Distribution, Habitats, and Tributary Linkages of Small and Nongame Fishes in the Lower Yellowstone River

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EXECUTIVE SUMMARY

The Yellowstone River is the longest undammed river in the conterminous United States. It has a relatively natural flow regime, which helps maintain diverse habitats and fish assemblages now unique in large rivers. The lower Yellowstone River supports a diverse nongame fish assemblage that includes several species of special concern. However, the small, nongame fish assemblage of the lower Yellowstone River remains inadequately studied; studies of small-bodied fishes have been limited to the Yellowstone River below Intake Diversion Dam. We compared efficiencies of several gears for sampling these fishes, determined the distribution and habitat use of these fishes in the Yellowstone River, and examined the movements of selected species between the Yellowstone River and its tributaries.

Prior to undertaking long-term monitoring projects, sampling gears and efforts need to be assessed to develop the most efficient sampling methods. We assessed the efficiency of fyke nets, seines, and otter trawls for sampling the shoreline and main channel habitats of the lower Yellowstone River to develop proper sampling methods. Fyke nets were more effective than seines at sampling the shoreline fish assemblage. Fyke nets consistently had higher catch rates ($P < 0.01$) and captured more species ($P < 0.01$) than seines. Two fyke net sets in each macrohabitat were enough to characterize the abundances and distributions of dominant species. However, we recommend three fyke net sets in each macrohabitat to develop complete species lists that include rare species. Otter trawls were the best gear for sampling small-bodied fish in main channel habitats.

We captured 42 species (24 native and 18 nonnative) in the lower Yellowstone River with fyke nets. Native species constituted over 99% of the catch. Emerald shiners, western silvery minnows, flathead chubs, sand shiners, and longnose dace composed nearly 94% of fyke

net catch and were caught in every segment of the study area. We captured 24 species by otter trawling downstream of the Tongue River. Sturgeon chubs, channel catfish, flathead chubs, stonecats, and sicklefin chubs composed 89% of the otter trawl catch. The upstream distributional limit of sturgeon chubs was the Tongue River; only a few sicklefin chubs were captured above Intake Diversion Dam.

Spatial connectivity helps maintain population stability and viability for many organisms. However, inability to track the movements of small fishes had inhibited a complete understanding of how connectivity and movement affect prairie stream fish populations. We used otolith microchemistry analysis to reconstruct the movements of sand shiners, western silvery minnows, and flathead chubs in the lower Yellowstone River and its tributaries. All three species moved between the Yellowstone River and its tributaries. About 70% of western silvery minnows and flathead chubs moved between main-stem and tributary habitats. Only 50% of sand shiners moved between main-stem and tributary habitats. The proportion of residents and dispersers varied among tributaries and species indicating that local conditions affect movement patterns of each study species differently.

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Introduction

Prior and on-going research efforts have provided an excellent foundation of knowledge on fishes and their habitats in small prairie streams, as well as trends in abundance, habitat use and movements of selected large-bodied and game fishes in the Yellowstone River. However, we lack critical information or even a basic understanding of the composition, distribution, relative abundance, and habitat requirements of small and nongame fishes in the lower Yellowstone River—the longest undammed river in the contiguous United States and a rare model of the structure and function of large rivers. For example, what are the distributions, relative abundances, and habitat preferences of sturgeon chub, sicklefin chub, western silvery minnow, plains minnow, brassy minnow, and the other 11 cyprinid species in the lower Yellowstone River? Are these populations fragmented by the six diversion dams on the main-stem Yellowstone River? What will be the effect of providing fish passage at Intake and other main -stem diversion dams? Moreover, the linkages between the Yellowstone River and its tributaries are unresolved. For example, what is the magnitude of the contribution of the tributaries to the recruitment of cyprinids in the lower Yellowstone River, and which tributaries are most important? Such information is essential for developing effective management and conservation strategies to avoid or reduce declines in habitats and species, for developing monitoring protocols to assess the effectiveness of management and conservation strategies, and for prioritizing crucial elements of landscape-scale habitat conservation. Baseline information on these species and habitats is also needed before further development of energy resources such as coalbed natural gas or coal gasification projects. The objectives of this study were to 1) compare the effectiveness of fyke nets and seines for sampling the shoreline fish assemblage of the Yellowstone River, 2) determine the sampling effort needed to capture 95% of the expected species at shoreline sampling reaches, 3) assess spatiotemporal efficiency of the most effective gears for sampling small nongame fishes in the lower Yellowstone River, 4) determine which small nongame fishes were abundant, common, and rare in the lower Yellowstone River, 5) determine the longitudinal distribution of these species, 6) determine what habitat types these species used, 7) determine whether diversion dams fragmented lower Yellowstone River fish populations, 8) determine the proportions of resident and dispersing individuals of selected species in the lower Yellowstone River and its tributaries, and 9) identify dispersal patterns of these species.

Evaluation of Sampling Methods for Small Nongame Fishes in the Lower Yellowstone River

Introduction

Proper sampling methods must be identified before long-term monitoring efforts are initiated. Historically, fisheries management was used to maintain maximum sustainable yields of commercially or recreationally important fish (Krueger and Decker 1999). However, fisheries management now attempts to also understand broad-based processes that affect ecosystem structure and function (Gislason et al. 2000) and that require characterization of species interactions and temporal ecosystem variability (Francis et al. 2007). These new goals have increased the complexity of fisheries assessments because greater proportions of assemblages must be sampled now than formerly.

The scale at which studies are undertaken has also increased. Managing fisheries at the landscape level increased as biologists became aware of the importance of maintaining population connectivity and habitat heterogeneity within large river systems (Latour et al. 2003). This paradigm shift has led to greater cooperation among state and federal agencies (Gresswell and Vondracek 2010; Paukert and Galat 2010). However, differing sampling strategies can make collaboration and integration of data difficult if not impossible. Sampling standardization in large-scale studies enhances use and accurate interpretation of data collected by multiple agencies (Bonar and Hubert 2002; Hughes and Peck 2008; Bonar et al. 2009). The ability to use data collected by various entities is especially important when conducting species assessments. Therefore, standard sampling methods have been developed for sampling some large rivers such as the Missouri River (Drobish 2006; Drobish 2008).

A variety of sampling gears such as seines, electrofishing, hoop nets, and fyke nets have been used for sampling small-bodied fish along the shorelines of large rivers (e.g., Hesse et al. 1993; Johnson and Jennings 1998; Braaten and Guy 2002; Dieterman and Galat 2004; Koel 2004; Welker and Scarnecchia 2004; Barko et al. 2006). Several trawl designs (e.g., push, beam, and otter) have been used for sampling small-bodied fish in benthic main channel habitats (e.g., Dieterman and Galat 2004; Everett et al. 2004; Welker and Scarnecchia 2004; Herzog et al. 2005; Ridenour et al. 2009; Schloesser et al. 2012). However, using only the single most effective gear in either habitat increases statistical power by increasing sample sizes (Brown and Guy 2007) and decreasing zero catches (Bayley and Peterson 2001) and simplifies data analysis (Arab et al. 2008). A formal analysis of gear efficiencies will help identify the best gear for sampling nongame fishes in large rivers and thus simplify sampling methodologies and data analysis. Furthermore, it will assess if sampling efforts used for Missouri River assessments are sufficient for properly characterizing the small nongame fish assemblage of the Yellowstone River where the small nongame fish remain little studied.

The Yellowstone River maintains a wide diversity of instream habitats, which are thought to support a nearly intact fish assemblage (White and Bramblett 1993). However, assessments of lower Yellowstone River fishes have primarily been limited to endangered species (e.g, pallid sturgeon *Scaphirhynchus albus*) or important recreational species (e.g., sauger *Sander canadensis*). The only sampling of small nongame fishes in the Yellowstone River was restricted to a few select species below Intake Diversion Dam (Pegg and Pierce 2002; Dieterman and Galat 2004; Everett et al. 2004; Welker and Scarnecchia 2004; Welker and Scarnecchia 2006) resulting in a lack of information on the distribution, abundance, and habitat use of nearly all small nongame fishes in the Yellowstone River. Furthermore, these studies used potentially inefficient gears (e.g., seines) for sampling small nongame fishes as fyke nets have proven to be more effective than seines for sampling shoreline fishes in a variety of habitats (Gritters 1994; Clark et al. 2007). Seines are ineffective at sampling fish, especially benthic species, in habitats with cobble substrate and woody debris (Guy et al. 2009), which are commonly encountered in the lower Yellowstone River. The inclusion of both seines and fyke nets in sampling methodologies is warranted if sufficiently different data are obtained (Ruetz et al. 2007). However, the additional effort is unnecessary if both gears provide the same information or if one is more effective than the other at sampling the entire assemblage.

High habitat heterogeneity in the Yellowstone River presents unique challenges for sampling benthic fish in the main channel. Push trawls are inefficient in the deep main channel habitats of the Yellowstone River (Everett et al. 2004) because they are most effective in depths of less than 2 m (Drobish 2008). Beam trawls were more difficult to use, took longer to deploy, entrained more cobble substrate, and were more prone to snags than otter trawls in the Yellowstone River (M. Duncan, unpublished data). Therefore, we deemed otter trawls the best option for sampling benthic fishes in the Yellowstone River. However, the spatiotemporal efficiency of otter trawls in the lower Yellowstone River remained unclear.

Our objectives were to 1) compare the effectiveness of fyke nets and seines for sampling the shoreline fish assemblage of the Yellowstone River, 2) determine the sampling effort needed to capture 90% and 95% of the expected species at shoreline sampling reaches, and 3) assess the spatiotemporal efficiency of fyke nets and otter trawls for sampling small nongame fishes in the lower Yellowstone River.

Methods

Our study area was the Yellowstone River between the confluences of the Clarks Fork and Missouri rivers. The river was separated into 13 longitudinal segments using diversion dams, major tributaries, the city of Billings, Montana, and the transition from cobble to sand substrate near Sidney, Montana (Figure 1.1). A stratified random sampling approach was used to select from two to four reaches within each segment, which were sampled between 1 July and 31 October 2008, 2009, or 2010. Five additional reaches located at tributary mouths (Tongue River, Sunday Creek, Powder River, O'Fallon Creek, and Cabin Creek) were also sampled in 2009. Reaches (i.e., river bends) were composed of three continuous (channel crossover, inside bend, and outside bend) and two discrete (secondary and seasonal secondary channels) macrohabitats when present (Drobish 2008). Each reach was classified as either an alluvial, bluff, terrace, stabilized alluvial, or stabilized bluff-terrace pool (Jaeger et al. 2005).

Fish sampling.—Three fyke nets (i.e., standard fyke net sampling) were randomly deployed in each macrohabitat in sampling reaches from 2008 to 2010. Fyke nets (H. Christiansen Co., Duluth, Minnesota; $290/fyke net) consisted of 4.5 × 0.6-m leads, two 0.6 × 1.2-m rectangular frames, and two 0.6-m circular hoops. The leads had floats on the top and lead lines on the bottom. All netting was 3.2-mm "ace" mesh. The nets were 7.5 m long when fully extended. The leads were tied to rods on the shorelines and the nets were set as close to perpendicular to the banks as conditions would allow. Nets were pulled taut and weighted with cinder blocks that were tied to the ends of nets. Nets were set in the evenings and fished for about 12 hours. Depth and water velocity measurements were recorded at the mouth of each net. The substrates surrounding the mouth of nets were qualitatively categorized as silt, sand, gravel, pebble, cobble, boulder, or bedrock and assigned numerical values ranging from one to seven, respectively. Water temperatures were recorded at each reach.

When time and conditions permitted, at least one seine haul was completed within each macrohabitat at each sampling reach in 2008 and 2009. Seining was not attempted in fast water velocities (> 0.5 m/s), deep waters (> 1.0 m), silty habitats that made wading difficult, seasonal channels with abundant woody debris, most outside bends, most riprapped banks, or when high fyke net catches or travel time between sampling reaches limited time for sampling. Seines (Memphis Net & Twine Co., Inc., Memphis, Tennessee; $263/seine) were 15.2 m long and 1.8 m high and made of 6.4-mm "ace" mesh. The dimensions of the bags were 1.8 m long × 1.8 m high ×1.8 m wide. Seines were pulled downstream along the shorelines for 100 m after which the person wading made an arc towards the shorelines while the person on the banks remained stationary. Dominant substrate was recorded for the areas sampled. Depth and velocity were both measured at nine randomly selected locations in the areas seined and means for each were calculated.

Otter trawls were used to sample sicklefin chub *Macrhybopsis meeki* and sturgeon chub *Macrhybopsis gelida* in the Yellowstone River downstream of the Clark's Fork River in 2008. To help restrict otter trawling efforts to probable sicklefin chub and sturgeon chub habitats in 2009 and 2010, longitudinal distributions for both species were estimated using 2008 otter trawl data. Otter trawls (Innovative Net Systems, Milton, Louisiana; $500/trawl; $150/set of trawl doors) were 3.8 m wide, 0.9 m tall, and 7.6 m long. Trawls were made of 6.3-mm inner mesh and 38-mm protective outer mesh. Trawl doors were 76.2 cm × 38.1 cm. Trawls were attached to the bow of the boat and towed downstream in reverse for 300 m if no snags occurred. Data were discarded and another trawl was completed if a snag occurred prior to trawling 150 m or if a snag prevented quick retrieval of captured fish from trawls longer than 150 m. Three tows were completed in each macrohabitat in each reach when conditions permitted. The length of each tow was measured using a handheld GPS unit. Trawls were not used in macrohabitats that were too short to deploy and retrieve nets without drifting into downstream macrohabitats. The length and number of trawls were also limited in outside bends, near bridges, and stabilized reaches because of recurring snags.

We randomly selected four "gear efficiency test reaches" for the intensive sampling needed to collect data to estimate how much sampling effort is needed to capture 90% and 95% of expected small and nongame shoreline species using fyke nets and seines. In 2010, a total of 20 fyke nets and 4 to 6 seines were evenly distributed and randomly deployed among macrohabitats in these four reaches. Reach 1 was a terrace pool where all five macrohabitats were sampled. Reach 2 was a scour pool where four macrohabitats (no secondary channel) were sampled. Reach 3 was a scour pool where four macrohabitats (no secondary channel) were sampled. Reach 4 was a stabilized alluvial pool where the crossover, inside bend, and secondary channel were sampled.

The following protocol was used in processing fish from all of our sampling efforts. The lengths of up to 25 haphazardly selected individuals of each species from each sample were measured. If many age-0 fish were sampled, a voucher collection of about 50 fish was preserved in 10% buffered formalin for later identification in the laboratory. The remaining age-0 fish were counted and released. The relative abundances from the voucher sample were then applied to the total count of age-0 fish from which the sample was taken.

Data analysis.—Length frequency histograms from this study and other age and growth reports (Auer 1982; Wallus et al. 1990; Kay et al. 1994; U.S. Fish and Wildlife Service

[USFWS] 2001; Herzog 2004; Dattilo et al. 2008a; Dattilo et al. 2008b; Herman et al. 2008a; Herman et al. 2008b) were used to classify fish as either age-0 (juveniles) or age-1 and older (adults).

To compare the effectiveness of fyke nets and seines in sampling the shoreline fish assemblage, we randomly paired catch data from each seine haul with catch data from a fyke net deployed in the same reach during the same sampling event in the same macrohabitat. This resulted in 174 paired seine and fyke net subsamples. A paired data analysis permitted a clear understanding of the sampling variability associated with each gear by eliminating the confounding effects of differing numbers of gear deployments between the two gears. Paired t tests were used to compare habitat characteristics, catch-per-unit-effort (CPUE; $x + 0.5$ log-transformed), species richness, diversity, evenness, and mean length between gears. The Shannon-Wiener function (H'; Shannon and Weaver 1949) was used to evaluate diversity and calculate evenness (J'). Percent similarity (Curtis 1959) was used to compare species composition between the two gears.

Rarefaction curves, which estimate species richness for a given number of individual samples (Hulbert 1971), were used to compare the species accumulation of fyke nets and seines. Rarefaction curves were generated using 10,000 random iterations to determine the average increase in species richness for abundances of 25 to 500 fish in increments of 25.

Linear regression was used to assess spatiotemporal changes in the CPUE of all three gears. The proportion of sites where *Macrhybopsis* spp. were captured with otter trawls was calculated. The proportion of tows needed to detect either species was also calculated for reaches where they were captured.

Species accumulation curves were used to determine the sampling effort needed to catch 90% and 95% of the shoreline species expected at the four gear efficiency test reaches. Species accumulation curves illustrate the number of expected species as a function of sampling effort by using iterations of the catch data. We used the asymptote of the fyke net accumulation curve to estimate the expected species richness at the four gear efficiency test reaches. Curves were developed using 10,000 random iterations of the catch data.

To assess how fyke net sampling effort affected the CPUE of the five dominant species (emerald shiner *Notropis atherinoides*, flathead chub *Platygobio gracilis*, longnose dace *Rhinichthys cataractae*, sand shiner *Notropis stramineus*, and western silvery minnow *Hybognathus argyritis*; Chapter 2), we calculated the mean CPUE for those species using either two or three fyke net sets in each macrohabitat at all reaches sampled from 2008 to 2010. The mean reach CPUEs were calculated by randomly selecting two or three fyke net samples from each macrohabitat in each reach. Paired t tests were used to compare mean reach CPUE of the dominant species using either two or three fyke nets in each macrohabitat.

Results

The 174 fyke nets that were paired with seines captured 34,595 fish representing 10 families and 35 species, including 8 unique species not collected by seining (Table 1.1). The 174 seine hauls captured 13,521 fish representing 8 families and 28 species, including 1 unique species. Emerald shiners, flathead chubs, and western silvery minnows were the dominant species in both gears. These three species together composed 78% of fyke net catch and 92% of seine catch. Fyke nets were more effective than seines at capturing benthic fish such as longnose dace, stonecats, and suckers. Fyke nets also captured more small-bodied fishes such as longnose dace, fathead minnows, and sand shiners than seines. Characteristics of the habitats (substrate, depth, and water velocity) sampled with each gear were not significantly different ($P = 0.12$, 0.91, and 0.35, respectively; Table 1.2). Water temperatures decreased as the sampling seasons progressed (Figure 1.2).

Mean CPUE, species richness, diversity (H'), and evenness (J') of fyke net catches were greater than those of seines ($P \leq 0.01$; Table 1.3). Mean CPUE of fyke net catches was greater than that of seines in inside bends and secondary channels (Table 1.4). Mean species richness of fyke net catches was greater than that of seines in every macrohabitat (Table 1.4). The mean percent similarity of catches from the two gears was 37% (SE = 2.41) and ranged from 0% to 100%. Rarefaction curves indicated that species richness was greater in fyke net catches than in those of seines at all abundances (Figure 1.3). However, species richness of catches was nearly the same for both gears after 500 individuals were captured.

Age-0 fish composed 60% (20,895 fish) of the fyke net catch as opposed to only 14% (1,866 fish) of the seine catch. Catch-per-unit-effort of adults was similar for fyke net (mean CPUE = 78.7 fish/net night; SE = 13.8) and seine catches (mean CPUE = 58.4 fish/100 m; SE = 8.2; $P = 0.07$). However, adult species richness of fyke net catches (mean = 3.7 species/net night; SE = 0.2) was greater than that of seines (mean = 2.7 species/100 m; SE = 0.2; $P < 0.01$). Fyke net sets captured six unique species (bluegill, brook stickleback, burbot, sicklefin chub, white crappie, and Yellowstone cutthroat trout) of adult fish. Seines captured one unique species (freshwater drum). Zero catches of adult fish occurred in only 6% of the fyke net sets compared to 16% of the seine hauls.

Adult fyke net CPUE declined significantly ($r^2 = 0.04$; $P = 0.03$) as the sampling season progressed (Figure 1.4) whereas the CPUE of adults in seines remained constant (Figure 1.5). The CPUE and relative abundance of age-0 fish in fyke nets increased as the sampling season progressed (Figure 1.6). The CPUE of age-0 fish increased, but not significantly, throughout the sampling season (Figure 1.7). However, the relative abundance of age-0 fish in seine catches increased later in the season (Figure 1.7).

Otter trawl catch varied both temporally and spatially. Mean otter trawl catch nearly doubled from the beginning to the end of the 2008 sampling season (Figure 1.8). *Macrhybopsis* spp. were captured in 6 of the 12 reaches sampled with otter trawls downstream of the Tongue River in 2008. In reaches where they were detected, at least one individual was captured in 61% of trawl tows. Over 98% of *Macrhybopsis* spp. were captured in main channel habitats (i.e., channel crossover, inside bend, and outside bend).

The expected species richness at the four gear efficiency test reaches sampled with 20 fyke nets in 2010 ranged from 11.7 to 21.7 species (Figure 1.9). Based on the accumulation curves, we estimated that three fyke nets were needed within each macrohabitat in each reach to capture at least 90% of the expected species in each reach using 20 fyke nets. Four fyke nets in each macrohabitat were needed to capture at least 95% of the species. Based on the regression models (Figure 1.9), the range of seine hauls needed to capture 90% of the observed species in the four reaches was from about 21 (Reach 3) to 8,400 (Reach 2). Seining did not result in the capture of any unique species in any of these reaches.

No significant differences existed between mean catches of emerald shiners ($P = 0.51$), flathead chubs ($P = 0.42$), longnose dace ($P = 0.68$), sand shiners ($P = 0.71$), and western silvery minnows ($P = 0.07$) calculated using two and three fyke net catches in each macrohabitat (Table 1.5). Species ranks for these species were the same for both sampling efforts.

Discussion

Fyke nets captured more individual fish and more species of fish and were therefore more effective than seines at characterizing shoreline fish assemblages of the Yellowstone River. Woody debris and other large substrates are common in the Yellowstone River because it maintains much of its natural flow regime (and therefore recruits debris during spring runoff). These snags make seining difficult in many habitats where fyke nets can be easily deployed. Moreover, water depths and velocities are often too great in outside bends, which make seining ineffective and unsafe. Silt in many backwater habitats made seining difficult and ineffective; backwaters are often the most productive areas of lotic environments and serve as nursery areas for many fishes (Junk et al. 1989; Sheaffer and Nickum 1986).

Fyke net and seine catches varied temporally because of behavioral changes by certain species and differing rates of recruitment of juveniles to each gear. Low catch rates of adults in fyke nets later in the season may have been a result of cold water temperatures, which affects the vulnerability of warmwater species to passive sampling gears (Hubert 1996; Pope et al. 2009). Conversely, adult catch rates in seines were relatively consistent throughout the entire sampling season. Seines had larger mesh than fyke nets, which reduced the efficiency of seines to capture age-0 fish. Age-0 fyke net catch increased about two months after peak spring runoff as these fish grew large enough to be recruited to the gear. Limiting sampling to short time periods or temporally and spatially stratifying effort will help to limit biases associated with the proportional changes in the catches of adults and juveniles during the year.

Three fyke net sets are needed in each macrohabitat to capture at least 90% of the expected species and four net sets are needed to capture 95%. Two sets are enough to characterize the dominant species (i.e., western silvery minnow, flathead chub, emerald shiner, longnose dace, and sand shiner) at the reach scale, but at least three nets are needed to detect rare species. Low effort is adequate if relative abundances are the primary concern (Angermeier and Smogor 1995). However, limiting sampling effort to two fyke net sets in each macrohabitat can increase the number of reaches sampled, which will increase the number of vulnerable individuals, and thus compensate for the decreased effort within a sampling reach (Bayley and Peterson 2001). However, close attention should be paid to selecting sampling reaches in proportion to their availability (Paller 1995), especially if strong habitat preference is likely or the sampling area is patchy.

Fyke nets and seines have different logistical and financial constraints for sampling the Yellowstone River fish assemblage. Active gears such as seines require only a single trip to a sampling location. Conversely, two trips must be made when fyke nets are used unless crews remain at the sampling location overnight, which results in less efficient use of personnel. However, three crew members are needed to efficiently and safely sample using seines whereas only two are needed to deploy fyke nets. Variability in sampling efficiency because of differences in gear deployment among personnel is less for fyke nets than seines, which probably results in more reliable sampling with fyke nets than with seines. Passive gears are also better than active gears at capturing mobile fish such as minnows (Weaver et al. 1993; Fago 1998). Although the initial monetary investment is higher for fyke nets than seines, the efficiency and reliability of fyke nets warrants their use.

Benthic trawls are the only viable option available for sampling small-bodied benthic fishes in the main channels of large rivers. Sampling during baseflow, rather than spring runoff, allowed better detection of potential snags and increased boat maneuverability, which contributed to higher catch rates. This approach helped to increase detection in subsequent sampling efforts and thus better identify the distribution of *Macrhybopsis* spp. in the lower Yellowstone River (Chapter 2). Faster water velocities, shallower water, and shorter reach lengths limited trawling upstream of Huntley Diversion Dam. However, the primary objective of otter trawling was to determine the distribution, abundance, and habitat use of sicklefin chubs and sturgeon chubs. Although sturgeon chubs were historically found upstream of the Bighorn River, they are currently thought to be restricted to the Yellowstone River below the Tongue River (USFWS 2001; Chapter 2). Sicklefin chub distribution is limited to reaches downstream of the Powder River (USFWS 2001; Chapter 2). Therefore, otter trawl sampling upstream of Cartersville Diversion Dam is probably unnecessary unless conservation efforts restore sturgeon chubs to their historic range. Sampling secondary and seasonal secondary channels with otter trawls is also unnecessary as both species tend to occupy only main channel habitats.

The relatively large mesh sizes of our otter trawls probably contributed to low catch rates of *Macrhybopsis* spp. Several trawl designs have recently been evaluated for sampling benthic fishes (Dettmers et al. 2001; Herzog et al. 2005; Drobish 2008; Herzog et al. 2009). Small meshed trawls (e.g., the mini-Missouri trawl; Herzog et al. 2009) should be tested on sicklefin chubs and sturgeon chubs in the Yellowstone River; such trawls may provide more accurate abundance estimates and more precisely identify upstream ranges of these species in the river than the trawls we used.

We recommend using fyke nets throughout the entire river and otter trawls downstream of Cartersville Diversion Dam for future monitoring efforts. Two fyke net sets in each macrohabitat should be enough to characterize the structure of the Yellowstone River shoreline fish assemblage in a reach and monitor long-term changes in the distribution and abundance of dominant species. However, greater sampling effort (i.e., three or four subsamples in each macrohabitat) is needed to more accurately quantify the distribution and abundance of rare species.

Table 1.1. Total numbers of individuals captured (TC), numbers of observations with at least one individual captured (*O*), and mean total lengths of individuals captured (TL; mm; ± SE) in a subset of fyke nets and seines deployed in the lower Yellowstone River in 2008 and 2009. Total catches and TL were pooled across reaches and sampling events.

Family/Species	Fyke net			Seine		
	TC	*O*	TL[a]	TC	*O*	TL[a]
Catostomidae						
River carpsucker *Carpiodes carpio*	694	52	140.5 ± 14.6	87	24	76.7 ± 5.5
Longnose sucker *Catostomus catostomus*	621	44	64.5 ± 4.0	106	25	75.6 ± 3.5
White sucker *Catostomus commersonii*	412	44	68.2 ± 9.6	172	24	81.6 ± 5.6
Shorthead redhorse *Moxostoma macrolepidotum*	219	41	93.2 ± 18.2	142	34	78.2 ± 4.0
Smallmouth buffalo *Ictiobus cyprinellus*	61	4	34.5 ± 0.5	17	8	142.2 ± 104.5
Mountain sucker *Catostomus platyrhynchus*	6	2	168.3 ± 9.8	1	1	83.5 ± 11.5
Bigmouth buffalo *Ictiobus cyprinellus*	1	1	27	0	0	--
Unidentified catostomids	8	2		5	1	
Centrarchidae						
Smallmouth bass *Micropterus dolomieu*	47	20	108.6 ± 15.3	36	16	122.7 ± 15.6
White crappie *Pomoxis annularis*	43	15	102.0 ± 8.6	8	3	62.9 ± 4.3
Green sunfish *Lepomis cyanellus*	35	19	54.5 ± 4.5	13	7	56.8 ± 6.3
Black crappie *Pomoxis nigromaculatus*	26	13	73.6 ± 13.0	9	3	70.3 ± 8.1
Pumpkinseed *Lepomis gibbosus*	14	7	69.9 ± 16.9	14	3	68.5 ± 5.3
Bluegill *Lepomis macrochirus*	12	8	52.5 ± 1.5	0	0	--
Largemouth bass *Micropterus salmoides*	2	2	33.0	2	2	64.5 ± 5.5
Cyprinidae						
Western silvery minnow *Hybognathus argyritis*	12,275	128	71.2 ± 0.5	6,130	111	77.9 ± 0.5
Flathead chub *Platygobio gracilis*	9,410	115	75.9 ± 1.4	2,049	100	80.1 ± 0.9
Emerald shiner *Notropis atherinoides*	5,355	106	65.9 ± 0.5	4,235	120	78.4 ± 0.3
Longnose dace *Rhinichthys cataractae*	1,961	89	40.1 ± 0.5	20	8	63.3 ± 3.9

[a] SE not reported for TL when only one fish was measured.

Table 1.1. Continued.

Sand shiner *Notropis stramineus*	1,580	78	43.8 ± 0.3	161	37	51.9 ± 0.6
Fathead minnow *Pimephales promelas*	809	57	44.1 ± 0.5	23	5	49.4 ± 1.2
Common carp *Cyprinus carpio*	37	19	84.6 ± 20.2	51	19	165.9 ± 35.7
Sturgeon chub *Macrhybopsis gelida*	23	7	36.8 ± 3.2	21	8	45.4 ± 2.6
Creek chub *Semotilus atromaculatus*	7	5	53.8 ± 2.0	8	5	49.4 ± 1.7
Sicklefin chub *Macrhybopsis meeki*	2	2	67.0 ± 39.0	0	0	--
Lake chub *Couesius plumbeus*	1	1	--	0	0	--
Plains minnow *Hybognathus placitus*	1	1	46.0	0	0	--
Unidentified cyprinids	482	4		1	0	
Cyprinodontidae						
Northern plains killifish *Fundulus kansae*	7	6	50.2 ± 1.0	4	1	58.0 ± 1.9
Gasterosteidae						
Brook stickleback *Culaea inconstans*	20	8	37.5 ± 2.5	0	0	--
Hiodontidae						
Goldeye *Hiodon alosoides*	35	10	228.5 ± 23.5	43	14	108.4 ± 14.9
Ictaluridae						
Stonecat *Noturus flavus*	187	60	144.2 ± 4.4	10	6	94.3 ± 22.4
Channel catfish *Ictalurus punctatus*	170	42	158.0 ± 29.2	128	28	294.4 ± 32.5
Black bullhead *Ameiurus melas*	9	8	165.3 ± 22.4	3	1	610.0
Lotidae						
Burbot *Lota lota*	3	3	472.0 ± 48.0	0	0	--
Percidae						
Sauger *Sander canadensis*	19	12	296.0 ± 18.1	21	13	245.0 ± 20.4

[a] SE not reported for TL when only one fish was measured.

