0	0.0
HD			0.0	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.7 ± 0.7	0.0			0.0	0.0		

Table A-25. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for emerald shiners (*Notropis atherinoides*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	1.6 ± 0.9	292.8 ± 268.2	52.4 ± 11.5	63.5 ± 21.2	0.5 ± 0.2	6.2 ± 2.0	53.1 ± 31.8	16.2 ± 7.4	0.0	0.5 ± 0.5
HD			49.9 ± 27.5	130.0 ± 56.0			25.5 ± 20.8	7.0 ± 7.0		
UP			38.8 ± 24.0	31.4 ± 11.9			2.3 ± 2.3	10.2 ± 5.5		
US			96.0 ± 42.9	153.4 ± 117.7			112.3 ± 80.5	7.3 ± 7.3		
DP			19.5 ± 5.9	32.5 ± 9.5			1.8 ± 1.2	46.6 ± 27.9		
DS			13.8 ± 7.3	11.7 ± 5.9			9.1 ± 5.6	0.0		
TL			56.1 ± 20.1	4.0 ± 1.7			173.8 ± 166.5	3.6 ± 2.1		

Table A-26. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for bluntnose minnow (*Pimephales notatus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.0	0.0	0.0	0.1 ± 0.1	0.0	0.0*	0.6 ± 0.4	3.4 ± 2.0	0.0*	0.0
HD				0.0	0.0		0.0	12.3 ± 8.3		
UP				0.0	0.0		0.0	4.3 ± 4.3		
US				0.3 ± 0.3	0.0		0.0	0.0		
DP				0.0	0.0		1.3 ± 0.8	0.0		
DS				0.0	0.0		0.0	0.0		
TL				0.0	0.0		2.2 ± 2.2	0.0		

Table A-27. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for white and black crappie (*Pomoxis annularis/nigromaculatus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. An asterisk means larval fish were present at the location, but in too low a density to report. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.1 ± 0.0	0.0	0.2 ± 0.1	0.0	0.0	0.0*	0.0	0.0	0.0	0.0
HD			0.9 ± 0.7	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.0	0.0			0.0	0.0		

Table A-28. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for sauger and walleye (*Sander canadense/vitreum*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.1 ± 0.1	4.8 ± 4.6	1.3 ± 1.1	1.8 ± 1.0	0.1 ± 0.1	1.1 ± 0.8	0.0	0.0	0.0	0.7 ± 0.7
HD			0.0	0.0			0.0	0.0		
UP			0.0	0.9 ± 0.9			0.0	0.0		
US			0.9 ± 0.9	6.3 ± 6.3			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	1.5 ± 1.5			0.0	0.0		
TL			8.0 ± 7.2	1.8 ± 1.8			0.0	0.0		

Table A-29. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for pallid and shovelnose sturgeon (*Scaphirhynchus albus/platorynchus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.1 ± 0.0	0.0	0.0	0.2 ± 0.2	0.0	0.0	0.0	0.0	0.0	0.0
HD			0.0	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.0	0.6 ± 0.6			0.0	0.0		

Table A-30. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for creek chub (*Semotilus atromaculatus*) collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	0.5 ± 0.5	1.0 ± 1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HD			0.0	0.0			0.0	0.0		
UP			0.0	0.0			0.0	0.0		
US			0.0	0.0			0.0	0.0		
DP			0.0	0.0			0.0	0.0		
DS			0.0	0.0			0.0	0.0		
TL			0.0	0.0			0.0	0.0		

Table A-31. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error for unidentifiable larval fishes collected in the primary and secondary channels, within the aquatic terrestrial transition zone (ATTZ) of point and wing-dike sandbars, and within each of the six sandbar regions. HD = head, UP=upstream primary, US=upstream secondary, DP=downstream primary, DS=downstream secondary, TL=tail.

