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[Article]

Influences of Fragmentation on Three Species of Native Warmwater Fishes in a Colorado River Basin Headwater Stream System, Wyoming

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Abstract.—We investigated the effects of constructed instream structures on movements and demographics of bluehead suckers *Catostomus discobolus*, flannelmouth suckers *C. latipinnis*, and roundtail chub *Gila robusta* in the upstream portion of Muddy Creek, an isolated headwater stream system in the upper Colorado River basin of Wyoming. Our objectives were to (1) evaluate upstream and downstream movements of these three native species past a small dam built to divert irrigation water from the stream and a barrier constructed to prevent upstream movements of nonnative salmonids and (2) describe population characteristics in stream segments created by these structures. Our results indicated that upstream and downstream movements of the three target fishes were common. Fish of all three species moved frequently downstream over both structures, displayed some upstream movements over the irrigation diversion dam, and did not move upstream over the fish barrier. Spawning migrations by some fish into an intermittent tributary, which was not separated from Muddy Creek by a barrier, were observed for all three species. Both the irrigation diversion dam and the fish barrier contributed to fragmentation of the native fish populations, and considerable differences in population features were observed among segments. The instream structures may eventually cause extirpation of some native species in one or more of the segments created by the structures.

Native fishes of North America have declined since the early 20th century (Williams et al. 1989; Moyle and Leidy 1992), and some of the most substantial declines have occurred among fishes in the Colorado River basin (CRB; Minckley and Deacon 1968; Douglas and Marsh 1998; Minckley et al. 2003). Of the large-bodied warmwater species that are native to the CRB, four are listed as endangered under the U.S. Endangered Species Act and three (i.e., bluehead sucker *Catostomus discobolus*, flannelmouth sucker *C. latipinnis*, and roundtail chub *Gila robusta*) now occur in about half of their historic range within the CRB (Bezzerides and Bestgen 2002). Within the CRB of Wyoming, bluehead suckers, flannelmouth suckers, and roundtail chub occur in the Green River and Little Snake River drainages, where they are classified as sensitive, declining, or vulnerable to extinction according to the U.S. Bureau of Land Management, Wyoming Game and Fish Department, or Wyoming Natural Diversity Database. A rangewide conservation agreement among natural resource management agencies in the CRB has been made in an effort to "ensure persistence of roundtail chub, bluehead sucker, and flannelmouth sucker populations throughout their ranges" (Karpowitz 2006).

Fragmentation of bluehead sucker, flannelmouth sucker, and roundtail chub populations through water development and land use activities is a substantial threat to the species' continuing existence in many watersheds (Bestgen and Probst 1989; Martinez et al. 1994; Bestgen and Crist 2000). Dams have altered instream habitat, changed the natural hydrograph and water temperatures, fragmented populations, and prevented movements to spawning, rearing, and

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wintering habitats (Martinez et al. 1994; Burdick 1995; Anderson 1997). Fish that are endemic to the CRB often exhibit complex life histories, including movements over large distances, and dams and barriers can prevent necessary movements. Movement patterns of fishes in desert streams of the southwestern United States are poorly understood, and knowledge of bluehead sucker, flannelmouth sucker, and roundtail chub movements is minimal (Bestgen et al. 1987). For these three species, most studies have focused on temporal patterns of fishes moving in and out of tributary streams, typically to spawn (Minckley and Holden 1980; Weiss et al. 1998).

The upstream portion of the Muddy Creek watershed is one of only two Wyoming stream systems in which sympatric populations of bluehead suckers, flannelmouth suckers, and roundtail chub are known to remain, and these populations may be threatened in several ways. Recent studies suggest that introduced white suckers *C. commersonii* are hybridizing with native bluehead suckers and flannelmouth suckers in Muddy Creek (Bower 2005; Compton 2007) and that hybrids can be readily identified in the field (Douglas and Douglas 2003; McDonald et al. 2008). Also, introduced creek chub *Semotilus atromaculatus* may compete with the native fishes for food and may prey upon the young of native species (Quist et al. 2006a) in the upstream portion of Muddy Creek. In addition to the effects of nonnative fish introductions, anthropogenic barriers in the upstream portion of Muddy Creek are also affecting native fishes. These barriers include a headcut stabilization structure that has isolated populations in the upstream portion of the watershed, a small dam built to divert irrigation water from the stream, and a barrier constructed to prevent upstream movements of nonnative salmonids as part of a program to re-establish Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* in the system. The purpose of this research was to investigate the effects of constructed instream structures on populations of the three species in the upstream portion of Muddy Creek, which serves as an example of an isolated, headwater stream system. Our objectives were to evaluate upstream and downstream movements of the three species past the irrigation diversion dam and the fish barrier and to describe population characteristics in segments created by these structures.

