To the Graduate School:

The members of the Committee approve the thesis of Ryan J. Beatty presented on May 24, 2005:

Frank J. Rahel, Co-Chairman

Wayne A. Hubert, Co-Chairman

Ronald E. Beiswenger

Approved:

Graham Mitchell, Head, Department of Zoology and Physiology

Don Roth, Dean, The Graduate School

Beatty, Ryan J., Catostomid spawning migrations and late-summer fish assemblages in lower Muddy Creek, an intermittent watershed in southern Carbon County, Wyoming, M.S., Department of Zoology and Physiology, August 2005.

Muddy Creek is a high-elevation cold-desert stream in the Colorado River Basin in Wyoming that commonly becomes intermittent. A headcut stabilization structure isolates fish in the lower watershed from the upper watershed and wetland impoundments may act as additional movement barriers. Populations of bluehead suckers (*Catostomus discobolus*), flannelmouth suckers (*Catostomus latipinnis*), and roundtail chubs (*Gila robusta*) were known to occur in Muddy Creek. Previous sampling during the spring of 2002 suggested that flannelmouth suckers, bluehead suckers, and white suckers (*Catostomus commersoni*) from the Little Snake River ascended Muddy Creek to spawn. Catostomid spawning migrations were monitored in spring 2004, but only white suckers were captured. Radio telemetry indicated that upstream movements of white suckers were restricted to the mainstem of Muddy Creek downstream from a wetland impoundment, and fish returned downstream prior to intermittence in early summer. Stream flow and water temperature were believed to be suitable for spawning by both white suckers and flannelmouth suckers, but conditions believed to be suitable for spawning by bluehead suckers were not observed. Intermittency occurred throughout the lower watershed during the summer 2004 and flannelmouth suckers and bluehead suckers were rarely captured. An 8-km reach in the upper portion of the study area maintained perennial flow and had the largest proportion of native fishes. The wetland impoundments contained only non-native species. Late-summer fish assemblages appeared to have been affected by the locations of source populations of both native and non-native fishes, periods of intermittent stream flow, and fragmentation by barriers that restrict fish movements.

CATOSTOMID SPAWNING MIGRATIONS AND LATE-SUMMER FISH ASSEMBLAGES IN LOWER MUDDY CREEK, AN INTERMITTENT WATERSHED IN SOUTHERN CARBON COUNTY, WYOMING

By
Ryan J. Beatty

A thesis submitted to the Department of Zoology and Physiology and The Graduate School of the University of Wyoming in partial fulfillment of requirements for the degree of

MASTER OF SCIENCE
in
ZOOLOGY AND PHYSIOLOGY

Laramie, Wyoming
August, 2005

Acknowledgements

I thank Dr. Frank J. Rahel and Dr. Wayne A. Hubert for their guidance and support throughout my graduate program. I am grateful to Dr. Ronald E. Beiswenger for participating on my committee. Additional thanks to the U.S. Bureau of Land Management for providing funding for the project and Michael Bower and Mark Gorges for their enthusiastic support. I would also like to thank the Carbon County landowners who supported the project by allowing access to private lands. I express gratitude for the insight provided by Larry Hicks of the Little Snake River Conservation District in Baggs, Wyoming. A special thanks to my technician, Jason Herreman, for his dedication and hard work during the field season. A very special thanks to my mentor Jeff Dimick, his guidance during the fledgling years of my undergraduate work proved invaluable. Finally, for my parents Patrick and Melinda Beatty, without their support and encouragement my pursuit of a higher education in aquatic ecology would not have been possible.

List of Tables

Chapter 1

Chapter 2

List of Figures

Chapter 1

Chapter 2

Chapter 1. Movements during the spawning season by native and non-native catostomids in an intermittent stream of the Colorado River Basin

Abstract

Muddy Creek is a high-elevation cold-desert stream in the Colorado River Basin in south-central Wyoming that commonly becomes intermittent. Fish populations are fragmented by a headcut stabilization structure and wetland impoundments may act as additional movement barriers. Previous sampling by the United States Bureau of Land Management during the spring of 2002 suggested that bluehead suckers (*Catostomus discobolus*), flannelmouth suckers (*Catostomus latipinnis*), and white suckers (*Catostomus commersoni*) from the Little Snake River ascended Muddy Creek during the spawning season. My objectives were to determine if these three species of suckers (catostomids) migrated from the Little Snake River into Muddy Creek for spawning and to assess how water temperature and stream discharge were related to spawning migrations. A fish trap was used to monitor upstream movements of fishes into Muddy Creek from March through June of 2004. Only white suckers, a non-native species, were captured. Radio telemetry indicated that movements of white suckers were restricted to the mainstem of Muddy Creek downstream from a wetland impoundment, and fish returned downstream prior to intermittent stream flow in the summer. Stream discharge and water temperatures were believed to be suitable for spawning by both white suckers and flannelmouth suckers, but conditions believed to be suitable for spawning by bluehead suckers were not observed. Based on previous sampling in 2002 and the current study in 2004 it appears that catostomid spawning migrations in Muddy Creek may be highly variable among years.

1. Introduction

1.1 Rationale

Tributary streams can provide important spawning sites for many fish species because they may have conditions important for survival of eggs and fry missing from large rivers or lakes. In some instances, tributaries provide water temperatures suitable for spawning earlier than mainstem river habitats (Erman and Hawthorne 1976; Lucas and Baras 2001). Identifying such spawning tributaries and ensuring that fish can access them is important for managing both sport and non-game fishes (Hayes and Petrusso 1998; Lucas and Baras 2001).

Tributary streams can be intermittent, flowing during cooler months but drying during summer. The value of such streams as spawning and nursery areas may depend on interactions among streamflow conditions, water temperatures, and the spawning requirements of various fish species. The occurrence of streamflow during spawning activity and the ability of fish to return to mainstem habitats prior intermittent stream flow may be important in determining spawning success. Low flows during spawning migrations may trap fish in isolated pools. The ability of fish to persist in isolated pools until flows are reestablished may also be important in determining spawning success. The use of intermittent streams for spawning has been described in tropical systems, although little information exists concerning fish in intermittent tributaries of North America (Erman and Hawthorne 1976; Alkins 2000; Lucas and Baras 2001).

I examined spawning runs of three species of suckers (family Catostomidae) in an intermittent headwater tributary in the Colorado River Basin of Wyoming. The Colorado River Basin encompasses seven western states and its endemic fish community has suffered dramatic declines since the early twentieth century (Holden and Stalnaker 1975; Ono et al. 1983; Bezzerides and Bestgen 2002). The environmental conditions in streams of the Colorado River

Basin tend to be widely fluctuating with frequent droughts and floods, high sediment loads, extreme variation in water temperature, and intermittent flows. Warmwater fishes of the Colorado River Basin have adapted to such an environment (Ono et al. 1983). The fish community of the Colorado River Basin in Wyoming has suffered extirpations and declines of native fish species. Colorado pikeminnows *(Ptychocheilus lucius)*, razorback suckers (*Xyrauchen texanus)*, and bonytail chubs *(Gila elegans)* are thought to have been extirpated from Wyoming. Flannelmouth suckers (*Catostomus latipinnis*), bluehead suckers (*Catostomus discobolus*), and roundtail chubs *(Gila robustus)* exist as fragmented populations in the Little Snake River and Green River watersheds (Bezzerides and Bestgen 2002).

Reservoir construction has altered flows and water temperatures, reduced habitat heterogeneity, and altered fish movements throughout the Colorado River Basin. Such alterations are thought to be a primary cause of the extirpation of Colorado pikeminnows, razorback suckers, and bonytail chubs, and the reduced distributions of roundtail chubs, flannelmouth suckers, and bluehead suckers (Tyrus and McAda 1984; Chart and Bergersen 1992; Childs and Clarkson 1996). Water developments, such as small dams, irrigation diversions, and canals can prevent the downstream movements of larvae and juveniles to rearing areas and upstream movement of adults to spawning areas, and enhance the establishment and dispersal of non-native fish species (Chart and Bergersen 1992; Burdick 1997; Marchetti et al. 2004). Hybridization has been observed between native and non-native species, particularly among the native catostomids and non-native white suckers (*Catostomus commersoni*) (Douglas and Douglas 2003).

Flannelmouth suckers and bluehead suckers are two of the least studied native fishes in the Colorado River Basin. They are estimated to remain in only 45% and 50% of their historical range, respectively. Because of substantial declines in distributions, these species are of management concern throughout the Colorado River Basin. Efforts to assess the status of flannelmouth suckers and bluehead suckers have been implemented by state and federal management agencies, and they are regarded as imperiled throughout much of the upper Colorado River Basin including Wyoming (Bezzerides and Bestgen 2002; Weitzel 2002). Within Wyoming, the U.S. Bureau of Land Management (BLM) classifies the flannelmouth sucker and bluehead sucker as sensitive species. The Wyoming Game and Fish Department regards the flannelmouth sucker and bluehead sucker as species with continuing habitat loss, restricted or declining populations, and where extirpation within Wyoming seems possible.

Colorado pikeminnows, razorback suckers, and bonytail chubs were rarely observed in small tributaries and primarily used mainstem habitats (Bezzerides and Bestgen 2002). Mainstem habitats in the Colorado River have been drastically altered, and it has been suggested that one of the reasons for the persistence of flannelmouth suckers and bluehead suckers in the Colorado River Basin is their extensive use of tributary habitats, which may offer habitats similar to natural conditions (Bezzerides and Bestgen 2002). The use of tributaries with perennial flow for spawning by flannelmouth suckers and bluehead suckers has been documented but there is little information about the use of tributaries with intermittent flow (Maddux and Kepner 1988; Wick et al. 1991; Martinez et al. 1994; Weiss et al. 1998).

The Wyoming portion of the Colorado River Basin exists west of the Continental Divide and consists of the Green River Drainage. The Colorado River Basin in Wyoming has a drainage area of 42,813 km^2, and the Little Snake River watershed accounts for 5,330 km^2 of this area (Ostresh et al. 1990). The mainstem of the Little Snake River is an unregulated river, though water diversions exist. The Larval Fish Laboratory at Colorado State University compiled previous fish sampling data over 180 km of the Little Snake River, from Baggs, Wyoming to its confluence with the Yampa River in Colorado. Flannelmouth suckers and bluehead suckers were abundant in the Little Snake River, and white suckers also occurred but were far less abundant than the two native catostomid species (Hawkins 2001).

Muddy Creek is a warmwater tributary that joins the Little Snake River near the town of Baggs in south-central Wyoming. Muddy Creek is an intermittent stream that can be classified as a cold-desert steppe stream (Goertler 1992). The upper reaches of Muddy Creek are known to support populations of flannelmouth suckers and bluehead suckers (Bower 2005). The fish community in the lower reaches of Muddy Creek is isolated from upstream reaches by a barrier that prevents upstream movements by fish. Little information about the fish community in the lower reaches existed, although the presence of flannelmouth suckers and bluehead suckers was documented in 1982 and 1995 (Oberholtzer 1987; Wheeler 1997).

Much of the Muddy Creek watershed is managed by the BLM, and their interest in native fish conservation in lower Muddy Creek was enhanced by the abundant native fish populations in the Little Snake River, and the possibility of connectivity between fish populations in these two systems (Mike Bower, BLM, personnel communication). During the spring of 2002, sampling efforts were undertaken by the BLM to determine if flannelmouth suckers and bluehead suckers from the Little Snake River were migrating into Muddy Creek to spawn. A stationary fish trap was installed 8-km upstream from the confluence of Muddy Creek with the Little Snake River and monitored daily from April through June, 2002. The catch was dominated by flannelmouth suckers, but bluehead suckers, white suckers, and catostomid hybrids were also captured. Many of the captured fishes expressed gametes and were presumed to be part of a spawning movement. In response to these findings, the BLM funded my study through the University of Wyoming to further investigate the potential for spring spawning migrations of native and non-native catostomids from the Little Snake River into Muddy Creek.

1.2 Objectives

Objective 1: Determine if sexually mature flannelmouth suckers, bluehead suckers, and white suckers move upstream in lower Muddy Creek during spring.

Objective 2: Describe stream discharge and water temperatures associated with movements by catostomids in lower Muddy Creek during spring.

1.3 Study Area

Muddy Creek originates in the Sierra Madre, Carbon County, Wyoming. The Muddy Creek watershed encompasses 471 km^2, ranges in elevation from 1,920 to 2500 m, and extends from the Sierra Madre Range to the Red Desert. The upland watershed is dominated by sagebrush (family: Asteraceae), and riparian vegetation is primarily willow (*Salix* spp.) and greasewood (*Sarcobatus vermiculatus*). Although the headwaters have perennial flow, intermittency occurs throughout much of the Muddy Creek watershed during summer (Goertler 1992).

The Muddy Creek watershed can be divided into two major segments, upper Muddy Creek and lower Muddy Creek. Upper Muddy Creek extends from the headwaters downstream to a large headcut stabilization structure (Figure 1). The headcut stabilization structure inhibits upstream movements of fishes and marks the upstream boundary of lower Muddy Creek. Lower Muddy Creek has four major tributaries that also experience intermittent flows. The confluence of the southern most tributary, Deep Creek, is 16.0 km upstream from the confluence of Muddy

Creek with the Little Snake River. The confluence of Cherokee Creek is 38.0 km from the Little Snake River, Wild Cow Creek is 45.4 km, and Cow Creek is 51.1 km from the Little Snake River (Figure 1).

Based on 1:24,000 hydrography data, the total length of the mainstem of Muddy Creek from the Little Snake River to the headcut stabilization structure is approximately 100 km (http://nhd.usgs.gov/data.html). A large wetland complex occurs 78-84 km upstream from the confluence of Muddy Creek with the Little Snake River. Muddy Creek flows through the wetland complex, which consists of impoundments, man-made channels, vertical drop structures, headgate structures for water diversion, overflow spillways, and a braided stream-channel network.

Lower Muddy Creek is highly erosional and has abundant channel incision. Substrates are dominated by fine clays and sand, although areas of rock substrates (i.e. gravel and cobble) occur sporadically. Most of the rock substrate occurs in the reaches upstream from the wetlands and downstream from the headcut stabilization structure, 78-100 km upstream from the Little Snake River. Spring runoff is snow-melt dominated, and generally occurs in March. Base flow and intermittency can occur as early as April and as late as February, but is most common from July through September (Goertler 1992).

2. Methods

2.1 Objective 1: Determine if sexually mature flannelmouth suckers, bluehead suckers, and white suckers move upstream in lower Muddy Creek during spring.

2.1.1 *Fish sampling*

A stationary fish trap was used to determine if adult catostomids were making upstream movements into Muddy Creek in 2004. The trap consisted of frames and 2-m-long and 1.5-m-long aluminum rods that slid down to compensate for channel down-cutting under the trap. Wings spanned the stream channel to bank full with a box trap near the thalweg. The spacing between the rods was 10 mm. The 1-m^2 box had a 150-mm opening to permit fish entry. The trap was installed approximately 8 km upstream from the confluence of Muddy Creek with the Little Snake River to capture fish from runoff through the onset of intermittency. Total length (mm), weight (g), and phenotypic identification to species or hybrid form were obtained for all catostomids captured in the trap (Table 1). Fishes were sexed based on the expulsion of gametes when ventral pressure was applied.

Additionally, a 9.1-m-long bag seine with 6.3-mm mesh was used to assess the occurrence of catostomids near the trap. Seining was conducted periodically within 200-m-long reaches upstream and downstream of the trap to determine if large catostomids were in close proximity, but not captured in the trap. A large pool 100 m upstream from the trap site that had a 24-m^2 surface area and was 1-m-deep during May and June was sampled with a backpack electrofishing unit and seine to capture transmitter-implanted catostomids that had returned to the trap site after upstream migrations.

2.1.2 Radio telemetry

All white suckers $\geq$ 400 g captured in the trap were implanted with 8-g radio-transmitters, equipped with mortality sensors, 12-hour duty cycles, and a pulse rate of 55 pulses per minute (model F1820; Advance Telemetry Systems (ATS) Isanti, Minnesota). The 400-g threshold was used to stay within a 2% body weight burden (Winter 1996). The shielded needle technique was utilized to surgically implant transmitters in anesthetized fish (Ross and Kleiner 1982). Following surgery, fish were retained for 15-30 minutes in a recovery receptacle filled with water from Muddy Creek.

Transmitter-implanted fish were released upstream of the trap. The presence of transmitter-implanted fish at the trap site was determined daily with a scanning receiver (ATS) and a three element yaggi antenna, by standing on a stream-bank 15 m above the stream at the trap site. Fish detected at this location were recorded as remaining at the trap site. Fish not detected at the trap site were assumed to have made an upstream migration. The maximum distance upstream at which frequencies were detectable was approximately 300 m. Locations of transmitter-implanted fish upstream of the trap were determined on foot, by canoeing, and in fixed-wing aircraft. Fish locations were recorded with a handheld GPS unit (Trimble GeoXT®), and later downloaded with geographical information system software (ArcVIew 3.2®, Environmental Research Institute, Redlands, California) to depict movement patterns. Some transmitter-implanted fish that returned downstream to the trap site following upstream movements were recaptured to determine if gametes had been expelled during spawning activity upstream. Several fish were released downstream of the trap to determine if movements would continue to the Little Snake River. Based on locations where transmitter-implanted white suckers were located, maps were generated to describe patterns of upstream and downstream movement.

2.2 Objective 2: Describe stream discharge and water temperatures associated with movements by catostomids in lower Muddy Creek during spring.

2.2.1 Data collection and analyses

Data loggers were used at four locations in the lower Muddy Creek watershed to monitor stage (cm) and water temperature (C^{o}). Stage was monitored with Aquarods® (Sequoia Scientific, Inc.) placed at the trap site in the mainstem of Muddy Creek, and in Cow, Wild Cow, and Cherokee creeks. Measurements were logged at 15 minute intervals and used to compute mean daily water temperature and stage at each site. Cross-sectional velocity measurements were taken with a flow meter (Marsh-McBurney, Flowmate®) at each site on multiple occasions and used to calculate discharge (Bain and Stevenson 1999). Linear regression between stage (x) and discharge (y) provided a stage-discharge relationship that was used to predict mean daily discharge (m^3/s). Mean daily water temperature and discharge were compared to daily trap catch. These data were also used to document temporal variation in the occurrence of measurable surface flow at hydrologic monitoring sites.

3. Results

3.1 Objective 1: Determine if sexually mature flannelmouth suckers, bluehead suckers, and white suckers move upstream in lower Muddy Creek during spring.

3.1.1 Catch composition at the trap site

Muddy Creek had low flows and was congested with ice jams on March 8, 2004. Stream flows increased on March 10 and peak runoff occurred from March 12 to March 14, 2004. The trap was successfully installed on March 15, 2004, and the catch was monitored daily until June 18, 2004. No adult flannelmouth suckers or bluehead suckers were captured, one *Catostomus* hybrid was captured, and 58 white suckers were captured (Figure 2). The majority of white suckers were sexually mature and expelled gametes when ventral pressure was applied. The catch of white suckers consisted of 28 females, 16 males, and 14 fish of undetermined sex. The minimum total length of white suckers captured in the trap was 104 mm, maximum total length was 481 mm, and mean total length was 246 mm (Figure 3). The minimum weight of white suckers captured in the trap was 9 g, maximum weight was 1,220 g, and mean weight was 239 g.

Seining downstream of the trap did not reveal the presence of large catostomids ($\geq$ 200 mm total length, 150 g). All white suckers captured by seining were $\leq$ 200 mm total length. Six juvenile bluehead suckers ($\leq$ 80 mm total length) and two juvenile flannelmouth suckers ($\leq$ 100 mm total length) were captured (Figure 4). Seining was conducted upstream of the trap less frequently than downstream, but revealed fewer species and no large catostomids (Figure 5).

3.1.2 Movements of transmitter-implanted white suckers

Eleven white suckers captured in the trap were implanted with transmitters between April 15 and May 9, 2004. Following surgery and release upstream of the trap, all fish made upstream movements of at least 300 m within 48 hours (Table 2). One-hundred meters upstream of the trap a beaver (*Castor canadensis*) dam with a 0.2-0.5 m vertical drop did not impede upstream movements.

White suckers remained upstream for 10-30 days, with a mean upstream residency of 20 days (Table 2). Ten of the 11 transmitter-implanted white suckers were able to be sexed based on the presence of gametes when they were captured, and eight of these fish were females and two were males. The maximum extent of upstream movements was approximately 62 km, to an area downstream from a vertical drop structure that served as a water control device associated with the wetland complex (Figure 6). No fish were observed to enter the tributaries of lower Muddy Creek.

Following upstream movements, transmitter-implanted white suckers made relatively synchronous downstream movements to the trap site. Two transmitters emitted mortality signals upstream of the trap, but the remaining nine fish returned to the trap between May 4 and 28, 2004. And seven of those fish returned within the same week, May 11-18 (Table 2, Figure 7). Following their return downstream, all fish remained in close proximity to the trap. I was able to recapture six of the nine fish. Four of the recaptured white suckers had retained the transmitters but two fish had expelled them (Table 2). These fish also appeared to have spawned based on a lack of gamete expression when ventral pressure was applied. Four transmitter-implanted white suckers that were recaptured upstream of the trap were released downstream of the trap. These fish continued movements toward the Little Snake River (Table 2, Figure 7). By July 20, 9 of 11 transmitters were emitting mortality signals, although it is unknown if fish suffered mortality or if tags had been expelled.

3.2 Objective 2: Describe stream discharge and water temperatures associated with movements by catostomids in lower Muddy Creek during spring.

3.2.1 Hydrologic conditions March – August, 2004

On March 6, 2004, Muddy Creek was congested with ice and had minimal flow at the trap site. By March 10, flows had increased and most of the ice had been flushed from the system. Peak runoff occurred March 12-14. Stage and water temperature monitoring began on March 15, 2004 when lower Muddy Creek was on the descending limb of the spring hydrograph with a mean daily stream discharge of 1.56 m^3/s (Figure 8). Stream discharge decreased to near intermittent conditions on April 3, and substantial flows returned by April 10, 2004 (0.39 m^3/s). Stream discharge continued to increase until April 22 (0.95 m^3/s), and then declined until June 10, when no measurable surface flow occurred at the trap site (Figure 8). The lack of surface flow at the trap site resulted in isolated pools, and this continued until July 16 when precipitation events caused a sharp increase in the hydrograph from July 17 to 29, peaking at 2.94 m^3/s on July 24. By July 30 surface flows had receded and the stream again consisted of isolated pools near the trap site, and this condition persisted throughout the rest of the summer in 2004.

From March 15 through the onset of no surface flow on June 10, 2004, mean daily water temperatures ranged from 5.6^o to 20.2^o C. Temperatures generally increased as the season progressed. Extreme lows in water temperature were associated with high stream discharge, and extreme highs in water temperature were associated with low to intermittent flow conditions (Figure 8).

3.2.2 Trap catch composition and hydrologic conditions

Only white suckers made movements during the spring of 2004, and a relationship with stream discharge and water temperature was observed. Between March 15 and 26, white suckers captured in the trap were relatively small (mean total length = 199 mm, range = 147-280 mm, n = 37). However, the majority of these fish were sexually mature and expressed gametes when ventral pressure was applied (Figure 3). During that time, the stream was flowing at the trap site, and mean daily water temperatures ranged from 5.6^{o} to 10.9^{o} C (Figure 9; Figure 10). After March 26, stream flow declined sharply at the trap site, and no measurable surface flow occurred from April 3 through April 8. No white suckers were captured in the trap during this period (Figure 9).

Flows resumed on April 9, coinciding with a second pulse of white suckers captured in the trap from April 13 through May 9 (Figure 9). These fish tended to be larger than those captured in March (mean total length = 325 mm, range = 104-481 mm, n = 21). All white suckers implanted with transmitters were from that group. After May 9, no additional fish were captured in the trap, and by June 10 lower Muddy Creek had no measurable surface flow at the trap site.

3.2.3 Downstream movements in relation to stream discharge

Transmitter-implanted white suckers demonstrated an ability to move long distances upstream, and then return downstream to the trap site prior to the onset of no measurable surface flow in June 2004. Nine of the 11 transmitter-implanted white suckers survived or held their tags long enough to make both upstream and downstream movements (Figure 6, Figure 7). Following downstream movements and aggregation of fish immediately upstream of the trap site, I was able to recapture four individuals and place them downstream of the trap. These fish were later observed further downstream in Muddy Creek or in the mainstem of the Little Snake River (Figure 7, Table 2). On June 18, I removed the trap to allow free movement of fish, although at that time lack of surface flow inhibited movements. However, a precipitation event caused a sharp increase in stream discharge from July 17 through July 29 (Figure 8). During this period two transmitter-implanted white suckers that had been in refuge pools near the trap moved downstream to the confluence of Muddy Creek with the Little Snake River. On July 20, one of the transmitters was still active, indicating the fish was still alive and in retention of the transmitter. The other transmitter was emitting a mortality signal, indicating either mortality or tag expulsion.

4. Discussion

Muddy Creek is a tributary to the Little Snake River in the Colorado River Basin of Wyoming and Colorado so the fish assemblages in Muddy Creek are related to those in the Little Snake River. Hawkins and O'Brien (2001) compiled data on fish assemblages in the Little Snake River from 1972, 1981, 1988, 1994, and 1995 (Table 3). Sampling was conducted within a 180-km segment from Baggs, Wyoming to the confluence of Little Snake River with the Yampa River in Colorado. Total catch composition was dominated by native species, ranging from 64 to 96% among years. Flannelmouth suckers and bluehead suckers were often the most abundant species. White suckers were rare during all years ($\leq$ 1% catch composition). Hawkins et al. (1997) collected fish larvae in the Little Snake River to determine which species were spawning successfully. Flannelmouth suckers and bluehead suckers were the most abundant larval fish collected in 1994, and white sucker larvae were rare. However, no information about catostomid spawning movements or use of tributaries in the Little Snake River drainage was obtained.

Flannelmouth suckers and bluehead suckers ascend tributaries to spawn in the Colorado River Basin, and tributary use is considered important to the persistence of these species (Maddux and Kepner 1988; Weiss et al. 1998; Bezzerides and Bestgen 2002). Thus, it seemed reasonable that these species might use Muddy Creek for spawning. Although, I did not find evidence of a spawning run by flannelmouth suckers and bluehead suckers in Muddy Creek in 2004, trap monitoring by the BLM during spring 2002 suggested that native catostomids may spawn in Muddy Creek during some years (Mike Bower, personal communication).

In 2002, catostomids that were presumed to be from the Little Snake River migrated into Muddy Creek during the spawning season. A fish trap identical to the one used in my study was installed and monitored daily from April 18 through June 6, in the same location as my trap. The catch was dominated by flannelmouth suckers (n = 26), although a bluehead sucker, white suckers (n = 4), and *Catostomus* hybrids (n = 3) were also captured (Figure 11). Due to the potential for hybridization among the three species (Douglas and Douglas 2003), some uncertainty exists as to the accuracy of the phenotypic identifications . However, the fisheries biologist (Michael Bower) supervising the project for the BLM, was confident that pure forms of flannelmouth suckers, bluehead suckers, and white suckers were correctly identified.

Annual variation in the use of Muddy Creek for spawning by catostomids from the Little Snake River may occur. Three factors could explain the differences in catch composition between 2002 and 2004: (1) differences in the timing of trap installation, (2) variation in spring flows and the onset of intermittency, and (3) differences in water temperatures needed for spawning.

The timing of trap installation in 2002 differed from 2004. In 2002, the trap may have been installed too late in the spring (April 18) to capture all the white suckers migrating upstream. In 2004, I began daily trap-monitoring on March 15. This allowed me to sample the range of spring flows, from near peak runoff through summer intermittency. No adult flannelmouth suckers or bluehead suckers were captured, and adult white suckers comprised 100% of sexually mature catostomids captured in the trap in 2004. Installation of the trap prior to spring runoff was prevented by ice flows, and I was unable to successfully install the trap during peak runoff. Gravid flannelmouth suckers have been observed from February to May in the Colorado River, and were observed to enter tributaries during February with water temperatures ranging from 2^o to 8^oC (Weiss et al.1998, Mueller and Wydoski 2004). It may be possible that flannelmouth suckers and bluehead suckers moved into Muddy Creek prior to trap installation on March 15, 2004. However, this is unlikely because these two species were not captured in seining efforts upstream of the trap. Also, post-spawning individuals would likely have congregated at the trap on their downstream movement to the Little Snake River and no large catostomids were captured immediately upstream of the trap other than transmitter-implanted white suckers.

