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Compton, Robert I., Population fragmentation and white sucker introduction affect populations of bluehead suckers, flannelmouth suckers, and roundtail chubs in a headwater stream system, Wyoming, M.S., Department of Zoology and Physiology, August, 2007.

I evaluated the effects of human-made instream structures on populations of bluehead sucker *Catostomus discobolus*, flannelmouth sucker *Catostomus latipinnis*, and roundtail chub *Gila robusta* in Muddy Creek, Carbon County, Wyoming. Movements and population features were assessed among adjacent segments partitioned by three instream structures. Instream structures prevented or severely limited upstream movements, but downstream movements over structures occurred. Within each segment, roundtail chubs were most abundant and flannelmouth suckers were least abundant among the three native species. A core population of the three native species existed in one segment and supported the highest densities of juveniles and adults and the broadest length ranges. Non-native white suckers *Catostomus commersoni* were the most abundant species in the study area, their highest densities occurred in altered habitat and substantial hybridization with the two native catostomid species was evident. Native fish populations in the most upstream segment may be at risk of extirpation due to low abundance and reproduction. Connectivity among habitats is required to carry out the life cycles of native fishes and fragmentation by human-made structures is affecting their abundance and distribution patterns.

POPULATION FRAGMENTATION AND WHITE SUCKER INTRODUCTION AFFECT POPULATIONS OF BLUEHEAD SUCKERS, FLANNELMOUTH SUCKERS, AND ROUNDTAIL CHUBS IN A HEADWATER STREAM SYSTEM, WYOMING

by
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Introduction

Native fishes of North America have been in decline since the early 20th century (Williams et al. 1989; Moyle and Leidy 1992). The Colorado River Basin (CRB) has experienced a substantial decline in native fishes (Minckley and Deacon 1968; Minckley et al. 2003). The distribution and abundance of bluehead sucker *Catostomus discobolus*, flannelmouth sucker *Catostomus latipinnis*, and roundtail chub *Gila robusta* have declined throughout the species' ranges in the CRB (Bezzerides and Bestgen 2002). The United States Bureau of Land Management (BLM) considers all three species "sensitive" throughout their range in Wyoming. The Wyoming Game and Fish Department (WGFD) has classified the three species as NSS1 species, meaning they are rare and their habitat is declining or vulnerable. The Wyoming Natural Diversity Database describes the roundtail chub as "imperiled" and the bluehead sucker and flannelmouth sucker as "vulnerable to extinction." Because of these apparent declines, a rangewide conservation agreement, signed and supported by the BLM and WGFD, was established in 2006 with a goal to "ensure persistence of roundtail chub, bluehead sucker, and flannelmouth sucker populations throughout their ranges" (Karpowitz 2006).

These three species may be the least studied fishes of the CRB (Bezzerides and Bestgen 2002). Human impacts such as water development, land use activities, and non-native fish introductions have negatively influenced these native fishes (Bestgen and Propst 1989; Martinez et al. 1994; Bestgen and Crist 2000; Bestgen et al. 2006). Understanding the mechanisms impacting native fish populations is critical for their conservation.

Within the CRB of Wyoming, bluehead suckers, flannelmouth suckers, and roundtail chubs are found in the Green River and Little Snake River drainages, and sympatric populations are known to persist only in the Blacks Fork River of the Green River drainage and Muddy Creek of the Little Snake River drainage. The headwater portion of Muddy Creek appears to have the highest densities of these fishes in Wyoming; therefore, the populations in Muddy Creek may be extremely important to the conservation of these species in the state.

The distributions of bluehead suckers, flannelmouth suckers, and roundtail chubs within the upper Muddy Creek watershed were described in 2003 and 2004 (Bower 2005). Bluehead suckers were widely distributed and relatively common, while flannelmouth suckers were found sporadically and were the least common of the three species. Roundtail chubs were found throughout the study area and were the most common of the three species. Introduced white suckers *Catostomus commersoni* were abundant and morphological evidence of hybridization with the two native suckers was commonly observed. Bower (2005) suggested that management issues result from disruption of stream connectivity due to instream structures within upper Muddy Creek. Because native fish preservation is a priority for the BLM, an assessment of the effects of instream structures on the native fish community was deemed necessary.

Bluehead sucker, flannelmouth sucker, and roundtail chub life histories

Environmental conditions in most river systems are highly variable, especially throughout desert regions of western North America. Fish in these river systems often exhibit complex life cycles that can extend over large spatial and temporal scales.

Understanding life cycles and population dynamics is necessary to determine effects of artificially restricted movements within a riverscape (Fausch et al. 2002). Stream fish vary considerably in size from embryo to adult. Life cycle and habitat-use patterns are associated with this variation, and are achieved by movements or migrations within river systems. Life begins with egg fertilization at spawning and hatched fry usually move to nursery and rearing habitats where rapid growth can occur (Schlosser 1995). As juveniles and adults, fish may move between favorable summer feeding habitats and winter refugia, emigrate from unsuitable habitats, exploit beneficial habitat, and recolonize areas after local extinction (Siebert 1980; Cunjak 1988; Labbe and Fausch 2002). Upon sexual maturity, fish often undertake spawning movements and the cycle is reinitiated. Because different life stages may require dissimilar habitats, connectivity of habitat patches and spatial heterogeneity are critical for completion of life cycles (Bisson et al. 1982). Optimal habitat can vary as conditions change, and fishes subjected to variable river conditions may move more than fishes occupying more stable environments. Factors such as food availability, predator avoidance, climate, and homing behavior may stimulate migratory movements (Lucas and Baras 2001). Connectivity within a river system is critical, and movements or migrations can enhance the probability of life cycle completion.

General life history traits of bluehead suckers, flannelmouth suckers, and roundtail chubs are known, but can vary among segments of large rivers and tributary systems. The three species usually spawn in spring and early summer on the descending limb of the snowmelt hydrograph (Carlson et al. 1979; Brouder 2001; McAda and Wydoski 1985; Robinson et al. 1998; Sigler and Sigler 1996; Weiss et al. 1998).

Bluehead suckers and flannelmouth suckers deposit adhesive, demersal eggs over gravel and cobble in swift flowing riffles (Sublette 1990; Maddux and Kepner 1988; McAda and Wydoski 1985; Weiss et al. 1998), whereas roundtail chubs deposit adhesive, demersal eggs over gravel in pools, runs, or riffles (Neve 1976; Muth et al. 1985; Keading et al. 1990). Newly-hatched protolarvae with enlarged yolk sacs and no fin rays are relatively immobile and remain in the interstitial spaces of the spawning substrate. The yolk sac is nearly absorbed and the mouth and gut develop during the mesolarvae stage when these young fish emerge from the interstitial spaces to feed and inflate their swim bladders. Mesolarvae are exposed to river currents and transported downstream.

Bluehead sucker, flannelmouth sucker, and roundtail chub dominated samples of drifting larvae from the Upper Colorado River, and were frequently captured as mesolarvae during a three-week period in late July when water temperatures increased and discharge decreased dramatically (Carter et al. 1986). In the Little Colorado River, bluehead suckers and flannelmouth suckers actively drifted, sought out nearshore habitat, and were considered a primary source of recruitment to the Grand Canyon reach of the Colorado River (Robinson et al. 1998). Larvae of all three species seek out low-velocity shoreline habitat or backwaters, where warmer water temperatures facilitate rapid growth (Robinson et al. 1998).

Age 0 and 1 bluehead suckers, flannelmouth suckers, and roundtail chubs often reside in habitats with low current velocities (Muth et al. 1985; Haines and Tyus 1990; and Robinson and Childs 2001). Juvenile roundtail chubs less than 150 mm total length (TL) in Fossil Creek, Arizona selected velocities of about 0.15 m/s and sand substrate (Barrett and Maughan 1995). Bluehead suckers and flannelmouth suckers in the San

Juan River, New Mexico and Utah, showed positive associations with areas having low water velocities and silt bottoms (Gido and Propst 1999).

The most notable habitat association for adult bluehead suckers, flannelmouth suckers, and roundtail chubs was described as pools with rock substrate in upper Muddy Creek (Bower 2005). Bluehead sucker adults often reside in habitat with rocky substrate and moderate-to-fast current (Holden and Stalnaker 1975; Carlson et al. 1979; McAda et al. 1980). Flannelmouth suckers use a wide variety of habitats including moderate-to-deep areas with vertical structure in the Little Colorado River (Gorman et al. 1994), riffles, eddies, backwaters, and areas with fast current in the Green River (Holden and Stalnaker 1975), and pools in the Virgin River (Holden and Abate 1999). Roundtail chubs prefer slow-moving water in deep pools with access to feeding areas and woody debris, undercut banks, or large rock cover (Vanicek and Kramer 1969; McAda et al. 1980; Bestgen 1985; Sigler and Sigler 1996; Brouder et al. 2000).

Bluehead sucker, flannelmouth sucker, and roundtail chub movements

Movement patterns and home ranges of fishes in desert rivers of the southwestern United States are poorly understood (Bestgen et al. 1987). Most studies have focused on temporal patterns of large-river fishes moving in and out of tributary streams. Sampling during the spring of 2002 suggested that bluehead suckers and flannelmouth suckers ascended Muddy Creek from the Little Snake River to spawn (Beatty 2005). Minckley and Holden (1980) stated that flannelmouth suckers typically inhabit pools and deeper runs and often enter mouths of small tributaries. Flannelmouth suckers have also been shown to enter the Paria River and Bright Angel Creek from the Colorado River to spawn

in early spring (Weiss et al. 1998). Movements of flannelmouth suckers into the Little Colorado River resulted in high numbers being caught in either mid-summer or early autumn (Douglas and Marsh 1998). Flannelmouth suckers in the Yampa River are known to congregate and spawn at the upstream ends of cobble bars (McAda and Wydoski 1985).

Chart and Bergersen (1992) examined the impact of Taylor Draw Dam on movements and distribution of flannelmouth suckers in the White River, Colorado. They studied movements while the river was free-flowing and after impoundment. Flannelmouth suckers in the White River were generally mobile as more fish moved than were sedentary. Before impoundment, the flannelmouth suckers that moved did so randomly. Movements seemed to be related to fish length, with individuals of 300–400 mm TL exhibiting the greatest net movements. They hypothesized that larger (> 400 mm TL) sexually mature fish established smaller home ranges. After impoundment, there was a general increase in average net movement and movements appeared more directed. These movements may have occurred as fish left newly created lentic habitat and tailrace areas in response to reduced water temperatures. Some tagged fish were recaptured within the immediate vicinity of their original capture, and the majority of the recaptured fish were over 400 mm TL, reflecting the sedentary nature of larger individuals. The study concluded that Taylor Draw Dam did not impact the flannelmouth sucker population as a barrier to fish migrations because movements were generally random prior to impoundment (Chart 1987). Flannelmouth suckers in the Colorado River at Lee's Ferry exhibited similar movement patterns as in the White River. Forty-one percent of recaptures at Lee's Ferry were tagged between 98 and 231 km downriver;

however, 53% of recaptured fish were sedentary (McKinney et al. 1999). Flannelmouth suckers aggregated below the impoundments in both studies, indicating a blockage of migration routes (Chart and Bergerson 1992; Holden 1991; McKinney et al. 1999).

Few studies have addressed movements of juvenile or adult bluehead suckers or roundtail chubs. Radio-tagged bluehead suckers exhibited downstream movements up to 35 km, but averaged less than 10 km in the Green River (Cavalli 2000). In the Colorado River near Grand Junction, Colorado, Beyers et al. (2001) found bluehead suckers made small, localized movements during the night and day. Roundtail chubs at the Black Rocks area of the Colorado River moved extensively during the spawning season and had a mean maximum displacement of 34 km (Kaeding et al. 1990). In Aravaipa Creek, Arizona, roundtail chubs resided in valley reaches in the summer and moved into canyon reaches in the winter (Siebert 1980). Other studies reported that roundtail chubs were relatively sedentary (Bestgen et al. 1987; Beyers et al. 2001).

Status of bluehead suckers, flannelmouth suckers, and roundtail chubs in the upper CRB

The CRB covers about 632,000 km^2 of the most arid terrain in western North America encompassing portions of seven states and Mexico (Bezzerides and Bestgen 2002, Douglas and Marsh 1998). Thieme et al. (2001) stated that the Colorado River is one of the largest desert rivers in the world and one of the most hydrologically modified. The hydrograph is dominated by snowmelt-runoff in spring, followed by periods of low flow from late summer through winter, but rain events can create short-duration floods throughout the year (Carothers and Brown 1991). High salinity and fine sediment transport are common in the CRB. These harsh river characteristics have led to the

evolution of a unique group of endemic fishes (Ono et al. 1983). Morphological characteristics of these fishes include streamlined bodies, leathery skins, humped or keeled dorsal surfaces, and large fins.

Human-induced changes have limited the effectiveness of morphologic and life-history adaptations that allowed native fishes to thrive in harsh, fluctuating environments (Bezzerides and Bestgen 2002). Approximately 140 dams and water diversion structures are present on the major rivers and tributaries throughout the CRB (Bishop and Porcella 1980). Effects of barriers may include alteration of habitat, modification of the natural hydrograph and temperature characteristics, fragmentation of fish populations, and prevention of upstream and downstream movements to spawning, rearing, and over-wintering habitat (Martinez et al. 1994; Burdick 1995; Anderson 1997).

The big-river fishes of the CRB have declined due to human activities. Bonytail *Gila elegans*, humpback chub *Gila cypha*, Colorado pikeminnow *Ptychocheilus lucius*, and razorback sucker *Xyrauchen texanus* are federally endangered species. A recent status review by Bezzerides and Bestgen (2002) found that bluehead suckers occupy only 45%, flannelmouth suckers occupy 50%, and roundtail chubs occupy approximately 55% of their historical habitats.

Colorado River Basin fishes in Wyoming

The CRB encompasses 17% (40,000 km^2) of the land area of Wyoming. The two major CRB watersheds in the state are the Little Snake River and Green River drainages. Baxter and Stone (1995) reported that there are 11 native fishes of the CRB in Wyoming. Four of these species usually occur in cold-water systems and the remaining seven are

classified as warm-water, riverine species. The warm-water species include bluehead sucker, flannelmouth sucker, razorback sucker, bonytail, humpback chub, roundtail chub, and Colorado pikeminnow. Bonytail, humpback chub, Colorado pikeminnow, and razorback sucker have probably been extirpated from Wyoming as the result of impoundments, habitat alterations, introduction of exotic fishes, and chemical treatment of the Green River watershed prior to construction of Flaming Gorge Reservoir (Bosley 1960; Baxter and Stone 1995). In 1990, a female Colorado pikeminnow was collected in the Little Snake River, but the species' occurrence in Wyoming is exceedingly rare (Marsh et al. 1991). Bluehead suckers, flannelmouth suckers, and roundtail chubs are found in the Green River and Little Snake River drainages but they are species of concern throughout their native distribution.