Methods

Study area.—Muddy Creek (a tributary of the Little Snake River) and its tributary, McKinney Creek, occur in a 2,470-km^2 watershed in south-central Wyoming (Figure 1; Goertler 1992). Muddy Creek flows through a high-elevation, relatively treeless, cold desert region. There is little riparian canopy cover, but willows *Salix* spp., mountain alder *Alnus tenuifolia*, Utah juniper *Juniperus osteosperma*, and water birch *Betula occidentalis* are present. The prevailing vegetative communities in this erosive landscape are made up of desert shrubs, sagebrush *Artemisia* spp., and grasses. Grazing is the primary land use (Hawkins and O'Brien 2001), but natural gas production is increasing in the watershed. The hydrograph of Muddy Creek is dominated by snowmelt runoff; the highest annual discharge occurs during early April through early June, and periods of base flow occur during July through March. Segments of Muddy Creek often become intermittent during late summer, but surface flow is occasionally restored during this period by precipitation from thunderstorms over the watershed. The geology, climate, and sparse vegetation of the drainage contribute to high loads of fine sediment in Muddy Creek.

Upper Muddy Creek was isolated in 2002 by a 5-m-high headcut stabilization structure that was used to halt a downcutting erosion event 100 km upstream of the confluence with the Little Snake River. The distributions of bluehead suckers, flannelmouth suckers, and roundtail chub extend 60–63 km upstream from the headcut stabilization structure to where salmonid species dominate the fish community (Quist et al. 2006b). Within the isolated upstream system occupied by all three species, there are two constructed instream structures that may fragment the fish populations. One structure, a 1-m-high dam used to divert irrigation water from the stream, is located 10.2 km downstream from the confluence with McKinney Creek (Figure 1). The date of initial construction of this structure is unknown, but it was rebuilt in 2000. The second structure is a barrier used to prevent upstream movements of nonnative salmonids in Muddy Creek and is located just upstream of the confluence with McKinney Creek. The fish barrier was constructed in 1992 to prevent movements by brook trout *Salvelinus fontinalis* from the headwaters of McKinney Creek into the headwaters of Muddy Creek.

The study area extended 63 km upstream from the headcut stabilization structure on Muddy Creek and also included 12.2 km of McKinney Creek upstream of its confluence with Muddy Creek (Figure 1); elevation ranged from 2,115 to 2,225 m above mean sea level. The study area was stratified into four study segments based on instream structures. Segment 1 was 52.6 km long and was bounded at the downstream end by the headcut stabilization structure and at the upstream end by the irrigation diversion dam. Only the upstream-most 5.0 km of segment 1 was perennially flowing. Segment 2 was perennially flowing over its length and

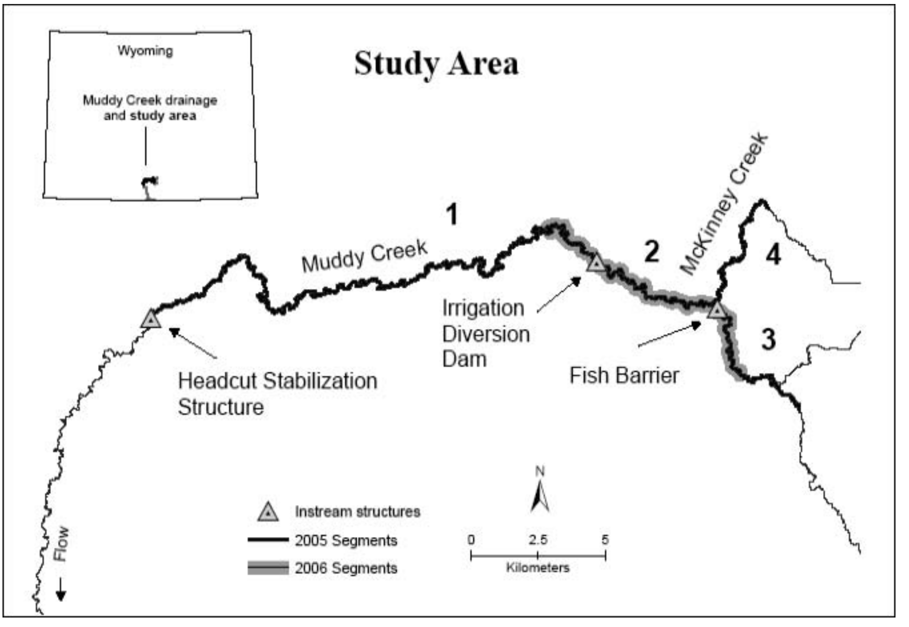

FIGURE 1.—Map of the Muddy Creek, Wyoming, study area, showing the locations of three instream structures and four study segments sampled in 2005 and 2006 to determine the movements and population characteristics of bluehead suckers, flannelmouth suckers, and roundtail chub.