Differences in stream discharge patterns and the timing of intermittent flows also may cause annual variability in catostomid migrations. For example, by early April 2004 flows at the trap site had receded to near zero and fish movement through riffles was unlikely (Figure 8). Between spring 1986 and 1990, zero flow was not observed in Muddy Creek near Dad, Wyoming, approximately 58 km upstream from the trap site (Goertler 1992). Near the confluence of Muddy Creek with the Little Snake River, stream discharge during the spring did not approach zero between 1987 and 1991 (United States Geological Survey). Similarly, extreme low-flow conditions were not observed at the trap site in April 2002 (Mike Bower, personnel communication). The low-flow period I observed in early April 2004 appears to have been relatively unique and extreme. Although the onset of sustained periods of no measurable surface flow occurred in mid-June during both 2002 and 2004, the exceptionally early period in April of 2004 may account for variability in catostomid migrations.

Differences in water temperature and habitat needed for spawning by flannelmouth suckers, bluehead suckers, and white suckers may account for annual variability in migrations. A review of the literature indicated that water temperatures associated with spawning by flannelmouth suckers and white suckers were similar and in the range of 6-19^{o} C (Table 4). Conditions suitable for spawning occurred for white suckers and flannelmouth suckers, based on the presence of stream flows navigable by fish and water temperatures within the range reported for spawning activity occurred in lower Muddy Creek in spring of 2004 (Figure 12). Temperatures associated with spawning of bluehead suckers are generally warmer, in the range of 16-25^{o}C. In 2004, few days occurred in which stream flows were navigable and water temperatures were within the range observed for spawning activity by bluehead sucker (Figure 13). Bluehead suckers prefer warmer temperatures than flannelmouth suckers for spawning, and appear to be more selective for gravel and cobble substrates during spawning activity (Maddux and Kepner 1988). Rock substrates were rare in lower Muddy Creek and were mainly in shallow riffles that probably serve as movement barriers during extreme low-flow periods.

An important aspect of catostomid spawning in Muddy Creek that was not investigated is the occurrence of spawning migrations in the extreme downstream portion of Muddy Creek. Catostomid spawning migrations may only have extended short distances upstream in Muddy Creek, in close proximity to the Little Snake River. The trap was 8 km upstream from the confluence, and would not detect short upstream spawning movements. Spawning migrations by flannelmouth suckers in the Paira River, Arizona did not extend beyond 10 km upstream of the river mouth and upstream migrations in Bright Angel Creek, Arizona were not observed beyond 1.2 km upstream (Weiss et al. 1998). My inability to detect a run by flannelmouth suckers and bluehead suckers into Muddy Creek during 2004 may be due to native catostomids spawning in close proximity to the confluence of Muddy Creek and the Little Snake River.

White suckers made upstream movements over a long segment of lower Muddy Creek during the spawning season of 2004. A total of 58 white suckers were captured at the trap and 44 of these expressed gametes when ventral pressure was applied. On the descending limb of the hydrograph near the end of spring runoff but prior to low-flow conditions in early April, the first group of white suckers captured consisted mainly of small but sexually mature fish (Figure 3). It is unknown if these were fish from the Little Snake River or resident in Muddy Creek. Upon a substantial increase in discharge, a second group of generally large white suckers were captured (Figure 3, Figure 9). I suggest that these larger individuals may have been from the Little Snake River for three reasons. First, transmitter-implanted white suckers made substantial upstream movements soon after release and relatively synchronous movements downstream just prior to the formation of isolated pools in early June. Second, transmitter-implanted white suckers were gravid prior to upstream movement and spent upon their return, indicating spawning activity upstream. Third, although small white suckers were relatively abundant in the seine catch, no large ($\geq$ 200 mm TL) catostomids were present while seining near the trap. This indicates that large white suckers were not present in the lower reaches of Muddy Creek until they moved upstream from the Little Snake River.

Within the lower Muddy Creek watershed, resource managers are interested in the extent of upstream movements by native catostomids to spawning areas and the existence of barriers that prevent upstream movements. Although movements by native catostomids were not monitored in 2004, data for white suckers provided valuable insight into the potential for movement by large catosomids in the lower Muddy Creek watershed. In years when catostomids do move into Muddy Creek, their movement may be limited by four factors. First, their upstream movements appear to be limited to reaches downstream of the wetland complex because a spillway with a 1.0-m vertical drop at the downstream end of the wetland complex appeared to inhibit upstream movement. Second, small beaver dams downstream of the wetland complex may inhibit dispersal in some conditions. A beaver dam spanned Muddy Creek approximately 100 m upstream of the trap site. The vertical drop varied with stream flow and woody components varied as maintenance was conducted by beavers. Higher flows caused the stream to form channels over and through the dam. Transmitter-implanted white suckers were able to pass the dam in the spring. During low-flows the vertical drop was approximately 0.2-0.5 m. Thus, during low-flow periods it may have served as a dispersal barrier to catostomids.

Third, the lack of continuous surface flows during the period of migration and spawning in the tributaries of lower Muddy Creek may prevent catostomid spawning movements. Transmitter-implanted white suckers were not observed to move into the tributaries of lower Muddy Creek. Deep Creek was probably not accessible, because I observed no surface flow from early April throughout the summer. A similar situation exists for Cherokee Creek, which had no surface flow on April 17, 2004. Cow Creek and Wild Cow Creek had limited surface flow but were approaching the formation of isolated pools when transmitter-implanted white suckers were present in Muddy Creek. Thus, extensive upstream movements in the tributaries of

Muddy Creek may have been inhibited by low-flow conditions. However, access to the mouths of these tributaries and short upstream migrations may not be as limited during low-flow conditions. The BLM sampled isolated pools in Deep Creek during June 2002 (Mike Bower, personal communication). One adult white sucker (230 mm) and unidentified larval fish were captured. Hydrologic variability will dictate if the tributaries to lower Muddy Creek will be suited to catostomid spawning or fish residency.

Fourth, downstream movement of catostomids after spawning may be limited by lack of surface flow in the mainstem of Muddy Creek. Following downstream movement and the aggregation of transmitter-implanted white suckers at the trap site, fish were trapped in isolated pools during a period of no surface flow (Figure 7). Two individuals that were in isolated pools at the trap site moved downstream toward the Little Snake River after a large increase in stream flow in July. Catostomids that are trapped in refuge pools by intermittency appear to have the ability to survive, and move downstream when summer precipitation restores stream flow. The conditions in an intermittent system may require such behavior for adult survival and downstream dispersal of larvae.

In the Colorado River Basin, flannelmouth suckers and bluehead suckers have persisted, whereas the Colorado pikeminnow and bonytail chub have substantially declined or been extirpated. Bezzerides and Bestgen (2002) suggested adaptive life history traits and the use of unregulated tributary habitats by flannelmouth suckers and bluehead suckers as reasons for the persistence of these species. Weiss et al. (1998) observed spawning by flannelmouth suckers in the Paira River and Bright Angel Creek, tributaries to the lower Colorado River, Arizona. Flannelmouth suckers were observed to enter the Paira River in February and spawn in upstream areas during late March and early April when temperatures ranged from 8^{o} to 10^{o}C. By late

April the flannelmouth suckers in the Paira River moved back downstream toward the confluence after spawning. Maddux and Kepner (1988) observed bluehead suckers spawning in Kanab Creek, a tributary to the lower Colorado River, Arizona. A total of 63 spawning acts were observed during a 12-hour period. The largest aggregation of fish observed during spawning activity was 28.

Other studies have described irregular or variable spawning movements by catostomids. Parker and Franzin (1991) observed that the upstream spawning migration distance of quillback (*Carpiodes cyprinus*) decreased from 32 km during periods of high discharge to 3 km during periods of low discharge. Thus, early migrants tended to move further upstream than later migrants. Similarly, stream discharge was related to the number of white suckers migrating upstream in a tributary in Alberta, Canada (Barton 1981). During low-water years, migrations within close proximity to the confluence or reduced numbers of migrants appear to be traits of catostomid spawning movements. Lost River suckers (*Deltistes luxatus*) and shortnose suckers (*Chamistes brevirostris*) migrate from lakes to spawn in tributary habitats. Perkins and Scoppetone (1996) used radio-telemetry to assess spawning movements by these species in the Clear Lake drainage, California. Most transmitter-implanted shortnose suckers moved into Willow Creek, an intermittent tributary, during the spawning season. Spawning by Lost River suckers in Willow Creek appeared irregular. Variable flow conditions were suggested as a reason for irregular spawning movements into Willow Creek.

My study provided insight into the frequency and potential for large catostomids to move upstream, spawn, and return downstream in a tributary with intermittent stream flows prior to being trapped in isolated pools. My results also indicate that fish trapped in isolated pools can utilize large precipitation events and return of surface flow to move downstream to mainstem river habitats with more suitable refuge or perennial flow. The differences in catch composition between 2002 and 2004 suggest variability in catostomid spawning migrations due to widely varying hydrologic conditions. However, much uncertainty exists as to how drought and the magnitude of spring runoff affect the composition of catostomids and the extent of movements in Muddy Creek.

Small headwater tributaries can be important as spawning and rearing habitat for fishes. Consequently, management actions and habitat alterations in small tributary streams may have strong implications for mainstem river fishes. However, these streams can have widely varying hydrologic conditions seasonally and among years. Thus, is seems logical that the timing of spawning movements, fish assemblage composition, the spatial extent of movements, and success of different species will also vary widely across years. Understanding the causes of this variation will require long-term monitoring across a range of streamflow conditions. For management agencies to successfully conserve native fish species, there is a need for further research addressing the use of tributaries for spawning.

5. Management considerations

In order to make informed decisions about management of native catostomids utilizing lower Muddy Creek, it is critical to understand the composition of the catostomid spawning run and the extent of upstream movements by catostomids in this system. Based on the two years of data available for lower Muddy Creek, it appears that spawning runs by native catostomids may occur during some years. Sampling in 2002 and 2004 was conducted during drought, and numbers of catostomids utilizing lower Muddy Creek for spawning may increase with greater stream flow in the spring and summer. It remains unclear which stream reaches are sought for spawning, but catostomids from the Little Snake River appear to be able to access lower Muddy Creek upstream to the wetland complex.

Based on what was learned as well as the uncertainties that remain, the management of native catostomids in lower Muddy Creek should involve four components. First, continued monitoring is needed to determine the magnitude of catostomid spawning migrations across years relative to stream flow and runoff conditions. The two years of data collection yielded different patterns with native catostomids entering lower Muddy Creek during the spawning season in 2002 but not in 2004. More monitoring is needed to determine the factors affecting these patterns. Trap installation and maintenance should extend from near peak runoff through June. The U. S. Geological Survey currently maintains a streamflow monitoring gauge 1 km downstream from the trap site and this can be used to monitor flow while using the trap to capture migrating catostomids. A temperature logger should be used in conjunction with the streamflow gauge to achieve a greater understanding of conditions associated with catostomid spawning. In order to understand the variation in catostomid spawning movements, monitoring must be performed across years and flow conditions. For example, it would be informative to know if native catostomids are more likely to use lower Muddy Creek for spawning during high water years. Annual monitoring may not be feasible, but trap monitoring performed on a multi-year cycle may be realistic for long term monitoring, and would ensure sampling during a range of flow conditions. The trap location that was selected in 2002 and repeated in 2004 was 8 km upstream from the Little Snake River and should be reconsidered. Flannelmouth suckers and bluehead suckers use tributaries for spawning, although most observations of spawning activity ranged from 1 to 12 km upstream. The current trap site may be too far upstream to fully capture all of catostomids that may migrate into Muddy Creek to spawn.

Second, construction of additional movement barriers in the Muddy Creek watershed should be considered relative to their potential impacts on native fishes. Further fragmentation would decrease the potential of lower Muddy Creek to accommodate spawning migrations by native catostomids.

Third, it is unknown if the construction of small impoundments in the tributaries could further alter hydrologic conditions in lower Muddy Creek and reduce flows during spring and summer, thus reducing the period when the Muddy Creek watershed is navigable by fishes during the spawning season. The potential influences of small impoundments on the discharge in Muddy Creek during spring and summer need to be determined.

Fourth, it would be useful to determine the distribution and abundance of native and non-native age-0 catostomids in late summer. This would provide insight into which catostomid species are successfully spawning in lower Muddy Creek. Such sampling would involve seining during the summer, or drift-net sampling in late spring. In either case, specimens would require preservation and shipment to a laboratory equipped to identify age-0 catostomids to species. If performed in conjunction with trap monitoring, a richer understanding of spawning success by native and non-native catostomids in lower Muddy Creek could be obtained.

In conclusion, relatively few flannelmouth suckers and bluehead suckers were captured downstream of the wetland complex in the spring and summer of 2004. It is unknown if populations of these two species upstream from the wetlands and the headcut stabilization structure contribute to the populations of these fishes downstream of the wetland complex. The water control structures and altered lotic habitats may prevent large numbers of fish from moving downstream through the wetlands to colonize the lower reaches of Muddy Creek. Thus, spawning migrations may be critical to maintaining populations downstream of the wetlands.

Even if resident populations of flannelmouth suckers and bluehead suckers are not a feature of lower Muddy Creek, this stream may serve as valuable spawning habitat for populations of these species in the Little Snake River.

Literature Cited

Alkins, K.M. 2000. Reproductive timing of fishes in a tropical intermittent stream. Environmental Biology of Fishes 57:49-66.

Bain, M.B., and N.J. Stevenson. 1999. Common Methods: Aquatic habitat assessment. The American Fisheries Society, Bethesda, Maryland.

Barton, B.A. 1981. Spawning migrations, age and growth, and summer feeding of white and longnose suckers in an irrigation reservoir. Canadian Field Naturalist 94:300-304.

Baxter, G.T. and M.D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish Department, Cheyenne.

Bezzerides, N., and K. Bestgen. 2002. Status review of roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus* in the Colorado River Basin. Contribution 118 of the Larval Fish Laboratory, Colorado State University, Fort Collins.

Burdick, B.D. 1997. Minimum flow recommendation for passage of Colorado squawfish and razorback sucker in the 2.3 mile reach of the lower Gunnison River: Redlands diversion dam to the Colorado River confluence. Recovery Program Project number 57, Final report prepared for Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, Colorado.

Chart, T.E., and E.P. Bergersen. 1992. Impact of mainstream impoundment on the distribution and movements of the resident flannelmouth sucker *Catostomus latipinnis* population in the White River, Colorado. The Southwestern Naturalist 37: 9-14.

Childs, M.R., and R.W. Clarkson. 1996. Temperature effects on swimming performance of larval and juvenile Colorado squawfish: implications for survival and species recovery. Transactions of the American Fisheries Society 125:940-947.

Corbett, B., and Powles, P.W. 1983. Spawning and early-life ecological phases of the white sucker in Jack Lake, Ontario. Transactions of the American Fisheries Society. 112:308-313.

Douglas, M.R., and M.E. Douglas. 2003. Yampa River hybrid sucker genetic assessment. Project # 5-30477. Colorado State University, Fort Collins.

Erman, D.C., and V.H. Hawthorne. 1976. The quantitative importance of an intermittent stream in the spawning of rainbow trout. Transactions of the American Fisheries Society 6:675-681.

Goertler, C.M. 1992. Sediment dynamics within channel and riparian zone types along a cold-desert Wyoming stream. Master's thesis, University of Wyoming, Laramie.

Hamel, P., P. Magnan, M. Lapointe, and P. East. 1997. Timing of spawning and assessment of a degree-day model to predict in situ embryonic developmental rate of white sucker, *Catostomus commersoni*. Canadian Journal of Fisheries and Aquatic Sciences 54:2040-2048.

Hayes, D.B., and P.A. Petrusso. 1998. The role of tributaries in the sustainability of Great Lakes fisheries. Fisheries 23(8) 42-43.

Hawkins, J.A., and J. O'Brien. 2001. Research plan for developing flow recommendations in the Little Snake River, Colorado and Wyoming, for endangered fishes of the Colorado River Basin. Contribution 92 of the Larval Fish Laboratory, Colorado State University, Fort Collins.

Holden, P.B. 1973. Distribution, abundance, and life history of the fishes of the upper Colorado River Basin. Ph.D. dissertation, Utah State University, Logan, Utah.

Holden, P.B., and C.B. Stalnaker. 1975. Distribution and abundance of mainstream fishes of the middle and upper Colorado River Basins, 1967-1973. Transactions of the American Fisheries Society 104: 217-231.

Lucas, M. C., and E. Baras. 2001. Migration of freshwater fishes. Blackwell Science Ltd., Oxford, United Kingdom.

Maddux, H.R., and W.G. Kepner. 1988. Spawning of bluehead sucker in Kanab Creek, Arizona (Pisces: Catostomidae). Southwestern Naturalist 33:364 – 365.

Marchetti, M. P., T. Light, P. B. Moyle, and J. H. Viers. 2004. Fish invasions in California watersheds: testing hypotheses using landscape patterns. Ecological Applications 14:1507-1525.

Martinez, P.J., T.E. Chart, M.A. Trammel, J.G. Wullschleger and E.P. Bergensen. 1994. Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. Environmental Biology of Fishes 40:227-239.

Meffe, G. K. and W.L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist 117:177-191.

Mueller, G.A. and R. Wydoski. 2004. Reintroduction of the flannelmouth sucker in the Lower Colorado River. North American Journal of Fisheries Management 24:41-46.

Oberholtzer, M. 1987. A fisheries survey of the Little Snake River Drainage, Carbon County, Wyoming. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Ono, R.D., J.D. Williams and A. Wagner. 1983. Vanishing Fishes of North America.

Stone Wall Press, Inc., Washington, D.C.

Ostresh, L.M.J., R.A. Martson and W.M. Hudson. 1990. Wyoming Water Atlas. Wyoming Water Development Commission, Cheyenne and the University of Wyoming, Laramie.

Parker, B.R., and W.G. Franzin. 1991. Reproductive biology of the quillback, *Carpiodes cyprinus*, in a small prairie river. Canadian Journal of Zoology 69:2133-2139.

Perkins, D.L., and G.G. Scoppettone. 1996. Spawning migration of Lost River suckers (*Deltistes luxatus*) and shortnose suckers (*Chamistes brevirostris*) in the Clear Lake Drainage, Modo County, California. National Biological Service, California Science Center, Reno, Nevada.

Ross, M.J., and C.F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. Progressive Fish Culturist 44:41-43.

Snyder, D.E., and R.T. Muth. 2004. Catostomid fish larvae and early juveniles of the upper Colorado River Basin – morphological descriptions, comparisons, and computer-interactive key. Technical publication No. 42. Colorado Division of Wildlife.

Stacey, N.E., D.S. MacKenzie, T.A. Marchant, A.L. Kyle and R.E. Peter. 1984. Endocrine changes during natural spawning in the white sucker, *Catostomus commersoni.* General and Comparative Endocrinology 56:333-348.

Tyrus, H.M., and C.W. McAda. 1984. Migration, movements and habitat preferences of Colorado squawfish, *Ptychocheilus lucius*, in the Green, White and Yampa rivers, Colorado and Utah. The Southwestern Naturalist 29:289-299.

Weiss, S.J., E.O. Otis and O.E. Maughan. 1998. Spawning ecology of flannelmouth sucker, *Catostomus latipinnis* (Catostomidae), in two small tributaries of the lower

Colorado River. Environmental Biology of Fishes 52:419-433.

Wick, E.J., J.A. Hawkins and T.P. Nesler. 1991. Occurrence of two endangered fishes in the Little Snake River, Colorado. The Southwestern Naturalist 36:251-254.

Winter, J.D. 1996. Advances in underwater bio-telemetry. Pages 555-590 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Table 1. Relative morphological characteristics used to identify bluehead suckers, flannelmouth suckers, white suckers and catostomid hybrids.

	Morphological feature					
Species	Scale pattern	Dorsal fin shape	Caudle peduncle depth	Head length	Cartilaginous biting ridge	Lateral notch in lips
Bluehead sucker	fine	not sickle-shaped	shallow	short	present	yes
Flannelmouth sucker	fine	sickle-shaped	shallow	long	absent	no
White sucker	large	not sickle-shaped	deep	intermediate	absent	no

Table 2**.** Characteristics and movement information for eleven white suckers implanted with radio-transmitters in Muddy Creek during spring 2004. Sex is male (M), female (F) or unknown (U). Release date is when the fish was implanted and released upstream of the trap; upstream migration date is when the fish moved upstream of the trap; downstream migration date is when a fish returned to the trap site; downstream release date is when a fish was recaptured and released downstream of the trap. Date mortality signal was first emitted is when transmitter remained stationary for at least 24 hours indicating death or tag expulsion. Upstream residency was the number of days fish resided upstream of the trap. Letters indicate (a) fish did not return to trap site, (b) fish moved past the trap site after trap removal on June 18, (c) fish not recaptured, (d) fish that still alive or that retained transmitters as of July 20, 2004, and (e) fish died or expelled transmitters upstream and did not return to the trap site.

Fish ID #	Sex	Total length (mm)	Weight (g)	Release date	Upstream migration date	Dowmstream return date	Downstream release date	Date mortality signal first emitted	Upstream residency (days)
1	F	468	1220	4/16/2004	4/17/2004	5/11/2004	6/3/2004	7/20/2004	23
2	M	429	847	4/16/2004	4/17/2004	5/11/2004	6/1/2004	7/20/2004	23
3	F	395	669	4/16/2004	4/17/2004	5/17/2004	5/17/2004	7/20/2004	30
4	U	481	1156	4/16/2004	4/17/2004	5/4/2004	b	d	17
5	F	391	669	4/18/2004	4/19/2004	5/12/2004	c	6/1/2004	23
6	F	418	836	4/18/2004	4/19/2004	a	c	7/20/2004	e
7	M	378	585	4/21/2004	4/22/2004	5/12/2004	c	6/15/2004	20
8	F	424	716	4/22/2004	4/26/2004	5/11/2004	b	7/20/2004	15
9	F	355	559	4/25/2004	4/26/2004	a	c	6/1/2004	e
10	F	445	995	5/7/2004	5/8/2004	5/18/2004	c	5/31/2004	10
11	F	465	1079	5/10/2004	5/10/2004	5/28/2004	6/8/2004	d	18

Table 3. The occurrence of fish species in the Little Snake River, the upper Muddy Creek watershed, and lower Muddy Creek. Species occurrence is denoted by an X. Data sources are (a) Hawkins and O'Brien 200, (b) Bower 2005, and (c) current study. The data for the Little Snake River was compiled for sampling conducted in the lower 180 km of Little Snake River, from Baggs, Wyoming to the confluence of the Little Snake River with the Yampa River, Colorado.

Common name	Scientific name	Little Snake River[a]	Upper Muddy Creek watershed[b]	Lower Muddy Creek[c]
	Native species			
Bluehead sucker	*Catostomus discolobus*	X	X	X
Flannelmouth sucker	*Catostomus latipinnis*	X	X	X
Mountain sucker	*Catostomus platyrhynchus*		X	
Roundtail chub	*Gila robusta*	X	X	X
Colorado pikeminnow	*Ptychocheilus lucius*	X		
Speckled dace	*Rhinichthys osculus*	X	X	X
Mottled sculpin	*Cottus bairdi*	X		
Colorado River cutthroat trout	*Oncorhynchus clarki pleuriticus*	X	X	
	Non-native species			
White sucker	*Catostomus commersoni*	X	X	X
Common carp	*Cyprinus carpio*	X		
Fathead minnow	*Pimephales promelas*	X		X
Red shiner	*Cyprinella lutrensis*	X		
Redside shiner	*Richardsonius balteatus*	X		X
Sand shiner	*Notropis stramineus*	X		X
Creek chub	*Semotilus atromaculatus*	X	X	X
Black bullhead	*Ameiurus melas*	X		
Channel catfish	*Ictalurus punctatus*	X		
Brook trout	*Salvelinus fontinalis*		X	
	Hybrids			
Flannelmouth sucker x Bluehead sucker	*C. latipinnis x C. discobolus*	X	X	
Flannelmouth sucker x White sucker	*C. latipinnis x C. commersoni*	X	X	X
Bluehead sucker x White sucker	*C. discobolus x C. commersoni*	X	X	
Humpback chub x Roundtail cuhb	*G. cypha x G. robusta*	X		

Table 4. Ranges of water temperature reported for spawning movements or spawning activity by flannelmouth sucker, bluehead sucker, and white sucker.

Species	Spawning activity temperatures °C	Waterbody	Reference
Flannelmouth sucker	13 - 15	Paria River, Arizona	Weiss et al. 1998
Flannelmouth sucker	9 - 18	Bright Angel Creek, Arizona	Weiss et al. 1998
Flannelmouth sucker	6 - 19	*Literature review*	Bezzerides and Bestgen 2002
Flannelmouth sucker	6 - 13	*Literature review*	Snyder and Muth 2004
Bluehead sucker	≥18	*Literature review*	Snyder and Muth 2004
Bluehead sucker	18 - 25	Kanab Creek, Arizona	Maddux and Kepner 1988
Bluehead sucker	16 - 25	*Literature review*	Bezzerides and Bestgen 2002
White sucker	7 - 19	*Literature review*	Snyder and Muth 2004
White sucker	14	Yampa River, Colorado	Holden 1973
White sucker	7 - 10	Jack Lake, Ontario	Corbett and Powles 1983
White sucker	10 - 13	St. Lawrence River, Quebec	Hamel et al. 1997

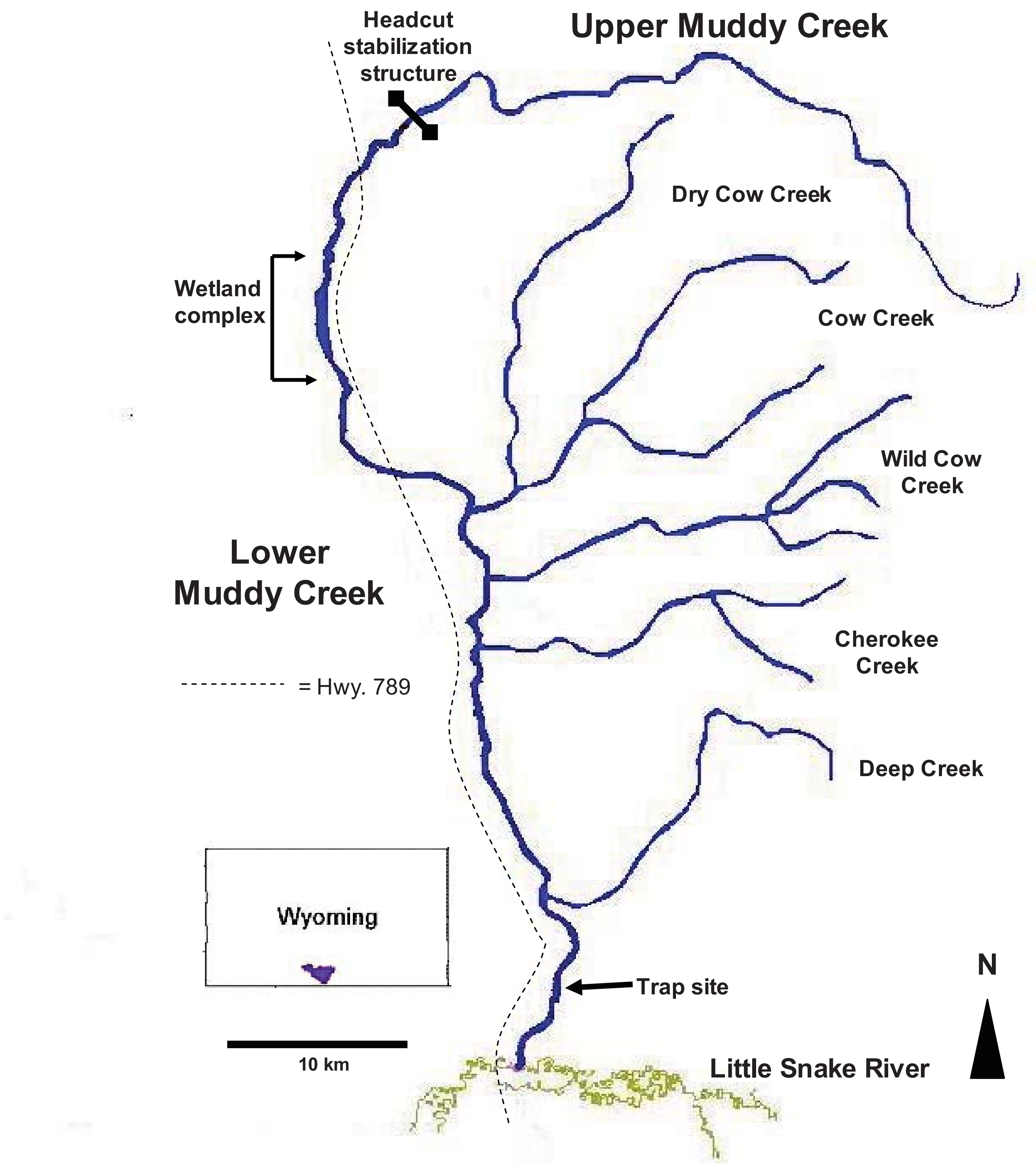

Figure 1. Map of the study area showing Muddy Creek and its major tributaries. Upper Muddy Creek is upstream of the headcut stabilization structure and lower Muddy Creek occurs downstream.