	2002				**2003**				**2004**	
	Channel		Sandbar		Channel		Sandbar		Channel	
	Pri	**Sec**	**PT**	**WD**	**Pri**	**Sec**	**PT**	**WD**	**Pri**	**Sec**
Macrohabitat	3.7 ± 1.9	1.8 ± 0.6	4.2 ± 0.9	8.8 ± 1.9	0.7 ± 0.3	1.1 ± 0.5	0.1 ± 0.1	0.0	0.6 ± 0.4	0.0
HD			4.4 ± 2.0	7.9 ± 3.4			0.0	0.0		
UP			1.3 ± 0.4	7.4 ± 2.5			0.0	0.0		
US			5.8 ± 2.5	4.3 ± 1.9			0.0	0.0		
DP			2.8 ± 1.2	6.2 ± 2.9			0.0	0.0		
DS			2.1 ± 1.0	18.1 ± 11.8			0.0	0.0		
TL			7.1 ± 3.7	7.2 ± 3.4			0.6 ± 0.6	0.0		

Appendix B

Tables of day and night collection CPUE by taxa

Table B-1. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of freshwater drum (*Aplodinotus grunniens*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Aplodinotus grunniens

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	0.0	21.9 ± 14.6, *n=14*	0.0
	Night	3.8 ± 2.5, *n=2*	6.1 ± 2.3, *n=4*	10.7 ± 3.7, *n=7*
7/3/1996	Day	2.3 ± 2.3, *n=1*	28.1 ± 16.0, *n=17*	13.8 ± 9.0, *n=7*
	Night	5.8 ± 4.3, *n=4*	26.2 ± 12.2, *n=16*	14.3 ± 9.6, *n=9*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	6.4 ± 4.8, *n=4*	0.0	0.0
	Night	58.8 ± 22.2, *n=33*	5.0 ± 2.5, *n=3*	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	3.0 ± 1.9, *n=21*
	Night	0.0	0.0	0.2 ± 0.1, *n=2*
6/6/2002	Day	0.0	0.0	11.8 ± 3.5, *n=73*
	Night	0.0	0.0	2.4 ± 0.7, *n=13*

Table B-1. Continued.

6/18/2002	Day	8.1 ± 3.6, *n=6*	6.8 ± 2.3, *n=7*	3.9 ± 1.7, *n=20*
	Night	8.1 ± 4.2, *n=6*	8.7 ± 2.5, *n=9*	3.3 ± 1.2, *n=24*
6/27/2002	Day	0.0	0.0	1.7 ± 1.0, *n=11*
	Night	5.2 ± 5.2, *n=2*	0.0	29.6 ± 15.2, *n=96*
7/17/2002	Day	1.5 ± 1.5, *n=1*	0.9 ± 0.9, *n=1*	0.3 ± 0.3, *n=1*
	Night	0.0	0.9 ± 0.9, *n=1*	0.0
8/1/2002	Day	0.0	0.0	2.0 ± 1.6, *n=14*
	Night	0.0	0.9 ± 0.9, *n=1*	1.6 ± 0.7, *n=9*
8/8/2002	Day	0.0	0.0	0.1 ± 0.1, *n=1*
	Night	0.0	0.0	0.2 ± 0.2, *n=2*

Table B-2. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of carpsuckers and buffalo (*Carpiodes* spp. and *Ictiobus* spp.) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

***Carpiodes* spp. and *Ictiobus* spp.**

Date	Day/Night	NSS	NSD	OW
Scour				
6/26/1996	Day	802.0 ± 415.2, *n=441*	1.5 ± 1.5, *n=1*	
	Night	939.6 ± 748.8, *n=491*	13.3 ± 9.0, *n=9*	1.4 ± 1.4, *n=1*
7/3/1996	Day	4.5 ± 3.2, *n=3*	0.0	0.0
	Night	18.9 ± 17.2, *n=11*	26.4 ± 12.1, *n=16*	4.5 ± 2.2, *n=3*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	62.0 ± 27.2, *n=34*	0.0	0.0
	Night	277.9 ± 127.4, *n=154*	140.1 ± 58.3, *n=85*	62.2 ± 25.2, *n=39*
Sandbars				
		Shoreward	**Riverward**	**Channel**
5/30/2002	Day	47.5 ± 27.0, *n=37*	20.0 ± 14.9, *n=21*	19.9 ± 6.8, *n=135*
	Night	231.4 ± 106.5, *n=180*	67.0 ± 28.9, *n=71*	16.4 ± 6.4, *n=133*
6/6/2002	Day	43.1 ± 18.9, *n=23*	3.1 ± 2.0, *n=2*	17.7 ± 10.1, *n=115*
	Night	100.0 ± 36.7, *n=66*	85.8 ± 27.4, *n=46*	8.8 ± 1.7, *n=50*

Table B-2. Continued.