Colorado River Basin fishes in the Green River drainage of Wyoming

Bluehead suckers, flannelmouth suckers, and roundtail chubs were once widespread throughout the Green River drainage, a main contributor (flow and area) to the Colorado River. Since 1965, these fishes have experienced dramatic declines in both abundance and distribution (Wheeler 1997).

Flannelmouth suckers have the widest distribution of these three native fishes in Wyoming. A large-scale distribution study conducted by WGFD from 2003 to 2006 revealed the presence of flannelmouth suckers in the Green River upstream and downstream of Fontenelle Reservoir and its tributaries, including the Big Sandy and Little Sandy rivers, Bitter Creek, Blacks Fork River, Hams Fork River, Henrys Fork River, Muddy Creek, New Fork River, Sage Creek, and Smiths Fork River (Gill et al.

2004, 2005; Kern et al. 2006, 2007). The only population of flannelmouth suckers that does not occur in sympatry with white suckers is thought to be in the headwaters of Bitter Creek. There, intermittent downstream segments and a road crossing likely act as barriers preventing upstream invasions by exotic species, particularly white suckers. Flannelmouth suckers also occupy lentic habitats including Big Sandy Reservoir, Burnt Lake, Eden Valley Reservoir, Flaming Gorge Reservoir, Fontenelle Reservoir, Freemont Lake, Halfmoon Lake, Little Halfmoon Lake, and Willow Lake (Craig Amadio and Pete Cavalli, WGFD, personal communication).

The WGFD study found that bluehead suckers occupy relatively few water bodies in the Green River drainage. The only suspected genetically pure population occurred in Ringdahl Reservoir, within the Henrys Fork drainage. This population was relocated to Kemmerer City Reservoir, Murray Reservoir, and Fairgrounds Pond 2 in Rock Springs because Ringdahl Reservoir was drained in 2006. Other populations co-exist with white suckers and are restricted to isolated reaches on the Big Sandy River upstream of Big Sandy Reservoir and the Little Sandy River upstream of the Eden diversion structure near Pinedale. Bluehead suckers were collected in the Green River downstream of Fontenelle Reservoir, Blacks Fork River, and Henrys Fork River (Gill et al. 2004, 2005; Kern et al. 2006, 2007).

Roundtail chubs in the Green River drainage, Wyoming, were restricted to the Blacks Fork River and Hams Fork River (Gill et al. 2004, 2005; Kern et al. 2006, 2007). Burnt Lake, Freemont Lake, Halfmoon Lake, Little Halfmoon Lake, and Willow Lake also support roundtail chubs (Pete Cavalli, WGFD, personal communication). Both lotic and lentic populations appeared to have low abundances.

Colorado River Basin fishes in the Little Snake River drainage of Colorado and Wyoming

The Little Snake River drainage in Wyoming is smaller in land area than the Green River drainage and contributes less flow to the CRB, but is an important source of sediment. The Little Snake River is relatively unimpacted by water development, and its flow dynamics and habitat characteristics are relatively natural. The effects of harsh, natural hydrologic conditions on the fish community are unknown but potentially important given the relatively low abundance of non-native fish species and occurrence of endangered fish in the Little Snake River drainage. Sampling within the Little Snake River drainage in 1994 and 1995 revealed a fish assemblage dominated by native fishes. In the Little Snake River of Colorado, 69% (4,290 fish) sampled in 1994 and 72% (11,370 fish) sampled in 1995 were native species (Hawkins et al. 1997, 2001; Hawkins and O'Brien 2001).

Within the Little Snake River drainage of Wyoming, bluehead suckers have been collected in Littlefield Creek, McKinney Creek, Muddy Creek, Grove Creek, and Savery Creek (Bower 2000; Gill et al. 2004, 2005; Kern et al. 2006, 2007). Flannelmouth suckers have been found in the Little Snake River, Littlefield Creek, McKinney Creek, Muddy Creek, Savery Creek, and Wild Cow Creek. Roundtail chub have been collected in the Little Snake River, Littlefield Creek, McKinney Creek, and Muddy Creek. Littlefield and McKinney creeks are tributaries of Muddy Creek in the upper portion of the watershed. Besides bluehead suckers in the Little Sandy River, it is likely the Little Snake River drainage had the highest densities of roundtail chubs and bluehead suckers in Wyoming.

Bower (2000) conducted the first intensive fish sampling in the Muddy Creek watershed during 1999 and 2000. Like the Little Snake River, the upper portion of Muddy Creek watershed maintains relatively natural flow dynamics, but an artificially created wetland complex has altered the flow dynamics in the lower portion of the watershed. Sampling in 1999 and 2004 confirmed that bluehead suckers, flannelmouth suckers, and roundtail chubs were present in the system, but non-native fishes (creek chub *Semotilus atromaculatus*, fathead minnow *Pimpephales promelas*, and white sucker) dominated the lower watershed (Beatty 2005). However, reaches upstream of a headcut stabilization structure (Figure 1) on the upper portion of the watershed were dominated by native fishes including bluehead suckers, flannelmouth suckers, roundtail chubs, and speckled dace.

Although upper Muddy Creek supports sympatric populations of the three native fishes, it is not void of fragmentation, habitat alteration, water development, or non-native fish issues. Upper Muddy Creek is essentially an isolated headwater stream system. The artificial wetland complex located 78-84 km upstream from the confluence of Muddy Creek with the Little Snake River and the headcut stabilization structure located 16 km upstream of the wetland complex prevent upstream fish movements between the Little Snake River and the upper portion of Muddy Creek (Beatty 2005). Within the isolated upstream system, fish populations may be fragmented by additional instream structures, habitat has been altered by grade-control structures (e.g., gully plugs), water is diverted for irrigation, and non-native white suckers and creek chubs are abundant.

The BLM and WGFD funded this project to investigate the effects of instream structures and white suckers on bluehead suckers, flannelmouth suckers, and roundtail chubs in upper Muddy Creek.

Objectives

My objectives were to:

(1) Evaluate upstream and downstream movements of bluehead suckers, flannelmouth suckers, and roundtail chubs over three instream structures from fall 2004 through October 2006;

(2) Describe the population characteristics of the target species by estimating abundances, age structures, and length frequencies in three segments formed by the instream structures;

(3) Investigate the influences of white suckers on the native bluehead suckers and flannelmouth suckers in the study area; and

(4) Assess the potential viability of the three target species throughout the upper Muddy Creek watershed using information from this research and other studies.

To accomplish these objectives, upstream and downstream movements and fragmentation were evaluated and population characteristic data were collected in 2005 and 2006.

Methods

Study Area

Research was conducted on Muddy Creek, a major tributary of the Little Snake River, and McKinney Creek, a tributary of Muddy Creek, in south-central Wyoming (Figure 1). Muddy Creek originates in the foothills of the Sierra Madre at about 2,450 m in elevation. The watershed area is 2470 km^2 and the stream length is 112 km (Goertler 1992). Muddy Creek flows onto a high-elevation, relatively treeless, cold-desert region and transitions into a low-gradient, warm-water stream. Muddy Creek's confluence with the Little Snake River is near Baggs, Wyoming. There is little riparian canopy cover, but willow *Salix* spp., mountain alder *Alnus tenuifolia*, and Utah juniper *Juniperus osteoperma* are present and provide some riparian shading. The prevailing vegetative community in this erosive landscape is composed of desert shrubs and sagebrush grasslands. Grazing is the primary land use (Hawkins and O'Brien 2001), but oil and gas production is increasing in the area.

The hydrograph of Muddy Creek is dominated by snowmelt runoff from early April through early June, followed by periods of low base flow or no flow during summer. Segments of Muddy Creek often become intermittent during dry years, restricting stream biota to isolated pools. The geology, climate, and vegetation of the drainage contribute to elevated loads of fine sediments during periods of high flow, making Muddy Creek the major contributor of sediment to the Little Snake River. This natural sediment load from upper and lower Muddy Creek and its tributaries is critical to

the CRB, as it helps maintain sediment dynamics and nursery habitat for endangered fishes in the alluvial reaches of the Green River (Hawkins and O'Brien 2001).

The upstream boundary of the study area on McKinney Creek was 12.2 km upstream of its confluence with Muddy Creek. The upstream boundary on Muddy Creek was a culvert at the BLM Road 3304 crossing that prevented upstream movements by fish and the downstream boundary of the study area was an irrigation head gate at the upstream end of the George Dew wetland complex. The length of Muddy Creek within the study area was approximately 80 km and the elevation range was 2,115 to 2,225 m.

Landscape features influenced the structure of the river channel and riverine habitat throughout the study area. The upper portion of Muddy Creek, from the upstream end of the study area down to the confluence of McKinney Creek, had low-gradient, meandering reaches with perennial flow that pass through grass meadows and small hills (segment 4; Figure 1). Riffles, runs, and pools were present, and substrate ranged from clay to cobble. Nine grade control structures, termed gully plugs, were installed to reduce stream incision and have altered the habitat in this segment (Figure 2). Water velocity was reduced and fine sediment has accumulated covering rock substrates in pools created by individual gully plugs. McKinney Creek, an ephemeral tributary of Muddy Creek, shared a similar morphology with the uppermost portion of Muddy Creek, but it also had a noteworthy abundance of uncompacted gravel riffles and lacked gully plugs (segment 5; Figure 1).

The middle portion of upper Muddy Creek was bounded upstream by the confluence of McKinney Creek and downstream by Sulfur Springs (segment 3 and the upstream portion of segment 2; Figure 1). This portion experienced perennial flow,

passed through a canyon, and had the highest overall stream gradient in the study area. Riffle, run, and pool complexes were present, and substrate ranged from clay to boulders. This segment contained the highest densities of hard substrates and deep pools, as well as spring seeps that contributed water from north facing sand hills.

The lowest portion began at the downstream end of the canyon near Sulfur Springs and meandered through rolling hills and sage brush flats to the downstream end of the study area (the downstream portion of segment 2 and segment 1; Figure 1). This low-gradient portion had intermittent flow and contained riffles, long runs, and pools. Substrate ranged from clay to boulders, but silt and sand were most common.

Within the study area there were three major human-made structures and several of the nine gully plugs that likely impede upstream fish movements (Figure 1). The most upstream of the major human-made structures was on Muddy Creek, just upstream of the confluence with McKinney Creek. This rock gabion structure was constructed as a barrier to prevent upstream movements by fish (Figure 3). It was installed in 1992 as part of a Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* restoration project in the headwater portion of the watershed. The second major structure, an irrigation diversion dam near the downstream end of the canyon, was 10.2 km downstream from the confluence of Muddy and McKinney creeks and was rebuilt in 2000 (Figure 4). Diverted water was used to irrigate an adjacent hay field. A headcut stabilization structure, constructed in 2002, was the third and most downstream structure and was 6 km upstream of Wyoming State Highway 789 (Figure 5). Coordinates of these instream structures are reported in Appendix A.

The study area was stratified into five study segments (Figure 1). The most downstream segment, segment one, began at an irrigation headgate just upstream from the George Dew wetland complex and ended at the headcut stabilization structure. Segment two was bounded at the downstream end by the headcut stabilization structure and at the upstream end by the irrigation diversion dam. Segment three was between the irrigation diversion dam and the fish barrier. Segment four extended from the fish barrier upstream to the culvert under BLM Road 3304. Segment five was McKinney Creek from its confluence with Muddy Creek upstream 12.2 km.

Fish movements and fragmentation

Passive integrated transponder (PIT) tag technology was used to assess upstream and downstream movements over instream structures, as well as fragmentation of bluehead sucker, flannelmouth sucker, and roundtail chub populations in the Muddy Creek study area.

Fish were captured by electrofishing and tagged in fall of 2004 during a period of cool water temperatures (<10 ^{o}C). Bluehead suckers, flannelmouth suckers, and roundtail chubs were tagged at several localities in segments two, three, and four, while white suckers were only tagged in segment four. Fish greater than or equal to 92 mm TL were tagged with half-duplex tags (23.1 mm long, 3.9 mm in diameter, weighing 0.6 g in air, and manufactured by Texas Instruments). Fish were individually anesthetized with a clove oil solution, 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 non-absorbable surgical suture. Chlorhexidine was used to sterilize tags, sutures, and all

surgical instruments. The PIT tagging and surgical technique followed the procedures outlined by Roussel et al. (2000). Table 1 identifies the number of fish tagged of each species and their mean total lengths.

Five passive monitoring stations were installed in Muddy Creek during April and May of 2005 and operated through August 2005 (Table 2). One station was placed immediately downstream from each of the three major instream structures; a forth was placed in segment two near the downstream end of the perennial flowing section of the creek; and a fifth station was placed in McKinney Creek, approximately 200 m upstream from its confluence with Muddy Creek (Figure 1). Once a station was installed, tagged fish were identified as they passed through the antenna loop. Data were retrieved and batteries were changed weekly. This system did not differentiate upstream or downstream movement. All five stations, excluding the station in the perennial flow section in Muddy Creek in segment two, were re-installed in April and May of 2006 and operated through October 2006 (Table 2).

The antenna configuration of the monitoring stations is shown in Figure 6. Antennas were constructed as open-coil inductor loops with 8-gauge multi-strand wire passed through 2.5-cm-diameter PVC pipe on the stream bed and suspended over the water with the support of aircraft 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 Amp hours per battery) connected in parallel. A palmtop computer received data output from the readers and displayed individual tag identification, date, and time of detection. Weather-proof reader boxes and batteries were placed in vertical culverts outside of the immediate flood zone

and locked to prevent theft. Once data were collected, they were converted to Microsoft Excel files for analysis.

The PIT tag detection efficiencies of the five stations were tested in two ways. First, prior to weekly data retrieval at each monitoring station, a PIT tag attached parallel to a wooden stake was passed though the antenna at six evenly-spaced distances perpendicular to the stream bank. The wooden stake was also manually submerged and passed through the antenna approximately 10 cm from the bottom of the stream bed at six evenly-spaced localities. This small-scale detection process was again conducted after data retrieval. Second, after each station was installed, a thorough, large-scale detection test was completed. A wooden stake with an attached PIT tag was passed though each antenna at 50-cm intervals across the river on a horizontal plane as well as 50-cm intervals on a vertical plane. The stake was passed through twice at each locality, parallel to the antenna on the first pass and perpendicular to the antenna on the second pass.

The PIT tag detection frequencies from the small-scale and large-scale tests were used to estimate "capture probabilities" of PIT tagged fish that pass through the antennas as described by Zydlewski et al. (2006). In situ efficiency ($E_{in\ situ}$) was calculated for each antenna. In situ efficiency was the ratio of fish detected at an antenna to the number of fish known to have passed through an antenna. $E_{in\ situ}$ was the product of (1) path efficiency (E_{path}), the probability a fish passed through an antenna, and (2) antenna efficiency ($E_{antenna}$), the probability the antenna successfully detects and decodes the tag: $E_{in\ situ} = E_{path} \times E_{antenna}$.