Table 1.1. Continued.

Salmonidae						
Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri*	1	1	59.0	0	0	--
Sciaenidae						
Freshwater drum *Aplodinotus grunniens*	0	0	--	1	1	380.0

[a] SE not reported for TL when only one fish was measured.

Table 1.2. Mean substrate scores, depths (m), and velocities (m/s) at a subset of 174 fyke net and seine sample locations in the lower Yellowstone River in 2008 and 2009. Substrates were categorized as silt, sand, gravel, pebble, cobble, boulder, or bedrock and given numerical values ranging from one to seven, respectively. Standard deviations are presented in parentheses.

	Substrate	Depth	Velocity
Fyke net	3.7 (1.3)	0.38 (0.18)	0.23 (0.19)
Seine	3.9 (1.2)	0.39 (0.19)	0.22 (0.19)

Table 1.3. Mean CPUE, species richness, diversity (*H'*), and evenness (*J'*) of fish captured in a subset of 174 fyke nets and seines deployed in the lower Yellowstone River in 2008 and 2009. Standard errors are shown in parentheses.

	CPUE	Species richness	*H'*	*J'*
Fyke net	199 (34.4)	6.0 (0.2)	1.05 (0.04)	0.63 (0.02)
Seine	77 (9.2)	4.6 (0.3)	0.65 (0.04)	0.56 (0.03)

Table 1.4. Mean species richness and CPUE of fish captured in a subset of fyke nets and seines deployed in the lower Yellowstone River in 2008 and 2009 among macrohabitats. Mean CPUE was greater for fyke nets than seines in inside bends (P < 0.01) and secondary channels (P = 0.03). Mean species richness of fyke net catches was greater than that of seines in every macrohabitat (P < 0.01 for all macrohabitats). Standard errors are shown in parentheses.

	CPUE			Richness		
Macrohabitat	Fyke net	Seine	*P*	Fyke net	Seine	*P*
Inside ($n = 64$)	283.8 (76.8)	85.1 (19.2)	< 0.01	5.6 (0.3)	3.8 (0.3)	< 0.01
Secondary ($n = 21$)	218.4 (78.5)	55.4 (12.6)	0.03	6.5 (0.6)	3.9 (0.6)	< 0.01
Outside ($n = 12$)	150.6 (54.3)	77.0 (38.4)	0.09	6.2 (0.8)	3.2 (0.7)	< 0.01
Seasonal ($n = 34$)	134.4 (47.9)	87.8 (17.3)	0.18	6.6 (0.5)	3.6 (0.4)	< 0.01
Crossover ($n = 43$)	127.1 (54.3)	69.9 (17.0)	0.14	5.7 (0.4)	3.1 (0.4)	< 0.01

Table 1.5. Mean reach CPUE of dominant species captured in the lower Yellowstone River from 2008 to 2010 using two and three fyke net sets in each macrohabitat.

	Emerald shiner	Flathead chub	Longnose dace	Sand shiner	Western silvery minnow
Two fyke nets	39.0	3.5	4.0	6.4	23.4
Three fyke nets	36.2	3.3	4.1	6.1	20.1

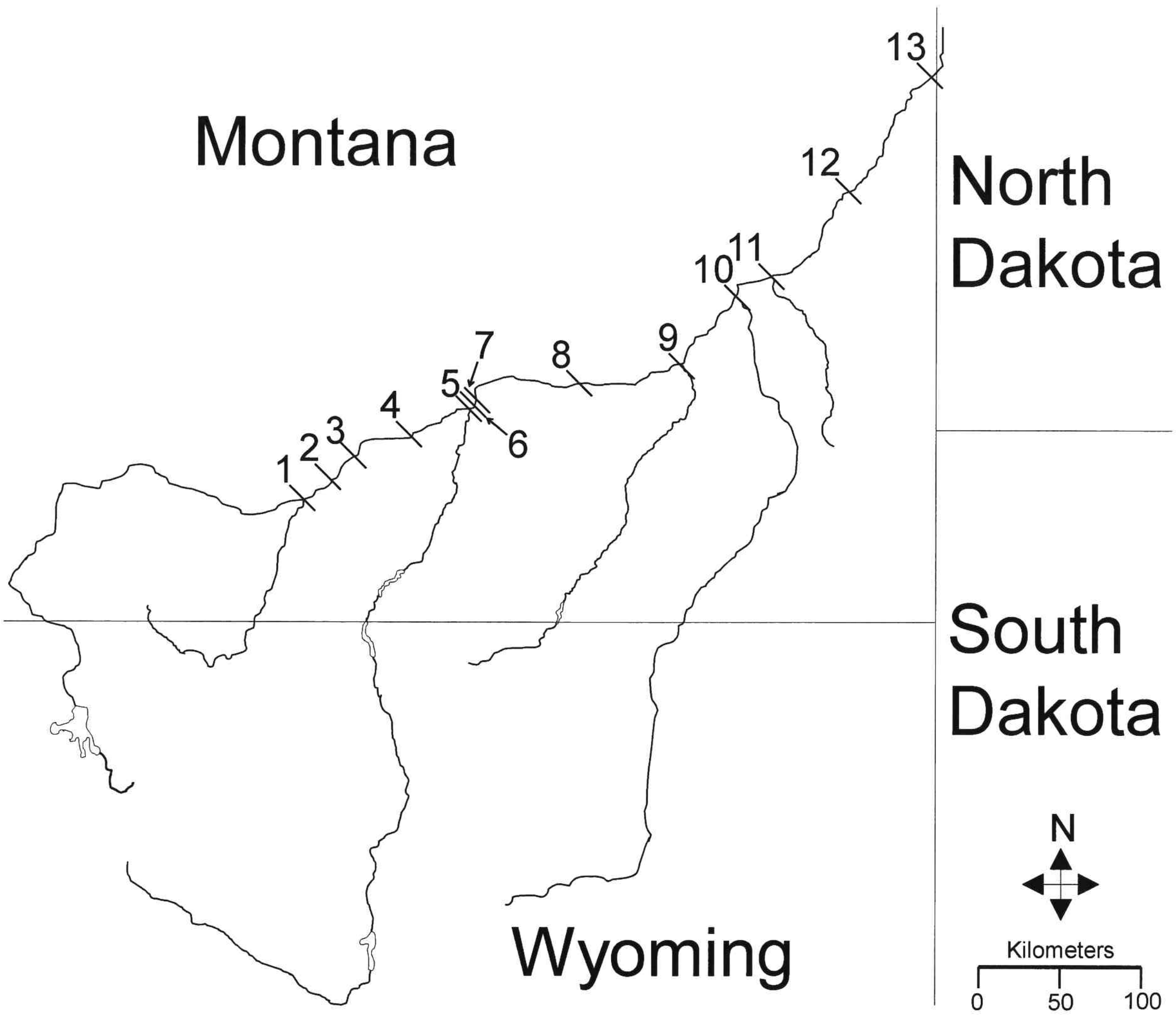

Figure 1.1. Yellowstone River Basin. Bars and numbers delineate upstream end of river segments: 1–Clarks Fork (river kilometer [RKM] 617); 2–Billings (RKM 589), 3–Huntley Diversion Dam (RKM 572), 4–Waco Diversion Dam (RKM 515), 5–Bighorn River (RKM 480), 6–Rancher Diversion Dam (RKM 476), 7–Meyers Diversion Dam (RKM 454), 8–Cartersville Diversion Dam (RKM 384), 9–Tongue River (RKM 297), 10–Powder River (RKM 240), 11–O'Fallon Creek (RKM 207), 12–Intake Diversion Dam (RKM 117), and 13–Sidney (RKM 49).

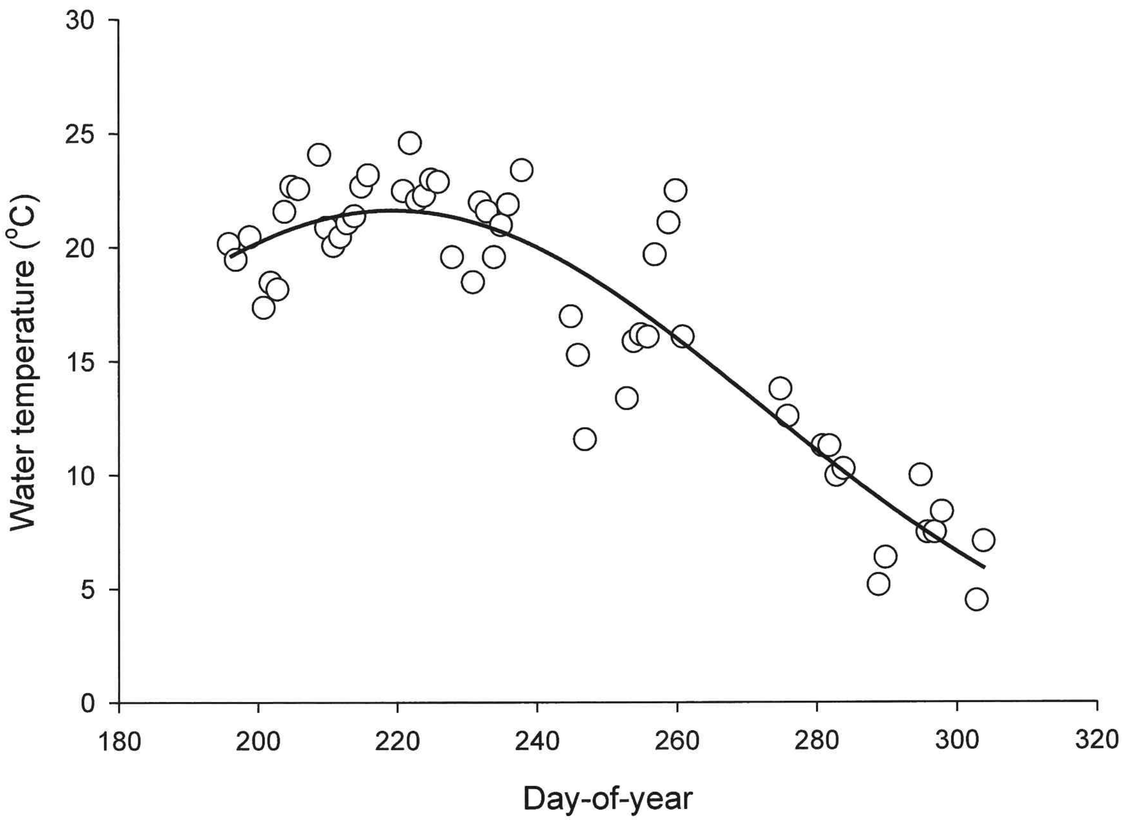

Figure 1.2. Water temperature as a function of day-of-year ($r^2 = 0.84$; $P < 0.01$).

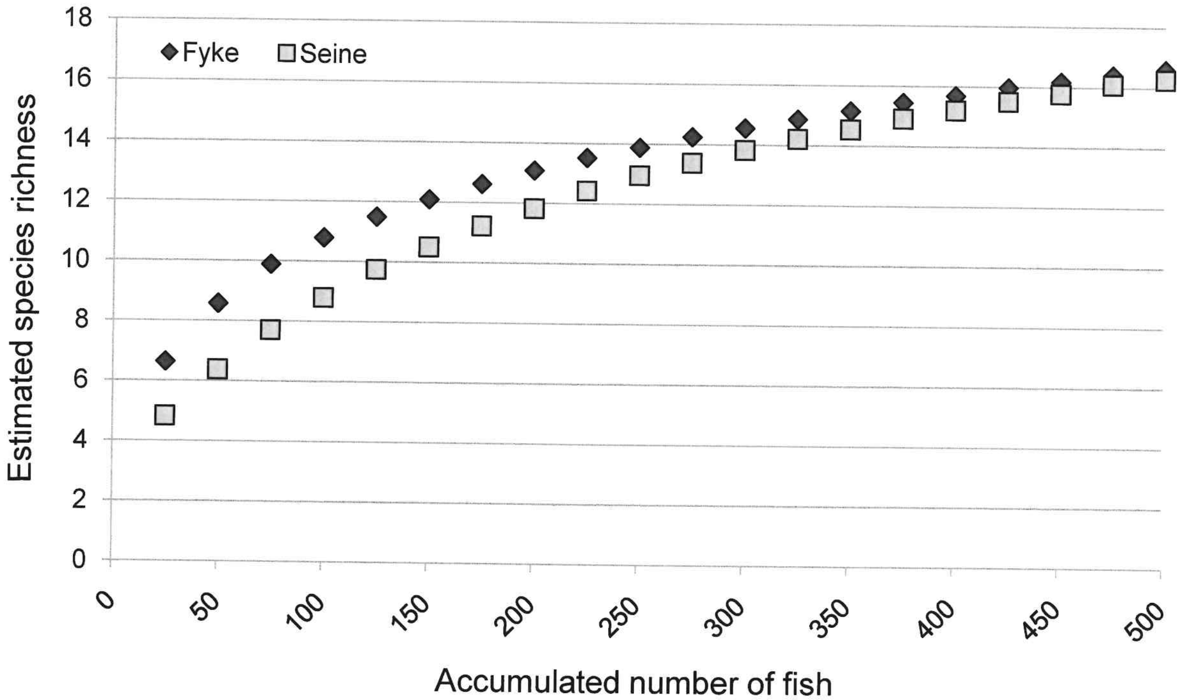

Figure 1.3. Rarefaction curves for fyke net and seine samples of the lower Yellowstone River fish assemblage in 2008 and 2009 (10,000 iterations).

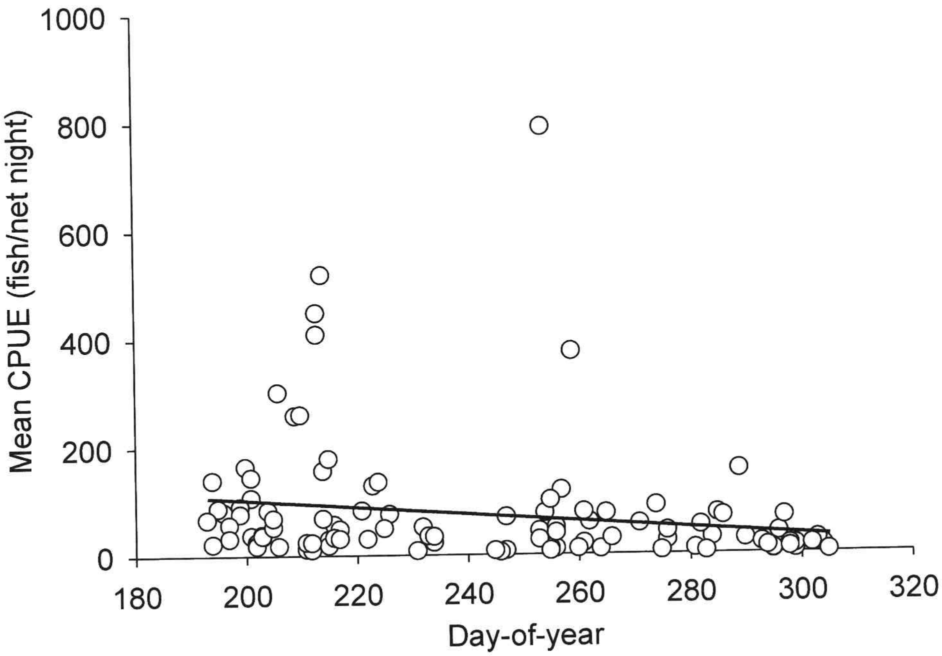

Figure 1.4. Adult fyke net CPUE as a function of day-of-year ($r^2 = 0.04$; $P = 0.03$).

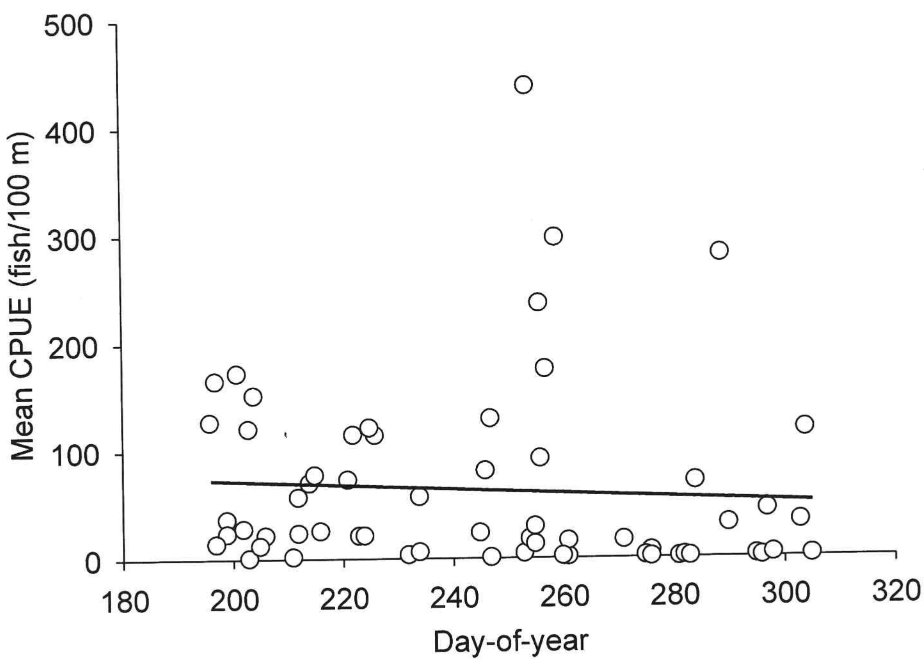

Figure 1.5. Adult seine CPUE as a function of day-of-year ($r^2 = 0.08$; $P = 0.55$).

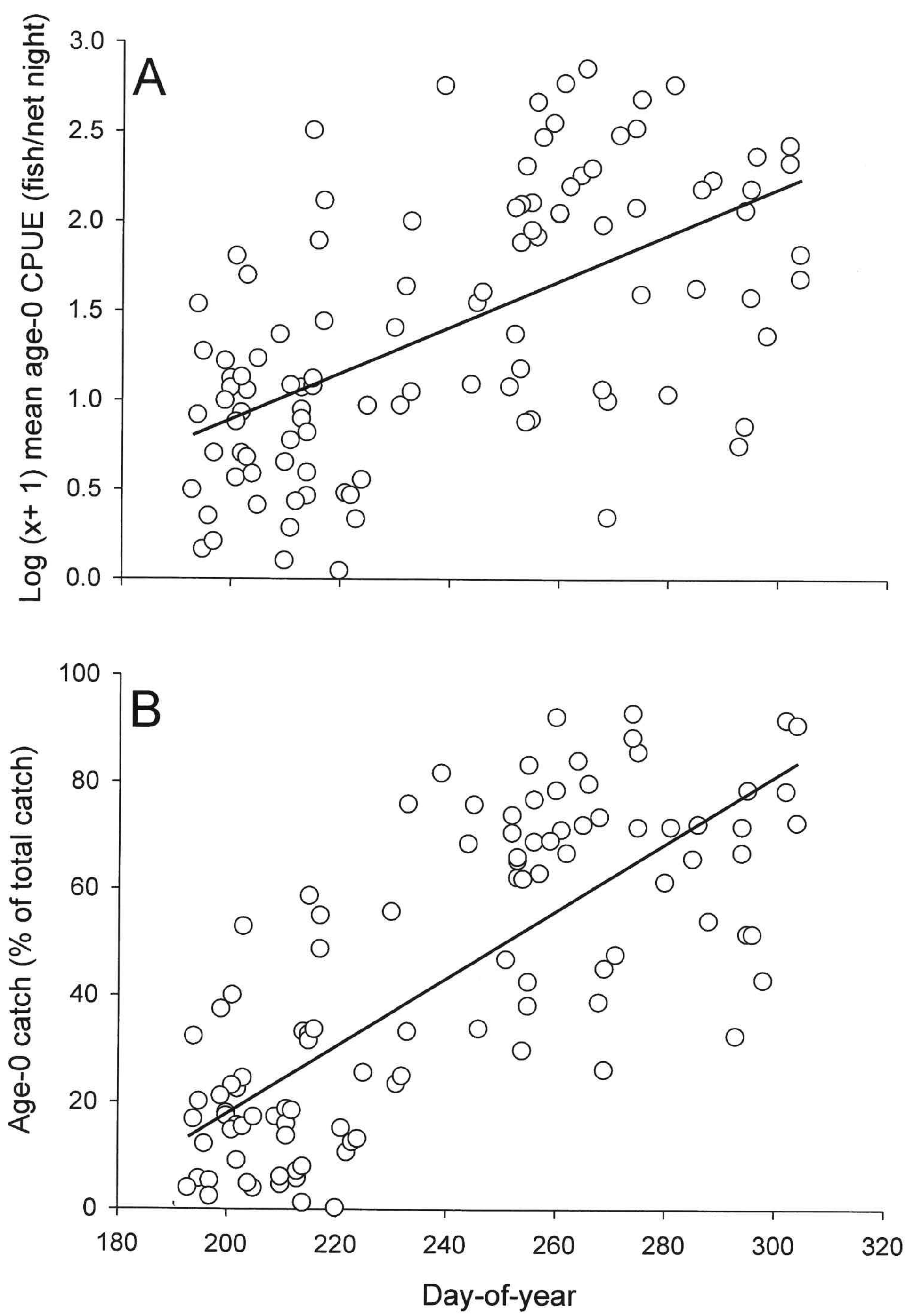

Figure 1.6. Age-0 (A) CPUE ($r^2 = 0.34$; $P < 0.01$) and (B) percent of total fyke net catch ($r^2 = 0.58$; $P < 0.01$) as a function of day-of-year.

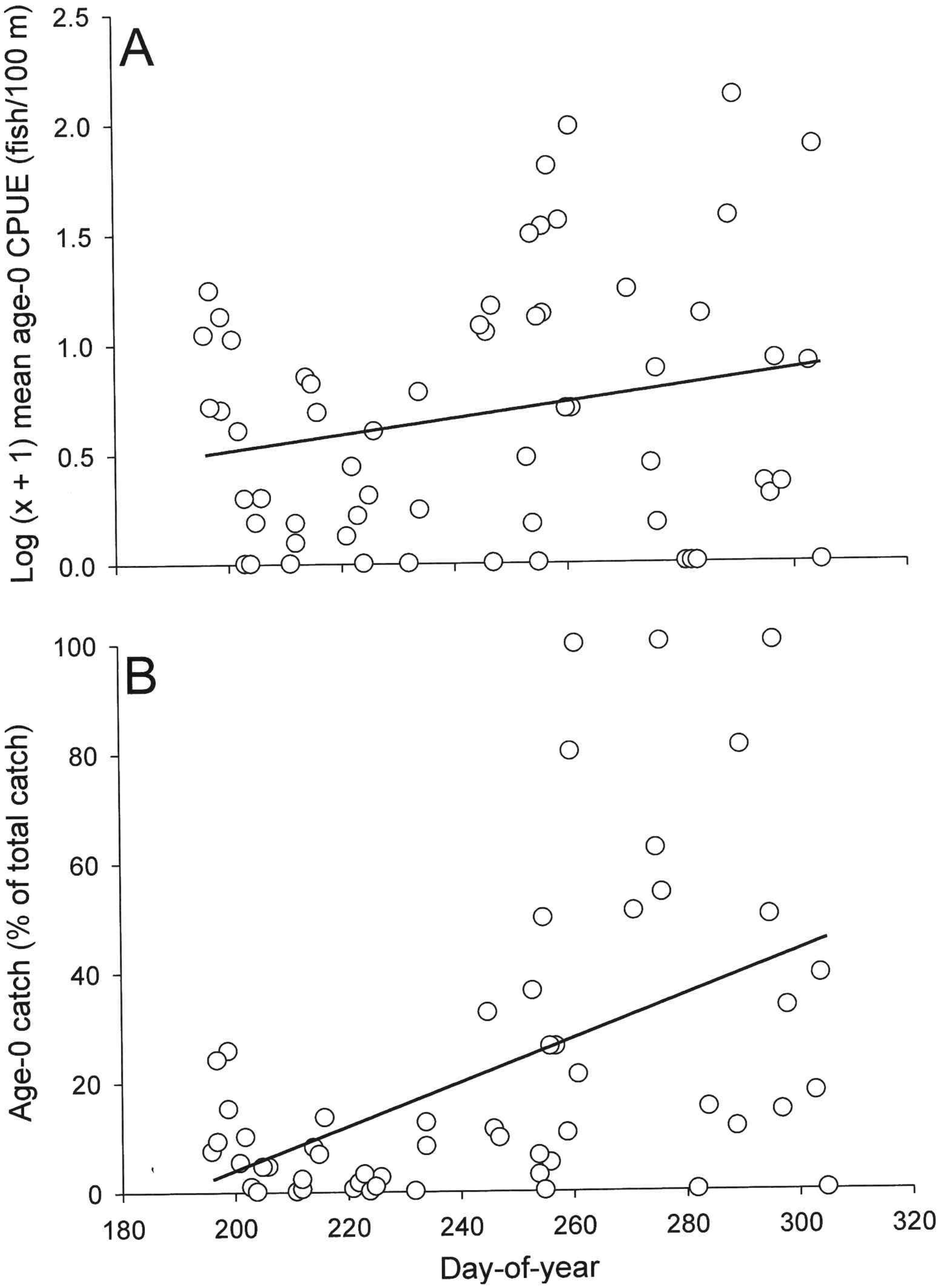

Figure 1.7. Age-0 (A) CPUE ($r^2 = 0.21$; $P = 0.10$) and (B) proportion of total seine catch ($r^2 = 0.49$; $P < 0.01$) as a function of day-of-year.

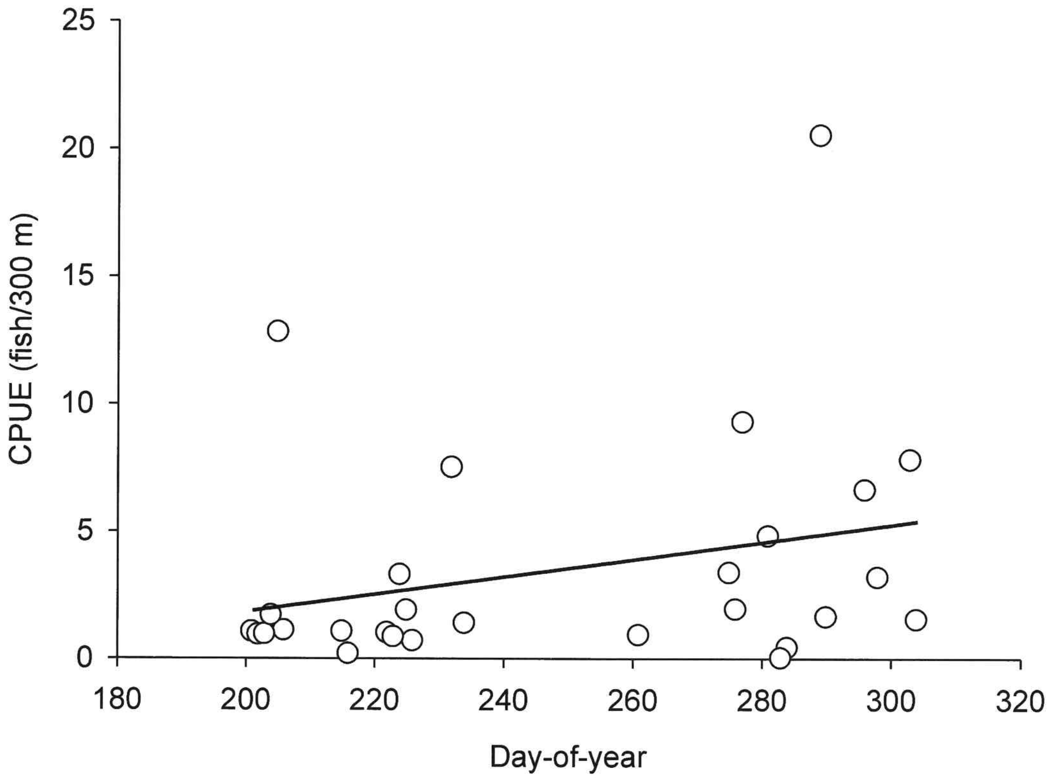

Figure 1.8. Otter trawl CPUE as a function of day-of-year ($r^2 = 0.08$; $P = 0.15$).