6/18/2002	Day	786.6 ± 418.6, *n=577*	347.3 ± 232.9, *n=353*	20.9 ± 16.4, *n=95*
	Night	829.9 ± 854.4, *n=609*	407.5 ± 474.4, *n=617*	15.7 ± 4.1, *n=93*
6/27/2002	Day	30.0 ± 10.3, *n=10*	27.6 ± 14.8, *n=12*	33.7 ± 16.3, *n=185*
	Night	173.0 ± 90.6, *n=54*	82.2 ± 69.8, *n=34*	77.5 ± 22.4, *n=248*
7/17/2002	Day	72.9 ± 33.3, *n=48*	102.9 ± 40.7, *n=98*	4.5 ± 1.7, *n=31*
	Night	25.7 ± 20.9, *n=17*	51.0 ± 28.1, *n=50*	0.5 ± 0.5, *n=4*
8/1/2002	Day	0.0	1.0 ± 1.2, *n=1*	0.9 ± 0.5, *n=7*
	Night	4.4 ± 3.0, *n=3*	7.3 ± 3.8, *n=7*	1.0 ± 0.8, *n=4*
8/8/2002	Day	1.1 ± 1.1, *n=1*	0.0	0.5 ± 0.3, *n=3*
	Night	6.5 ± 4.4, *n=5*	7.1 ± 7.1, *n=6*	2.2 ± 1.3, *n=9*

Table B-3. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of grass carp (*Ctenopharyngodon idella*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Ctenopharyngodon idella

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	13.1 ± 5.5, *n=7*	143.8 ± 83.2, *n=95*	17.8 ± 10.5, *n=13*
	Night	99.1 ± 44.0, *n=60*	57.5± 24.4, *n=38*	40.5 ± 16.2, *n=26*
7/3/1996	Day	1.5 ± 1.5, *n=1*	0.0	0.0
	Night	7.0 ± 7.0, *n=4*	16.5 ± 10.3, *n=10*	3.0 ± 3.0, *n=2*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	3.3 ± 2.1, *n=2*	0.0	1.4 ± 1.4, *n=1*
	Night	29.0 ± 16.9, *n=17*	0.0	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	5.1 ± 5.1, *n=4*	0.0	12.2 ± 8.2, *n=76*
	Night	22.0 ± 19.0, *n=17*	3.7 ± 3.7, *n=4*	3.0 ± 3.0, *n=29*
6/6/2002	Day	1.9 ± 1.9, *n=1*	4.4 ± 2.9, *n=3*	3.3 ± 2.4, *n=20*
	Night	74.4 ± 26.6, *n=42*	61.1 ± 28.0, *n=39*	44.6 ± 36.7, *n=141*

Table B-3. Continued.

6/18/2002	Day	32.4 ± 21.8, *n=24*	5.8 ± 2.1, *n=6*	169.8 ± 128.1, *n=938*
	Night	200.4 ± 100.8, *n=148*	0.0	304.3 ± 147.5, *n=2088*
6/27/2002	Day	0.0	116.7 ± 71.1, *n=121*	0.2 ± 0.2, *n=2*
	Night	0.0	2.1 ± 2.1, *n=1*	0.1 ± 0.1, *n=1*
7/17/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Table B-4. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of common carp (*Cyprinus carpio*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Cyprinus carpio

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/3/1996	Day	0.0	0.0	0.0
	Night	5.2 ± 5.2, *n=3*	1.6 ± 1.6, *n=1*	4.6 ± 4.6, *n=3*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.7 ± 0.3, *n=6*
	Night	0.0	0.9 ± 0.9, *n=1*	0.2 ± 0.1, *n=2*
6/6/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Table B-4. Continued.