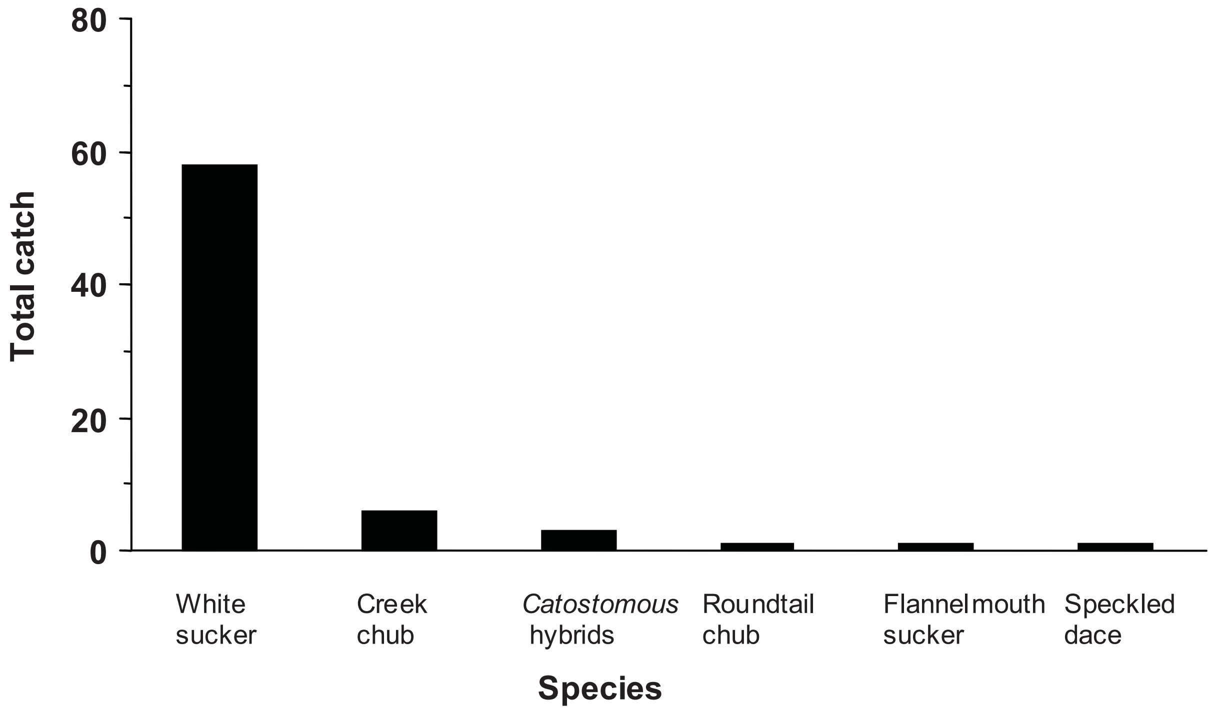

Figure 2. Total catch at Muddy Creek trap site, March 15 through June 18, 2004

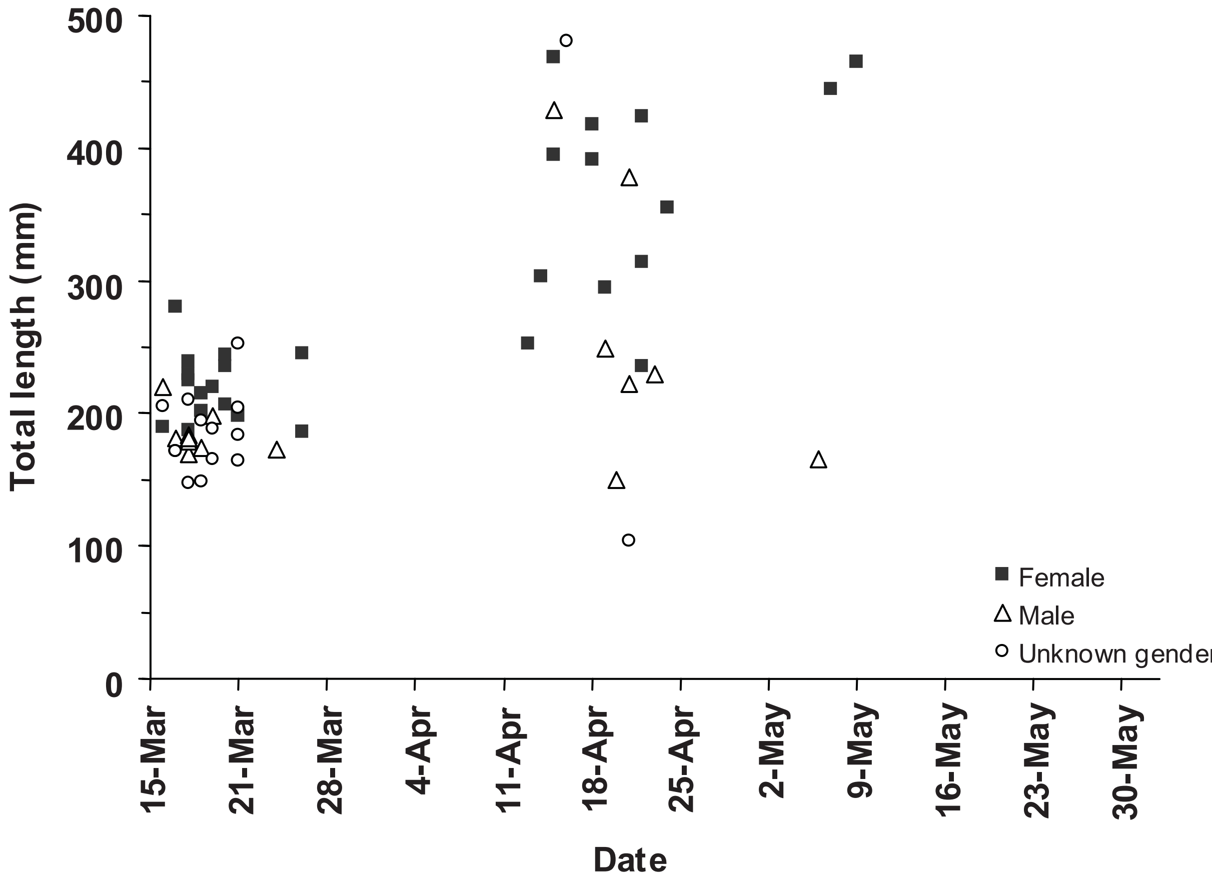

Figure 3. The total length of white suckers captured at trap site in Muddy Creek, March 15 through May 30, 2004.

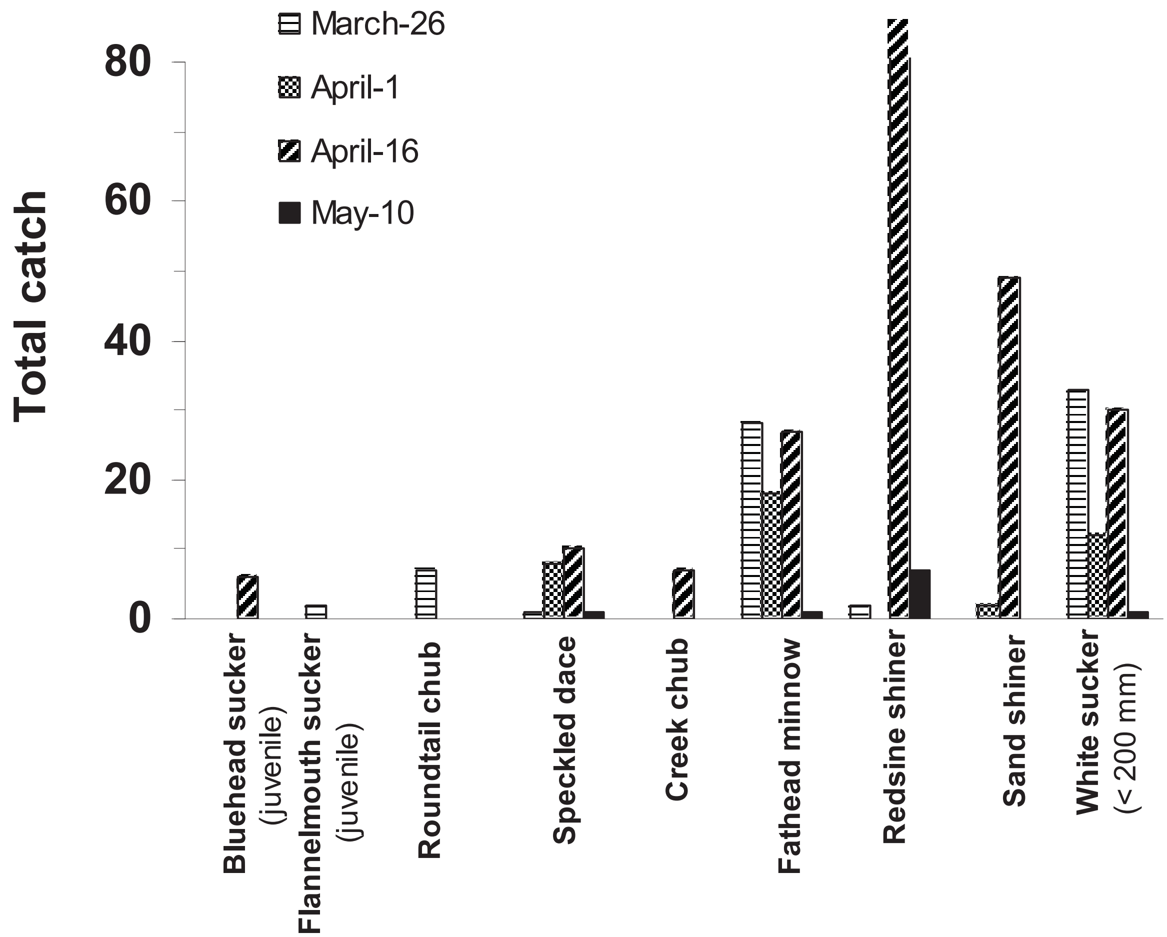

Figure 4. Seine catch composition for a 200 meter reach downstream of the trap site in Muddy Creek in 2004.

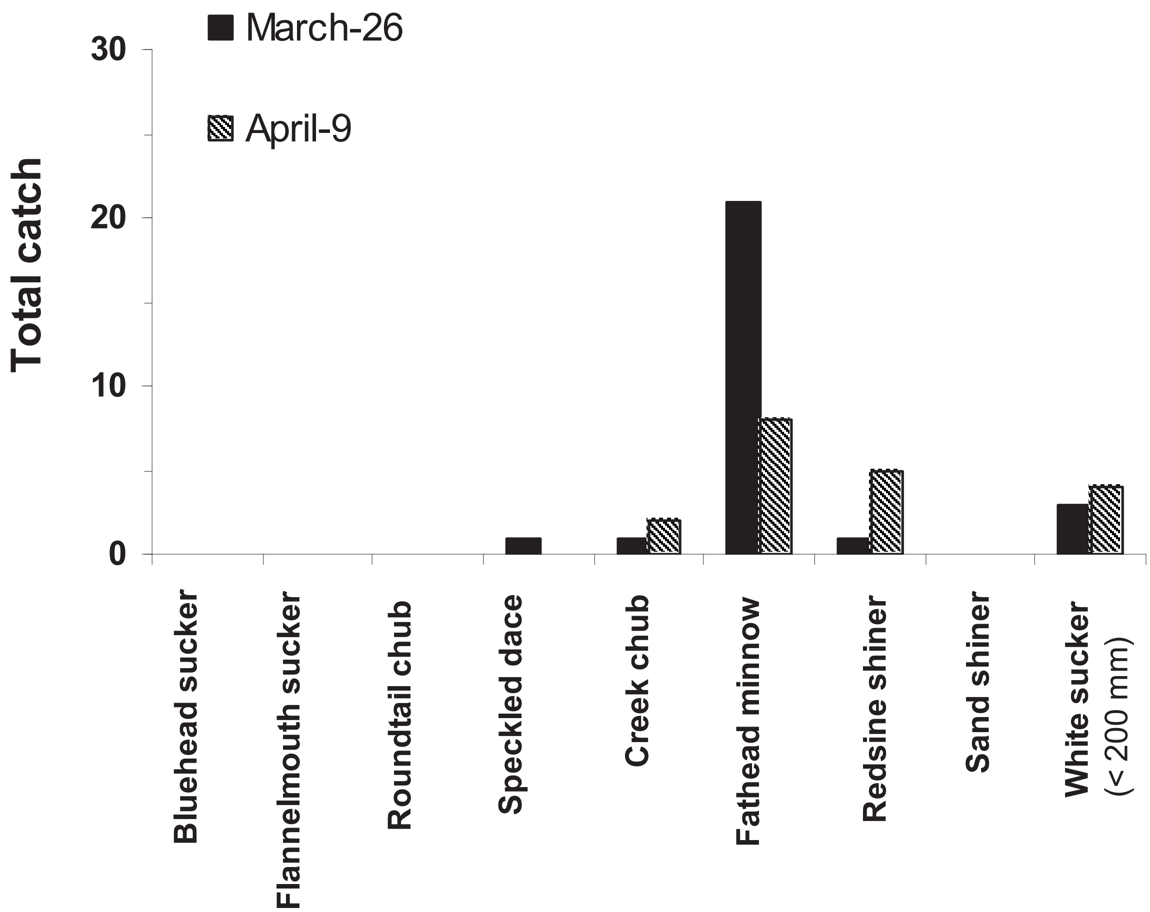

Figure 5. Seine catch composition for a 200 meter reach upstream of the trap site in Muddy Creek in 2004. No bluehead suckers, flannelmouth suckers, or roundtail chubs were captured.

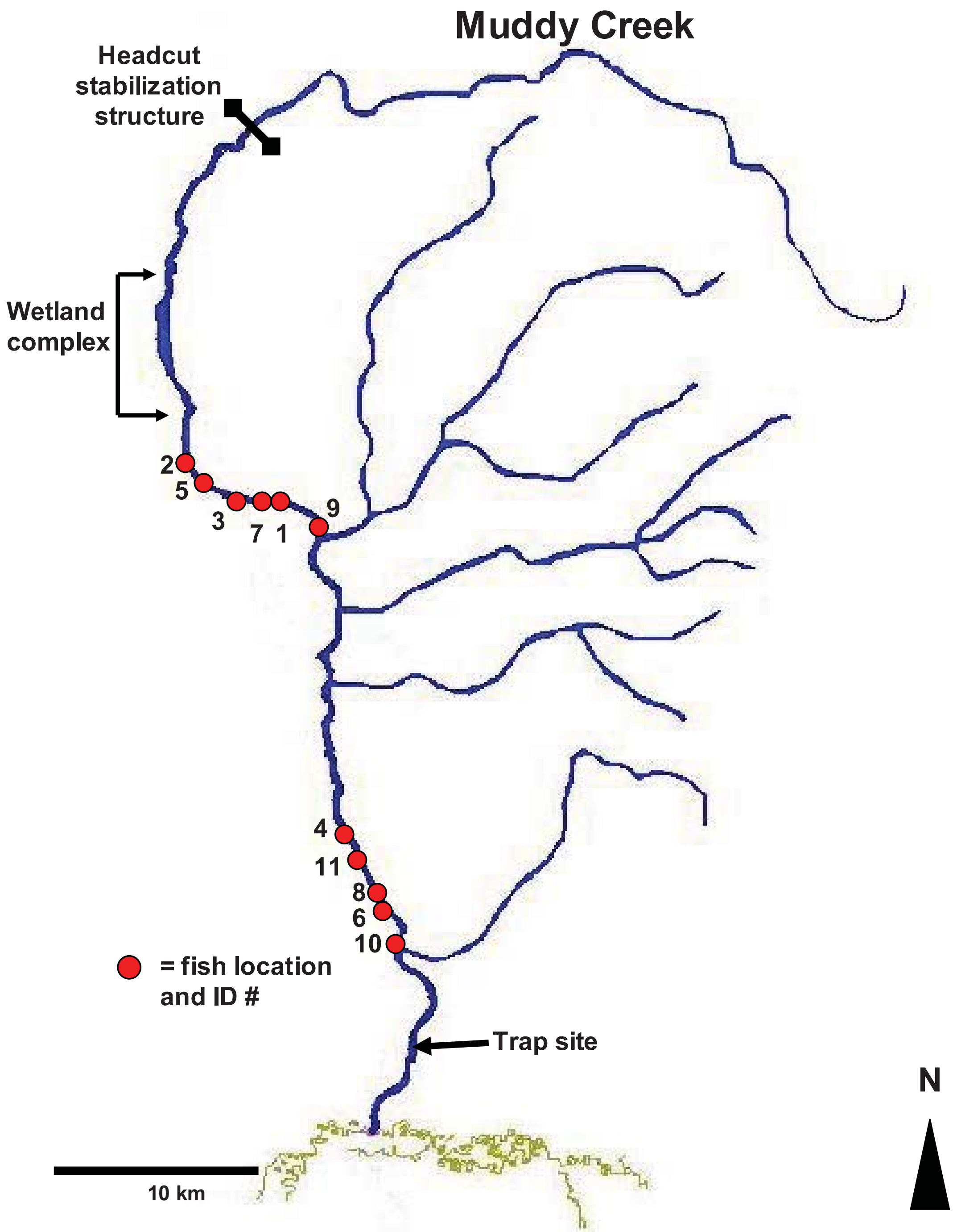

Figure 6. Maximum upstream locations observed from April 19 through May 18, 2004 for eleven white suckers implanted with radio transmitters. Numbers refer to identification numbers in Table 1.

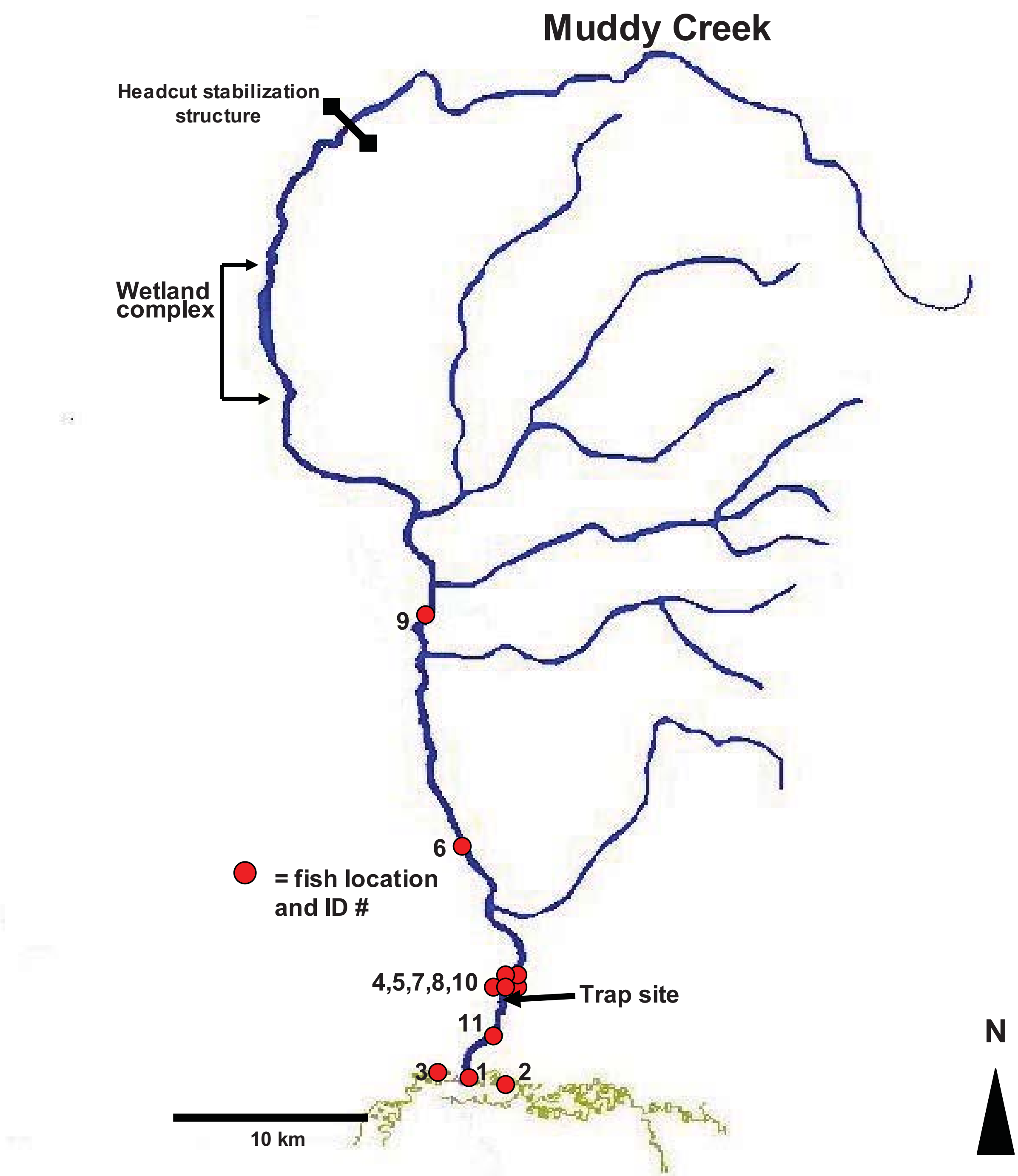

Figure 7. Maximum downstream locations of eleven transmitter-implanted white suckers during June, 2004. Numbers refer to fish identification numbers in Table 1.

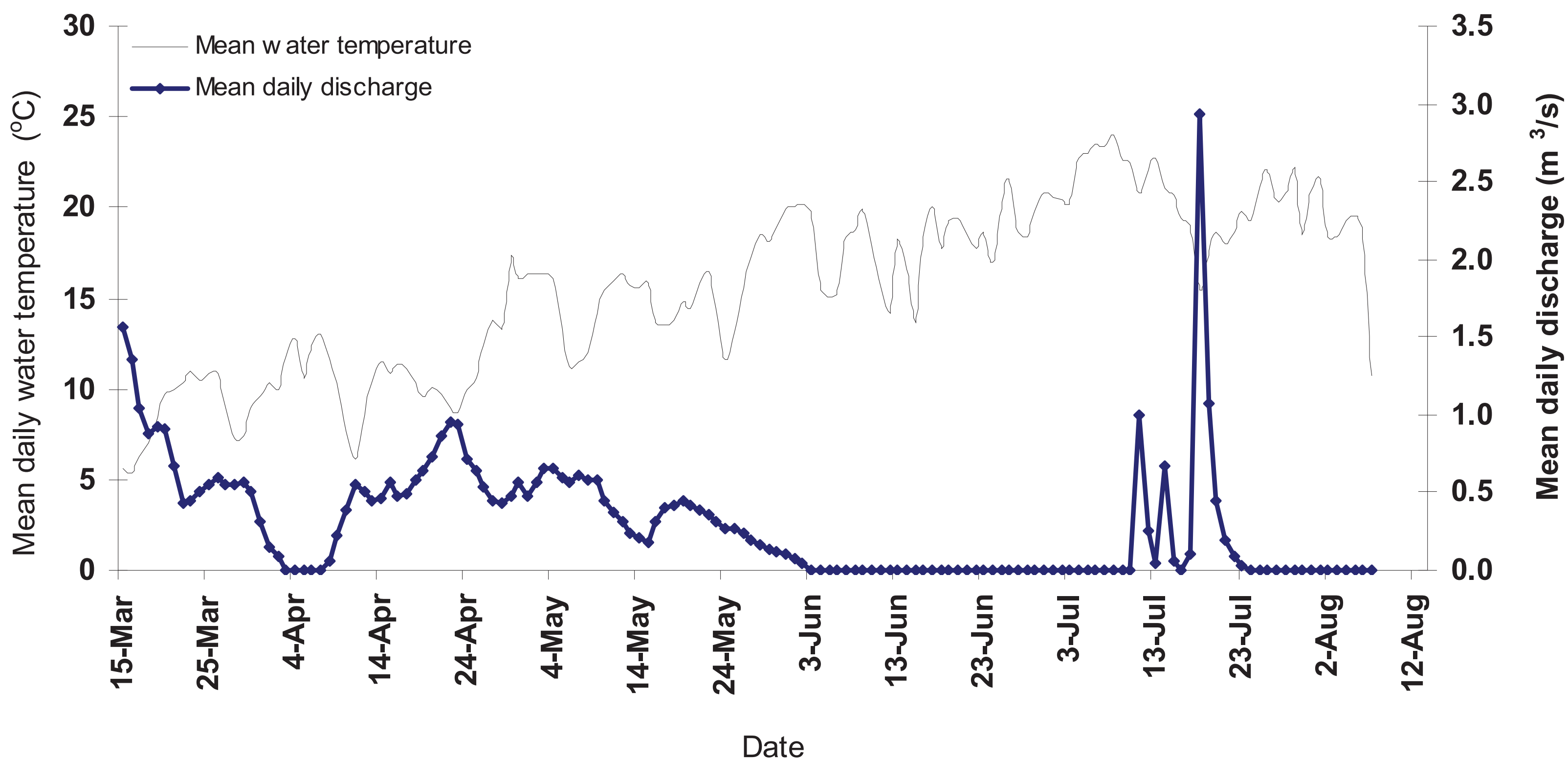

Figure 8. Mean daily water temperature and mean daily discharge measured in Muddy Creek at the trap site from March 15 through August 13, 2004.

