Habitat Use by Fishes in Periodically and Continuously Connected Lower Missouri River Floodplain Water Bodies

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Table of Contents

List of Tables

List of Figures

ABSTRACT

Knowledge of how fishes use floodplain habitats is essential to guide efforts to restore ecological integrity of altered large river ecosystems. Spatial and temporal distributions of juvenile and adult fishes among habitats were investigated in two representative lower Missouri River floodplain scour basins created by the "Great Flood of 1993". One scour basin was continuously connected (CC site) to the river, whereas the other connected to the river periodically (PC site).

Habitats sampled in both sites included near-shore shallow, near-shore deep, open water, and woody debris. Near-shore shallow with current, woody debris with current, and rock dike were sampled only at the CC site. Sampling was conducted approximately biweekly at each site from 15 July 1996 to 18 December 1997. Four random sample locations were chosen for each available habitat on each sampling date. Fishes were collected using prepositioned areal electrofishing devices (PAEDs). Water depth (m), temperature (°C), current velocity (m/s), secchi depth (cm) and dissolved oxygen (mg/L) were measured in conjunction with each sample.

Thirty-eight species representing 11 families were collected from the two scour basins. Twenty-five of these species were collected from the PC site and 33 were collected from the CC site. Catch composition was similar between the two scours, with gizzard shad and/or emerald shiner dominating abundance in catch from both sites during all seasons. Mean CPUE for the five most abundant taxa at the PC site, three of the four most abundant taxa at the CC site, and species richness in most habitats at both sites were highest during summer or fall and lowest during spring.

Species richness, mean CPUE for all species combined and mean CPUE for 11 of 13 individual taxa were significantly higher in either near-shore shallow or woody debris compared to all other habitats at both sites. Differences in connectivity between the two scour basins appeared to have little influence on fish habitat use within sites. Greater use of near-shore shallow and woody debris by juvenile and adult fishes compared to

other habitats appeared to be primarily related to shallower depth, presence of cover, and/or absence of current.

Extent of shallow (<0.6 m), near-zero velocity, aquatic habitat should be a primary consideration in efforts to acquire, design, or construct floodplain water bodies that will maximize optimal habitat for juvenile and adult fishes that use off-channel habitats. Restoration, maintenance, or enhancement of floodplain habitat for fishes should also incorporate large woody debris sources for the lower Missouri River (riparian vegetation along tributaries and in the floodplain) and a hydrologic regime that promotes both import and retention of large woody debris in off-channel aquatic habitats.

INTRODUCTION

Most of the aquatic biomass in unaltered, large, floodplain rivers is derived directly or indirectly from production within the floodplain (Junk et al. 1989). Geomorphic features within the floodplain (e.g. sloughs, side channels, backwaters) are largely responsible for retention of organic matter and nutrients in large, low-gradient rivers. Seasonal pulsing of flood flows into the floodplain, termed the "flood pulse" (Junk et al. 1989), is the driving force controlling the river-floodplain complex (Welcomme 1985, Sparks et al. 1990, Bayley 1991). Fishes that use this highly productive environment capitalize on feeding, spawning, nursery, and refuge attributes characteristic of river-floodplain systems (Ward 1989). Floodplain wetlands are considered an essential component responsible for the high fish production recorded in large, low-gradient rivers (Risotto and Turner 1985, Welcomme 1985, Copp 1989, Ward 1989, Bayley 1991). Recognition that rivers and their floodplains are so intimately linked that they should be understood, managed, and restored as integral parts of a single system make up the foremost integrative concept of large river ecology (National Research Council 1992).

The dynamic river-floodplain linkage has been disrupted in the Missouri River, as in many of the world's large river systems. Approximately the upper one-third of its 3768 km length is free-flowing, the middle one-third is impounded, and the lower one-third, extending from Sioux City, Iowa, to the river mouth near St. Louis, Missouri, and referred to as the lower Missouri River, has been channelized (Hesse et al. 1988). The formerly shallow, braided channel of the lower Missouri River was converted to a single, deep, swift navigation channel (Hesse and Sheets 1993, Latka et al. 1993), resulting in a 50% reduction in river-floodplain water surface area (Funk and Robinson 1974) and a 39% decrease in area of floodplain wetlands (Hesse et al. 1988). Upstream from Missouri, a series of flood-control dams and reservoirs have altered the pre-impoundment annual hydrograph of the lower Missouri River that created and destroyed floodplain waterbodies. The lower Missouri River historically exhibited a bimodal flood pulse in April and June (Galat and Lipkin 2000), with the June flood being the larger of the two pulses and coinciding with spawning of many floodplain-dependent fishes (Galat et al. 1998, Galat and Lipkin 2000). The present annual hydrograph of the lower Missouri River is characterized by a regulated stage increase in early spring that levels off and remains constant through autumn to provide flows for navigation (Galat and Lipkin 2000). Flood height has been truncated and late summer discharge increased. Only about 10% of the original lower Missouri River floodplain is inundated on average during annual flooding, as agricultural levees confine the river to a width of 183-335 m (Schmulbach et al. 1992). Loss of side- and off-channel habitats and alteration of historical flow regimes resulted in substantial changes in the composition, structure, and function of plant, invertebrate, and fish communities (Hesse et al. 1988, 1989, Schmulbach et al. 1992, Galat and Frazier 1996, Galat et al. 2005), as well as declines in harvest of commercial and sport fishes (Whitley and Campbell 1974, Groen and Schmulbach 1978).

The "Great Flood of 1993" in the Midwest U.S. surpassed all previously recorded floods in terms of precipitation amounts, river levels, flood duration, and area of flooding (Parrett et al. 1993, Wahl et al. 1993, Interagency Floodplain Management Review Committee 1994) and reconnected most of the lower Missouri River to its ancestral floodplain for the first time in over 20 years. Floods overtopped and breached over 500 flood-control levees along the lower Missouri River between Kansas City and St. Louis (Scientific Assessment and Strategy Team 1994). Increased hydraulic heads and concentrated flow through narrow openings in levee breaks created zones of intense scour downstream and upstream of breaks (Scientific Assessment and Strategy Team 1994); this intense erosion produced over 450 new steep-sided water bodies or "scour basins" (Galat et al. 1997). Scour basins exhibit a range of connectivity to the Missouri River from isolated to continuously connected and may function as analogs of floodplain waterbodies which existed along the lower Missouri River prior to impoundment and channelization (Galat et al. 1997).

Post-flood research along the lower Missouri River indicated that fish assemblages differ among scour basins that exhibit different degrees of connectivity with the river (Galat et al. 1998). Scours can be classified into three categories based on seasonal predictability of their connectivity with the Missouri River (Galat et al. 1998). Continuously-connected scours remain connected with the river throughout most of the year, disconnecting only during extreme low-water events. Periodically-connected scours connect with the river during periods of high water and may connect and disconnect several times during a year. Periodic scours may not connect to the river in low water years. Isolated scours remain separated from the river by levees and only connect with the river during catastrophic floods that over-top levees. Catch rates, biomass, and species richness of juvenile and small adult fishes were significantly higher in continuously and periodically-connected scours compared to isolated scours (Kubisiak 1997). Larval fish taxa richness was highest in continuously-connected scours, intermediate in periodically-connected scours, and lowest in isolated scours; increases in taxa richness with increasing connectivity likely resulted from addition of larvae of rheophilic fishes (Galat et al. 2004a). However, catch rates and species richness of larval fishes were not significantly different between continuously-connected scours formed by water entering the floodplain compared to continuously-connected scours created by water exiting the floodplain (Tibbs and Galat 1997).

This post-flood research provided valuable insights into patterns of fish use among basin types. However, logistics of sampling multiple sites over long distances precluded intensive assessment of site-specific temporal changes in habitat use by fishes within scours that connect to the lower Missouri River. Consequently, objectives of this study were to: 1) intensively compare spatial and temporal distribution of juvenile and adult fishes among habitats within a representative periodically-connected and a continuously-connected scour basin; and, 2) relate fish distribution to spatial and temporal variation in hydrology, morphology, and environmental variables within each scour basin. An intensive study of larval fish habitat use in these two scour basins indicated that most taxa were primarily or exclusively collected in low-velocity, near-shore, shallow water habitats (Galat et al. 2004b). Knowledge of spatiotemporal patterns of juvenile and adult fish habitat use within periodically and continuously-connected scour basins will further improve our understanding of how connectivity affects use of floodplain water bodies by all life stages of fishes and help guide future decisions regarding restoration and management of aquatic resources in large river floodplains.

STUDY SITES

One representative periodically-connected scour basin and one continuously-connected scour basin were selected as study sites based on results from Kubisiak (1997) who evaluated small fish use across the range of scour types present following the 1993 flood. Both were formed as "entrance scours" (Galat et al. 1997) during the flood of 1993. Periodically-connected (PC, designated NC-11 in the MRPE study) and continuously-connected (CC, designated S-19 in the MRPE study) sites were located 421 km and 387 km upstream from the Missouri-Mississippi River confluence, respectively (Figure 1).

Bathymetric surveys of the two scours were conducted by the Natural Resources Conservation Service (NRCS) during November 1996. The PC site (Figure 2) had a surface area of 3.8 ha when bank-full, but not connected to the river. Overland connection with the river occurred at river stages ≥194 m above MSL (~203.5 m above MSL at the Waverly, MO gauge; river km 472.4). The flood-control levee that ruptured during formation of this scour was rebuilt landward from the basin, forming its northern, eastern, and southern margins. The scour basin was ovoid and steep-sided, especially riverward, with mean and maximum depths of 5.7 and 16 m, respectively, when bank-full (Knowlton and Jones 2003).

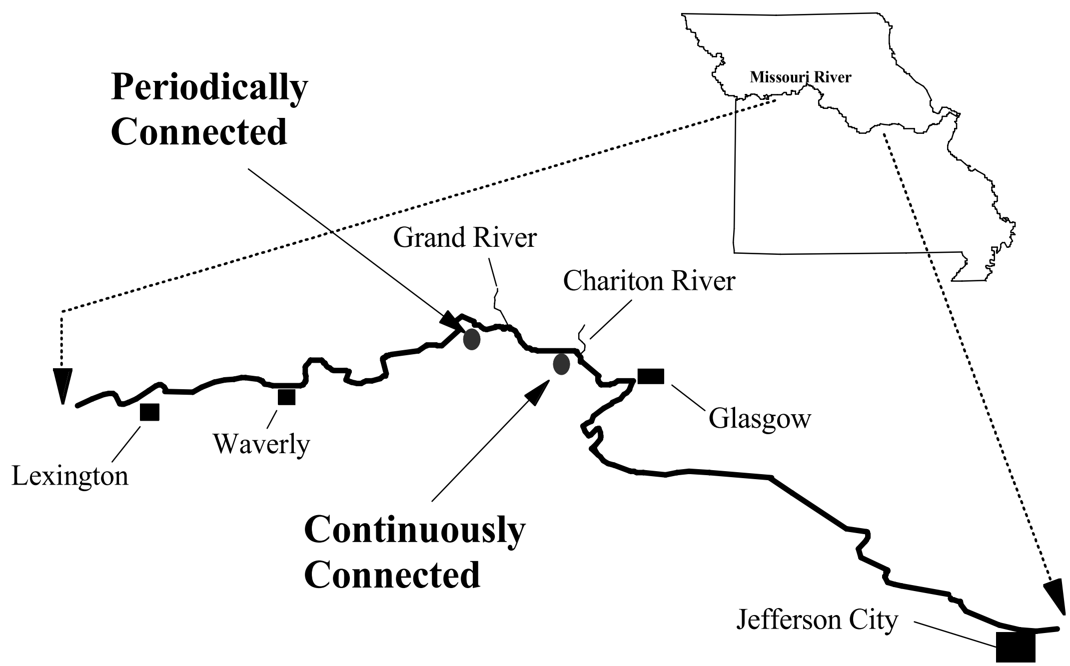

Figure 1. Location of two scour basins and selected landmarks along the Lower Missouri River, Missouri.

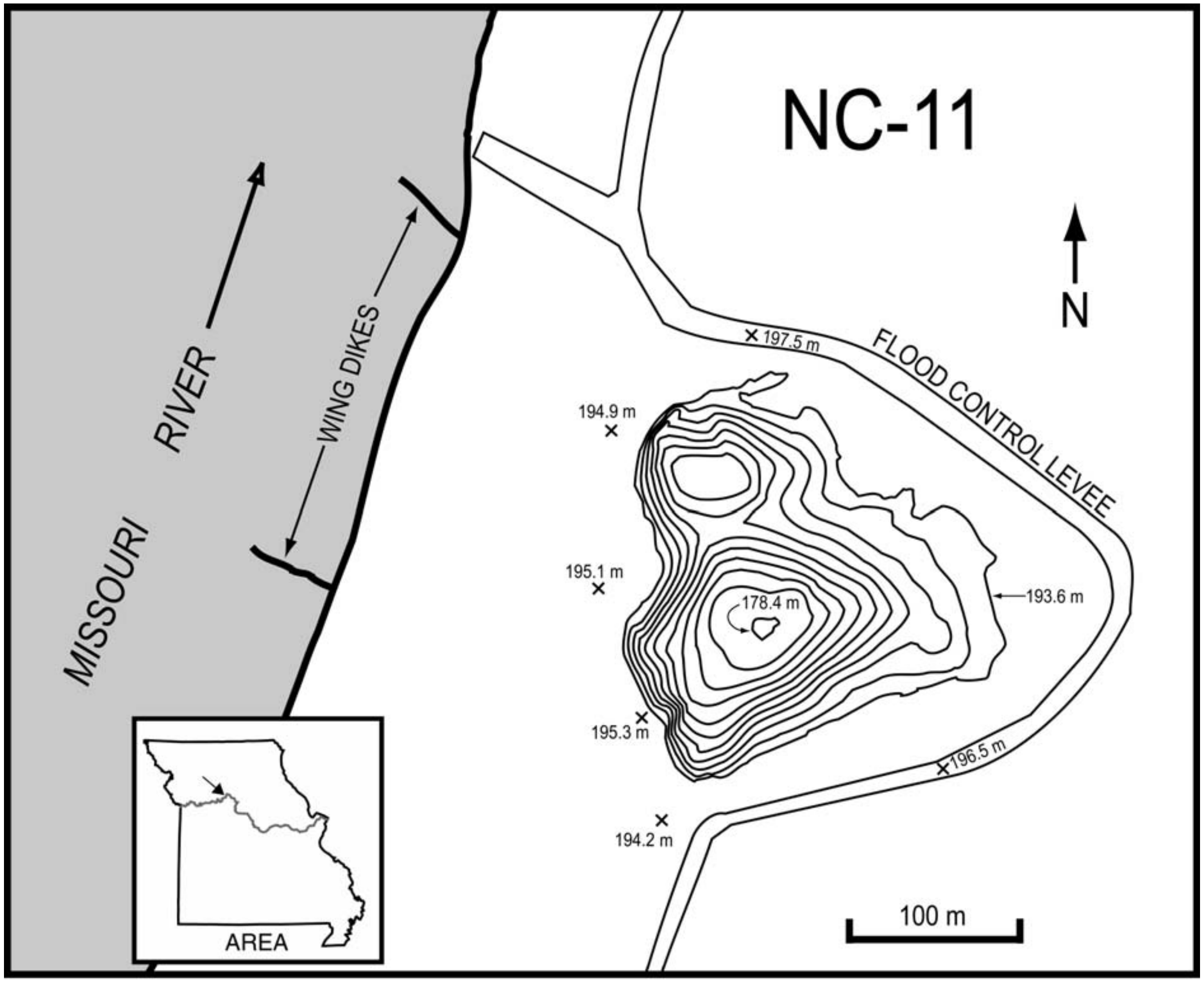

Figure 2. Map of the periodically connected (PC) site, km 421 (source: Knowlton and Jones 2003). Bathymetric contours are at 1.52 m (5 ft) intervals.