extended for 10.4 km from the irrigation diversion dam to the fish barrier. Segment 3 also was also perennially flowing and extended for 10.0 km from the fish barrier to just beyond the upstream distribution of the three species. Segment 4 encompassed a 12.2-km reach of McKinney Creek from its confluence with Muddy Creek to just above the point where the three target species were no longer found. McKinney Creek usually becomes intermittent during late summer (Bower 2005). The perennially flowing portions of Muddy Creek had a mean wetted width of 3.2 m during the summer base flow period. Because more than 90% of segment 1 was dry with widely scattered residual pools during the 2005, fish sampling in 2006 was limited to the upper 5 km where perennial flows occurred. In 2006, segment 3 was reduced to the 5 km immediately upstream from the fish barrier, because fish in the upper 5 km were killed by piscicides in fall 2005 as part of Colorado River cutthroat trout restoration efforts.

Fish movements.—Passive integrated transponder (PIT) tag technology was used to assess upstream and downstream movements over instream structures. Fish greater than or equal to 92 mm total length (TL) were captured by electrofishing and tagged in segments 1–3 during fall 2004, when water temperatures were less than 10°C. Half-duplex tags (23.1 mm long, 3.9 mm in diameter, 0.6 g in air; Texas Instruments) were surgically implanted into anesthetized fish by the methods of Roussel et al. (2000). A 0.5-cm incision was made on the ventral surface near the pelvic fin, a PIT tag was inserted into the body cavity, and the incision was closed with a nonabsorbable surgical suture. Chlorhexidine was used to sterilize tags, sutures, and surgical instruments.

Three monitoring stations were installed in Muddy Creek during April or May 2005 and were operated through August 2005. Stations were placed immediately downstream from the irrigation diversion dam (station 1) and the fish barrier (station 2); a third station was placed in McKinney Creek (station 3), approximately 200 m upstream from its confluence with Muddy Creek. Antennas were open-coil inductor loops with 8-gauge multistrand wire passed through 2.5-cm-diameter, polyvinyl chloride pipe on the streambed and were suspended over the water with the support of a cable stretched across the river channel. Each antenna was connected to a radio frequency identification (RFID), half-duplex, single-antenna reader powered by two sealed, 12-V, deep-cycle batteries (100 ampere–hours/battery) connected in parallel (Oregon RFID, Portland, Oregon) and secured in streamside metal boxes. A computer received data output weekly from the readers and displayed individual tag identification, date, and time of detection. Once a station was installed, tagged fish were identified as they passed through the antenna loop. This system did not differentiate upstream or downstream movements. All three stations were re-installed in April and May 2006 and operated through October 2006.

The PIT tag detection efficiency at each of the three stations was tested in two ways. First, after each station was installed, a thorough, large-scale detection test was completed by passing a wooden stake with an attached PIT tag through antennas at 50-cm intervals across the river on a horizontal plane and 50-cm intervals on a vertical plane. The stake was passed through twice at each location; it was held parallel to the antenna on the first pass and perpendicular to the antenna on the second pass. Detection efficiency was estimated by the methods of Zydlewski et al. (2006). Second, prior to and after weekly data retrieval at each monitoring station, a PIT tag that was attached parallel to a wooden stake was passed through the antenna at six evenly spaced distances perpendicular to the streambank at the midcolumn water depth and at 10 cm above the bottom.

Fish were sampled in the study area during summer 2005 to recover PIT-tagged individuals. Sampling was conducted using a backpack electrofisher and a systematic sampling design. In each of the four segments, 12–13 evenly spaced, 400-m reaches were identified and sampled in a random order by a single pass in an upstream direction. Bluehead suckers, flannelmouth suckers, and roundtail chub larger than 40 mm TL were measured to the nearest millimeter, and fish greater than 90 mm TL were examined for a PIT tagging scar. The tag number was detected by scanning tagged fish with a hand-held PIT tag detection wand. Upon recapture, locations of PIT-tagged fish were recorded (Universal Transverse Mercator projection, North American Datum of 1983, Zone 13) using a Garmin Global Positioning System unit (Model 12 XL) with a root mean square accuracy of 15 m. In addition to the predetermined 400-m reaches, all tagging localities, areas above and below each instream structure, and areas containing deep pools were also sampled.

The lengths of PIT-tagged fish in 2004 were compared with those of PIT-tagged fish that were observed to have moved among the study area segments. Chi-square tests were used to determine whether the proportions of tagged juveniles and adults of each species differed from proportions of fish exhibiting movement among segments (Ramsey and Schafer 2002). Based on observations by Bower (2005), bluehead suckers and roundtail chub greater than 150 mm TL and flannelmouth suckers greater than 250 mm TL were considered to be adults.