In addition to obtaining movement information via the passive monitoring stations, fish were sampled in the study area during the summer of 2005 to recover tagged

fish. Sampling was conducted using a gasoline powered backpack electrofisher and a systematic sampling design. Twelve evenly spaced 400-m reaches in each of segments one, three, four, and five and 13 reaches in segment two, were sampled by a single pass in an upstream direction. Downstream coordinates for each reach (Appendix B) were generated using ArcGIS version 9.0. All reaches were paired by closest proximity because two reaches were completed per day. The chronological order in which paired reaches were sampled was randomly generated to eliminate spatial or temporal sampling bias. Each 400-m reach was measured using a tape measure and sub-divided into 100-m units.

Sampling occurred in 100-m units within each reach and fish larger than young-of-year were collected. These fish, excluding speckled dace, were identified to species or as catostomid hybrids, measured to the nearest millimeter (TL), and examined for a PIT tagging scar. The PIT tagged fish were visible by an identifiable surgical scar, and the tag number was detected by scanning the fish with a hand held PIT tag detection wand. All fish were returned to the 100-m unit where they were captured. Hybrid catostomids were identified based on intermediate morphologies identified by Baxter and Stone (1995) and Bower (2005). The morphological characteristics observed were coloration, scale pattern, dorsal fin shape, caudle peduncle depth, and mouth morphology. Upon recapture, locations of PIT tagged fish were recorded (UTM projection, NAD 83, Zone 13) using a Garmin Model GPS 12 XL with 15 m root mean square accuracy. In addition to the pre-determined 400-m reaches, all tagging localities, areas above and below each instream structure, and areas containing preferred habitat (i.e., deep pools) were also

sampled. Capture locality, date, and PIT tag number were entered into a database to track fish movements.

The lengths of fish PIT tagged in 2004 were compared to the lengths of PIT tagged fish that were recaptured and moved among the study area segments. Chi-square tests were used to determine if the proportions of tagged juvenile and adults differed from proportions that moved for each species (Ramsey and Schafer 2002).

Abundance estimates

Estimates of abundance of fishes greater than 100 mm TL were made in three segments of Muddy Creek during the summer of 2006. A 100-mm TL threshold was used because catostomids are generally identifiable to species and are recruited into the sampling gear at this length. Estimates were computed for the upper 5 km of segment two, all of segment three, and the lower 5 km of segment four. Total length of segment two was reduced in 2006 (Figure 1) in order to sample the upper portion known to have perennial flow, and segment four was reduced to the portion downstream of a 2006 rotenone treatment performed by WGFD and BLM.

A random sampling design was used to select reaches in segments two (Figure 7) and three (Figure 8), and a stratified random sampling design was used to select reaches in segment four (Figure 9). All reaches were 200 m in length. Fifteen, 30, and 12 reaches were selected in segments two, three, and four, respectively. Segment four was stratified into natural and altered habitat types to determine if fish abundance differed between the two habitat types. Altered habitat occurred upstream of gully plugs and was characterized by slow water velocities, high silt deposition, and abundant aquatic

vegetation. Natural habitat was characterized by visible current and no noticeable siltation. Altered and natural habitats were mapped in May 2006 by walking the entire segment. The GPS points were recorded every 3 seconds and line features of the two habitat types were recorded into a Pathfinder Office 2.90 data dictionary using a Trimble GeoXT handheld GPS unit (1-5 root mean square accuracy). The spatial data was downloaded into ArcGIS 9.0, and total length of each habitat type was calculated. Reaches within segment four were randomly selected in each habitat type and the number of reaches selected in each habitat type was proportional to the total length of each type.

Abundance estimates were conducted using a three-pass removal method. An evaluation of the use of removal estimates versus mark-recapture estimates is described in Appendix C. Each reach was closed by placing fine mesh block nets (0.6-cm openings) at the downstream and upstream ends. Electrofishing was conducted by a two-person team (one person operating a gasoline powered Smith-Root backpack electrofishing unit using pulsed DC current and another person netting fish), and constant sampling effort was applied by electrofishing the entire area on each pass. After each electrofishing pass, bluehead suckers, flannelmouth suckers, white suckers, catostomid hybrids, and roundtail chubs were counted and measured. Fish from each pass were temporarily retained until all passes were completed, after which native fishes were released back into the reach while white suckers and catostomid hybrids were removed.

Abundance estimates were calculated for bluehead suckers, flannelmouth suckers, white suckers, catostomid hybrids, and roundtail chubs over 100 mm TL. Program CAPTURE (White et al. 1982) was used to compute abundance estimates and standard errors for individual reaches with a generalized jackknife modification of model M_{bh}

developed by Pollock and Otto (1983), which accounts for varying capture probability of individual animals and behavioral response to first capture. 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:

$$\hat{N} = \frac{\text{Segment length}}{\text{Length sampled}} \times \sum \hat{N} \text{ of reaches sampled}$$

Standard errors were estimated for each segment by:

$$\hat{SE} = \frac{\text{Segment length}}{\text{Length sampled}} \times \sqrt{\sum SE^2}$$

Age structure

Age and growth of the three native fish species in segment three were investigated. Bluehead suckers, flannelmouth suckers, and roundtail chubs greater than 100 mm TL were sampled by electrofishing in mid-June 2006 after spawning movements had probably ceased based on temporal movements observed in McKinney Creek in 2005 (Figure 10). A goal of collecting 200 fish of each species was established. The first 20 fish of each species captured within a 200-m reach were collected for aging. Fin rays were used to estimate ages because they provide ages similar to otoliths (Quist et al. in press) and could be obtained without sacrificing fish. Each fish was measured and the left pectoral fin was removed by cutting the fin where it met the body. Fins were dried in paper envelopes, embedded in epoxy, and sectioned (0.3-0.6 mm thick) using a low speed

isomet saw as detailed by Koch and Quist (in press). Sectioned fin rays were examined using a stereoscope with transmitted light.

Three independent readers were used to estimate age. The first and second readings were completed by two different people. If agreement occurred between the two readers, the age was recorded. If agreement was not achieved between the two readers, a third person estimated age. The recorded age was the one that agreed between the third reader and either the first or second reader or the median age if three different ages were observed.

Length at sexual maturity

All bluehead suckers, flannelmouth suckers, and roundtail chubs electrofished in 2005 and 2006 were examined for reproductive condition. Fish were inspected for tuberculation, gamete expression, and spawning coloration. Total lengths were recorded for all fish exhibiting any of these characteristics and were used to describe the range of lengths of adult fish.

The estimated number of adult fish in each segment was derived by dividing the number of collected fish into juvenile and adult groups based on observed lengths of sexually mature fish. The proportion of each group to the total number of collected fish greater than 100 mm TL was multiplied by the abundance estimate for each species in each segment. A 150-mm TL threshold was used to separate juvenile and adult bluehead suckers and roundtail chubs, and a 250-mm TL threshold was used to separate juvenile and adult flannelmouth suckers following Bower (2005). Observations of fish with

reproductive conditions during my study were used to verify that these thresholds were approximately valid.

Reproduction

All bluehead suckers, flannelmouth suckers, and roundtail chubs of 41-100 mm (excluded larvae) sampled by electrofishing in reaches during 2005 and 2006 were to the nearest millimeter. Larvae were collected in McKinney Creek on July 11, 2005 to determine which species were spawning and producing larvae within the creek. Approximately 100 m of McKinney Creek was walked and larvae were netted with fine mesh dip nets. Specimens were preserved in a 10% buffered formalin solution. Fish were identified to species using the Snyder and Muth (2004) computer interactive key to the Catostomidae of the Upper Colorado River Basin and measured to the nearest millimeter (TL). Preserved fish were curated at the Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

Results

Antenna efficiency

In situ antenna efficiencies were calculated by multiplying path efficiency by antenna efficiency (Table 3). Path efficiency (the probability a fish will pass through an antenna) was estimated to be 1.0 because antennas were positioned on top of the stream substrate and suspended above the water, therefore all fish would have passed through the antenna arrays. Individual antenna efficiencies were calculated by summing both small-

scale tests and the large-scale test. In situ efficiency results were 1.0 for stations one, two, and five, 0.90 for station three, and 0.98 for station four. All but seven PIT tags were detected during small-scale tests (3,377 out of 3,384 tag passes), and 109 tags were not detected during large-scale tests (679 out of 788). Most tags passed parallel to the antenna went undetected at station three (Table 3). In 2005, the antenna in McKinney Creek was functional at a minimum of 76% of the time it was installed, and the antenna downstream of the irrigation diversion dam was functional at a minimum of 98% of the time, representing the lowest and highest percentages of the five antennas. In 2006, the antenna in McKinney Creek was functional a minimum of 58% of the time it was installed, and the antenna downstream of the fish barrier was functional at a minimum of 89% of the time (Appendix D).

Fish movements

A total of 1,395 bluehead suckers, flannelmouth suckers, and roundtail chubs were implanted with PIT tags in segments two, three, and four in 2004 (Table 1) and movements were recorded in 2005 and 2006. Downstream movements of PIT tagged fish over the headcut stabilization structure, irrigation diversion dam, and the fish barrier and upstream movements of tagged fish over the irrigation diversion dam and into McKinney Creek were noted (Appendices E – H).

Of fish tagged upstream of the headcut stabilization structure in segment two, 27 bluehead suckers and one flannelmouth sucker were observed in segment one, downstream of the structure (Table 4). Twenty-one of these bluehead suckers were observed in segment one in 2005, and six more were observed in 2006 (10.5% of

bluehead suckers tagged in segment two). One of three flannelmouth suckers tagged in segment two was observed in segment one in 2005. All fishes observed in segment one were scanned at the antenna downstream of the headcut stabilization structure (Table 4).

The three species were tagged near the downstream end of segment two. Bluehead sucker was the only species observed to move from the downstream end of segment two upstream to the antenna below the irrigation diversion dam (2 fish) in segment two (Table 5) or above the irrigation diversion dam into segment three (1 fish; Table 4). Electrofishing efforts in 2005 and 2006 recovered 34 bluehead suckers, one flannelmouth sucker, and 10 roundtail chubs within segment two that had been tagged in the segment (Table 5).

Most (891 fish) of the three species were tagged in segment three (Table 1). Bluehead suckers tagged in segment three were recaptured by electrofishing in the segment, detected at antennas below the headcut stabilization structure in segment one, the irrigation diversion dam in segment two, the fish barrier in segment three, and in McKinney Creek (segment five; Tables 6 and 7). Twenty-eight bluehead suckers in 2005 and eight in 2006 moved downstream into segment two. Of 36 fish that moved downstream into segment two over the irrigation diversion dam, eight returned upstream in segment three. One bluehead sucker was detected in segment one in both 2005 and 2006. Of the bluehead suckers tagged in segment three, 122 were observed in 2005, 54 were observed in 2006, and 40 of these fish were recorded both years in McKinney Creek (Table 8).

Seventy flannelmouth suckers were tagged in segment three. Of these, two were scanned by the antennas in segment two and 25 were recaptured by electrofishing in

segment three or detected at the antenna in McKinney Creek (segment five, Tables 7 and 8). No flannelmouth suckers were detected at the antenna below the fish barrier. Of 21 fish detected in McKinney Creek, six were recorded both years (Table 8).

Of 248 roundtail chubs tagged in segment three, 85 fish were recaptured by electrofishing in segment three, detected at the antenna below the fish barrier in segment three, or observed in McKinney Creek (segment 5, Table 7). Twenty-four were observed downstream over the irrigation diversion dam in segment two in 2005, and eight of these fish moved back into segment three (Table 6). Sixty-two tagged roundtail chubs were detected in McKinney Creek in 2005 or 2006, and 17 of those fish were detected both years (Table 8).

Among the fish tagged in segment four, both bluehead suckers and roundtail chubs were later observed downstream of the fish barrier. Of 79 bluehead suckers tagged above the fish barrier, three were observed in segment three and 13 were observed in segment four (Table 9). All three fish that moved over the fish barrier into segment three were later observed in McKinney Creek in 2005, and one of these fish returned to McKinney Creek in 2006 (Table 8). Only three flannelmouth suckers were tagged in segment four, and two were recaptured within the segment (Table 6). Among 82 roundtail chubs tagged in segment four, three fish were detected at the antenna below the fish barrier in segment three and 26 fish were recaptured by electrofishing in segment four (Table 10).

Electrofishing recaptured fish that remained within their respective tagging segments. Tagged fish in every segment were recaptured near their original tagging localities and several were recaptured in the same pools where they were tagged. Of 40

fish recaptured in segment two, 38 fish were recaptured by electrofishing and two were detected at a passive monitoring station (Tables 4 and 5). Five bluehead suckers and one roundtail chub were collected in the same perennial pool where they were tagged.

Temporal patterns of tagged bluehead suckers, flannelmouth suckers, and roundtail chubs were observed at the antenna in McKinney Creek. All three species were detected on May 5, 2005, the day after the station was installed, and on May 1, 2006, the day the station was re-installed (Table 2). In 2005, the maximum number of bluehead suckers scanned per day (15 fish) occurred on June 20, the maximum number of flannelmouth suckers scanned per day (3 fish) occurred on May 10, 11, and 12, and the maximum number of roundtail chubs scanned per day (8 fish) occurred on June 5. Fish continued to pass through the antenna into mid-July but then detections became infrequent (Figure 10). In 2006, the maximum number of bluehead suckers scanned per day (11 fish) occurred on June 1, the maximum number of flannelmouth suckers scanned per day (2 fish) occurred on May 14 and 19, and the maximum number of roundtail chubs scanned per day (8 fish) occurred on May 31. Fish continued to pass through the antenna into late June but then detections became infrequent (Figure 11). McKinney Creek did not become intermittent in 2005, but became intermittent July 20–25, 2006. Flow returned to McKinney Creek by September 14, 2006, and roundtail chubs were detected by the antenna on September 23, 25, and 28 (Figure 11, Table 11).

Comparisons of proportions of juveniles and adults tagged in 2004 to the proportions of tagged fish that either moved out of a tagging segment or downstream of a tagging segment revealed that there were no significant differences for bluehead suckers or flannelmouth suckers, but a significantly higher proportion of adult roundtail chubs

moved (Table 12). The proportion of adults of the three species that moved into McKinney Creek from segment three was significantly higher than the proportions of adults that were tagged in segment three (Table 13).

Population characteristics

Population dynamics of the three target species in upper Muddy Creek were examined using length frequency histograms, length ranges of fish exhibiting sexual characteristics, abundance estimates, age structures, and recruitment indices.