The CC site (Figure 3) was formed when the river cut across a meander bend, forming a temporary secondary channel. The scour basin was >1 km long and had a surface area of 26 ha when bank-full (Kubisiak 1997). Levees that were breached when the scour basin was formed were not repaired, allowing the site to be inundated with chute-like flow during large floods. When water levels were within the bounds of the scour basin, the CC site was comprised of two sub-basins (Figure 3). The riverward (front) sub-basin was separated from the river by rock dikes. These dikes were notched and were heavily eroded during floods in 1995 and 1996, allowing water from the river to flow through the riverward sub-basin at most river stages. The remainder of the scour basin functioned as a backwater and did not have visually detectable current except dur-

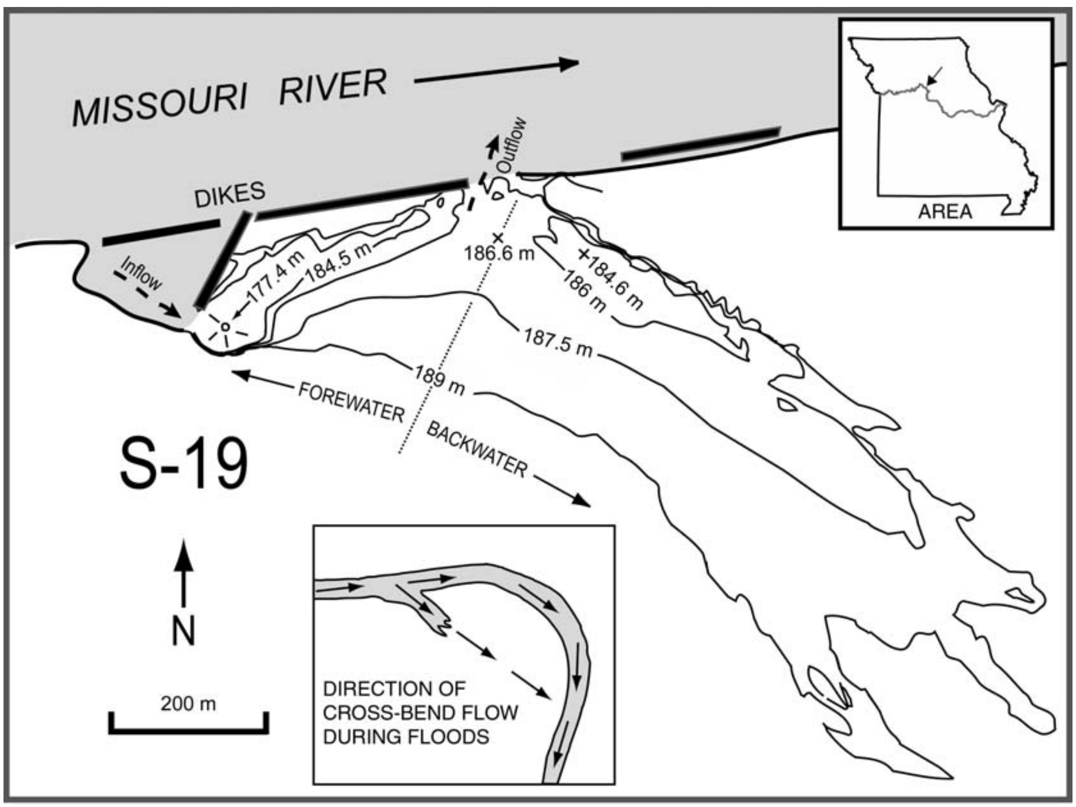

Figure 3. Map of the continuously connected (CC) site, km 387(source: Knowlton and Jones 2003). Landward boundary of basin is approximately defined by the 189 m contour, except during floods. Dashed arrows labeled "Inflow" (IF) and "Outflow" (IF) indicate major flow paths of water through the forewater basin during non-flood periods and the IF and OF habitats sampled. Straight line perpendicular to depth contours indicates location of sill separating forewater and backwater sub-basins. Lower insert shows local site location on the Little Missouri Bend and the direction of cross-bend flow during floods.

ing periods of chute-like flow across the meander bend. A shallow sill composed of sand and silt was present at the interface of the two sub-basins. When chute-like flow was not present, the sill inhibited water exchange between the two sub-basins, particularly at river stages ≤202 m above MSL at the Waverly, MO gauge (Knowlton and Jones 2003). The front sub-basin had a mean depth of 4.4 m and the backwater sub-basin had a mean depth of 1.3 m at bank-full elevation (189 m above MSL). Mean depth of the backwater sub-basin declined to about 0.7 m when the two sub-basins were disconnected by the sill. Scour and deposition continually altered the morphology of this site. Elevation of the sill increased about 0.3 m during the study, reducing connectivity of the backwater sub-basin (Knowlton and Jones 2003).

METHODS

Field sampling

Physical habitats were divided into seven categories at the continuously-connected (CC) site and four categories at the periodically-connected (PC) site based on average depth, proximity to shore, and presence or absence of current and structure (Table 1). Habitat categories at the CC site included near-shore shallow, near-shore deep, open water, and woody debris in the backwater sub-basin and near-shore shallow with current, woody debris with current, and rock dike in the forewater sub-basin. Habitat categories at the PC site included near-shore shallow, near-shore deep, open water, and woody debris.

Fishes were sampled approximately biweekly at each site from 15 July 1996 to 16 December 1997, except that the PC site was not sampled during January 1997. Four random sample locations were chosen within each available habitat category on each sampling date. Habitats were delimited using bathymetric maps of each scour, depth soundings, and visual observation of presence or absence of water current, woody debris, and rock dikes.

Table 1. Criteria used to categorize seven within -scour habitat types and sites where these habitats occurred in a periodically -connected (PC) and a continuously -connected (CC) scour, Missouri River, Missouri.

Habitat	Description	Sites
Near-shore shallow (NSS)	Average depth <0.6 m, <30 m from shore, current and woody debris absent	PC, CC
Near-shore deep (NSD)	Average depth >0.6 m, <30 m from shore, current and woody debris absent	PC, CC
Open water (OW)	Average depth >0.6 m, >30 m from shore, current and woody debris absent	PC, CC
Woody debris (WD)	Woody debris present, current absent	PC, CC
Near-shore shallow with current (NSSC)	Average depth <0.6 m, <30 m from shore, current present, woody debris absent	CC
Woody debris with current (WDC)	Woody debris and current present	CC
Rock dike (ROCK)	Adjacent to rock dikes at site -river interface, current present	CC

Comparisons of fish densities and assemblage structure among habitats were facilitated by use of identical sampling gear in each habitat. We adapted prepositioned areal electrofishing devices (PAEDs; Bain et al. 1985, Fisher and Brown 1993) to assess fish habitat use in the two scours. The devices were similar to the bottom parallel electrode PAED described in Fisher and Brown (1993). Each PAED consisted of two, 2.44-m parallel copper rods (1.91 cm diameter) spaced 60 cm apart that served as electrodes. PAEDs were suspended from floats at one-half of water depth for near-shore shallow and near-shore shallow with current samples and 0.5 m below the surface in all other habitats. Alternating current was employed to limit attraction of fish to PAEDs by electrotaxis.

A minimum of 20 minutes elapsed between deployment of PAEDs and sampling on each sample date to allow fishes to recover from possible disturbance associated with PAED placement. Bain et al. (1985) found no significant correlations between fish capture rates and time between PAED deployment and sampling when time delays exceeded 11 minutes. Each PAED was connected to an alternator (one PAED at a time), energized for 1 minute, and stunned fishes were collected with dip nets. Measurements of voltage gradient (V/cm) between and outside of electrodes were conducted on one of the near-shore shallow PAEDs on each sampling date to estimate area being shocked and to adjust alternator output (amps and volts) to account for temporal changes in water conductivity and thereby minimize variation in water volume sampled among dates. Identical alternator output was used on all PAEDs on a given sampling date to produce consistent sample volume among collections from different habitats.

Several physical habitat parameters were measured in conjunction with each fish sample. Water depth (m) was measured at the middle and at each end of all PAEDs. Current velocity (m/s), water temperature (°C), dissolved oxygen concentration (DO, mg/L), and secchi depth (cm) were measured at each sample location. Current velocity was measured at the depth of each PAED with a Marsh-McBirney model 201d flow meter. Temperature and dissolved oxygen concentration were measured at PAED depth with a YSI Inc. Model 57 oxygen meter and polarographic oxygen probe. A secchi disk was used to estimate water transparency.

<u>Data analysis</u>

River stage and temperature

Daily river stages (m above MSL) during the study were obtained from the U.S.

Army Corps of Engineers gauge at Waverly, Missouri. Daily river temperatures (°C) were obtained from the water treatment plant in Lexington, Missouri (river km 510.8).

Four "seasons" were defined for temperature comparisons: '*winter*' (river temperatures <10° C, November through early April), '*spring*' temperature rise (river temperatures from 10-25° C, mid-April through June), '*summer*' (river temperatures >25° C, July through early September), and "*fall*" temperature decline (river temperatures from 10-25° C, mid-September through October). Mean differences in water temperature between each site (all habitats combined) and the Missouri River on sampling dates during these seasons were assessed using paired t-tests ($P<0.05$) to determine how closely the scour temperatures tracked the open river. Tests were corrected for multiple comparisons using a Bonferroni adjusted P-value for the acceptable level of significance ($P = 0.0125$).

Temperature, secchi depth, and dissolved oxygen among habitats

Differences in mean water temperatures and mean secchi depths among habitats within each site over time were compared using repeated measures ANOVAs. Fisher's LSD was used as the post-hoc test for separation of means among habitats on each sampling date ($P<0.05$). Analyses were performed separately for periodically-connected and continuously-connected sites as our objectives were within site comparisons. Secchi depths exceeded water depths for all four measurements taken in near-shore shallow on twelve sampling dates at the periodically-connected site (10 of which occurred on or after 15 July 1997) and in near-shore shallow (NSS) and near-shore shallow with current (NSSC) on one date (12 March 1997) at the continuously-connected site, prohibiting inclusion of NSS and NSSC in assessments of inter-habitat differences in secchi depth on those dates. We evaluated the applicability of secchi depth as a surrogate measure of turbidity in Missouri River scours by regressing turbidity data reported by Knowlton and Jones (1997) from open-water sites in each scour where and when secchi depths were measured.

Differences in mean dissolved oxygen concentration among habitats within sites were evaluated on sampling dates in which at least one habitat exhibited a mean dissolved oxygen concentration <5 mg/L, the recommended standard for dissolved oxygen minima in warmwater streams (Welch and Lindell 1992). Mean dissolved oxygen concentrations <5 mg/L did not occur on any sampling dates at the periodically-connected site and were recorded on only one sampling date (29 August 1996) at the continuously-connected site. Inter-habitat differences in mean dissolved oxygen concentration at the continuously-connected site on this date were assessed using one-way ANOVA followed by Fisher's LSD test for separation of means ($P<0.05$).

Area sampled using PAEDs

Measurements of voltage gradient (V/cm) around one PAED in near-shore shallow habitat on each sampling date were used to estimate area sampled. Electrofishing effectiveness depends on power transfer between water and fish, which varies with water and fish conductivity (Kolz 1989); fish response to electric fields is species- and size-specific (Reynolds 1996, Dolan and Miranda 2003). Voltage gradient threshold for electrofishing effectiveness using our PAEDs in lower Missouri River scours is unknown. Therefore, we calculated means and standard errors for area sampled per PAED (m^2) for each site assuming voltage gradient thresholds for electrofishing effectiveness of 0.1, 0.3, 0.6, and 0.8 V/cm for a rectangular area surrounding PAEDs. These voltage gradient levels encompass the range of values reported as limits for electrofishing effectiveness using PAEDs and other electrofishing apparatus when conductivity is >100 µS/cm (Bain et al. 1985, Fisher and Brown 1993, Reynolds 1996).

Temporal and spatial distribution of catch composition, species richness, and CPUE

Captured fishes were identified using Pflieger (1975). Percent composition of fish taxa collected was calculated for each site over the entire study and by seasons previously described to characterize adult and juvenile fish assemblage structure.

Differences in mean CPUE (number of individuals/sample) for all taxa combined and species richness (number of species/sample) among habitats during the four seasons were assessed using two-way ANOVAs ($P<0.05$) with season and habitat as main effects. It was not necessary to adjust species richness data for rarefaction due to similar sampling effort among habitats (James and Rathbun 1981). Data were rank transformed prior to analyses, as departures from normality could not be corrected with other simple transformations. Fisher's LSD was used as the post-hoc test for separation of means among habitats and seasons ($P<0.05$). Analyses were performed separately for periodically-connected and continuously-connected sites.

Inter-habitat differences in CPUE (number of individuals/sample) for relatively abundant individual taxa were evaluated for each site. Common carp (*Cyprinus carpio*), emerald shiner (*Notropis atherinoides*), freshwater drum (*Aplodinotus grunniens*), gizzard shad (*Dorosoma cepedianum*), largemouth bass (*Micropterus salmoides*), and red shiner (*Cyprinella lutrensis*) CPUEs were analyzed individually. Catches for species from seven less common taxa groups were combined for statistical analyses: *Pimephales* spp., *Pomoxis* spp., Ictaluridae, *Ictiobus* spp., *Carpiodes* spp., *Macrhybopsis* spp., and *Lepomis* spp. Differences in mean CPUE among habitats for taxa represented by $\geq$50 individuals in total catch at a site were assessed by season (defined above) using two-way ANOVAs ($P<0.05$) with season and habitat as main effects. Inter-habitat differences in mean CPUE were assessed for taxa represented by $\geq$15 but <50 individuals in the total catch at a site for all sampling dates combined using one-way ANOVA ($P<0.05$). Data were rank transformed prior to analyses, as departures from normality could not be corrected with other simple transformations. Fisher's LSD was used as the post-hoc test for separation of means for all ANOVAs ($P<0.05$). Analyses were performed separately for periodically-connected and continuously-connected sites.

RESULTS

River stage and temperature

River stage at Waverly, Missouri, ranged from <200.5 m above MSL during late December 1996 through mid-February 1997 to 204.7 m above MSL on 13 April 1997 (Figure 4). Floods connected the periodically-connected site with the Missouri River on 21-23 July and 19 November 1996, and on 22 February, 12-27 April, 2-5 May, and 9-10 May 1997. River temperature was ≥25° C only during the 21-23 July 1996 connection.

River temperatures at the water treatment plant in Lexington, Missouri ranged from 1° C to 30° C during the study (Figure 4). River temperatures exceeded 25° C on most dates from 1 July through 8 September during 1996 and 1997 and declined to 10° C by 3

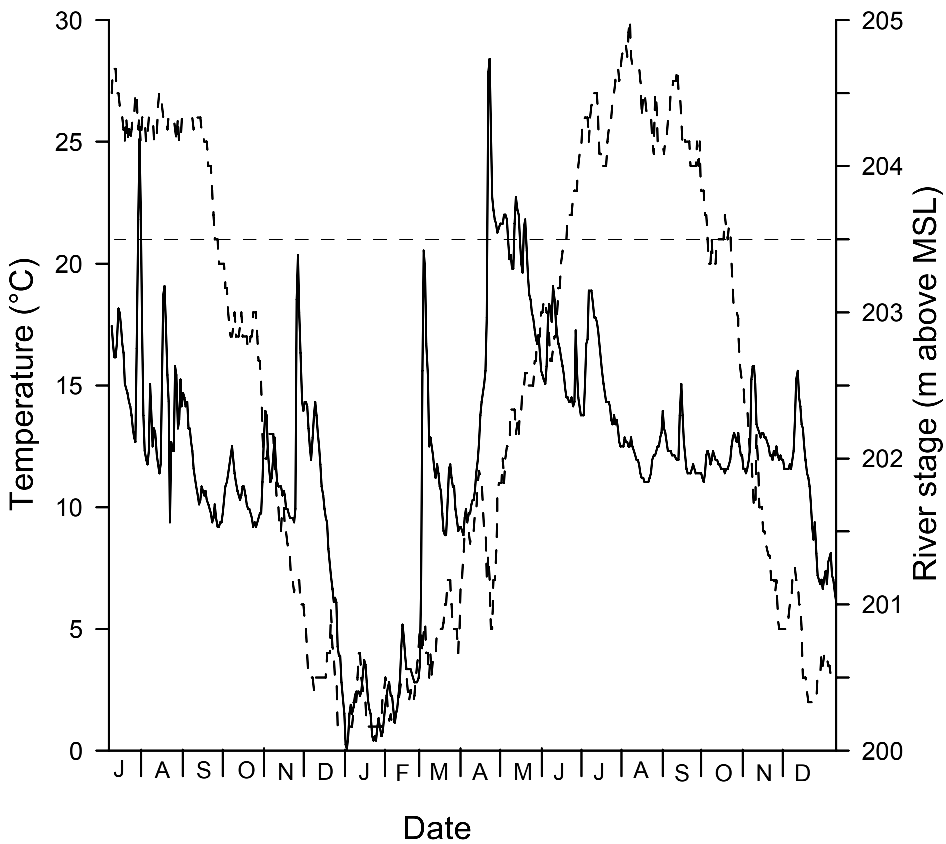

Figure 4. Missouri River temperatures (°C, variable dashed line) measured at the water treatment plant in Lexington, Missouri (river km 510.8) and river stages (m above mean sea level, solid line) at the Waverly, Missouri gauge (river km 472.4) from July 1996 through December 1997. Connection stage for the PC site is 203.65 m above mean sea level (horizontal dashed line).

November during both years. River temperatures remained below 10° C from 5 November 1996 until 19 April 1997, and then rose to 25° C again by 24 June 1997. Floods during fall 1996, winter 1996-1997, and early spring 1997 usually reduced river temperatures, while the late July 1996 flood did not appreciably lower river temperature.

Mean water temperatures at the periodically-connected site were significantly warmer than river temperatures during each of the four designated seasons (Bonferroni corrected paired t-tests, $P<0.0125$, Table 2). Mean water temperature at the continuously-connected site was significantly warmer than the Missouri River only during spring (Bonferroni corrected paired t-tests, $P<0.0125$, Table 2). Largest mean differences in water temperature between the periodically-connected site and the Missouri River (5.1 °C) and the continuously-connected site and the Missouri River (2.1° C) occurred during spring temperature rise.

Temperature, secchi depth, and dissolved oxygen among habitats

There were no significant differences in mean water temperature among habitats at the periodically-connected site on any of the 32 sampling dates (see Appendix A for data). Significant differences in mean water temperature between one or more of the habitats without current (near-shore shallow, near-shore deep, open water, and woody debris) and one or more of the flowing-water habitats (near-shore shallow with current, rock dike, and woody debris with current) accounted for nearly all significant inter-habitat water temperature differences at the continuously-connected site (see Appendix B for data). Therefore, water temperature data for each of the non-flowing and each of the flowing-water habitats were combined (Figure 5). Mean water temperature in habitats without current was significantly warmer than in flowing-water habitats on 10 of 35 sampling dates, mainly during spring and summer 1997. Habitats with current were significantly warmer than non-flowing habitats on 4 sampling dates, mainly during late summer and fall 1997.

Table 2. Mean differences in water temperature (°C) between representative periodically-connected (PC) and continuously-connected (CC) scours and the Missouri River ± SE for all 1996-1997 sampling dates during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April). Missouri River temperatures were measured at the water treatment plant in Lexington, Missouri (river km 510.8). Asterisks indicate mean site-river temperature differences that were significantly different from zero (Bonferroni corrected paired t-tests, $P \leq 0.0125$).