6/18/2002	Day	0.0	0.0	0.2 ± 0.2, *n=1*
	Night	0.0	0.0	0.0
6/27/2002	Day	71.8 ± 67.8, *n=21*	0.0	32.5 ± 31.9, *n=68*
	Night	0.0	2.5 ± 2.5, *n=1*	0.0
7/17/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.9 ± 0.9, *n=1*	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.3 ± 0.3, *n=1*

Table B-5. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of fishes that could not be separated further than cyprinid group A (*Hybognathus argyritis, H. hankinsoni, H. placitus*, and *Notemigonus crysoleucas*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Cyprinid Group A

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	15.1 ± 8.8, *n=10*	0.0	0.0
	Night	20.9 ± 8.5, *n=12*	3.0 ± 2.0, *n=2*	0.0
7/3/1996	Day	0.0	0.0	0.0
	Night	11.3 ± 7.6, *n=6*	5.0 ± 3.5, *n=3*	0.0
7/3/1997	Day	1.5 ± 1.5, *n=1*	1.5 ± 1.5, *n=1*	0.0
	Night	112.0 ± 43.0, *n=74*	27.2 ± 12.3, *n=18*	0.0
7/10/1997	Day	42.0 ± 13.9, *n=25*	0.0	0.0
	Night	239.5 ± 96.5, *n=137*	8.0 ± 5.4, *n=5*	1.6 ± 1.6, *n=1*

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
6/6/2002	Day	9.8 ± 7.8, *n=6*	1.7 ± 1.7, *n=1*	0.0
	Night	0.0	0.0	0.3 ± 0.2, *n=2*

Table B-5. Continued.

6/18/2002	Day	5.5 ± 4.1, *n=4*	2.0 ± 2.0, *n=2*	0.4 ± 0.3, *n=2*
	Night	12.3 ± 6.6, *n=9*	3.9 ± 2.0, *n=4*	1.7 ± 1.5, *n=12*
6/27/2002	Day	37.6 ± 30.2, *n=11*	2.5 ± 2.5, *n=1*	26.3 ± 22.1, *n=52*
	Night	10.3 ± 10.3, *n=3*	9.9 ± 9.9, *n=4*	1.3 ± 1.0, *n=4*
7/17/2002	Day	1464.1 ± 768.2, *n=966*	444.5 ± 189.3, *n=350*	0.6 ± 0.5, *n=3*
	Night	961.2 ± 684.2, *n=626*	729.7 ± 448.6, *n=571*	0.1 ± 0.1, *n=1*
8/1/2002	Day	73.7 ± 52.7, *n=51*	15.2 ± 14.2, *n=13*	0.5 ± 0.4, *n=3*
	Night	521.2 ± 323.8, *n=358*	173.4 ± 145.4, *n=146*	1.8 ± 1.5, *n=7*
8/8/2002	Day	62.0 ± 43.1, *n=45*	11.5 ± 10.5, *n=10*	1.8 ± 0.8, *n=9*
	Night	320.2 ± 205.0, *n=235*	112.8 ± 76.1, *n=96*	6.2 ± 2.2, *n=29*

Table B-6. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of fishes that could not be separated beyond cyprinid group B (*Cyprinella spiloptera, Lythrurus umbratilis, Notropis blennius, N. buchanani, N. shumardi, N. stramineus, N. wickliffi,* and *Phenacobius mirabilis*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River. Emerald shiner (*Notropis atherinoides* was included in Cyprinid group B in the scour data set; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Cyprinid group B

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	107.0 ± 57.3, *n=53*	3.0 ± 2.0, *n=2*	1.8 ± 1.8, *n=1*
	Night	116.0 ± 46.4, *n=62*	15.1 ± 6.4, *n=10*	0.0
7/3/1996	Day	33.6 ± 16.6, *n=22*	9.6 ± 4.8, *n=6*	0.0
	Night	50.1 ± 39.4, *n=28*	61.4 ± 36.3, *n=37*	7.9 ± 4.1, *n=5*
7/3/1997	Day	0.0	0.0	0.0
	Night	4.7 ± 3.3, *n=3*	1.5 ± 1.5, *n=1*	0.0
7/10/1997	Day	649.7 ± 299.4, *n=395*	15.2 ± 5.0, *n=9*	74.6 ± 44.3, *n=45*
	Night	1766.7 ± 1017.0, *n=1027*	572.8 ± 278.5, *n=355*	535.4 ± 252.9, *n=341*

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Table B-6. Continued.