Length frequency histograms - In 2005, 61 400-m reaches were sampled among the five study segments in Muddy and McKinney creeks (Appendix B). The highest frequency of small bluehead suckers of 41-100 mm TL occurred in McKinney Creek (segment five). This length class was also found in segments one, two, and three, but it was nearly absent in segment four above the fish barrier. Bluehead suckers greater than 100 mm TL had the highest frequencies in segment three, followed by segment two (Figure 12). Small flannelmouth suckers of 41-100 mm TL were most frequent in segment five, found in segments two and three, and nearly absent in segments one and four. Segment three had the highest frequency of flannelmouth suckers greater than 100 mm TL with a large number of 300-420 mm TL fish (Figure 13). Small roundtail chubs of 41-100 mm TL were present in segments one, two, three, and five, but nearly absent in segment four, with the highest frequencies in segment two and three. Roundtail chubs greater than 100 mm TL had the highest frequency of occurrence in segment three, followed by segment two, and all 10-mm length classes were represented up to 310 mm

TL in both segments. Fish greater than 160 mm TL were rare in segments one and five (Figure 14).

In 2006, 52 200-m reaches were sampled in the upstream portion of segment two, along the entire length of segment three, and in a downstream portion of segment four. The highest frequencies of 41-100 mm TL fish of all three species occurred in segment three, but they were rare in segment four. Bluehead suckers of every 10-mm length class were found in segment three, except for the 281-290 mm TL class (Figure 15). Flannelmouth suckers had the highest frequencies of 41-100 mm TL and greater than 100 mm TL in segment three, whereas segment four had an extremely low occurrence of all length classes (Figure 16). Roundtail chubs were the most common of the target species. A total of 1,040 roundtail chubs 41-100 mm TL were sampled in segment three, compared to 195 in segment two and nine in segment four. The lowest frequency of roundtail chubs greater than 100 mm TL occurred in segment four (Figure 17).

Lengths of sexually mature fish - The minimum total lengths of fish displaying visual signs of sexual maturity were 133 mm TL for bluehead suckers (Figure 18), 251 mm TL for flannelmouth suckers (Figure 19), and 142 mm TL for roundtail chubs (Figure 20). These observations tended to validate the use of a 150 mm TL threshold for bluehead suckers and roundtail chubs and 250 mm TL threshold for flannelmouth suckers when identifying fish as sexually mature in Muddy Creek.

The majority of roundtail chubs and bluehead suckers in reproductive condition were collected in segment three in early June of 2005. Groups of up to 20 adults were sampled in riffles approximately 0.3 m deep. The fish were all in close proximity of one another, showed spawning characteristics, and expressed gametes.

Abundance estimates - Abundances of bluehead suckers, flannelmouth suckers, and roundtail chubs were estimated. Twelve reaches (46% of the total segment length) in segment two and 25 reaches (52% of the total segment length) in segment three were randomly sampled beginning June 13, 2006. In segment four, 12 reaches (58%) of the natural habitat stratum and three reaches (28%) of the altered habitat stratum were sampled, resulting in a sampling of 48% of the length of the segment (Table 14).

Individual reach abundance estimates (Tables 15-17) were extrapolated to produce an estimate for each segment (Table 18 and 19). In every segment, estimates were highest for roundtail chubs and lowest for flannelmouth suckers. For every species, estimates were highest in segment three and lowest is segment four. Within the study area, totals of about 1,700 bluehead suckers, 500 flannelmouth suckers, and 2,600 roundtail chubs greater than 100 mm TL were estimated.

Abundance estimates for bluehead suckers resulted in approximately 290 fish (95% confidence interval, 250-328) in segment two, 1,270 fish (95% confidence interval, 1,191-1,347) in segment three, and 140 fish in segment four (95% confidence interval, 117-171). Approximately 110 flannelmouth suckers (95% confidence interval, 84-126) were estimated in segment two, 340 fish (95% confidence interval, 298-372) in segment three, and 40 fish in segment four (95% confidence interval, 19-51). Estimates for roundtail chubs resulted in approximately 450 fish (95% confidence interval, 391-498) in segment two, 1,940 fish (95% confidence interval, 1,826-2,044) in segment three, and 220 fish in segment four (95% confidence interval, 246-293).

The estimated number of reproducing bluehead suckers, flannelmouth suckers, and roundtail chubs varied among the three segments (Table 20). The proportions of

juvenile and adult bluehead suckers, flannelmouth suckers, and roundtail chubs similar in segments two and three, but adults were proportionally higher for all species in segment four. Adult estimates of abundance for the three species were highest in segment three. Totals of 159, 533, and 124 adult bluehead suckers, 43, 164, and 23 flannelmouth suckers, and 222, 871, and 253 were estimated in segments two, three, and four, respectively. In segment three, 42% of the bluehead suckers were adults (≥ 150mm TL), 49% of the flannelmouth suckers were adults (≥ 250mm TL), and 45% of the roundtail chubs were adults (≥ 150mm TL). In segment four, 87% percent of sampled bluehead suckers, 64% of flannelmouth suckers, and 94% of roundtail chubs were adults (Table 19).

Densities (fish/100 m) of bluehead suckers, flannelmouth suckers, and roundtail chubs were highest in segment three and lowest in segment four. In segment three, 18.5 roundtail chubs/100 m were estimated and represented the highest density of any species, whereas 0.5 flannelmouth suckers/100 m were estimated in the natural habitat in segment four and represented the lowest density of any species (Table 18).

In segment four, abundance estimates and densities of bluehead suckers and roundtail chubs were highest in the natural habitat. Flannelmouth sucker abundance and density were low in both habitat types. Natural habitat supported an estimated 129 bluehead suckers (95% confidence interval, 107-151), 21 flannelmouth suckers (95% confidence interval, 21-21), and 217 roundtail chubs (95% confidence interval, 185-249), while altered habitat supported 14 (95% confidence interval, 0-30), 14 (95% confidence interval, 0-30), and 52 (95% confidence interval, 28-75) fish, respectively. Roundtail chub densities in natural habitat were the highest of all three species (Table 18).

Reproduction - Fish of 41-100 mm TL were counted at all sampled reaches in 2005 and 2006 (Appendix I) to identify the spatial distributions and frequencies of this length class (termed juvenile) among all five segments. Bluehead sucker, flannelmouth sucker and roundtail chub juveniles were observed in all five segments, but low frequencies for all three species occurred in segment four during both years (Figures 12-17). Bluehead sucker and roundtail chub juveniles were relatively abundant, but flannelmouth suckers were rare in segment one during 2005. Segment five had high numbers of juveniles of bluehead suckers, flannelmouth suckers, and roundtail chubs. However, low numbers of juvenile bluehead suckers, flannelmouth suckers, and roundtail chubs were found in segment four.

Densities (fish/100 m) were calculated in 2006 from fish sampled in segment two, three, and four to provide a comparative index. Lowest densities of juveniles of all species occurred in segment four, while highest densities occurred in segment three. Among the three species, roundtail chubs were observed at the highest densities followed by bluehead suckers and flannelmouth suckers (Table 21).

Larvae were collected in McKinney Creek on July 11, 2005. Of the 208 identified larvae, 53 bluehead suckers (mean TL=15 mm) and 13 flannelmouth suckers (mean TL=18 mm) were found (Table 22). No roundtail chub larvae were collected.

Age structure – The age structures and length ranges of fish sampled from Muddy Creek in 2005 indicated that aging with fin rays missed the first annulus because estimated mean total lengths did not correspond with length frequency histograms. The original estimated mean total length for age 1 fish from annuli on fin rays was 110 mm TL for bluehead suckers, 120 mm TL for flannelmouth suckers, and 113 mm TL for

roundtail chubs. Age 1 and 2 year classes were apparent in the juvenile length frequency histograms compiled for fish collected in June, July, and August 2005. The first mode in the histogram occurred at 61-75 mm TL and a second mode occurred at 91-155 mm TL for bluehead suckers (Figure 21). The first mode occurred at 66-95 mm TL and a second mode occurred at 101-125 mm TL for flannelmouth suckers (Figure 22). For roundtail chubs, the first mode occurred at 51-80 mm TL and second mode at 76-120 mm TL (Figure 23). The first mode represented in the histograms for all three species likely represents the length ranges of age 1 fish, but the estimated mean total lengths of aged age 1 fish did not fall within the these ranges; therefore one year was added to the aged fish results to compensate for this shortcoming.

A total of 199 bluehead suckers, 141 flannelmouth suckers, and 199 roundtail chubs from segment three were aged. All fish were a minimum of 2 years old. Maximum age for bluehead suckers was 9 years (Table 23, Figure 18), 17 years for flannelmouth suckers (Table 24, Figure 19), and 12 years for roundtail chubs (Table 25, Figure 20). Mean total length at age increased every year for bluehead suckers and roundtail chubs, but increased up to age 9 and varied thereafter for flannelmouth suckers. Noticeable overlap of length ranges and confidence intervals began to occur at ages 8 or 9 for each of the three species.

White sucker influences

White suckers were PIT tagged in segment four (Table 1) and 13 of 47 tagged fish were found in segment three, downstream of the fish barrier, during 2005 (Table 9). Ten of these white suckers moved upstream into McKinney Creek in 2005, and four of

these returned to McKinney Creek in 2006 (Table 10). Temporal patterns of white sucker occurrence at the antenna in McKinney Creek were similar to the two native catostomid species (Figure 10 and 11). White suckers were recorded shortly after antenna installation (May 4, 2005 and May 2, 2006) and the maximum numbers of fish recorded per day occurred on June 23, 2005 (10 fish) and May 14, 2006 (5 fish). Reproduction by white suckers in McKinney Creek was confirmed by collected larvae. A sample taken July 11, 2005 had 142 white sucker larvae (68% of the total catch; Table 22).

Length frequency histograms in 2005 revealed that 41-100 mm TL white suckers were found in all five segments, and the highest frequencies of this length class were collected in segment five. The highest frequency of white suckers greater than100 mm was collected in segment four, but white suckers of 251 mm TL or greater were most frequently captured in segment three (Figure 24).

White suckers (≥ 100 mm TL) were the most abundant taxa in 2006 with a total of 3,585 fish estimated (95% confidence interval, 3,454-3716; Table 18 and Table 19). Densities of white suckers were greatest in segment four, with 30 fish/100 m in natural habitat and 46 fish/100 m in altered habitat. Of the 858 white suckers collected in segment four, 85% were 101-200 mm TL (Figure 25).

Morphological evidence of white sucker hybridization with both flannelmouth suckers and bluehead suckers was observed. The highest densities of hybrids occurred in segment three (4.4 fish/100 m), and it was estimated that 781 hybrids (95% confidence interval, 728-834) resided in the abridged 2006 study area (Figures 25 and 26, Table 18). Of the 334 hybrids sampled in 2006, flannelmouth sucker x white sucker hybrids

accounted for 71% of the sample and they were found throughout the study area. Nineteen percent of the hybrids showed bluehead sucker x flannelmouth sucker x white sucker characteristics and ten percent showed bluehead sucker x white sucker characteristics (Figure 28).

Discussion

Tagging methodology and antenna efficiency

The PIT tagging procedure resulted in high tag retention. Of the PIT tagged fish that were recaptured and handled, only four fish had visible surgical scars but PIT tags were not detected (1.4%). Additionally, two of the four fish had healed wounds near the surgical scars that were likely the result of tag expulsion. In the fall of 2004, Michael Bower and Michael Quist experimentally tagged longnose suckers *Catostomus catostomus*, a surrogate for bluehead suckers and flannelmouth suckers, using the surgical procedure described previously, and the tag retention rate was approximately 95% (unpublished data). PIT tag retention for Colorado pikeminnow and razorback sucker was 97%, and survival after an 18-month period was 100% in a previous study (Burdick and Hamman 1993). Roussel et al. (2000) found that all Atlantic salmon *Salmo salar* PIT tagged over 84 mm TL survived and had a 100% tag retention rate through a 32-d observation period. A laboratory study by Zydlewiski et al. (2001) resulted in 99% survival and tag retention of both hatchery and stream-reared Atlantic salmon.

PIT tag detection efficiencies at the five antennas were high. A small fraction of tags passed parallel to one antenna were not detected during the large-scale detection test, but were detected when an angle of 10-30 degrees was achieved. The likelihood of a fish passing with the PIT tag parallel to the antenna without any angle changes is extremely low; therefore, I assumed high detection capability for all antennas. Previous studies reported high detection efficiencies by PIT tag antennas. Brannas et al. (1994) observed 100% detection in fish passing through antennae, Zydlewski et al. (2001) reported their stationary detection system to be 93 $\pm$ 2% efficient, but stated that tags which passed through the center of the antenna exactly parallel to the antenna plane were not detected. Tag detection problems were also reported when two or more tagged fish were in the antenna loop at the same time (Brannas et al 1994; Zydlewski et al. 2001).

Although the antennas were operational for the majority of the time they were installed, problems occurred periodically throughout the study (Appendix D). Battery power depletion was the primary cause of antenna failure, and occurred when high numbers of tags were detected.

Movements and fragmentation

Bluehead suckers, flannelmouth suckers, and roundtail chubs tagged in Muddy Creek exhibited downstream movements, upstream movements, and movements into McKinney Creek to spawn. Overall, movement patterns were similar to what has been observed among these species in larger streams. Within larger rivers, bluehead suckers have exhibited both downstream movement and sedentary patterns (Cavalli 2000; Beyers et al. 2001). Flannelmouth suckers have moved in and out of tributary streams, and

mobile and sedentary movement patterns have been described (Minckley and Holden 1980; Chart 1987; Douglas and Marsh 1988; Weiss et al. 1998; Cavalli 1999; McKinney et al. 1999; Beatty 2005). Roundtail moved extensively during the spawning season, seasonally, and remained sedentary at other times (Siebert 1980; Bestgen et al. 1987; Kaeding et al. 1990; Beyers et al. 2001).

Downstream movements were observed over all three of the major instream structures in the Muddy Creek study area. Tagged bluehead suckers and a single tagged flannelmouth sucker moved downstream over the headcut stabilization structure into an intermittent portion of Muddy Creek (segment one). All three species moved downstream over the irrigation diversion dam into segment two. Tagged bluehead suckers and roundtail chubs exited segment four downstream into segment three, the portion of Muddy Creek with the highest densities of native fish. Although the study was not designed to calculate exit rates of tagged fish, it is apparent that downstream emigrations of fish greater than 100 mm TL occurred and reduced populations in the segments that have little recruitment, but may have supplemented populations (immigration) in downstream segments.

Upstream movements of bluehead suckers, flannelmouth suckers, and roundtail chubs were detected in segments two and three during periods of low and high flows. Bluehead suckers and roundtail chubs tagged in segment three were detected at the antenna in segment three downstream of the fish barrier, reflecting an inclination to move upstream. Interestingly, no flannelmouth suckers tagged in segment three were detected below the fish barrier, but they were repeatedly detected in McKinney Creek. This suggests that flannelmouth suckers may prefer McKinney Creek and not the most

upstream reaches of Muddy Creek. Other studies have identified flannelmouth sucker congregations below impoundments and hypothesized that historic migration routes had been blocked (Chart and Bergerson 1992, McKinney et al. 1999).