PC site

Season	Mean site-river temperature difference	SE
Spring	5.07*	0.27
Summer	1.99*	0.46
Fall	1.12*	0.33
Winter	1.15*	0.33

CC site

Season	Mean site-river temperature difference	SE
Spring	2.13*	0.49
Summer	1.10	0.45
Fall	-0.32	0.42
Winter	0.74	0.40

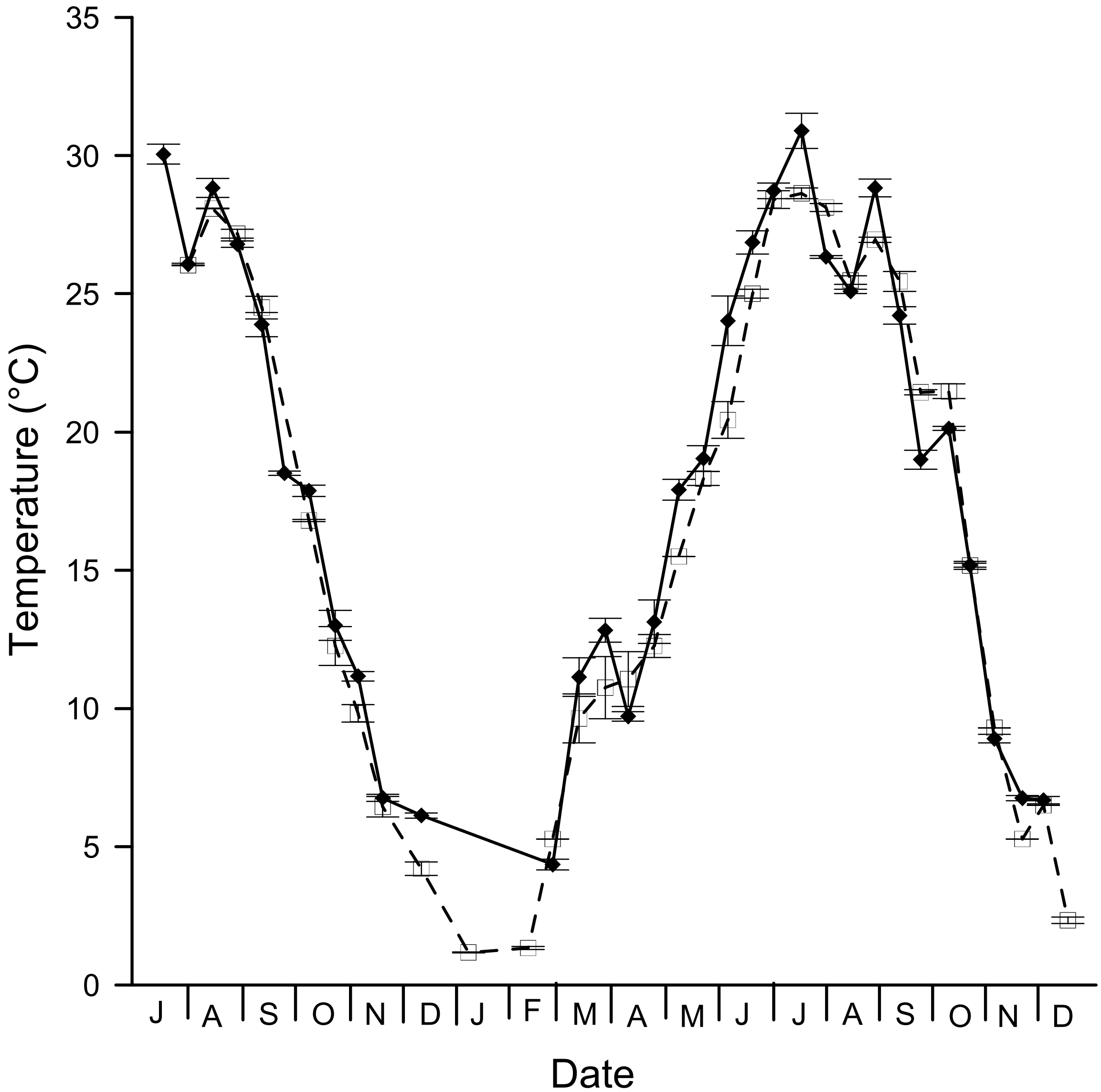

Figure 5. Mean water temperatures (°C) ± SE in habitats without current (near-shore shallow, near-shore deep, open water, and woody debris, solid line) and in flowing-water habitats (near-shore shallow with current, rock dike, and woody debris with current, dashed line) at the continuously connected site on all sampling dates from 18 July 1996 to 16 December 1997.

Mean secchi depths at the periodically-connected site ranged from 11-114 cm during the study (Figure 6, Appendix C). Mean secchi depth was significantly lower in near-shore shallow compared to at least one of the other three habitats on 12 of 25 sampling dates from July 1996 through August 1997. Mean secchi depth exceeded water depth in near-shore shallow on two of 12 dates (27 August and 11 December) during 1996 and on 10 of 11 sampling dates after 15 July 1997. Open water had significantly higher water transparency compared to near-shore deep and woody debris on five dates during summer and early fall 1997.

Significant differences in mean secchi depth between one or more of the habitats without current (near-shore shallow, near-shore deep, open water, and woody debris) and one or more of the flowing-water habitats (near-shore shallow with current, rock dike, and woody debris with current) accounted for nearly all significant inter-habitat secchi depth differences at the continuously-connected site (see Appendix D for data). Therefore, water transparency data for each of the non-flowing and each of the flowing-water habitats were combined (Figure 7). Mean secchi depth was significantly higher in habitats without current compared to flowing-water habitats on 15 of 35 sampling dates during the study, whereas mean secchi depth was significantly higher in flowing-water habitats compared to non-flowing habitats on six sampling dates, mainly during late summer and early fall 1997. The relationship between turbidity and secchi depth for open-water sites within scours was highly significant ($P<0.0001$) with an R^2 of 0.79 (Appendix E).

Mean dissolved oxygen concentration (DO) was never <5.6 mg/L in any habitat on any of the 32 sampling dates at the periodically-connected site (Appendix F). Mean DO was <5.0 mg/L in at least one habitat on only one of 35 sampling dates (29 August 1996) at the continuously-connected site (Appendix G). Mean DO was significantly higher in near-shore shallow, near-shore deep, and woody debris compared to near-shore shallow with current and woody debris with current on this date.

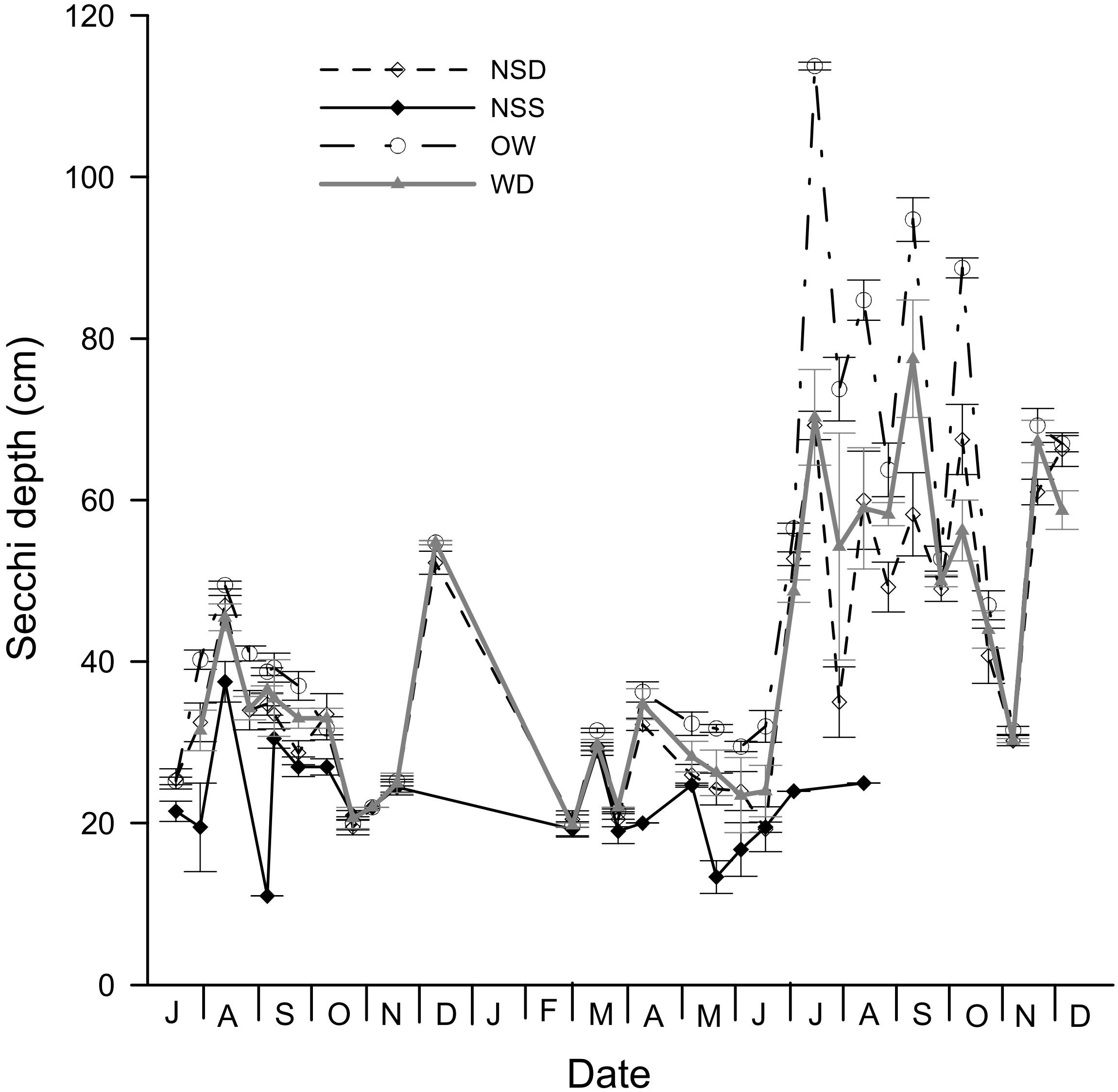

Figure 6. Mean secchi depths (cm) ± SE in near-shore shallow (NSS), near-shore deep (NSD), open water (OW), and woody debris (WD) habitats at the periodically-connected site on all sampling dates from 16 July 1996 to 3 December 1997.

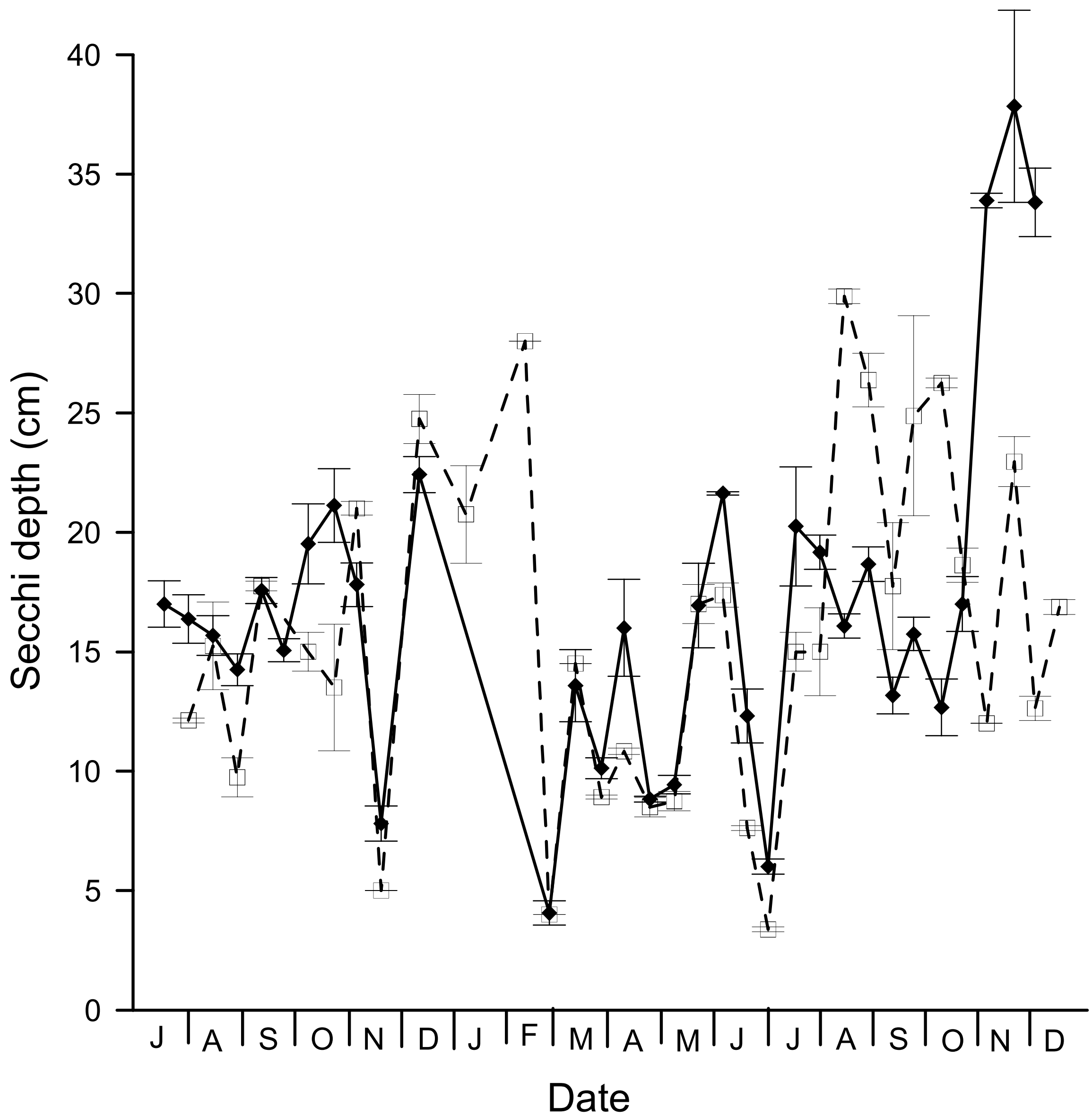

Figure 7. Mean secchi depths (cm) ± SE in habitats without current (near-shore shallow, near-shore deep, open water, and woody debris, solid line) and in flowing-water habitats (near-shore shallow with current, rock dike, and woody debris with current, dashed line) at the continuously connected site on all sampling dates from 18 July 1996 to 16 December 1997.

Area sampled using PAEDs and scour basin conductivity

Estimates of mean area sampled per PAED ranged from 1.88-1.91 m^2 assuming an effective voltage gradient threshold of 0.8 V/cm to 4.50-4.81 m^2 assuming an effective voltage gradient threshold of 0.1 V/cm (Figure 8). Conductivity averaged 495 µS/cm (± 11 µS/cm SE, n=22 dates) at the periodically-connected site and 695 µS/cm (± 31 µS/cm SE, n=23 dates) at the continuously-connected site. Estimates of area sampled per PAED at continuously-connected and periodically-connected sites were within 2 SE of one another for all levels of voltage gradient threshold despite inter-basin differences in mean conductivity. Coefficients of variation for estimates of area sampled per PAED ranged from 8.3 at a voltage gradient threshold of 0.8 V/cm to 18.0 at a voltage gradient threshold of 0.1 V/cm.