Population characteristics.—Estimates of fish abundance (>100 mm TL) were made during summer 2006 using a three-pass removal method. Fifteen randomly selected, 200-m reaches were sampled in segment 1, 30 reaches were sampled in segment 2, and 12 reaches were sampled in segment 3. Reaches were closed by placing fine-mesh block nets (mesh size = 0.6 cm) at the downstream and upstream ends. Electrofishing was conducted by a two-person team (one person operated a pulsed-DC backpack electrofishing unit, and the other person netted the fish), and the entire reach was sampled on each pass. Program CAPTURE (White et al. 1982) was used to compute abundance estimates and standard errors for individual reaches with a generalized jackknife modification of the abundance model M_{bh} developed by Pollock and Otto (1983). The modified model accounts for varying capture probability of individual animals and behavioral response to capture attempts. Estimates of abundance were extrapolated for each segment by summing individual reach estimates and variances and multiplying those statistics by the ratio of segment length divided by length sampled. Standard errors were estimated for each segment as (segment length/length sampled) $\times \sqrt{\Sigma \mathrm{SE}^2}$. The estimated number of adult fish in each segment was derived by multiplying the total estimate by the proportion of fish exceeding the adult length threshold. All target fish greater than 40 mm TL that were collected by electrofishing in 2006 were measured to the nearest millimeter.

Results

Fish Movements

Antenna efficiency was 0.90 at station 1, 0.98 at station 2, and 1.0 at station 3. During the testing of PIT tag detection efficiency, only tags passed parallel to the antenna at station 1 went undetected. The percentage of time during which antennas were functioning properly ranged from 65% for station 3 in McKinney Creek to 87% for station 2 downstream of the fish barrier.

Passive integrated transponder tags were implanted in a total of 1,395 bluehead suckers, flannelmouth suckers, and roundtail chub (Table 1). Downstream movements of PIT-tagged fish over the irrigation diversion dam and fish barrier and upstream movements of tagged fish over the irrigation diversion dam and into McKinney Creek were indicated by these data.

Bluehead suckers tagged in segment 2 moved downstream over the irrigation diversion dam into segment 1 as well as upstream within segment 2 to just below the fish barrier (Table 1). Thirty-six bluehead suckers moved downstream into segment 1, but nine of these fish subsequently moved back upstream over the irrigation diversion dam. Of the bluehead suckers that

TABLE 1.—Number tagged, total length (TL, mm), and number of recaptures among passive integrated transponder tagged bluehead suckers, flannelmouth suckers, and roundtail chub that were initially tagged in segments 1–3 (tagging segment) of the Muddy Creek, Wyoming, study area (Figure 1) during fall 2004 and later detected while passing through antennas or during electrofishing in 2005 and 2006. Numbers in parentheses represent fish that were recaptured in both 2005 and 2006.

Tagging segment	Number tagged	Mean TL	Recapture segment 1	Recapture segment 2	Recapture segment 3
Bluehead sucker					
1	258	154	40	1	0
2	573	181	36 (9)	232	0
3	79	154	0	3	14
Flannelmouth sucker					
1	3	179	1	0	0
2	70	211	2	34	0
3	3	254	0	0	4
Roundtail chub					
1	79	147	11	0	0
2	248	180	24 (8)	114	0
3	82	199	0	3	35

were tagged in segment 2, 40 were recorded in McKinney Creek (segment 4) during both years (Table 2). Three bluehead suckers that were tagged in segment 3 moved downstream into segment 2.

Of the 70 flannelmouth suckers that were tagged in segment 2, two were scanned by the antenna in segment 1 (Table 1). No flannelmouth suckers were detected at the antenna just below the fish barrier, but 21 fish were detected in segment 4 and 6 of these were recorded during both years (Table 2).

No roundtail chub tagged in segment 1 were observed upstream in segment 2 (Table 1). Of the 248 roundtail chub tagged in segment 2, 24 were observed to have moved downstream over the irrigation diversion dam in segment 1 and 8 of these fish moved back into segment 2 (Table 1). Of the roundtail chub tagged in segment 2, 62 fish were detected in segment 4 and 17 of these were detected during both years (Table 2).

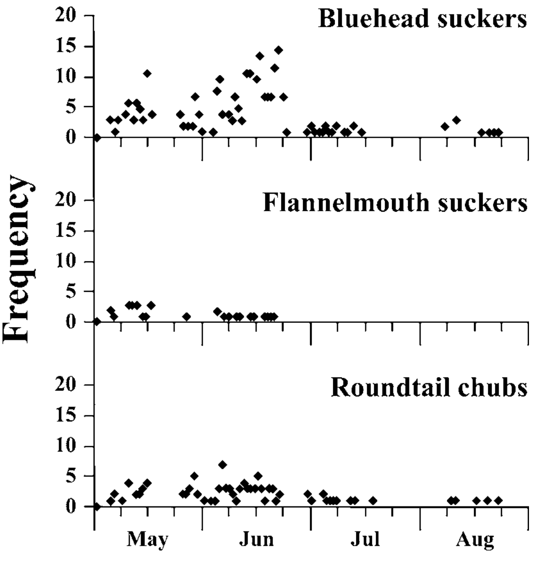

FIGURE 2.—Numbers of passive integrated transponder tagged bluehead suckers, flannelmouth suckers, and roundtail chub detected as moving between Muddy and McKinney creeks, Wyoming, during May–August 2005 on days when the antenna near the mouth of McKinney Creek was functioning. The antenna was nonoperational during May 16–25, June 1–2, June 22–29, and July 16–22.