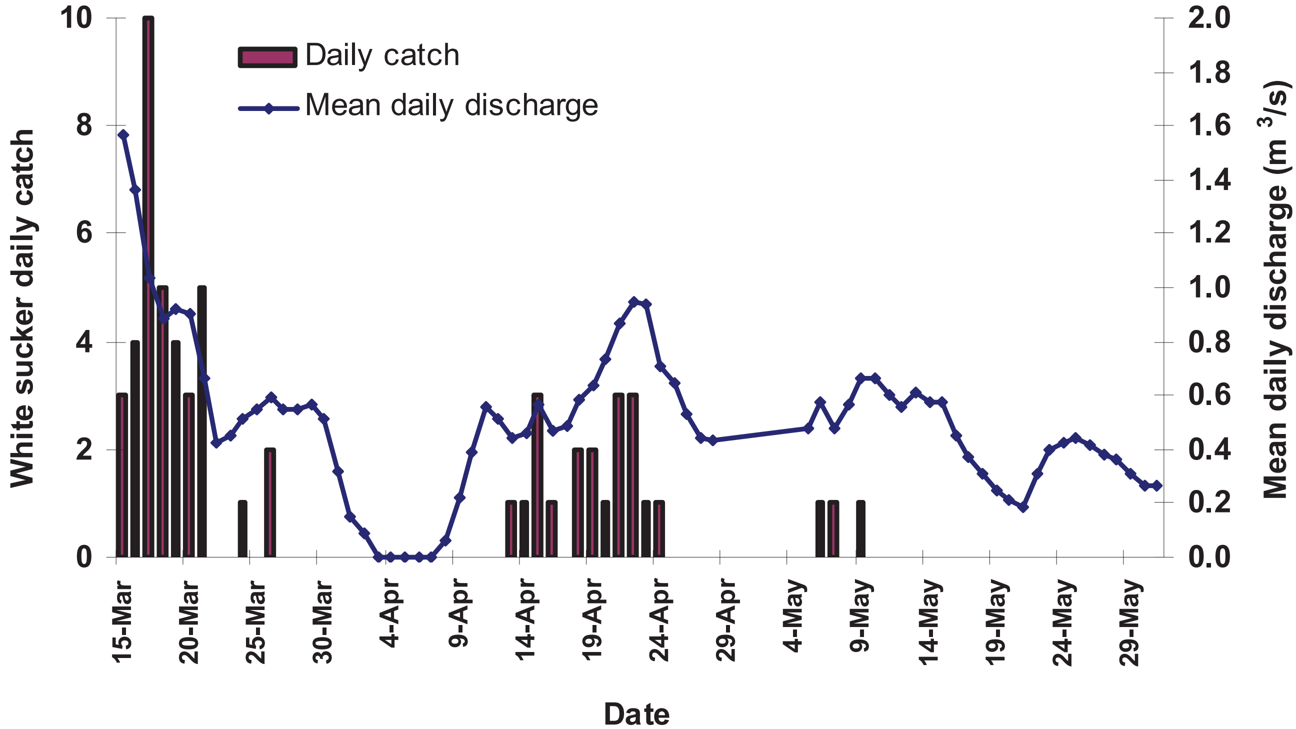

Figure 9. Number of white suckers captured per day at the trap in Muddy Creek from March 15 through May 30, 2004, and mean daily stream discharge measured at the trap site.

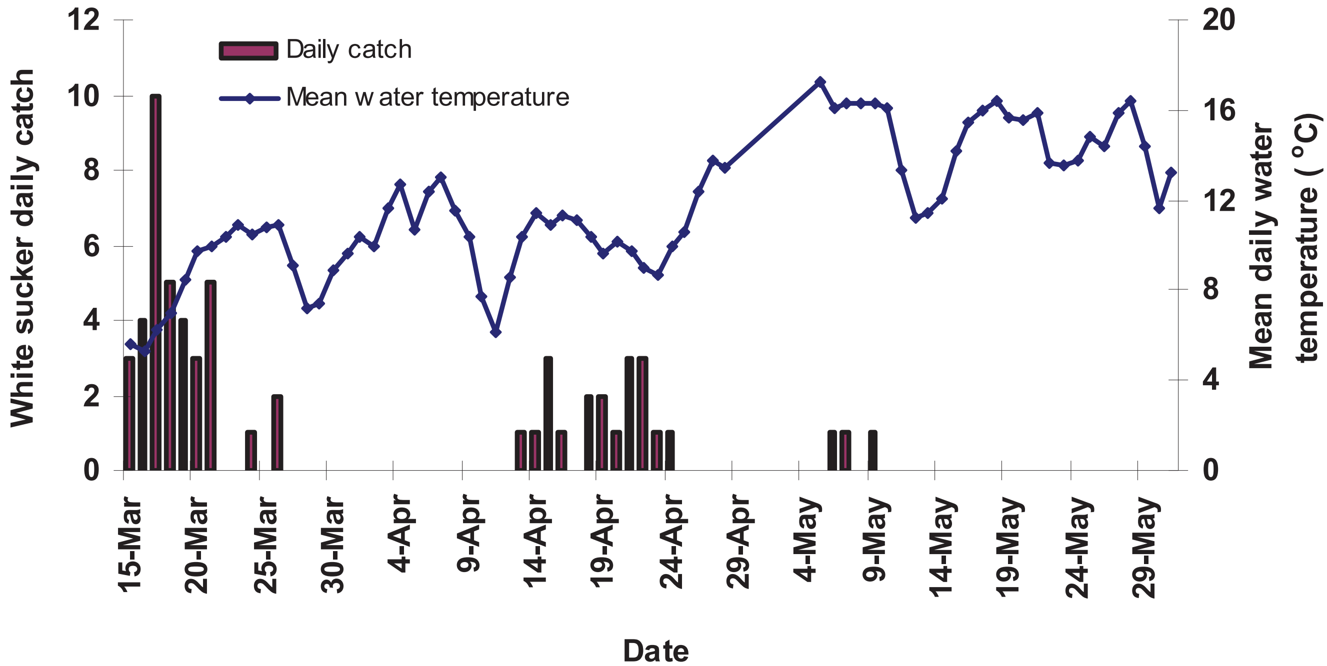

Figure 10. Number of white suckers captured per day at the trap in Muddy Creek from March 15 through May 30, 2004, and mean daily water temperature measured at the trap site.

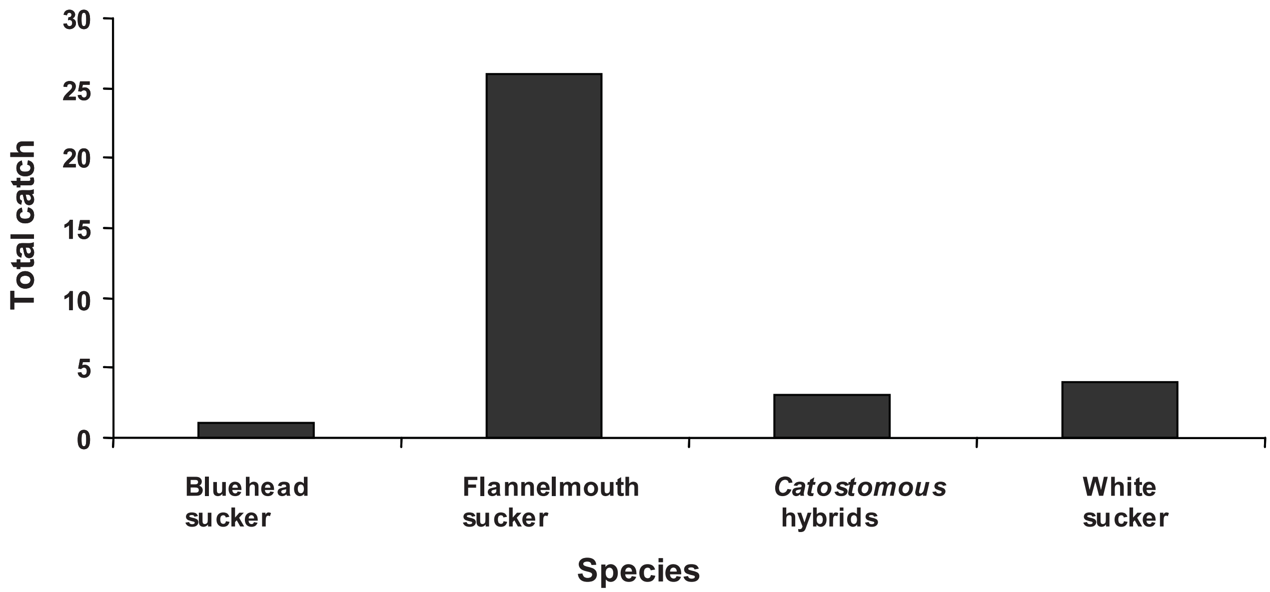

Figure 11 – Total catch at Muddy Creek trap site, April 18 through June 6, 2002, during sampling by the U.S. Bureau of Land Management

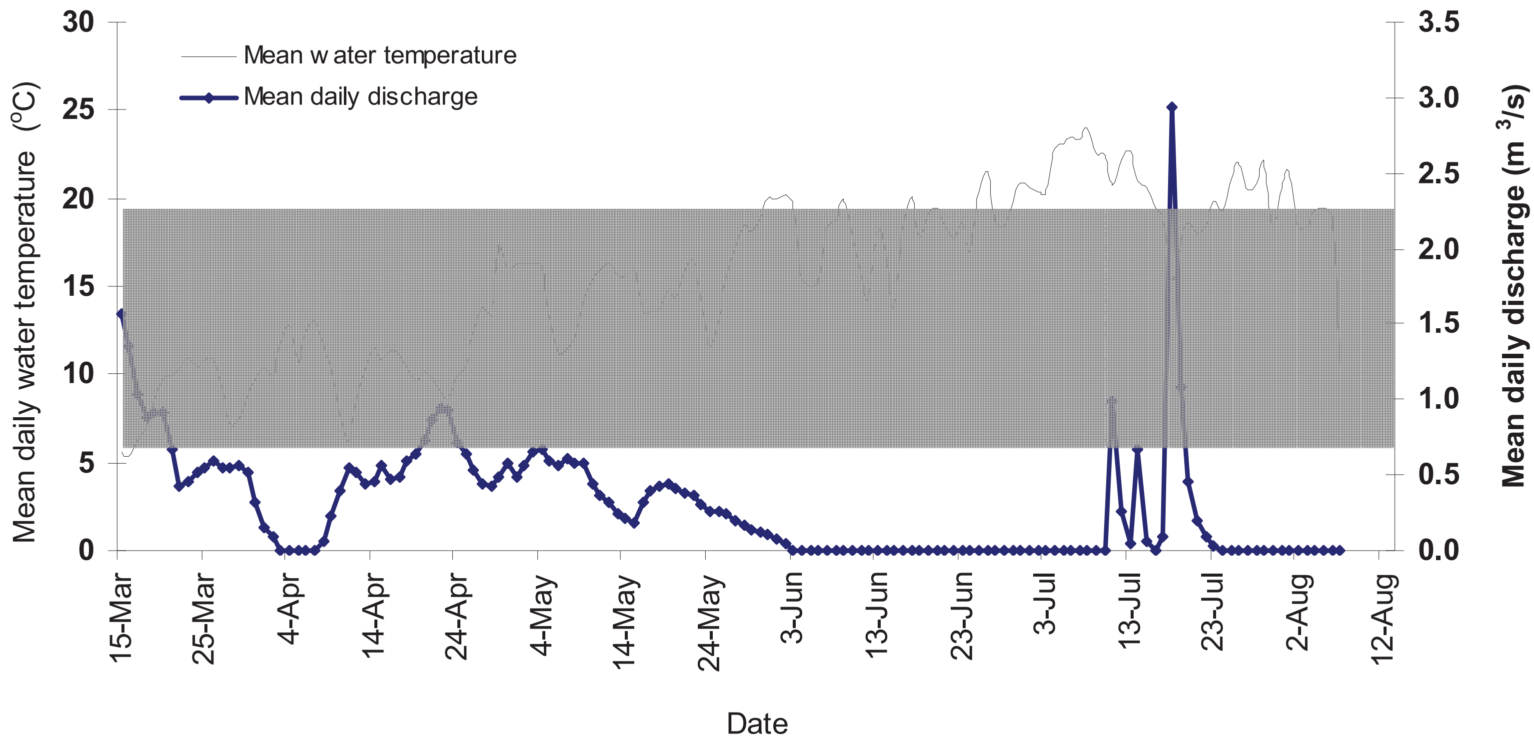

Figure 12. Potential spawning conditions for flannelmouth suckers and white suckers in relation to mean daily water temperature and mean daily discharge at the trap site from March 15 through August 13, 2004. Shaded area depicts range of water temperature at which spawning activity has been reported (6 - 19 °C).

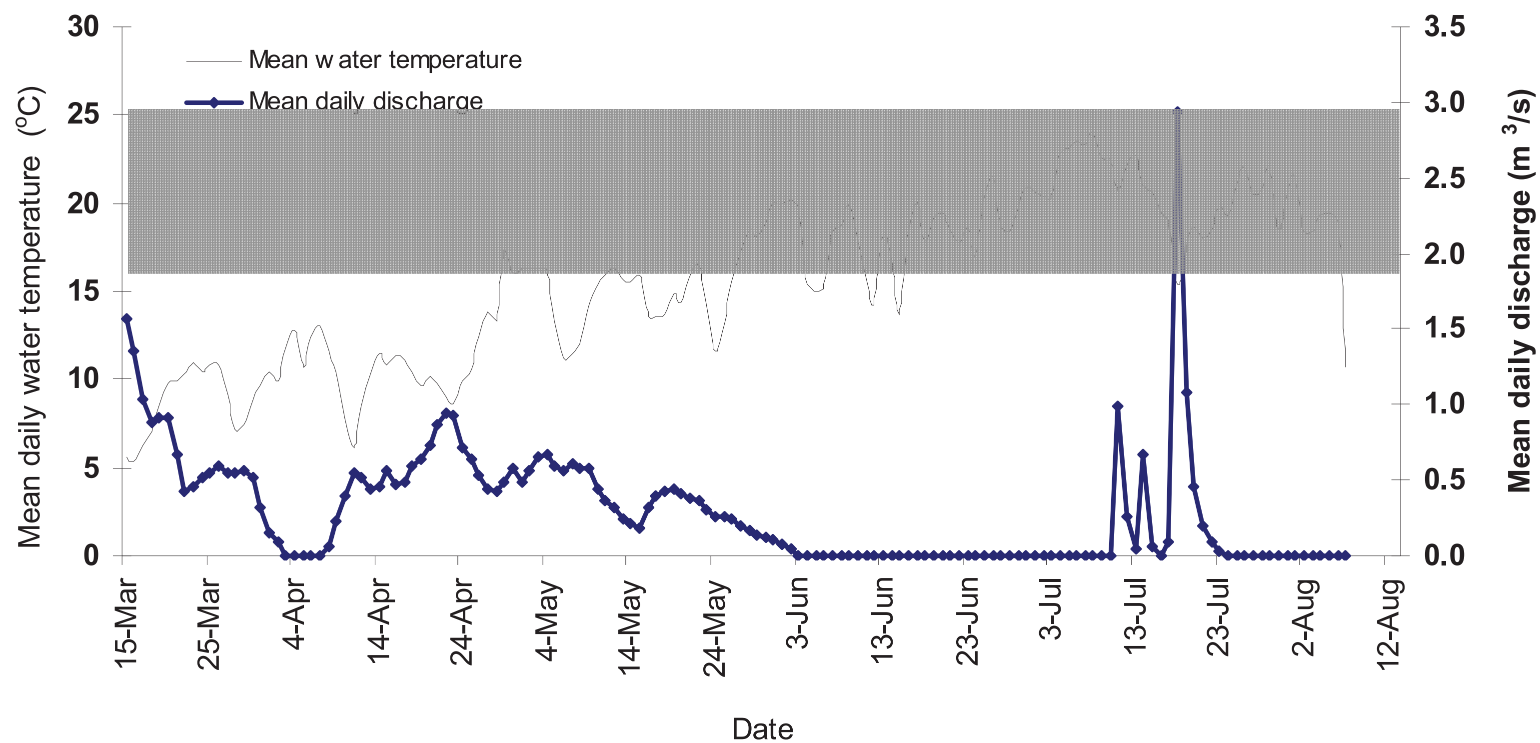

Figure 13. Potential spawning conditions for bluehead suckers in relation to mean daily water temperature and mean daily discharge at the trap site from March 15 through August 13, 2004. Shaded area depicts range of water temperature at which spawning activity has been reported for bluehead suckers (16 – 25 °C).

Chapter 2. Native and non-native fish distribution in relation to intermittency and fragmentation in a high-elevation desert stream of the Colorado River Basin in Wyoming.

Abstract

Muddy Creek is a high-elevation desert stream in the Colorado River Basin in Wyoming that commonly becomes intermittent, especially throughout the lower 100 km. Three fish species of management concern in the watershed are flannelmouth suckers (*Catostomus latipinnis*), bluehead suckers (*Catostomus discobolus*), and roundtail chubs (*Gila robusta*). Anthropogenic structures have resulted in three fragmented stream segments in the lower Muddy Creek watershed. The farthest downstream segment begins at the confluence of Muddy Creek with the Little Snake River and extends upstream to a wetland complex with water-control structures that inhibited fish movement. The farthest downstream segment experienced periods of no surface flow with isolated pools and was dominated by non-native fishes in 2004. The middle segment consists of a wetland complex with numerous water control structures and was dominated by non-native species, particularly the fathead min now (*Pimephales promelas*). The upstream segment extended from upstream of the wetland complex to a headcut stabilization structure that prevents upstream movement by fish. The upstream segment was dominated by two native species: roundtail chub (*Gila robusta*) and speckled dace (*Rhinichthys osculus*). Constructed wetlands and barriers to upstream movements by fishes appear to influence native fishes and the structure of fish communities in lower Muddy Creek, similar to the effects of fragmentation and intermittent stream flows in other areas of the Colorado River Basin.

6. Introduction

6.1 Rationale

Hydrologic variability can affect the structure of stream fish assemblages (Poff and Ward 1989). Frequent and extreme hydrologic events can drastically reduce fish abundance in intermittent and flood prone streams of North America, particularly during drought cycles (Poff and Allan 1985; Lake 2003; Magoulick and Kobza 2003; Matthews and Matthews 2003). Such disturbances have been related to the presence of colonizing species and species with physiological adaptations for survival in desiccating lotic habitats (Poff and Allan 1985; Meffe and Minckley 1987; Poff and Ward 1989; Fausch and Bramblett 1991).

The effects of extreme hydrologic variation can be amplified by the presence of movement barriers, which inhibit fish dispersal necessary to seek refuge from receding flows, reach spawning habitat, or recolonize defaunated reaches (Lucas and Baras 2001; Herbert and Gelwick 2003). Movement barriers are often associated with impoundments of varying size and function. Lentic habitats formed by impoundments are often sources of invasive species (Wilde and Ostrand 1999; Marchetti et al. 2004). Habitat generalists that reproduce in lentic environments can disperse into adjacent lotic habitats (Herbert and Gelwick 2003). Additionally, modified flow regimes associated with water development activities may favor non-native fish species (Marchetti and Moyle 2001; Herbert and Gelwick 2003).

The Little Snake River watershed in Wyoming and Colorado is characterized by extreme hydrologic variability. Peak runoff generally occurs in May, but varies widely among years. From 1984 to 2004, mean monthly discharge of the Little Snake River during May ranged from 10.7 m^3/s in 2002 to 60.2 m^3/s in 1984 at Slater, Colorado. Conversely, low-flow conditions occur from July through November and can force fish into refuge pools (Hawkins et al. 1997). The largest tributary to the Little Snake River is Muddy Creek, a stream subject to frequent and extreme periods of intermittent surface flows. Abundant populations of roundtail chubs (*Gila robusta*), speckled dace (*Rhinichthys osculus*), flannelmouth suckers (*Catostomus latipinnis),* and bluehead suckers (*Catostomus discobolus*) exist in the Little Snake River (Hawkins and O'Brien 2001). Populations of these species also occur in the upper Muddy Creek watershed, where they currently comprise the only known sympatric populations of these fishes in Wyoming (Bower 2005, Table 1). Information about the fish community in the lower Muddy Creek watershed was scant, although fish were sampled in 1982 and 1995 and all three species were documented (Oberholtzer 1987; Wheeler 1997).

The Muddy Creek watershed is fragmented by a large headcut stabilization structure that occurs 100 km from the Muddy Creek-Little Snake River confluence (Figure 1). The portion of Muddy Creek downstream of the headcut stabilization structure, which I refer to as lower Muddy Creek, is further fragmented by a large wetland complex that extends between 78 and 84 km upstream from the confluence of Muddy Creek with the Little Snake River. Habitat fragmentation in lower Muddy Creek results in the potential for source-sink dynamics, whereby populations in sink habitats are influenced by emigration from source habitats (Delibes et al. 2001). However, it was unknown if the wetland complex serves as a source of non-native fish, a sink for native fish, or refuge habitat for native or non-native fishes during periods with no surface flow and isolated pools in the mainstem of Muddy Creek.

Three of the fish species found in Muddy Creek, flannelmouth suckers, bluehead suckers, and roundtail chubs, have experienced substantial declines throughout the Colorado River Basin. These declines are largely due to habitat alterations, creation of movement barriers associated with reservoir construction, and the introduction of non-native species. It has been estimated that these species now exist in about 50% of their historical native range (Bezzerides and Bestgen 2002). Thus, the potential occurrence of these species in the lower Muddy Creek watershed is of importance to natural resource management agencies charged with managing and conserving native fishes.

6.2 Objectives

Objective 1: Describe flow conditions (surface flow, isolated pools, and dry stream bed) within the lower Muddy Creek watershed from June through September, 2004.

Objective 2: Determine spatial distributions of native and non-native fish species within lower Muddy Creek during the summer of 2004.

6.3 Study Area

Muddy Creek originates in the Sierra Madre, Carbon County, Wyoming. The Muddy Creek watershed encompasses 471 km^2, ranges in elevation from 1,920 to 2500 m, and extends from the Sierra Madres to the Red Desert. The upland watershed is dominated by sagebrush (family: Asteraceae), and riparian vegetation is primarily willow (*Salix* spp.) and greasewood (*Sarcobatus vermiculatus*). Although the headwaters have perennial flow, intermittency occurs throughout most of the Muddy Creek watershed during summer (Goertler 1992).

The Muddy Creek watershed can be divided into two major segments, upper Muddy Creek and lower Muddy Creek. Upper Muddy Creek extends from the headwaters downstream to a large headcut stabilization structure (Figure 1). The headcut stabilization structure inhibits upstream movements of fishes and marks the upstream boundary of lower Muddy Creek. Lower

Muddy Creek has four major tributaries that also experience intermittent flows. The confluence of the southern most tributary, Deep Creek, is 16.0 km upstream from the confluence of Muddy Creek with the Little Snake River. The confluence of Cherokee Creek is 38.0 km from the Little Snake River, Wild Cow Creek is 45.4 km, and Cow Creek is 51.1 km from the Little Snake River (Figure 1).

Based on 1:24,000 hydrography data, the total length of the mainstem of Muddy Creek from the Little Snake River to the headcut stabilization structure is approximately 100 km (http://nhd.usgs.gov/data.html). A large wetland complex occurs 78-84 km upstream from the confluence of Muddy Creek with the Little Snake River. Muddy Creek flows through the wetland complex, which consists of impoundments, man-made channels, vertical drop structures, headgate structures for water diversion, overflow spillways, and a braided stream-channel network (Figure 2).

Lower Muddy Creek is highly erosional and has abundant channel incision. Substrates are dominated by fine clays and sand, although areas of rock substrates (i.e. gravel and cobble) occur sporadically. Most of the rock substrate occurs upstream from the wetland complex and downstream of the headcut stabilization structure, 78-100 km upstream from the Little Snake River. Spring runoff is snow-melt dominated, and generally occurs in March. Base flow and intermittency can occur as early as April and as late as February, but is most common from July through September (Goertler 1992).

7. Methods

7.1 Objective 1: Describe flow conditions (surface flow, isolated pools, and dry stream bed) within the lower Muddy Creek watershed from June through September, 2004.

7.1.1 Mapping of flow conditions

Spatial patterns of surface flow were determined by flying over the lower Muddy Creek watershed in a fixed wing aircraft (France Flying Service, Rawlins, Wyoming), three times during the summer in June, July, and September. Flights started at the confluence of Muddy Creek with the Little Snake River and progressed upstream to the headcut stabilization structure (Figure 1). Surface flows in tributaries were determined by starting at the tributary mouth and progressing upstream to the headwaters. My goal was to record points of transition between three classes of flow conditions: (1) stream channel with surface flow, (2) intermittent reaches with isolated pools typically < 200 m apart, and (3) dry stream channel. Approximate locations for transitions among the three types of flow conditions were recorded with a handheld GPS unit (Trimble GeoXT®). Locations were downloaded to a geographical information system (ArcVIew 3.2®, Environmental Research Institute, Redlands, California) to create maps depicting spatial patterns of the three classes of flow conditions in the lower Muddy Creek watershed.

7.2 Objective 2: Determine spatial distributions of native and non-native fish species within lower Muddy Creek during the summer of 2004.

7.2.1 Site selection

A total of 173 pools were sampled throughout the mainstem of lower Muddy Creek, from July 28 to August 18, 2004. Sites were sampled within each of the three stream segments (Figures 1 and 3). Segment 1 extended 78 km upstream from the Little Snake River to a large pool immediately downstream of a spillway structure at the downstream end of the wetland complex (Figure 2). Segment 2 included the entire wetland complex, including impoundments and natural and man-made channels within the complex. The upstream end of the wetland complex was marked by a headgate structure in Muddy Creek that diverts flow into the wetland impoundments. Segment 3 was upstream of the headgate structure extending 22 km upstream to the headcut stabilization structure.

I sampled the largest pools remaining during summer throughout each segment of lower Muddy Creek. Pools that were visually estimated to be $\geq$ 0.5 m deep or the largest relative to nearby pools were sampled. On each sampling day, I made an effort to sample 10 pools distributed over approximately 1 km of stream. Within the wetland complex (segment 2), I sampled isolated pools in the network of stream channels during August. In addition, I sampled the four largest wetland impoundments during June and August. Approximate surface area of the impoundments ranged from 1 to 5 ha with maximum depths of 2 to 3 m. Three 200-m stream reaches with surface flow downstream of water-control structures were also sampled during June.

7.2.2 Fish and habitat sampling

Pools were sampled with a 9.1-m-long bag seine with 6.3-mm mesh. At least one seine haul was made in each pool, but several large pools received multiple seine hauls. When pools with surface water connectivity to nearby pools were seined, I blocked the downstream end of the pool 6.3-mm mesh net to prevent fish from evading capture. For each pool sampled, a suite of habitat characteristics was measured: maximum pool depth (m), average pool width (m), pool area (m^2), pool area $\geq$ 0.5 m deep (m^2), and depth (cm) of water in the channel connecting the nearest pool downstream. Fish were identified to species and enumerated in 10-mm total length classes. Cyprinids $\leq$ 40-mm total length were classified as age-0 fish, fish $\geq$ 41-mm total length were classified as age-1 and older (Snyder 1981). Catostomids $\leq$ 50-mm total length were classified as age-0 fish and fish $\geq$ 51-mm were classified as fish age-1 and older (Snyder et al. 2004).

The wetland impoundments were sampled with gill nets, hoop nets, and minnow traps. Experimental gill nets were 48-m-long, 2-m-deep, and had three 16-m panels of different mesh sizes (5.0, 7.0, and 10.0 cm bar mesh). Hoop nets were 5-m-long with a 10-m-long, 1-m-deep lead, and 6.3-mm mesh. Wire minnow traps were 42-cm-long and 21 cm in diameter with 5-mm wire mesh and 30-mm-diameter throat openings, and were baited with pieces of dead fish from Muddy Creek. The four largest wetland impoundments were sampled in late May and again in August. During May I used two gill nets, 10 minnow traps, and three hoop nets, for two consecutive 24-hour sets in each of the four impoundments. During August, I used two gill nets and ten minnow traps for two consecutive 24-hour sets in each of the four impoundments sampled. During May, I conducted one-pass electrofishing surveys with a backpack electrofisher

(Smith-Root® model 12-B) in three 200-m reaches within stream channels downstream of water-control structures.

7.2.3 Data analyses

Descriptive statistics were used to summarize fish distribution data and habitat features of the sampled pools. Total catch of each species in each pool was summarized with scatter plots of catch versus the distance from the Little Snake River. Pool distances from the Little Snake River were estimated with 1:24,000 hydrography data and ArcView GIS 3.2. One-way analysis of variance (ANOVA) was used to test for differences among mean habitat measurements for all pools sampled in each of the three segments. This allowed me to suggest if pool habitat characteristics differed among the three segments. If p-values were less than 0.05, I inferred that mean pool habitat values differed among the three segments. If differences occurred among mean habitat values based on one-way ANOVA, I conducted pairwise ANOVA among the means to determine which segments differed. The alpha level for pairwise ANOVA was adjusted with a Bonferroni correction in which an alpha level of 0.05 was divided by the number of comparisons. Thus, 0.05 divided by 3 yielded an alpha level of 0.017 for pairwise comparisons.

8. Results

8.1 Objective 1: Describe flow conditions (surface flow, isolated pools, and dry stream bed) within the lower Muddy Creek watershed from June through September, 2004.