6/6/2002	Day	0.0	1.7 ± 1.7, *n=1*	129.4 ± *129.4*
	Night	0.0	0.0	0.0
6/18/2002	Day	0.0	5.9 ± 5.9, *n=6*	96.5 ± 96.5, *n=457*
	Night	16.4 ± 16.4, *n=12*	11.8 ± 11.8, *n=12*	0.6 ± 0.5, *n=5*
6/27/2002	Day	0.0	14.8 ± 14.8, *n=6*	3.6 ± 3.6, *n=7*
	Night	24.9 ± 11.5, *n=8*	0.0	1.1 ± 1.0, *n=2*
7/17/2002	Day	19.2 ± 19.2, *n=17*	21.9 ± 21.9, *n=17*	0.8 ± 0.8, *n=3*
	Night	0.0	16.5 ± 15.2, *n=19*	0.0
8/1/2002	Day	12.8 ± 9.8, *n=9*	1.2 ± 1.2, *n=1*	0.4 ± 0.3, *n=2*
	Night	24.4 ± 17.0, *n=17*	36.8 ± 26.2, *n=32*	0.3 ± 0.3, *n=1*
8/8/2002	Day	13.6 ± 10.1, *n=17*	0.0	2.7 ± 2.5, *n=2*
	Night	63.2 ± 40.6, *n=51*	5.6 ± 4.6, *n=5*	0.8 ± 0.5, *n=3*

Table B-7. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of gizzard shad (*Dorosoma cepedianum*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Dorosoma cepedianum

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	160.2 ± 63.4, *n=96*	909.5 ± 161.6, *n=601*	0.0
	Night	139.5 ± 33.4, *n=84*	690.1 ± 215.4, *n=456*	0.0
7/3/1996	Day	26.1 ± 17.9, *n=16*	136.4 ± 47.0, *n=86*	9.6 ± 7.3, *n=7*
	Night	27.7 ± 16.8, *n=16*	23.3 ± 9.0, *n=14*	9.2 ± 3.8, *n=6*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	4.5 ± 3.2, *n=3*	1.4 ± 1.4, *n=1*
7/10/1997	Day	50.1 ± 19.6, *n=31*	25.2 ± 8.3, *n=14*	8.1± 4.2, *n=5*
	Night	56.6 ± 18.6, *n=34*	9.9 ± 6.5, *n=6*	1.5 ± 1.5, *n=1*

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	1.9 ± 1.9, *n=2*	0.3 ± 0.2, *n=2*
	Night	1.3 ± 1.3, *n=1*	0.0	0.0
6/6/2002	Day	7.6 ± 7.6, *n=4*	13.4 ± 7.9, *n=10*	3.2 ± 1.4, *n=10*
	Night	0.0	3.5 ± 2.2, *n=2*	2.8 ± 1.0, *n=14*

Table B-7. Continued.

6/18/2002	Day	43.1 ± 35.0, *n=32*	15.4 ± 9.6, *n=16*	2.0 ± 0.7, *n=9*
	Night	20.4 ± 10.9, *n=15*	5.9 ± 2.2, *n=6*	2.8 ± 1.3, *n=19*
6/27/2002	Day	0.0	0.0	2.0 ± 1.6, *n=4*
	Night	3.4 ± 3.4, *n=1*	0.0	0.5 ± 0.5, *n=1*
7/17/2002	Day	0.0	0.0	0.1 ± 0.1, *n=1*
	Night	1.1 ± 1.1, *n=1*	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Table B-8. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of goldeye (*Hiodon alosoides*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Hiodon alosoides

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	1.5 ± 1.5, *n=1*	1.5 ± 1.5, *n=1*	2.8 ± 1.9, *n=2*
	Night	0.0	1.5 ± 1.5, *n=1*	3.1 ± 2.0, *n=2*
7/3/1996	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	5.1 ± 2.5, *n=4*	8.5 ± 4.4, *n=9*	2.9 ± 0.9, *n=23*
	Night	30.9 ± 9.2, *n=24*	34.9 ± 8.2, *n=37*	2.1 ± 0.8, *n=16*
6/6/2002	Day	3.5 ± 2.2, *n=2*	5.3 ± 5.3, *n=4*	7.8 ± 1.3, *n=43*
	Night	20.9 ± 12.6, *n=13*	23.0 ± 11.1, *n=16*	6.4 ± 1.6, *n-27*

Table B-8. Continued.