Among the fish tagged in segment 3, both bluehead suckers and roundtail chub were later observed downstream of the fish barrier in segment 2. Of the 79 bluehead suckers tagged above the fish barrier, 3 fish were observed in segment 2 (Table 1) and all three were later observed in segment 4 (Table 2). Among the 82 roundtail chub tagged in segment 3, three fish were detected in segment 2 (Table 1).

Temporal movement patterns by tagged bluehead suckers, flannelmouth suckers, and roundtail chub were observed in segment 4, representing McKinney Creek. For all three species, some individuals moved from segment 2 into segment 4 during early May (Figures 2, 3) through mid-July (2005) or late June (2006). The highest number of fish scanned per day occurred

TABLE 2.—Origin of passive integrated transponder tagged bluehead suckers, flannelmouth suckers, and roundtail chub that were tagged in Muddy Creek, Wyoming (segment 2 or 3; Figure 1), and later recorded at the antenna in McKinney Creek during 2005, 2006, or both years.

Species	Segment 2: Number tagged	Segment 2: Recapture year 2005	2006	Both	Segment 3: Number tagged	Segment 3: Recapture year 2005	2006	Both
Bluehead sucker	573	122	54	40	79	3	1	1
Flannelmouth sucker	70	14	7	6	3	0	0	0
Roundtail chub	248	37	25	17	83	0	0	0

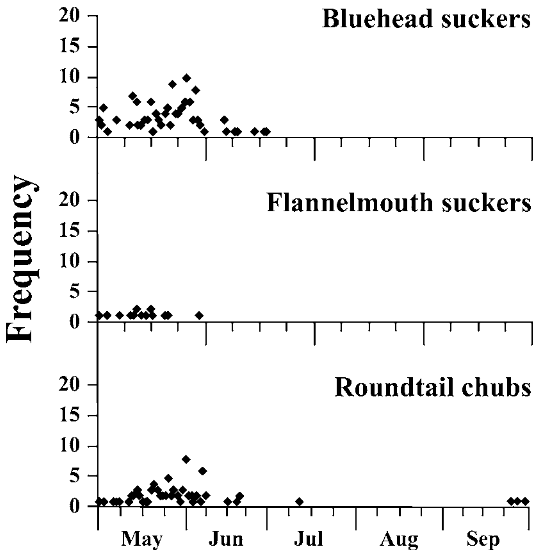

FIGURE 3.—Numbers of passive integrated transponder tagged bluehead suckers, flannelmouth suckers, and roundtail chub detected as moving between Muddy and McKinney creeks, Wyoming, during May–September 2006 on days when the antenna near the mouth of McKinney Creek was functioning. The antenna was nonoperational during May 5–11, June 28–July 6, July 11–20, and August 9–September 14.

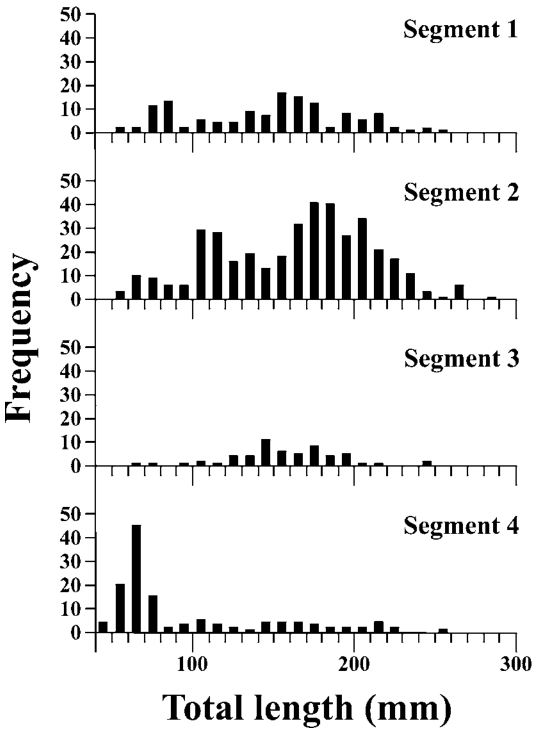

FIGURE 4.—Length frequency distributions of bluehead suckers collected within segments 1–4 of the Muddy Creek, Wyoming, study area (Figure 1) during 2005.

during mid-May for flannelmouth suckers, from late May to early June for roundtail chub, and during the first half of June for bluehead suckers. McKinney Creek did not become intermittent in 2005 but became intermittent during late July 2006.