On June 9, 2004 the entire mainstem of lower Muddy Creek had surface flow but was approaching the point of discontinuous surface flow and pool isolation (Figure 4). Dry stream channel and isolated pools were the dominant flow conditions within the tributaries on June 9, 2004. The mouth of Cow Creek and a reach approximately 10 km upstream of the confluence were the only areas within the tributaries that had observable surface flow.

On July 20, 2004, the mainstem of Muddy Creek had observable surface flow from the Little Snake River upstream to the mouth of Cow Creek (Figure 5). Mean daily discharge at a monitoring station 8 km upstream from the confluence of Muddy Creek with the Little Snake River was 0.66 m^3/s. Extreme hydrologic variation resulted from summer precipitation events (Figure 6). No observable surface flow occurred during the first half of July, but precipitation events caused flow to return between July 17 and July 29, with a peak discharge of 2.94 m^3/s. These flows quickly receded, and no observable surface flow with isolated pools occurred again on July 30, 2004 (Figure 6). Muddy Creek near the mouth of Cow Creek upstream to the headcut stabilization structure had discontinuous surface flow and isolated pools on July 20 (Figure 5). However, downstream from the headcut stabilization structure a short reach of approximately 8 km had continuous surface flow (Figure 5). Within the wetland complex, the channels consisted of isolated pools with no surface flow. Two tributaries, Cow Creek and Wild Cow Creek, which had consisted mostly of isolated pools in June, had observable surface flows due to a large precipitation event in mid-July. However, this event did not appear to impact flow conditions in Cherokee Creek and Deep Creek which had isolated pools in June but entirely dry channels on July 20, 2004 (Figure 5, Figure 6).

On September 1, 2004, the mainstem of Muddy Creek mostly lacked surface flows and consisted of isolated pools (Figure 7). However, two small reaches had observable surface flows. Within segment 1, a reach that extended 6 km upstream from Little Snake River, and within segment 3, a reach that extended 6 km downstream from the headcut stabilization, had observable surface flows on September 1, 2004. The majority of the stream channel within the tributaries was dry, but isolated pools did exist in Cow, Wild Cow, and Cherokee creeks (Figure 7).

8.2 Objective 2: Determine spatial distributions of native and non-native fish species within lower Muddy Creek during the summer of 2004.

8.2.1 Fish presence in lower Muddy Creek

Fish ($\geq$ age-1 and age-0 combined) were present in nearly every one of the 173 pools sampled in lower Muddy Creek during the late summer of 2004. Fish were present in 99 of 100 pools in segment 1, 12 of 20 pools in segment 2, and all 53 pools in segment 3. I captured four native fish species and five non-native species (Table 1). Non-native redside shiners (*Richardsonius balteatus*) and sand shiners (*Notropis stramineus*) were documented for the first time in Muddy Creek.

8.2.2 Segment 1 – fish $\geq$ age-1

Non-native species comprised 93.5% of the total catch, whereas native species were only 6.5% (Table 2, Figure 8). Fathead minnows (*Pimephales promelas*) and creek chubs (*Semotilus atromaculatus*) were present in 65% of the 100 pools sampled, and accounted for 57.7% of the total catch (Table 2, Figures 9 and 10). White suckers (*Catostomus commersoni*) and redside shiners were less abundant, but present in 35% of pools sampled (Table 2, Figures 11 and 12). The distributions of redside shiners and sand shiners in lower Muddy Creek extended to a pool below the furthest downstream vertical drop spillway in the wetland complex that I used to define as the upstream boundary of segment 1 (Table 2, Figures 12 and 13). Speckled dace and roundtail chubs were present in 27% and 12% of pools, respectively (Table 2, Figures 14 and 15). One adult flannelmouth sucker was captured, but bluehead suckers were not captured during late-summer sampling (Table 2, Figure 16).

8.2.3 Segment 1 – age-0 fish

Age-0 catostomids, creek chubs, and cyprinids too small to identify in the field were present in 72%, 61%, and 57% of pools, respectively (Table 3, Figures 17-19). Redside shiners and fathead minnows were less abundant and present in 15% and 28% of pools, respectively (Table 3, Figures 20 and 21). Only one sand shiner was captured (Table 3). Speckled dace and roundtail chubs I was able to identify in the field were present in 11% and 4% of pools, respectively (Table 3, Figures 22 and 23).

8.2.4 *Segment 2 - fish ≥ age-1*

Four impoundments were sampled from May 25 to June 2, 2004 (early sampling period) and again from August 9 to August 14, 2004 (late sampling period). The fish assemblages in the four impoundments consisted of three non-native species. Fathead minnows were abundant in all four ponds and accounted for 97.9% of the total catch during the early sampling period, and 44.8% of the total catch during the late sampling period (Table 4). White suckers accounted for 1.9% of the total catch in the four impoundments during the early sample period and 55.2% during the late sample period (Table 4). Only five creek chubs were captured, and this occurred in one 24-hour hoop-net set during the early sampling period where they constituted 0.2% of the total catch in the impoundments.

Within the channels of the wetland complex, fathead minnows were the most abundant species, and constituted 96.1% of the catch in the channels during the early period and 44.8% of the catch in the late sample period (Table 4, Figure 9). White suckers and creek chubs were present, but occurred in fewer pools and were less abundant (Table 4, Figures 10 and 11). Native species were rare and only three speckled dace were captured.

8.2.5 Segment 2 – age-0 fish

No age-0 fish were captured within the wetland ponds. Within the channels, no age-0 fish were captured during early sampling, but unknown catostomids and cyprinids were relatively abundant in isolated pools during the late sampling period (Table 4). Age-0 fathead minnows and creek chubs were also captured. Twelve age-0 speckled dace and 15 age-0 roundtail chubs were captured in the wetland complex (Table 4, Figures 22 and 23). However, all these fish were captured from one pool near the headgate structure that served as the upstream boundary of the wetland complex (Figure 2).

8.2.6 Segment 3 - fish ≥ age-1

Segment 3 supported the most abundant populations of native species (Table 2, Figure 8). In 53 pools, a total of 2,789 fish was captured, and 65.6% of these were native species. In total, 1,020 roundtail chubs were captured and they were present in 62.3% of the pools, and accounted for 36.6% of the total catch (Table 2, Figure 15). Most of the roundtail chubs were clustered in a 6-km reach that had abundant rock substrates and pools with surface water connectivity (Figures 7 and 15). In one pool, I collected 390 roundtail chubs ≥ age-1; this represented the largest catch of any species in all pools sampled in 2004. Within the more isolated pools in the lower reaches of segment 3, roundtail chubs were rare or absent, but speckled dace were present. Speckled dace were present in 81.1% of the pools, although fewer were captured than roundtail chubs (Table 2, Figures 14 and 15). A total of 14 bluehead suckers were captured in the upper reaches of segment 3 (Table 2, Figure 16). Only one adult flannelmouth sucker was captured in segment 3 (Table 2).

Three non-native species were abundant and widely distributed in segment 3 (Table 2, Figure 8). Creek chubs and fathead minnows accounted for nearly all non-native species, and were widely distributed at 83.0% and 71.7% of the pools, respectively (Table 2, Figures 9 and 10). White suckers were far less abundant and only present in 20.8% of the pools (Table 2, Figure 11).

8.2.7 Segment 3 – age-0 fish

A total of 786 age-0 fish was captured in segment 3. Catostomids and cyprinids too small to identify to species and creek chubs were the most abundant and widely distributed taxa, and accounted for 70.3% of the total catch (Table 3, Figures 17-19). Fathead minnows were also present but less abundant (Table 3, Figure 21). A total of 126 roundtail chubs and 28 speckled dace were captured, accounting for nearly 20% of the total catch (Table 3, Figures 22 and 23).

8.2.8 Habitat features for sampled pools

Based on one-way ANOVA and an alpha level of 0.05, mean values for pool length, maximum pool depth, and pool area $\geq$ 0.05 m deep were not significantly different among segments 1, 2, and 3 (Table 5). However, based on pairwise ANOVA and a Bonferroni adjusted alpha level of 0.017, mean values of pool width and pool area in segment 2 were significantly less than in segment 1 and segment 3 (Tables 5 and 6).

9. Discussion

There were distinctive spatial patterns in the fish assemblages in lower Muddy Creek during the late summer 2004. The farthest downstream segment (segment 1) experienced discontinuous surface flows during summer. In this segment, isolated pools served as fish refuge, and pools were dominated by non-native species. Two of the non-native fish species, redside shiners and sand shiners, were found only in segment 1. The fish assemblage in the wetland complex (segment 2) consisted almost entirely of non-native species and was dominated by fathead minnows. The farthest upstream segment (segment 3) was unique for two reasons. First, native species were widely distributed and accounted for most of the total catch. Second, it maintained perennial surface flows during the summer of 2004 and had abundant rock substrates, which were uncommon in the rest of lower Muddy Creek.

The longitudinal pattern of fish assemblages observed in lower Muddy Creek in 2004 was similar to that described for the San Rafael River, a tributary to the Green River in the Upper Colorado River Basin, Utah (McAda et al. 1980). Like Muddy Creek, the San Rafael River was an intermittent stream with sympatric populations of flannelmouth suckers, bluehead suckers, roundtail chubs, and speckled dace. The upper reaches of the San Rafael River had abundant large pools during periods of no surface flows, abundant rock substrates, and a fish assemblage dominated by native species. Non-native fish dominated the lower reaches of this system which consisted of sparse isolated pools, less diverse habitat, and mostly fine substrates. Red shiners (*Notropis lutrensis*) and fathead minnows were the most abundant non-native fishes in the San

Rafael River, followed by black bullheads (*Ictalurus melas*) and channel catfish (*Ictalurus punctatus*). However, the San Rafael River did not contain fish movement barriers, suggesting that geomorphologic gradients were the major determinants of longitudinal patterns of fish assemblage composition.

In addition to geomorphologic gradients, other factors that influenced longitudinal patterns of fish assemblages in lower Muddy Creek in 2004 were: (1) the existence of anthropogenic barriers that inhibit fish movement and dispersal, (2) the occurrence of different source populations among the three stream segments, and (3) differences in hydrologic variability and the extent of habitat alterations among the three stream segments.

9.1 Movement barriers

Dams associated with large impoundments, as well as smaller anthropogenic obstructions in stream channels can inhibit fish movements and dispersal (Lucas and Baras 1999; Newbrey and Bozek 2001). Warren and Padrew (1998) examined road crossings as barriers to movements by small-stream fishes during spring and summer. Twenty species from the families Catostomidae (suckers), Centrarchidae (sunfishes), Cyprinidae (minnows), Fundulidae (topminnows), and Percidae (darters) were marked near road crossings. Culverts of 1 m in diameter with varying lengths, water depths, and water velocities were monitored for fish passage with mark-recapture methods. A low-head dam with a 0.25-m vertical drop, 4-m width, and negligible water velocity over the dam during the summer was also monitored. These channel obstructions inhibited both upstream and downstream movements of most fishes, including creek chubs and white suckers (Warren and Padrew 1998).

Barriers to fish movement likely occur in lower Muddy Creek, as I noted differences in fish assemblages upstream and downstream of constructed barriers. Redside shiners and sand shiners were present within segment 1, but none were captured in segment 2 or segment 3. The downstream end of the wetland complex (segment 2) is marked by a pair of vertical drop structures approximately 1.0 and 1.5 m in height (Figure 2). Pools formed by these structures contained redside shiners, but this species was not captured upstream of these structures. Spawning migrations of white suckers in the spring of 2004 also provided evidence that these structures inhibited upstream fish movements (Chapter 1). The upstream extent of movements by white suckers implanted with radio-transmitters was an area just downstream of the wetland complex. Thus, fish in segment 1 appear to be isolated from upstream areas due to anthropogenic channel obstructions associated with the wetland complex.

Sampling of the fish assemblage in the upper Muddy Creek watershed (Bower 2005) yielded no fathead minnows upstream of the headcut stabilization structure (Figure 24). Within segment 3, downstream of the headcut stabilization structure, I found that fathead minnows were abundant. Thus, it appears the headcut stabilization structure has inhibited the upstream dispersal of fathead minnows.

Other studies have shown that barriers to fish movements can be important in structuring fish assemblages. Barriers can have dramatic effects on fish assemblages in intermittent streams or during stream-drying associated with drought. Wilde and Ostrand (1999) noted the extirpation of two native cyprinid species upstream from an impoundment on the Brazos River, Texas. Fish were unable to recolonize upstream areas following disturbance and this led to local extirpations. Similarly, Winston et al. (1991) noted the extirpation of four native cyprinid species upstream of an impoundment of the North Fork of the Red River, Oklahoma. Species more adapted to reaches downstream of the dam probably only occurred in upstream areas sporadically, thus local extirpation was due to the loss of source populations. Similar reasons were suggested for the local extirpation of two native cyprinid species upstream from dams in the Arkansas River Basin (Lutrell et al. 1999).

The presence of barriers to movements by fishes in Muddy Creek may have implications for the persistence of native fishes both upstream and downstream of the barriers. The inability of native fishes from the Little Snake River to disperse into upstream areas of Muddy Creek has resulted in genetically isolated populations. Also, recolonization of upstream areas of Muddy Creek by native fishes from the Little Snake River is inhibited. This could have implications for the recovery of native fish populations following catastrophic disturbance events. During most levels of stream flow, fish movement barriers in the wetland complex probably inhibit downstream dispersal by native fishes from persistent populations upstream. Thus, the wetland complex has reduced the source of colonists from upstream areas that may be important to the maintenance of native fish populations downstream of the wetland complex during drought years.

9.2 *Source populations*

Barriers to movement by fishes in lower Muddy Creek appear to have created three fragmented stream segments, each with unique combinations of potential sources populations. Downstream of the wetland complex (segment 1), two source areas for colonization may exist. Fish can migrate upstream from the Little Snake River during periods of streamflow in the spring. There is evidence that flannelmouth suckers, bluehead suckers, and white suckers do this (Chapter 1). Fish from the wetland complex may also disperse downstream into segment 1, but this would involve mainly non-native species (fathead minnows and white suckers). It is unknown if native fishes from upstream of the wetland complex and in upper Muddy Creek move downstream through the wetlands to colonize segment 1. Movement barriers and dry stream channels in the wetland complex inhibit such movements during low flow periods, but downstream movements may be possible during periods of high stream flow.

Segment 2, the wetland complex, could support potential source populations that may colonize the upper reach of lower Muddy Creek (segment 3). At the upstream end of the wetland complex the mainstem of Muddy Creek is fragmented by a headgate structure (Figure 2). Downstream of this structure the mainstem continues for approximately 500 m before the channel begins to braid in a palustrine wetland. Immediately upstream of this structure, flow is diverted into a channel that feeds the northern most wetland impoundment. Overflow spillways with vertical drops of 1 to 3 m link the subsequent impoundments. Four adult speckled dace, 12 age-0 speckled dace, and 16 age-0 roundtail chubs were captured within a 200-m reach downstream from this structure. Native fish were not captured in any other areas of the wetland complex. This suggests that extensive immigration from upstream areas either does not occur or fish that enter the wetland complex do not survive. Given the susceptibility of age-0 fishes to downstream displacement (Harvey 1987), the intermittent channels may serve as a sink habitats. High numbers of gravid fathead minnows were captured within the impoundments, and fathead minnows dominated the catch in the channels. The major source of fathead minnows is probably from reproduction within the wetland complex. Persistent fish populations other than fathead minnows did not appear to occur in the shallow wetland impoundments. Fathead minnows are adapted to abitotic extremes in shallow wetlands (Becker 1983); however, it appears that other fish species found in lower Muddy Creek are not able to persist in the impoundments.

Two areas that may harbor source populations for segment 3 are the wetland complex and Muddy Creek upstream of the headgate stabilization structure. Fathead minnows $\geq$ age-1were relatively abundant in segment 3, and age-0 fish were also captured. Thus, it appears fathead minnows that reproduce in the wetland complex can move upstream and colonize upstream areas. Bluehead suckers from upper Muddy Creek were observed to move downstream over the headcut stabilization structure in the spring of 2005 (R. Compton, University of Wyoming, unpublished data). Thus, it appears that native and non-native fishes from the upper Muddy Creek watershed may contribute to the fish assemblage in segment 3.

Other studies have described impoundments as sources of non-native fish species in lotic systems. Herbert and Gelwick (2003) compared fish assemblages in two intermittent drainages with and without mainstem impoundments. The drainage with impoundments was dominated by non-native habitat generalists that were able to proliferate in the lentic source habitat and then colonize less optimal habitats in the stream. The abundance of native fluvial specialists was greatly reduced in the impounded drainage. Schrank et al. (2001) suggested that impoundments served as dispersal barriers and sources of non-native fish detrimental to the Topeka shiner (*Notropis topeka*) in Kansas streams. Fathead minnows are well adapted to waters with high turbidity, high salinity, high water temperatures and low dissolved oxygen levels (Van Der Elk 1989). Thus, this species is well-suited to persisting in small isolated pools throughout lower Muddy Creek, and this may explain why this species had the widest distribution of all species found in lower Muddy Creek.

9.3 Hydrologic variability and disturbance

Factors that operate on spatial scales larger than individual pools may be responsible for the differences in fish assemblages among the three segments. In addition to fragmentation and source populations, drought likely played a major role in structuring the fish assemblages. Below average precipitation since 1999 (Figure 25) has resulted in relatively frequent and severe disturbance events in Muddy Creek. Segment 1 experienced the most severe low flow conditions, with vast stretches of dry channel and isolated pools from mid-June through the end of the summer. Disturbance in the form of stream desiccation may have been important in structuring the fish assemblages. For example, in 2004, Muddy Creek had abundant isolated pools for fish refuge in a reach that was 8 km from the confluence of Muddy Creek with the Little Snake River. Based on my observations, this same area was completely dry for most of the summer and fall in 2002.

Habitat that may provide refugia varies among fish species and the extent of spatial and temporal disturbance (Matthews 1998). Small cyprinids such as fathead minnows and creek chubs were abundant and widely distributed in segment 1, suggesting that most of the isolated pools served as suitable refugia. Speckled dace have been observed to occupy small isolated pools in Bitter Creek, Wyoming (Carter and Hubert 1995). Speckled dace also occurred in small isolated pools in segment 1 of lower Muddy Creek, but they were less abundant and more sparsely distributed than non-native species. This may indicate that source habitats both upstream and in the Little Snake River may contribute fewer speckled dace than non-native species. It has been suggested that small early-maturing colonizing species such as fathead minnows, creek chubs, and redside shiners dominate following severe disturbance whereas larger-bodied species such as catostomids experience reduced abundance (Fausch and Bramblett

1991; Poff and Ward 1989). Larger-bodied native species such as the bluehead suckers, flannelmouth suckers, and roundtail chubs were rare in segment 1 during 2004. Harsh disturbance events can result in mortality or cause fish to seek refuge, and it seems plausible that native fishes in segment 1 found refuge in the Little Snake River during drought years. Following disturbance events, species are rarely extirpated and fish communities are often resilient with recolonization time ranging from days to years (Matthews 1998; Magoulick and Kobza 2003). My results indicate that abundant populations of native fishes may not be a feature of lower Muddy Creek during drought years, but further monitoring is needed to determine the temporal extent of this pattern.

Fausch and Bramblett (1991) described fish assemblages in intermittent tributaries of the Purgatoire River, Colorado, that were disturbed by both stream drying and flood events. Most species found refuge by moving downstream to within 1 km of the confluence of the tributaries with the Purgatoire River. Fathead minnows and white suckers persisted the farthest upstream, recolonized disturbed reaches the fastest, and were designated colonizing species. The authors also summarized presence or absence data for fish species and determined that disturbance events had short-term effects on fish assemblages, but populations appeared to have recovered. Similarly, Meffe and Minckley (1987) determined that disturbance events had short-term effects on the structure of the fish assemblages in a frequently disturbed desert stream, but, in the long-term, disturbance did little to affect fish species composition.

Within the wetland complex (segment 2) fish refuge during harsh conditions in the summer 2004 consisted of the impoundments and a few isolated pools in the channels. Fathead minnows were present at nearly every site sampled. The extreme dominance of the fish fauna in the wetland impoundments by fathead minnows may indicate conditions generally too harsh for other species. The impoundment that contained an abundant white sucker population was the deepest one sampled, and probably experiences anoxic conditions less frequently than the smaller ponds that only contained fathead minnows. In the event that an impoundment loses its fish fauna, surrounding source populations will allow for a rapid colonization by fathead minnows (Zimmer et al. 2001).

Segment 3 had a short reach with perennial surface flows during the summer of 2004. However, the lower reaches of segment 3, upstream of the wetland complex were generally dry with few isolated pools. Native fishes appeared to have primarily sought refuge in pools in the upper reaches where flow conditions were more stable Non-native fish also crowded into pools in upstream reaches. However, non-natives also occupied small isolated pools in the lower reaches of segment 3 where native fishes were rare.

9.4 Conclusion

The longitudinal patterns of fish assemblages in lower Muddy Creek appeared to result from a combination of fragmentation, source-sink dynamics, and hydrologic disturbance. The extent to which drought influenced the fish assemblages remains unclear and more monitoring in lower Muddy Creek is needed. However, the wetland complex appeared to have a substantial effect on the patterns of fish assemblages. Management of native fish species in lower Muddy Creek is complicated by anthropogenic barriers to fish movements and source populations of non-native fishes.

Literature Cited

Bezzerides, N., and K. Bestgen. 2002. Status review of roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus* in the Colorado River Basin. Colorado State University, Fort Collins, Colorado. Larval Fish Lab Contribution # 118.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Bower, M.R. 2005. Distributions and habitat associations of bluehead suckers, flannelmouth suckers, and roundtail chubs in the upper Muddy Creek watershed on southern Carbon County, Wyoming. Masters Thesis. University of Wyoming, Laramie.

Carter, B., and W.A. Hubert. 1995. Factors influencing fish assemblages of a high-elevation desert stream system in Wyoming. Great Basin Naturalist 55:169-173.

Delibes, M., P. Ferreras, and P. Gaona. 2001. Attractive sinks, or how behavioural decisions determine source-sink dynamics. Ecology Letters 4:401-403.

Fausch, K.D., and R.G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. Copeia 1991:659-674.

Goertler, C.M. 1992. Sediment dynamics within channel and riparian zone types along a cold-desert Wyoming stream. Masters Thesis, University of Wyoming.

Harvey, B. C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. Transactions of the American Fisheries Society 116:851-855.

Hawkins, J.A., and J. O'Brien. 2001. Research plan for developing flow recommendations in the Little Snake River, Colorado and Wyoming, for endangered fishes of the Colorado River Basin. Contribution 92 of the Larval Fish Laboratory, Colorado State University, Fort Collins.

Hawkins, J.A., E.J. Wick, and D.E. Jennings. 1997. Ichthyofauna of the Little Snake River, Colorado, 1994. Contribution 91 of the Larval Fish Laboratory, Colorado State University, Fort Collins.

Herbert, M.E., and F.P. Gelwick. 2003. Spatial variation of headwater fish assemblages explained by hydrologic variability and upstream effects of impoundment. Copeia 2003:273-284.

Lake, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biology 48:1161-1172.

Lucas, M. C., and E. Baras. 2001. Migration of freshwater fishes. Blackwell Science Ltd., Oxford, UK.

Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the *Macrhybopsis aestivalis* complex (Teleosti: Cyprinidae) in the Arkansas River Basin and related effects of reservoirs as barriers to dispersal. Copeia 1999:981-989.

Magoulick, D.D., and R.M. Kobza. 2003. The role of refugia for fishes during drought: a review and synthesis. Freshwater Biology 48:1186-1198.

Marchetti, M. P., T. Light, P. B. Moyle, and J. H. Viers. 2004. Fish invasions in California watersheds: testing hypotheses using landscape patterns. Ecological Applications 14:1507-1525.

Marchetti, M.P., and P.B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11:530-539.

Matthews, W.J. 1998. Patterns in Freshwater Fish Ecology. Chapman & Hall, New York.

Matthews, W.J., and E. Marsh-Matthews. 2003. Effects of drought on fish across axis of space, time, and ecological complexity. Freshwater Biology 48:1232-1253.

McAda, C.W., C.R. Berry, Jr., and C.E. Phillips. 1980. Distribution of fishes in the San Rafael River system of the Upper Colorado River Basin. Southwestern Naturalist 25:41-50.

Meffe, G. K. and W.L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist 117:177-191.

Meffe, G. K. and W.L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist 117:177-191.

Newbrey, M.G., and M.A. Bozek. 2001. Effects of stream barriers as impediments to warmwater fish movement with an emphasis on culverts and siltation: An annotated bibliography. Wisconsin Cooperative Fishery Research Unit, USGS Biological Resources Division, University of Wisconsin – Stevens Point, Sevens Point WI, 54481.

Ostrand, K.E., and G.R. Wilde. 2004. Changes in prairie stream fish assemblages restricted to isolated streambed pools. Transactions of the American Fisheries Society 133:1329-1338.

Poff, L.N., and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76:606-627.

Poff, N.L., and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences 46:1805-1818.

Schrank, S. J., C. S. Guy, M. R. Whiles, and B. L. Brock. 2001. Influence of instream and landscape-level factors on the distribution of Topeka Shiners *Notropis topeka* in Kansas streams. Copeia 2001:413-421.

Snyder, D.E. 1981. Contributions to a guide to the Cypriniform fish larvae of the upper Colorado River Basin. Number 3 Biological Sciences Series. Bureau of Land Management, Denver Colorado.

Snyder, D.E., and R.T. Muth. 2004. Catostomid fish larvae and early juveniles of the upper Colorado River Basin – morphological descriptions, comparisons, and computer-interactive key. Technical publication No. 42. Colorado Division of Wildlife, Denver.

Van Der Elk, A. 1989. Northern Prairie Wetlands. Iowa State Press, Ames.

Warren, M. L., and M. G. Padrew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127:637-644.

Wilde, G. R., and K. G. Ostrand. 1999. Changes in the fish assemblage of an intermittent prairie stream upstream from a Texas impoundment. Texas Journal of Science 51:203-210.

Winston, M.R., and C.M. Taylor, J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120:98-105.

Winston, M.R., and C.M. Taylor, J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120:98-105.

Zimmer, K.D., M.A. Hanson, and M.G. Butler. 2001. Effects of fathead minnow colonization and removal on a prairie wetland ecosystem. Ecosystems 2001:346-357.

Table 1. The occurrence of fish species in the Little Snake River, the upper Muddy Creek watershed, and lower Muddy Creek. Species occurrence is denoted by an X. Data sources are (a) Hawkins and O'Brien 200, (b) Bower 2005, and (c) current study. The data for the Little Snake River was compiled for sampling conducted in the lower 180 km of Little Snake River, from Baggs, Wyoming to the confluence of the Little Snake River with the Yampa River , Colorado.

Common name	Scientific name	Little Snake River[a]	Upper Muddy Creek watershed[b]	Lower Muddy Creek[c]
	Native species			
Bluehead sucker	*Catostomus discolobus*	X	X	X
Flannelmouth sucker	*Catostomus latipinnis*	X	X	X
Mountain sucker	*Catostomus platyrhynchus*		X	
Roundtail chub	*Gila robusta*	X	X	X
Colorado pikeminnow	*Ptychocheilus lucius*	X		
Speckled dace	*Rhinichthys osculus*	X	X	X
Mottled sculpin	*Cottus bairdi*	X		
Colorado River cutthroat trout	*Oncorhynchus clarki pleuriticus*	X	X	
	Non-native species			
White sucker	*Catostomus commersoni*	X	X	X
Common carp	*Cyprinus carpio*	X		
Fathead minnow	*Pimephales promelas*	X		X
Red shiner	*Cyprinella lutrensis*	X		
Redside shiner	*Richardsonius balteatus*	X		X
Sand shiner	*Notropis stramineus*	X		X
Creek chub	*Semotilus atromaculatus*	X	X	X
Black bullhead	*Ameiurus melas*	X		
Channel catfish	*Ictalurus punctatus*	X		
Brook trout	*Salvelinus fontinalis*		X	
	Hybrids			
Flannelmouth sucker x Bluehead sucker	*C. latipinnis x C. discobolus*	X	X	
Flannelmouth sucker x White sucker	*C. latipinnis x C. commersoni*	X	X	X
Bluehead sucker x White sucker	*C. discobolus x C. commersoni*	X	X	
Humpback chub x Roundtail cuhb	*G. cypha x G. robusta*	X		

Table 2. The number and relative abundance of ≥ age-1 fish collected in pools throughout segments 1-3, and the percent of pools where a species was present in lower Muddy Creek from July 28 – August 18, 2004. Most pools sampled contained fish except for 14 pools in segment 1, six pools in segment 2, and three pools in segment 3.