Catch composition at each site

Thirty-eight species representing 11 families were collected from the two scour basins (Table 3). Twenty-five of these species were collected from the periodically-connected site and 33 were collected from the continuously-connected site. *Hypopthalmichthys nobilis*, *Pimephales vigilax*, *Notropis stramineus*, *Sander vitreum*, and *Cyprinella spiloptera* were collected exclusively from the periodically-connected site. Species collected only at the continuously-connected site included *Ictalurus furcatus*, *Ictalurus punctatus*, *Carassius auratus*, *Osmerus mordax*, *Macrhybopsis aestivalis*, *Macrhybopsis storeriana*, *Lepomis humilis*, *Gambusia affinis*, *Notropis volucellus*, *Lepisosteus osseus*, and *Hybognathus placitus*. Either gizzard shad (*Dorosoma cepedianum*) or emerald shiner (*Notropis atherinoides*) was the most abundant species in the catch at both scour basins during all seasons. The most abundant species collected from the continuously-connected site overall and for each of the four seasons were emerald shiner, gizzard shad, freshwater drum (*Aplodinotus grunniens*) and common carp (*Cyprinus carpio*). Other species represented by at least 20 individuals in the catch at

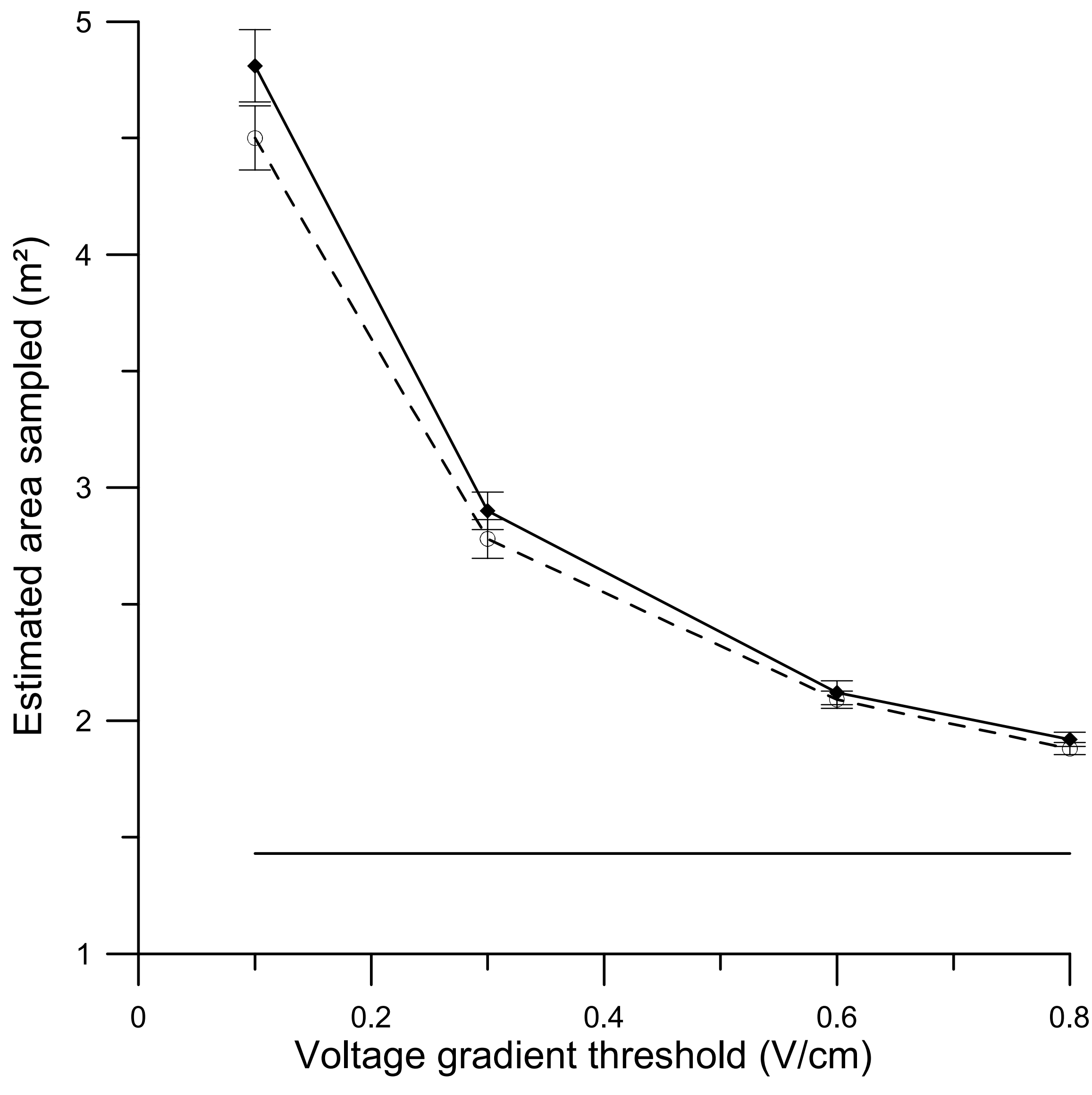

Figure 8. Mean estimated area sampled (m²) per prepositioned areal electrofishing device (PAED) ± SE given effective voltage gradient thresholds ranging from 0.1 to 0.8 V/cm at the periodically-connected (solid line) and continuously-connected (dashed line) sites. The solid horizontal line near the bottom of the figure indicates the area of each PAED (1.43 m²).

Table 3. Scientific names of fishes collected from the periodically -connected (PC) and continuously-connected (CC) scour basins and number of each species collected (n) from each site on all 1996 -1997 sampling dates during the four seasons listed in Table 2. Species are listed from most - to least-frequently collected for each season at each site.

Spring

PC Species	n	CC Species	n
Dorosoma cepedianum	13	*Dorosoma cepedianum*	17
Aplodinotus grunniens	6	*Cyprinus carpio*	8
Cyprinus carpio	5	*Aplodinotus grunniens*	7
Pomoxis annularis	4	*Notropis atherinoides*	4
Ictiobus cyprinellus	3	*Cyprinella lutrensis*	4
Lepomis macrochirus	2	*Ictiobus bubalus*	4
Micropterus salmoides	2	*Ictiobus cyprinellus*	2
Pomoxis nigromaculatus	1	*Lepomis macrochirus*	2
Pimephales notatus	1	*Pimephales notatus*	1
		Unidentified centrarchid	1
		Lepomis cyanellus	1
		Carpiodes carpio	1
		Lepisosteus platostomus	1
		Morone chrysops	1
		Macrhybopsis aestivalis	1

Summer

PC Species	n	CC Species	n
Notropis atherinoides	157	*Notropis atherinoides*	131
Dorosoma cepedianum	116	*Aplodinotus grunniens*	62
Lepomis macrochirus	33	*Dorosoma cepedianum*	33
Aplodinotus grunniens	27	*Cyprinus carpio*	23
Cyprinella lutrensis	27	*Lepomis macrochirus*	15
Micropterus salmoides	10	*Carpiodes carpio*	12

Table 3 (continued)

PC

Species	n
Pylodictis olivaris	6
Ictiobus bubalus	5
Cyprinus carpio	4
Sander canadense	3
Pomoxis annularis	3
Ictiobus cyprinellus	2
Morone chrysops	2
Hypopthalmichthys nobilis	1
Pomoxis nigromaculatus	1
Hiodon alosoides	1
Lepomis cyanellus	1
Carpiodes carpio	1
Lepisosteus platostomus	1

CC

Species	n
Macrhybopsis storeriana	10
Pomoxis annularis	10
Ictalurus punctatus	9
Ictiobus bubalus	8
Cyprinella lutrensis	7
Pomoxis nigromaculatus	6
Pylodictis olivaris	6
Lepisosteus platostomus	6
Morone chrysops	5
Macrhybopsis aestivalis	3
Ictalurus furcatus	2
Hybognathus spp.	2
Sander canadense	2
Ictiobus cyprinellus	1
Hiodon alosoides	1
Micropterus salmoides	1
Lepomis cyanellus	1
Lepisosteus osseus	1

Fall

PC

Species	n
Dorosoma cepedianum	94
Cyprinella lutrensis	77
Lepomis macrochirus	19
Notropis atherinoides	18
Aplodinotus grunniens	18
Pimephales vigilax	15
Carpiodes carpio	4
Cyprinus carpio	2
Micropterus salmoides	2
Pomoxis annularis	2
Hiodon alosoides	1
Morone chrysops	1

CC

Species	n
Notropis atherinoides	162
Cyprinus carpio	33
Dorosoma cepedianum	32
Aplodinotus grunniens	15
Carpiodes carpio	6
Pomoxis annularis	6
Ictiobus bubalus	5
Cyprinella lutrensis	4
Ictalurus punctatus	4
Hybognathus spp.	2
Lepisosteus platostomus	2
Pomoxis nigromaculatus	1

Table 3 (continued)

PC Species	n	CC Species	n
Sander vitreum	1	*Lepomis macrochirus*	1
Ictiobus bubalus	1	*Ictiobus cyprinellus*	1
Notropis stramineus	1	*Macrhybopsis storeriana*	1
Cyprinella spiloptera	1	*Macrhybopsis aestivalis*	1

Winter

PC Species	n	CC Species	n
Dorosoma cepedianum	98	*Dorosoma cepedianum*	178
Cyprinella lutrensis	26	*Notropis atherinoides*	120
Notropis atherinoides	22	*Cyprinus carpio*	28
Lepomis macrochirus	9	*Aplodinotus grunniens*	27
Pimephales vigilax	9	*Carpiodes carpio*	12
Pomoxis annularis	8	*Pomoxis annularis*	10
Aplodinotus grunniens	5	*Morone chrysops*	9
Cyprinus carpio	3	*Lepomis humilis*	7
Carpiodes cyprinus	2	*Lepomis macrochirus*	6
Pomoxis nigromaculatus	1	*Ictiobus cyprinellus*	3
Ictiobus cyprinellus	1	*Ictalurus punctatus*	3
Lepomis cyanellus	1	*Lepomis cyanellus*	3
Micropterus salmoides	1	*Micropterus salmoides*	3
Carpiodes carpio	1	*Cyprinella lutrensis*	3
Sander canadense	1	*Macrhybopsis aestivalis*	3
		Pomoxis nigromaculatus	2
		Carassius auratus	2
		Hybognathus placitus	2
		Ictiobus bubalus	2
		Pimephales notatus	1
		Hybognathus spp.	1
		Gambusia affinis	1
		Carpiodes cyprinus	1
		Macrhybopsis storeriana	1
		Osmerus mordax	1

the continuously-connected site were bluegill, river carpsucker (*Carpiodes carpio*), and white crappie (*Pomoxis annularis*). The most abundant taxa collected from the periodically-connected site were gizzard shad, emerald shiner, red shiner (*Cyprinella lutrensis*), bluegill (*Lepomis macrochirus*), and freshwater drum. Bullhead minnow (*Pimephales vigilax*) was the only other species represented by at least 20 individuals in the catch at the periodically-connected site.

Length statistics for 18 species where ≥10 individuals were collected (Table 4) indicated a wide range of sizes were captured by the PAEDs. Catches were clearly not restricted to age-0 or juveniles of these species.

Species richness among habitats

Mean species richness (number of species/sample) was as high as or significantly higher in near-shore shallow than in all other habitats at the periodically-connected site during all seasons (Figure 9, Appendix H). Open water had the lowest mean species richness among the four habitats at the periodically-connected site during all seasons. No significant differences in mean species richness for near-shore deep or woody debris were evident during any season. Mean species richness peaked during summer and fall for near-shore shallow, near-shore deep, and woody debris. There were no significant differences in mean species richness in open water among seasons.

Mean species richness was as high as or significantly higher in near-shore shallow and woody debris compared to all other habitats at the continuously-connected site during all seasons (Figure 10, Appendix I). No significant differences in mean species richness for near-shore deep or near-shore shallow with current were evident during any season, nor were any significant differences in mean species richness detected among open water, rock dike, and woody debris with current habitats during any season. Mean species richness was as low as or significantly lower during spring compared to all other seasons for near-shore shallow, woody debris, near-shore shallow with current, open

Table 4. Means, standard deviations (SD), minimum (Min), and maximum (Max) lengths (mm) for fish species with >10 individuals collected (N). Mean length at age (mm) and approximate age (~Age) are included for comparative purposes for species collected from the same segment (25) during 1996 -1998 by the Missouri River Benthic Fishes study (Pierce et al. 2004).

Species	Mean	SD	N	Mean length at age	~Age	Min	~Age	Max	~Age
Aplodinotus grunniens	98	53	170	96	1	20	0	334	9
Carpiodes carpio	155	134	37	176	2	28	0	457	8+
Cyprinella lutrensis	36	9	149			17		58	
Cyprinus carpio	401	64	106			61		622	
Dorosoma cepedianum	122	59	581			15		450	
Ictalurus punctatus	65	54	16	64	1	25	0	250	3
Ictiobus bubalus	278	62	25	275	4	46	0	355	6+
Ictiobus cyprinel lus	364	82	13			278		550	
Lepisosteus platostomus	485	164	10			51		634	
Lepomis macrochirus	51	45	88			13		248	
Macrhybopsis storeriana	31	19	12			15		73	
Micropterus salmoides	272	124	19			98		463	
Morone chrysops	149	87	18			48		350	
Notropis ather inoides	38	11	614	41	1	11	0	82	2+
Pimephales vigilax	39	6	24			27		51	
Pomoxis annularis	170	94	43			18		351	
Pomoxis nigromaculatus	180	88	12			19		280	
Pylodictis olivaris	271	129	12	266	3	57	0	545	6

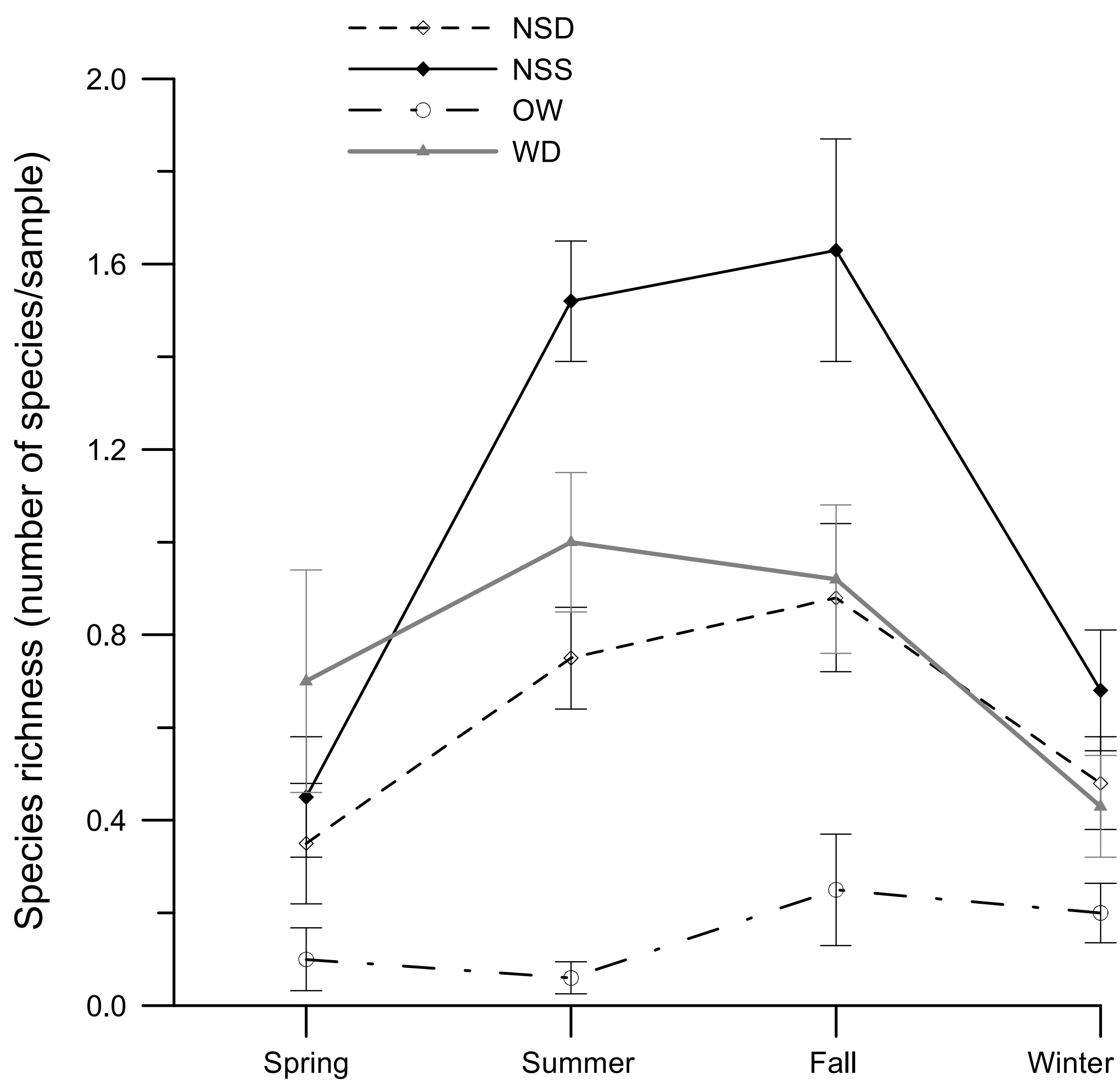

Figure 9. Mean species richness (number of species/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), open water (OW), and woody debris (WD) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the periodically-connected site.

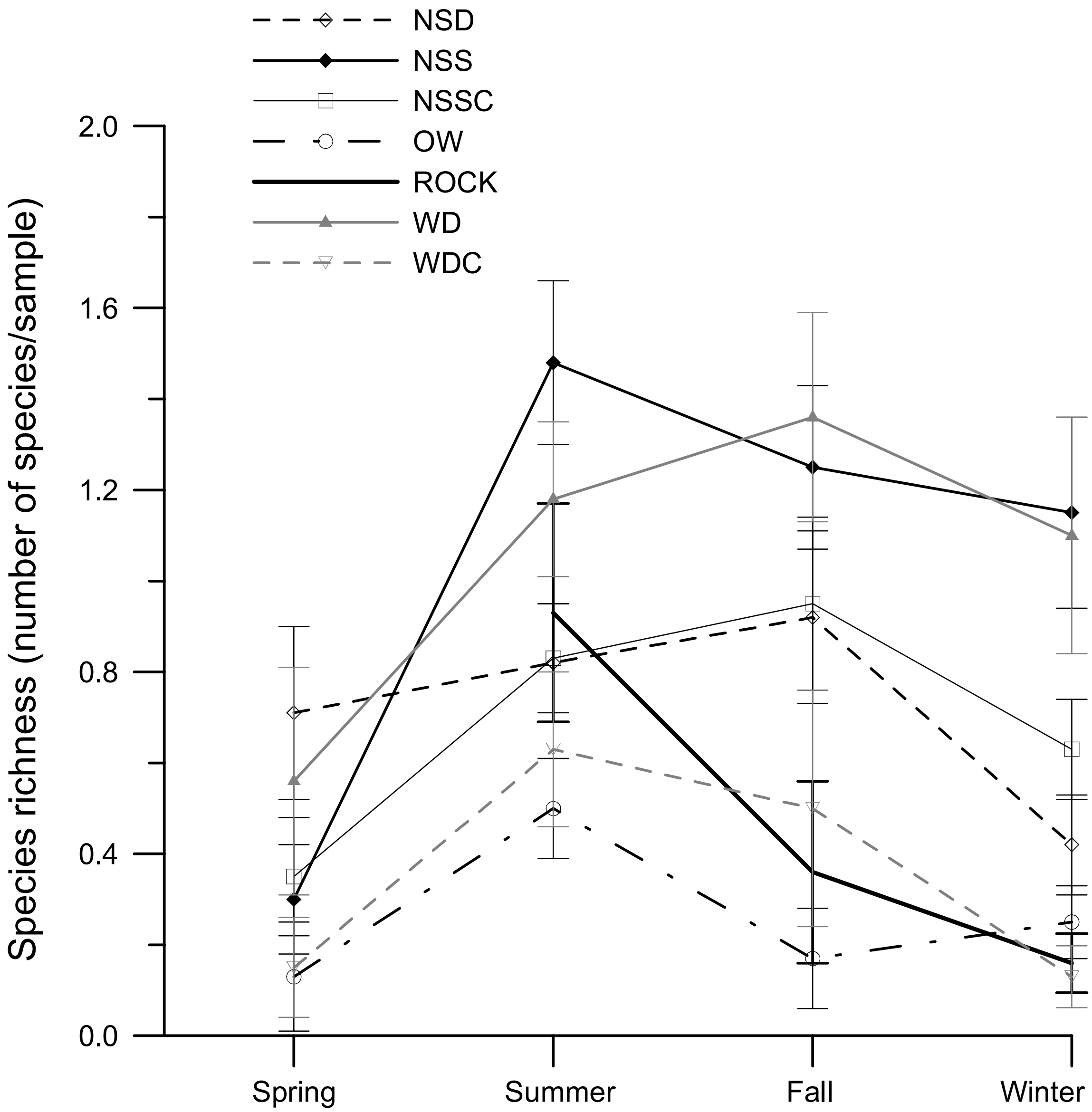

Figure 10. Mean species richness (number of species/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), near-shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD), and woody debris with current (WDC) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the continuously-connected site.

water, and woody debris with current. Highest mean species richness for rock dike (not sampled during spring) occurred during summer. Mean species richness was significantly lower during winter compared to all other seasons in near-shore deep and was significantly lower during winter than in summer for woody debris with current.