Tagged bluehead suckers and roundtail chubs from segment three moved downstream over the irrigation diversion dam into segment two and then returned upstream to segment three. Three roundtail chubs were detected at the antenna just below the irrigation diversion dam in late May, and later detected in McKinney Creek in early June, 2005, indicating upstream movements by fish from segment two. In 2006, one of the three roundtail chubs moved over or through the irrigation diversion dam again in late May and was recorded 10.3 km upstream in McKinney Creek in early June. These movements occurred during spring runoff and the spawning season. Two bluehead suckers and one roundtail chub were detected in segment two between August 10 and 12, 2005, and detected 3-5 days later in segments three or five. These fish overcame the irrigation diversion dam during a period of low flow in which no water was pouring over the dam (Table 11) by likely swimming through the interstitial rock spaces and under the iron apron. The irrigation diversion dam was constructed with iron and rock fill on the downstream end, and was approximately 1.5 m high and 20 m wide (Figure 4). Cavalli (2000) reported that tagged bluehead suckers and flannelmouth suckers were able to overcome the Tusher Wash Diversion Dam in the Green River at flows of approximately 137 m^3/second. Tusher Wash Diversion Dam was built in 1906 and was constructed with wood cribbing filled with rock and a concrete cap, and was 2.4 m high and 256 m wide. The two diversion dams were likely not constructed similarly and discharge in the two rivers was drastically different, but they are the only diversion dams that have been

documented to restrict, but not prohibit, upstream movements of bluehead suckers and flannelmouth suckers.

Fish movements during periods of increased water discharge were observed in summer and such periods may be important for dispersal. On July 25, 2006, a large rain event occurred and substantially increased flow in Muddy Creek. Intermittency had already been observed below the irrigation diversion dam before the rain event. Ryan Beatty, BLM fish technician, witnessed one fish that moved downstream over the diversion dam and several fish that attempted to move upstream over the diversion dam the day after the rain event. Beatty (2005) found that two white suckers in isolated pools within lower Muddy Creek also dispersed downstream towards the Little Snake River after increased stream flow. In the San Rafael River system, bluehead suckers and flannelmouth suckers moved from the San Rafael River and repopulated Ferron Creek in October after streamflow returned to this intermittent creek (McAda et al. 1980).

It was hypothesized that fish in the downstream end of segment two would move upstream into perennial water near the upstream end of the segment prior to periods of intermittency, but large numbers of tagged fish were not observed to move into the perennial water. Only two bluehead suckers tagged in the downstream end of segment two were detected upstream at the antenna below the irrigation diversion (May 24, 2005 and July 19, 2005), and one of these fish was later sampled above the irrigation diversion dam in segment three, reflecting probable spawning movements. Most fish were recaptured in pools near tagging localities or moved downstream into segment one. Siebert (1980) found that roundtail chubs in Aravaipa Creek, a desert stream in southeastern Arizona that experiences dramatic fluctuations in discharge and water

temperature, moved into a canyon segment during summer and into valley segments during other seasons. The canyon segment had cooler water temperatures and abundant shade during the summer, and roundtail chubs actively sought out these features. In Muddy Creek, fish that occupied segment two experienced intermittency and increased water temperatures, but did not actively move upstream into segment three. Few adult fish in segment three, within a canyon, moved downstream into the lower segments. It is possible that the fishes in segment three were often sedentary because of the channel features and pool habitat the canyon provided.

McKinney Creek, a tributary without barriers to fish movements, may play a vital role in the persistence of bluehead suckers, flannelmouth suckers, and roundtail chubs in upper Muddy Creek. Adults of all three species moved upstream into McKinney Creek to spawn, with the majority of these tagged fish originating in segment three. All three bluehead suckers that moved downstream from segment four moved up into McKinney Creek, and three roundtail chubs moved upstream from segment two during late May 2005. Flannelmouth suckers also demonstrated a preference for McKinney Creek. Bluehead suckers have not been documented to display a migratory spawning pattern, however, bluehead sucker spawning activity was observed in Kanab Creek and the researchers suspected they moved in from the Colorado River (Maddux and Kepner 1988). Flannelmouth sucker spawning migrations have been observed in tributaries to the Colorado River (Weiss et al. 1998). Roundtail chubs are known to migrate during the spawning season, but movements into smaller tributaries have not been described (Kaeding et al. 1990). Bezzerides and Bestgen (2002) suggested that one of the reasons flannelmouth suckers and bluehead suckers have fared better than the federally

endangered species in the CRB is their extensive use of tributary, as well as mainstem, habitats.

Instream structures restrict fish movements and fragment populations in upper Muddy Creek. Tagged fish moved downstream over the headcut stabilization structure and the fish barrier, but upstream movements over these structures were not observed. Therefore, the headcut stabilization structure and fish barrier are likely upstream movement barriers. Downstream and upstream movements occurred over the irrigation diversion dam, but it probably restricted movements in both directions. In headwater systems like upper Muddy Creek, seasonal upstream immigration or downstream emigration may be critical for maintaining populations on the periphery of the species' ranges (Bezzerides and Bestgen 2002). Fragmented headwater systems may exhibit declines or extirpations of native fishes due to impeded movements required to fulfill life cycles.

Age and growth

Growth rates were lower and ages were greater for flannelmouth suckers and roundtail chubs of age 2 or greater collected in segment three of Muddy Creek compared to populations studied in other rivers of the CRB. Fish less than 100 mm TL were not aged in this study, so length frequency histograms were used to compare age 1 fish. Age 1 length frequencies of the three species in Muddy Creek were similar to length frequencies from other fishes collected in the Little Snake, White, and Yampa rivers (Carlson et al. 1979; Hawkins et al. 1997; Robinson and Childs 2001). No information on bluehead sucker age and growth was found, but information on flannelmouth suckers

and roundtail chubs was found. Lengths of flannelmouth suckers age 3 or greater were smaller at every age group in Muddy Creek compared to fish from the Colorado, Green, White, and Yampa rivers. One flannelmouth sucker reached age 17 in Muddy Creek, whereas fish in the Colorado, Green, White, and Yampa rivers reached a maximum of age 8 (Table 26). The largest flannelmouth sucker collected in Muddy Creek was 470 mm TL compared to fish of 571-580 mm TL from the Green or Yampa rivers (McAda 1977). Age 2 or greater roundtail chubs collected in Muddy Creek were smaller than roundtail chubs from the Gila, Green, and Verde rivers (Table 27; Vanicek and Kramer 1969; Bestgen 1985; and Brouder 2006). Age 12 roundtail chubs were collected in Muddy Creek, but age 7 roundtail chubs were the oldest fish collected in the Gila, Green, and Verde rivers (Table 27). The largest roundtail chub collected in Muddy Creek was 374 mm TL compared to 405 mm TL from the Gila River, 366 mm TL from the Green River, and 428 mm TL from the Verde River.

It is likely that growth rates of bluehead suckers, flannelmouth suckers, and roundtail chubs are slow in Muddy Creek because of environmental conditions. The elevation range of the Muddy Creek study area was 2,115 to 2,225 m and cold water temperatures through most of the year likely reduced annual growth. Others have suggested growth rates were dependent on water temperatures (Vanicek and Kramer 1969; McAda and Wydoski 1983; and Robinson and Childs 2001). However, periods of low water or intermittency and increased water temperatures in the summer, witnessed in 2005 and 2006, could also reduce growth rates. Roundtail chubs in the Gila River, New Mexico, grew faster and lived longer than chubs in Turkey Creek, a tributary of the Gila

River, and it has been suggested that variations in life-history strategies reflected adaptations to local environmental conditions and habitat sizes (Bestgen 1985).

Most bluehead suckers, flannelmouth suckers, and roundtail chubs in Muddy Creek appeared to become mature between the ages of 3 and 5, and bluehead suckers and roundtail chubs reached maturity at smaller lengths than flannelmouth suckers. Bluehead suckers that showed reproductive characteristics ranged from 133 to 284 mm TL, and likely reached sexual maturity at age 3 or 4 (Figure 18). Only four flannelmouth suckers displaying reproductive characteristics were sampled and they ranged from 251 to 417 mm TL. Of the 15 flannelmouth suckers that entered McKinney Creek during the spawning season, mean total length was 286 mm and the range was 180 to 390 mm TL. Based on these length ranges, flannelmouth suckers probably reproduce in Muddy Creek by age 4 or 5 (Figure 19). Length ranges of roundtail chubs displaying reproductive condition were 142-334 mm TL, and they likely reproduce first at age 4 (Figure 20). Bluehead suckers typically mature at smaller sizes in small tributaries, and were observed to be sexually mature at lengths of 90-200 mm TL in the San Juan River and Little Colorado River (Smith 1966, McAda and Wydoski 1983). Flannelmouth suckers in the Colorado, Green, Gunnison, and Yampa rivers began to mature at age 4 and most were mature by age 6, and the smallest mature fish was 391 mm TL (McAda and Wydoski 1985). Roundtail chubs usually mature between the ages of 3 and 5 and at 150-300 mm TL (Bestgen 1985; Brouder et al. 2000). Bluehead sucker and roundtail chub ages and lengths at maturity in Muddy Creek were similar to other populations in the Colorado River Basin, but flannelmouth sucker lengths at maturation in Muddy Creek were much smaller than fish residing in larger rivers.

Although ages from pectoral fin rays were not validated, the results provided insight into the age structure of populations of the three species within upper Muddy Creek. Pectoral fin rays were used to age the three species because high agreement occurred between fin rays and otoliths in a previous study conducted with fish from Muddy Creek, and because fin rays provided a non-lethal aging method (Quist et al. in press). Brouder (2006) validated the use of otoliths for roundtail chubs in the Verde River. Because otoliths were previously validated for roundtail chubs and high agreement was found between otoliths and pectoral fin rays for the three species, the aging method used in this study was assumed to be accurate. A comparison of estimated mean ages using pectoral fin rays to length frequency histograms resulted in the addition of 1 year to all aged fish. This correction factor likely improved the precision of the estimated mean ages of the three species.

Scales have been the primary structure used to age flannelmouth suckers and roundtail chubs (Table 26 and Table 27). Beamish and McFarlane (1983) validated the use of fin rays to age white suckers and found that scales often underestimated older fish when growth became minimal. The ages of flannelmouth suckers and roundtail chubs reported in Table 26 and 27 may be underestimated because of the use of scales. Bestgen (1985) also questioned the precision of scales used to age roundtail chubs in the Gila River, as roundtail chub opercula from large specimens showed up to 13 annulus-like marks. Scoppettone (1988) validated the use of opercula to age cui-ui *Chasmistes cujus* and discovered many fish were as old as 41 years. Other catostomids and cyprinids in Western North America were aged using opercula and many species reached old ages. The maximum age of June sucker *Chasmistes liorus* was 42 years, lost river sucker

Catostomus luxatus reached a maximum age of 43 years, and bluehead suckers and flannelmouth suckers collected from the Green River, Utah, reached maximum ages of 20 and 28 years.

Population characteristics

Considerable differences in abundances, juvenile fish densities, and length structures of the three species occurred among the study area segments, suggesting that fish at different life stages utilized different segments within Muddy Creek and instream structures were negatively influencing their persistence. Because fish often carry out critical aspects of their entire life histories at intermediate scales of 1-100 km, minimal fragmentation within the riverscape can be detrimental to the entire population (Fausch et al. 2002). Similar to Schlosser's conclusions (1995), landscape processes including large-scale spatial habitat relationships affect fish movements and resource use. The occurrence of refugia habitats, and their influence on fish survival and immigration and emigration rates, appears to affect population and community dynamics in Muddy Creek.

Segment three supported the highest numbers of the three species, the broadest ranges of length classes and ages, the highest juvenile fish densities, and the highest frequencies of reproducing adults to probably represent a "core" population. Abundance estimates for the three species in segment three were more than two times greater than in segments two and four combined. My observations during the study suggest that segment three had abundant rock substrate, pools, and perennial flows. Segment three was also connected to McKinney Creek. Compared to the other segments, the highest densities of willows, mountain alders, and junipers, which contributed to riparian

shading, were found in segment three. In addition, during 2005 and 2006, it was observed that the three native fish species were collected in aquatic vegetation on the margins of pools and runs, especially during low flow periods in July and August. Bower (2005) found positive associations with rock substrates, pools, and perennial flows for bluehead sucker and flannelmouth sucker adults. Roundtail chubs preferred rock substrates and pools, and were positively associated with reaches having isolated pools. Because the genus *Gila* appears to avoid direct sun-light (Deacon and Minckley 1974), shade and cover may be habitat selected for in segment three. It is likely that all these habitat attributes are driving the persistence of the three species of native fishes in this segment.

McKinney Creek may be critical to the reproductive success of the three species. Movement data revealed spawning in this tributary, length frequency histograms and larval collections revealed the presence of age 0 and 1 fishes, and the majority of PIT tagged fish that entered and exited McKinney Creek were adults. Length frequencies of bluehead suckers, flannelmouth suckers, and roundtail chubs in McKinney Creek indicated few fish greater than 100 mm TL (age 2 or greater), but large numbers of the three species less than 100 mm TL. It is possible that McKinney Creek provides rearing habitat for age 0 and juvenile fish, but is unsuitable for larger fish. Habitat was not measured in McKinney Creek, but loose gravel riffles free of sediment due to high spring flows likely provide adequate spawning habitat for the three species.

Habitat complementation probably occurs between segment three of Muddy Creek and McKinney Creek, and together these areas are likely population sources for the upper watershed. Habitat complementation refers to the spatial proximity of suitable

habitat types required by a species, and may include spawning, feeding, and refugia habitat for stream fishes (Schlosser 1995). Pulliam (1988) defined sources as areas that exhibit high juvenile recruitment and provide immigrants to less productive habitats on the landscape. Spawning movements of adult fish in and out of McKinney Creek from segment three, probable emigration of age 0 and 1 fish from McKinney Creek and segment three, and high juvenile densities in both segments support these ideas. Spawning aggregations of bluehead suckers and roundtail chubs were observed in segment three in June 2005, suggesting reproduction also occurs within Muddy Creek, but the greatest spawning activity may occur in McKinney Creek.

Muddy Creek downstream of the canyon area is likely a natural sink area for bluehead suckers, flannelmouth suckers, and roundtail chubs, and the irrigation diversion dam and headcut stabilization structure may have magnified this dynamic. Local 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). But sink habitats can sustain large populations even though the sink population would disappear without consistent immigration (Schlosser 1995). The downstream portion of segment two and all of segment one have low gradients, few riffle-run-pool complexes, and are dominated by silt and sand. Spawning habitat is probably limiting in these segments. Length frequency histograms showed that fish of all three species less than 150 mm TL (typically age 3 or less) outnumbered fish greater than 150 mm TL in these segments, and the frequency of mature fish was less than segment three. It is not known if larvae drift or juveniles move downstream to rear in segments two and one, but many young fish occupied these segments. The reproductive and

rearing strategies of the three species can result in source-and-sink population dynamics. Larvae are probably displaced downstream by high velocity spring run-off, and disperse or drift downstream to preferable low-velocity habitats with warmer water temperatures (Carter et al. 1986, Robinson et al. 1998). Upon reaching the juvenile stage, roundtail chubs have been known to seek velocities about 0.15 m/s and sand substrate (Barrett and Maughan 1995) and this may explain why juveniles emigrate to segments one and two. Muddy Creek downstream of the canyon may be a recruitment area for larval and juvenile bluehead suckers, flannelmouth suckers, and roundtail chubs based on their habitat preferences.