6/18/2002	Day	34.1 ± 14.7, *n=25*	3.8 ± 1.9, *n=4*	1.1 ± 0.5, *n=5*
	Night	13.6 ± 7.5, *n=10*	7.8 ± 5.8, *n=8*	1.3 ± 0.9, *n=10*
6/27/2002	Day	0.0	2.5 ± 2.5, *n=1*	2.0 ± 0.9, *n=4*
	Night	6.0 ± 3.9, *n=2*	0.0	1.7 ± 1.1, *n=4*
7/17/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Table B-9. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error, and in italics the number of bighead and silver carps (*Hypophthalmichthys molitrix and nobilus*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Hypophthalmichthys molitrix/nobilus

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	176.9 ± 115.1, *n=107*	154.4 ± 68.7, *n=102*	32.2 ± 6.5, *n=21*
	Night	80.7 ± 30.7, *n=39*	34.8 ± 9.3, *n=23*	32.3 ± 7.7, *n=22*
7/3/1996	Day	4.7 ± 3.2, *n=3*	7.7 ± 4.2, *n=5*	0.0
	Night	19.5 ± 11.9, n=11	13.3 ± 7.6, *n=7*	7.8 ± 4.0, *n=5*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	13.5 ± 6.1, *n=8*	0.0	0.0
	Night	72.8 ± 26.8, *n=43*	6.4 ± 3.5, *n=4*	3.2 ± 2.1, *n=2*

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	6.4 ± 6.4, *n=5*	53.5 ± 53.5, *n=58*	756.5 ± 336.5, *n=6187*
	Night	208.4 ± 137.8, *n=163*	529.4 ± 215.4, *n=558*	949.0 ± 250.4, *n=7411*
6/6/2002	Day	234.9 ± 131.0, *n=127*	138.8 ± 45.4, *n=92*	519.4 ± 133.1, *n=2244*
	Night	246.9 ± 104.1, *n=138*	565.3 ± 214.3, *n=352*	489.2 ± 185.2, *n=1667*

Table B-9. Continued.

6/18/2002	Day	1571.1 ± 1265.5, *n=1152*	464.1 ± 329.4, *n=471*	1952.1 ± 367.5, *n=10,125*
	Night	487.1 ± 118.6, *n=359*	288.6 ± 87.3, *n=295*	969.3 ± 205.9, *n=6808*
6/27/2002	Day	7.8 ± 7.8, *n=3*	26.8 ± 24.3, *n=11*	4.3 ± 1.8, *n=17*
	Night	74.4 ± 67.3, *n=22*	56.7 ± 56.7, *n=23*	27.1 ± 14.5, *n=61*
7/17/2002	Day	12.4 ± 12.4, *n=11*	4.3 ± 4.3, *n=5*	0.8 ± 0.5, *n=3*
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.6 ± 0.6, *n=6*

Table B-10. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error, and in italics the number of fishes that could not be separated beyond sunfishes (*Lepomis cyanellus, L. humilis, L. macrochirus, and L. megalotis*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

***Lepomis* spp.**

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	7.9 ± 6.4, *n=4*	0.0	0.0
	Night	1.5 ± 1.5, *n=1*	0.0	0.0
7/3/1996	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/3/1997	Day	283.6 ± 83.5, *n=185*	2020.3 ± 992.3, *n=1335*	20.4 ± 8.5, *n=13*
	Night	505.1 ± 288.1, *n=323*	563.0 ± 170.7, *n=372*	42.3 ± 9.7, *n=26*
7/10/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	1.4 ± 1.0, *n=12*
	Night	0.0	0.0	0.1 ± 0.1, *n=12*
6/6/2002	Day	1.6 ± 1.6, *n=1*	3.5 ± 2.2, *n=2*	0.1 ± 0.1, *n=12*
	Night	0.0	0.0	0.0

Table B-10. Continued.