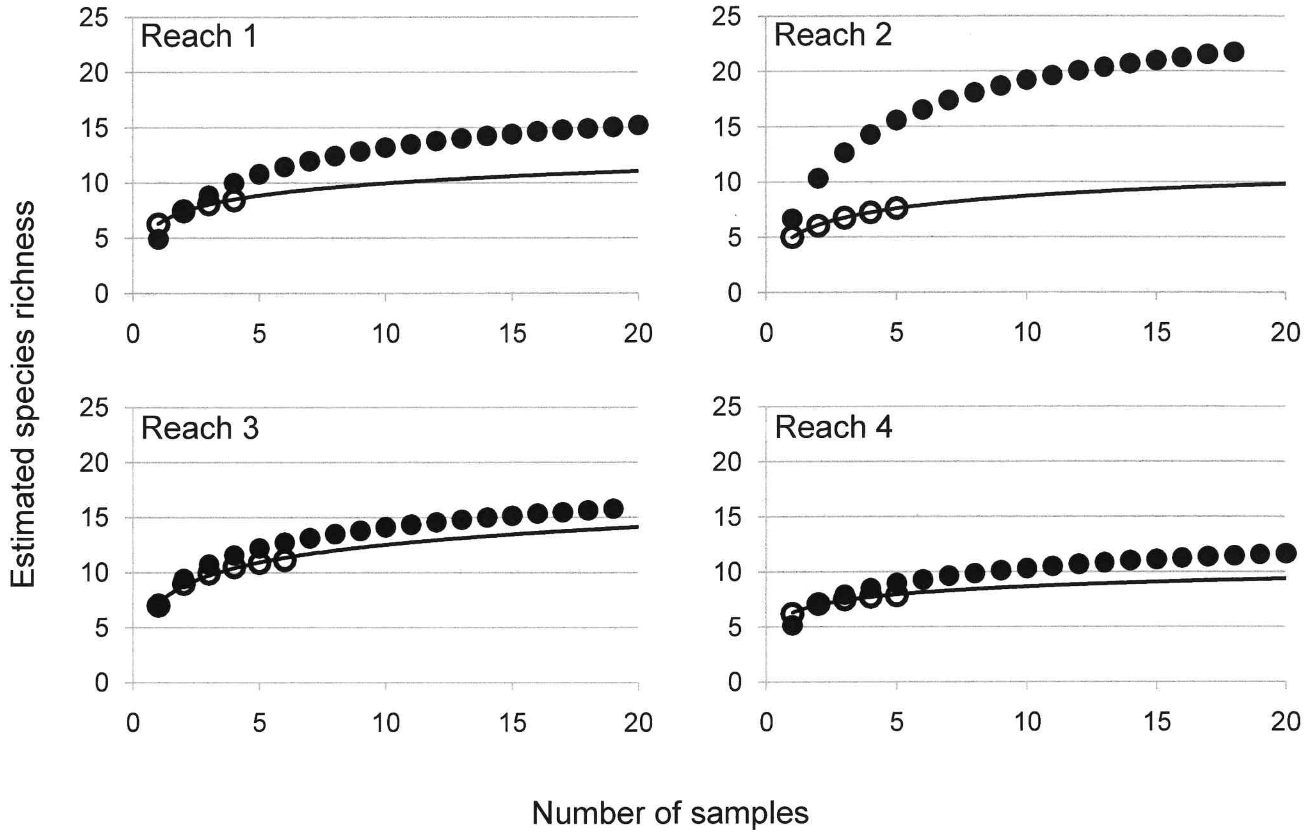

Figure 1.9. Species accumulation curves for samples collected with fyke nets (black) and seines (white) at four lower Yellowstone River reaches in 2010 (10,000 iterations). Regression lines estimate species accumulation with increased seine effort.

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Distribution and Habitat Use of Small Nongame Fishes in the Lower Yellowstone River

Introduction

Most large rivers in the United States have been altered by humans (Dynesius and Nilsson 1994; Nilsson et al. 2005). These modifications have inundated river channels (Junk et al. 1989), altered flow (Poff et al. 1997) and thermal regimes (Ward and Stanford 1983), disconnected floodplains (Junk et al. 1989; Galat et al. 1998; Tockner and Stanford 2002), decreased channel migration (Ligon et al. 1995), changed turbidity (Ward and Stanford 1983), and increased habitat fragmentation (Dynesius and Nilsson 1994; Nilsson et al. 2005) leading to the decline of many large river fishes. The Missouri River Basin supports about 176 species of fish (Cross et al. 1986) with almost half of those being considered large river fish (Galat et al. 2005). Much of the information on these species is from altered systems (e.g., Missouri River); thereby precluding a comprehensive understanding of fish assemblages relatively unaffected by human disturbance.

The Yellowstone River is the longest undammed river in the conterminous United States (Benke 1990). Although several lowhead diversion dams span the Yellowstone River and several of its tributaries are impounded, the main-stem river maintains much of its natural flow regime (*sensu* Poff et al. 1997). In addition to its free flowing state, the river supports at least 37 native fish species representing 12 families (White and Bramblett 1993). Some of these are imperiled in several states (Galat et al. 2005). The Yellowstone River includes a transition zone between a clear, coldwater environment and a turbid, warmwater river as well as a shift from cobble to sand substrate (White and Bramblett 1993). This combination of factors provides a unique model of the natural structure and function of large-river fish assemblages.

Small nongame fish are prey for both aquatic and terrestrial predators (Lagler 1943; Korschgen 1958; Melquist and Hornocker 1983; Bur et al. 2008), influence nutrient cycling in aquatic environments (Stewart 1987; Haag and Warren 1997), and are hosts for the glochidia of many freshwater mussels (Zale and Neves 1982; Haag and Warren 1997). Yet, little is known about most small nongame fishes in the Yellowstone River as studies have been limited to a select few species in reaches primarily downstream of Intake Diversion Dam (Pegg and Pierce 2002; Dieterman and Galat 2004; Everett et al. 2004; Welker and Scarnecchia 2004; Welker and Scarnecchia 2006). Two species in the Yellowstone River are of particular concern: the sicklefin chub *Macrhybopsis meeki* and sturgeon chub *Macrhybopsis gelida*. These large-river fishes are restricted to the Missouri River and its major tributaries and serve as prey for pallid sturgeon *Scaphirhynchus albus* (Gerrity et al. 2006). Damming has caused range reductions and decreased abundances of both species (Hesse and Wallace 1976; Pflieger and Grace 1987; Kelsch 1994; Haslouer et al. 2005; Hoagstrom et al. 2006b), which have led to their listing as globally vulnerable species (Galat et al. 2005). Other nongame species experiencing declining abundances or distributions (Jones 1963; Hesse and Wallace 1976; Pflieger and Grace 1987; Peters et al. 1989; Hesse et al. 1993; Patton et al. 1998; Harland and Berry 2004; Haslouer et al. 2005; Kral and Berry 2005; Hoagstrom et al. 2006a; Hoagstrom et al. 2006b; Hoagstrom et al. 2007) and that are thought to inhabit the Yellowstone River include flathead chub *Platygobio gracilis* and western silvery minnow *Hybognathus argyritis* (White and Bramblett 1993). Understanding the ecology of these species in the naturally-functioning Yellowstone River may help provide information needed to develop conservation strategies elsewhere.

Our objectives were to 1) determine which small nongame fishes were abundant, common, or rare in the lower Yellowstone River, 2) determine the longitudinal distribution of these species, 3) determine what habitat types these species used, and 4) determine whether diversion dams fragmented lower Yellowstone River fish populations.

Methods

Fish sampling.—Fyke net sampling occurred in the Yellowstone River between the confluences of the Clarks Fork and Missouri rivers (Table 2.1; Figure 2.1) from 2008 to 2010 using the standard fyke net sampling methodology described in Chapter 1. Maximum (i.e., peak) and mean daily discharges were greater for each sampling year than the 10- (2001-2010) and 30-year (1981-2010) averages (Table 2.2; Figure 2.2; USGS gauge 06295000 near Forsyth, Montana). Minimum daily discharges (i.e., baseflow) were also greater in 2008 and 2010 than the 10- and 30-year averages. However, minimum daily discharge was less in 2009 than the 10- and 30-year averages. Our trawl sampling in 2008 indicated that sicklefin chubs and sturgeon chubs were restricted to main channel habitats in the Yellowstone River below the Tongue River (Chapter 1). Therefore, otter trawl sampling in 2009 and 2010 was limited to those habitats using the methodologies described in Chapter 1 (Table 2.3). Main channel habitats were defined as areas in and adjacent to the thalweg. Three depth and velocity measurements (beginning, midpoint, and end) were recorded 0.3 m above the bottom with a Marsh-McBirney Flo-Mate portable current meter for each trawl, and a mean was calculated.

Fish processing.—Fish were processed using the methods described in Chapter 1.

Data analysis.—Length frequency histograms from this study and other age and growth reports (Auer 1982; Wallus et al. 1990; Kay et al. 1994; U.S. Fish and Wildlife Service [USFWS] 2001; Herzog 2004; Dattilo et al. 2008a; Dattilo et al. 2008b; Herman et al. 2008a; Herman et al. 2008b) were used to classify fish as either age-0 (juveniles) or age-1 and older (adults). Only adults were included in our analysis. Limiting analysis to adult fish presents a more accurate representation of species abundances and distributions by eliminating variability caused by inconsistent spatial and temporal abundances of juvenile fish that have not yet recruited to the adult population.

A Kruskal-Wallis test was used to test for differences in adult fyke net catch-per-unit-effort (CPUE; by ranks) among years, segments, pool types, and macrohabitats of fishes in aggregate, species with relative abundances greater than 5% of the total catch, and species of conservation priority (flathead chub and pallid sturgeon). Post hoc pairwise comparisons between pool types or macrohabitats were performed using the Mann-Whitney (Wilcoxon) rank sum test when the Kruskal-Wallis test identified significant differences ($P < 0.05$) among habitat medians. Longitudinal discontinuities in assemblage structure between segments were assessed using the percent similarity index (Kwak and Peterson 2007). Mann-Whitney rank sum tests were also used to assess differences between areas where pallid sturgeon were or were not detected. Contour plots were used to assess longitudinal and habitat (i.e., water velocity and depth) trends in CPUE for selected species. A nearest neighbor smoothing function was used for interpolation. Figure 2.3 shows the water velocities of all fyke net sets, which were used to develop the contour plots.

Results

Fyke net catch.—Fyke nets captured adults of 42 species (24 native and 18 nonnative) representing 12 families (Table 2.4). Native species composed 99% of the total adult catch. Cyprinids were the most speciose family (12 native and 3 nonnative species) and represented 97% of the catch. Six catostomid species, all of which are native, were captured and composed 1% of the catch. Seven centrarchid species, all of which are nonnative, were captured and composed 1% of the catch.

Adult CPUE differed among years ($\chi^2 = 7.2$, df = 2, $P = 0.03$; Figure 2.4) with catch rates increasing from 2008 to 2009 ($P = 0.01$). However, CPUE was not different in 2009 and 2010 ($P = 0.23$). Adult CPUE differed among segments ($\chi^2 = 25.9$, df = 12, $P = 0.01$; Figure 2.5). Catch rates were high from the O'Fallon Creek to Sidney (segments 11 and 12) and declined both upstream and downstream. Pool type ($\chi^2 = 3.7$, df = 4, $P = 0.44$; Figure 2.6) or macrohabitat ($\chi^2 = 3.5$, df = 4, $P = 0.48$; Figure 2.7) had no effect on total adult CPUE.

Species richness was low in segments 1, 8 and 13 and increased immediately downstream of the Bighorn and Powder rivers (Figure 2.8). Three longitudinal discontinuities were observed in assemblage structure (Figure 2.9). The greatest difference in assemblage structure of adjacent sampling segments occurred between segments 1 and 2. Other discontinuities occurred between segments 5 and 6 and segments 11 and 12.

Emerald shiner, western silvery minnow, sand shiner, longnose dace, and flathead chub, were the five most abundant species, respectively (Table 2.4). These species represented 94% of the total catch, and were captured in every segment (Table 2.5; Figure 2.10). Emerald shiners composed 47% of the total catch and at least 25% of the catch in segments 7 to 13, but were most abundant in segments 11 and 12. Fyke net sets that captured at least 100 emerald shiners (6% of the sets deployed) accounted for 79% of total adult emerald shiner catch. In the seven sets that each captured more than 1,000 emerald shiners, emerald shiner total catch was 13,841. Although emerald shiner CPUE was similar among pool types ($\chi^2 = 6.0$, df = 4, $P = 0.20$; Table 2.6; Figure 2.11) and macrohabitats ($\chi^2 = 2.1$, df = 4, $P = 0.72$; Table 2.7; Figure 2.12), abundance was highest in water velocities from 0.3 to 0.6 m/s (Figure 2.13).

Western silvery minnows occupied the entire study area and were abundant in some reaches, but no trends in their CPUE existed among segments (Table 2.5; Figure 2.10). Nets that captured at least 100 western silvery minnows (4% of nets) accounted for 78% of the total catch of the species. Western silvery minnow CPUE was similar among pool types ($\chi^2 = 4.0$, df = 4, $P = 0.40$; Table 2.6; Figure 2.11) and macrohabitats ($\chi^2 = 4.7$, df = 4, $P = 0.32$; Table 2.7; Figure 2.12). However, the CPUE of western silvery minnows was generally high in water velocities less than 2.0 m/s (Figure 2.14).

Sand shiners were captured throughout the study area but did not account for more than 25% of the catch in any sampling reach (Table 2.5; Figure 2.10). Sets that captured at least 100 sand shiners (1% of nets) accounted for 51% of the total catch of the species. Sand shiner CPUE was greater in bluff and terrace pools than in other pool types ($\chi^2 = 16.7147$, df = 4, $P < 0.01$; Tables 2.6 and 2.8; Figure 2.11) but was similar among macrohabitats ($\chi^2 = 5.0629$, df = 4, $P = 0.28$; Table 2.7; Figure 2.12). Sand shiner CPUE was greatest in slow water habitats (Figure 2.15).

Longnose dace CPUE was greatest in water velocities faster than 1.0 m/s (Figure 2.16) in segments 1 through 6 (Table 2.5). Nets that captured at least 100 longnose dace (< 1% of nets) accounted for 18% of the total catch of the species. Longnose dace CPUE was similar among pool types ($\chi^2 = 2.5$, df = 4, $P = 0.64$; Table 2.6; Figure 2.11), but different among macrohabitats ($\chi^2 = 9.3$, df = 4, $P = 0.05$; Tables 2.7 and 2.9; Figure 2.12).

Flathead chubs were detected in nearly every reach in low abundances (Figure 2.10); more than 100 adults occurred in only two net sets. Catch rates were higher between O'Fallon Creek and Sidney, Montana (segments 11 and 12), than in most upstream reaches (Table 2.5; Figure 2.10). Flathead chub CPUE was greater in bluff and terrace pools than in other pool types ($\chi^2 = 13.1$, df = 4, $P = 0.01$; Tables 2.6 and 2.8; Figure 2.11) but similar among macrohabitats (χ^2

= 4.1, df = 4, $P = 0.40$; Table 2.7; Figure 2.12) and most water velocities below 0.8 m/s (Figure 2.17).

Four of the five sucker species captured in fyke nets occupied large portions of the lower Yellowstone River but mean reach CPUE of each species never exceeded 3 fish/net night (Table 2.5) nor constituted more than 5% of the catch at a sampling reach (Figure 2.18). White sucker CPUE was greatest upstream of segment 3 (Table 2.5) in water velocities less than 0.2 m/s (Figure 2.19). Longnose sucker distribution was similar to that of white suckers (Table 2.5; Figure 2.20). River carpsucker abundance was generally highest downstream of the Bighorn River (Table 2.5) in slow water velocities (Figure 2.21). Low abundances of shorthead redhorse were captured along the entire river downstream of Billings (Table 2.5; Figures 2.18); they occupied similar water velocities to those of white suckers (Figure 2.22). Mountain suckers were not captured downstream of the Bighorn River (Table 2.5; Figure 2.18). Mountain sucker CPUE was highest in water velocities of about 0.4 m/s (Figure 2.23).

Sunfishes were distributed throughout much of the study area in low abundances (Figure 2.24); however, co-occurrence was low as three or more sunfish species were captured in only 29% of the reaches. Sixty-three percent of the sunfish were captured in seasonal secondary channels. Sunfish were typically restricted to water velocities less than 0.2 m/s (Figures 2.25-2.28). No sunfish were captured in water velocities faster than 0.6 m/s and 73% were captured in velocities less than 0.1 m/s.

Stonecats represented 1% of the total fyke net catch and were captured in most reaches (Table 2.4). Brook stickleback were captured in low abundances upstream of segment 13. Goldeye were also captured throughout the study area in low abundances. Game fish such as channel catfish, sauger, and smallmouth bass were also frequently captured with fyke nets (Table

2.4). Channel catfish were found primarily in main channel habitats downstream of the Bighorn River. Sauger distribution was restricted to reaches downstream of Meyers Diversion Dam. Smallmouth bass were captured between Huntley Diversion Dam and the Tongue River.

Otter trawl catch.—We captured adults of 24 species (21 native and 3 nonnative) representing 9 families in otter trawls (Table 2.4). Five species each composed over 5% of the catch: sturgeon chub (38%), channel catfish (22%), stonecat (12%), flathead chub (11%), and sicklefin chub (6%). Sturgeon chub CPUE was greatest from O'Fallon Creek to Intake Diversion Dam (Table 2.9; Figure 2.29) in main channel habitats with mean depths of 1.3 m and mean water velocities of 0.8 m/s (Figure 2.30). Flathead chubs were widely distributed (Table 2.10; Figure 2.29), but CPUE was greatest in shallow depths (Figure 2.31) from the Tongue River to Intake Diversion Dam (segments 9-11; Table 2.9). Sicklefin chub CPUE was greatest downstream of Intake Diversion Dam (Table 2.8; Figure 2.29) in main channel habitats with mean depths of 2.0 m and mean water velocities of 0.8 m/s (Figure 2.32).

Seven pallid sturgeon ranging in size from 185 to 347 mm were captured in four reaches downstream of Intake Diversion Dam. Pallid sturgeon were captured in all three main channel habitats and in a variety of pool types. No differences existed in mean depths ($P = 0.69$) or water velocities ($P = 0.12$) between areas where pallid sturgeon were (depth = 2.0 m; velocity = 0.7 m/s) or were not (depth = 2.0 m; velocity = 0.9 m/s) detected.

Discussion

Although we captured 42 fish species, just five species—emerald shiner, western silvery minnow, sand shiner, longnose dace, and flathead chub—made up 94% of the total catch. All five species occurred from the mouth of the Clark's Fork to the confluence with the Missouri River. Emerald shiner and longnose dace had the strongest longitudinal patterns, with emerald shiner most common below the Bighorn River and longnose dace common from the Clarks Fork to Waco Diversion Dam. Western silvery minnows attained their highest relative abundance from Billings to the Tongue River.

Longitudinal trends in the lower Yellowstone River fish assemblage were evident based on species distributions and discontinuities in assemblage structure. The relatively low similarity between sampling segments upstream of the Bighorn River illustrate changes in the fish assemblage that occurred as a result of the Yellowstone River transitioning from a clear, coldwater environment to a turbid, warmwater river. Reaches upstream of Huntley Diversion Dam were dominated by longnose dace, which is a coldwater species that occupies fast water velocities. Emerald shiners and western silvery minnows, which are eurythermal species, increased in abundance downstream of Billings and began to dominate the small, nongame fish assemblage below the Bighorn River. Similarity was higher downstream of the Bighorn River than upstream, which was probably a result of decreased habitat variability between segments downstream of the Bighorn River as maximum water temperatures and turbidity probably began to stabilize.

The distribution of some species may have been a function of local habitat characteristics (e.g., substrate and water velocity) rather than longitudinal patterns. Sand shiners were captured in habitats composed primarily of small substrates, which upstream of Sidney are mostly restricted to backwaters (i.e., seasonal secondary channels) and tributary mouths (M. Duncan, personal observation). Most centrarchids prefer slow water velocities (Moyle and Cech 2004), which primarily restricts their distribution to seasonal secondary channels or main channel habitats with slow water velocities. The uncommon co-occurrence of multiple centrarchids in reaches may also be a result of local introductions from nearby farm ponds or tributary populations as main-stem recruitment and movement among isolated backwater habitats may be low.

The longitudinal trend in CPUE of adult fish in the lower Yellowstone River may be a consequence of multiple factors. The Yellowstone River near Billings transitions from a clear, coldwater environment to a turbid, warmwater river (White and Bramblett 1993). Therefore, water temperatures and turbidities were not ideal for many species resulting in relatively low fish abundances in this stretch of river. The high catch rates between O'Fallon Creek and Sidney were a result of exceptionally high catches (> 1,000 fish) of emerald shiners, western silvery minnows, and sand shiners in several fyke nets. The surprisingly low CPUE of fyke net catches below Sidney was probably a result of decreased habitat heterogeneity caused by the high proportion of stabilized reaches that were sampled and the transition to sand substrate in this segment.

Although the lack of historical data precludes any inferences on population trends, exceptional maximum lengths, the presence of multiple age classes, high catch rates of native species, and a low relative abundance of nonnative species indicate that the lower Yellowstone River supports a relatively intact small nongame fish assemblage. The maximum lengths of most of the native cyprinids captured in our study are close to or exceed the reported maximum lengths for each species (Brown 1971; Lee at al. 1980; Fisher et al. 2002; Berry et al. 2004; Herzog 2004; Montana Fish, Wildlife & Parks [MFWP] 2012). The growth rates and longevity of native cyprinids in the Yellowstone River may be indicative of high quality habitat. The high abundances of native species and low proportion of nonnative species relative to other large rivers such as the Missouri River (R. Wilson, USFWS, unpublished data; T. Haddix, MFWP, unpublished data) also indicate that the lower Yellowstone River maintains productive and diverse native fish assemblages.

Several native cyprinids maintain widespread and abundant populations in the lower Yellowstone River while their distributions and abundances have declined elsewhere. Western silvery minnows were formerly common in the Missouri River Basin (Hesse and Wallace 1976; Pflieger and Grace 1987), but have experienced widespread declines in abundance and distribution (Grady and Milligan 1998; Berry et al. 2004; Galat et al. 2005) caused by the damming and channelization of large main-stem rivers (Pflieger and Grace 1987). Western silvery minnows are common throughout the entire lower Yellowstone River especially in slow habitats with silty or sandy substrate. The high abundances of western silvery minnows is probably a result of the Yellowstone River's natural flow regime, which creates and maintains these backwater habitats (*sensu* Poff et al. 1997), which are now uncommon in much of the Missouri River (Hesse and Sheets 1993). Similarly, flathead chubs, which historically had a similar distribution in the Missouri River Basin to that of western silvery minnows, have also experienced decreased abundances and ranges throughout much of their historical range (Pflieger and Grace 1987; Kelsch 1994; Berry et al. 2004). However, flathead chubs are common throughout the lower Yellowstone River. Our otolith microchemistry study (Chapter 3) revealed that tributary habitats, which are abundant in the lower Yellowstone River Basin, function as spawning and nursery habitats for these two species and probably help maintain large main-stem populations (Chapter 3).

Sturgeon chubs and sicklefin chubs are priorities for conservation in many areas as the abundances and distributions of both species have declined in recent years (Pflieger and Grace 1987; Hesse 1994; Kelsh 1994; Galat et al. 2005) leading to their listing or consideration for listing as vulnerable, threatened, or endangered (Williams et al. 1989; Werdon 1993; Haslouer et al. 2005; Jelks et al. 2008). However, the Yellowstone River remains a stronghold for both species. Sicklefin chubs were primarily restricted to reaches below Intake Diversion Dam whereas sturgeon chubs were captured as far upstream as the Tongue River confluence. Both species were captured in nearly every reach below Intake Diversion Dam. Although we found sicklefin chubs to be the dominant cyprinid in main channel habitats below Sidney, sturgeon chubs were more abundant downstream of Sidney in other studies (Everett et al. 2004; Welker and Scarnecchia 2004). These conflicting results may be because of differences in gear efficiencies or interannual variability of the two populations. Continued monitoring is needed to accurately assess these two species in the lower Yellowstone River.

Sicklefin chubs, sturgeon chubs, and flathead chubs co-occurred at many reaches in the lower Yellowstone River. High habitat heterogeneity created by a natural flow regime in the Yellowstone River may provide suitable habitat for all three species (Welker and Scarnecchia 2006), which might permit sufficient resource partitioning to enable these three fishes to coexist in the lower Yellowstone River. Greater competition for suitable habitat and other resources in altered rivers elsewhere may be responsible for the declining ranges and abundances of all three species.

The pallid sturgeon we captured were all relatively young and probably hatchery-reared individuals as the only natural reproduction documented for many decades occurred in 2012 (T. Haddix, MFWP, unpublished data), which was after our sampling efforts. Although our sample size is small, the pallid sturgeon captured in our trawls used slightly shallower depths with faster water velocities than pallid sturgeon captured in the Missouri River (Jordan et al. 2006; Gerrity et al. 2008; Spindler et al. 2012). Differences in habitat use between pallid sturgeon in the

Yellowstone and Missouri rivers may be a result of availability rather than preference. Controlled flows decrease channel migration and incise main channel habitats (Williams and Wolman 1984; Friedman et al. 1998; Shields et al. 2000), which limits shallow habitats along the main channel margins. The pallid sturgeon we captured occupied slightly shallower habitats than larger, wild pallid sturgeon in the lower Yellowstone River (Bramblett and White 2001). Sturgeon chub and sicklefin chub, the primary prey of juvenile pallid sturgeon in the Missouri River (Gerrity et al. 2006), are restricted in the Yellowstone River to reaches downstream of the Tongue River and may limit the upstream distribution of juvenile pallid sturgeon. Restoring sturgeon chub populations between the Tongue and Bighorn rivers, where they historically occurred, may help to increase pallid sturgeon distribution and abundances in the Yellowstone River.

Several of the diversion dams on the Yellowstone River limit fish movement during baseflow (Helfrich et al. 1999). However, diversion dams do not limit the distribution of any small nongame fishes in the lower Yellowstone River. Minor discontinuities in assemblage structure occurred at Rancher and Intake diversion dams because of changes in emerald shiner, sand shiner, and western silvery minnow abundances. However, artificial and natural side channels or high spring flows may facilitate enough passage, which coupled with long main-stem reaches and connectivity to tributaries, may help maintain viable populations upstream of these structures. For example, the dissimilarity in assemblage structures above and below Rancher Diversion Dam might be caused by increased turbidities and water temperatures downstream of the Bighorn River rather than a lack of fish passage as a natural side channel permits passage for much of the year.

Although CPUE of two species abruptly declined upstream of several diversion dams, those declines were probably a result of habitat limitations rather than passage issues. Although sand shiner CPUE declined above Huntley Diversion Dam, sand shiners, which are often associated with warm water temperatures and small substrates (Rahel and Hubert 1991; Conklin et al. 1995), are probably limited by cool water temperatures and large cobble substrates above Huntley Diversion Dam. The transition from sand to cobble substrates near Sidney rather than Intake Diversion Dam probably limits the upstream distribution of sicklefin chubs in the lower Yellowstone River (Everett et al. 2004; Welker and Scarnecchia 2004). The otter trawl catch data from individual reaches indicates that sicklefin chub CPUE and the percentage of reaches where they were captured declined gradually upstream of Sidney, which is not apparent when combining data by segments. The progressive decrease in substrate particle sizes from Intake Diversion Dam to Sidney is also probably responsible for the relatively low percent similarity of fish assemblages in segments 11 and 12.

The Yellowstone River supports a diverse and relatively structurally and functionally intact small nongame fish assemblage, which is a rarity. The diverse habitat found in the Yellowstone River supports many species that are experiencing declining abundances and distributions elsewhere. This study provides baseline data for future monitoring efforts and previously unavailable information on abundance, distribution, and habitat use of important prey species, which can be used to help direct the management and conservation of valued endangered and game species in the lower Yellowstone River.

Table 2.1. Lower Yellowstone River fyke net sampling reaches.

Reach	Segment	River kilometer	Pool	Years sampled	Coordinates
1	1	608	Stabilized alluvial	2008	45.69313, -108.64030
2	1	605	Alluvial	2009	45.70556, -108.60437
3	1	604	Alluvial	2008	45.71289, -108.59743
4	1	599	Alluvial	2008-2010	45.73220, -108.55159
5	1	593	Stabilized alluvial	2008	45.74857, -108.49501
6	1	590	Bluff	2010	45.76680, -108.46997
7	2	588	Stabilized bluff-terrace	2008-2010	45.78521, -108.47529
8	2	587	Stabilized alluvial	2008	45.79562, -108.46943
9	2	586	Bluff	2008	45.80417, -108.46603
10	2	582	Alluvial	2008	45.82899, -108.42295
11	2	576	Stabilized bluff-terrace	2009	45.86043, -108.38287
12	2	575	Stabilized bluff-terrace	2010	45.86260, -108.37933
13	3	567	Stabilized alluvial	2008-2010	45.90504, -108.31794
14	3	563	Alluvial	2009	45.93750, -108.29330
15	3	551	Stabilized alluvial	2008	45.99234, -108.18980
16	3	549	Alluvial	2008	45.99760, -108.17591
17	3	537	Alluvial	2008	45.99494, -108.08530
18	3	516	Alluvial	2010	46.03721, -107.81760
19	4	514	Stabilized alluvial	2009	46.04936, -107.80091
20	4	510	Alluvial	2008	46.06049, -107.75424
21	4	502	Bluff	2008-2010	46.09070, -107.68703
22	4	498	Alluvial	2008	46.10960, -107.66334
23	4	484	Alluvial	2010	46.14969, -107.52148
24	4	480	Alluvial	2008	46.15261, -107.47849
25	5	480	Alluvial	2008-2010	46.15545, -107.47608
26	5	479	Alluvial	2009	46.18398, -107.42745
27	5	479	Alluvial	2008	46.16133, -107.46587
28	5	477	Bluff	2008	46.16856, -107.44913
29	5	477	Bluff	2010	46.17168, -107.44582
30	6	475	Alluvial	2009	46.15884, -107.46707
31	6	468	Stabilized bluff-terrace	2008	46.22957, -107.41737
32	6	466	Alluvial	2008-2010	46.24368, -107.40105
33	6	464	Alluvial	2008	46.24440, -107.38209
34	6	456	Alluvial	2008	46.27279, -107.32017
35	6	454	Alluvial	2010	46.27427, -107.27427
36	7	407	Alluvial	2008-2010	46.32058, -107.18010
37	7	407	Alluvial	2008	46.28019, -106.88779

Table 2.1. Continued.