	Segment 1			Segment 2			Segment 3		
Species	Number captured	% total catch	% pools present	Number captured	% total catch	% pools present	Number captured	% total catch	% pool presence
Native fish species									
Bluehead sucker	0.0	0.0	0.0	0.0	0.0	0.0	14	0.5	15.1
Flannelmouth sucker	1	0.1	1.0	0.0	0.0	0.0	1	0.0	1.9
Roundtail chub	44	2.5	12.0	0.0	0.0	0.0	1020	36.6	62.3
Speckled dace	70	3.9	28.0	3	1.6	10.0	795	28.5	81.1
Non-native fish species									
White sucker	186	10.5	36.0	5	2.7	10.0	29	1.0	20.8
Creek chub	536	30.2	66.0	14	7.4	20.0	578	20.7	83
Fathead minnow	488	27.5	66.0	166	88.3	60.0	352	12.6	71.7
Redside shiner	393	22.1	23.0	0.0	0.0	0.0	0.0	0.0	0.0
Sand shiner	59	3.3	22.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	1777			188			2789		

Table 3. The number and relative abundance of age-0 fish collected in pools throughout segments 1-3, and the percent of pools where a species occurred in lower Muddy Creek from July 28 – August 18, 2004. Most pools sampled contained fish, except for eight pools in segment 1, five pools in segment 2, and seven pools in segment 3.

	Segment 1			Segment 2			Segment 3		
Species	Number captured	% total catch	% pools present	Number captured	% total catch	% pools present	Number captured	% total catch	% pools present
				Native fish species					
Bluehead sucker	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flannelmouth sucker	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Roundtail chub	17	0.8	4.0	16	7.7	5.0	126	16.0	37.7
Speckled dace	39	1.8	11.0	12	5.8	5.0	28	3.6	20.8
				Non-native fish species					
Catostomus spp.	728	34.3	72.0	37	17.8	20.0	183	23.3	64.2
Creek chub	609	28.7	61.0	28	13.5	35.0	176	22.4	81.1
Fathead minnow	158	7.4	28.0	60	28.8	30.0	80	10.2	32.1
Redside shiner	115	5.4	15.0	0.0	0.0	0.0	0.0	0.0	0.0
Sand shiner	1	< 0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprinidae	454	21.4	57.0	55	26.4	45.0	193	24.6	71.7
Total	2121			208			786		

Table 4. Percent total catch in impoundments and in stream channels within the wetland complex during early sampling (May 25 – June 2, 2005) and late sampling events (August 1 – August 18). The number of fish captured is reported in parentheses.

Species	Early sample period		Late sample period	
	% catch impoundments	% catch channels	% catch impoundments	% catch channels
		Native fish species		
Speckled dace	0.0	0.9 (5)	0.0	0.8 (3)
Speckled dace (age-0)	0.0	0.0	0.0	3.0 (12)
Roundtail chub	0.0	0.2 (1)	0.0	0.0
Roundtail chub (age-0)	0.0	0.0	0.0	4.0 (16)
		Non-native fish species		
Fathead minnow	97.9 (2,117)	96.1 (547)	44.8 (56)	41.9 (166)
Fathead minnow (age-0)	0.0	0.0	0.0	15.2 (60)
White sucker	1.9 (40)	0.4 (2)	55.2 (69)	1.3 (5)
Creek chub	0.2 (5)	2.5 (14)	0.0	3.5 (14)
Creek chub (age-0)	0.0	0.0	0.0	7.1 (28)
Cyprinidae (age-0)	0.0	0.0	0.0	13.9 (55)
Catostomus spp.(age-0)	0.0	0.0	0.0	9.3 (37)

Table 5. Comparison of habitat variables of pools sampled among three stream segments. Values are mean ± standard error with the range in parentheses. Overall P-values are for single factor ANOVA. Segments with the same superscript did not differ for that habitat parameter.

	Segment			
Variable	1	2	3	P-value
Pool length (m)	[a] 16.9 ± 0.80 (5.3 - 45.5)	[a] 14.0 ± 1.95 (4.0 - 35.0)	[a] 15.9 ± 0.96 (6.5 - 36.0)	0.277
Pool width (m)	[a] 3.1 ± 0.13 (1.6 - 10.8)	[b] 2.4 ± 0.22 (1.2 - 4.7)	[a] 3.3 ± 0.11 (2.0 - 5.2)	0.008
Pool area (m^2)	[a] 56.5 ± 4.38 (12.9 - 243.6)	[b] 32.5 ± 4.53 (4.8 -71.3)	[a] 51.7 ± 3.42 (15.5 - 138.0)	0.038
Maximum pool depth (m)	[a] 0.7 ± 0.02 (0.3 - 1.3)	[a] 0.6 ± 0.03 (0.4 - 1.0)	[a] 0.7 ± 0.02 (0.4 - 1.1)	0.115
Pool area> 0.5m deep (m^2)	[a] 7.2 ± 1.13 (0 - 60.0)	[a] 4.0 ± 1.34 (0 - 21.0)	[a] 4.0 ± 0.65 (0 - 18.0)	0.536

Table 6. P-values for pairwise one-way ANOVA comparisons for habitat variables of pools sampled among three stream segments.

Variable	Segment 1 and segment 2	Segment 1 and segment 3	Segment 2 and segment 3
Pool length (m)	0.141	0.407	0.349
Pool width (m)	0.013	0.477	<0.001
Pool area (m^2)	0.018	0.516	0.003
Maximum pool depth (m)	0.096	0.583	0.007
Pool area> 0.5m deep (m^2)	0.632	0.312	0.413

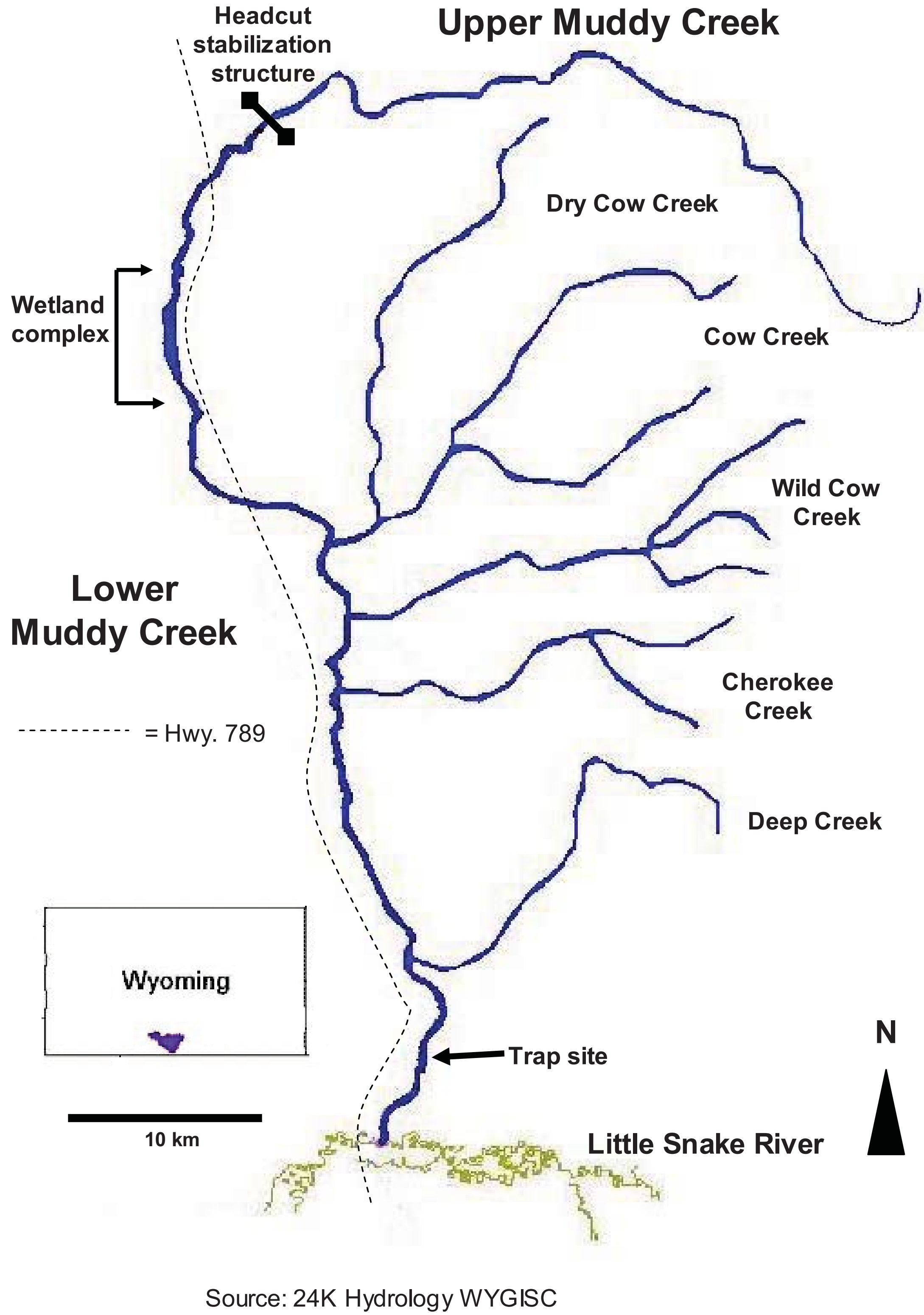

Figure 1. Map of the study area showing Muddy Creek and its major tributaries. Upper Muddy Creek is upstream of the headcut stabilization structure and lower Muddy Creek occurs downstream.

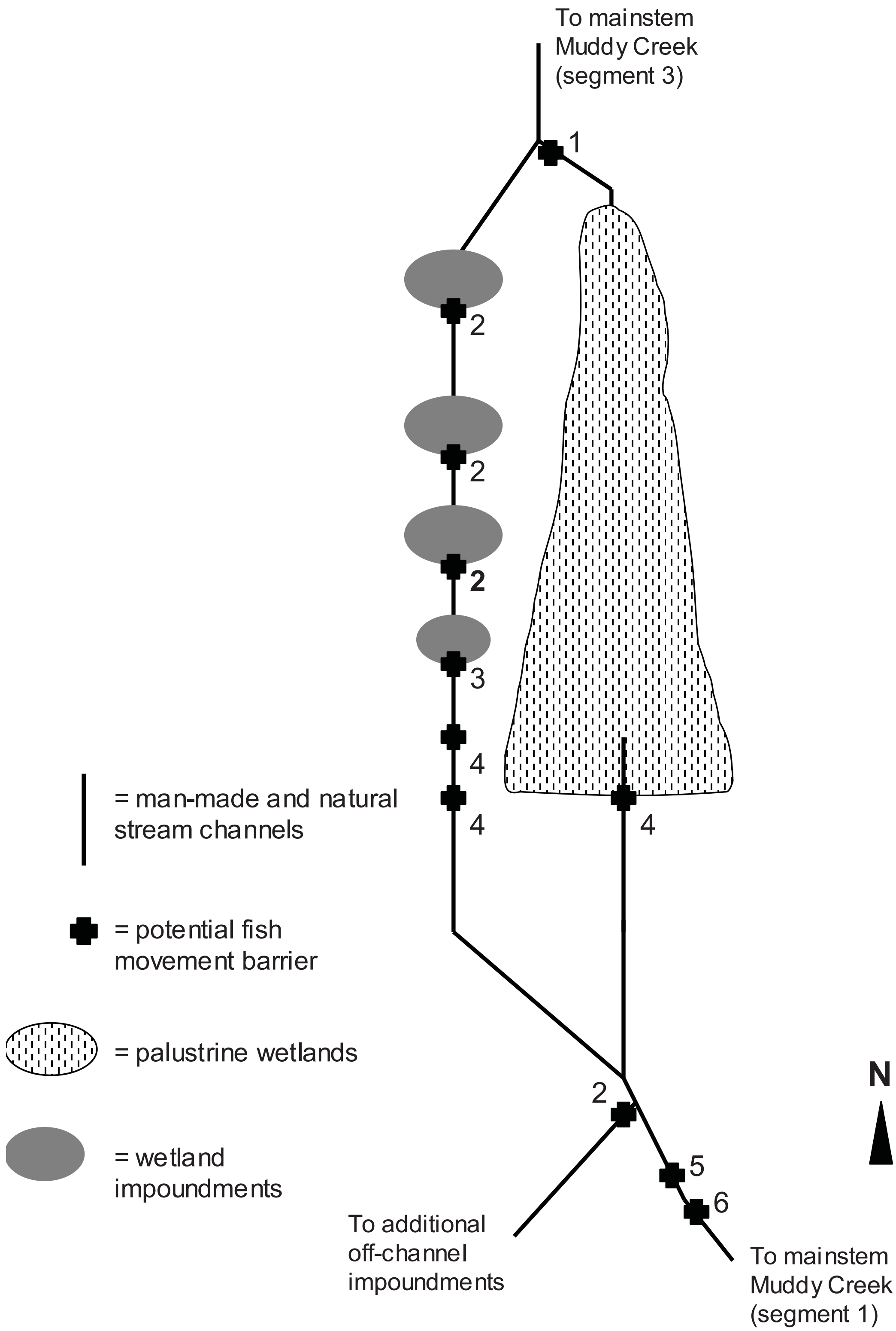

Figure 2. Diagram of the wetland complex (segment 2). Numbers correspond to the type of water control structure believed to inhibit fish movement presented as pictures in the Appendix. Channels represent primary movement pathways within the wetland complex.

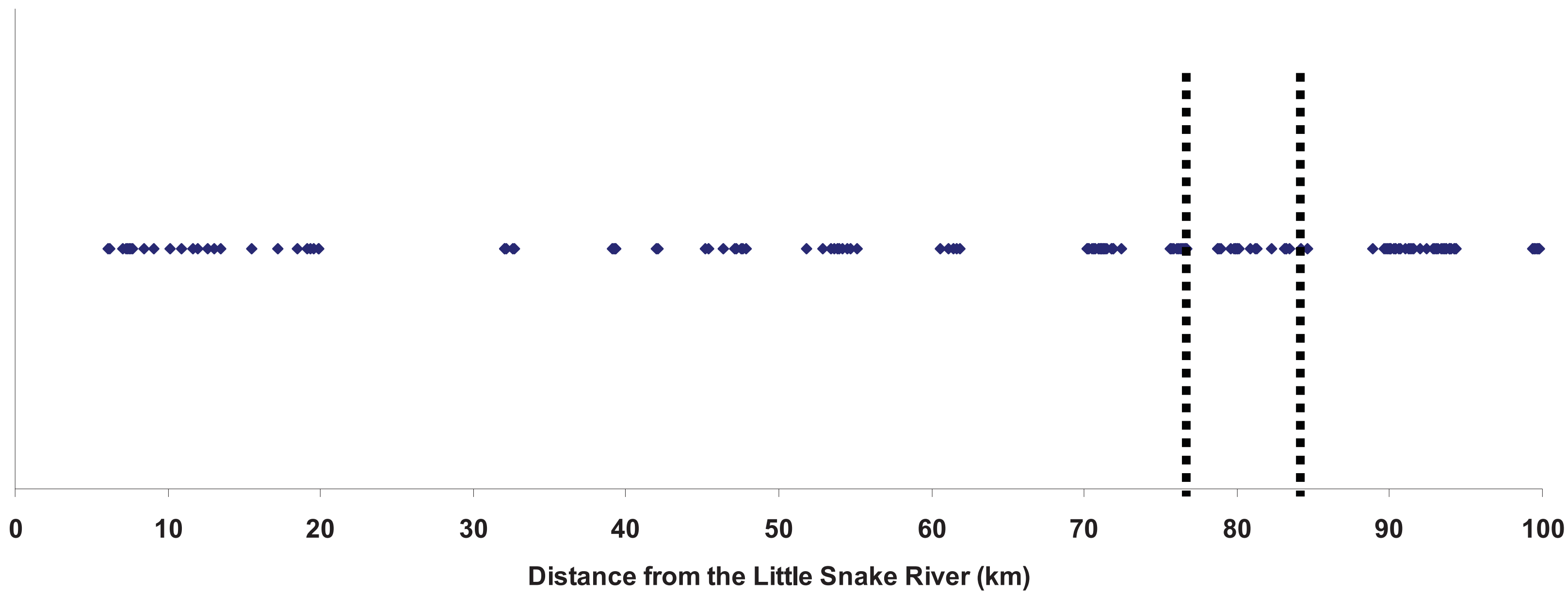

Figure 3. The distance of each pool from the Muddy Creek-Little Snake River confluence. Number of pools sampled in each segments is given by n in parentheses, and the dashed lines segregate segments.

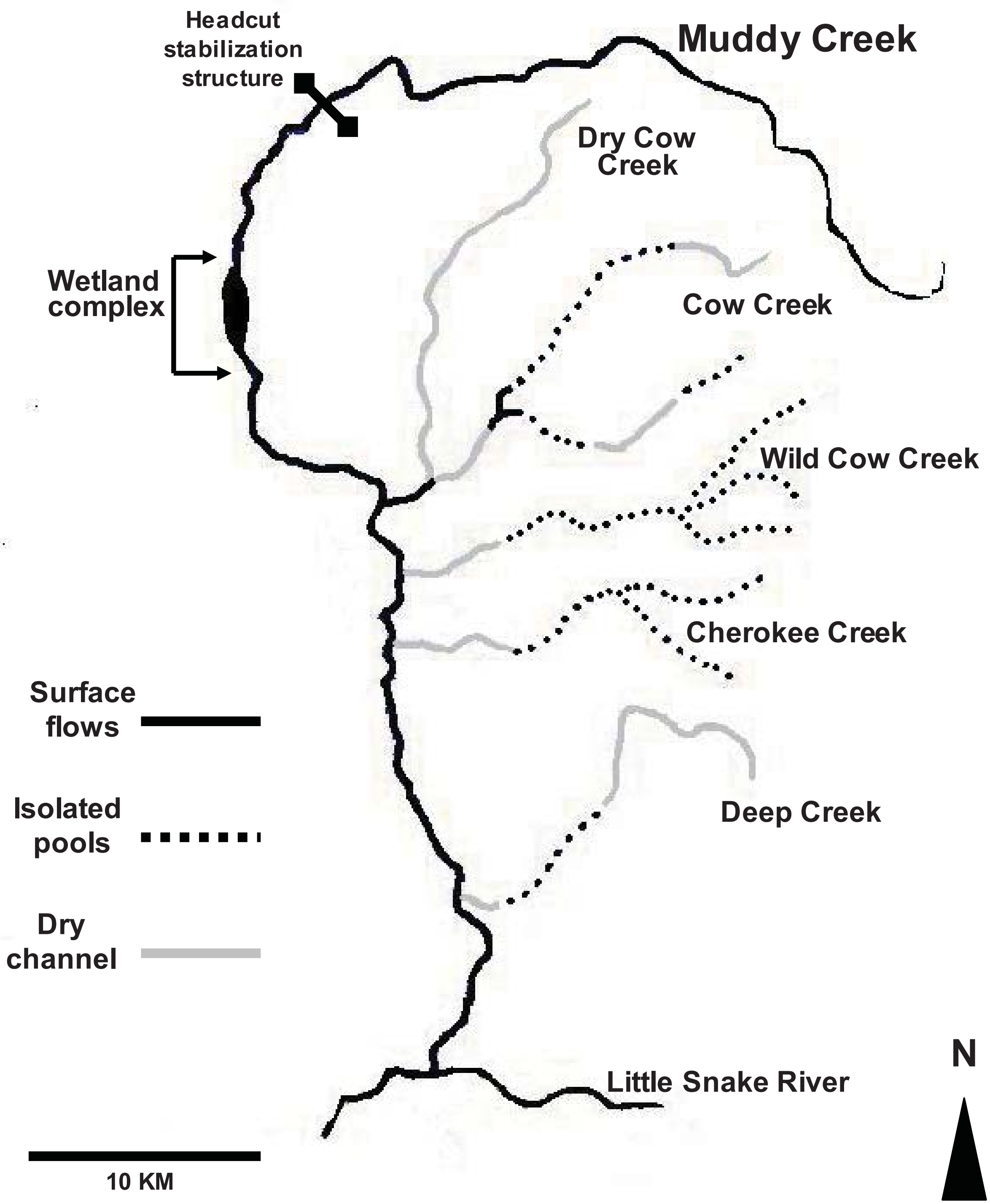

Figure 4. Flow conditions in the lower Muddy Creek watershed on June 9, 2004.

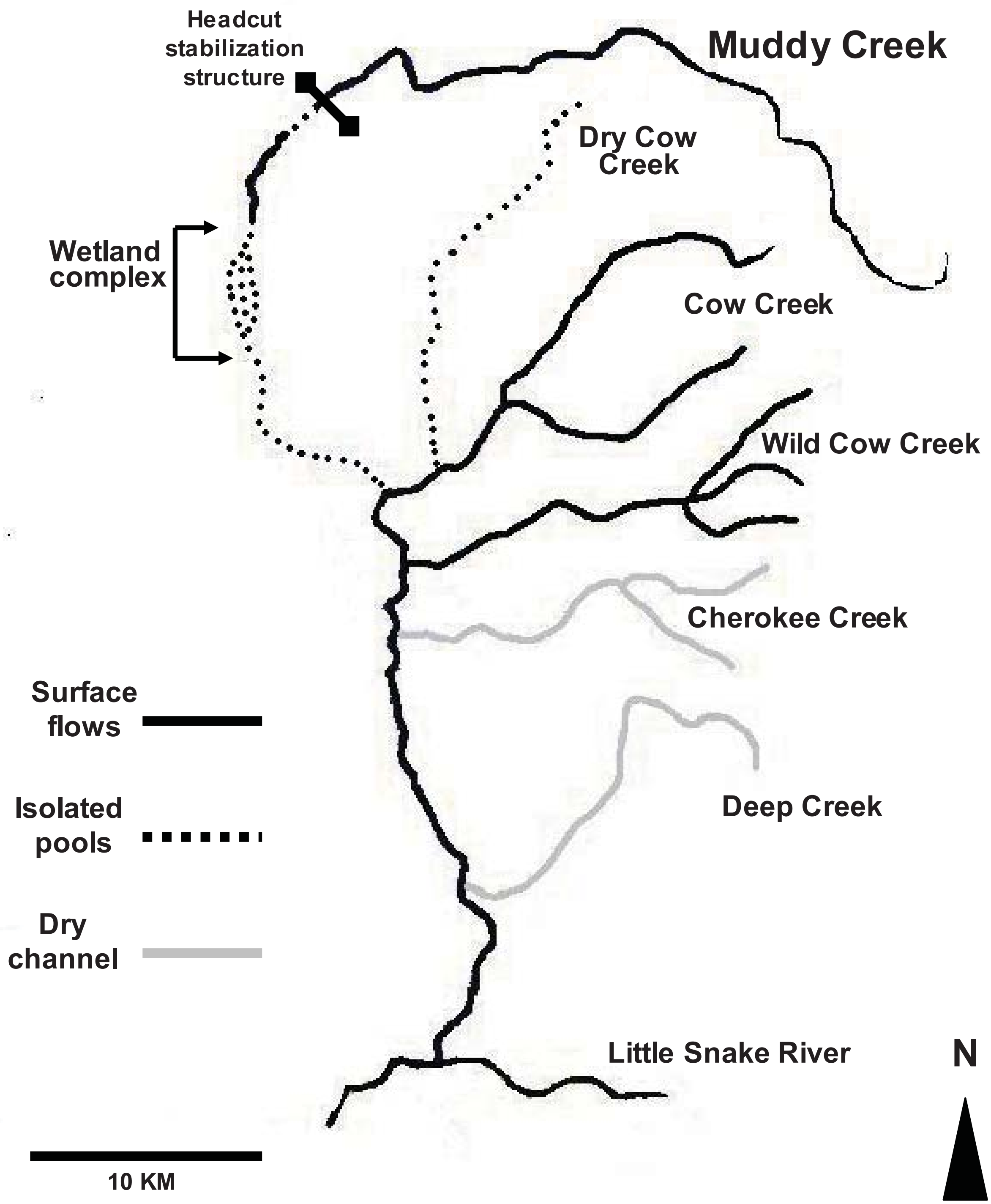

Figure 5. Flow conditions in the lower Muddy Creek watershed on July 20, 2004.

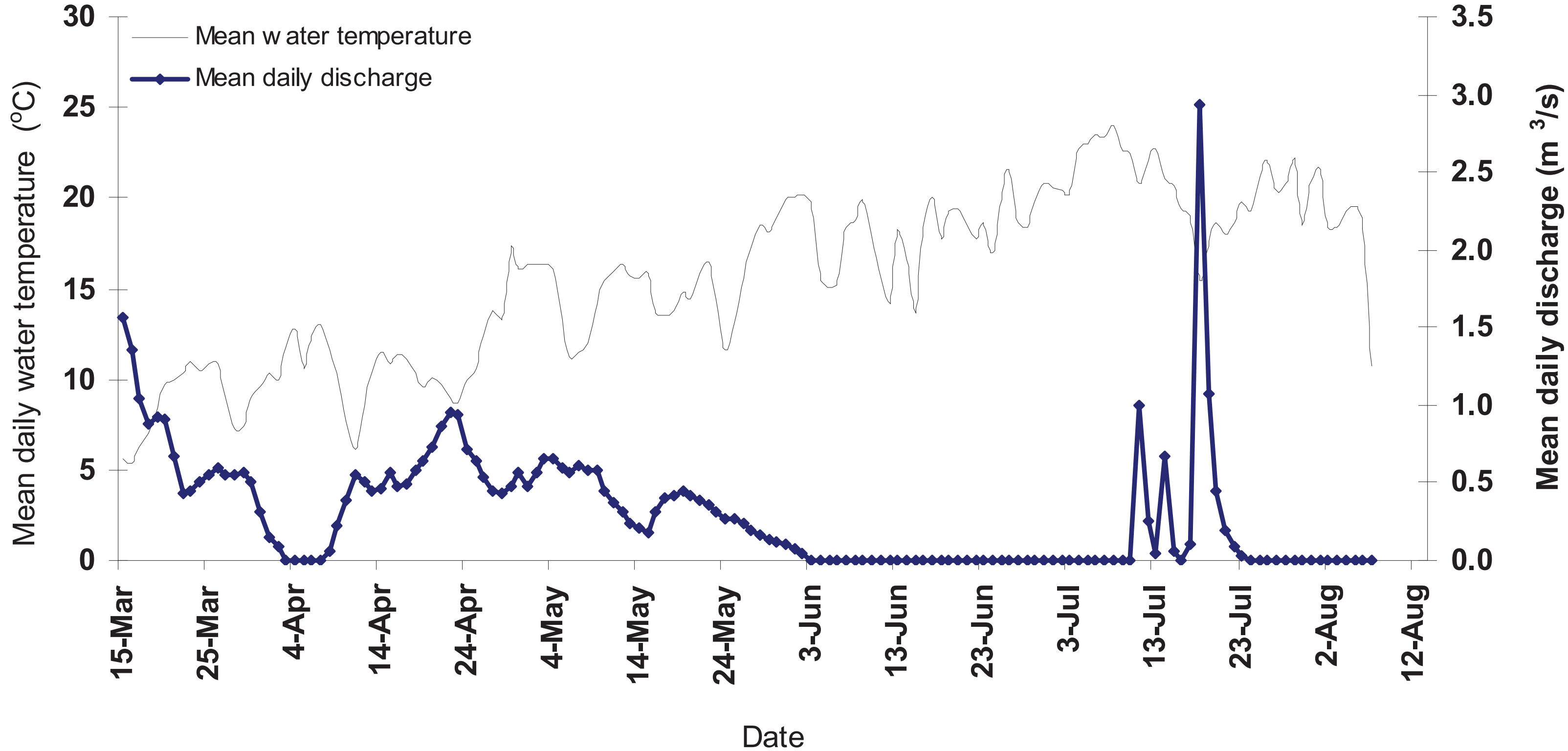

Figure 6. Mean daily water temperature and mean daily discharge measured in Muddy Creek at the trap site from March 15 through August 13, 2004.