The fishes that reside in reaches below the canyon in Muddy Creek often experience intermittent flows. As adults, Bower (2005) found negative associations with intermittency for bluehead suckers and flannelmouth suckers, but positive associations with intermittency for roundtail chubs. Results from my study support his findings, as frequencies of adult bluehead suckers and flannelmouth suckers were low, and roundtail chub frequencies were highest among the three species in the lower two segments. A lack of adult fish in the lower segments can be explained either by upstream movements of adults into segment three, upstream movements into segment three by juveniles, or low survival rates of adults during periods of intermittency. No strong upstream movement patterns were detected among tagged fish, so fish may either move from segment two back into segment three as juveniles or do not survive as adults. If juveniles do attempt to move into segment three, the irrigation diversion dam and headcut stabilization structure likely restrict their movements and habitat complementation that may exist between the two downstream segments and segment three is negligible.

Bluehead suckers, flannelmouth suckers, and roundtail chubs above the fish barrier in segment four may be in peril because there is emigration, little recruitment, and no immigration. Low numbers of older fish (age 4+ bluehead suckers, age 4+ flannelmouth suckers, and age 6+ roundtail chubs) resided primarily in pools within the natural habitat stratum of segment four. The fish barrier has prohibited upstream movements and eliminated access to complementary habitat in segment three. The consequences appear to be an overall reduction in the populations and possible extirpation of the three species in segment four. Gully plugs have reduced the amount of suitable habitat within this segment and probably have exacerbated these problems.

White sucker influences

White suckers were the most abundant species throughout the study area, and their densities were higher than both native catostomid species in every segment except for bluehead suckers in segment three. Estimated abundance of white suckers in the study area was approximately 3,600 fish, compared to 1,700 bluehead suckers and 470 flannelmouth suckers. Competition and habitat overlap may exist among all the sucker species within the larval and juvenile life stages, but adult white sucker competition with flannelmouth suckers may be greater than with bluehead suckers because of overlapping habitat preferences. Non-native white sucker, a generalist species, has impacted Muddy Creek severely, just as it has proven problematic throughout the CRB in Wyoming. Rahel (2002) described how biotic homogenization, an increased similarity of biotas through time caused by a replacement of native species with non-native species, can be increased if generalist species are introduced. Such introductions can lead to native

species extirpation, and habitat alteration can accelerate it. Several processes can drive a reduction or extirpation of native species: non-natives can dominate and displace natives through competition even when habitat remains relatively intact, a loss of native species may allow non-natives to increase as resources and habitat are freed up, or habitat alterations can lead to an establishment of non-native species. Homogenization has occurred in Wyoming with white suckers (and other non-native fishes), and white suckers are now the most abundant species of sucker of in cool and warm water lotic environments. Out of approximately 77,000 fish sampled from 2003 to 2006 in the Green River and Little Snake River basins, 8,600 white suckers, 140 bluehead suckers, and 700 flannelmouth suckers were collected (K. Gelwicks, WGFD, personal communication).

The highest densities of white suckers in Muddy Creek occurred in the altered habitat in segment four. Nearly 50 white suckers/100 m were estimated in the altered habitat, compared to 10 fish/100 m in segment three, the second highest density of white suckers outside of segment four. Altered habitat appears to have firmly established white suckers in segment four.

Muddy Creek above the fish barrier (segment four) and McKinney Creek are probable source areas for white suckers. At least 13 white suckers emigrated from segment four, and 10 of the 13 fish moved into McKinney Creek during the spawning period. Larval collections confirmed successful reproduction by white suckers in McKinney Creek, and they dominated composition of captured larvae. Frequencies of white suckers between 100 and 200 mm TL were highest in segment four. White sucker migrations during spawning periods have been documented in lower Muddy Creek and

other rivers (Bunt et al. 2001; Beatty 2005). Knowing that white suckers readily move downstream from segment four and that densities are highest in this segment suggests it is a source area.

Hybridization between white suckers and the two native catostomid species occurs in Muddy Creek. Hybrids were phenotypically identified in the field, and genetically identified in the laboratory by David McDonald, University of Wyoming, using amplified fragment length polymorphism (AFLP) genotypes and principal components (PC) analysis. White sucker gene frequencies from the Laramie River, Wyoming were added to the PC analysis with bluehead suckers, flannelmouth suckers, and catostomid hybrids from Muddy Creek. The phenotypically pure white suckers from the Laramie River (native range on the eastern slope of the Continental Divide) did not overlap with the white suckers from Muddy Creek, suggesting that most white suckers collected from Muddy Creek were introgressed with genomes of the two native species, especially flannelmouth suckers. The proportion of first generation (F1) hybrids that become fertile is not known in Muddy Creek, but some are able to reproduce based on McDonald's genetic results and the presence of hybrids that have phenotypic characteristics of all three sucker species. Hybrids likely backcross with pure flannelmouth suckers and bluehead suckers, and are creating a hybrid swarm among the three catostomid species. Hybrid swarms are defined by Allendorf et al. (2001) as "a population of individuals that all are hybrids by varying numbers of generations of backcrossing with parental types and mating among hybrids." Hybridization in many animal taxa has led to extinction, and the severity of this problem has been underestimated by conservation biologists (Rhymer and Simberloff 1996). Hybrid

catostomids outnumbered flannelmouth suckers in Muddy Creek and are evidence of this problem.

The spawning periods of flannelmouth suckers and white suckers overlap more than bluehead suckers and white suckers, and may explain why the majority of hybrids collected appeared to be flannelmouth sucker x white sucker. Additionally, reproductive isolation due to non-overlap of spawning flannelmouth suckers and bluehead suckers may result in few bluehead sucker x flannelmouth sucker hybrids. Based on water temperature ranges reported during spawning activities, flannelmouth suckers reproduce when water temperatures are 9-18 ^{o}C and white suckers reproduce when water temperatures are 7-19 ^{o}C (Holden 1973; Corbett and Powles 1983; Hamel et al. 1997; Weiss et al. 1998; Bezzerides and Bestgen 2002; and Snyder and Muth 2004). Bluehead suckers spawn later when warmer water temperatures are 16-25 ^{0}C (Maddux and Kepner 1988; Bezzerides and Bestgen 2002; and Snyder and Muth 2004).

Management implications

Population viability. - Long term viability of the three native species in upper Muddy Creek must be maintained by recruitment from within since it is isolated from downstream portions of Muddy Creek and the Little Snake River drainage. Furthermore, instream structures within upper Muddy Creek have caused population fragmentation and the dynamics of populations within each fragmented segment are somewhat independent. Consequently, the populations within each segment were evaluated based on conservation biology concepts. Soule (1980) developed guidelines for managers that addressed minimum viable populations. The 50/500 guideline states that there should be

a minimum of 50 adults contributing gametes to the gene pool (effective population size) to avoid inbreeding over short periods of time, and 500 adults contributing gametes within the population to adapt to environmental change over long periods of time.

Using the 50/500 rule as general conservation guidance, bluehead suckers and roundtail chubs in segment three were the only populations likely to be viable, but bluehead suckers and roundtail chubs in segment two may be viable if other factors are considered. Within segment two, the number of bluehead sucker (N=159) and roundtail chub (N=212) adults contributing gametes was adequate for short term requirements, but less than 500 adults of each species were estimated in this segment. Knowing that bluehead suckers and roundtail chubs in segment two likely recruit larvae, juveniles, and adults from segment three, their persistence within segment two may be in jeopardy. Flannelmouth sucker populations were inadequate in every segment, but 164 adults were estimated in segment three, representing the highest abundance of any segment. None of the target species had adequate population numbers in segment four. In addition, the proportion of adults in that segment was high for all species (87% for bluehead suckers, 64% for flannelmouth suckers, and 94% for roundtail chubs). The populations in segment four probably have the highest probability of inbreeding or extinction.

Although the 50/500 guideline provides direction for conservation management, it may not be adequate because it is hard to accurately estimate effective population size, and life history strategies can complicate viability. Hilderbrand and Kershner (2000) examined the prognosis of long-term persistence of isolated cutthroat trout *Oncorhynchus clarki* populations and found that 2,500 individuals (>75 mm) would be necessary to maintain an effective population size of 500 reproducing adults. Simulation models

conducted by Reiman and Allendorf (2001) found that loss of heterozygosity was increased dramatically by fish with complex life histories and variable environmental conditions. Bluehead suckers, flannelmouth suckers, and roundtail chubs are long lived, do not necessarily reproduce every year if environmental conditions are not optimal, and growth and age at maturation can vary due to local environmental conditions. It is safe to say that the three species have complex life histories and reside in aquatic ecosystems with variable environmental conditions; therefore, the 50/500 guideline for these species should be considered a minimal management goal. Additionally, the dynamics of persistence or extinction involve the abiotic and biotic factors of the fishes' environment and parameters of this nature should be collected to thoroughly investigate population viability (Gilpin and Soule 1986).

Oil and gas development. - Fossil fuel extraction has accelerated throughout the Powder River and Green River basins in Wyoming in recent years, including the Atlantic Rim area surrounding Muddy Creek. The Atlantic Rim Development Area encompasses the majority of Muddy Creek (approximately 1,093 km^2) near Townships 13 to 20 North and Ranges 89 to 92 West, south and west of Rawlins, Wyoming. A total of 1,800 coalbed methane and 200 conventional natural gas wells with 32 ha well pad spacing have been proposed to be drilled over the next 30-50 years. No permits for surface discharge into upper Muddy Creek have been filed, but surface discharge permits have been granted in Dry Cow and Wild Cow creeks, tributaries of lower Muddy Creek (Patrick Lionberger, BLM, personal communication). The Wyoming Department of Environmental Quality has also approved surface discharge into the upper Colorado River Basin if water quality standards are met. Coalbed methane development can alter

ephemeral watercourses by discharging water pumped from wells into stream channels (Patz et al. 2004). Modified flows, water temperatures, and water quality from surface discharge or seepage of re-injected water could adversely affect the hydrology of Muddy Creek and its tributaries. The threat of negative impacts on the native fishes increases upstream in the core population areas (segments three and five). Potential threats include water contamination due to inadvertent surface water discharge of low quality (high sodium and bi-carbonate concentrations) or chemical contamination, sedimentation and erosion from road, pipeline and bridge construction, run-off from gas seeps, and alteration of the riparian community. Surface water discharge in upper Muddy Creek could impact the habitat and life history needs of the native fish assemblage. Additionally, fluctuations in shallow aquifers caused by drilling could lead to decreased flows. Coalbed methane development in the Atlantic Rim should proceed only with monitoring programs, adequate mitigation measures, and ground water disposal practices that do not impact the native fish assemblage.

Conclusions and Recommendations

Conclusions

The headcut stabilization structure and fish barrier have fragmented the bluehead sucker, flannelmouth sucker, and roundtail chub populations and the irrigation diversion dam has restricted upstream movements of fish in upper Muddy Creek. Fish move into McKinney Creek to spawn, and source-and-sink dynamics are likely. Length and age structures, abundance estimates, and juvenile densities are considerably different among segments, and instream structures appear to have contributed to these differences. Non-native white suckers were the most abundant species in the study area, and altered habitat

in segment four appears to have promoted their proliferation. Hybridization is negatively impacting bluehead suckers and flannelmouth suckers. Low abundance and hybridization may be putting flannelmouth suckers in peril of extirpation in upper Muddy Creek. Although problems exist in upper Muddy Creek, active management to allow these sympatric populations to persist is possible.

Research recommendations

It is likely that larvae of all three target species drifted downstream into segment two causing a loss of potential recruits to the population in segment three, the "core" population. In order to confirm the extent of larval drift, drift nets could be set at the downstream end of the canyon during runoff and the spawning period to verify downstream drift of larvae below the irrigation diversion dam. If large numbers of larvae are collected, removal or modification of the irrigation diversion may be warranted.

All fish identified as white suckers and hybrid catostomids captured in 2006 were removed from the system. Approximately 40% (1424 removed, 3,585 estimated) of white suckers and 43% (332 removed, 781 estimated) of hybrid catostomids were removed. Electrofishing could be an effective mechanical means of removal for white suckers and hybrid catostomids from Muddy Creek. The potential for use of electrofishing as a means of removal of white suckers and hybrid catostomids should be investigated in more detail, particularly to assess the potential of injury to the three native species.

The importance of McKinney Creek within the Muddy Creek drainage supports other research that has documented tributary stream usage by bluehead suckers,

flannelmouth suckers, and roundtail chubs. Tributary use within smaller stream systems like Muddy Creek should be investigated and connectivity and habitat protection should be a priority.

Possible effects from pectoral fin removal techniques of the three species should be investigated. A study that evaluates the long term effects of fin removal before this technique is repeated in other studies is recommended. Several studies have reported that pectoral fin removal did not reduce growth or survival of brown trout *Salmo trutta* or bull trout *Salvelinus confluentus* (Brynildson and Brynildson 1967; Zymonas and McMahon 2006). Conversely, survival of rainbow trout *Onchorinchus mykiss* with pectoral fin rays removed was reduced by as much as 70 to 80%, but growth was not reduced (Nicola and Cordone 1973). McNeil and Crossman (1979) found that the removal of a pectoral fin was more detrimental than the loss of a pelvic fin for muskellunge *Esox masquinongy*. No studies were found that examined growth or survival of bluehead suckers, flannelmouth suckers, or roundtail chubs with pectoral fin rays removed.

Management recommendations

Non-native and hybrid catostomid fish removal should be considered in McKinney and Muddy creeks during periods of low flow or intermittency. Populations in entire segments could be affected by electrofishing in perennial reaches and pools in intermittent reaches. Mechanical removal could significantly reduce the populations of white suckers and hybrid catostomids if the entire length of upper Muddy Creek were electrofished and the procedure was repeated annually over a few years.

Weirs could also be installed in McKinney Creek upstream of its confluence with Muddy Creek and in segment three of Muddy Creek. Large numbers of mature white suckers and hybrid catostomids could be removed as they move upstream to enter McKinney Creek to spawn. If white suckers and catostomid hybrids were removed from McKinney Creek, native suckers could spawn in the absence of white suckers, preserving the genetic makeup of the native catostomids. This action could reduce hybridization and competition for optimal spawning habitat. Weirs would also allow managers to monitor the reproductive portions of the native sucker, white sucker, and hybrid catostomid populations. Trend data could be established by counting the numbers of fish of each taxon that enter McKinney Creek each year to spawn. A draw-back to the use of weirs is that they need to be installed each spring prior to major spawning movements of each species to be successful, but spring weather conditions can make travel into upper Muddy Creek difficult.