Proportions of juveniles and adults that were tagged in 2004 were compared with the proportions of tagged fish that moved out of the tagging segment. No significant differences were detected for bluehead suckers or flannelmouth suckers; however, for roundtail chub, the proportion of tagged adults that moved out of the tagging segment was significantly higher than the proportion of adults among tagged fish ($P = 0.0021$). Of the 401 roundtail chub that were tagged, 66% were adults; of the fish that were observed outside of the tagging segment, 91% were adults. Most movements were by adults that were tagged in segment 2 and moved downstream into segment 1.

Population Characteristics

Small (41–100-mm TL) bluehead suckers, flannelmouth suckers, and roundtail chub had the highest frequencies of occurrence in segments 2 and 4, whereas they were nearly absent in segment 3 above the fish barrier. Small bluehead suckers and flannelmouth suckers were most frequently found in segment 4. Roundtail chub were most frequently observed in segments 1 and 2 (Figures 4–6; data from 2005). Similarly, the lowest densities of small fish (all three species) in 2006 occurred in segment 3, and the highest densities occurred in segment 2 (Table 3). Among the three species, small roundtail chub were observed at the highest densities, bluehead suckers were intermediate in density, and flannelmouth suckers exhibited the lowest densities.

The frequencies of larger (>100 mm TL) bluehead suckers, flannelmouth suckers, and roundtail chub were highest in segment 2 and lowest in segment 4 (Figures 4–6). Segment 2 had a high number of 300–420-mm TL flannelmouth suckers (Figure 5). Almost all roundtail chub 10-cm length-classes up to 310 mm TL were represented in segments 1 and 2, but fish greater than 160 mm TL were rare in segment 4 (Figure 6).

Abundances of bluehead suckers, flannelmouth suckers, and roundtail chub were estimated in 46–52% of the available 200-m reaches (i.e., 20 reaches were available over the 5.0 km in segment 1; 52 were available over the 10.4 km in segment 2; 20 were available over the 5.0 km in segment 3). In every segment, abundance estimates were highest for round-

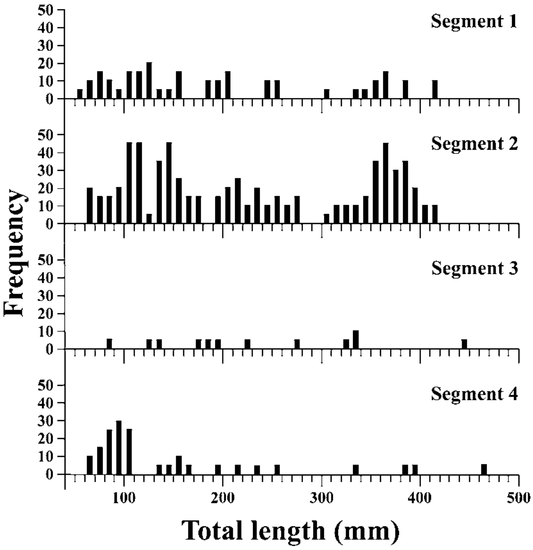

FIGURE 5.—Length frequency distributions of flannelmouth suckers collected within segments 1–4 of the Muddy Creek, Wyoming, study area (Figure 1) during 2005.

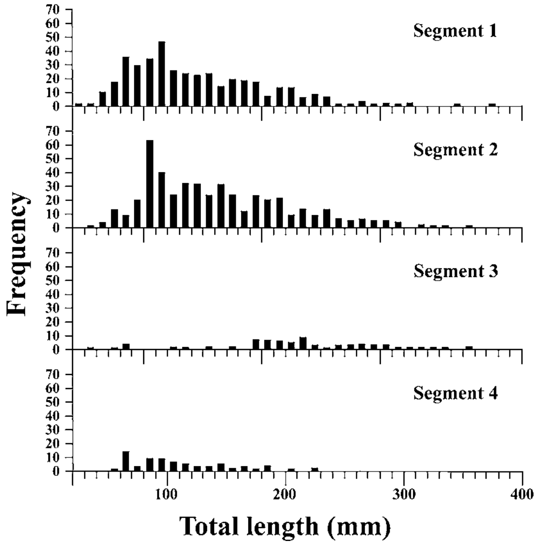

FIGURE 6.—Length frequency distributions of roundtail chub collected within segments 1–4 of the Muddy Creek, Wyoming, study area (Figure 1) during 2005.

tail chub and lowest for flannelmouth suckers; for every species, abundance estimates were highest in segment 2 and lowest in segment 3 (Table 4). Estimated numbers of adult bluehead suckers, flannelmouth suckers, and roundtail chub varied among the three segments but were highest in segment 2 (Table 5).