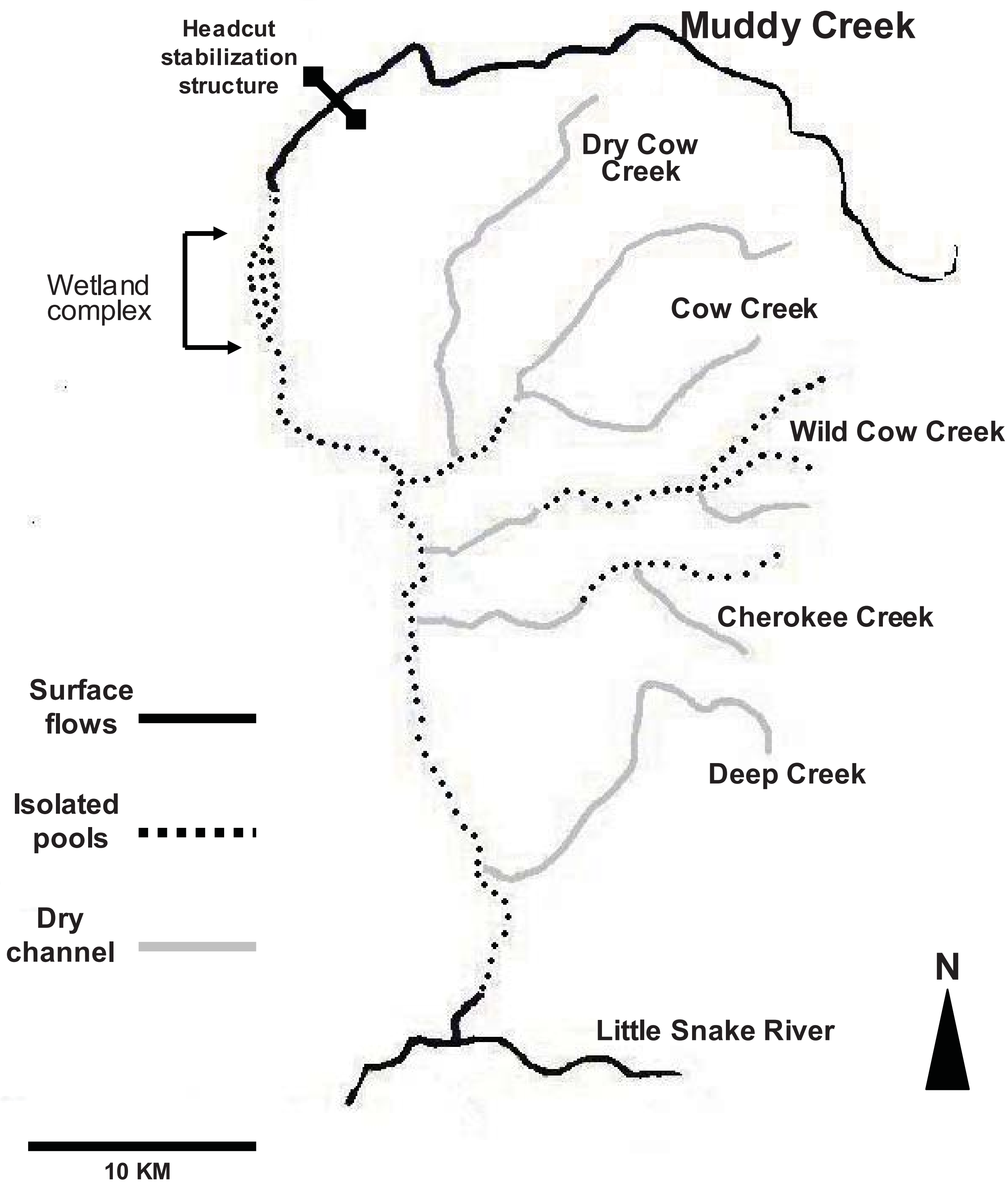

Figure 7. Flow conditions in the lower Muddy Creek watershed on September 1, 2004.

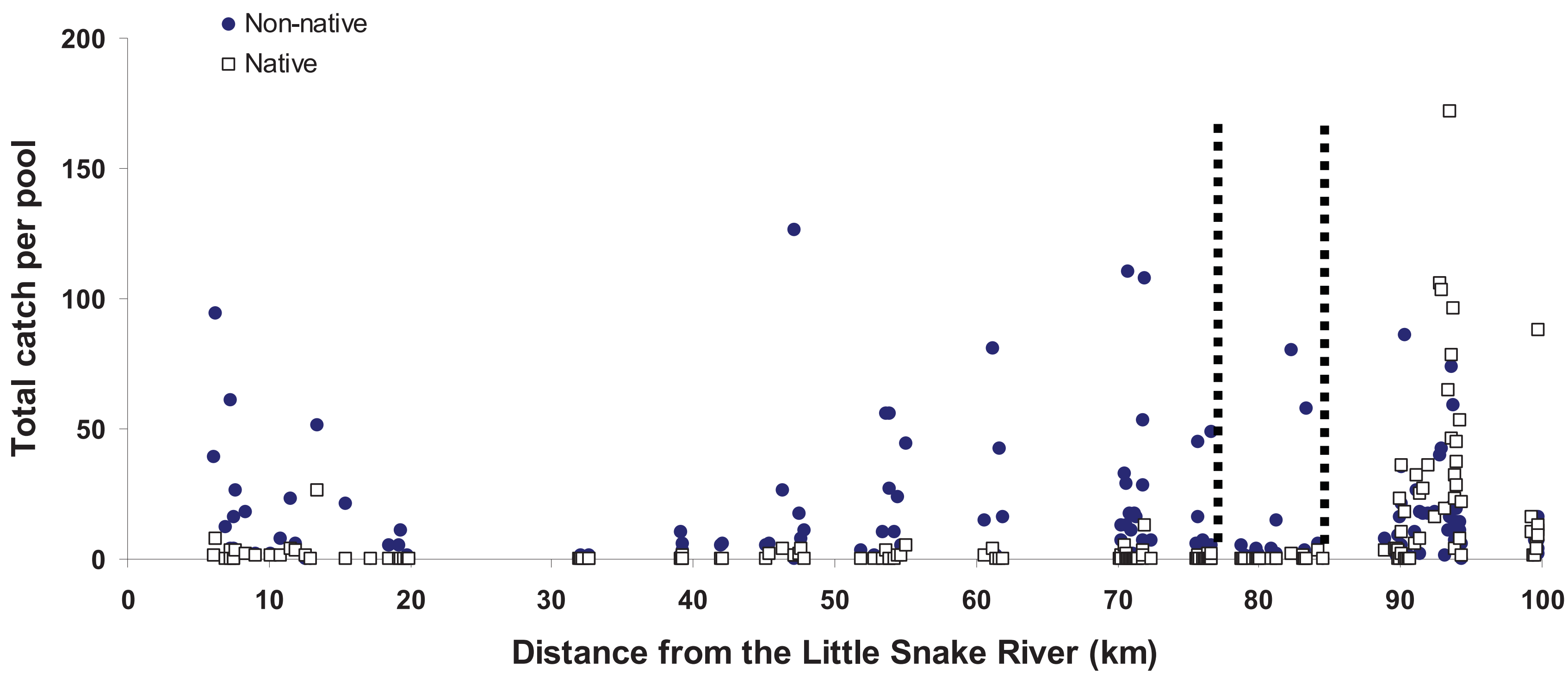

Figure 8. The total catch of ≥ age-1 non-native fish and native fish species in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

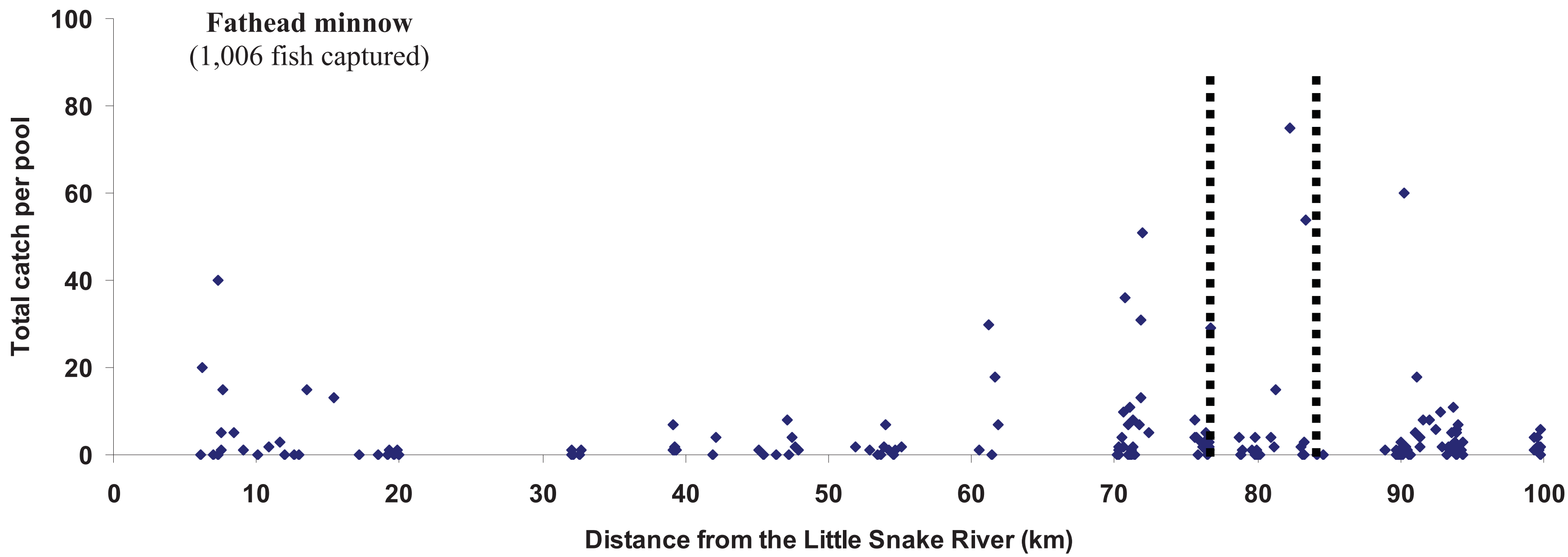

Figure 9. The total catch of ≥ age-1 fathead minnow in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

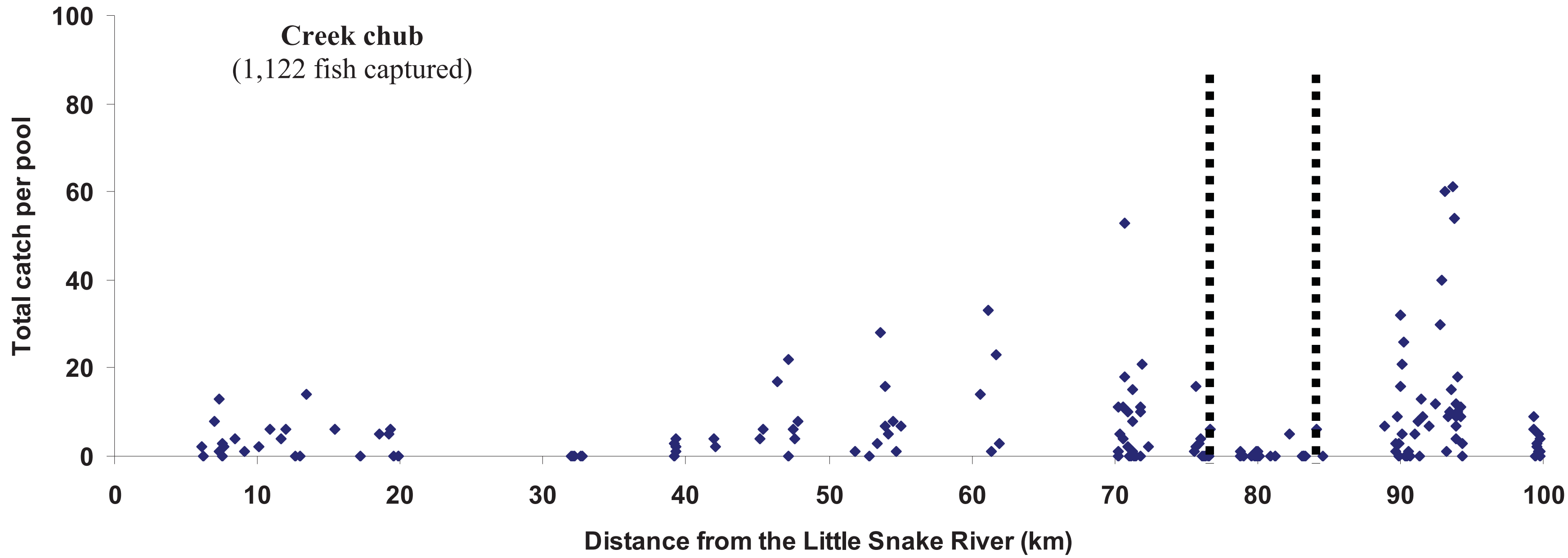

Figure 10. The total catch of ≥ age-1 creek chub in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

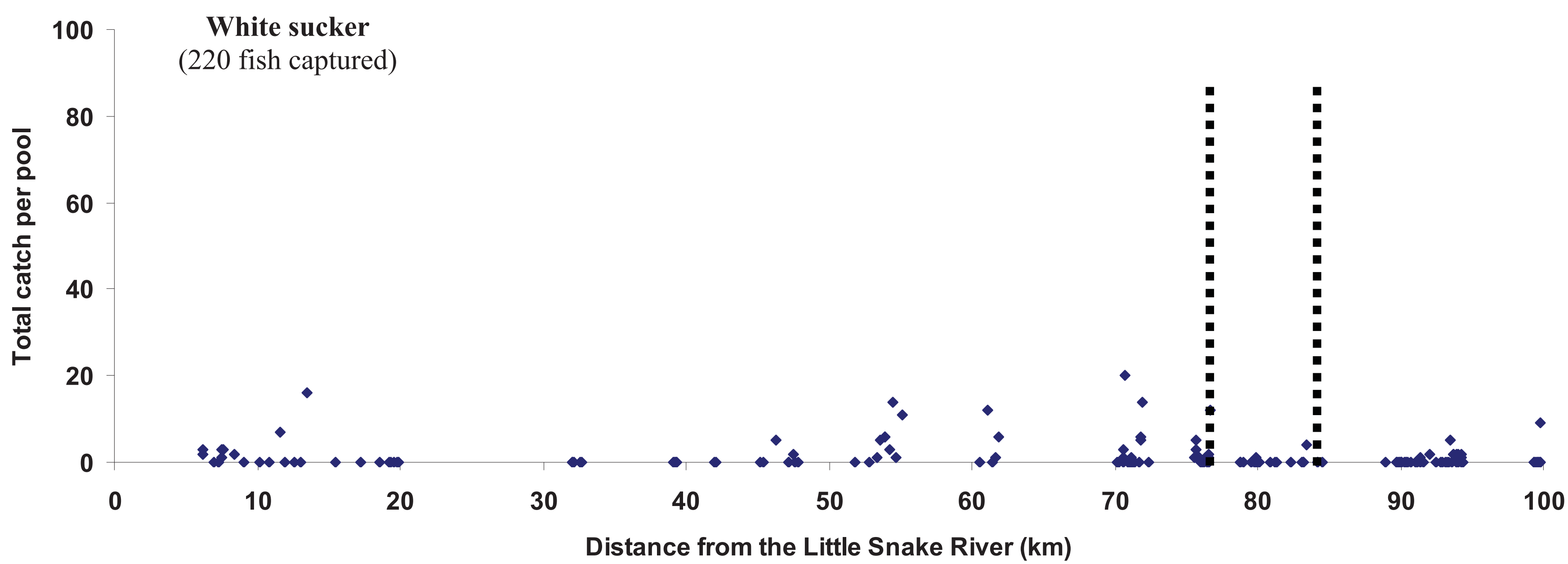

Figure 11. The total catch of ≥ age-1 white sucker in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

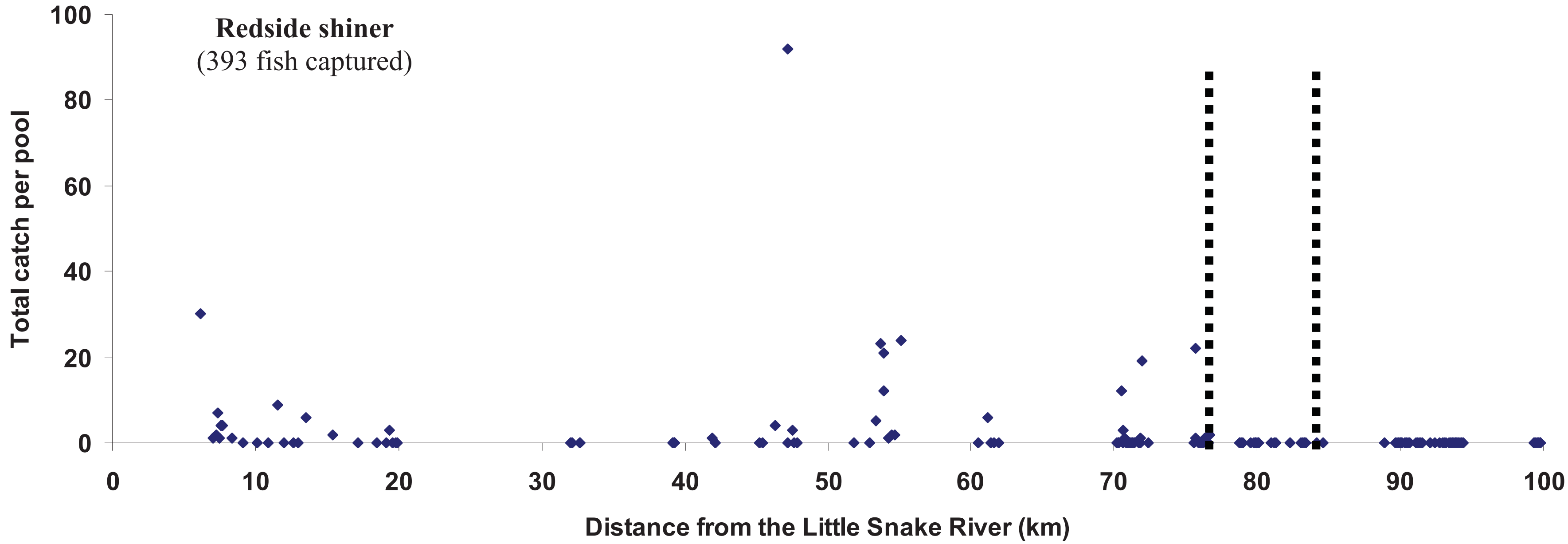

Figure 12. The total catch of ≥ age-1 redside shiners in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

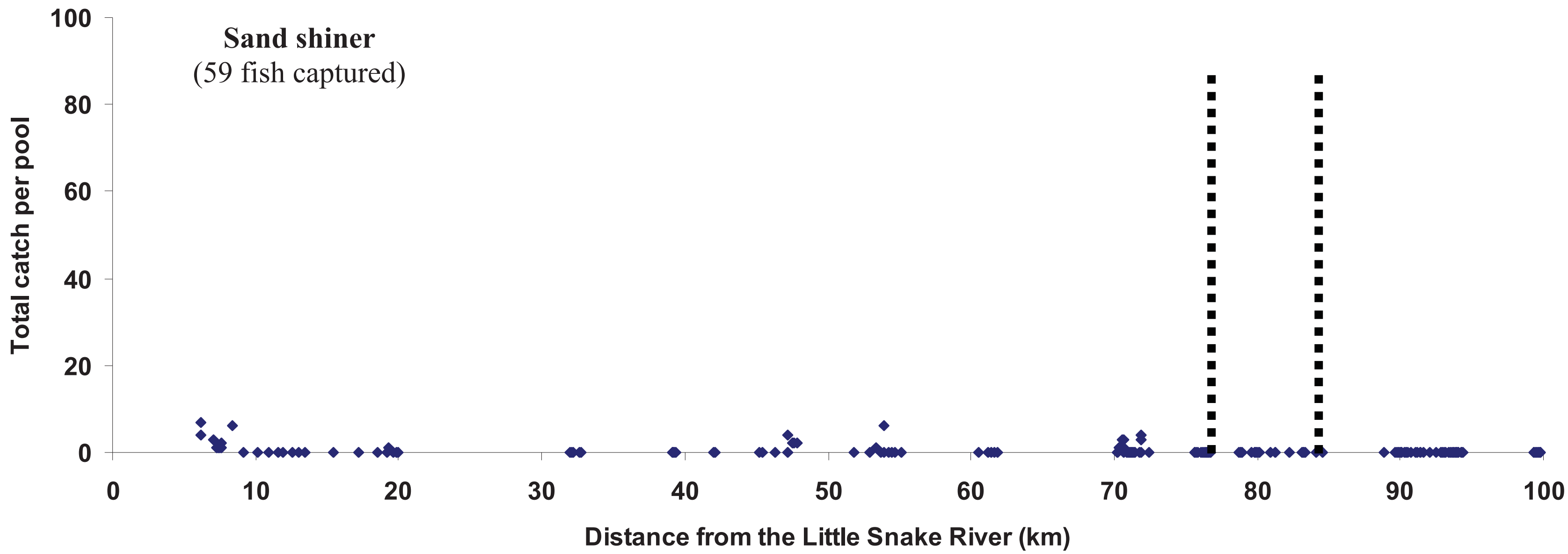

Figure 13. The total catch of ≥ age-1 sand shiner in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

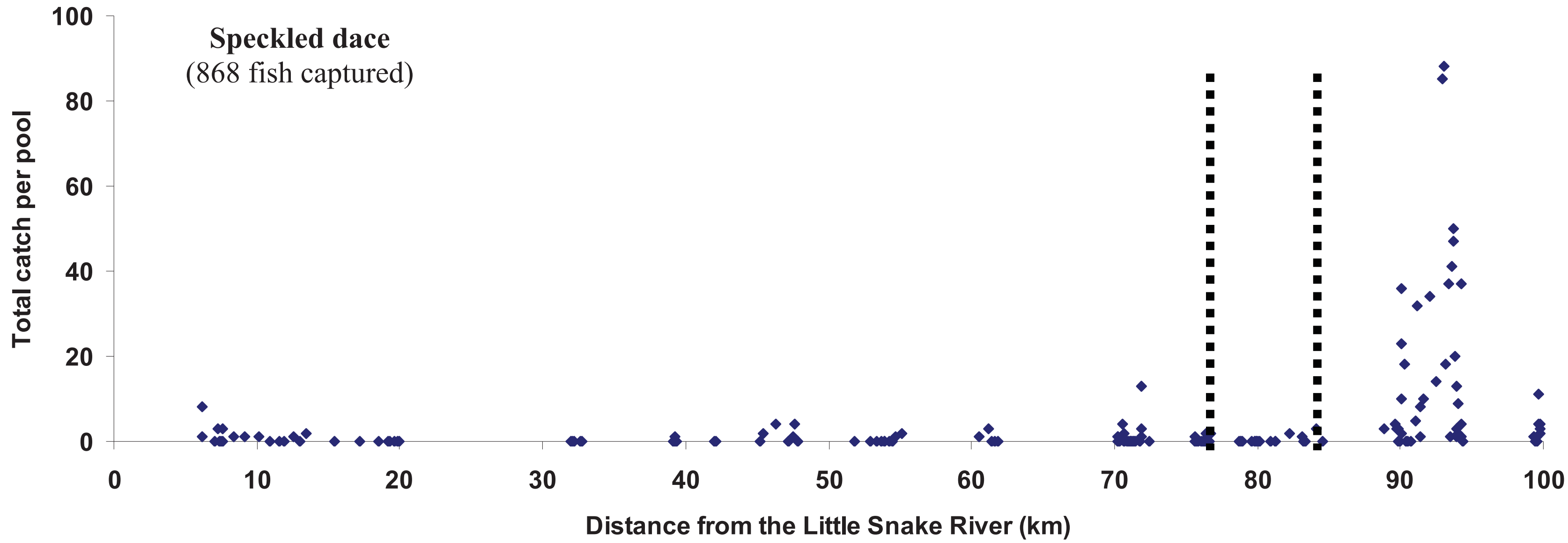

Figure 14. The total catch of ≥ age-1 speckled dace in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

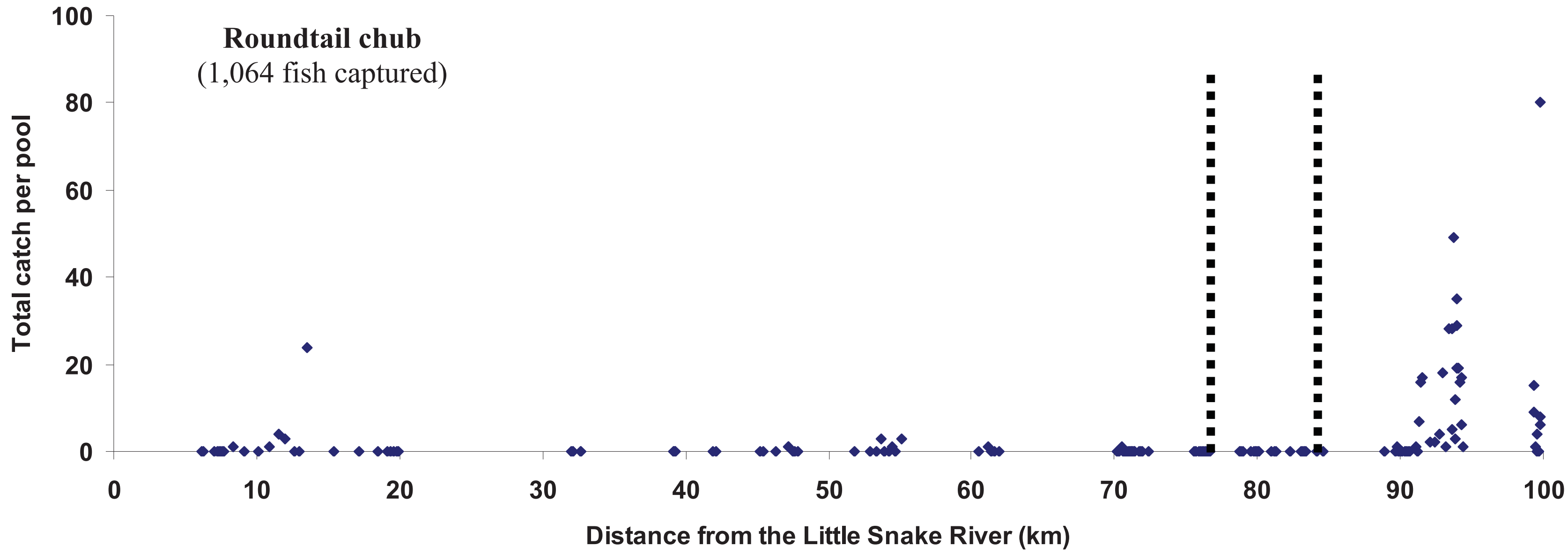

Figure 15. The total catch of ≥ age-1 roundtail chub in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