Mechanical removal of white suckers and hybrid catostomids can be initiated while the feasibility of piscicide application to remove these undesired fishes is evaluated. There are many challenges that would have to be overcome to successfully eradicate white suckers, hybrid catostomids, and other non-native fishes (i.e., creek chubs) from the upper Muddy Creek watershed. These challenges include obtaining permission from multiple private landowners, eradicating non-native fishes and hybrids from the headwaters of McKinney Creek and its tributaries, evaluating survival of the three native species if they need to be held off-channel while piscicides are applied, and investigating the costs needed to perform a successful operation.

Full connectivity within the upper watershed could allow for successful completion of life cycles of the three native species. With spatially restricted populations, a required habitat component may be insufficient or missing for a life history stage, or the absolute physical space necessary to maintain viable populations may be inadequate (Dunning et al. 1992).

Replacing gully plugs with other structures that allow fish passage would result in full connectivity in segment four. The structures should limit erosion and prevent stream incision, while allowing downstream transport of accumulated sediment. Altered habitat, preferred by white suckers, could be eliminated. Rock-grade structures have been proposed and will be tested in coming years.

The removal of the fish barrier would benefit the native warmwater fish populations immediately and eliminate the threat of extirpations in segment four. A fish barrier established above the upstream distribution of the three species' range would allow for movements between segments three and four, but would not jeopardize previous Colorado cutthroat trout restoration efforts in the headwaters of Muddy Creek. If brook trout are eliminated from McKinney Creek and its tributaries, the fish barrier could be removed.

Modification that allows for upstream passage of all fish life stages over the irrigation diversion dam or removal of the irrigation diversion dam would probably benefit the native fish populations in Muddy Creek. Investigation of alternatives to facilitate fish passage is recommended.

It is recommended that the headcut stabilization structure at the downstream end of my study area not be altered. Although the headcut stabilization structure has

fragmented population fragmentations, it has also prevented upstream colonization of additional non-native fish species. Non-native fathead minnows, redside shiners *Richardsonius balteatus*, and sand shiners *Notropis stramineus* are present in Muddy Creek below the headcut stabilization structure (Beatty 2005). Other non-native cyprinids (common carp *Cyprinus carpio*, plains killifish *Fundulus zebrinus*, and red shiner *Cyprenella lutrensis*) have become established downstream in the Yampa or Little Snake rivers and compete or prey on early life stage native fishes (Ruppert et al. 1993). Introduced predators (channel catfish *Ictalurus punctatus*, green sunfish *Lepomis cyanellus*, northern pike *Esox lucius*, and smallmouth bass *Micropterus dolomieui*) also occur in the Yampa or Little Snake rivers and have decimated native fish populations in portions of their range.

Establishment of the upper Muddy Creek drainage as a native fish conservation area should be considered, possibly through a BLM Special Management Area designation. Colorado River cutthroat populations have been re-established in the cold water portions of Muddy Creek, mountain suckers *Catostomus platyrhynchus* persist in the cool water habitats, and the highest densities of bluehead suckers and roundtail chubs in Wyoming occur there. A conservation area within Muddy Creek would provide an opportunity to educate the public about ecosystem and watershed management, native fish conservation, and collaboration among private landowners and public agencies. Because angling pressure is not significant in the watershed, the likelihood of negative feedback from the angling public is minimal.

Research conducted on the fishes of Muddy Creek since 2000 has provided a foundation for adaptive management opportunities. Many conservation actions

prescribed by the range-wide conservation agreement for the three species have been completed. Status assessments have been concluded; population demographics, life history, habitat requirements and conservation needs have been determined; and populations have been genetically characterized. It is now up to management agencies to implement activities that will increase and enhance populations, control the threats of non-native species, establish monitoring programs, and implement outreach programs in accordance with the range-wide conservation agreement.

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Table 1. The numbers and mean total lengths (TL, millimeters) of bluehead suckers, flannelmouth suckers, white suckers, and roundtail chubs implanted with PIT tags in segments two, three, and four in 2004.

	Bluehead sucker			Flannelmouth sucker			White sucker			Roundtail chub		
Segment	Number	Mean TL	Range	Number	Mean TL	Range	Number	Mean TL	Range	Number	Mean TL	Range
2	258	147	92 - 220	3	179	145 - 219	0	0	0	79	147	102 - 300
3	573	181	110 - 296	70	211	101 - 390	0	0	0	248	180	105 - 399
4	79	154	110 - 284	3	254	151 - 307	47	178	100 - 279	82	199	122 - 344

Table 2. Dates of antenna installation and removal in the Muddy Creek study area during 2005 and 2006.

Date		
Month	Day (s)	Event
		2005
April	4	Antenna downstream of headcut stabilization structure installed in segment one
May	4	Antenna downstream of fish barrier installed in segment three
May	4	Antenna in McKinney Creek installed (segment five)
May	5	Antenna downstream of irrigation diversion dam installed in segment two
May	19	Antenna at previous intermittency locality installed
August	22	Antenna downstream of headcut structure removed
August	24	Remaining antennas removed
		2006
March	30	Antenna downstream of headcut stabilization structure installed in segment one
May	1	Antenna downstream of fish barrier installed in segment three
May	1	Antenna in McKinney Creek installed (segment five)
May	2	Antenna downstream of irrigation diversion dam installed in segment two
October	12 - 13	Antennas removed

Table 3. In situ antenna efficiency (antenna efficiency X path efficiency) for passive monitoring stations for both the small-scale and large-scale PIT tag detection tests. The number of times a tag was passed is represented by P, and the actual number of detections are represented by A.

	2005						2006		2005 and 2006 Combined				
			Large-scale										
	Small-scale		Parallel		Perpendicular		Small-scale				Efficiency		
Station	P	A	P	A	P	A	P	A	P	A	Antenna	Path	In situ
1	372	372	74	74	74	74	480	480	1,000	1,000	1.00	1.00	1.00
2	276	276	84	84	84	84			444	444	1.00	1.00	1.00
3	372	372	102	7	102	102	408	408	984	889	0.90	1.00	0.90
4	372	365	60	46	60	60	432	432	924	903	0.98	1.00	0.98
5	336	336	74	74	74	74	336	336	820	820	1.00	1.00	1.00

Table 4. Observations of fish PIT tagged in segment two and later found passing through antennas or collected by electrofishing in 2005 and 2006. Numbers in parentheses reflect the total number of fish recorded, the number preceding represents new fish in 2006.

		Recapture location							
		Upstream				Tagging segment		Downstream	
	Number	Segment 4		Segment 3 and 5		Segment 2		Segment 1	
Species	Tagged	2005	2006	2005	2006	2005	2006	2005	2006
Bluehead sucker	258	0	0	0	1	31	3(9)	21	6
Flannelmouth sucker	3	0	0	0	0	1	0(0)	1	0
White sucker	0	0	0	0	0	0	0(0)	0	0
Roundtail chub	79	0	0	0	0	5	5(6)	0	0

Table 5. Observations following tagging of fish PIT tagged in segment two by antennas (A), electrofishing (E), or both techniques (B) during 2005 and 2006.

	Upstream												Tagging segment						Downstream					
	Segment 4						Segment 3 and 5						Segment 2						Segment 1					
	2005			2006			2005			2006			2005			2006			2005			2006		
Species	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B
Bluehead sucker	0	0	0	0	0	0	0	0	0	0	1	0	2	29	0	0	9	0	21	2	2	8	0	0
Flannelmouth sucker	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
White sucker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Roundtail chub	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	6	0	0	0	0	0	0	0

Table 6. Observations of fish PIT tagged in segment three and later found passing through antennas or collected by electrofishing in 2005 and 2006. Numbers in parentheses reflect the total number of fish recorded, the number preceding represents new fish in 2006.

		Recapture location							
		Upstream		Tagging segment		Downstream			
	Number	Segment 4		Segment 3 and 5		Segment 2		Segment 1	
Species	Tagged	2005	2006	2005	2006	2005	2006	2005	2006
Bluehead sucker	573	0	0	178	22(54)	28	8	1	1
Flannelmouth sucker	70	0	0	21	4(13)	2	0	0	0
White sucker	0	0	0	0	0(0)	0	0	0	0
Roundtail chub	248	0	0	68	17(46)	24	0	0	0

Table 7. Observations following tagging of fish PIT tagged in segment three by antennas (A), electrofishing (E), or both techniques (B) during 2005 and 2006.

	Upstream						Tagging segment						Downstream											
	Segment 4						Segment 3 and 5						Segment 2						Segment 1					
	2005			2006			2005			2006			2005			2006			2005			2006		
Species	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B
Bluehead sucker	0	0	0	0	0	0	134	79	35	58	22	4	28	2	2	7	1	0	1	0	0	1	0	0
Flannelmouth sucker	0	0	0	0	0	0	14	10	3	9	4	0	2	0	0	0	0	0	0	0	0	0	0	0
White sucker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Roundtail chub	0	0	0	0	0	0	42	34	8	26	24	4	23	1	1	8	0	0	0	0	0	0	0	0

Table 8. PIT tagged fish recorded at the antenna in McKinney Creek from tagging segment origin. The segment sub-columns are divided into the number tagged and the number recaptured in 2005, 2006, or both years.

	Segment 4				Segment 3				Segment 2			
Species	Number Tagged	2005	2006	Both Years	Number Tagged	2005	2006	Both Years	Number Tagged	2005	2006	Both Years
Bluehead sucker	79	3	1	1	573	122	54	40	258	0	0	0
Flannelmouth sucker	3	0	0	0	70	14	7	6	3	0	0	0
White sucker	47	10	4	4	0	0	0	0	0	0	0	0
Roundtail chub	82	0	0	0	248	37	25	17	79	0	0	0

Table 9. Observations of fish PIT tagged in segment four and later found passing through antennas or collected by electrofishing in 2005 and 2006. Numbers in parentheses reflect the total number of fish recorded, the number preceding represents new fish in 2006.

		Recapture location							
		Tagging segment		Downstream					
	Number	Segment 4		Segment 3 and 5		Segment 2		Segment 1	
Species	Tagged	2005	2006	2005	2006	2005	2006	2005	2006
Bluehead sucker	79	5	8(9)	3	0	0	0	0	0
Flannelmouth sucker	3	2	0(2)	0	0	0	0	0	0
White sucker	47	3	2(0)	13	0	0	0	0	0
Roundtail chub	82	16	10(19)	2	1	0	0	0	0

Table 10. Observations following tagging of fish PIT tagged in segment four by antennas (A), electrofishing (E), or both techniques (B) during 2005 and 2006.

	Tagging segment						Downstream																	
	Segment 4						Segment 3 and 5						Segment 2						Segment 1					
	2005			2006			2005			2006			2005			2006			2005			2006		
Species	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B	A	E	B
Bluehead sucker	0	5	0	0	9	0	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flannelmouth sucker	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White sucker	0	3	0	0	2	0	11	3	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Roundtail chub	0	16	0	0	19	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 11. Dates of notable discharge patterns of the Muddy Creek study area in 2005 and 2006.

Date		
Month	Day (s)	Event
		2005
July	13	Intermittency at irrigation diversion
July	26	Intermittency at headcut structure
		2006
June	29	Minimal water over irrigation diversion, likely impassible
July	8 - 18	Intermittency at headcut structure within this period
July	20	Intermittency at irrigation diversion
July	20 - 25	Intermittency at the McKinney Creek station
July	25	Large rain event occurred in segment three
July	26	Flow returned at stations below headcut structure and irrigation diversion
July	26	McKinney Creek station remained intermittent
August	3	Intermittency at headcut structure
August	9	Intermittency at irrigation diversion
September	14	Flows returned to McKinney Creek and station below irrigation structure
September	14 - 28	Substantial flows returned to station below headcut structure

Table 12. The number and proportion of juvenile and adult bluehead suckers, flannelmouth suckers, and roundtail chubs that were tagged in the study area, moved out of a tagging segment, or moved downstream of a tagging segment. P-values from chi-square tests assessing the proportions of tagged fish to the proportions of tagged fish that moved.

Category	Number		Proportion of adults	P-value
	Juvenile	Adult		
Bluehead suckers				
Tagged	305	605	0.66	
Moved out of tagging segment	28	47	0.63	0.6958
Moved downstream of tagging segment	26	42	0.62	0.8211
Flannelmouth suckers				
Tagged	55	21	0.28	
Moved out of tagging segment	2	1	0.33	0.8289
Moved downstream of tagging segment	2	1	0.33	0.8289
Roundtail chubs				
Tagged	138	271	0.66	
Moved out of tagging segment	3	32	0.91	0.0021
Moved downstream of tagging segment	3	24	0.89	0.0149

Table 13. The number and proportion of juvenile and adult bluehead suckers, flannelmouth suckers, and roundtail chubs that were tagged in segment three and were detected in McKinney Creek. P-values from chi-square tests comparing the total numbers of tagged fish to the numbers of tagged fish that moved.

	Tagged in Segment 3			McKinney Creek			
Species	Juvenile	Adult	Adult proportion	Juvenile	Adult	Adult proportion	P-value
Bluehead sucker	117	456	0.80	10	123	0.93	0.0005
Flannelmouth sucker	52	18	0.26	5	10	0.67	0.0022
Roundtail chub	76	172	0.69	6	37	0.86	0.0247

Table 14. Number of reaches sampled, total length (m) of each segment, length of segment sampled (m), and proportions of segments sampled in 2006.

Segment	Reaches sampled	Total length (m)	Length sampled (m)	Proportion sampled (%)
2	12	5,038	2,300	45.7
3	25	10,460	5,400	51.6
4	15	6,310	3,000	47.5

Table 15. Abundance estimates (N) and standard errors (SE) for 200-m reaches sampled in segment two of the Muddy Creek study area during 2006.

	Bluehead sucker		Flannelmouth sucker		White sucker		Hybrid catostomids		Roundtail chub	
Reach	N	SE	N	SE	N	SE	N	SE	N	SE
1					2	< 0.01	1	< 0.01		
4	16	3.46	1	< 0.01	15	4.24	7	< 0.01	3	2.45
5	5	2.45	5	< 0.01	31	4.90	4	< 0.01		
6			6	2.45	4	< 0.01	3	< 0.01	1	< 0.01
7	5	2.45	10	3.46	17	3.46	8	2.45	9	3.46
8	13	2.45	4	< 0.01	7	2.45	4	< 0.01	25	4.90
9	46	4.90	3	< 0.01	14	< 0.01	5	< 0.01	61	6.48
10	8	< 0.01	10	< 0.01	20	3.46	7	< 0.01	12	3.46
14	4	< 0.01	1	< 0.01	2	< 0.01	2	< 0.01	26	5.48
21	15	4.24	2	< 0.01	22	4.24	11	< 0.01	26	4.24
22	13	2.45	1	< 0.01	7	< 0.01	13	3.46	13	2.45
23	7	2.45	5	2.45	44	6.93	12	3.46	27	2.45

Table 16. Abundance estimates (N) and standard errors (SE) for 200-m reaches sampled in segment three during 2006.