38	7	406	Stabilized alluvial	2009	46.27736, -106.87900
39	7	391	Stabilized bluff-terrace	2010	46.26118, -106.75830
40	7	387	Stabilized bluff-terrace	2008	46.26397, -106.70049
41	8	349	Alluvial	2008	46.28567, -106.32915
42	8	339	Alluvial	2008	46.28165, -106.23863
43	8	304	Bluff	2009	46.38043, -105.92661
44	8	301	Stabilized alluvial	2008-2010	46.39088, -105.89610
45	8	300	Bluff	2010	46.39931, -105.89586
46	9	298	Stabilized alluvial	2009	46.40598, -105.87378
47	9	282	Alluvial	2009	46.49681, -105.74502
48	9	271	Alluvial	2008	46.55660, -105.64666
49	9	268	Stabilized bluff-terrace	2008	46.56461, -105.61335
50	9	265	Alluvial	2008	46.59032, -105.59709
51	9	248	Alluvial	2008-2010	46.68741, -105.48576
52	9	244	Terrace	2009	46.71640, -105.46637
53	9	242	Terrace	2010	46.72145, -105.44332
54	10	240	Terrace	2008	46.74542, -105.43719
55	10	240	Terrace	2009	46.74327, -105.43419
56	10	227	Alluvial	2008-2010	46.79838, -105.37720
57	10	220	Bluff	2009	45.78683, -105.42181
58	10	220	Bluff	2008	45.80384, -105.29636
59	10	210	Terrace	2010	46.82487, -105.18462
60	10	209	Terrace	2008	46.82853, -105.15777
61	11	207	Terrace	2009	46.82991, -105.15976
62	11	196	Alluvial	2009	46.85518, -105.03261
63	11	181	Terrace	2009	46.92294, -104.87183
64	11	155	Alluvial	2008	47.07872, -104.75502
65	11	150	Terrace	2008	47.11531, -104.71183
66	11	139	Alluvial	2008-2010	47.19017, -104.66649
67	11	123	Alluvial	2010	47.27010, -104.57987
68	12	110	Bluff	2008-2010	47.30769, -104.46182
69	12	88	Alluvial	2008	47.44643, -104.33381
70	12	73	Alluvial	2008	47.53327, -104.26152
71	12	67	Alluvial	2009	47.56607, -104.23207
72	12	62	Alluvial	2008	47.60081, -104.21404
73	12	50	Stabilized alluvial	2010	47.67365, -104.15940
74	13	48	Alluvial	2009	47.68292, -104.13624
75	13	42	Stabilized alluvial	2008-2010	47.72221, -104.08759
76	13	35	Stabilized bluff-terrace	2008	47.75670, -104.06271

Table 2.1. Continued.

77	13	32	Alluvial	2008	47.77378, -104.03502
78	13	14	Bluff	2008	47.87321, -103.96045
79	13	5	Alluvial	2010	47.93688, -103.95762

Table 2.2. Mean, maximum, and minimum daily discharges (ft^3/s) for the Yellowstone River near Forsyth, Montana (USGS gauge 06295000).

Year(s)	Mean	Maximum	Minimum
1981-2010	10,080	43,930	3,227
2001-2010	8,538	40,820	3,097
2008	11,471	53,200	3,710
2009	12,508	50,600	3,050
2010	10,755	51,700	4,460

Table 2.3. Lower Yellowstone River otter trawl sampling reaches.

Reach	Segment	River kilometer	Pool	Years sampled	Coordinates
1	9	298	Stabilized alluvial	2009	46.40598, -105.87378
2	9	282	Alluvial	2009	46.51223, 105.73228
3	9	248	Alluvial	2009, 2010	46.68741, -105.48576
4	9	246	Terrace	2010	46.71146, -105.47213
5	9	244	Terrace	2009	46.71640, -105.46637
6	9	242	Terrace	2010	46.72145, -105.44332
7	10	227	Alluvial	2009, 2010	46.79838, -105.37720
8	10	225	Terrace	2009	46.80542, -105.35010
9	10	222	Terrace	2010	46.80750, -105.31314
10	10	220	Bluff	2009	45.78683, -105.42181
11	10	214	Terrace	2009	46.81270, -105.21375
12	10	212	Stabilized bluff-terrace	2010	46.81731, -105.19777
13	10	210	Terrace	2010	46.82487, -105.18462
14	11	196	Alluvial	2009	46.85518, -105.03261
15	11	179	Terrace	2010	46.93338, -104.87740
16	11	169	Alluvial	2009	47.97591, -104.77714
17	11	167	Terrace	2009	47.99260, -104.78502
18	11	151	Alluvial	2010	47.10831, -104.72059
19	11	139	Alluvial	2009, 2010	47.19017, -104.66649
20	11	123	Alluvial	2010	47.27010, -104.57987
21	12	110	Bluff	2009, 2010	47.30769, -104.46182
22	12	107	Alluvial	2010	47.32905, -104.43933
23	12	79	Alluvial	2009	47.49428, -104.27179
24	12	67	Alluvial	2009	47.56607, -104.23207
25	12	63	Alluvial	2009	47.59379, -104.22203
26	12	56	Alluvial	2010	47.63036, -104.18411
27	12	50	Stabilized alluvial	2010	47.67365, -104.15940
28	13	48	Stabilized alluvial	2009	47.68292, -104.13624
29	13	47	Stabilized alluvial	2009	47.68248, -104.12668
30	13	44	Alluvial	2010	47.69560, -104.10852
31	13	42	Stabilized alluvial	2009, 2010	47.72221, -104.08759
32	13	6	Alluvial	2009	47.93737, -103.98978
33	13	5	Alluvial	2010	47.93688, -103.95762
34	13	4	Alluvial	2010	47.95033, -103.96047

Table 2.4. Total numbers of individuals captured (N), maximum lengths of individuals captured (TL), relative abundances (RA), and numbers of fyke net sets or otter trawls in which at least one individual of a species was captured (*O*) in the lower Yellowstone River from 2008 to 2010.

	Fyke net				Otter trawl			
Family/Species	N	TL	RA	*O*	N	TL	RA	*O*
Acipenseridae								
Shovelnose sturgeon *Scaphirhynchus platorynchus*	0	--	0.00	0	67	1040	3.11	20
Pallid sturgeon *Scaphirhynchus albus*	0	--	0.00	0	7	347	0.32	4
Catostomidae								
White sucker *Catostomus commersonii*	400	406	0.50	40	3	400	0.14	2
Longnose sucker *Catostomus catostomus*	203	400	0.25	33	1	165	0.05	1
River carpsucker *Carpiodes carpio*	127	488	0.16	41	10	421	0.46	7
Shorthead redhorse *Moxostoma macrolepidotum*	104	491	0.13	38	42	415	1.95	21
Mountain sucker *Catostomus platyrhynchus*	57	195	0.07	9	0	--	0.00	0
Blue sucker *Cycleptus elongatus*	0	--	0.00	0	1	731	0.05	1
Bigmouth buffalo *Ictiobus cyprinellus*	0	--	0.00	0	1	624	0.05	1
Unidentified catostomid	12	--	0.01	1	0	--	0.00	0
Centrarchidae								
Green sunfish *Lepomis cyanellus*[a]	93	145	0.12	31	0	--	0.00	0
White crappie *Pomoxis annularis*[a]	92	274	0.11	25	0	--	0.00	0
Black crappie *Pomoxis nigromaculatus*[a]	70	260	0.09	27	1	203	0.05	1
Pumpkinseed *Lepomis gibbosus*[a]	60	124	0.07	19	0	--	0.00	0
Smallmouth bass *Micropterus dolomieu*[a]	31	371	0.04	22	7	277	0.33	4
Bluegill *Lepomis macrochirus*[a]	16	94	0.02	9	0	--	0.00	0
Largemouth bass *Micropterus salmoides*[a]	2	249	< 0.01	2	0	--	0.00	0

[a] Nonnative to lower Yellowstone River.

Table 2.4. Continued.

Cyprinidae								
Emerald shiner *Notropis atherinoides*	37,681	115	46.94	96	9	95	0.42	6
Western silvery minnow *Hybognathus argyritis*	22,707	152	28.29	99	11	101	0.51	9
Sand shiner *Notropis stramineus*	6,897	77	8.59	86	3	52	0.14	3
Longnose dace *Rhinichthys cataractae*	4,401	95	5.48	87	23	89	1.07	9
Flathead chub *Platygobio gracilis*	3,592	240	4.47	99	241	235	11.20	31
Fathead minnow *Pimephales promelas*	2,388	89	2.97	88	0	--	0.00	0
Common carp *Cyprinus carpio*[a]	26	664	0.03	21	3	657	0.14	3
Sturgeon chub *Macrhybopsis gelida*	27	77	0.03	10	826	93	38.40	30
Creek chub *Semotilus atromaculatus*	10	76	0.01	8	0	--	0.00	0
Lake chub *Couesius plumbeus*	4	76	< 0.01	2	0	--	0.00	0
Brassy minnow *Hybognathus hankinsoni*	3	53	< 0.01	3	0	--	0.00	0
Sicklefin chub *Macrhybopsis meeki*	2	106	< 0.01	2	134	116	6.23	19
Plains minnow *Hybognathus placitus*	2	92	< 0.01	2	0	--	0.00	0
Golden shiner *Notemigonus crysoleucas*[a]	1	80	< 0.01	1	0	--	0.00	0
Spottail shiner *Notropis hudsonius*[a]	1	48	< 0.01	1	0	--	0.00	0
Macrhybopsis spp.	0	--	0.00	0	1	--	0.05	1
Cyprinodontidae								
Northern plains killifish *Fundulus kansae*[a]	24	66	0.03	15	0	--	0.00	0
Esocidae								
Northern pike *Esox lucius*[a]	3	721	< 0.01	2	0	--	0.00	0
Gasterosteidae								
Brook stickleback *Culaea inconstans*	153	68	0.19	32	0	--	0.00	0

[a] Nonnative to lower Yellowstone River.

Table 2.4. Continued.

Hiodontidae								
Goldeye *Hiodon alosoides*	65	363	0.08	23	3	338	0.14	3
Ictaluridae								
Stonecat *Noturus flavus*	770	234	0.96	84	254	255	11.81	18
Channel catfish *Ictalurus punctatus*	93	691	0.12	28	464	655	21.57	37
Black bullhead *Ameiurus melas*[a]	16	224	0.02	12	0	--	0.00	0
Yellow bullhead *Ameiurus natalis*[a]	2	198	< 0.01	2	0	--	0.00	0
Lotidae								
Burbot *Lota lota*	23	545	0.03	14	1	205	0.05	1
Percidae								
Sauger *Sander canadensis*	103	562	0.13	33	37	381	1.72	20
Yellow perch *Perca flavescens*[a]	2	247	< 0.01	2	0	--	0.00	0
Walleye *Sander vitreus*[a]	1	515	< 0.01	1	0		0.00	0
Salmonidae								
Rainbow trout *Oncorhynchus mykiss*[a]	4	452	< 0.01	3	0	--	0.00	0
Brown trout *Salmo trutta*[a]	3	505	< 0.01	3	0	--	0.00	0
Sciaenidae								
Freshwater drum *Aplodinotus grunniens*	3	320	< 0.01	2	1	322	0.05	1

[a] Nonnative to lower Yellowstone River.

Table 2.5. Mean reach CPUE (fish/net night) of selected adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010. Standard deviations are shown in parentheses.

	Segment												
Species	1	2	3	4	5	6	7	8	9	10	11	12	13
Emerald shiner	< 0.1	2.1	4.8	5.4	1.2	9.5	15.8	26.8	49.4	47.4	125.2	123.5	35.4
	(0.1)	(6.0)	(10.8)	(11.2)	(1.9)	(23.9)	(27.7)	(60.2)	(125.3)	(101.1)	(214.9)	(177.3)	(57.6)
Western silvery minnow	0.4	15.6	23.6	9.7	10.0	36.6	37.7	21.4	7.1	10.6	62.9	23.9	1.8
	(0.7)	(33.7)	(66.1)	(15.2)	(26.4)	(85.1)	(105.9)	(51.3)	(15.4)	(20.7)	(151.3)	(50.6)	(3.2)
Sand shiner	< 0.1	< 0.1	0.6	0.5	3.4	4.2	5.3	6.5	7.4	10.6	22.6	6.6	8.5
	(0.1)	(0.1)	(1.4)	(1.0)	(8.1)	(6.9)	(9.9)	(10.3)	(14.8)	(17.6)	(49.4)	(12.0)	(20.9)
Longnose dace	6.8	6.7	18.4	5.7	3.1	4.6	0.6	0.2	0.8	1.4	2.0	2.7	0.1
	(7.2)	(8.5)	(24.5)	(8.2)	(3.3)	(6.2)	(0.9)	(0.3)	(1.9)	(2.5)	(4.6)	(6.8)	(0.3)
Flathead chub	1.6	6.5	2.1	1.2	2.2	3.1	0.6	1.3	3.3	3.2	5.4	10.7	1.2
	(2.3)	(11.5)	(3.5)	(2.1)	(3.7)	(5.0)	(1.2)	(1.7)	(3.2)	(4.3)	(7.5)	(20.7)	(2.3)
Fathead minnow	0.8	0.6	8.0	1.7	6.4	3.4	1.2	0.4	0.5	0.3	1.3	3.8	1.0
	(1.7)	(1.0)	(16.4)	(3.0)	(16.5)	(5.8)	(2.9)	(0.8)	(1.1)	(0.7)	(2.4)	(7.4)	(1.1)
White sucker	0.3	0.6	0.2	0.5	0.3	2.7	0.1	0.0	< 0.1	< 0.1	0.0	0.1	0.0
	(0.7)	(1.4)	(0.6)	(1.5)	(0.7)	(4.6)	(0.2)	(0.0)	(< 0.1)	(< 0.1)	(0.0)	(0.5)	(0.0)
Longnose sucker	0.4	0.5	1.1	< 0.1	0.2	0.3	0.1	0.0	< 0.1	0.0	< 0.1	0.1	0.0
	(0.7)	(1.1)	(3.2)	(0.1)	(0.5)	(0.6)	(0.2)	(0.0)	(< 0.1)	(0.0)	(< 0.1)	(0.1)	(0.0)
River carpsucker	0.0	0.0	0.1	0.1	< 0.1	0.2	< 0.1	0.1	0.2	0.3	0.1	0.2	0.1
	(0.0)	(0.0)	(0.3)	(0.4)	(0.1)	(0.4)	(0.1)	(0.2)	(0.5)	(0.6)	(0.3)	(0.3)	(0.2)
Shorthead redhorse	0.0	< 0.1	< 0.1	0.1	0.1	0.4	0.3	0.1	0.1	0.1	< 0.1	< 0.1	0.1
	(0.0)	(0.1)	(< 0.1)	(0.3)	(0.2)	(0.7)	(0.8)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)
Mountain sucker	0.6	0.1	< 0.1	< 0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(1.3)	(0.2)	(< 0.1)	(< 0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Green sunfish	0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	0.2	0.1	0.1	< 0.1	0.1	0.1	0.0
	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.4)	(0.3)	(0.2)	(< 0.1)	(0.3)	(0.2)	(0.0)

Table 2.5. Continued.

White crappie	0.0	0.0	< 0.1	0.2	0.0	< 0.1	0.1	0.2	0.2	0.2	0.0	0.1	0.1
	(0.0)	(0.0)	(0.1)	(0.4)	(0.0)	(0.1)	(0.1)	(0.3)	(0.2)	(0.3)	(0.0)	(0.2)	(0.4)
Black crappie	< 0.1	< 0.1	0.1	0.2	0.0	< 0.1	0.1	0.0	0.1	0.1	0.0	0.1	< 0.1
	(0.1)	(< 0.1)	(0.1)	(0.4)	(0.0)	(< 0.1)	(0.2)	(0.0)	(0.2)	(0.1)	(0.0)	(0.1)	(0.0)
Pumpkinseed	0.0	0.1	0.2	0.2	< 0.1	< 0.1	0.1	0.0	0.0	< 0.1	< 0.1	0.0	0.0
	(0.0)	(0.1)	(0.2)	(0.3)	(0.1)	(0.1)	(0.2)	(0.0)	(0.0)	(< 0.1)	(< 0.1)	(0.0)	(0.0)
Bluegill	0.0	0.1	0.0	< 0.1	< 0.1	0.0	< 0.1	0.0	< 0.1	0.0	0.0	0.0	0.0
	(0.0)	(0.1)	(0.0)	(< 0.1)	(< 0.1)	(0.0)	(< 0.1)	(0.0)	(< 0.1)	(0.0)	(0.0)	(0.0)	(0.0)
Stonecat	1.0	1.7	1.2	1.1	0.2	0.3	0.3	0.5	1.1	1.0	0.4	0.4	< 0.1
	(1.6)	(2.2)	(1.3)	(1.6)	(0.5)	(0.6)	(0.5)	(0.7)	(1.3)	(1.0)	(0.7)	(0.8)	(0.1)

Table 2.6. Mean reach CPUE (fish/net night) of selected adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 among pool types. Standard deviations are shown in parentheses.

	Alluvial	Bluff	Terrace	Stabilized alluvial	Stabilized bluff-terrace
Emerald shiner	25.6 (56.3)	53.8 (80.7)	92.4 (193.4)	24.5 (46.1)	8.0 (13.0)
Western silvery minnow	17.0 (26.0)	22.1 (32.8)	40.5 (90.3)	10.1 (17.6)	20.1 (24.3)
Sand shiner	4.5 (7.3)	8.8 (12.9)	18.4 (40.9)	1.6 (2.2)	1.0 (2.9)
Longnose dace	4.5 (10.4)	3.9 (5.4)	1.3 (1.7)	4.6 (8.4)	4.8 (6.8)
Flathead chub	2.0 (2.9)	6.8 (15.4)	5.6 (5.0)	1.2 (1.2)	4.7 (9.3)
Fathead minnow	3.0 (5.7)	2.1 (3.6)	0.9 (1.8)	1.0 (1.4)	1.8 (3.9)
White sucker	0.5 (2.8)	0.4 (0.8)	< 0.1 (< 0.01)	0.1 (0.2)	0.4 (0.6)
Longnose sucker	0.2 (1.0)	0.1 (0.1)	< 0.1 (0.1)	0.3 (0.6)	0.4 (0.5)
River carpsucker	0.1 (0.2)	0.1 (0.2)	0.2 (0.2)	0.1 (0.2)	0.1 (0.3)
Shorthead redhorse	0.1 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.4)	0.1 (0.2)
Mountain sucker	0.1 (0.6)	< 0.1 (0.1)	0.0 (0.0)	0.1 (0.2)	< 0.1 (0.1)
Green sunfish	0.1 (0.2)	< 0.1 (0.1)	0.1 (0.2)	< 0.1 (< 0.1)	0.1 (0.4)
White crappie	0.1 (0.2)	0.1 (0.4)	0.1 (0.2)	0.1 (0.2)	< 0.1 (0.1)
Black crappie	< 0.1 (0.1)	0.1 (0.3)	0.1 (0.3)	< 0.1 (0.1)	< 0.1 (0.1)
Pumpkinseed	< 0.1 (0.1)	0.1 (0.2)	< 0.1 (< 0.1)	0.1 (0.2)	0.1 (0.1)
Bluegill	< 0.1 (< 0.1)	< 0.1 (< 0.1)	0.0 (0.0)	< 0.1 (< 0.1)	0.0 (0.0)
Stonecat	0.5 (0.9)	0.7 (1.0)	1.3 (1.7)	0.8 (1.0)	1.0 (1.3)

Table 2.7. Mean reach CPUE (fish/net night) of selected adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 among macrohabitats. Standard deviations are shown in parentheses.

	Crossover	Inside	Outside	Seasonal	Secondary
Emerald shiner	40.2 (136.6)	26.8 (79.2)	49.6 (170.3)	16.4 (53.0)	25.0 (55.0)
Western silvery minnow	11.8 (46.0)	14.9 (38.1)	12.9 (38.5)	41.2 (136.3)	24.8 (51.7)
Sand shiner	3.4 (7.9)	5.6 (14.2)	5.6 (16.0)	10.2 (53.6)	4.8 (10.4)
Longnose dace	5.2 (11.9)	3.9 (9.4)	2.2 (6.9)	5.1 (15.1)	2.0 (4.3)
Flathead chub	4.4 (21.0)	2.7 (4.4)	2.3 (4.5)	4.0 (10.4)	3.0 (5.8)
Fathead minnow	1.6 (6.6)	1.1 (2.8)	0.6 (1.1)	3.8 (7.9)	7.1 (18.3)
White sucker	0.1 (0.4)	0.1 (0.3)	0.1 (0.5)	1.5 (7.0)	0.1 (0.5)
Longnose sucker	0.1 (0.3)	0.1 (0.6)	< 0.1 (0.1)	0.7 (2.6)	< 0.1 (0.1)
River carpsucker	0.1 (0.3)	0.1 (0.3)	0.1 (0.4)	0.2 (0.4)	0.1 (0.2)
Shorthead redhorse	< 0.1 (0.1)	0.1 (0.2)	0.1 (0.2)	0.3 (0.9)	0.1 (0.2)
Mountain sucker	< 0.1 (0.1)	0.1 (1.2)	< 0.1 (0.1)	< 0.1 (0.1)	0.0 (0.0)
Green sunfish	0.1 (0.3)	< 0.1 (0.1)	0.1 (0.2)	0.3 (0.6)	0.1 (0.2)
White crappie	0.1 (0.2)	< 0.1 (0.1)	< 0.1 (0.2)	0.3 (0.9)	0.1 (0.5)
Black crappie	< 0.1 (0.1)	< 0.1 (0.1)	< 0.1 (0.1)	0.3 (0.8)	< 0.1 (0.2)
Pumpkinseed	< 0.1 (0.1)	< 0.1 (0.1)	< 0.1 (1.3)	0.2 (0.6)	< 0.1 (0.2)
Bluegill	< 0.1 (0.1)	< 0.1 (0.1)	0.0 (0.0)	0.1 (0.3)	0.0 (0.0)
Stonecat	0.7 (1.4)	0.8 (1.5)	0.8 (1.3)	0.7 (1.2)	0.6 (1.1)

Table 2.8. Post hoc Mann-Whitney (Wilcoxon) rank sum test for differences in CPUE between pool types of adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010. Pool types in bold font have significantly higher CPUEs than the pool type they are paired with.

Species	Pool combination	*P*
Sand shiner	**Bluff**-stabilized alluvial	0.03
	Bluff-stabilized bluff-terrace	< 0.01
	Bluff-alluvial	0.19
	Bluff-terrace	0.47
	Stabilized alluvial-stabilized bluff-terrace	0.36
	Stabilized alluvial-alluvial	0.18
	Stabilized alluvial-**terrace**	0.01
	Stabilized bluff-terrace-**alluvial**	0.02
	Stabilized bluff-terrace-**terrace**	< 0.01
	Alluvial-**terrace**	0.03
Flathead chub	**Bluff**-stabilized alluvial	0.03
	Bluff-stabilized bluff-terrace	0.24
	Bluff-alluvial	0.02
	Bluff-terrace	0.35
	Stabilized alluvial-stabilized bluff-terrace	0.81
	Stabilized alluvial-alluvial	0.89
	Stabilized alluvial-**terrace**	0.02
	Stabilized bluff-terrace-alluvial	1.00
	Stabilized bluff-terrace-terrace	0.08
	Alluvial-**terrace**	< 0.01

Table 2.9. Post hoc Mann-Whitney (Wilcoxon) rank sum test for differences in CPUE between macrohabitats of adult longnose dace captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010. Macrohabitats in bold font have significantly higher CPUEs than the macrohabitat they are paired with.

Species	Macrohabitat combination	*P*
Longnose dace	Crossover-inside bend	0.22
	Crossover-outside bend	< 0.01
	Crossover-seasonal secondary channel	0.31
	Crossover-secondary channel	0.24
	Inside bend-outside bend	0.04
	Inside bend-seasonal secondary channel	0.99
	Inside bend-secondary channel	0.70
	Outside bend-seasonal secondary channel	0.86
	Outside bend-secondary channel	0.32
	Seasonal secondary channel-secondary channel	0.66

Table 2.10. Mean reach CPUE (fish/300 m) of selected adult fish captured in otter trawls deployed in the Yellowstone River downstream of the Tongue River in 2009 and 2010 among macrohabitats. Standard deviations are shown in parentheses.

	Segment				
Species	9	10	11	12	13
Flathead chub	1.0	1.2	2.1	0.8	0.1
	(0.9)	(0.7)	(0.8)	(0.6)	(0.1)
Sicklefin chub	0.0	0.0	0.1	0.6	1.6
	(0.0)	(0.0)	(0.2)	(0.3)	(0.9)
Sturgeon chub	0.1	2.8	7.2	3.5	1.1
	(0.1)	(2.9)	(6.1)	(5.0)	(1.8)

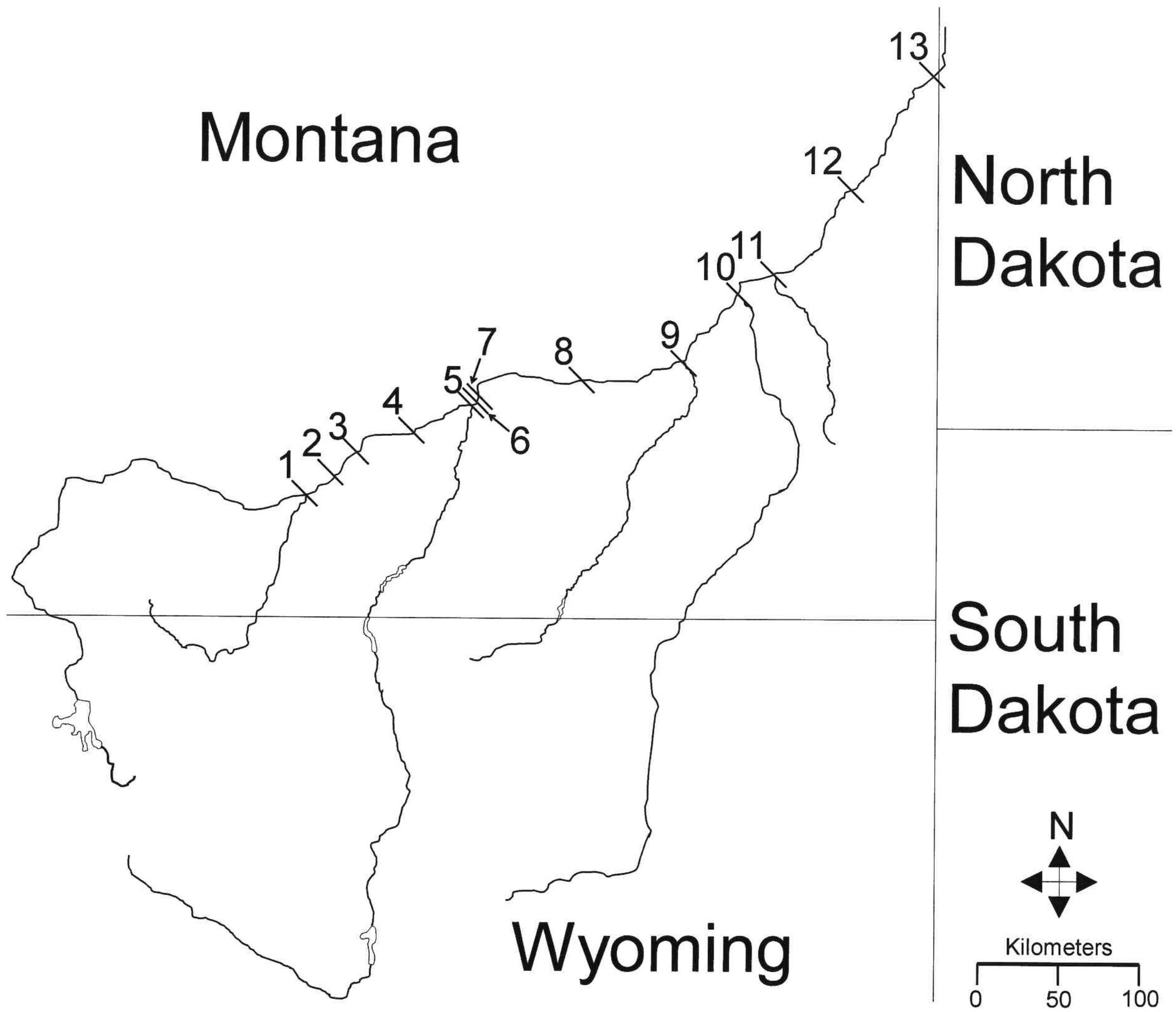

Figure 2.1. Yellowstone River Basin. Bars and numbers delineate upstream end of river segments: 1–Clarks Fork (river kilometer [RKM] 617); 2–Billings (RKM 589), 3–Huntley Diversion Dam (RKM 572), 4–Waco Diversion Dam (RKM 515), 5–Bighorn River (RKM 480), 6–Rancher Diversion Dam (RKM 476), 7–Meyers Diversion Dam (RKM 454), 8–Cartersville Diversion Dam (RKM 384), 9–Tongue River (RKM 297), 10–Powder River (RKM 240), 11–O'Fallon Creek (RKM 207), 12–Intake Diversion Dam (RKM 117), and 13–Sidney (RKM 49).

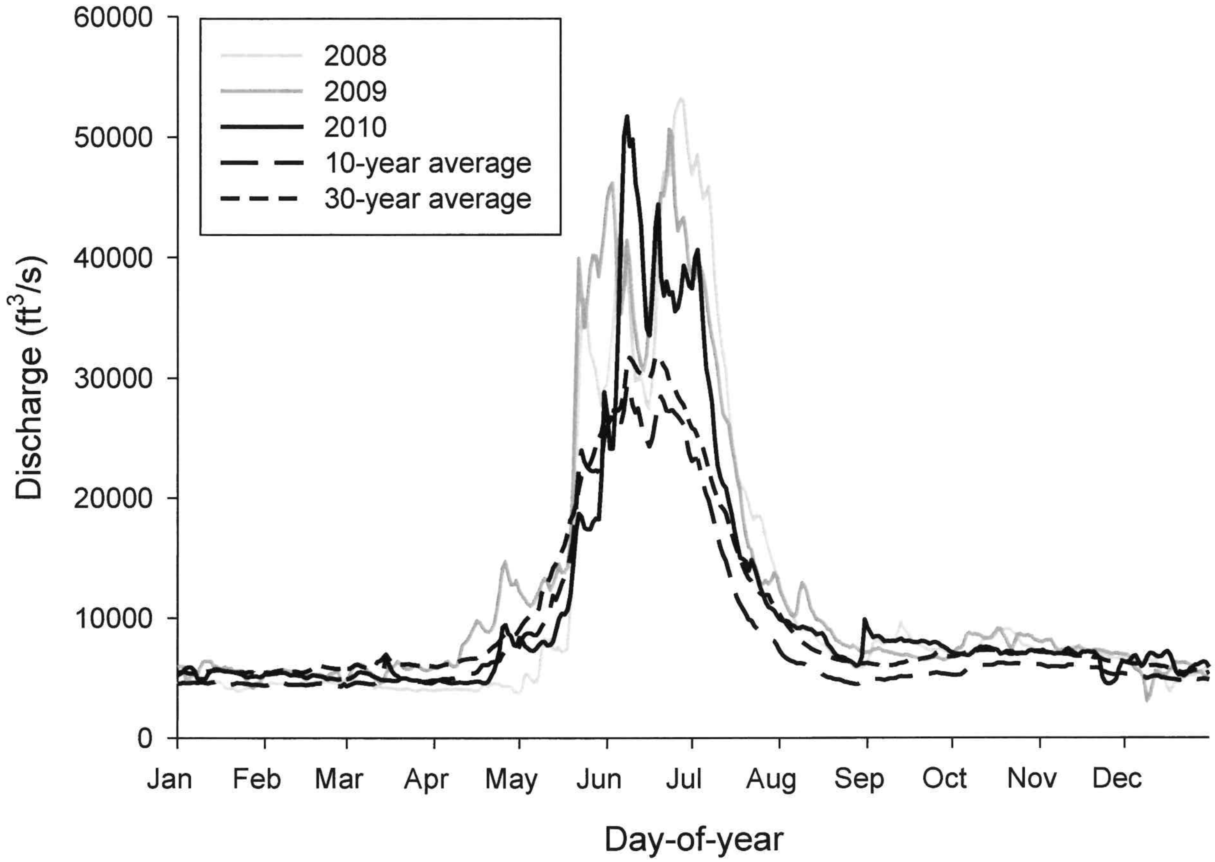

Figure 2.2. Mean daily discharge of the Yellowstone River near Forsyth, Montana (USGS gauge 06295000).