Mean CPUE for all species combined among habitats

Mean CPUE for all species combined (number of fish/sample) was as high as or significantly higher in near-shore shallow than in all other habitats at the periodically-connected site during all seasons (Figure 11, Appendix J). Mean CPUE was significantly lower in open water compared to all other habitats during summer and fall. No significant differences in mean CPUE for near-shore deep or woody debris were present during any season. Mean CPUE was significantly higher during summer, fall, or both summer and fall compared to spring and winter for near-shore shallow, woody debris, and near-shore deep. There were no significant differences in mean CPUE in open water among seasons.

Mean CPUE for all species combined was as high as or significantly higher in near-shore shallow and woody debris compared to all other habitats at the continuously-connected site during all seasons (Figure 12, Appendix K). Mean CPUE in near-shore shallow with current was significantly lower than mean CPUE in near-shore shallow only during summer and fall and was not significantly different from mean CPUE in either near-shore deep or woody debris during any season. No significant differences in mean CPUE were detected among open water, rock dike, and woody debris with current habitats during any season. Mean CPUE was significantly lower during spring compared to all other seasons for near-shore shallow, near-shore shallow with current and woody debris. Peak mean CPUE occurred during summer in rock dike. Mean CPUE was significantly higher during fall than during winter for near-shore deep.

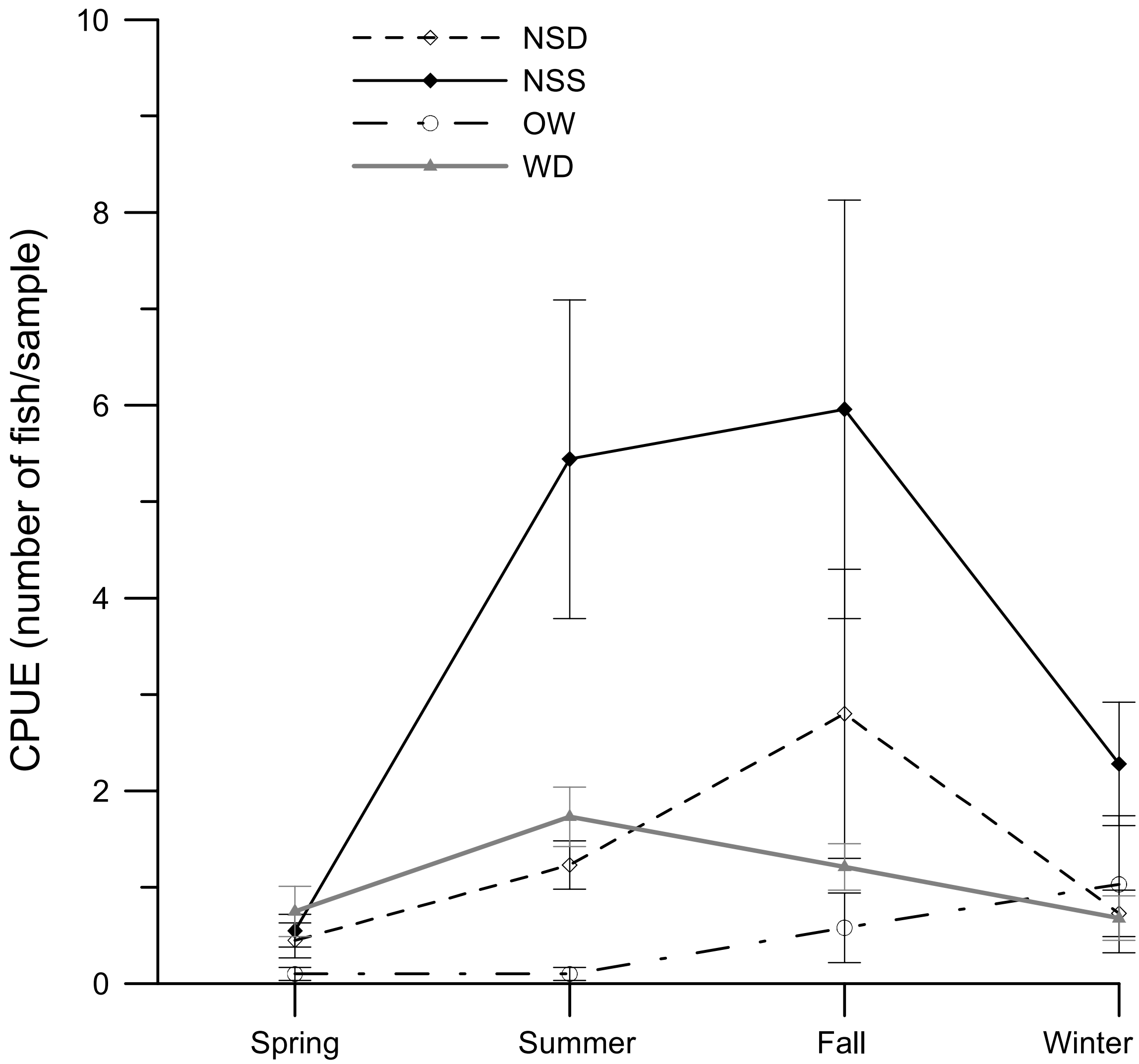

Figure 11. Mean CPUE for all taxa combined (number of fish/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), open water (OW), and woody debris (WD) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the periodically-connected site.

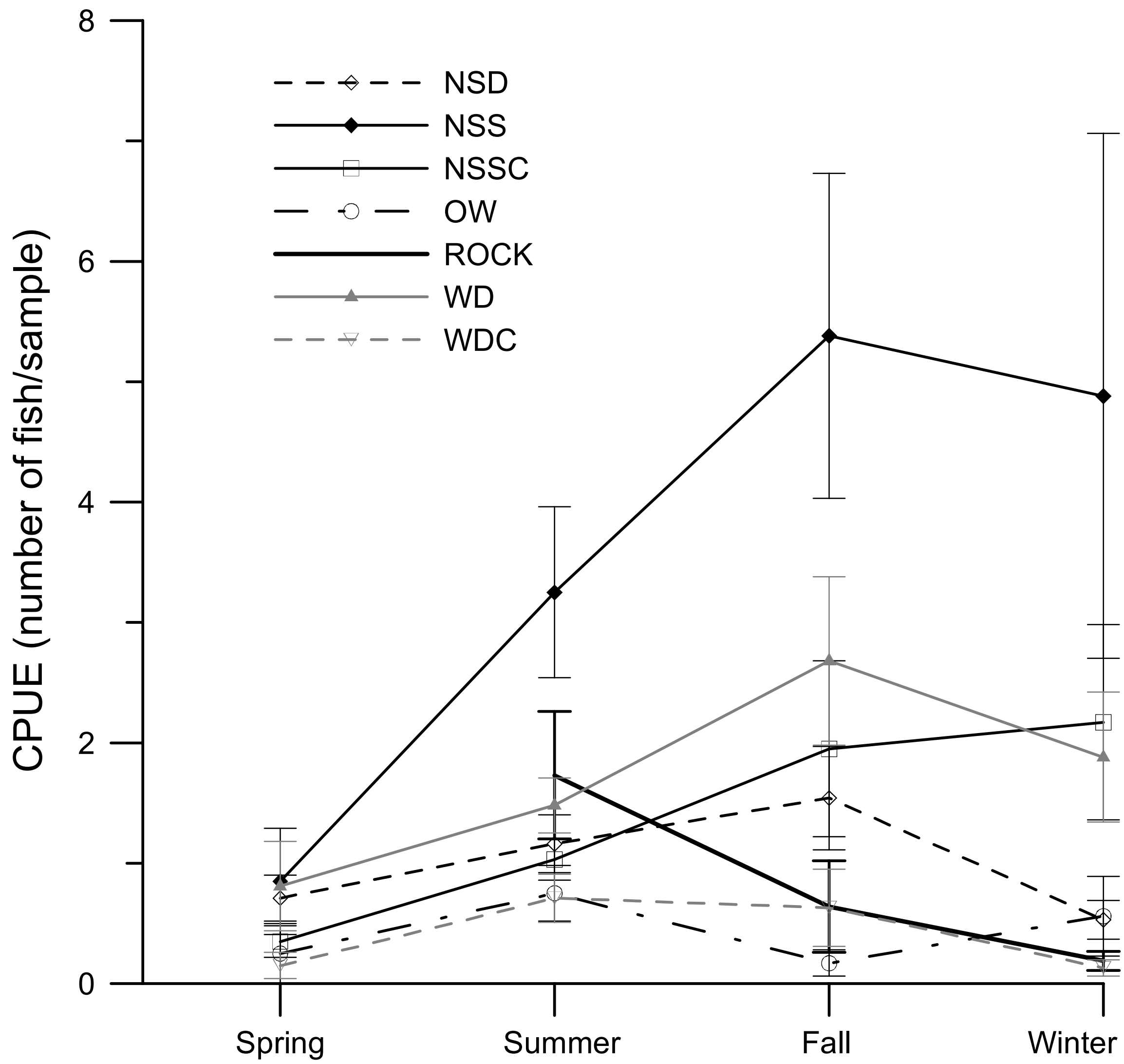

Figure 12. Mean CPUE for all taxa combined (number of fish/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), near-shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD), and woody debris with current (WDC) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the continuously-connected site.

Taxa-specific habitat use within each scour basin

Five taxa (*Lepomis* spp., emerald shiner, freshwater drum, gizzard shad, and red shiner) were collected in sufficient numbers at the periodically-connected site to permit statistical comparisons of mean CPUE among habitats by season (Table 5). *Lepomis* spp., freshwater drum, and red shiner were never collected in open water. Mean CPUE for *Lepomis* spp. was as high as or significantly higher in woody debris compared to all other habitats during all seasons, while mean CPUEs for emerald shiner, freshwater drum, and gizzard shad were as high as or significantly higher in near-shore shallow than in all other habitats during all seasons. No significant differences in mean CPUE for red shiner among habitats were detected during any season. Mean CPUE for *Lepomis* spp. and freshwater drum was significantly higher during summer and fall compared to spring and winter. Neither emerald shiner nor red shiner were collected during spring. Mean CPUE was highest during fall for red shiner and during summer for emerald shiner. Gizzard shad catch rates were significantly lower in spring compared to all other seasons.

Four species (common carp, emerald shiner, freshwater drum, and gizzard shad) were collected in sufficient numbers at the continuously-connected site to enable statistical comparisons of mean CPUE among habitats by season (Table 6). Mean CPUE for common carp was significantly higher in woody debris compared to all other habitats during all seasons. Mean CPUE for emerald shiner was as high as or significantly higher in near-shore shallow compared to all other habitats in all seasons except spring, when very few emerald shiners were collected. Freshwater drum catch rates did not differ among habitats except during summer, when mean CPUE for freshwater drum was significantly higher in each of the three near-shore habitats compared to all other habitats. Mean CPUE for gizzard shad was significantly higher in near-shore shallow compared to all other habitats during fall and winter. Highest catch rates occurred during summer for freshwater drum, during summer and fall for emerald shiner, and during fall and winter

Table 5. Mean CPUE (number of fish/sample) for all habitats combined by season ± SE and mean CPUE ± SE in near-shore deep (NSD), near-shore shallow (NSS), open water (OW), and woody debris (WD) habitats for taxa analyzed by season at the periodically-connected site. For each taxa, ranks of seasonal means or habitat means within a season bearing the same letter are not significantly different (ANOVA on ranked values, P<0.05).

		Seasonal	Habitat means by season (SE)			
Taxa	Season	mean (SE)	NSD	NSS	OW	WD
Lepomis spp.	Spring	0.025[y]	0.050[a]	0.000	0.000	0.050[a]
		(0.017)	(0.050)	(0.000)	(0.000)	(0.050)
	Summer	0.181[x]	0.146[b]	0.104[b]	0.000	0.500[a]
		(0.054)	(0.059)	(0.044)	(0.000)	(0.211)
	Fall	0.196[x]	0.080[b]	0.417[a]	0.000	0.292[a]
		(0.059)	(0.055)	(0.207)	(0.000)	(0.094)
	Winter	0.063[y]	0.025[b]	0.075[ab]	0.000	0.150[a]
		(0.028)	(0.025)	(0.042)	(0.000)	(0.104)
Notropis atherinoides	Spring	0.000	0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Summer	0.835[x]	0.313[b]	2.750[a]	0.083[b]	0.136[b]
		(0.388)	(0.130)	(1.488)	(0.065)	(0.095)
	Fall	0.186[xy]	0.080[b]	0.250[a]	0.291[ab]	0.125[ab]
		(0.081)	(0.055)	(0.108)	(0.291)	(0.091)
	Winter	0.138[y]	0.075[a]	0.075[a]	0.225[a]	0.175[a]
		(0.060)	(0.042)	(0.055)	(.0177)	0.151
Aplodinotus grunniens	Spring	0.075[y]	0.000	0.300	0.000	0.000
		(0.038)	(0.000)	(0.146)	(0.000)	(0.000)
	Summer	0.144[x]	0.104[b]	0.438[a]	0.000	0.023[c]
		(0.029)	(0.044)	(0.093)	(0.000)	(0.023)
	Fall	0.186[x]	0.120[b]	0.625[a]	0.000	0.000
		(0.057)	(0.066)	(0.197)	(0.000)	(0.000)
	Winter	0.031[y]	0.075[a]	0.050[a]	0.000	0.000
		(0.016)	(0.042)	(0.050)	(0.000)	(0.000)

Table 5 (continued)

Taxa	Season	Seasonal mean (SE)	Habitat means by season (SE)			
			NSD	NSS	OW	WD
Dorosoma cepedianum	Spring	0.163[y]	0.350[a]	0.150[a]	0.050[a]	0.100[a]
		(0.048)	(0.150)	(0.081)	(0.050)	(0.068)
	Summer	0.617[x]	0.437[b]	1.750[a]	0.000	0.250[b]
		(0.217)	(0.168)	(0.813)	(0.000)	(0.108)
	Fall	0.969[x]	1.840[a]	1.375[a]	0.250[b]	0.375[b]
		(0.406)	(1.517)	(0.389)	(0.137)	(0.188)
	Winter	0.613[x]	0.150[b]	1.450[a]	0.800[b]	0.050[b]
		(0.222)	(0.076)	(0.529)	(0.699)	(0.034)
Cyprinella lutrensis	Spring	0.000	0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Summer	0.144[y]	0.125[a]	0.188[a]	0.000	0.273[a]
		(0.049)	(0.105)	(0.105)	(0.000)	(0.135)
	Fall	0.794[x]	0.480[a]	2.540[a]	0.000	0.167[a]
		(0.501)	(0.301)	(1.987)	(0.000)	(0.098)
	Winter	0.163[y]	0.275[a]	0.375[a]	0.000	0.000
		(0.080)	(0.226)	0.225	(0.000)	(0.000)

Table 6. Mean CPUE (number of fish/sample) for all habitats combined by season ± SE and mean CPUE ± SE in near-shore deep (NSD), near-shore shallow (NSS), near-shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD) and woody debris with current (WDC) habitats for taxa analyzed by season at the continuously-connected site. For each taxa, ranks of seasonal means or habitat means within a season bearing the same letter are not significantly different (ANOVA on ranked values, $P<0.05$).