Discussion

The PIT tagging procedure resulted in high tag retention and detection, but the tag detection systems failed occasionally. Of the tagged fish that were recaptured and handled, four fish had visible surgical scars but lacked detectable PIT tags; a retention rate of 98.6% was indicated. Retention of PIT tags was therefore similar to that observed in other studies (97–100%; Burdick and Hamman 1993; Roussel et al. 2000; Zydlewski et al. 2001). Detection efficiency was high at the three antennas. However, a small fraction of tags that passed parallel to one antenna was not detected. These observations were similar to those of other researchers using PIT tag antennas (Brannas et al. 1994; Zydlewski et al. 2001). Antennas were operational 76–98% of the time in 2005 and 58–89% in 2006; periods of nonoperation were caused by battery depletion when high numbers of tags were detected.

We found that spawning migrations into an intermittent tributary (McKinney Creek) may be an important part of the life history of bluehead suckers, flannelmouth suckers, and roundtail chub in Muddy Creek. These species have been reported to be mobile in larger stream systems (Bestgen et al. 1987), and movements in small streams have been limited to descriptions of spawning migrations from rivers into small streams (Minckley and Holden 1980; Weiss et al. 1998). Tagged adults of all three species moved upstream into McKinney Creek during the spawning season and then returned downstream. Habitat was not measured in McKinney Creek, but gravel riffles free of sediment were available and probably provided spawning habitat for each species. Such habitat was rare in other portions of the study area. Similar spawning migrations into tributaries have been observed in other systems for all three species (Maddux and Kepner 1988; Kaeding et al. 1990; Weiss et al. 1998) and may be critical for maintaining populations (Bezzerides and Bestgen 2002).

Given the importance of movements in the ecology of bluehead suckers, flannelmouth suckers, and roundtail chub, it is important to consider how instream structures may influence populations. Neither of the two structures in Muddy Creek appeared to prevent downstream movements of fish. However, there was no upstream movement past the fish barrier (i.e., into segment 3), although some upstream movements past the irrigation diversion dam were detected. The limited upstream movements of fish past the irrigation diversion dam suggest that upstream movements were difficult for fish; most of these upstream movements occurred during high-flow events. Thus, the barriers

TABLE 3.—Number and density (fish/100 m) of bluehead suckers, flannelmouth suckers, and roundtail chub smaller than 100 mm total length that were collected in segments 1–3 of Muddy Creek, Wyoming (Figure 1), during 2006 (segment lengths: 1 = 5.0 km; 2 = 10.4 km; 3 = 5.0 km).

	Bluehead sucker		Flannelmouth sucker		Roundtail chub	
Segment	Number	Density	Number	Density	Number	Density
1	84	1.7	7	0.1	237	4.7
2	484	4.6	45	0.4	986	9.4
3	4	0.1	3	0.1	8	0.2

contributed to fragmentation of native fish populations in the Muddy Creek system, allowing fish to move downstream and supplement populations in those reaches but preventing or greatly impeding upstream movement by individuals of the three species.

Because fish often move to carry out critical aspects of their life histories, even a small degree of fragmentation within a riverscape can be detrimental to populations (Schlosser 1995; Fausch et al. 2002). There were considerable differences in population features of the three species among the study segments of Muddy Creek. Abundance estimates over the 5.0-km portion of segment 1 were low relative to those of segment 2. Higher estimates probably would have been obtained for segment 1 if its entire length of 52.6 km had been sampled in 2005. However, most of the 47.6-km downstream portion of segment 1 becomes intermittent during most summers and consists of only a few isolated pools. Survival in these isolated pools is probably limited, and few of the fish that find themselves in this portion of segment 1 are likely to survive and contribute to the reproducing population. Segment 2 had the highest numbers of the three species, the broadest ranges of length-classes, and the highest juvenile densities, as well as abundant rock substrates, pools, and perennial flows (features selected by juveniles and adults of all three species; Bower 2005); this segment was also connected to McKinney Creek. Together, the fish in perennially flowing segment 2 (length = 10.4 km) and segment 4 (length = 12.2 km) are likely to be population sources for the downstream portions of Muddy Creek. Pulliam (1988) defined population sources as areas that exhibit high juvenile recruitment and provide immigrants to less-productive habitats. The area of Muddy Creek downstream of the irrigation diversion dam may be a sink for bluehead suckers, flannelmouth suckers, and roundtail chub. Recruitment into sink habitat cannot maintain the population, and immigration from source areas is the key rate-dependent process influencing population dynamics in sinks (Pulliam 1988). However, sink habitats can sustain large populations even though a sink population would disappear without consistent immigration (Schlosser 1995). Whether larvae or juveniles drift downstream into segment 1 is unknown, but many young fish occupied this segment and the young of all three species are known to drift downstream (Carter et al. 1986; Robinson et al. 1998).