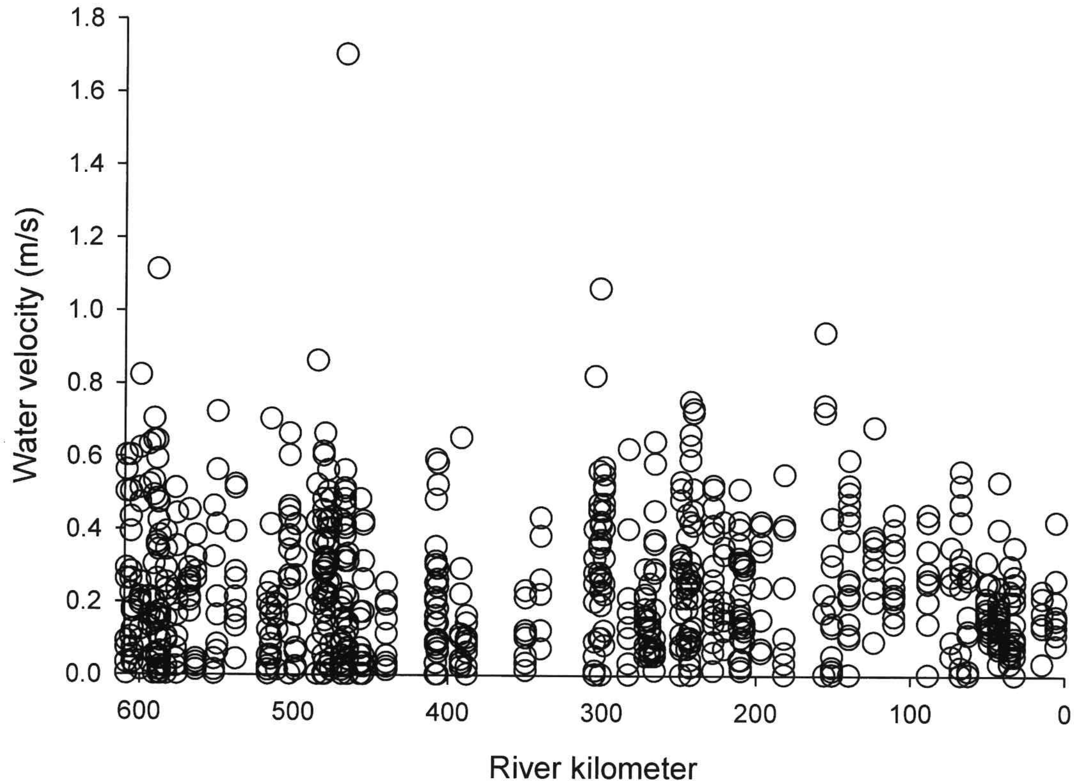

Figure 2.3. Water velocities of fyke net sets used to create contour plots.

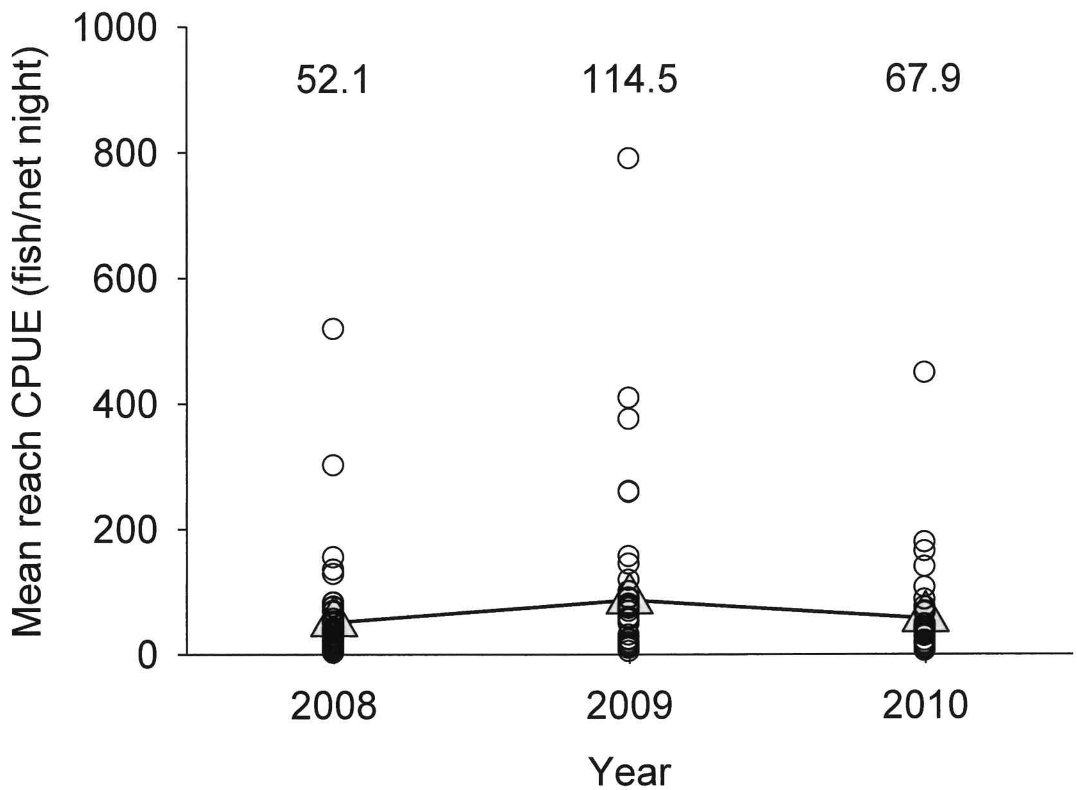

Figure 2.4. Mean reach CPUE of adult fish captured in fyke nets deployed in the lower Yellowstone River by year. Circles represent all reaches with the yearly mean indicated numerically above each histogram. Triangles represent the annual longitudinal sampling reach means.

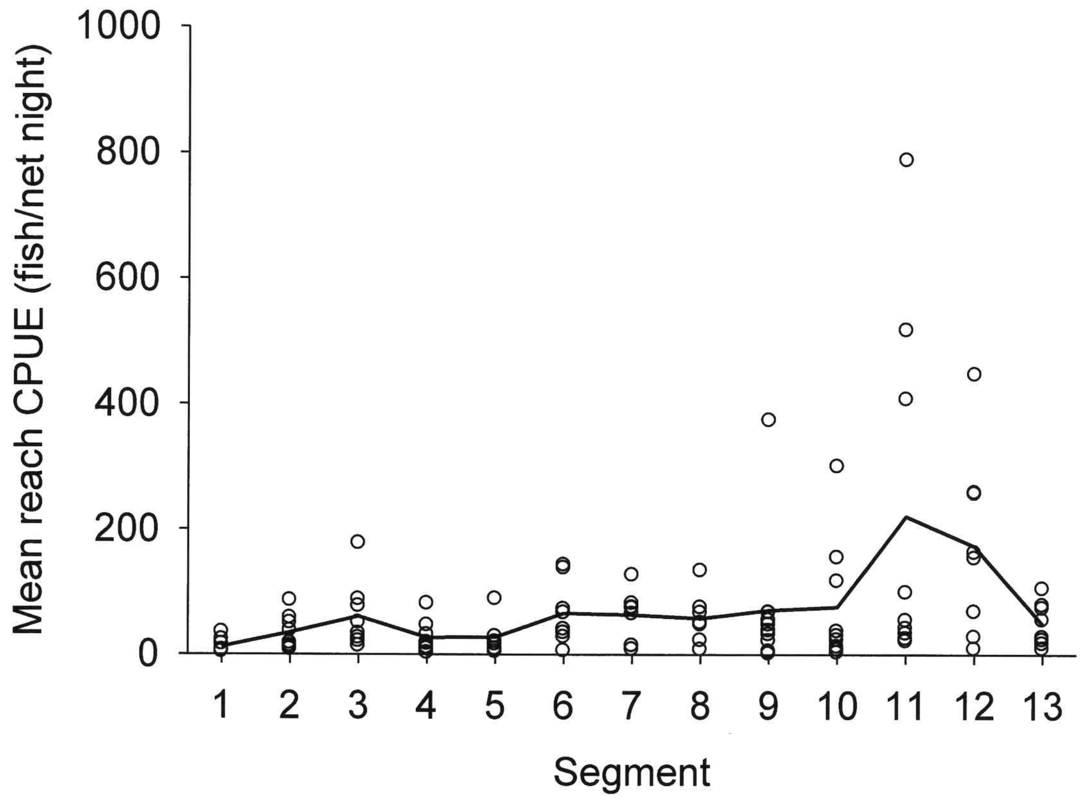

Figure 2.5. Mean reach CPUE of adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 in each segment. Line represents segment means.

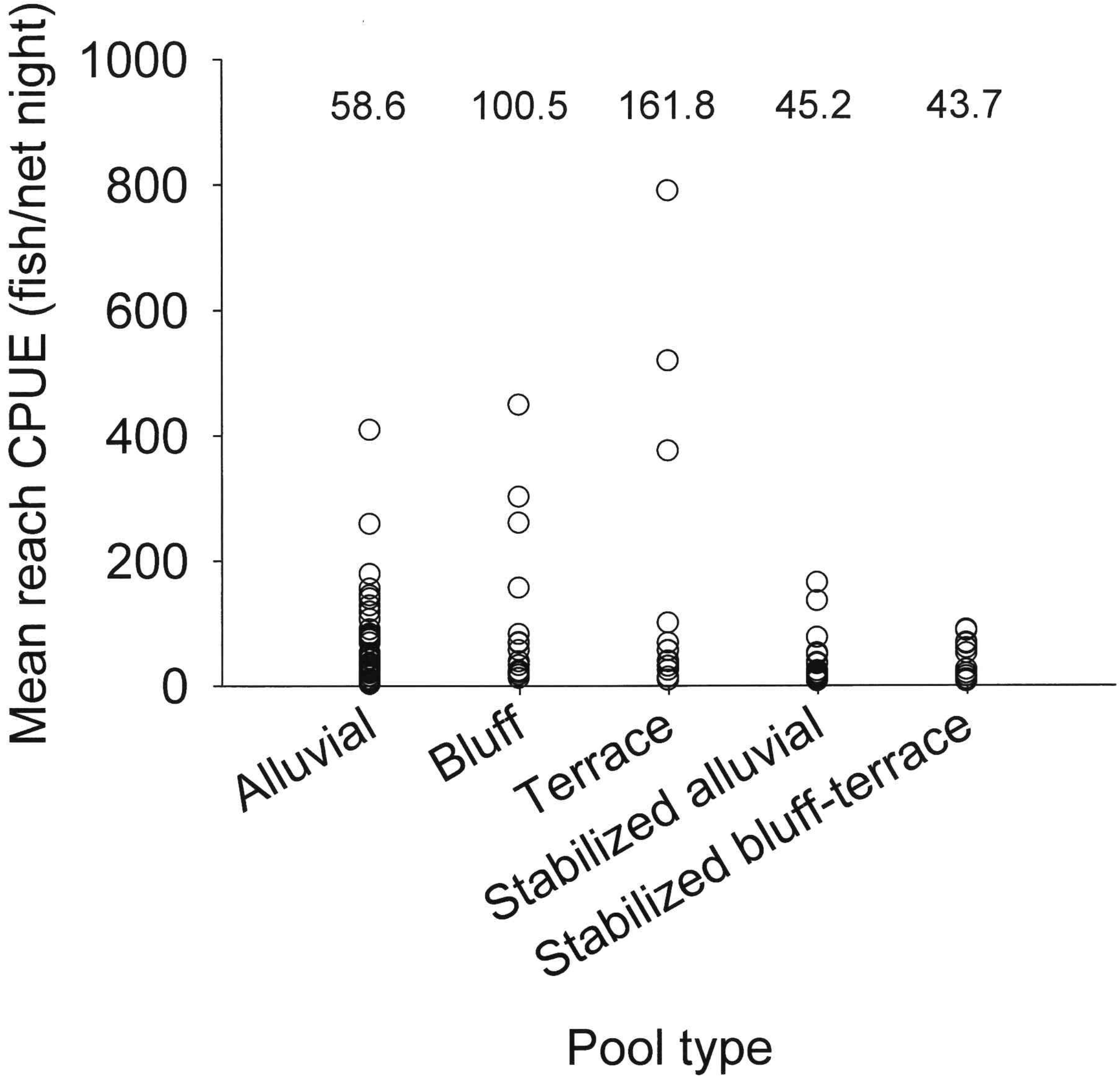

Figure 2.6. Mean reach CPUE of adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 among pool types. Numbers above histograms are the means for each pool type.

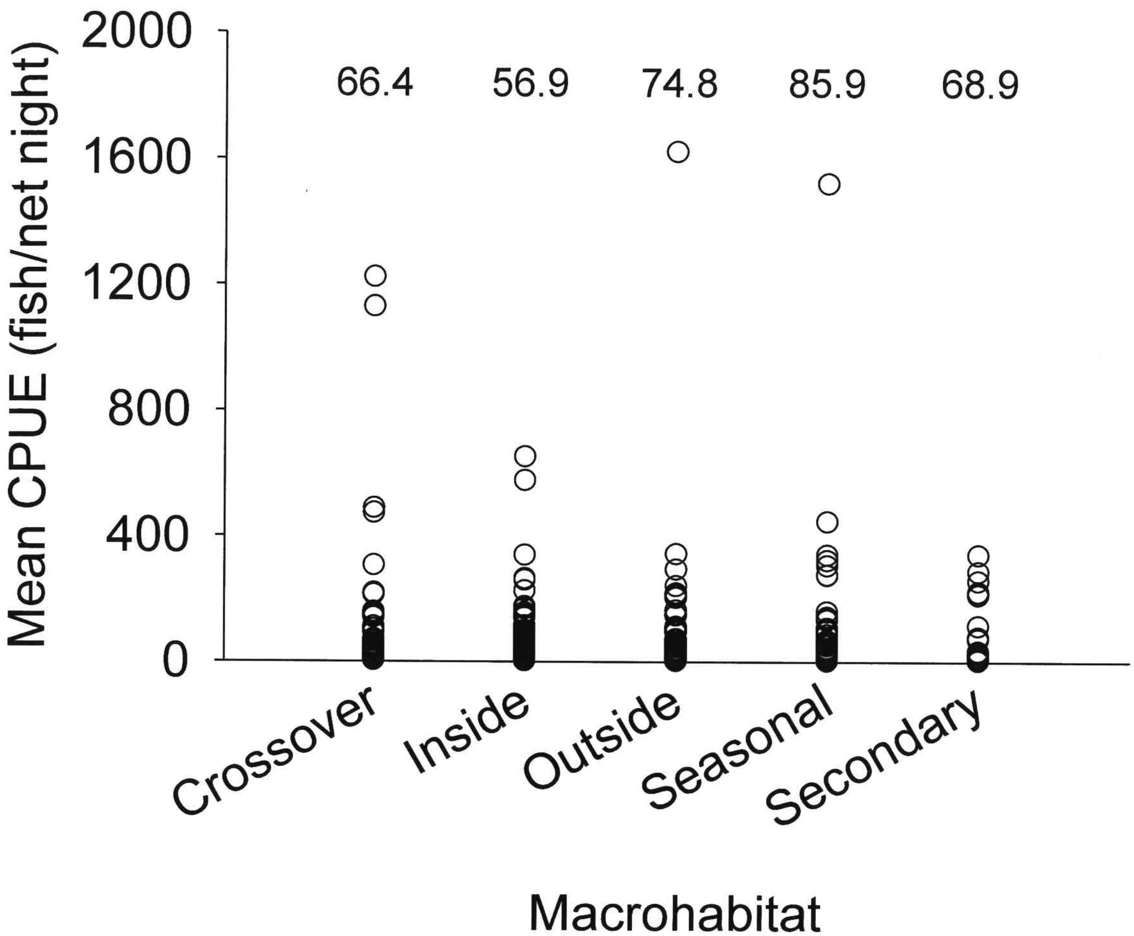

Figure 2.7. Mean reach CPUE of adult fish captured in fyke nets deployed in the lower Yellowstone River among macrohabitats. Numbers above histograms are the means for each macrohabitat.

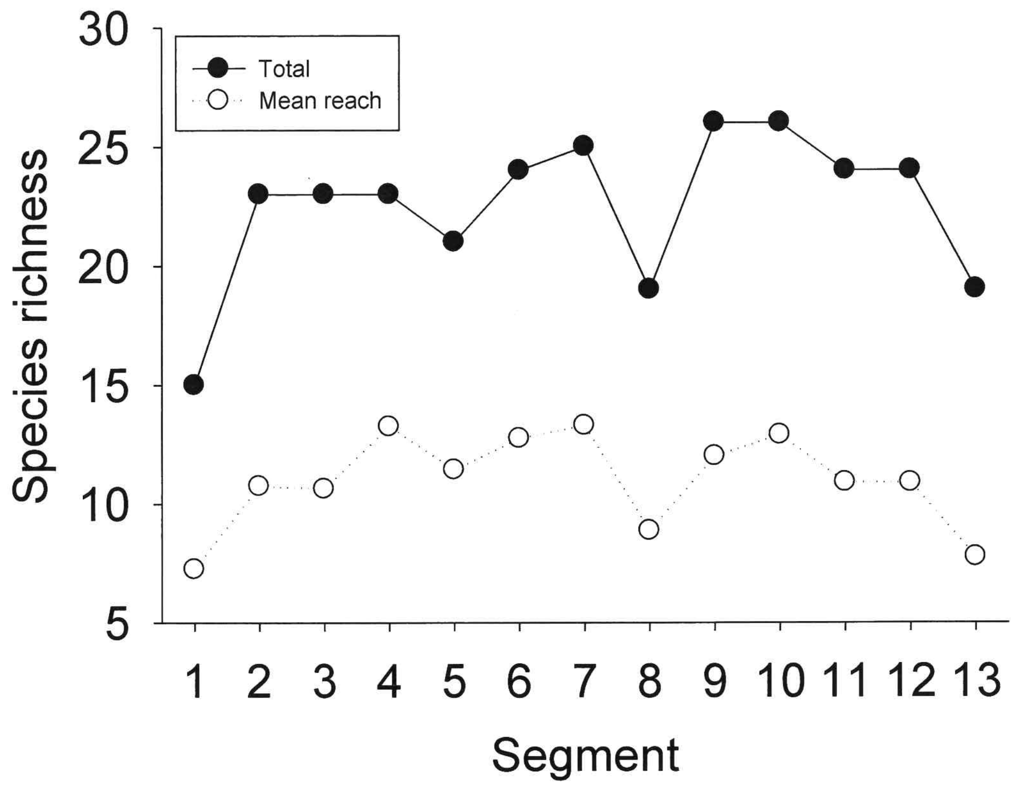

Figure 2.8. Total and mean reach species richness of adult fish captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010.

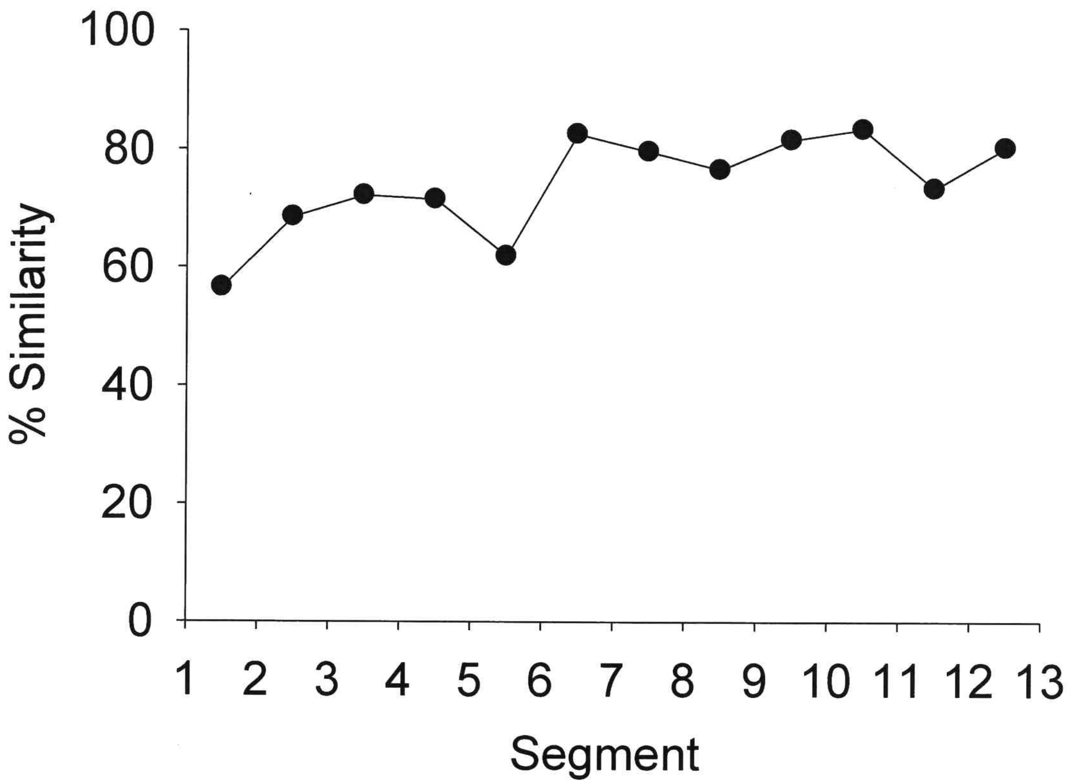

Figure 2.9. Assemblage similarity between pairs of adjacent Yellowstone River segments calculated from fyke net catch data collected from 2008 to 2010.

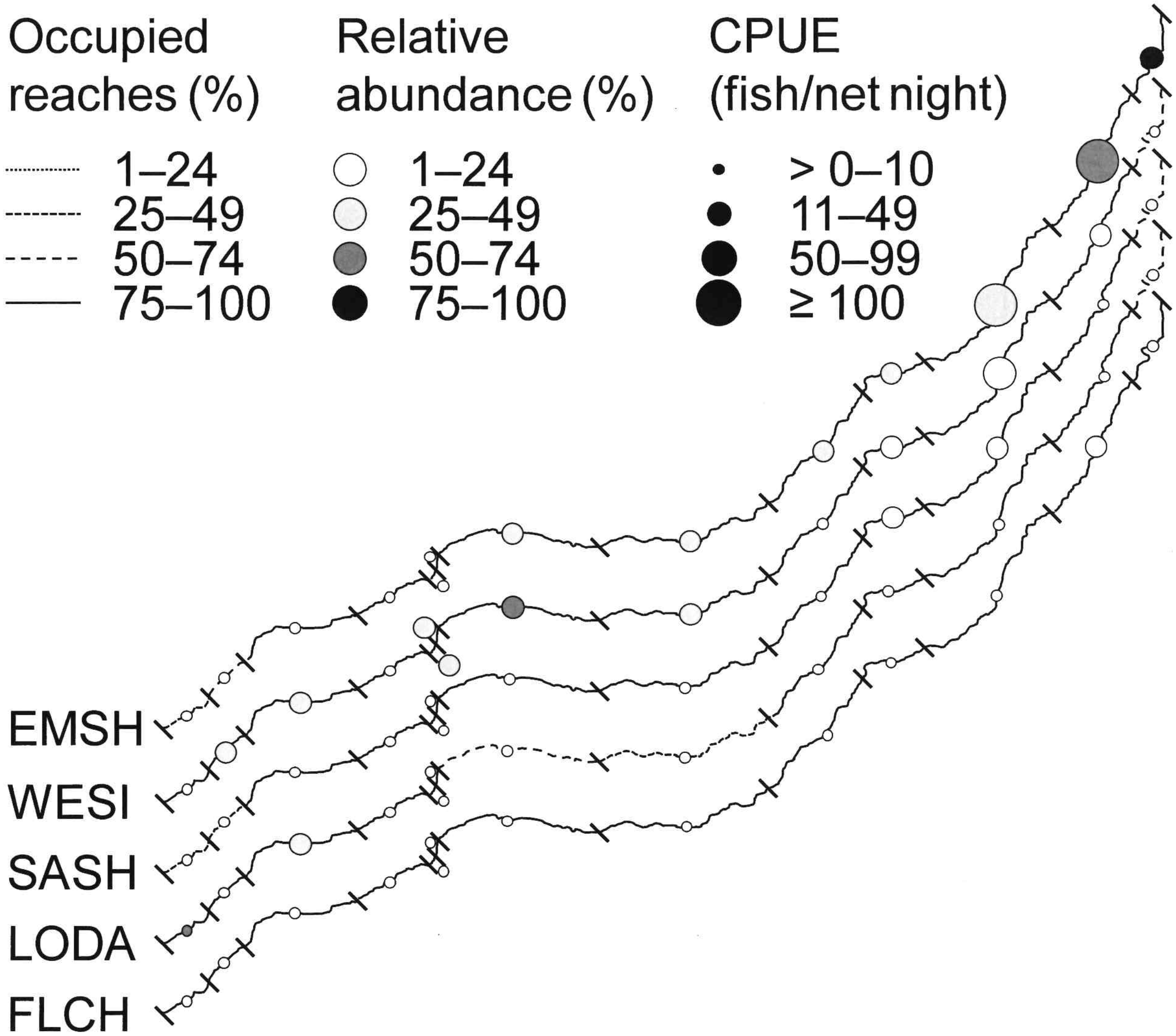

Figure 2.10. Distribution (percentage of occupied reaches) and abundance (mean reach relative abundance and CPUE) of adult emerald shiner (EMSH), flathead chub (FLCH), longnose dace (LODA), sand shiner (SASH), and western silvery minnow (WESI) captured with fyke nets. Sampling segments delineated by the black bars. The color and size of the circles represent the relative abundance and CPUE of each species, respectively.

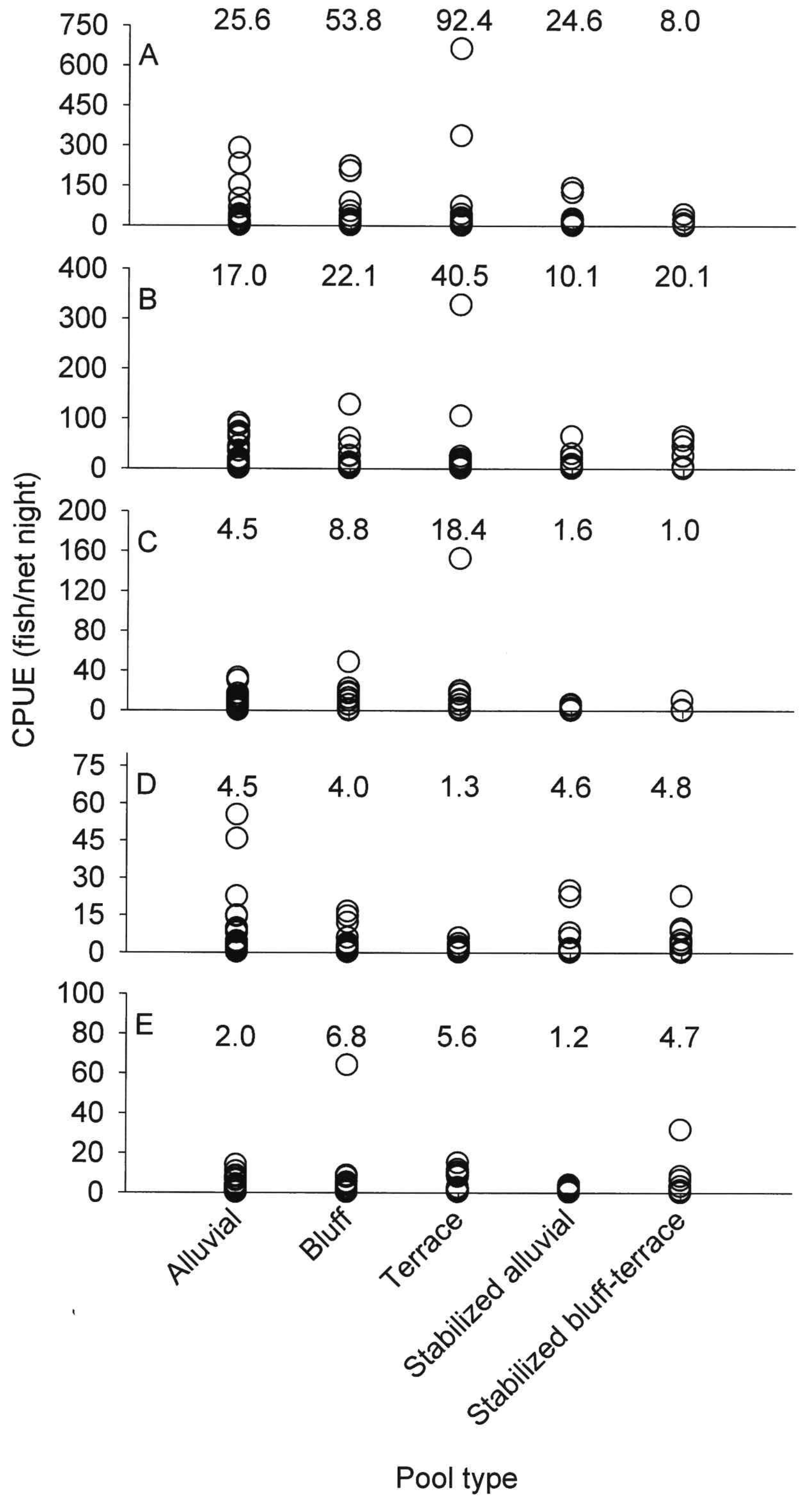

Figure 2.11. Mean reach CPUE of adult (A) emerald shiner, (B) western silvery minnow, (C) sand shiner, (D) longnose dace, and (E) flathead chub captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 among pool types. Numbers above histograms are the means for each pool type.