		Seasonal	Habitat means by season (SE)						
Taxa	Season	mean (SE)	NSD	NSS	NSSC	OW	ROCK	WD	WDC
Cyprinus carpio	Spring	0.071^{x}	0.048^{b}	0.000	0.050^{b}	0.000	0.000	0.313^{a}	0.050^{b}
		(0.030)	(0.048)	(0.000)	(0.050)	(0.000)	(0.000)	(0.176)	(0.050)
	Summer	0.097^{x}	0.023^{b}	0.000	0.000	0.071^{b}	0.000	0.425^{a}	0.125^{b}
		(0.025)	(0.023)	(0.000)	(0.000)	(0.049)	(0.000)	(0.118)	(0.091)
	Fall	0.272^{x}	0.167^{b}	0.000	0.050^{b}	0.000	0.091^{b}	1.227^{a}	0.000
		(0.114)	(0.098)	(0.000)	(0.050)	(0.000)	(0.091)	(0.584)	(0.000)
	Winter	0.108^{x}	0.000	0.025^{b}	0.000	0.000	0.063^{b}	0.625^{a}	0.000
		(0.044)	(0.000)	(0.025)	(0.000)	(0.000)	(0.062)	(0.269)	(0.000)
Notropis atherinoides	Spring	0.035^{z}	0.000	0.000	0.000	0.188^{a}	0.000	0.063^{a}	0.000
		(0.027)	(0.000)	(0.000)	(0.000)	(0.188)	(0.000)	(0.063)	(0.000)
	Summer	0.555^{xy}	0.409^{abc}	1.523^{a}	0.200^{c}	0.321^{c}	1.000^{ab}	0.200^{c}	0.208^{bc}
		(0.136)	(0.153)	(0.654)	(0.089)	(0.224)	(0.437)	(0.114)	(0.103)
	Fall	1.339^{x}	0.875^{b}	4.208^{a}	1.150^{b}	0.083^{c}	0.364^{bc}	0.545^{bc}	0.000
		(0.338)	(0.342)	(1.421)	(0.669)	(0.083)	(0.243)	(0.292)	(0.000)
	Winter	0.462^{y}	0.250^{abc}	1.200^{a}	0.904^{ab}	0.417^{bc}	0.031^{c}	0.000	0.000
		(0.174)	(0.108)	(0.800)	(0.562)	(0.334)	(0.031)	(0.000)	(0.000)

Table 6 (continued)

Taxa	Season	Seasonal mean (SE)	Habitat means by season (SE)						
			NSD	NSS	NSSC	OW	ROCK	WD	WDC
Aplodinotus grunniens	Spring	0.062^{y}	0.095^{a}	0.050^{a}	0.050^{a}	0.000	0.000	0.125^{a}	0.050^{a}
		(0.022)	(0.065)	(0.050)	(0.050)	(0.000)	(0.000)	(0.085)	(0.050)
	Summer	0.263^{x}	0.250^{ab}	0.500^{a}	0.400^{a}	0.036^{c}	0.125^{bc}	0.175^{bc}	0.125^{bc}
		(0.035)	(0.073)	(0.128)	(0.093)	(0.036)	(0.085)	(0.061)	(0.068)
	Fall	0.124^{y}	0.125^{a}	0.292^{a}	0.050^{a}	0.000	0.000	0.091^{a}	0.250^{a}
		(0.036)	(0.091)	(0.127)	(0.050)	(0.000)	(0.000)	(0.063)	(0.163)
	Winter	0.104^{y}	0.028^{a}	0.100^{a}	0.154^{a}	0.028^{a}	0.094^{a}	0.225^{a}	0.042^{a}
		(0.026)	(0.028)	(0.059)	(0.057)	(0.028)	(0.052)	(0.131)	(0.042)
Dorosoma cepedianum	Spring	0.150^{y}	0.000	0.750^{a}	0.050^{a}	0.063^{a}	0.000	0.000	0.000
		(0.081)	(0.000)	(0.440)	(0.050)	(0.063)	(0.000)	(0.000)	(0.000)
	Summer	0.140^{y}	0.114^{a}	0.386^{a}	0.100^{a}	0.143^{a}	0.000	0.075^{a}	0.000
		(0.041)	(0.093)	(0.173)	(0.059)	(0.084)	(0.000)	(0.055)	(0.000)
	Fall	0.264^{x}	0.125^{b}	0.708^{a}	0.250^{b}	0.083^{b}	0.000	0.182^{b}	0.250^{b}
		(0.067)	(0.068)	(0.272)	(0.123)	(0.083)	(0.000)	(0.106)	(0.250)
	Winter	0.685^{xy}	0.111^{bc}	2.925^{a}	0.885^{bc}	0.028^{bc}	0.000	0.250^{ab}	0.000
		(0.334)	(0.066)	(2.013)	(0.573)	(0.028)	(0.000)	(0.117)	(0.000)

for gizzard shad. There were no significant differences in mean CPUE for common carp among seasons.

Mean catch rates for three taxa (*Pimephales* spp., *Pomoxis* spp., and largemouth bass, *Micropterus salmoides*) from the periodically-connected site were compared among habitats with seasons combined (Table 7). *Pimephales* spp. was not collected from open water or woody debris. Mean CPUE for *Pimephales* spp. was significantly higher in near-shore shallow compared to near-shore deep. Mean CPUE for *Pomoxis* spp. was significantly higher in woody debris than in all other habitats. Largemouth bass were not collected from open water. Mean CPUE for largemouth bass was significantly higher in woody debris compared to near-shore deep, but not near-shore shallow. Ten of 14 common carp and 10 of 12 *Ictiobus* spp. collected from the periodically-connected site were recovered in woody debris habitat although data were not analyzed statistically due to low abundance.

Table 7. Mean CPUE (number of fish/sample) ± SE in near-shore deep (NSD), near-shoreshallow (NSS), open water (OW), and woody debris (WD) habitats for taxa analyzed with seasons combined at the periodically-connected site. For each taxa, ranks of means with the same letter are not significantly different (ANOVA on ranked values, P<0.05).

Taxa		NSD	NSS	OW	WD
Pimephales spp.	Mean	0.023b	0.167a	0	0
	SE	0.013	0.09	0	0
Pomoxis spp.	Mean	0.008b	0.008b	0.008b	0.133a
	SE	0.008	0.008	0.008	0.039
Micropterus salmoides	Mean	0.008b	0.038ab	0	0.071a
	SE	0.008	0.019	0	0.025

Mean catch rates for six taxa (catfishes: *Pylodictis olivaris*, *Ictalurus furcatus*, and *I. punctatus* combined; *Pomoxis* spp., *Ictiobus* spp., *Carpiodes* spp., *Macrhybopsis* spp., and *Lepomis* spp.) from the continuously-connected site were compared among habitats with seasons combined (Table 8). Mean CPUE for catfishes was significantly higher in rock dike and near-shore shallow with current compared to all other habitats. Catch rates for *Pomoxis* spp. and *Ictiobus* spp. were significantly higher in woody debris compared to all other habitats, while mean CPUE for *Lepomis* spp. was significantly higher in woody debris compared to all other habitats except near-shore shallow and near-shore deep. Mean CPUEs for *Carpiodes* spp. and *Macrhybopsis* spp. were significantly higher in near-shore shallow than in all other habitats. Nine of 10 *Lepisosteus* spp. collected from the continuously-connected site were captured in near-shore shallow or near-shore shallow with current although data not analyzed statistically due to low abundance.

DISCUSSION

Thirty-eight species of fishes were collected from the two connected scour types supporting the well established importance of seasonally-connected floodplain waterbodies as recruitment sites for large river fishes (Finger and Stewart 1987, Junk et al. 1989, Bayley 1991, Sparks et al. 1998, King et al. 2003). Although a diversity of fish sizes was collected from floodplain waterbodies, many appeared to be juveniles as maximum sizes for large species (e.g., common carp, buffaloes, catfishes) we collected from scours were frequently below the maximum lengths reported in the literature from the Missouri River (e.g., Pflieger 1975, Pierce et al. 2004).

Results here for juvenile and adult fishes corroborate the significance of floodplain wetlands and their connectivity to the lower Missouri River previously demonstrated for larval, juvenile, and adult fishes (Gelwicks 1995, Sargent 1996, Kubisiak 1997, Tibbs and Galat 1997, Chapman 2003, Galat et al. 2004a, 2004b). We do not know if growth or condition of some species is different between floodplain and channel habitats as we

Table 8. Mean CPUE (number of fish/sample) ± SE in near -shore deep (NSD), near -shore shallow (NSS), near -shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD) and woody debris with current (WDC) habitats for taxa analyzed with seasons combined at the continuously -connected site. For each taxa, ranks of means with the same letter are not significantly different (ANOVA on ranked values, $P<0.05$).

Taxa		NSD	NSS	NSSC	OW	ROCK	WD	WDC
Pylodictis olivaris and *Ictalurus* spp.	Mean	0.016[b]	0.008[b]	0.091[a]	0	0.119[a]	0.017[b]	0
	SE	0.011	0.008	0.034	0	0.054	0.011	0
Pomoxis spp.	Mean	0.032[b]	0.008[b]	0	0.022[b]	0	0.237[a]	0
	SE	0.019	0.008	0	0.015	0	0.051	0
Ictiobus spp.	Mean	0.008[b]	0.031[b]	0.008[b]	0.011[b]	0	0.161[a]	0
	SE	0.008	0.015	0.008	0.011	0	0.044	0
Carpiodes spp.	Mean	0.04[b]	0.141[a]	0.008[b]	0.011[b]	0	0.034[b]	0.039[b]
	SE	0.017	0.034	0.008	0.011	0	0.016	0.022
Macrhybopsis spp.	Mean	0.024[b]	0.094[a]	0.03[b]	0.011[b]	0	0	0
	SE	0.013	0.032	0.014	0.011	0	0	0
Lepomis spp.	Mean	0.064[ab]	0.086[ab]	0	0.011[c]	0	0.11[a]	0.039[bc]
	SE	0.021	0.033	0	0.011	0	0.044	0.022

did not collect fishes from the river channel or determine growth or condition. We cannot therefore distinguish if the species we collected are dependent on floodplain waterbodies or if they use them on an ad hoc basis as was shown for some young-of-year fishes in the Cosumnes River floodplain, California (Ribeiro et al. 2004).

Species richness, mean CPUE for all species combined, and mean CPUE for most individual taxa were significantly higher in either near-shore shallow or woody debris compared to all other habitats at both sites, indicating the importance of low-velocity, shallow-water habitat and the presence of large woody debris for fishes in lower Missouri River floodplain waterbodies. Highest densities of larval fishes at the periodically and continuously-connected scours also occurred in near-shore shallows; woody debris was not sampled for larval fishes (Galat et al. 2004b). Greater use of near-shore shallow and woody debris by juvenile and adult fishes at the periodically-connected site was probably not due to more favorable temperature, dissolved oxygen, or current velocity in these areas, as none of these variables differed significantly among habitats. Higher use by fishes for either near-shore shallow or woody debris may be due to reduced predation risk associated with higher turbidity (Johnson and Hines 1999) or woody cover (Lehtinen et al. 1997).

Highest densities of juvenile and adult small fishes often occur in shallow habitats where predation risk from larger fish predators is minimized (Schlosser 1987). Greater use of near-shore shallow and woody debris habitats by many fishes at the periodically-connected site may also have been due to higher food availability or foraging efficiency in these areas. Littoral habitats in large rivers and floodplain lakes support relatively high densities of potamoplankton (Thorp et al. 1994), zooplankton (Winemiller et al. 2000), and benthic invertebrates (Thorp 1992). Rich food resources in flooded nearshore areas can enhance fish production as Gutreuter et al. (1999) reported higher growth rates of bluegill and largemouth bass in the moving littoral zone of the Upper Mississippi River in flood years than in low-water years. Woody debris is also an important habitat for invertebrates in warmwater streams and large rivers with limited hard substrates (Benke et al. 1985, Thorp 1992, Rabeni 1993). In addition to the factors listed above that likely contributed to greater use of near-shore habitats at the periodically-connected site, many fishes may have exhibited greater use of near-shore shallow or woody debris habitats at the continuously-connected site due to warmer temperatures or lack of current that was present in rock dike, near-shore shallow with current, and woody debris with current. Warmer temperatures in floodplain wetlands would likely result in increased availability of invertebrate prey (Thorp et al. 1994) and greater fish growth potential (Weatherly and Gill 1987, Ribeiro et al. 2004). Absence of current would also increase growth potential by reducing energetic costs required to maintain position (e.g., critical velocity threshold; Pavlov 1994).

Habitat use patterns for taxa common to both periodically-connected and continuously-connected scours were similar among the two sites. Mean CPUEs for freshwater drum, emerald shiner and gizzard shad were highest in near-shore shallow at both sites, while catch rates for *Lepomis* spp., *Pomoxis* spp., common carp, and *Ictiobus* spp. were highest in woody debris at both sites. Differences in connectivity among the two scour basins appeared to have little influence on fish habitat use within sites. Catfishes (*Pylodictis olivaris* and *Ictalurus* spp.) were the only taxa for which mean CPUE was highest in flowing-water habitats at the continuously-connected site; these habitats were not sampled at the periodically-connected site as they were not present (rock dike) or only present briefly during connections with the river (near-shore shallow with current and woody debris with current).

Catch composition was generally similar between the two scours, with gizzard shad and emerald shiner dominating catch from both sites. Four of the six most frequently collected species from the periodically-connected site were among the seven most abundant species in catch at the continuously-connected site. Kubisiak (1997) reported that assemblage structure of juvenile and small adult fishes was similar among continuously-connected and periodically-connected lower Missouri River scours, but distinct from that of isolated and ditch-connected scours. However, three taxa (Ictalurids, *Hybognathus* spp., and *Macrhybopsis* spp.) were commonly collected by us at the continuously-connected site, but were uncommon or absent from catch at the periodically-connected site. We collected no sicklefin (*M. meeki*) or sturgeon (*M. gelida)* chubs from scours, and few have been collected by others in off-channel habitats (Grady and Milligan 1998, Fisher 1999, Dieterman 2000) reinforcing their status as an obligate fluvial species (Galat et al. 2004c).

Catch rates for larval *Hybognathus* spp. and *Macrhybopsis* spp. in lower Missouri River scours were positively associated with scour basin connectivity (Galat et al. 2004a). Greater similarity in catch composition for juvenile and adult fishes between the periodically-connected and continuously-connected sites than for larval fishes (Galat et al. 2004a) suggests that many larval taxa collected from these two scours passively drifted in from the Missouri River whereas juveniles actively migrated between the river and scour basins.

Lower species richness and mean CPUE in most habitats during the primary spawning period for most lower Missouri River fishes (mid-April through June; Galat et al. 1998) compared to other seasons suggests that, although many fishes use floodplain scours for larval nursery (Galat et al. 2004a, 2004b), their use for spawning may be limited. Alternatively, many fishes may use floodplain scours for spawning, but our biweekly sampling frequency may have been insufficient to detect brief spawning forays into scour basins by adult fishes. Significantly lower values for species richness and mean CPUE for all taxa combined during spring compared to other seasons occurred at both sites, suggesting that lower fish abundance and richness at the periodically-connected site during spring 1997 was not solely a consequence of inappropriate timing of site-river hydrologic connections relative to spawning temperatures (Galat et al. 2004b). Higher catch rates and species richness during summer and fall than in spring in many habitats at both sites may be due to recruitment of juvenile fishes to our sampling gear during the growing season. Many taxa were less abundant in the catch during winter compared to summer and fall, although gizzard shad remained in near-shore habitats during winter. Other fishes may have moved to the deeper water of the Missouri River during winter.

Water temperatures were warmer in scours compared to the Missouri River, particularly during spring and summer. Fishes may benefit from warmer temperatures in scours during the growing season through increased food availability (Thorp et al. 1994) and growth potential (Weatherly and Gill 1987, Ribeiro et al. 2004).

Differences in water temperature and secchi depth among habitats at the continuously-connected site were primarily a consequence of the division of that site into two distinct sub-basins. Horizontal differences in water temperature at the continuously-connected site likely resulted from a combination of greater solar heating of shallow water and limited exchange over the sill that separated the backwater and forewater sub-basins (Knowlton and Jones 2003). Flowing-water habitats generally had lower water transparency than non-flowing habitats due to the influx of relatively turbid river water into the forewater sub-basin. Water temperatures were never significantly different among habitats at the periodically-connected site, which was not divided into distinct sub-basins. Near-shore shallow had the lowest transparency among habitats at the periodically-connected site and among habitats without current at the continuously-connected site, perhaps due to wind-induced or biogenic turbidity. These factors have been implicated as causes of increased turbidity in shallow Missouri River oxbow lakes (Knowlton and Jones 1997).

Differences in electrofishing efficiency among habitats using PAEDs could potentially confound our conclusions regarding differences in species richness, CPUE for all species combined, and CPUE for individual taxa among habitats at each site. Many factors influence electrofishing efficiency, including water depth, turbidity, presence of cover, and water temperature (Reynolds 1996). All of these factors varied among habitats at one or both sites. Greater electrofishing efficiency in near-shore shallow and woody debris might be expected given that electrofishing becomes more effective with decreasing depth and is often more effective around structure than in open water (Reynolds 1996). Thus, our conclusions regarding the importance of near-shore shallow and woody debris to juvenile and adult fishes in lower Missouri River scours are valid only under the assumption that electrofishing efficiency was not substantially higher in these areas than in other sampled habitats. Environmental and biological factors (including species and fish size) also likely influenced catch composition at the two sites (Reynolds 1996). However, low coefficients of variation for estimates of area sampled per PAED at voltage gradient thresholds ranging from 0.1 to 0.8 V/cm indicated that adjustments to electrical output (amps and volts) limited variation in electric fields surrounding PAEDs among sampling dates and habitats at each site despite temporal and spatial changes in conductivity.