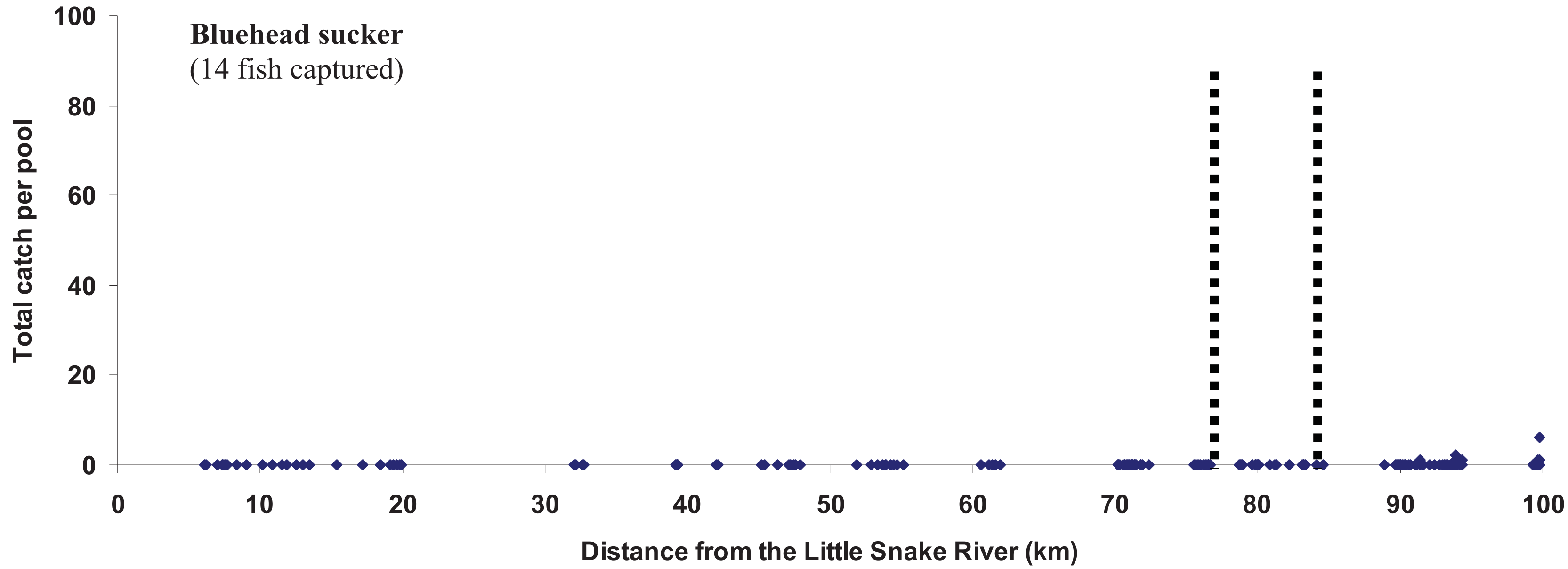

Figure 16. The total catch of ≥ age-1 bluehead sucker in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

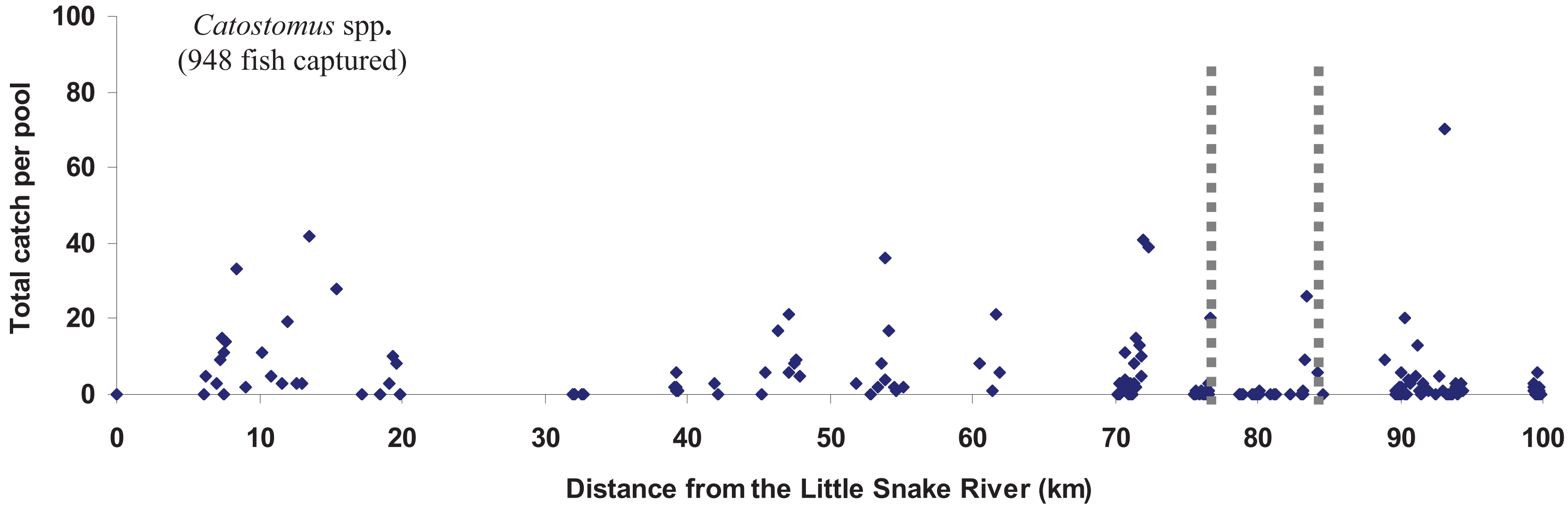

Figure 17. The total catch of age-0 *Catostomus* spp. each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

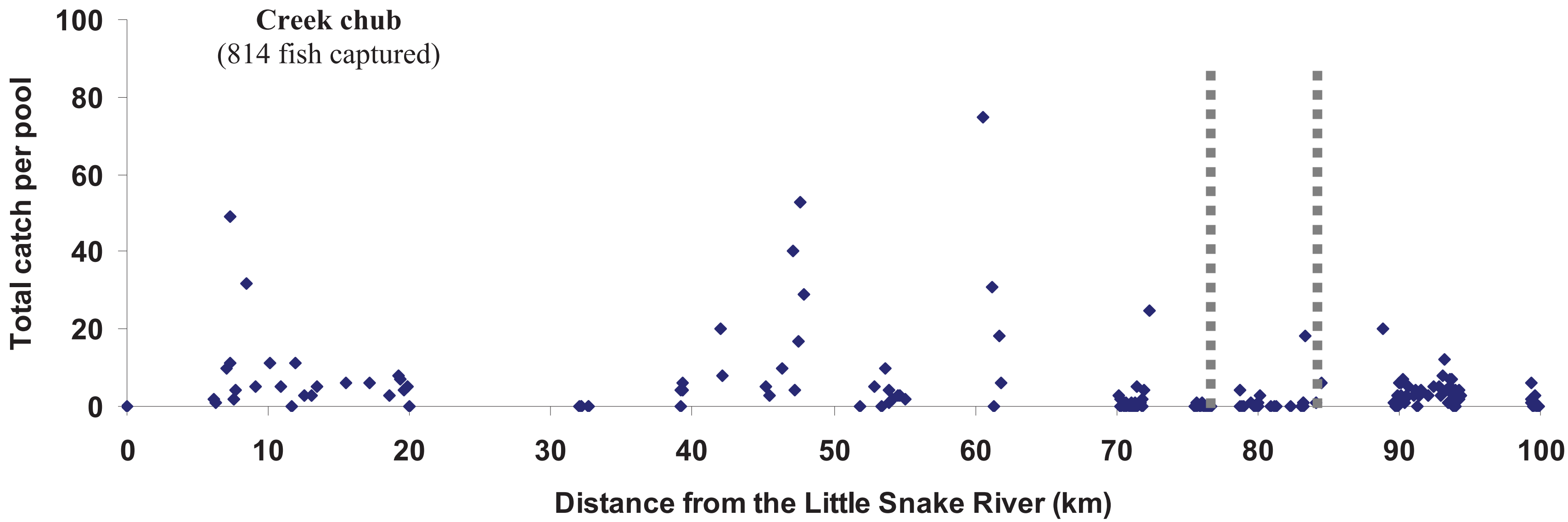

Figure 18. The total catch of age-0 creek chubs in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

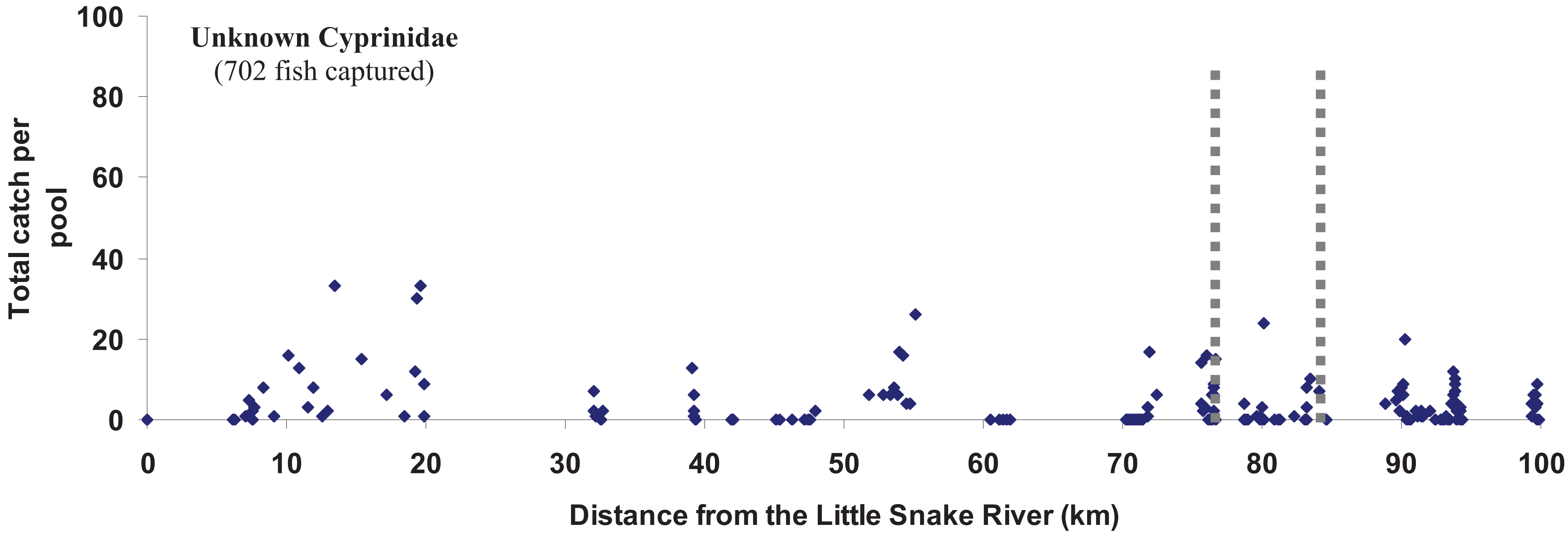

Figure 19. The total catch of age-0 cyprinids in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments. These represent age-0 cyprinids we were unable to identify to species.

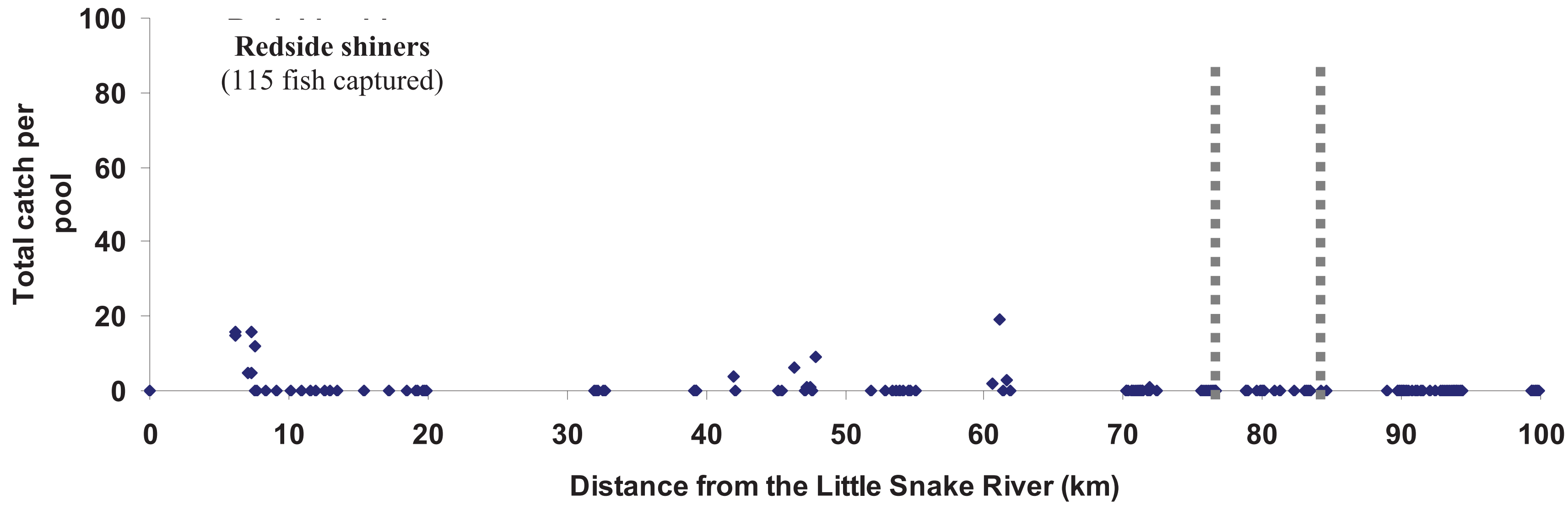

Figure 20. The total catch of age-0 redside shiners in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

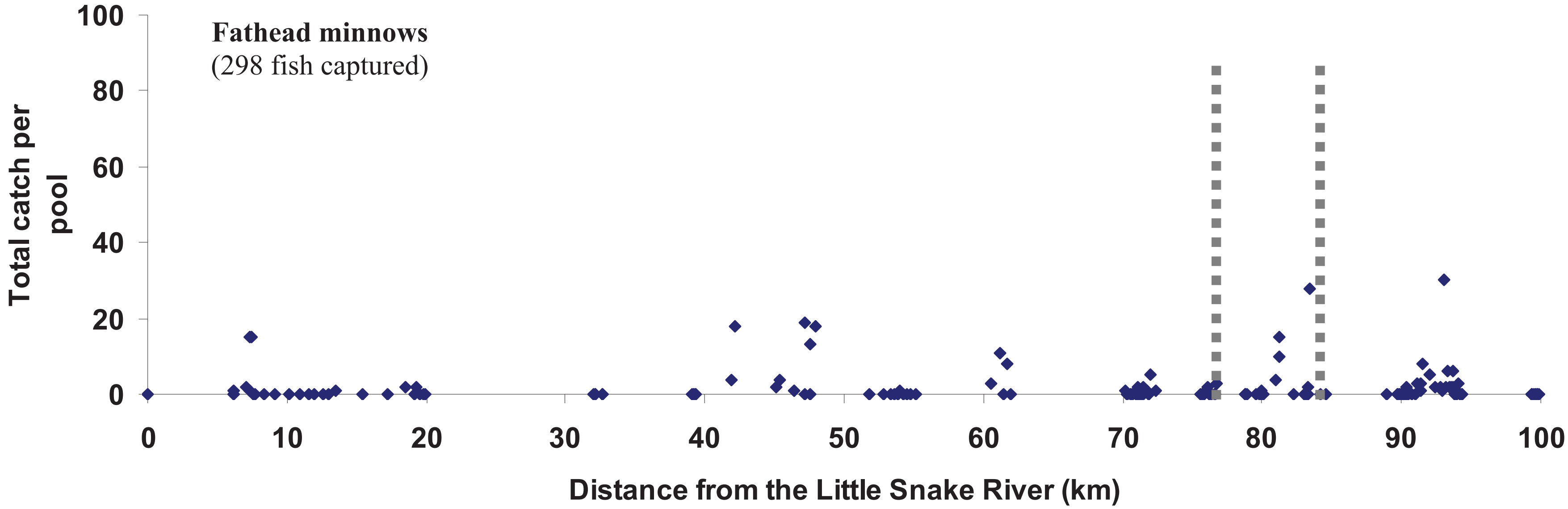

Figure 20. The total catch of age-0 fathead minnows in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

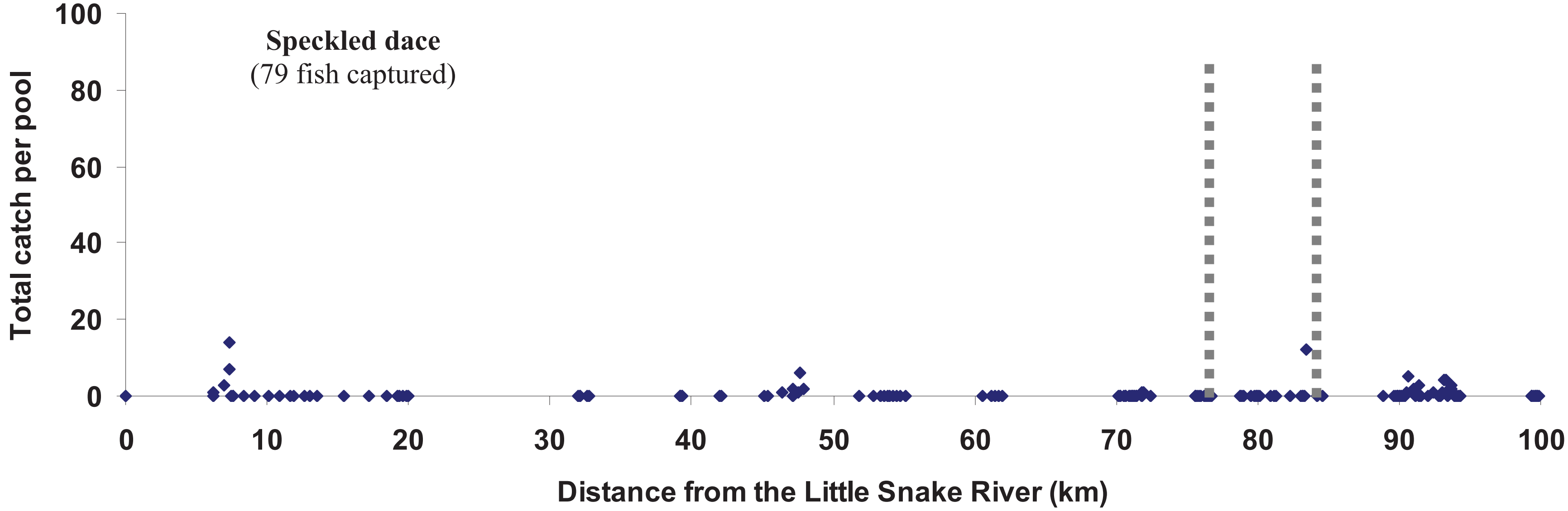

Figure 22. The total catch of age-0 speckled dace in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

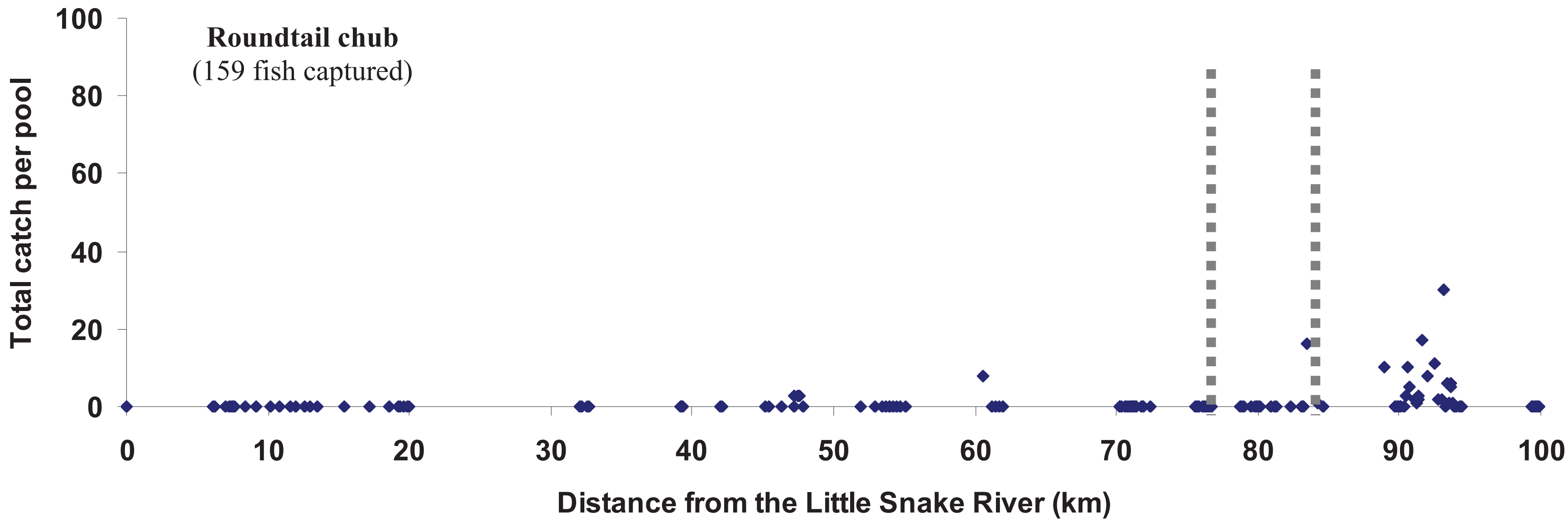

Figure 23. The total catch of age-0 roundtail chubs in each pool (n=173) and the distance of each pool from the confluence of Muddy Creek and the Little Snake River. The dashed lines segregate segments.

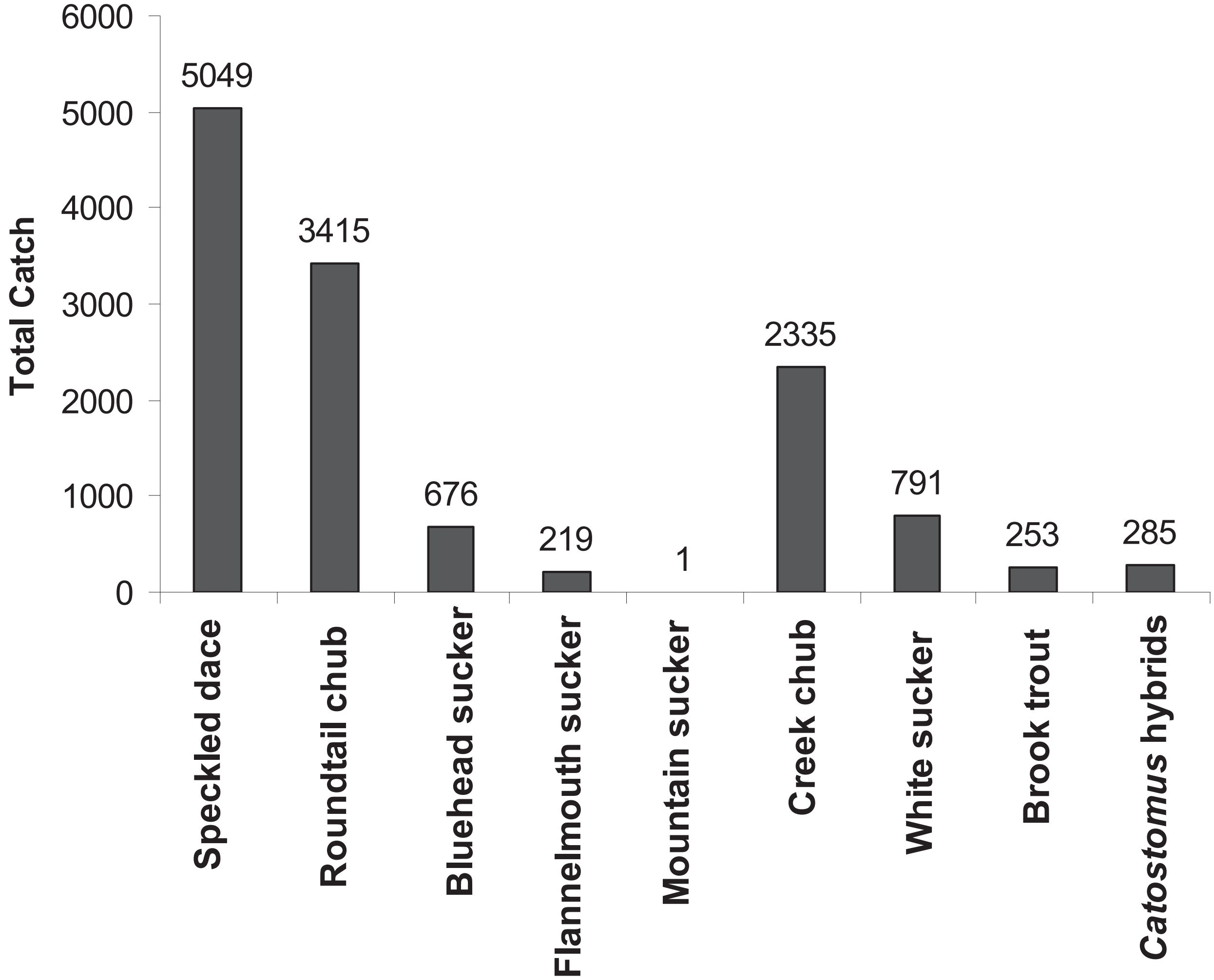

Figure 24. Total community composition of sites sampled within the upper Muddy Creek watershed during the summer and fall of 2003 and 2004 (Bower 2005). Total catch per species is presented on top of columns.

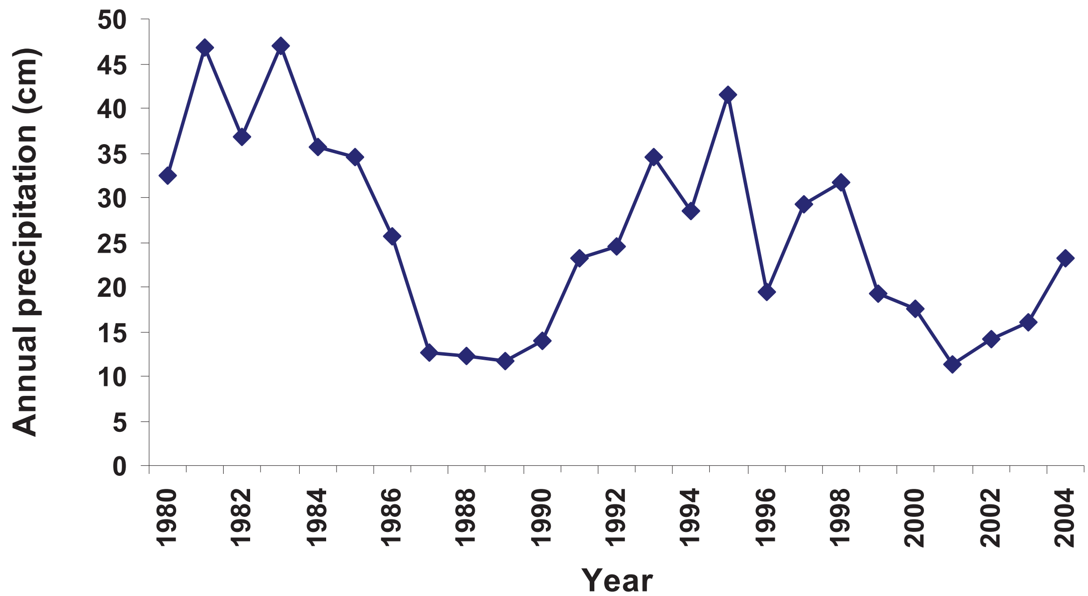

Figure 25. Mean annual precipitation (cm) reported at Baggs, Wyoming. Data provided by Western Regional Climate Center.

Appendix

The appendix contains pictures of water-control structures that existed within the wetland complex. Each type of structure was assigned a number which corresponds to those used in Figure 2. The date each photo was taken is also reported.

Appendix-1. Water control structure type 1 (Figure 2). Photo was taken June 3, 2004

Appendix-2. Water control structure type 2 (Figure 2). Similar vertical spillways connected most of the wetland impoundments. The top photo shows the overflow structure in the impoundment, and the bottom photo shows the outflow into a channel which lead into downstream impoundments. Photos were taken on May 26, 2004.

Appendix-3. Water control structure type 3 (Figure 2). Similar vertical spillways connected most of the wetland impoundments. The top photo shows the overflow structure in the impoundment, and the bottom photo shows the outflow into channel which led to downstream areas. Photos were taken on August 1, 2004.

Appendix-4. Water control structure type 4 (Figure 2). Photo was taken May 26, 2004

Appendix-5. Water control structure type 5 (Figure 2). Photo was taken May 26, 2004

Appendix-6. Water control structure type 6 (Figure 2). Photo was taken May 26, 2004