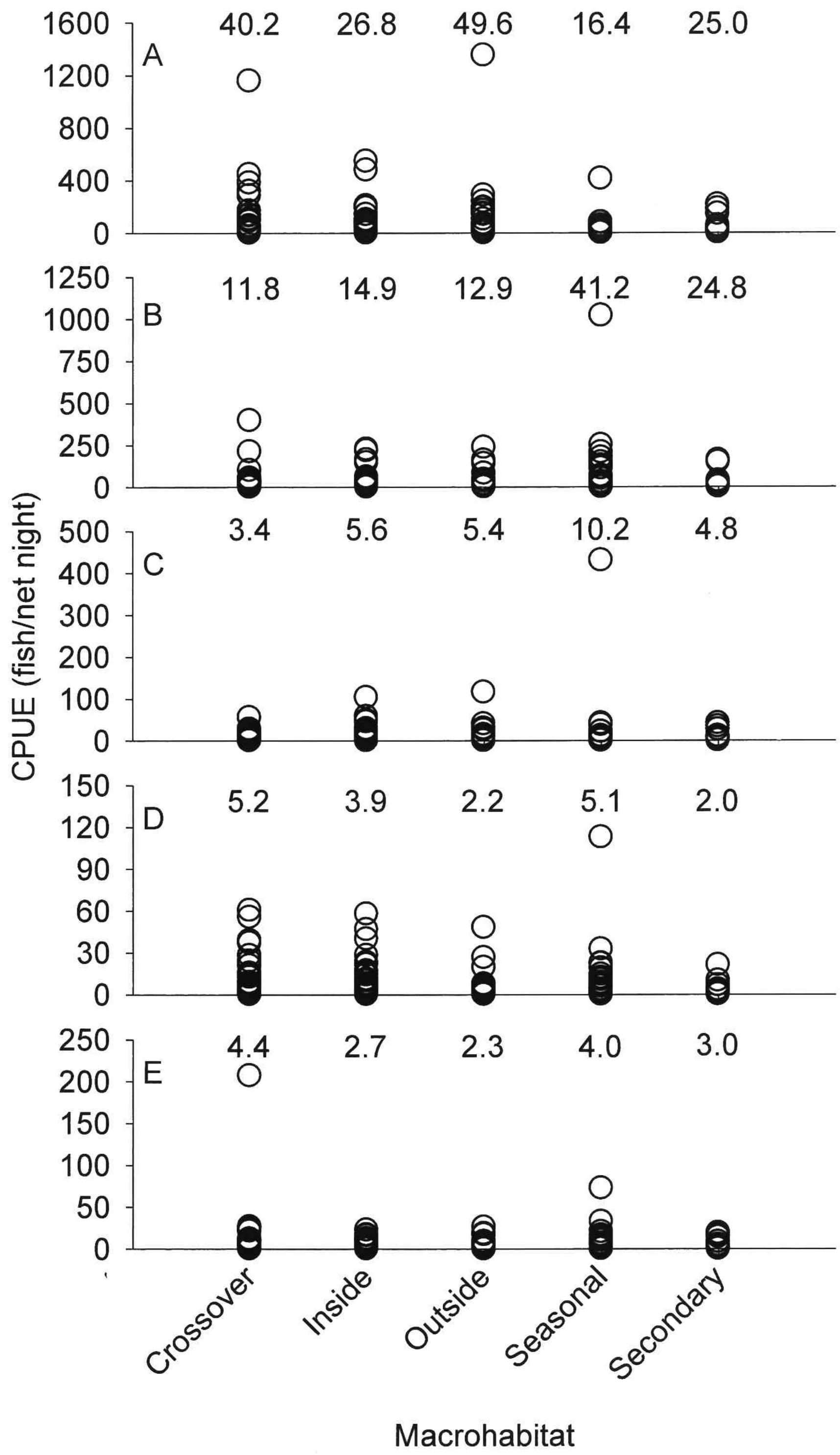

Figure 2.12. Mean reach CPUE of adult (A) emerald shiner, (B) western silvery minnow, (C) sand shiner, (D) longnose dace, and (E) flathead chub captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010 among macrohabitats. Numbers above histograms are the means for each macrohabitat.

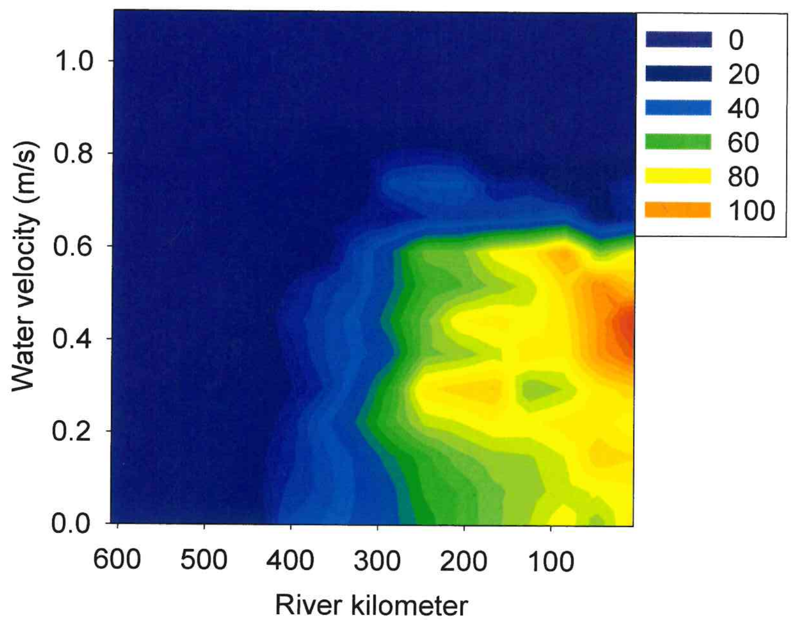

Figure 2.13. Fyke net CPUE (fish/net night) of adult emerald shiner in the lower Yellowstone River as a function of river kilometer and water velocity.

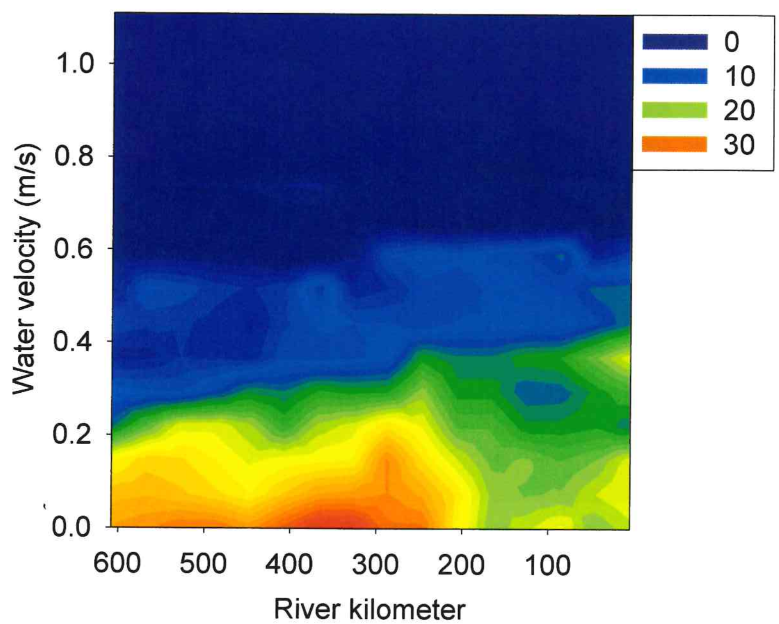

Figure 2.14. Fyke net CPUE (fish/net night) of adult western silvery minnow in the lower Yellowstone River as a function of river kilometer and water velocity.

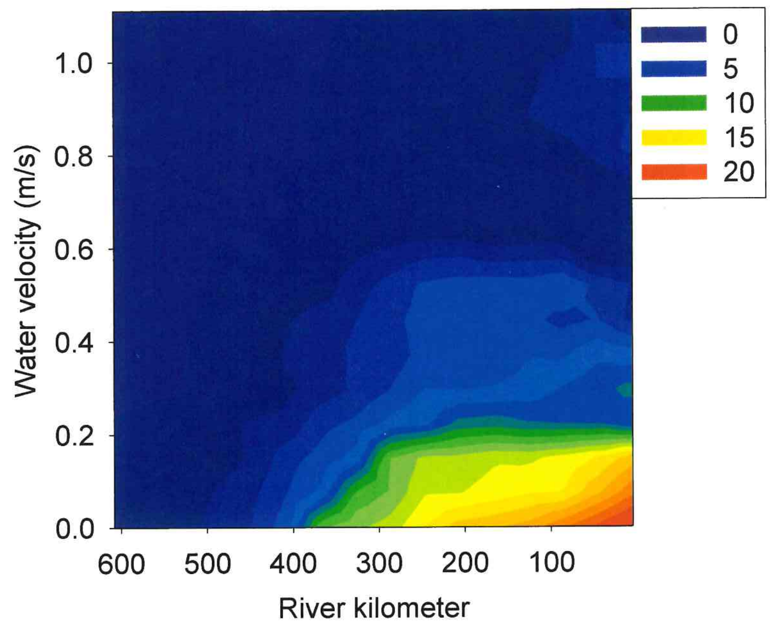

Figure 2.15. Fyke net CPUE (fish/net night) of adult sand shiner in the lower Yellowstone River as a function of river kilometer and water velocity.

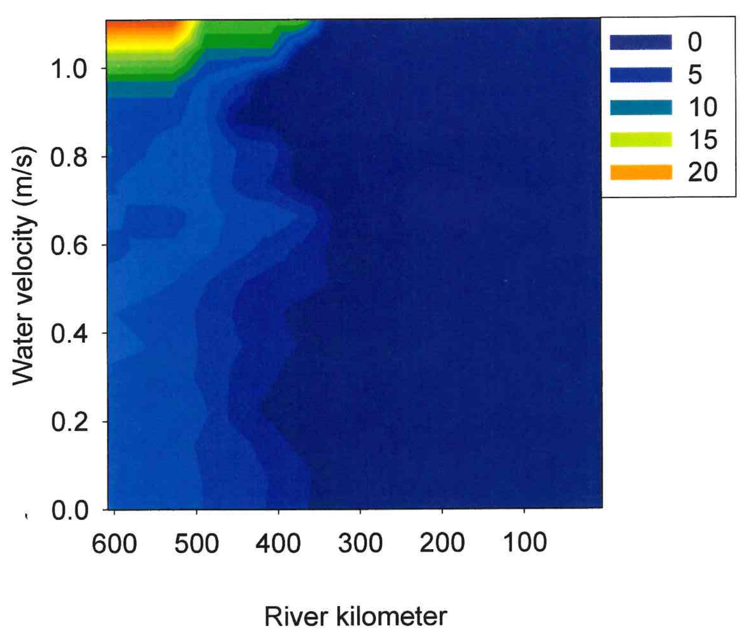

Figure 2.16. Fyke net CPUE (fish/net night) of adult longnose dace in the lower Yellowstone River as a function of river kilometer and water velocity.

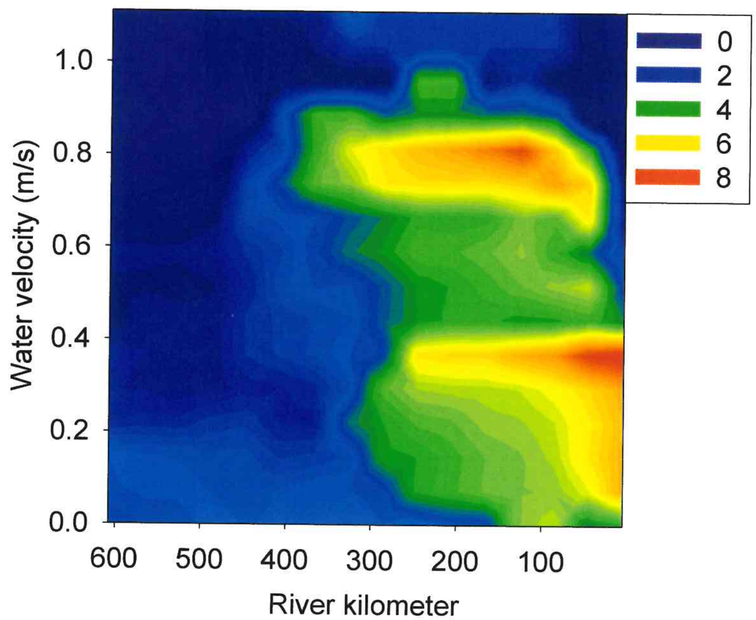

Figure 2.17. Fyke net CPUE (fish/net night) of adult flathead chub in the lower Yellowstone River as a function of river kilometer and water velocity.

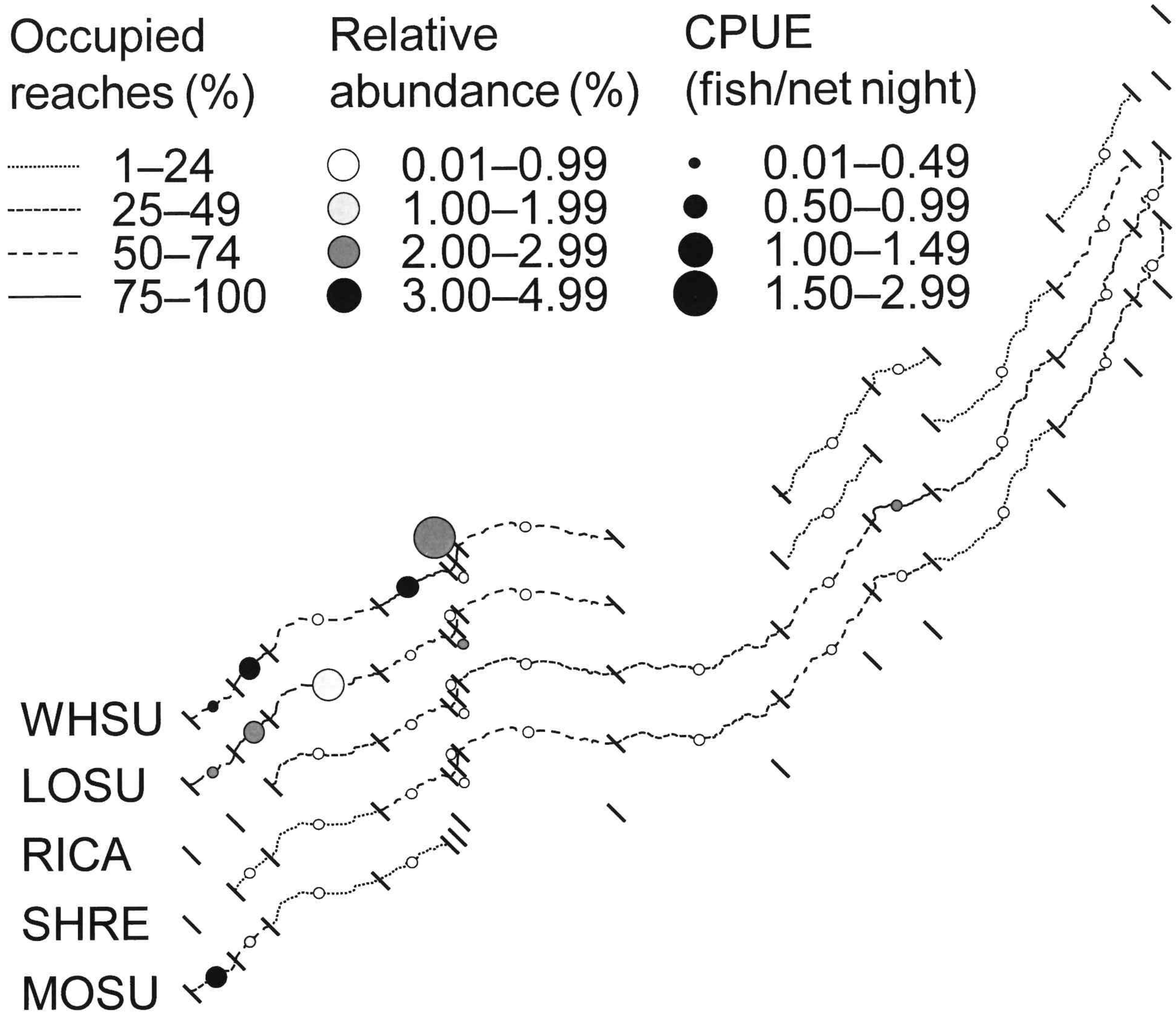

Figure 2.18. Distribution (percentage of occupied reaches) and abundance (mean reach relative abundance and CPUE) of adult longnose sucker (LOSU), mountain sucker (MOSU), river carpsucker (RICA), shorthead redhorse (SHRE), and white sucker (WHSU) captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010. Sampling segments delineated by the black bars. The color and size of the circles represent the relative abundance and CPUE of each species, respectively. No line indicates that the species was not captured in that segment.

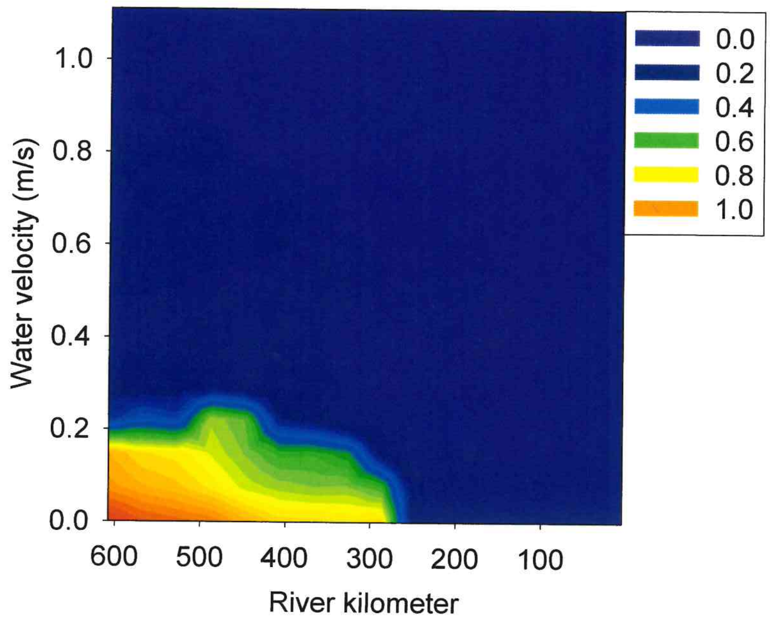

Figure 2.19. Fyke net CPUE (fish/net night) of adult white sucker in the lower Yellowstone River as a function of river kilometer and water velocity.

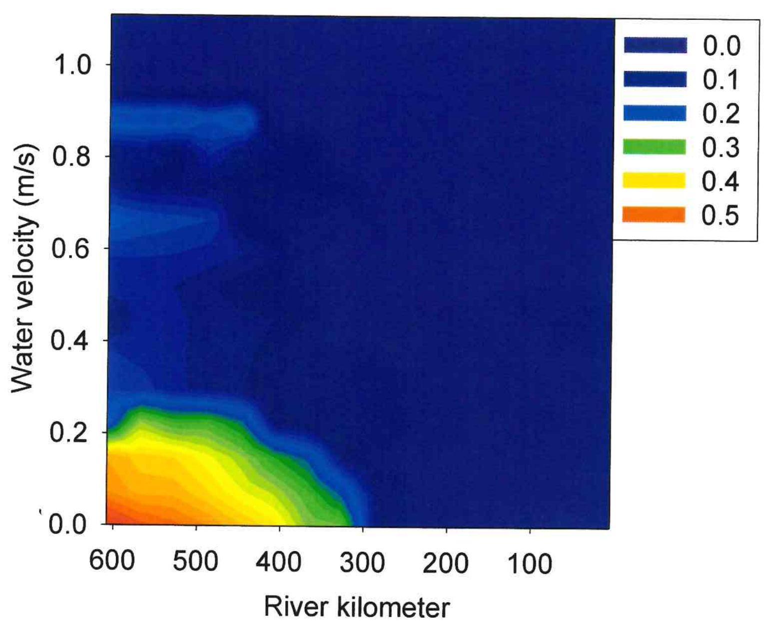

Figure 2.20. Fyke net CPUE (fish/net night) of adult longnose sucker in the lower Yellowstone River as a function of river kilometer and water velocity.

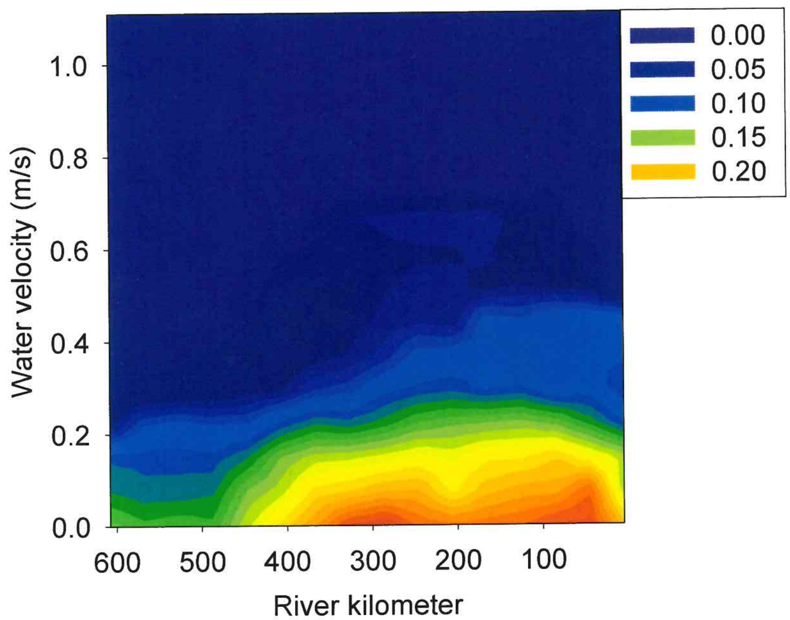

Figure 2.21. Fyke net CPUE (fish/net night) of adult river carpsucker suckers in the lower Yellowstone River as a function of river kilometer and water velocity.

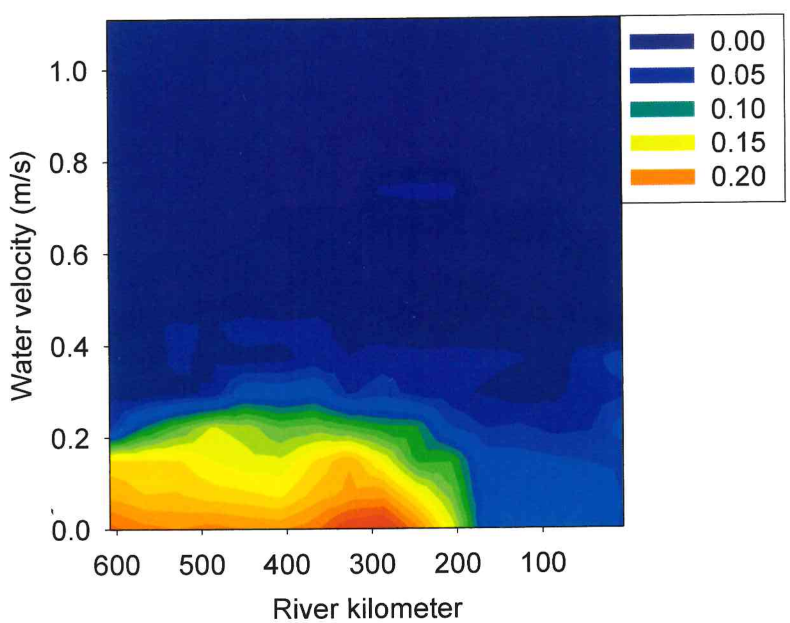

Figure 2.22. Fyke net CPUE (fish/net night) of adult shorthead redhorse in the lower Yellowstone River as a function of river kilometer and water velocity.

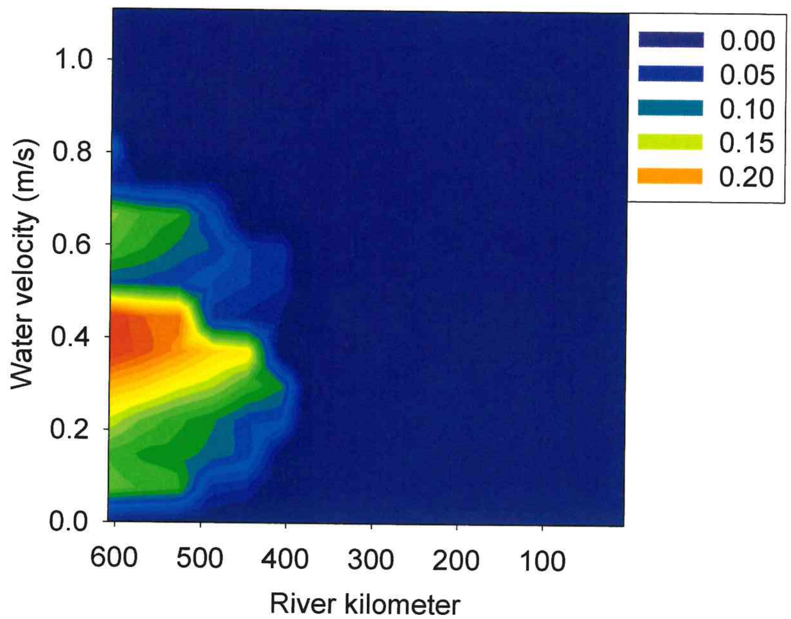

Figure 2.23. Fyke net CPUE (fish/net night) of adult mountain sucker in the lower Yellowstone River as a function of river kilometer and water velocity.

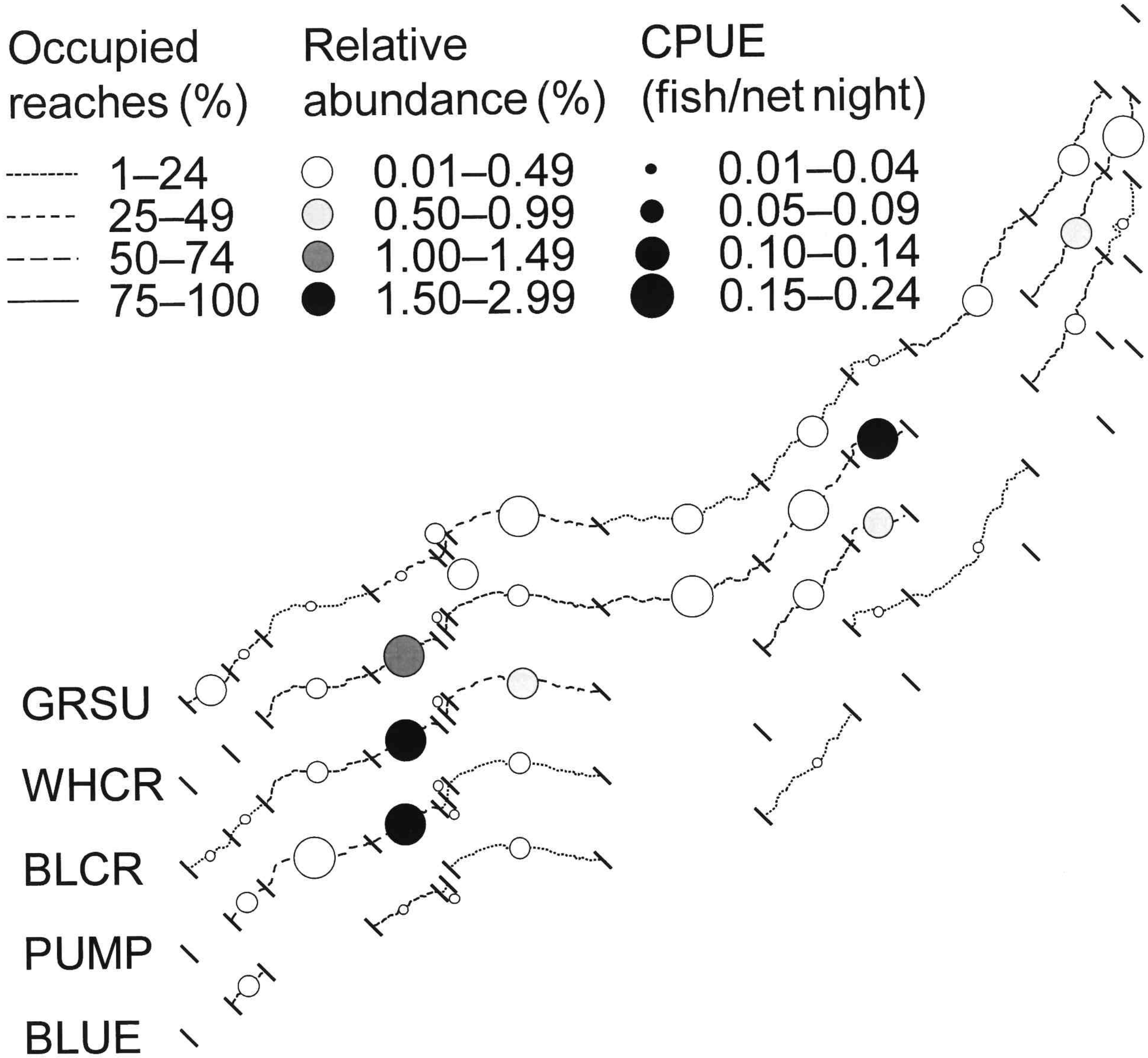

Figure 2.24. Distribution (percentage of occupied reaches) and abundance (mean reach relative abundance and CPUE) of adult bluegill (BLUE), green sunfish (GRSU), pumpkinseed (PUMP), black crappie (BLCR), and white crappie (WHCR) captured in fyke nets deployed in the lower Yellowstone River from 2008 to 2010. Sampling segments delineated by the black bars. The color and size of the circles represent the relative abundance and CPUE of each species, respectively. No line indicates that the species was not captured in that segment.