6/18/2002	Day	5.4 ± 1.7, *n=4*	2.9 ± 2.0, *n=3*	1.3 ± 0.8, *n=6*
	Night	9.5 ± 3.3, *n=7*	5.9 ± 3.1, *n=6*	1.0 ± 0.4, *n=6*
6/27/2002	Day	0.0	2.1 ± 2.1, *n=1*	0.0
	Night	5.2 ± 5.2, *n=2*	0.0	0.0
7/17/2002	Day	0.0	0.0	0.6 ± 0.4, *n=3*
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	2.7 ± 2.2, *n=18*
	Night	0.0	0.0	0.3 ± 0.3, *n=1*
8/8/2002	Day	0.0	0.0	1.1 ± 1.0, *n=9*
	Night	0.0	0.0	0.3 ± 0.2, *n=3*

Table B-11. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of speckled and silver chub (*Macrhybopsis aestivalis* and *storeriana*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Macrhybopsis aestivalis/storeriana

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/3/1996	Day	5.4 ± 2.7, *n=3*	0.0	0.0
	Night	2.2 ± 2.2, *n=1*	0.0	0.0
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	33.3 ± 11.4, *n=20*	0.0	0.0
	Night	126.0 ± 42.7, *n=74*	3.2 ± 3.2, *n=2*	4.7 ± 3.3, *n=3*

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
6/6/2002	Day	1.6 ± 1.6, *n=1*	1.3 ± 1.3, *n=1*	0.1 ± 0.1, *n=1*
	Night	12.7 ± 12.7, *n=8*	7.1 ± 3.9, *n=5*	0.4 ± 0.4, *n=1*

Table B-11. Continued

6/18/2002	Day	647.9 ± 253.6, *n=478*	528.9 ± 210.1, *n=542*	0.9 ± 0.7, *n=4*
	Night	545.6 ± 299.1, *n=401*	338.6 ± 228.3, *n=344*	0.4 ± 0.3, *n=2*
6/27/2002	Day	0.0	29.6 ± 18.7, *n=12*	20.8 ± 9.1, *n=41*
	Night	109.7 ± 44.3, *n=35*	73.3 ± 45.2, *n=30*	18.4 ± 13.7, *n=37*
7/17/2002	Day	21.5 ± 21.5, *n=14*	24.8 ± 21.9, *n=29*	0.1 ± 0.1, *n=1*
	Night	11.0± 7.9, *n=9*	99.5 ± 74.8, *n=85*	0.1 ± 0.1, *n=1*
8/1/2002	Day	1.1 ± 1.1, *n=1*	0.0	0.3 ± 0.3, *n=1*
	Night	23.8 ± 23.8, *n=21*	53.5 ± 25.4, *n=59*	1.4 ± 0.8, *n=11*
8/8/2002	Day	1.1 ± 1.1, *n=1*	1.7 ± 1.7, *n=2*	0.0
	Night	256.9 ± 170.2, *n=226*	38.5 ± 18.6, *n=45*	3.8 ± 1.5, *n=19*

Table B-12. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error, and in italics the number of sicklefin and sturgeon chub (*Macrhybopsis gelida* and *meeki*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Macrhybopsis gelida/meeki

Scours

Date	**Day/Night**	**NSS**	**NSD**	**OW**
6/26/1996	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/3/1996	Day	12.6 ± 6.8, *n=8*	0.0	0.0
	Night	26.4 ± 21.1, *n=13*	11.7 ± 4.7, *n=7*	10.6 ± 5.3, *n=7*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	57.9 ± 17.3, *n=35*	0.0	0.0
	Night	197.4 ± 92.7, *n=119*	35.6 ± 17.6 *n=22*	29.8 ± 17.8, *n=19*

Sandbars

		Shoreward	**Riverward**	**Channel**
5/30/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
6/6/2002	Day	1.9 ± 1.9, *n=1*	0.0	0.0
	Night	4.8 ± 3.2, *n=3*	4.0 ± 4.0, *n=3*	0.0

Table B-12. Continued.

6/18/2002	Day	383.0 ± 244.0, *n=281*	372.4 ± 137.0, *n=382*	2.7 ± 2.5, *n=12*
	Night	40.6 ± 16.7, *n=30*	199.1 ± 106.6, *n=203*	0.3 ± 0.2, *n=2*
6/27/2002	Day	9.4 ± 6.8, *n=3*	12.3 ± 12.3, *n=5*	8.1 ± 4.5, *n=16*
	Night	20.6 ± 11.0, *n=7*	0.0	7.4 ± 4.8, *n=16*
7/17/2002	Day	0.0	0.0	0.0
	Night	0.0	6.0 ± 6.0, *n=7*	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	3.4 ± 3.4, *n=3*	8.6 ± 7.6, *n=10*	0.5 ± 0.3, *n=4*