Higher catch rates for most fish species collected from the two scours in either near-shore shallow or woody debris compared to all other habitats has important implications for management of off-channel habitats along the lower Missouri River for the benefit of native and commercially and recreationally important fishes. Extent and duration of shallow, near-zero velocity, aquatic areas should be a primary consideration in efforts to acquire, design, or construct floodplain water bodies that will maximize optimal environmental conditons for macrohabitat generalist fishes as opposed to rheophilic species. Only 2-5% of the historical acreage of shallow water habitat is present along the lower Missouri River from Sioux City to the mouth (U.S. Fish and Wildlife Service 2000). The U.S. Fish and Wildlife Service has recommended that shallow water habitat (<5 ft [1.52 m] deep, current velocity <2.5 ft/s) should be increased by 20-30 acres/mile along the lower Missouri River for the benefit of endangered least terns and native fishes, including the endangered pallid sturgeon (U.S. Fish and Wildlife Service 2000). Results of this study indicate that species richness and mean CPUE for adults and juveniles of many fishes was highest in near-shore shallow where water depth was <0.6 m. Thus, areas >0.6 m but <1.52 m deep that would be characterized as "shallow" according to criteria established by the U.S. Fish and Wildlife Service may be too deep to constitute prime habitat for many fish species. Taxa richness and densities of many larval fishes were also highest in near-shore shallow (Galat et al. 2004b), indicating that areas where water depth is >0.6 m may also be too deep to serve as optimal larval nursery habitat.

Presence of woody debris was associated with higher catch rates overall and specifically for centrarchids, common carp, and *Ictiobus* spp. Large-woody debris (LWD) has been greatly reduced throughout the Missouri River during the past 200 years (Funk and Robinson 1974, Hesse 1996) and its decline was related to decoupling of the floodplain and river channel by bank stabilization and development in the riparian zone (Angradi et al. 2004). Angradi et al. (2004) reported the highest densities of LWD along unstabilized forested shorelines in the regulated Missouri River, North Dakota. Reduction of riparian forest and bank erosion removed both the source of LWD and the primary mechanism for its transport into the channel. Whereas bank erosion is important to transport of LWD to the river channel, an intact riparian forest corridor enhances bank stability. Dwyer et al. (1997) associated woody corridors of at least 90-m wide with reduced levee failure from the flood of 1993 along the lower Missouri River, Missouri.

Efforts to maintain, restore, or enhance floodplain habitat for fishes should include conservation of existing remnants of mature floodplain forests along the lower Missouri River and its major tributaries. Reforestation efforts along the lower Missouri River should emphasize planting early-successional, flood-tolerant tree species that historically occurred in the floodplain (Bragg and Tatschl 1977, Mazourek 1998, Harlan and Denny 2003). Additionally, reestablishing ecosystem functions of river-floodplain connectivity, lateral bank erosion, and a more natural flow regime will promote the import, retention, and submersion of large woody debris to in- and off-channel aquatic habitats to benefit fishes and other wildlife.

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LIST OF APPENDICES

Appendix A. Mean temperatures (°C) ± SE for each habitat at the periodically -connected site on each sampling date. Asterisks indicate habitat not sampled on a given date.

	NSD		NSS		OW		WD	
Date	mean	SE	mean	SE	mean	SE	Mean	SE
1996								
16-Jul	28.38	0.31	27.88	0.13	28.38	0.13	*	*
30-Jul	27.38	0.31	28.85	0.85	27.60	0.18	27.00	0.07
13-Aug	28.50	0.24	29.88	0.66	28.13	0.13	28.35	0.22
27-Aug	29.88	0.13	30.58	0.22	29.30	0.28	29.78	0.28
6-Sep	27.08	0.06	26.85	0.17	27.15	0.12	26.95	0.23
10-Sep	29.00	0.20	27.00	0.11	27.53	0.19	28.33	0.23
27-Sep	18.63	0.13	19.00	0.00	18.28	0.15	18.63	0.13
10-Oct	17.50	0.20	17.70	0.24	17.00	0.00	17.75	0.14
25-Oct	14.50	0.20	14.25	0.25	14.65	0.09	14.33	0.17
5-Nov	12.00	0.04	11.95	0.03	12.23	0.08	12.03	0.05
19-Nov	8.05	0.05	8.00	0.00	8.05	0.05	8.00	0.00
11-Dec	4.95	0.03	4.98	0.02	4.93	0.02	5.10	0.17
1997								
27-Feb	3.93	0.05	3.63	0.18	3.95	0.05	3.95	0.05
13-Mar	8.75	0.05	8.80	0.00	8.80	0.00	8.73	0.05
25-Mar	9.95	0.03	10.03	0.05	9.88	0.02	9.90	0.00
8-Apr	10.15	0.12	10.13	0.13	10.00	0.00	10.05	0.05
6-May	18.75	0.68	19.25	0.76	19.68	0.21	19.25	0.68
20-May	23.05	0.46	23.20	0.60	22.20	0.27	22.43	0.17
3-Jun	22.63	0.13	22.43	0.58	22.38	0.24	22.38	0.38
17-Jun	27.53	0.30	28.23	0.34	27.90	0.37	27.88	0.47
3-Jul	26.15	0.25	25.90	0.23	26.48	0.03	26.23	0.24
15-Jul	31.83	0.17	32.60	0.21	31.83	0.18	31.53	0.18
29-Jul	29.48	0.14	29.38	0.08	29.15	0.09	29.60	0.16
12-Aug	26.50	0.00	27.45	0.25	26.45	0.06	26.60	0.23
26-Aug	27.68	0.35	29.23	0.55	27.63	0.19	28.18	0.32
9-Sep	25.95	0.06	26.10	0.10	25.78	0.13	25.98	0.08
25-Sep	21.40	0.18	22.50	0.36	21.33	0.64	21.63	0.25
7-Oct	22.58	0.08	23.00	0.17	22.63	0.14	22.88	0.42
22-Oct	15.80	0.00	15.75	0.06	15.48	0.02	15.58	0.05
5-Nov	10.00	0.00	10.00	0.00	10.00	0.00	10.20	0.20
19-Nov	6.80	0.20	8.75	0.37	6.83	0.05	7.23	0.34
3-Dec	7.38	0.03	7.33	0.05	7.38	0.03	7.28	0.05

Appendix B. Mean temperatures (°C) ± SE for each habitat at the continuously-connected site on each sampling date. Asterisks indicate habitat not sampled on a given date.

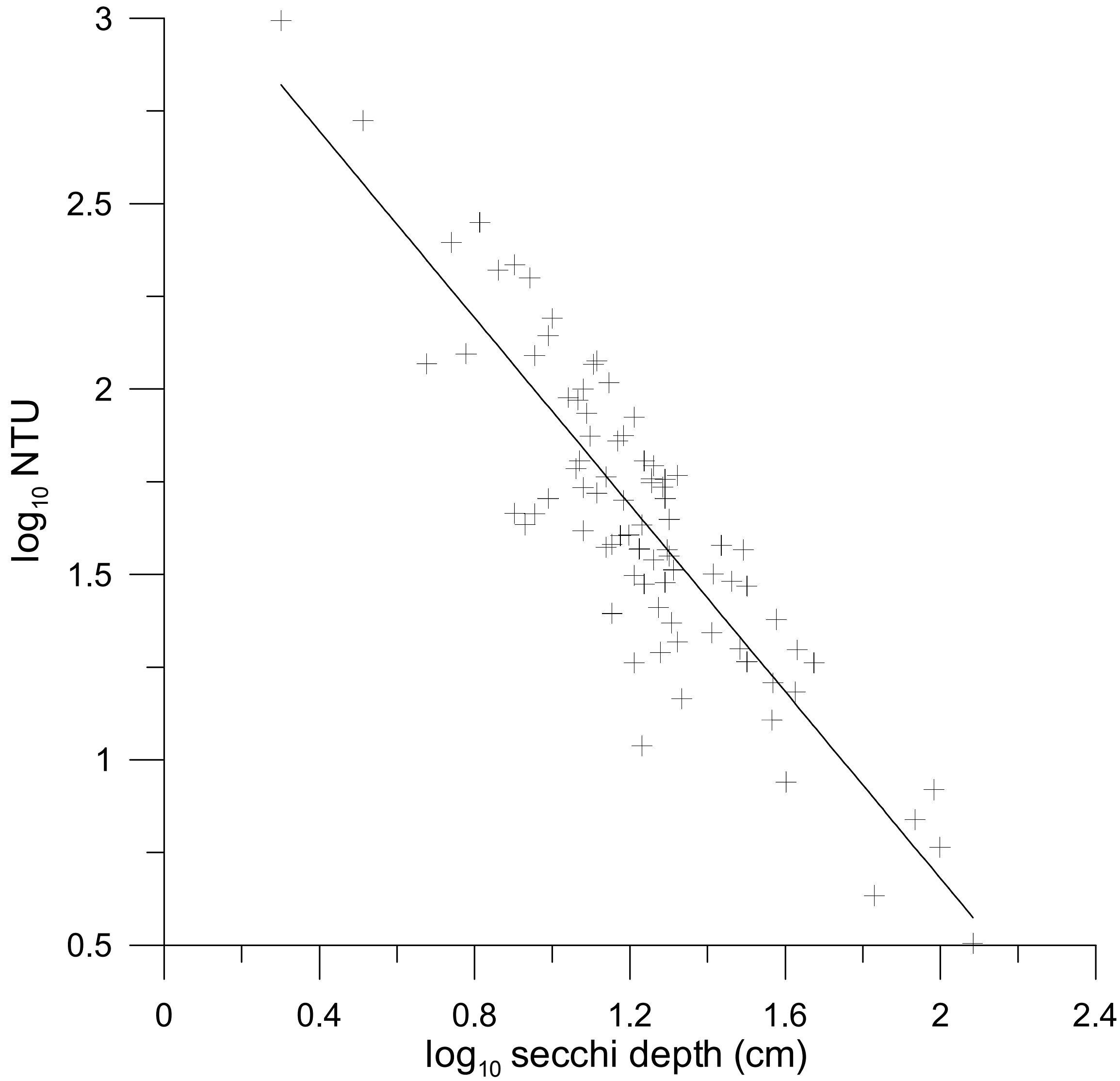
	NSD		NSS		NSSC		OW		ROCK		WD		WDC	
Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1996														
18-Jul	30.80	0.12	29.98	0.45	*	*	29.38	0.19	*	*	*	*	*	*
1-Aug	26.10	0.04	26.18	0.18	26.03	0.03	26.00	0.04	*	*	26.03	0.03	26.05	0.06
15-Aug	28.80	0.34	29.05	0.67	28.08	0.13	27.90	0.28	*	*	29.58	0.79	28.10	0.12
29-Aug	26.90	0.04	26.83	0.05	27.38	0.25	26.48	0.13	*	*	27.00	0.07	26.98	0.05
12-Sep	23.50	0.35	25.05	0.05	25.00	0.00	23.00	0.08	*	*	24.00	0.20	24.00	0.61
25-Sep	18.35	0.06	18.63	0.21	*	*	18.40	0.12	*	*	18.65	0.09		
9-Oct	18.33	0.23	18.05	0.10	16.85	0.05	17.38	0.36	*	*	17.75	0.18	16.75	0.18
24-Oct	13.78	0.26	13.13	0.30	13.13	0.34	13.70	0.23	*	*	11.43	0.05	11.40	0.07
6-Nov	11.18	0.12	11.63	0.18	10.30	0.17	10.83	0.14	9.23	0.03	11.03	0.02	9.93	0.28
20-Nov	6.90	0.00	6.38	0.32	6.00	0.00	6.90	0.00	*	*	6.90	0.00	6.90	0.00
12-Dec	*	*	6.32	0.57	4.50	0.29	5.95	0.05	3.90	0.06	6.13	0.13	*	*
1997														
8-Jan	*	*	*	*	1.20	0.41	*	*	1.15	0.12	*	*	*	*
11-Feb	*	*	*	*	1.40	0.20	*	*	1.27	0.03	*	*	*	*
25-Feb	4.38	0.31	4.88	0.13	5.28	0.24	4.00	0.00	*	*	4.15	0.12	*	*
12-Mar	10.83	0.14	13.18	0.25	10.73	1.02	10.08	0.05	*	*	10.45	0.14	8.55	0.52
27-Mar	13.18	0.12	13.65	0.25	9.75	0.14	11.63	0.24	9.50	0.00	12.88	0.13	13.00	0.91
9-Apr	9.73	0.24	10.13	0.13	12.28	0.99	9.28	0.43	*	*	9.73	0.23	9.85	0.05
24-Apr	12.03	0.18	14.25	0.55	12.78	0.58	*	*	*	*	*	*	11.75	0.09
8-May	18.83	0.46	16.98	0.24	15.50	0.00	17.83	0.17	*	*	18.00	0.08	15.50	0.00
22-May	18.88	0.14	20.30	0.65	18.63	0.38	18.03	0.03	*	*	18.95	0.33	18.00	0.00
5-Jun	24.38	0.99	26.13	0.66	21.25	0.63	21.78	0.99	*	*	23.80	1.42	19.63	0.13
19-Jun	27.10	0.21	26.33	0.23	25.20	0.11	26.10	0.30	*	*	27.95	0.36	24.80	0.44
1-Jul	28.78	0.10	29.13	0.35	28.03	0.06	27.93	0.08	*	*	29.10	0.13	28.80	0.44
17-Jul	31.38	0.24	29.90	0.29	28.88	0.05	29.83	0.29	*	*	32.48	0.67	28.40	0.07
31-Jul	26.33	0.12	26.45	0.17	28.30	0.17	*	*	27.95	0.05	26.25	0.14	*	*
14-Aug	24.95	0.06	25.25	0.10	25.68	0.14	*	*	25.30	0.04	25.05	0.06	*	*
28-Aug	28.28	0.29	29.53	0.19	27.08	0.15	*	*	26.85	0.05	28.70	0.31	*	*
11-Sep	23.90	0.30	24.95	0.45	25.90	0.49	*	*	25.00	0.00	23.80	2.01	*	*
23-Sep	19.50	0.20	18.20	0.34	21.33	0.16	*	*	21.55	0.13	19.30	0.14	*	*
9-Oct	19.98	0.05	20.15	0.13	21.80	0.20	*	*	21.15	0.05	20.28	0.18	*	*
21-Oct	15.05	0.09	15.35	0.13	15.35	0.05	*	*	15.00	0.00	15.15	0.12	*	*
4-Nov	9.23	0.23	8.53	0.48	9.30	0.00	8.83	0.02	9.30	0.00	9.05	0.36	*	*
20-Nov	6.70	0.37	6.60	0.18	5.28	0.02	*	*	5.28	0.02	6.98	0.17	*	*
2-Dec	6.88	0.15	6.90	0.06	6.50	0.00	6.33	0.06	*	*	6.65	0.09	6.50	0.00
16-Dec	*	*	*	*	2.48	0.19	*	*	2.20	0.00	*	*	*	*

Appendix C. Mean secchi depths (cm) ± SE for each habitat at the periodically-connected site on each sampling date. Asterisks indicate habitat not sampled on a given date. "B" indicates mean secchi depths that exceeded water depth in NSS.

	NSD		NSS		OW		WD	
Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1996								
16-Jul	25.50	1.26	21.50	1.26	25.25	0.48	*	*
30-Jul	32.50	2.40	19.50	5.50	40.25	1.18	31.50	2.50
13-Aug	47.00	1.22	37.50	2.50	49.50	0.50	45.50	1.66
27-Aug	34.00	2.45	B		41.00	0.91	34.25	1.44
6-Sep	34.75	1.38	11.00	0.00	38.75	0.48	36.50	0.50
10-Sep	33.50	1.04	30.50	1.19	39.25	1.80	35.50	4.73
27-Sep	28.75	1.49	27.00	1.22	37.00	1.78	33.00	1.22
10-Oct	33.50	2.53	27.00	1.00	31.75	1.44	33.00	1.22
25-Oct	19.50	0.96	21.00	0.58	20.00	0.82	20.67	1.33
5-Nov	22.00	0.00	22.00	0.00	22.00	0.00	22.00	0.00
19-Nov	24.50	0.65	24.50	0.96	25.25	0.63	25.00	1.22
11-Dec	52.25	1.44	B		54.75	0.25	54.75	0.25
1997								
27-Feb	20.50	1.04	19.25	0.95	19.75	1.31	19.75	0.25
13-Mar	29.50	0.50	29.00	0.58	31.50	0.29	29.75	0.63
25-Mar	20.50	0.96	19.00	1.53	21.50	0.29	22.00	0.00
8-Apr	32.25	0.75	20.00	0.00	36.25	1.25	34.75	1.89
6-May	26.00	1.29	24.75	0.25	32.33	1.45	28.25	1.89
20-May	24.25	1.97	13.33	2.03	31.75	0.48	26.25	2.81
3-Jun	24.00	2.42	16.75	3.30	29.50	0.65	23.50	4.66
17-Jun	19.25	2.78	19.50	0.65	32.00	1.96	24.00	3.19
3-Jul	52.75	0.85	24.00	0.00	56.50	0.65	48.75	1.38
15-Jul	69.25	1.75	B		113.75	0.48	70.25	5.94
29-Jul	35.00	4.36	B		73.75	3.92	54.25	14.05
12-Aug	60.00	6.08	25.00	0.00	84.75	2.50	59.00	7.49
26-Aug	49.25	3.09	B		63.75	3.33	58.25	1.44
9-Sep	58.25	5.14	B		94.75	2.69	77.50	7.26
25-Sep	49.00	1.53	B		52.75	1.55	50.00	0.71
7-Oct	67.50	4.33	B		88.75	1.25	56.25	3.75
22-Oct	40.75	3.42	B		47.00	1.78	44.00	2.35
5-Nov	30.25	0.63	B		31.50	0.50	30.25	0.25
19-Nov	61.00	1.58	B		69.25	2.10	67.25	2.66
3-Dec	66.25	2.10	B		67.00	1.00	58.75	2.39

Appendix D. Mean secchi depths (cm) ± SE for each habitat at the continuously-connected site on each sampling date. Asterisks indicate habitat not sampled on a given date. "B" indicates mean secchi depths that exceeded water depth.