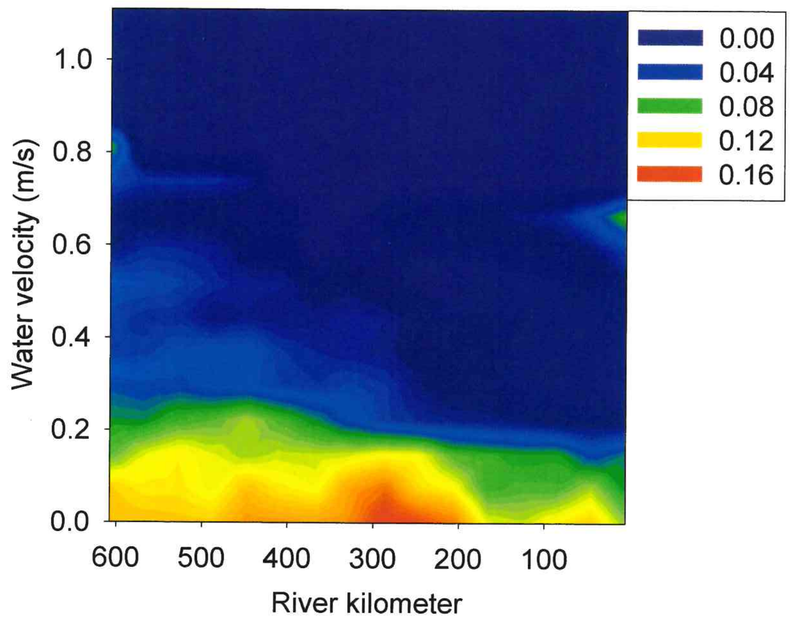

Figure 2.25. Fyke net CPUE (fish/net night) of adult green sunfish in the lower Yellowstone River as a function of river kilometer and water velocity.

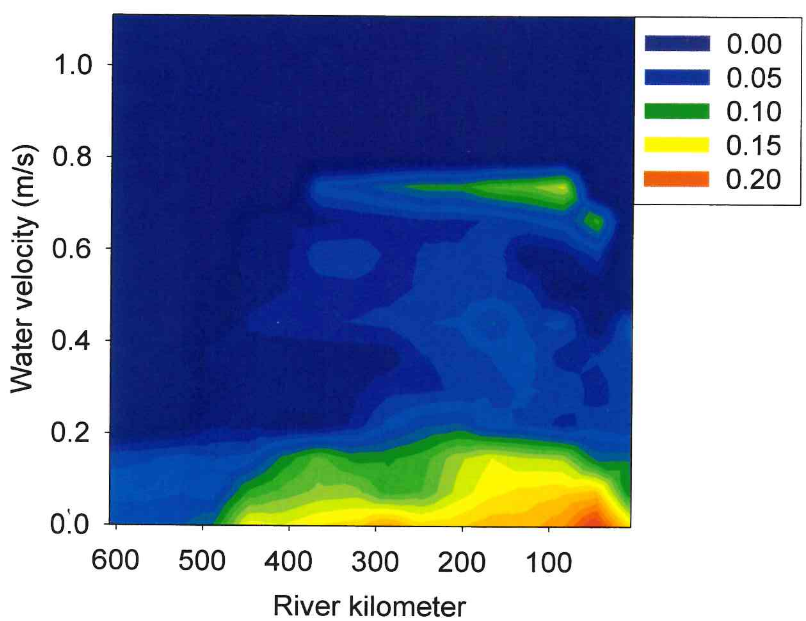

Figure 2.26. Fyke net CPUE (fish/net night) of adult white crappie in the lower Yellowstone River as a function of river kilometer and water velocity.

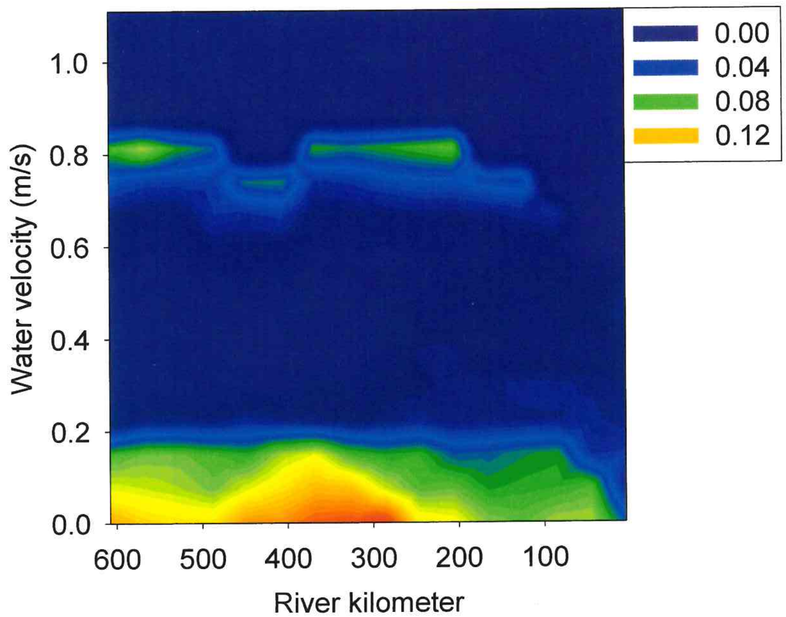

Figure 2.27. Fyke net CPUE (fish/net night) of adult black crappie in the lower Yellowstone River as a function of river kilometer and water velocity.

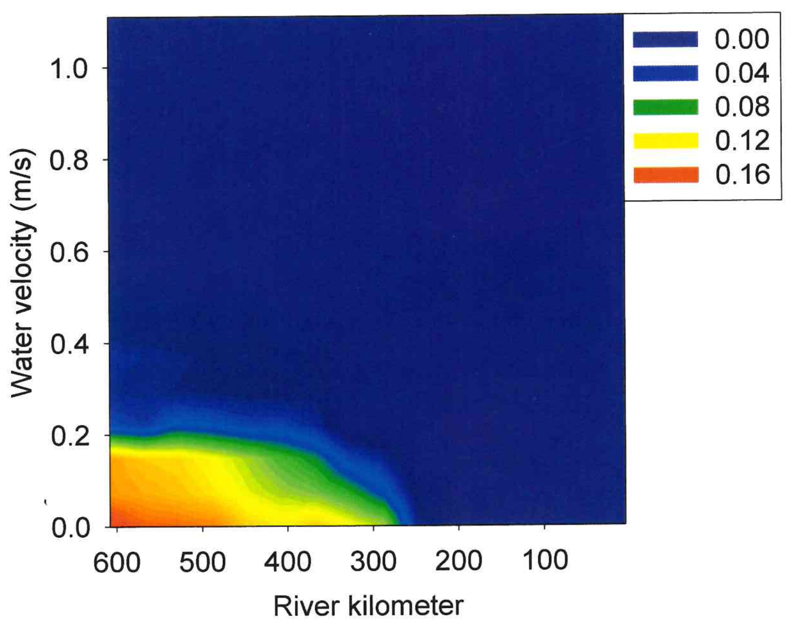

Figure 2.28. Fyke net CPUE (fish/net night) of adult pumpkinseed in the lower Yellowstone River as a function of river kilometer and water velocity.

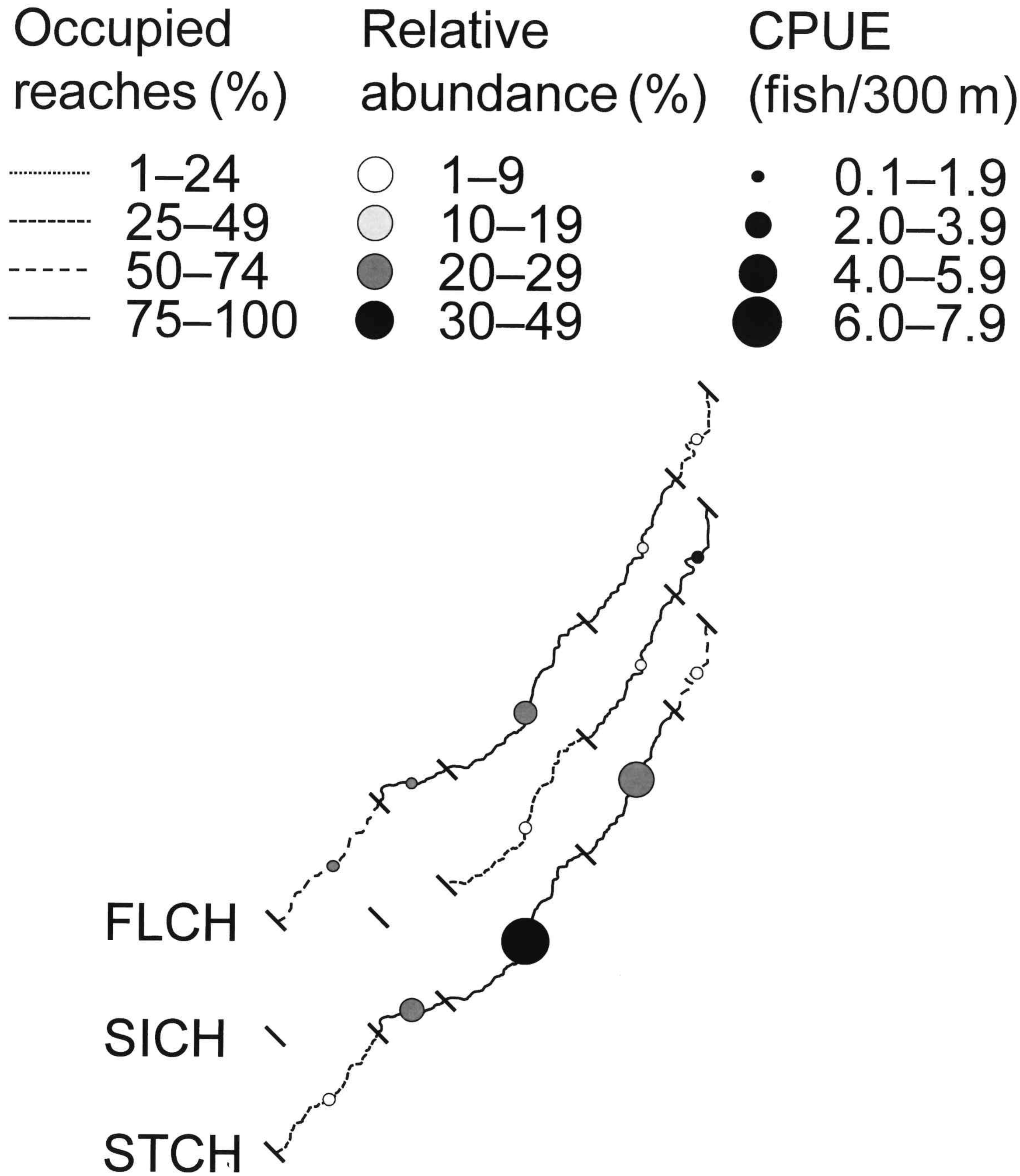

Figure 2.29. Distribution (percentage of occupied reaches) and abundance (mean reach relative abundance and CPUE) of adult flathead chub (FLCH), sicklefin chub (SICH), and sturgeon chub (STCH) captured in otter trawls deployed in the Yellowstone River downstream of the Tongue River. Sampling segments delineated by the black bars. The color and size of the circles represent the relative abundance and CPUE of each species, respectively. No line indicates that the species was not captured in that segment.

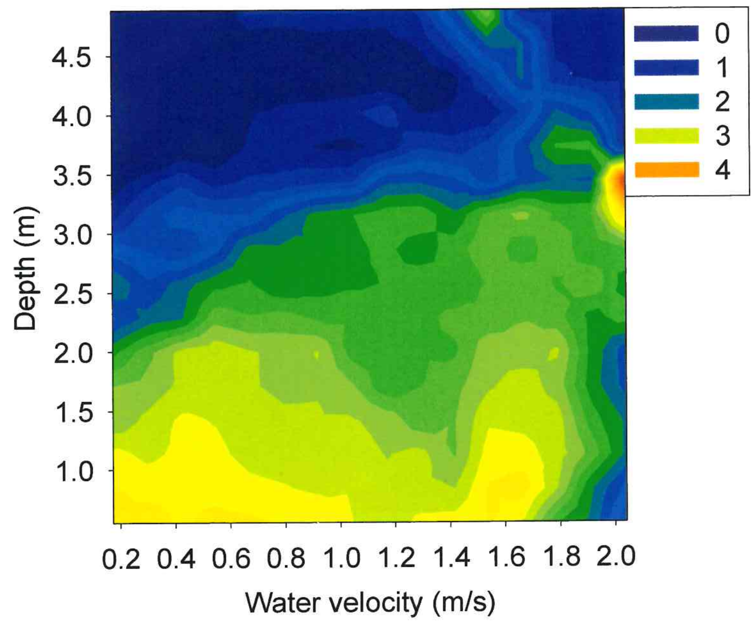

Figure 2.30. Otter trawl CPUE (fish/300 m) of adult sturgeon chub in the lower Yellowstone River as a function of depth and water velocity.

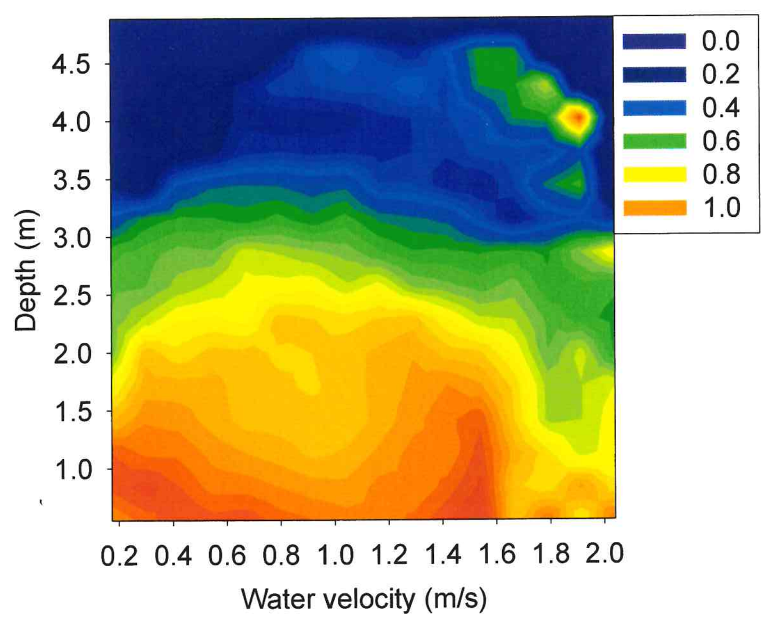

Figure 2.31. Otter trawl CPUE (fish/300 m) of adult flathead chub in the lower Yellowstone River as a function of depth and water velocity.

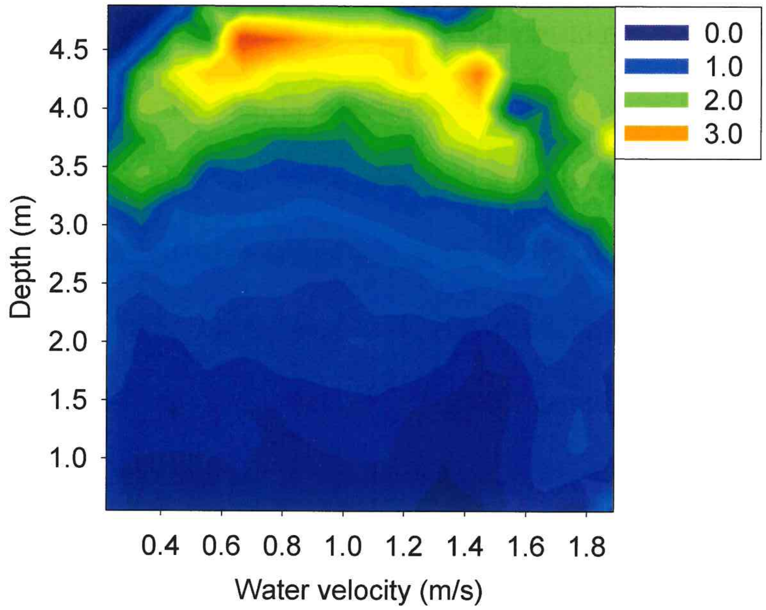

Figure 2.32. Otter trawl CPUE (fish/300 m) of adult sicklefin chub in the lower Yellowstone River as a function of depth and water velocity.

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Population Connectivity of Three Prairie Cyprinids in the Lower Yellowstone River and its Tributaries

Introduction

Dispersal, which is represented by the movement of an individual from its natal habitat to the place where it reproduces (Howard 1960), facilitates population connectivity and directs the interactions of individuals across the landscape (Kareiva 1986). Connectivity typically increases population viability of organisms (Brown and Kodric-Brown 1977) by buffering against temporally variable habitats, attenuating the effects of perturbations (Thomas and Jones 1993; Jones et al. 2009), permitting the colonization of new habitat patches, reducing inbreeding depression, and reducing competition (Hendry et al. 2004). This is especially true for many species living in small habitat patches (Fahrig and Merriam 1985; Henein and Merriam 1990; Saunders et al. 1991), which are inherently less stable than larger patches (MacArthur and Wilson 1967).

Naturally functioning prairie streams and rivers historically covered much of the interior United States (Dodds et al. 2004). The water flows, temperatures, and assemblage structures of prairie streams naturally varied seasonally and interannually (Poff and Ward 1989; Fausch and Bramblett 1991; Brown and Matthews 1995), creating instability in the distributions and abundances of fishes (Harrell 1978; Matthews and Hill 1980; Ross et al. 1985). However, prairie streams are becoming increasingly fragmented because of pollution, hydrologic disturbance, and physical modification from agriculture and urbanization, thereby increasing the instability of these habitats and their fish populations (Samson and Knopf 1994; Dodds et al. 2004). Intermittent discharge in small prairie streams can lead to unavoidable and intolerable water temperatures, salinities, turbidities, and hypoxic conditions in the absence of hyporheic recharge

(Schlosser 1991; Ostrand and Wilde 2002; Ostrand and Wilde 2004). Habitat shifts or increased predation may also occur in small isolated pools containing predators (Mathews et al. 1994). Flooding can increase lateral and longitudinal connectivity, but extirpations may also occur depending on the timing of the event (Dodds et al. 2004). Although prairie fishes may be more resilient to perturbations than other fishes, which helps to prevent local extirpations, recovery from extirpations may be slow because of extended isolation from source populations (Franssen et al. 2006). Isolation of small tributary populations in suboptimal habitats may result from diversion dams and main-stem reservoirs that have fragmented river networks (Winston et al. 1991). This combination of factors makes conservation of many prairie fishes difficult, especially when little is known about their movements.

Although the effects of population connectivity on stream fish assemblages have been thoroughly addressed (e.g., Winston et al. 1991; Fausch et al. 2002; Ward et al. 2002; Wiens 2002; Falke and Gido 2006; Franssen et al. 2006; Jansson et al. 2007), examining the specific role of dispersal in structuring small stream fish assemblages is difficult (Dodds et al. 2004). Telemetry is not feasible for monitoring movements of prairie stream fishes because their small size precludes attachment of transmitters. Mark-recapture studies are often short-term assessments (e.g., Lonzarich et al. 2000) limited to short stream segments (e.g., Freeman 1995; Petty and Grossman 2004) that result in distance-weighted movement data (Albanese et al. 2003). Although mark-recapture studies may provide habitat-use data, they lack the reliability to detect most large-scale movements over the entire lives of fish, which is information needed to develop basin-wide conservation strategies.

Analysis of natural chemical markers in the bones of fish has proven to be a reliable technique for directly monitoring the movements and environmental histories of many fishes. Otolith microchemistry and isotopic analyses are used for assessing natal origins (Thorrold et al.

1998; Warner et al. 2005), juvenile dispersal (Thorrold et al. 1997; Levin 2006), and adult movements (Kafemann et al. 2000; Zlokovitz et al. 2003). Trace element and isotope concentrations of otoliths reflect the surrounding environment and remain unchanged following deposition on the otolith (Campana and Thorrold 2001) allowing accurate and precise determination of fish movements among unique habitat patches if distinct chemical variation exists and individuals remain in locations long enough to incorporate signatures of those environments into otoliths (Kennedy et al. 2002). The ratio of ^{87}Sr:^{86}Sr is often used for isotopic analysis when geologic age differences and variable weathering processes exist within a watershed (Capo et al. 1989). We hypothesized that strontium isotopic analysis of fish otoliths would be a viable technique for determining movements among the main-stem Yellowstone River and its tributaries given the geological variability in the Yellowstone River Basin (Taylor et al. 1988).

Western silvery minnows *Hybognathus argyritis*, flathead chubs *Platygobio gracilis*, and sand shiners *Notropis stramineus* are common in the Yellowstone River (Chapter 2) and many of its tributaries (Mullen et al. 2011). Because these fishes live in both environments, they are ideal subjects to assess potential movements between the main-stem and its tributaries. Western silvery minnows and flathead chubs have experienced range reductions and population declines elsewhere (Pflieger and Grace 1987; Hesse et al. 1993; Harland and Berry 2004; Haslouer et al. 2005; Kral and Berry 2005) whereas sand shiners remain abundant throughout much of their range (Warren et al. 2000). Knowledge of species-specific movements between the Yellowstone River and its tributaries may help identify why western silvery minnows and flathead chubs are more susceptible to perturbation than sand shiners. For example, we can identify habitat fragmentation as a reason for decreasing abundances and distributions of flathead chubs and western silvery minnows if it is determined that these species require access to tributaries or long connected main-stem segments. Fisheries managers can also use this information to identify important populations, migration corridors, or nursery areas needed to maintain unique life histories and essential ecosystem services that these species provide in large river systems.

Our objectives were to 1) determine the proportions of resident and dispersing individuals of selected species in the lower Yellowstone River and its tributaries, and 2) identify dispersal patterns of these selected species.

Methods

Study area.—The Yellowstone River originates in the Rocky Mountains of northwest Wyoming and flows 1,114 km to its confluence with the Missouri River in North Dakota (Figure 3.1). The Tongue River originates in the Bighorn Mountains of north-central Wyoming, has a drainage basin area of 13,978 km^2, and flows into the Yellowstone River at river kilometer (RKM) 296 (Jenkins 2007). The Powder River also originates in the Bighorn Mountains of north-central Wyoming, has a drainage basin area of 34,159 km^2, and flows into the Yellowstone River at RKM 238 (Jenkins 2007). Sunday, O'Fallon, and Cabin creeks all originate in the Northwestern Great Plains ecoregion of southeast Montana (Woods et al. 1999) and flow into the Yellowstone River at RKMs 280, 206, and 179, respectively (Jenkins 2007). Sunday Creek has a drainage area of 1,900 km^2. O'Fallon Creek has a drainage area of 4,148 km^2. Cabin Creek has a drainage area of 1,000 km^2. Volcanic and sedimentary rocks from the Cambrian to Quaternary time periods compose most of the upper Yellowstone River Basin whereas the lower basin is composed of Cretaceous and Tertiary sedimentary sandstone and shale (Taylor et al. 1988; Zelt et al. 1999).

Water samples were collected for ^{87}Sr:^{86}Sr analysis from 17 locations (Figure 3.1). Analysis was limited to ^{87}Sr and ^{86}Sr because we deemed the underlying geologic variability among the Yellowstone River and its tributaries sufficient to identify individual $^{87}Sr{:}^{86}Sr$ river signatures. Samples (50 mL) were collected using ultra-clean vials, filtered with 0.45-µm sterile filters, and preserved with 0.5 mL of HNO_3. An inductively coupled plasma-mass spectrometer (ICP-MS) was used to measure ^{87}Sr and ^{86}Sr. The internal precision for Sr isotopic measurements was 5 to 10 ppm (2σ). The external precision was about 25 ppm, after instrument mass bias was corrected using a river water standard (SMR987) with a $^{87}Sr{:}^{86}Sr$ ratio of 0.71024.

Initial water chemistry analysis of Yellowstone River Basin and Missouri River (one site immediately downstream of the Yellowstone River) water samples collected during baseflow conditions on 28 and 29 August 2008 revealed spatial differences in $^{87}Sr{:}^{86}Sr$ (Table 3.1; Figure 3.2). In general, the large tributaries had relatively high $^{87}Sr{:}^{86}Sr$ ratios, the small tributaries had low ratios, and the ratios in the Yellowstone River downstream from the Clark's Fork were intermediate. Temporal $^{87}Sr{:}^{86}Sr$ variation in water chemistry was assessed monthly in the Yellowstone River at a site downstream of the Powder River from 30 August 2010 to 4 August 2011 and bimonthly in the Tongue River and Cabin Creek from 30 August 2010 to 27 June 2011 (Figure 3.3).

Main-stem and tributary $^{87}Sr{:}^{86}Sr$ signatures (mean $^{87}Sr{:}^{86}Sr \pm 2$ SD) quantified the expected $^{87}Sr{:}^{86}Sr$ values for the Yellowstone River and its tributaries based on the spatial and temporal water chemistry data above. Additional water chemistry data reported by Frost and Mailloux (2011) were also used for the Powder River. Sunday, O'Fallon, and Cabin creeks were combined into a single category (i.e., small tributaries) because of the similarity of the watershed areas (Jenkins 2007) and underling geology of each stream (Taylor et al. 1988), which resulted in similar $^{87}Sr{:}^{86}Sr$ signatures. River signatures were calculated using two standard deviations, rather than 95% confidence intervals, to help account for potentially greater $^{87}Sr{:}^{86}Sr$ variability during years prior to sampling or between temporal sampling events. The upper and lower

$^{87}Sr:^{86}Sr$ limits for the Yellowstone River were 0.70972 and 0.70909, respectively. The upper and lower $^{87}Sr:^{86}Sr$ limits for the Powder River were 0.71085 and 0.71035, respectively. The upper and lower $^{87}Sr:^{86}Sr$ limits for the Tongue River were 0.71004 and 0.70881, respectively. Signatures less than 0.70909 (the lower limit for the Yellowstone River) were representative of small tributaries for otoliths collected from fish captured at all sites other than the Tongue River or the reach immediately downstream of the Tongue River confluence (see below for site locations). Signatures less than 0.70881 were representative of small tributaries for fish captured in the Tongue River or in the Yellowstone River immediately downstream of the Tongue River. Two standard deviations were not used to calculate a small tributary $^{87}Sr:^{86}Sr$ signature because small streams in our study area may produce lower $^{87}Sr:^{86}Sr$ signatures than were observed for the small tributaries that were sampled.

Otolith microchemistry.—We captured 188 sand shiners, 169 western silvery minnows, and 182 flathead chubs from 10 different locations in the lower Yellowstone River Basin during the spring and summer of 2009 and 2010 (Table 3.2; Figure 3.2). The length of each fish was recorded. Yellowstone River sites were located 10 RKMs above or below tributary confluences. Tributary sites were 10 RKMs from their confluence with the Yellowstone River. These locations were sufficiently distant to detect significant movements as opposed to minor movements near tributary mouths. Fish were collected from at least three separate seine hauls at each site to enhance sample independence; fish collected from a single seine haul (i.e., school) may have the same life history strategy, which would have reduced our ability to detect multiple movement patterns. Total length (TL; mm) of each fish was measured before it was placed on ice for transportation to the laboratory where it was stored frozen until its otoliths were extracted.

The right sagittal otolith of each fish was extracted with nonmetallic acid-washed tools. Otoliths were triple-rinsed with ultrapure water (Milli-Q), scrubbed with a nylon brush, and triple-rinsed again. Otoliths were dried under a laminar-flow hood for 24 h and stored in centrifuge vials. Otoliths were mounted on petrographic slides sulcus side up using cyanoacrylate glue, ground to the planes of nuclei using 600- and 1500-grit sand paper, and polished with 0.5- and 0.1-μm diamond lapping film. Otoliths were scrubbed with a nylon brush, triple rinsed, and left to soak in water overnight. After the mounting glue dissolved, the polished otoliths were triple-rinsed and remounted on a new slide using double-sided tape.

An ICP-MS coupled with a 213-mm laser ablation system was used to measure isotopic concentrations of ^{86}Sr and ^{87}Sr along a transect on each otolith. Processing was randomized within and among species and collection sites. Ablated material was measured along a transect from the core to edge of the otolith at a rate of 5 μm/s using a 25-μm laser beam (10 Hz, 100% power). The ablated otolith material was carried by He gas to the ICP-MS where it was mixed with an Ar carrier gas and wet aerosol (2% HNO_3) from a 20-μL/min perfluoroalkoxy self-aspirating nebulizer. An aragonite otolith reference material (Yoshinaga et al. 2000) dissolved and diluted to 40 μg per gram of Ca in solution was periodically measured to assess instrument drift and changes in mass bias (Jackson and Hart 2006). All data were normalized based on mean observed SRM987 ^{87}Sr:^{86}Sr values for the day using a SRM987 ^{87}Sr:^{86}Sr value of 0.71024 and corrected for potential Rb and Kr interferences described by Jackson and Hart (2006). A three-point running mean was used to smooth variability of ^{87}Sr:^{86}Sr ratios along the otolith transect that probably resulted from measurement error. An "otolith profile" representing ambient ^{87}Sr:^{86}Sr ratios of inhabited environments over the lifetime of each fish was produced.

Data analysis.—The age of each fish was estimated using the same length-based analysis conducted in Chapters 1 and 2. An otolith profile exhibiting ^{87}Sr:^{86}Sr ratios entirely within the range of expected ^{87}Sr:^{86}Sr values for the location where the fish was captured represented a resident. An otolith profile with ^{87}Sr:^{86}Sr ratios outside the signature of the location where the fish was captured was considered a disperser. Dispersers were further classified as main-stem-tributary or tributary-main-stem dispersers based on the natal origin of the fish, which was determined using the core ^{87}Sr:^{86}Sr value, and any subsequent movements, which were determined using ^{87}Sr:^{86}Sr values outside of the core and capture locations. Tributary-tributary dispersers were fish with otolith profiles or capture locations that included at least two of the three tributary categories (i.e., Powder River, Tongue River, and small tributary). Otolith profiles containing ^{87}Sr:^{86}Sr values between river signatures were indicative of fish that inhabited mixing zones of the Yellowstone River and its tributaries as has been observed in other otolith microchemistry studies (e.g., Clarke et al. 2007).