Table B-13. Mean catch per unit of effort (CPUE=number of larval fish per $100m^3$ of water) ± standard error, and in italics the number of emerald shiners (*Notropis atherinoides*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River. NA means larval fish were not identified to this level of specificity; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Notropis atherinoides

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	NA	NA	NA
	Night	NA	NA	NA
7/3/1996	Day	NA	NA	NA
	Night	NA	NA	NA
7/3/1997	Day	NA	NA	NA
	Night	NA	NA	NA
7/10/1997	Day	NA	NA	NA
	Night	NA	NA	NA

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.1 ± 0.1, *n=1*
	Night	1.3 ± 1.3, *n=1*	0.9 ± 0.9, *n=1*	0.2 ± 0.1, *n=2*
6/6/2002	Day	0.0	4.4 ± 2.9, *n=3*	3.0 ± 1.9, *n=9*
	Night	0.0	1.3 ± 1.3, *n=1*	1.1 ± 0.6, *n=3*

Table B-13. Continued.

6/18/2002	Day	17.7 ± 11.5, *n=13*	8.8 ± 3.7, *n=9*	4.0 ± 2.6, *n=19*
	Night	153.5 ± 96.2, *n=113*	11.7 ± 5.8, *n=12*	1.9 ± 0.9, *n=15*
6/27/2002	Day	2.6 ± 2.6, *n=1*	64.1 ± 64.1, *n=26*	6.9 ± 4.5, *n=16*
	Night	6.0 ± 3.9, *n=2*	24.7 ± 15.6, *n=10*	3.6 ± 2.6, *n=7*
7/17/2002	Day	169.1 ± 106.2, *n=112*	225.0 ± 91.0, *n=180*	1.5 ± 0.5, *n=8*
	Night	42.9 ± 29.3, *n=29*	214.6 ± 123.6, *n=175*	0.0
8/1/2002	Day	12.0 ± 5.8, *n=10*	22.7 ± 22.7, *n=19*	1.4 ± 1.3, *n=6*
	Night	20.4 ± 20.4, *n=14*	16.5 ± 11.5, *n=15*	0.0
8/8/2002	Day	5.7 ± 4.6, *n=5*	12.5 ± 6.7, *n=12*	0.8 ± 0.4, *n=3*
	Night	3.4 ± 3.4, *n=3*	0.9 ± 0.9, *n=1*	0.5 ± 0.3, *n=2*

Table B-14. Mean catch per unit of effort (CPUE=number of larval fish per 100m^3 of water) ± standard error, and in italics the number of white and black crappie (*Pomoxis annularis* and *nigromaculatus*) collected for each sample date, and either day (collected at 12:00 or 18:00 for samples collected in off-channel scours, or 10:00, 14:00, or 18:00 for in-channel sandbar) or night (collected at 06:00 or 24:00 for off-channel scours, or 02:00, 06:00, or 22:00 for in-stream sandbars) in the lower Missouri River; NSS=near shore shallow, NSD=near shore deep, and OW=open water.

Pomoxis annularis/nigromaculatus

Scours

Date	Day/Night	NSS	NSD	OW
6/26/1996	Day	28.8 ± 16.7, *n=19*	127.1 ± 62.1, *n=84*	6.9 ± 3.8, *n=4*
	Night	94.1 ± 31.9, *n=57*	192.2 ± 114.8, *n=127*	13.6 ± 3.7, *n=7*
7/3/1996	Day	0.0	1.7 ± 1.7, *n=1*	2.3 ± 2.3, *n=1*
	Night	0.0	3.1 ± 2.1, *n=2*	1.6 ± 1.6, *n=1*
7/3/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
7/10/1997	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

Sandbars

		Shoreward	Riverward	Channel
5/30/2002	Day	0.0	0.0	0.1 ± 0.1, *n=1*
	Night	0.0	0.0	0.0
6/6/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.7 ± 0.4, *n=6*

Table B-14. Continued.

6/18/2002	Day	0.0	1.0 ± 1.0, *n=1*	0.0
	Night	0.0	289 ± 2.0, *n=3*	0.0
6/27/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.1 ± 0.1, *n=1*
7/17/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/1/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0
8/8/2002	Day	0.0	0.0	0.0
	Night	0.0	0.0	0.0

VITA

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