	NSD		NSS		NSSC		OW		ROCK		WD		WDC	
Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1996														
18-Jul	15.75	1.44	16.00	1.08	*	*	19.25	0.48	*	*	*	*	*	*
1-Aug	16.75	0.63	13.50	1.04	12.00	0.41	17.00	1.47	*	*	18.25	0.25	12.25	0.25
15-Aug	13.75	1.18	15.00	0.41	13.00	0.71	16.50	0.87	*	*	17.50	1.32	17.50	0.50
29-Aug	15.00	0.71	12.25	0.95	8.75	0.85	14.75	0.85	*	*	15.00	1.08	10.75	0.25
12-Sep	18.00	0.71	17.75	0.75	17.50	0.87	18.50	0.29	*	*	16.00	0.41	18.00	0.71
25-Sep	14.50	1.32	16.50	1.50			14.50	0.29	*	*	14.75	0.85		
9-Oct	22.25	1.70	17.33	0.33	14.00	0.41	22.50	0.65	*	*	16.00	0.82	16.00	0.71
24-Oct	18.75	1.70	25.00	1.00	16.75	2.93	22.25	0.48	*	*	18.50	1.32	10.25	0.48
6-Nov	16.50	0.65	16.00	1.08	21.50	1.32	19.25	0.48	20.50	0.29	19.50	0.29	21.00	0.71
20-Nov	6.25	0.75	9.75	0.48	5.00	0.00	8.00	0.00	*	*	7.25	0.25	5.00	0.00
12-Dec	*	*	21.00	1.34	26.00	1.00	24.00	2.12	23.50	1.50	22.25	1.03	*	*
1997														
8-Jan	*	*	*	*	23.25	1.18	*	*	18.25	2.95	*	*	*	*
11-Feb	*	*	*	*	28.00	0.00	*	*	28.00	0.00	*	*	*	*
25-Feb	3.00	0.00	4.50	0.50	4.00	0.00	5.25	0.75	*	*	3.50	0.50	*	*
12-Mar	11.25	0.75	B		B		17.00	0.00	*	*	12.50	1.66	14.50	1.44
27-Mar	9.25	0.25	9.50	0.50	9.00	0.58	10.75	0.25	8.75	0.25	11.00	0.58	9.00	0.00
9-Apr	19.00	1.00	10.00	0.00	10.67	1.33	17.75	1.03	*	*	17.25	0.75	11.00	0.71
24-Apr	8.67	0.33	9.00	0.41	8.00	0.00	*	*	*	*	*	*	9.00	0.41
8-May	8.75	0.75	9.00	0.58	8.25	0.25	10.50	0.29	*	*	9.50	0.65	9.25	0.25
22-May	15.00	1.73	13.00	1.73	16.00	0.41	20.50	0.29	*	*	19.25	0.85	18.00	0.71
5-Jun	21.75	1.03	21.50	0.87	18.00	0.41	21.50	1.32	*	*	21.75	0.63	16.75	0.75
19-Jun	11.25	1.65	10.00	0.41	7.75	0.48	12.75	0.25	*	*	15.25	0.95	7.50	1.55
1-Jul	6.25	0.48	5.75	0.48	3.25	0.25	6.75	0.63	*	*	5.25	0.25	3.50	0.29
17-Jul	21.00	2.38	13.00	1.41	14.00	2.65	23.00	1.15	*	*	24.00	0.71	16.00	0.41
31-Jul	20.00	0.00	17.50	0.50	17.25	0.25	*	*	12.75	0.25	20.00	0.00	*	*
14-Aug	17.25	0.25	15.50	0.29	29.50	3.23	*	*	30.25	1.49	15.50	0.50	*	*
28-Aug	19.50	0.50	17.00	0.58	27.75	1.03	*	*	25.00	0.00	19.50	0.50	*	*
11-Sep	14.50	2.02	11.50	0.65	14.50	1.55	*	*	21.00	1.58	13.50	0.65	*	*
23-Sep	17.00	0.41	14.25	0.25	19.75	0.63	*	*	30.00	0.41	16.00	0.71	*	*
9-Oct	15.00	0.41	10.25	0.95	26.50	0.96	*	*	26.00	1.08	12.75	1.31	*	*
21-Oct	19.00	0.58	14.50	0.65	19.50	0.50	*	*	17.75	0.25	17.50	0.96	*	*
4-Nov	34.50	0.87	34.33	0.33	12.00	0.00	33.25	0.63	12.00	0.00	33.50	0.50	*	*
20-Nov	47.00	3.34	32.00	0.00	21.67	0.33	*	*	24.25	1.31	34.50	4.50	*	*
2-Dec	32.75	0.25	38.00	0.00	13.25	0.63	31.50	1.32	*	*	33.00	1.22	12.00	0.00
16-Dec	*	*	*	*	17.25	0.25	*	*	16.50	0.29	*	*	*	*



Appendix E. Relationship between turbidity (NTU) and secchi depth (cm) for periodically-connected and continuously-connected scours. Solid line represents least-squares linear regression function fit to data (log NTU = 3.199 - 1.259 log secchi depth, $r^2 = 0.79$, $p<0.0001$).

Appendix F. Mean dissolved oxygen concentrations (mg/L) ± SE for each habitat at the periodically connected site on each sampling date. Asterisks indicate habitat not sampled on a given date.

	NSD		NSS		OW		WD	
Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1996								
16-Jul	13.50	0.25	11.68	0.11	12.75	0.24	*	*
30-Jul	13.80	0.21	12.75	0.25	14.40	0.16	6.43	0.09
13-Aug	11.15	0.10	11.05	0.05	11.18	0.13	11.60	0.18
27-Aug	8.75	0.39	8.35	0.17	8.95	0.13	8.18	0.13
6-Sep	8.03	0.27	7.23	0.24	8.20	0.21	7.75	0.53
10-Sep	11.30	0.62	11.18	0.24	11.08	0.27	11.55	0.42
27-Sep	5.70	0.27	6.50	0.31	5.58	0.05	5.73	0.42
10-Oct	7.05	0.29	7.28	0.17	6.73	0.08	7.23	0.12
25-Oct	9.03	0.16	8.85	0.09	9.08	0.02	8.80	0.06
5-Nov	9.35	0.12	8.93	0.18	9.20	0.20	9.03	0.09
19-Nov	10.53	0.05	10.48	0.05	10.48	0.13	10.43	0.09
11-Dec	11.93	0.11	12.08	0.25	11.83	0.13	12.00	0.20
1997								
27-Feb	10.85	0.10	10.95	0.05	10.85	0.05	11.08	0.15
13-Mar	11.95	0.03	12.05	0.12	12.00	0.00	11.88	0.05
25-Mar	12.18	0.24	11.95	0.05	11.93	0.05	12.00	0.00
8-Apr	9.90	0.04	9.53	0.22	9.88	0.05	9.53	0.33
6-May	14.25	0.52	14.93	0.48	16.40	0.07	14.75	0.52
20-May	13.38	0.25	13.75	0.39	14.00	0.22	14.18	0.14
3-Jun	12.75	0.13	13.55	3.02	12.30	0.17	11.70	0.24
17-Jun	11.10	0.45	10.78	0.56	11.18	0.22	11.57	0.48
3-Jul	6.53	0.05	6.55	0.17	6.53	0.06	6.45	0.17
15-Jul	7.28	0.19	7.08	0.15	7.30	0.07	6.98	0.06
29-Jul	7.03	0.08	6.50	0.14	6.98	0.16	6.95	0.16
12-Aug	8.23	0.28	8.15	0.15	8.38	0.08	8.13	0.20
26-Aug	9.45	0.21	9.00	0.26	9.33	0.36	9.33	0.12
9-Sep	8.58	0.11	8.28	0.16	8.60	0.18	8.53	0.23
25-Sep	7.95	0.14	8.20	0.17	7.95	0.12	8.20	0.15
7-Oct	8.13	0.11	7.95	0.24	8.70	0.11	8.30	0.11
22-Oct	7.65	0.06	7.88	0.30	7.38	0.10	7.58	0.08
5-Nov	9.25	0.22	9.23	0.12	9.40	0.26	9.18	0.13
19-Nov	11.20	0.11	11.73	0.20	11.23	0.06	11.55	0.19
3-Dec	10.95	0.30	11.00	0.14	10.90	0.07	10.75	0.09

Appendix G. Mean dissolved oxygen concentrations (mg/L) ± SE for each habitat at the continuously-connected site on each sampling date. Asterisks indicate habitat not sampled on a given date.

	NSD		NSS		NSSC		OW		ROCK		WD		WDC	
Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1996														
18-Jul	9.15	0.86	7.08	0.13	*	*	7.20	0.16	*	*	*	*	*	*
1-Aug	10.08	0.52	10.70	1.28	6.25	0.27	9.38	0.64	*	*	9.80	0.56	6.73	0.45
15-Aug	8.98	0.77	8.83	0.41	6.48	0.02	8.13	0.24	*	*	10.10	0.94	7.00	0.60
29-Aug	4.93	0.20	5.28	0.09	4.50	0.10	4.55	0.12	*	*	4.90	0.17	4.20	0.12
12-Sep	10.45	0.96	11.55	1.15	9.13	0.73	10.30	0.14	*	*	11.48	0.48	8.05	0.44
25-Sep	9.05	0.21	9.00	0.09	*	*	8.73	0.05	*	*	8.93	0.18	*	*
9-Oct	9.58	0.27	9.33	0.06	7.45	0.14	9.95	0.13	*	*	9.50	0.09	7.95	0.68
24-Oct	10.85	0.18	11.63	0.32	10.10	0.41	10.75	0.26	*	*	9.73	0.22	9.50	0.15
6-Nov	10.73	0.30	10.45	0.14	10.75	0.14	10.28	0.05	11.05	0.06	10.90	0.06	10.93	0.19
20-Nov	9.73	0.09	11.25	0.39	11.50	0.00	8.80	0.00	*	*	10.00	0.00	9.80	0.00
12-Dec	*	*	12.14	0.11	11.93	0.07	11.88	0.13	12.45	0.10	11.93	0.08	*	*
1997														
8-Jan	*	*	*	*	12.03	0.88	*	*	13.40	0.10	*	*	*	*
11-Feb	*	*	*	*	11.90	0.15	*	*	11.80	0.06	*	*	*	*
25-Feb	10.35	0.12	10.40	0.14	10.15	0.10	10.55	0.06	*	*	10.28	0.08	*	*
12-Mar	11.05	0.05	10.90	0.20	11.13	0.09	11.33	0.05	*	*	10.63	0.27	11.50	0.13
27-Mar	9.63	0.24	9.55	0.34	9.50	0.00	9.25	0.05	9.50	0.00	9.40	0.27	9.50	0.24
9-Apr	9.68	0.31	11.70	0.24	12.65	0.90	9.70	0.30	*	*	9.65	0.05	9.85	0.05
24-Apr	9.60	0.21	9.43	0.08	9.18	0.18	*	*	*	*	*	*	9.10	0.22
8-May	9.13	0.19	8.85	0.09	8.70	0.00	9.05	0.03	*	*	9.08	0.08	8.70	0.00
22-May	10.40	0.36	11.55	0.53	10.48	1.25	9.68	0.08	*	*	10.13	0.05	11.38	2.56
5-Jun	8.88	0.26	9.90	0.29	8.00	0.17	8.40	0.48	*	*	8.88	0.18	7.78	0.02
19-Jun	8.45	0.14	7.83	0.14	6.48	0.05	7.80	0.40	*	*	11.55	2.51	6.50	0.21
1-Jul	6.75	0.06	7.38	0.26	5.98	0.02	6.35	0.03	*	*	7.25	0.09	6.30	0.37
17-Jul	12.63	0.54	12.40	0.40	6.30	0.07	12.45	0.29	*	*	14.00	0.93	6.43	0.11
31-Jul	9.23	0.50	10.95	0.68	6.40	0.10	*	*	6.18	0.06	8.88	0.50	*	*
14-Aug	8.25	0.18	9.20	0.54	7.25	0.15	*	*	7.18	0.05	8.23	0.31	*	*
28-Aug	9.10	0.53	12.30	0.70	7.50	0.24	*	*	7.18	0.05	9.45	1.20	*	*
11-Sep	10.45	1.14	11.30	0.61	8.00	0.34	*	*	7.25	0.05	11.70	2.21	*	*
23-Sep	7.20	0.15	8.98	0.26	6.93	0.06	*	*	6.90	0.09	7.33	0.03	*	*
9-Oct	10.85	2.42	8.93	0.43	8.65	0.09	*	*	8.55	0.10	9.00	0.32	*	*
21-Oct	9.60	0.08	9.78	0.10	8.70	0.00	*	*	8.50	0.00	9.83	0.35	*	*
4-Nov	11.05	0.06	11.63	0.29	10.50	0.00	10.85	0.15	10.50	0.00	10.75	0.17	*	*
20-Nov	12.25	0.39	12.10	0.10	11.80	0.00	*	*	11.80	0.00	12.20	0.22	*	*
2-Dec	11.05	0.19	10.28	0.33	11.20	0.00	11.05	0.09	*	*	11.25	0.05	11.15	0.03
16-Dec	*	*	*	*	12.78	0.06	*	*	12.78	0.03	*	*	*	*

Appendix H. Mean species richness (number of species/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), open water (OW), and woody debris (WD) habitats during spring temperature rise (river temperatures from 10 -25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10 -25° C, mid-September through October), and 'winter' (river temperatures <10°C, November through early April) at the periodically-connected site. N = number of samples collected.

		Season			
Habitat	Statistic	Spring	Summer	Fall	Winter
NSD	Mean	0.35	0.75	0.88	0.48
	SE	0.13	0.11	0.16	0.11
	N	20	48	25	40
NSS	Mean	0.45	1.52	1.63	0.68
	SE	0.13	0.13	0.24	0.13
	N	20	48	24	40
OW	Mean	0.10	0.06	0.25	0.20
	SE	0.06	0.03	0.12	0.06
	N	20	48	24	40
WD	Mean	0.70	1.00	0.92	0.43
	SE	0.24	0.15	0.16	0.11
	N	20	44	24	40

Appendix I. Mean species richness (number of species/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), near-shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD) and woody debris with current (WDC) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the continuously-connected site. N = number of samples collected. ROCK was not sampled during spring.

		Season			
Habitat	Statistic	Spring	Summer	Fall	Winter
NSD	Mean	0.71	0.82	0.92	0.42
	SE	0.19	0.13	0.19	0.11
	N	21	44	24	36
NSS	Mean	0.30	1.48	1.25	1.15
	SE	0.12	0.18	0.18	0.21
	N	20	44	24	40
NSSC	mean	0.35	0.83	0.95	0.63
	SE	0.13	0.12	0.19	0.11
	N	20	40	20	52
OW	mean	0.13	0.50	0.17	0.25
	SE	0.13	0.11	0.11	0.08
	N	16	28	12	36
ROCK	Mean		0.93	0.36	0.16
	SE		0.24	0.20	0.06
	N		16	11	32
WD	Mean	0.56	1.18	1.36	1.10
	SE	0.25	0.17	0.23	0.26
	N	16	40	22	40
WDC	Mean	0.15	0.63	0.50	0.13
	SE	0.11	0.17	0.26	0.07
	N	20	24	8	24

Appendix J. Mean CPUE for all taxa combined (fish/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), open water (OW), and woody debris (WD) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10°C, November through early April) at the periodically-connected site. N = number of samples collected.

		Season			
Habitat	Statistic	Spring	Summer	Fall	Winter
NSD	Mean	0.45	1.23	2.80	0.73
	SE	0.18	0.25	1.50	0.24
	N	20	48	25	40
NSS	Mean	0.55	5.44	5.96	2.28
	SE	0.17	1.65	2.17	0.64
	N	20	48	24	40
OW	Mean	0.10	0.10	0.58	1.03
	SE	0.06	0.06	0.36	0.71
	N	20	48	24	40
WD	Mean	0.75	1.73	1.21	0.68
	SE	0.26	0.31	0.24	0.23
	N	20	44	24	40

Appendix K. Mean CPUE for all taxa combined (fish/sample) ± SE in near-shore deep (NSD), near-shore shallow (NSS), near-shore shallow with current (NSSC), open water (OW), rock dike (ROCK), woody debris (WD) and woody debris with current (WDC) habitats during spring temperature rise (river temperatures from 10-25° C, mid-April through June), 'summer' (river temperatures >25° C, July through early September), fall temperature decline (river temperatures from 10-25° C, mid-September through October), and 'winter' (river temperatures <10° C, November through early April) at the continuously-connected site. N = number of samples collected. ROCK was not sampled during spring.

		Season			
Habitat	Statistic	Spring	Summer	Fall	Winter
NSD	Mean	0.71	1.16	1.54	0.53
	SE	0.19	0.24	0.42	0.16
	N	21	44	24	36
NSS	Mean	0.85	3.25	5.38	4.88
	SE	0.44	0.71	1.35	2.19
	N	20	44	24	40
NSSC	Mean	0.35	1.03	1.95	2.17
	SE	0.13	0.17	0.73	0.81
	N	20	40	20	52
OW	Mean	0.25	0.75	0.17	0.56
	SE	0.25	0.23	0.11	0.33
	N	16	28	12	36
ROCK	Mean		1.73	0.64	0.19
	SE		0.54	0.38	0.08
	N		16	11	32
WD	Mean	0.81	1.48	2.68	1.88
	SE	0.36	0.23	0.71	0.54
	N	16	40	22	40
WDC	Mean	0.15	0.71	0.63	0.13
	SE	0.11	0.21	0.32	0.06
	N	20	24	8	24