Results

Otolith microchemistry.—Four life history strategies of fish captured in the Yellowstone River were identified using otolith profiles (Figure 3.5): main-stem resident, main-stem disperser (hatched in the Yellowstone River and moved into a tributary), tributary disperser (hatched in any tributary and moved into the Yellowstone River), and tributary-tributary disperser (inhabited multiple tributaries, but captured in the Yellowstone River). Four life history strategies of fish captured in tributaries were identified (Figure 3.5): tributary resident, main-stem disperser (hatched in the Yellowstone River and moved into the tributary in which it was captured), tributary disperser (hatched in a tributary and subsequently moved into the Yellowstone River), and tributary-tributary disperser (hatched in one tributary but captured in another). Movement patterns varied among the three study species and sampling locations (Table 3.3). We were unable to distinguish Tongue River residents from main-stem dispersers because ^{87}Sr:^{86}Sr values overlapped between the Tongue and Yellowstone rivers.

Fifty percent of all sand shiners were dispersers (Table 3.4). The sand shiners we captured in the Yellowstone River were from a mixed population of roughly equal main-stem residents, main-stem dispersers, and tributary dispersers (Table 3.3). About 50% of the sand shiners captured in the Powder and Tongue rivers were tributary-tributary dispersers. The remaining sand shiners captured in the Powder River were either main-stem or tributary dispersers. The remaining sand shiners captured in the Tongue River were either residents or main-stem dispersers. At least 90% of the sand shiners captured in each of the three small tributaries were residents, and none were tributary dispersers.

Seventy-two percent of all western silvery minnows captured were dispersers (Table 3.4). Most of the western silvery minnows captured in the Yellowstone River were main-stem dispersers that had returned to their natal habitat or residents (Table 3.3). Over half of the western silvery minnows captured in the Powder and Tongue rivers were tributary-tributary dispersers. Most of the remaining western silvery minnows captured in the Powder River dispersed from the Yellowstone River. There was only one tributary dispersing western silvery minnow captured in the Powder River, and none were Powder River residents. Thirty percent of western silvery minnows captured in the Tongue River were either residents or main-stem dispersers. Western silvery minnows captured in O'Fallon Creek were all either tributary dispersers or main-stem dispersers. In contrast, Sunday and Cabin creeks had 67% and 80% tributary resident western silvery minnows, respectively. However, many of these were age-0 fish; the few large individuals that were captured were dispersers.

Seventy-one percent of all flathead chubs were dispersers. The movement pattern proportions of flathead chubs captured in the Yellowstone River were similar to those of western silvery minnows. Most flathead chubs captured in the Powder and Tongue rivers were tributary-tributary dispersers. The Powder River also had main-stem and tributary dispersers, but had no tributary residents. The Tongue River also had either main-stem dispersers or tributary residents. Flathead chubs captured in O'Fallon Creek were either main-stem dispersers or tributary dispersers; there were no tributary residents captured. In contrast, Sunday and Cabin creeks had 40% and 55% tributary resident flathead chubs, respectively. However, many of these were age-0 fish; the few large individuals were dispersers.

Discussion

Dispersal between the Yellowstone River and its tributaries was pervasive among the three fish species we studied. About two thirds of all fish captured in the Yellowstone River had dispersed to tributaries at some point in their life history. Among tributaries, dispersal rates declined with watershed area. Dispersal was universal among fish from the Powder River; 100% of fish had dispersed to either the Yellowstone or another tributary. Whereas over half the fish from O'Fallon Creek were dispersers, only about 30% of fish from Sunday Cabin creeks were dispersers.

Although it is possible that migratory individuals exist among our study species, our otolith profiles indicate that dispersal is the common mode of movement in the lower Yellowstone River Basin. Similar to Hendry et al. (2004), we consider migration as the spatiotemporally predictable movement of animals between breeding, foraging, and wintering habitats. Otolith profiles would have indicated migration by showing movements of fish that dispersed from their natal habitats and subsequently returned. Although some profiles indicated migratory type movements, movements indicative of dispersal were more common. However, the small proportion of migratory profiles in our study may be the result of confounding effects of maternal isotopic concentrations or short rearing times in natal habitats. Maternal origins can affect the core chemistry of progeny otoliths (Volk et al. 2000; Ruttenburg et al. 2005). Detecting isotopic concentrations for natal habitats may be difficult if larval or juvenile fish leave the area prior to or soon after hatching. Western silvery minnows are thought to be broadcast spawners (Layher 2003; Milk River Fish Species at Risk Recovery Team 2008), with pelagic eggs that develop while drifting in the current. This form of development probably precludes the incorporation of chemical signatures for spawning habitats into the otolith cores of progeny. Therefore, it may be difficult or impossible to detect the natal origins of some species using otolith microchemistry.

Dispersal rates also differed among fish species, and differences were most pronounced in smaller tributaries. It appears that sand shiners have largely insular populations in small streams, as well as main-stem populations that disperse between main-stem and both tributary habitats. However, most western silvery minnow and flathead chubs are dispersers, regardless of capture location.

The differences in dispersal rates among the three study species might provide some insight into the reasons for their current distribution and status in the Mississippi River Basin. Sand shiners dispersed between main-stem and tributary habitats less than western silvery minnows and flathead chubs. Therefore, sand shiners, which remain abundant throughout much of their range (Propst and Carlson 1986; Warren et al. 2000; Hatch and Besaw 2001), may need only limited or periodic dispersal to sustain main-stem and tributary populations. Conversely, relatively high proportions of western silvery minnows and flathead chubs were dispersers in the lower Yellowstone River Basin, where they maintain large main-stem populations (Chapter 2). Furthermore, few adult western silvery minnows or flathead chubs were tributary residents, which may indicate an inability to live in isolated environments. The natural flow regime, the lack of main-stem reservoirs, and the absence of channelization, which are now unique to the Yellowstone River, may explain the continued persistence of western silvery minnows and flathead chubs in the Yellowstone River. In contrast, western silvery minnows and flathead chubs have declined in abundance and distribution in much the Missouri River Basin, which has largely been attributed to the damming of main-stem rivers (Pflieger and Grace 1987; Hesse 1994).

The large spatial differences in ^{87}Sr:^{86}Sr ratios among the Yellowstone River and most of its tributaries allowed us to identify movement of sand shiners, western silvery minnows, and flathead chubs between main-stem and most tributary environments in the lower Yellowstone River Basin. However, overlapping ^{87}Sr:^{86}Sr signatures between the Yellowstone and Tongue rivers prevented us from distinguishing Tongue River residents from Yellowstone River dispersers, which probably led to underestimated dispersion rates for fish captured in and around the Tongue River. The relatively variable ^{87}Sr:^{86}Sr ratios for the Tongue River, which were lower than expected, were probably a result of damming and water withdrawal. Damming and water withdrawal along the river reduced the contribution of strontium derived from headwater sources, which should have relatively high ^{87}Sr:^{86}Sr ratios as found in the Powder River. Therefore, the reduced instream flows originating from high elevation snowmelt would constitute a smaller proportion of the total Tongue River discharge near the Yellowstone River resulting in lower ^{87}Sr:^{86}Sr ratios. Controlled spring flows from the Tongue River Reservoir would also alter the natural seasonal ^{87}Sr:^{86}Sr variability expected from a snowmelt-dominated river. Further analysis of elemental concentrations (e.g., Ca, Sr, Ba, Mn, and Zn) of the main-stem and its tributaries may provide better signatures that will allow more accurate examination of fish movements among these habitats.

Our study provides the first conclusive evidence of large-scale movement of small-bodied cyprinids and provides inference on the consequences that loss of connectivity between main-stem and tributary habitats could have on prairie stream fishes. Inadequate connectivity between main-stem rivers and their tributaries as well as habitat fragmentation within tributaries typically decreases population viability. We recommend that conservation strategies identify and help maintain important habitats and life history strategies of small nongame fishes at the landscape level instead of managing streams or rivers on an individual basis. Future studies could investigate movement patterns of species of special concern such as sturgeon chub, which occur in both the Yellowstone and Powder rivers, identify important spawning and nursery habitats, and potentially assess the expansion and source of nonnative fish populations.

Table 3.1. Water chemistry sample locations and associated baseflow $^{87}Sr:^{86}Sr$ values. Sample locations are depicted in Figure 3.1.

Location	Location	$^{87}Sr:^{86}Sr$	$^{87}Sr:^{86}Sr$ Range
Yellowstone River			0.706660-0.710562
Below Yellowstone Lake	1	0.706660	
Livingston	2	0.710562	
Below the Clarks Fork	4	0.709559	
Below the Bighorn River	6	0.709371	
Below the Tongue River	11	0.709315	
Below the Powder River	13	0.709443	
Fairview Bridge	16	0.709423	
Large tributaries			0.709564-0.710675
Clarks Fork of the Yellowstone River	3	0.709778	
Bighorn River	5	0.709912	
Tongue River	9	0.709564	
Powder River	12	0.710675	
Small tributaries			0.708075-0.709216
Big Porcupine Creek	7	0.708751	
Rosebud Creek	8	0.709216	
Sunday Creek	10	0.708075	
O'Fallon Creek	14	0.709163	
Cabin Creek	15	0.708475	
Missouri River			
Below Yellowstone River confluence	17	0.709387	

Table 3.2. Total lengths (mm) of sand shiners, western silvery minnows, and flathead chubs collected in the lower Yellowstone River Basin for otolith microchemistry analysis.

Species and collection sites	*N*	TL			
		Mean	SD	Minimum	Maximum
Sand shiner					
Yellowstone River	95	51	10.5	33	77
Powder River	20	51	5.8	38	64
Tongue River	18	53	4.8	46	65
O'Fallon Creek	19	60	3.2	55	67
Sunday Creek	13	50	5.2	41	57
Cabin Creek	23	54	5.5	42	62
Western silvery minnow					
Yellowstone River	97	88	19.5	50	130
Powder River	19	86	17.6	57	116
Tongue River	20	67	21.5	40	118
O'Fallon Creek	8	99	18.8	67	122
Sunday Creek	15	89	15.0	74	127
Cabin Creek	10	75	24.1	53	129
Flathead chub					
Yellowstone River	95	108	26.4	57	213
Powder River	22	148	31.1	105	218
Tongue River	20	147	26.6	54	178
O'Fallon Creek	10	106	17.1	81	129
Sunday Creek	20	109	33.5	51	198
Cabin Creek	15	100	47.1	45	177

Table 3.3. Percentages of movement patterns of sand shiners, western silvery minnows, and flathead chubs collected in the lower Yellowstone River Basin. Main-stem residents could not be captured in tributaries nor could tributary residents be captured in the Yellowstone River hence the not applicable (NA) designation.

Species/location	Main-stem resident	Tributary resident	Main-stem disperser	Tributary disperser	Tributary-tributary
Sand shiner					
Yellowstone River	35.8	NA	34.7	29.5	0.0
Powder River	NA	0.0	50.0	5.0	45.0
Tongue River	NA	50.0	NA[a]	0.0	50.0
O'Fallon Creek	NA	89.5	5.3	0.0	5.3
Sunday Creek	NA	100.0	0.0	0.0	0.0
Cabin Creek	NA	91.3	8.7	0.0	0.0
Species total	**18.1**	**31.9**	**24.5**	**15.4**	**10.1**
Western silvery minnow					
Yellowstone River	23.7	NA	57.7	17.5	1.0
Powder River	NA	0.0	42.1	0.0	57.9
Tongue River	NA	30.0	NA[a]	0.0	70.0
O'Fallon Creek	NA	0.0	37.5	62.5	0.0
Sunday Creek	NA	66.7	13.3	13.3	6.7
Cabin Creek	NA	80.0	20.0	0.0	0.0
Species total	**13.6**	**14.2**	**42.0**	**14.2**	**16.0**
Flathead chub					
Yellowstone River	32.6	NA	53.7	12.6	1.1
Powder River	NA	0.0	22.7	13.6	63.6
Tongue River	NA	20.0	NA[a]	0.0	80.0
O'Fallon Creek	NA	0.0	70.0	30.0	0.0
Sunday Creek	NA	55.0	35.0	0.0	10.0
Cabin Creek	NA	40.0	20.0	33.3	6.7
Species total	**17.0**	**11.5**	**40.1**	**12.6**	**18.7**

[a] Because of overlapping CI with Yellowstone River

Table 3.4. Percentages of disperser (D) and resident (R) sand shiners, western silvery minnows, and flathead chubs collected in the lower Yellowstone River Basin.

	Drainage area (km^2)	Sand shiner		Western silvery minnow		Flathead chub		Total	
		D	R	D	R	D	R	D	R
Yellowstone River	178,980	64	36	76	24	67	33	69	31
Powder River	34,159	100	0	100	0	100	0	100	0
Tongue River	13,978	50	50	70	30	80	20	67	33
O'Fallon Creek	4,148	11	89	100	0	100	0	54	46
Sunday Creek	1,900	0	100	33	67	45	55	29	71
Cabin Creek	1,000	9	91	20	80	60	40	27	73
Total		50	50	72	28	71	29	64	36

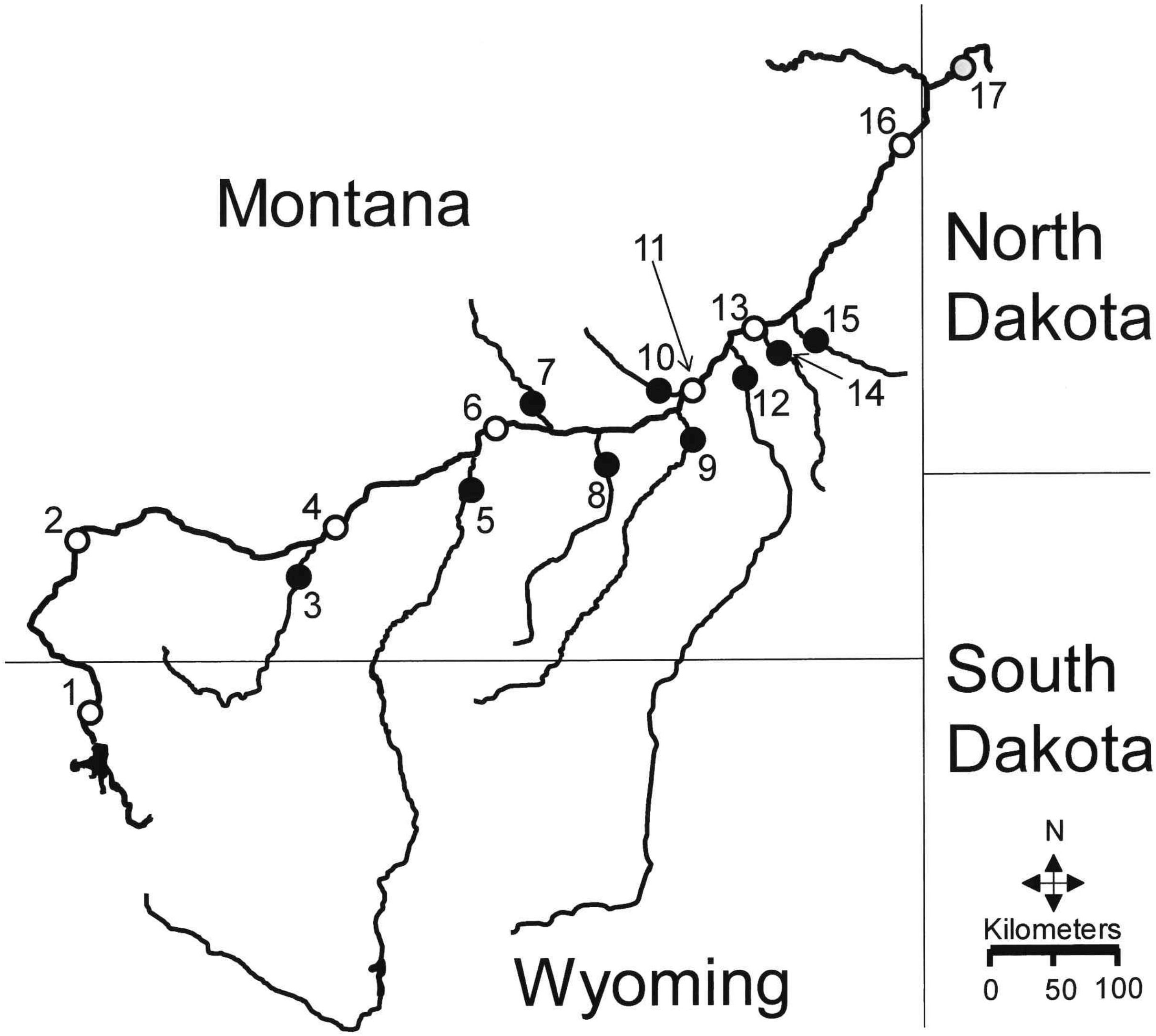

Figure 3.1. Water chemistry sample locations (white: Yellowstone River, black: tributaries, gray: Missouri River).

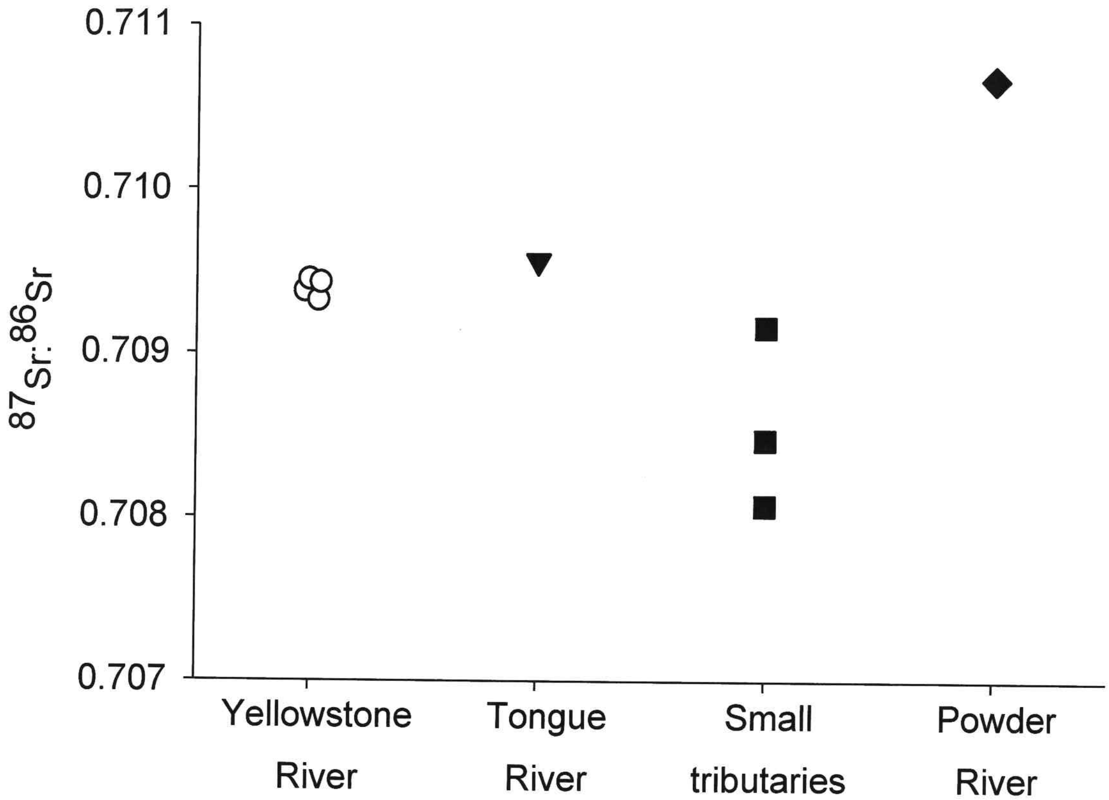

Figure 3.2. Baseflow ^{87}Sr:^{86}Sr values. Yellowstone River values (jittered) are from sites 6, 11, 13, and 16. Small tributaries group includes Sunday, O'Fallon, and Cabin creeks.

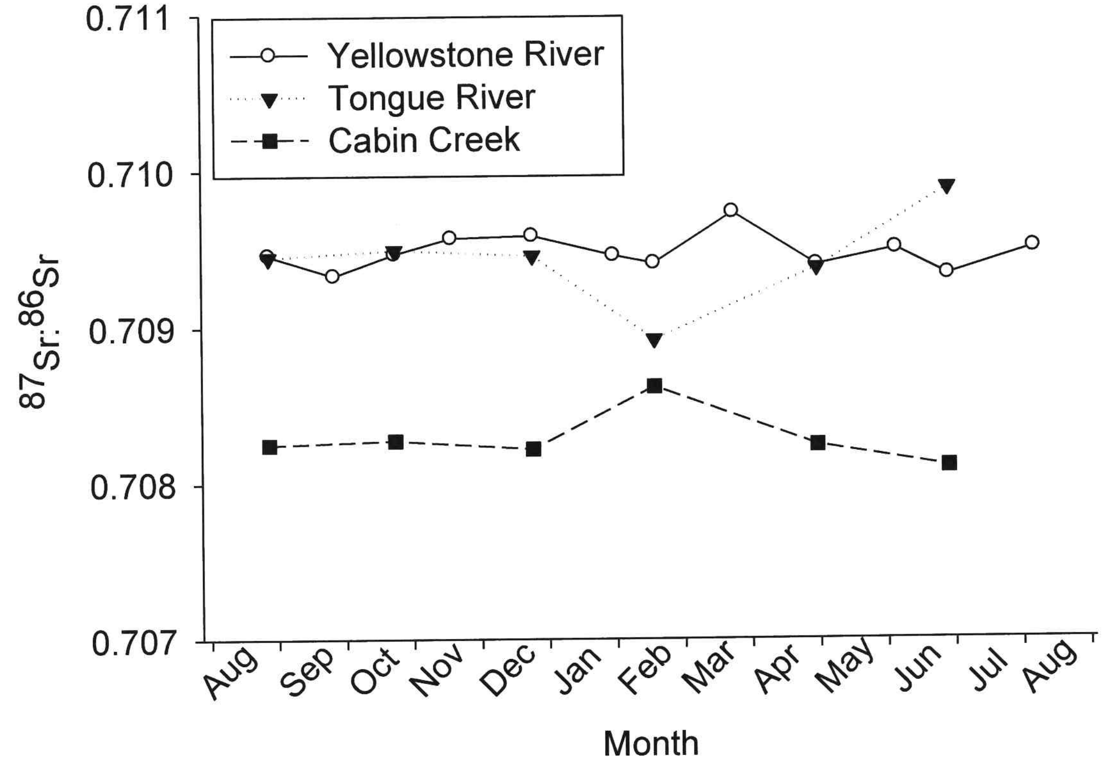

Figure 3.3. Seasonal ^{87}Sr:^{86}Sr variation of Yellowstone River, Tongue River, and Cabin Creek water samples collected from August 2009 to August 2010.

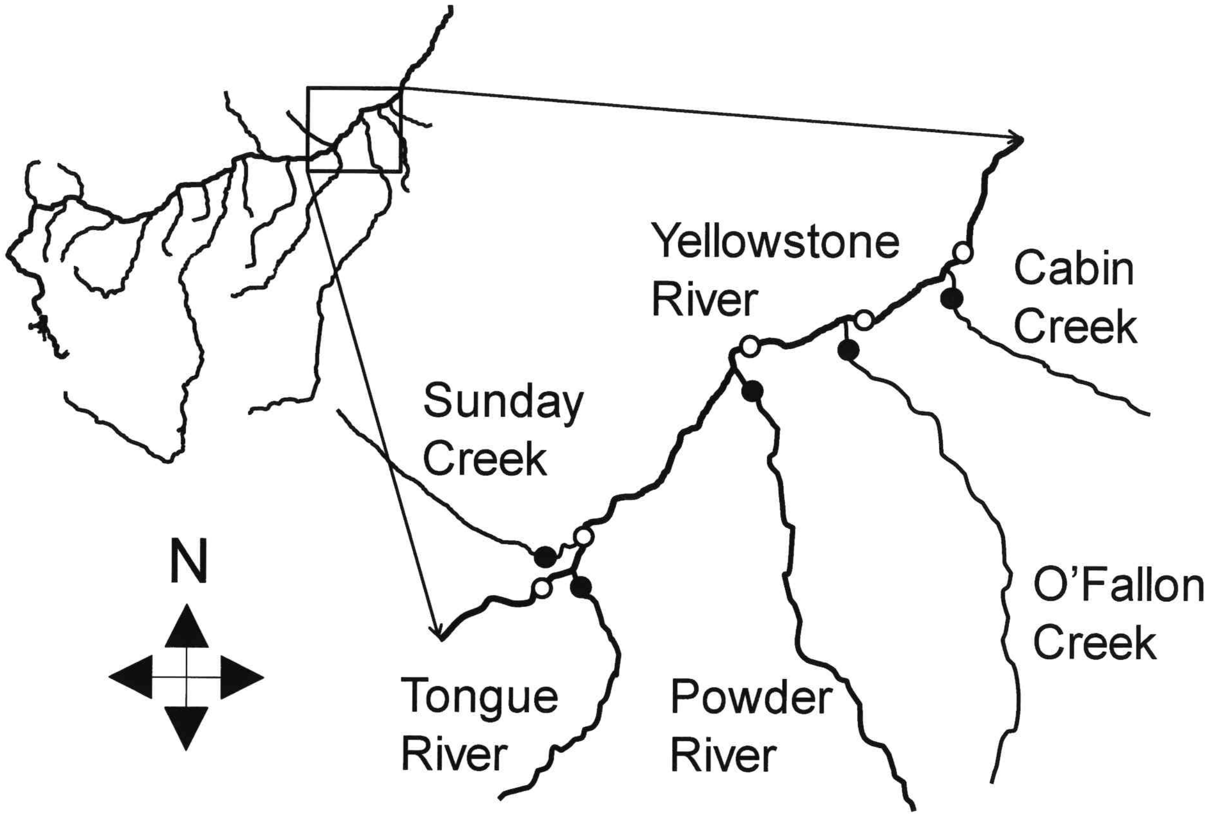

Figure 3.4. Fish collection sites (white: Yellowstone River, black: tributaries).

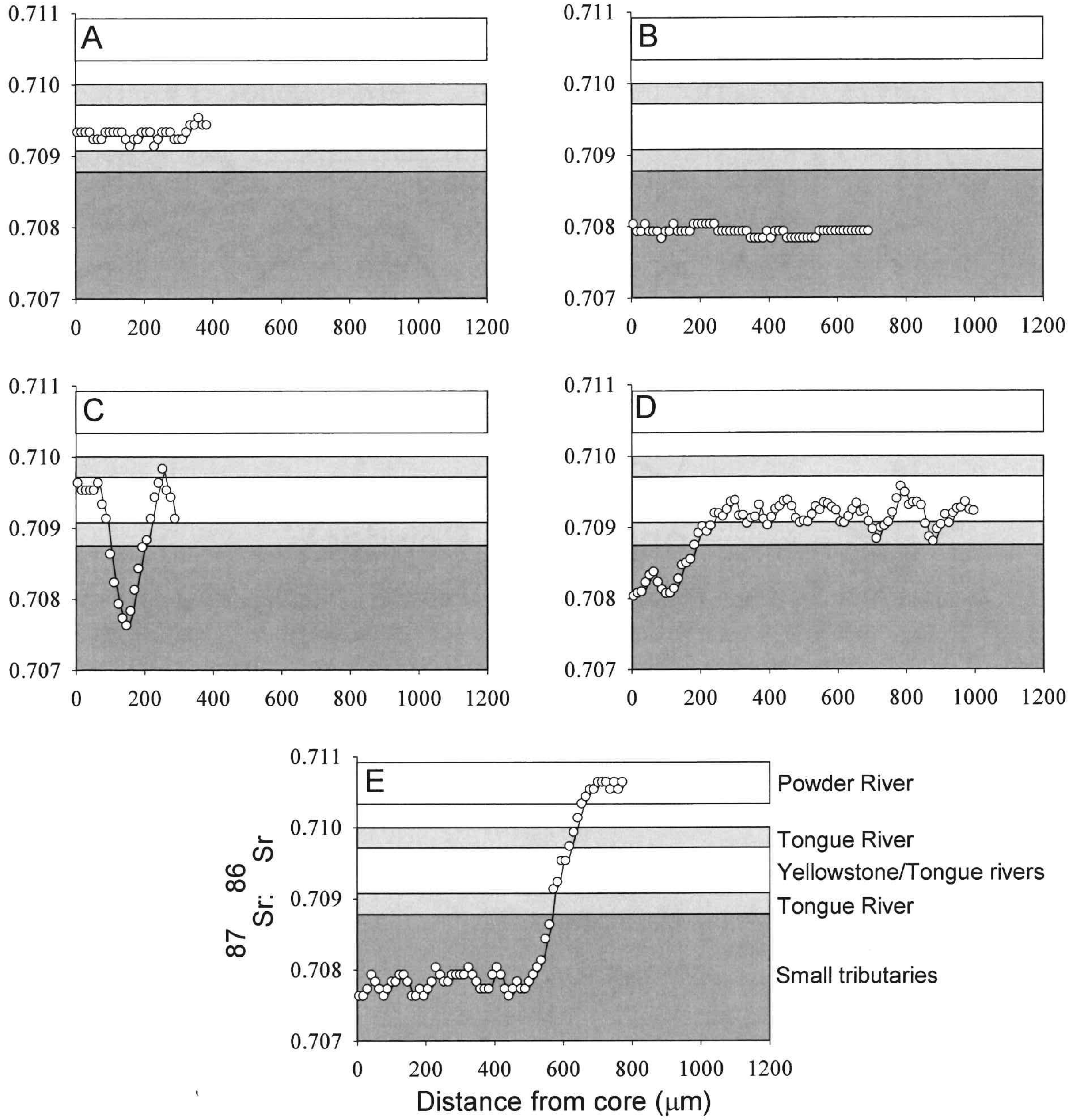

Figure 3.5. Example otolith profiles of a (A) main-stem resident, (B) tributary resident, (C) main-stem disperser, (D) tributary disperser, (E) and tributary-to-tributary disperser. The upper white box represents Powder River ^{87}Sr:^{86}Sr CIs, the light gray areas represent Tongue River CIs, the white area between the light gray areas represents ratios indicative of both the Yellowstone and Tongue rivers, and the dark gray area represents ratios indicative of small tributaries.

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