Bluehead suckers, flannelmouth suckers, and roundtail chub in segment 3 may be in peril due to the small adult populations, low recruitment, downstream emigration, and lack of immigration past the fish barrier. By preventing upstream movements of fish from downstream segments, the fish barrier may contribute to the eventual extirpation of all three species from segment 3.

Populations of bluehead suckers, flannelmouth suckers, and roundtail chub in the 5.0-km, perennially-flowing portion of segment 1 and in segments 2 and 3 were evaluated based on the 50/500 guideline proposed by Soule (1980). The 50/500 guideline states that there should be (1) a minimum of 50 adults contributing gametes to the gene pool (effective population size) to avoid inbreeding over short periods

TABLE 4.—Abundance estimates (*N*; each reported with standard error [SE] and 95% confidence interval [CI]) and densities (fish/100 m) of bluehead suckers, flannelmouth suckers, and roundtail chub in segments 1–3 of Muddy Creek, Wyoming (Figure 1) during 2006. Results reflect sampling in reduced lengths of segments 1 (due to intermittent flow) and 3 during 2006.

Segment	*N*	SE	95% CI	Density
Bluehead sucker				
1	289	20	250–328	5.7
2	1,269	40	1,191–1,347	12.1
3	143	14	117–171	2.6
All	1,701	47	1,608–1,793	8.3
Flannelmouth sucker				
1	105	11	84–126	2.1
2	335	19	298–372	3.2
3	35	8	19–51	0.5
All	475	23	430–520	2.3
Roundtail chub				
1	445	27	391–498	8.8
2	1,935	56	1,826–2,044	18.5
3	269	12	246–293	4.7
All	2,649	65	2,522–2,776	13.0

TABLE 5.—Proportions of juvenile and adult bluehead suckers, flannelmouth suckers, and roundtail chub in segments 1–3 of Muddy Creek, Wyoming (Figure 1) during 2006, calculated based on the actual numbers collected and on abundance estimates (*N*). Adults were defined as fish larger than 150 mm total length (TL) for bluehead suckers and roundtail chub or larger than 250 mm TL for flannelmouth suckers. Total abundance for each species was divided into juvenile and adult abundances based on their proportions among the total number collected.

			Juvenile		Adult	
Segment	Number collected	Total *N*	Proportion	*N*	Proportion	*N*
			Bluehead sucker			
1	99	289	0.45	130	0.55	159
2	492	1,269	0.58	736	0.42	533
3	84	143	0.13	19	0.87	124
			Flannelmouth sucker			
1	37	105	0.59	62	0.41	43
2	144	335	0.51	171	0.49	164
3	14	35	0.36	13	0.64	23
			Roundtail chub			
1	120	445	0.50	223	0.50	222
2	749	1,935	0.55	1,064	0.45	871
3	99	269	0.06	16	0.94	253

of time and (2) a minimum of 500 adults contributing gametes within the population to allow adaptation to environmental change over long periods of time. Using the 50/500 guideline as an evaluation tool, we determined that bluehead suckers and roundtail chub in segment 2 were the only populations in the study area with the potential for viability over long periods of time. Within the perennially flowing upstream end (5.0 km) of segment 1, the numbers of adult bluehead suckers ($N = 159$) and roundtail chub ($N = 212$) may be adequate for short periods of time. However, viability of bluehead sucker and roundtail chub populations in segment 1 probably depends upon enhancement by larvae, juveniles, and adults recruited from upstream. Flannelmouth sucker populations may not be viable over long periods of time in any segment, since the highest population estimate was 164 adults in segment 2. However, the 50/500 guideline may produce low estimates of viable population size, because it is hard to accurately estimate effective population size and because life history strategies can complicate viability. For example, Hilderbrand and Kershner (2000) examined the demographics of isolated populations of cutthroat trout *O. clarkii* and found that 2,500 individuals (>75 mm TL) would be necessary to maintain an effective population size of 500 reproducing adults.

Our data indicated that bluehead sucker, flannelmouth sucker, and roundtail chub populations have been fragmented by human-made structures in Muddy Creek. Habitat components required by various life history stages appeared to be insufficient or missing in some segments formed by instream structures (Bower 2005). Hybridization with nonnative white suckers also poses a major threat to bluehead suckers and flannelmouth suckers in the upstream portion of Muddy Creek. Additionally, prolonged drought throughout the western portion of the United States has probably affected native fish populations in the study area. The effects of hybridization and drought were not investigated in this study, but efforts to conserve native fishes should address these issues along with the issue of population fragmentation.

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