	Bluehead sucker		Flannelmouth sucker		White sucker		Hybrid catostomid		Roundtail chub	
Reach	N	SE	N	SE	N	SE	N	SE	N	SE
2	7	2.45	4	< 0.01	17	4.90	7	2.45	33	3.46
3	9	3.46	4	< 0.01	7	2.45	6	< 0.01		
4	2	< 0.01	2	< 0.01	11	3.46	3	< 0.01	3	< 0.01
5	1	< 0.01	7	2.45	12	< 0.01	6	< 0.01	7	2.45
6	3	< 0.01	8	2.45	5	2.45	5	2.45	3	2.45
8	26	2.45	1	< 0.01	19	2.45	4	< 0.01	29	4.90
9	36	4.24	3	< 0.01	16	3.46	18	3.46	43	5.48
10	13	3.46	4	< 0.01	21	2.45	14	2.45	22	3.46
11	35	3.46	5	< 0.01	16	2.45	18	4.24	45	5.48
14	1	< 0.01	7	2.45	34	4.24	3	< 0.01	28	4.24
15	21	3.46	8	2.45	27	3.46	8	< 0.01	24	4.24
16	34	4.24	13	3.46	13	2.45	16	2.45	46	7.35
17	14	3.46	14	3.46	21	2.45	1	< 0.01	44	6.00
19	74	8.49	2	< 0.01	19	< 0.01	6	2.45	49	7.35
20	6	< 0.01	9	2.45	45	4.90	7	< 0.01	47	6.48
21	12	2.45	6	2.45	12	< 0.01	6	2.45	67	8.12
26	16	2.45	8	< 0.01	34	4.90	20	4.24	103	9.49
27	11	3.46	3	< 0.01	19	4.24	3	< 0.01	63	8.49
30	49	5.48	6	2.45	11	< 0.01	8	< 0.01	58	7.35
37	66	6.00	8	< 0.01	23	3.46	2	< 0.01	47	5.48
43	29	3.46	17	4.24	27	4.24	15	3.46	37	6.00
47	17	4.90	14	2.45	23	3.46	5	< 0.01	43	5.48
48	25	3.46	6	< 0.01	22	4.90	5	< 0.01	58	6.48
50	117	9.80	9	2.45	37	6.00	23	3.46	46	6.00
51	31	3.46	5	< 0.01	34	2.45	28	4.90	54	4.90

Table 17. Abundance estimates (N) and standard errors (SE) for 200-m reaches sampled in segment four of the Muddy Creek study area during 2006.

	Bluehead sucker		Flannelmouth sucker		White sucker		Hybrid catostomid		Roundtail chub	
Reach	N	SE	N	SE	N	SE	N	SE	N	SE
2	6	< 0.01	1	< 0.01	37	4.24	11	< 0.01		
5					96	7.35	1	< 0.01	3	< 0.01
7	1	< 0.01			46	3.46	4	< 0.01	2	< 0.01
8	3	< 0.01			63	< 0.01	1	< 0.01	5	2.45
9	22	4.24	2	< 0.01	105	5.48	8	< 0.01	4	< 0.01
11	1	< 0.01			46	3.46	4	< 0.01	2	< 0.01
16			4	2.45	148	9.49	10	2.45	10	3.46
18	2	< 0.01			78	6.93	6	< 0.01	16	4.90
21	14	2.45	2	< 0.01	59	3.46	6	< 0.01	18	2.45
22	8	2.45	2	< 0.01	65	6.48	10	< 0.01	31	4.90
25	3	2.45			96	7.35			3	< 0.01
28	1	< 0.01			52	5.48	5	< 0.01	16	2.45
30	10	3.46	3	< 0.01	29	6.00	4	2.45	13	3.46
31	2	< 0.01			18	2.45	3	2.45	9	2.45
32	6	< 0.01	2	< 0.01	26	3.46	2	< 0.01	9	2.45

Table 18. Abundance estimates (N), standard errors (SE), and density (fish/100 m) within each segment for bluehead suckers, flannelmouth suckers, white suckers, hybrid catostomids, and roundtail chubs in 2006.

Segment	Habitat	Number	SE	95% Confidence Interval	Density
		Bluehead sucker			
2		289	20	250 - 328	5.74
3		1,269	40	1,191 - 1,347	12.13
4	Natural	129	11	107 - 151	3.11
4	Altered	14	8	0 - 30	0.64
All		1,701	47	1608 - 1793	8.31
		Flannelmouth sucker			
2		105	11	84 - 126	2.08
3		335	19	298 - 372	3.20
4	Natural	21	<0.001	21 - 21	0.50
4	Altered	14	8	0 - 30	0.64
All		475	23	430 - 520	2.32
		White sucker			
2		405	26	355 - 456	8.04
3		1,017	33	952 - 1,082	9.72
4	Natural	1,160	30	1,101 - 1,218	27.98
4	Altered	1,003	43	918 - 1,088	46.30
All		3,585	67	3,454 - 3716	17.52
		Hybrid catostomid			
2		169	12	145 - 192	3.35
3		459	22	415 - 503	4.39
4	Natural	105	6	93 - 117	2.53
4	Altered	48	8	44 - 65	2.23
All		781	27	728 - 834	3.82
		Roundtail chub			
2		445	27	391 - 498	8.83
3		1,935	56	1,826 - 2,044	18.50
4	Natural	217	16	185 - 249	5.23
4	Altered	52	12	28 - 75	2.39
All		2,649	65	2522 - 2776	12.95

Table 19. Abundance estimates within each segment for bluehead suckers, flannelmouth suckers, white suckers, hybrid catostomids, and roundtail chubs in 2006.

	Segment		
Species	2	3	4
Bluehead sucker	289	1,269	144
Flannelmouth sucker	105	335	35
White sucker	405	1,017	2,163
Hybrid catostomids	169	459	153
Roundtail chub	445	1,935	269

Table 20. The proportion of juveniles and adults in segments two, three, and four based on the actual number collected and abundance estimates (N). A 150-mm total length was used to separate bluehead sucker and roundtail chub juveniles from adults, and a 250-mm total length separated juvenile and adult flannelmouth suckers. Total species abundance estimates (N) were divided into juvenile and adult groupings based on the proportion of each group in the number sampled.

	Number		Juvenile		Adult	
Segment	collected	N	Proportion	N	Proportion	N
			Bluehead sucker			
2	99	289	0.45	130	0.55	159
3	492	1,269	0.58	736	0.42	533
4	84	143	0.13	19	0.87	124
			Flannelmouth sucker			
2	37	105	0.59	62	0.41	43
3	144	335	0.51	171	0.49	164
4	14	35	0.36	13	0.64	23
			Roundtail chub			
2	120	445	0.50	223	0.50	222
3	749	1,935	0.55	1064	0.45	871
4	99	269	0.06	16	0.94	253

Table 21. Density (fish/100 m) of bluehead suckers, flannelmouth suckers, and roundtail chubs less than 100 mm total length collected in 2006.

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

Table 22. The number and mean total length (TL, millimeters) of catostomid larvae collected from McKinney Creek on July 11, 2005.

	Species		
Variable	Bluehead sucker	Flannelmouth sucker	White sucker
Number	53	13	142
Mean TL	14.9	18.1	17.0

Table 23. Bluehead sucker estimated age, mean total length (TL, millimeters) at each age, 95% confidence intervals, range, and number captured in segment three, 2006.

Age	Mean TL	95% confidence interval	Range	Number
2	110	108 - 111	100 - 134	72
3	135	130 - 139	115 - 163	31
4	167	157 - 176	135 - 216	18
5	189	185 - 195	165 - 221	35
6	207	199 - 216	183 - 253	22
7	216	205 - 227	190 - 253	13
8	252	245 - 259	246 - 259	5
9	253	245 - 261	249 - 255	3

Table 24. Flannelmouth sucker estimated age, mean total length (TL, millimeters) at each age, 95% confidence intervals, range, and number captured in segment three, 2006.

Age	Mean TL	95% Confidence Interval	Range	Number
2	120	115 - 126	105 - 138	17
3	151	142 - 160	125 - 187	21
4	182	164 - 200	140 - 262	16
5	228	199 - 257	188 - 256	6
6	245	217 - 273	199 - 364	13
7	263	219 - 306	231 - 319	5
8	277	244 -311	244 - 342	7
9	373	321 - 426	315 - 415	5
10	361	325 - 398	270 - 430	9
11	375	340 - 409	308 - 470	10
12	382	350 - 414	344 - 443	7
13	384	372 - 396	357 - 404	9
14	397	382 - 412	374 - 410	7
15	386	363 - 410	379 - 397	3
16	387	367 - 407	366 - 408	5
17	358			1

Table 25. Roundtail chub estimated age, mean total length (TL, millimeters) at each age, 95% confidence intervals, range, and number segment three, 2006.

Age	Mean TL	95% Confidence Interval	Range	Number
2	113	108 - 117	100 - 156	36
3	117	113 - 120	100 - 154	63
4	144	134 - 154	105 - 193	24
5	166	160 - 171	147 - 186	17
6	191	172 - 209	157 - 260	12
7	195	172 - 218	155 - 257	9
8	222	206 - 239	172 - 275	18
9	247	166 - 328	205 - 311	4
10	258	218 - 297	210 - 295	5
11	272	233 - 312	214 - 339	7
12	280	239 - 321	242 - 299	4

Table 26. Comparison of mean total lengths (TL, millimeters) at ages of flannelmouth suckers collected from the Colorado, Green, Gunnison, and Yampa Rivers (McAda 1977) and collected from Muddy Creek, Wyoming.

Mean total length at age																	Background information	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Structure	Source
64	127	249	353	422	460	480	490										Scales	McAda, 1977
	120	151	182	228	245	263	277	373	361	375	382	384	397	386	387	358	Fin rays	This study

Table 27. Comparison of mean total lengths at ages (TL, millimeters) of roundtail chubs from past studies including river, state, structure aged, and author.

Mean total length at age												Background information			
1	2	3	4	5	6	7	8	9	10	11	12	River	State	Structure	Source
64	114	165	230	277	334	357						Green	WY	Scales	Vanicek and Kramer, 1969
79	131	179	218	252	287	294						Gila	NM	Scales	Bestgen, 1985
101	181	243	297	340	381	412						Verde	AZ	Otolith	Brouder, 2006
	113	117	144	166	191	195	222	247	258	272	280	Muddy	WY	Fin Rays	This study

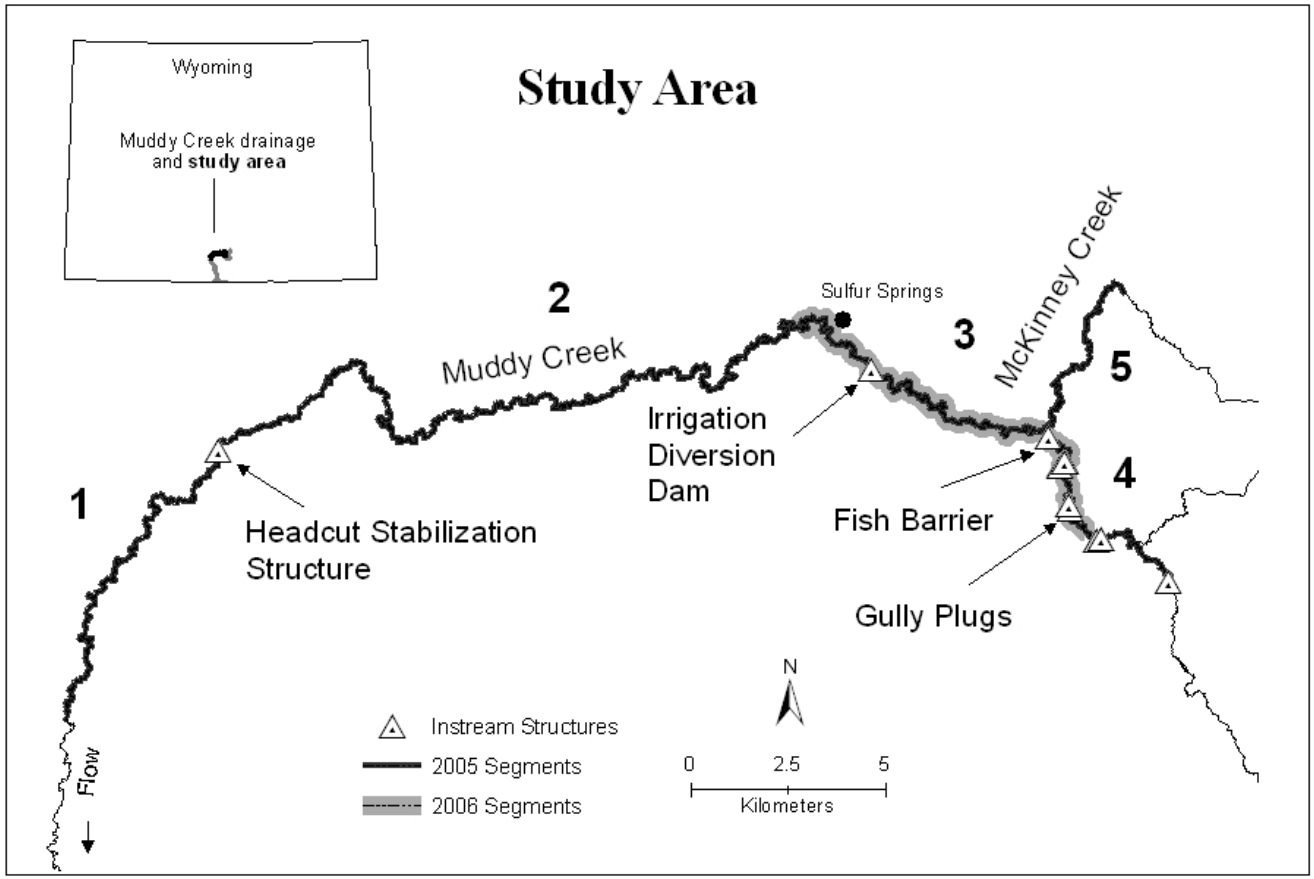


Figure 1. Study area and instream structures within Muddy Creek, Carbon County, Wyoming. Segments are represented by bold numbers.

Figure 2. Gully plugs located in segment four. Photograph was taken June 25, 2005.

Figure 3. Fish barrier constructed of rock gabions and located between segments three and four. Photograph was taken May 5, 2005.

Figure 4. Irrigation diversion dam located between segments two and three. Top photograph was taken May 6, 2005 and bottom photograph was taken August 7, 2005.

Figure 5. Headcut stabilization structure located between segments one and two. Photograph was taken April 13, 2005.

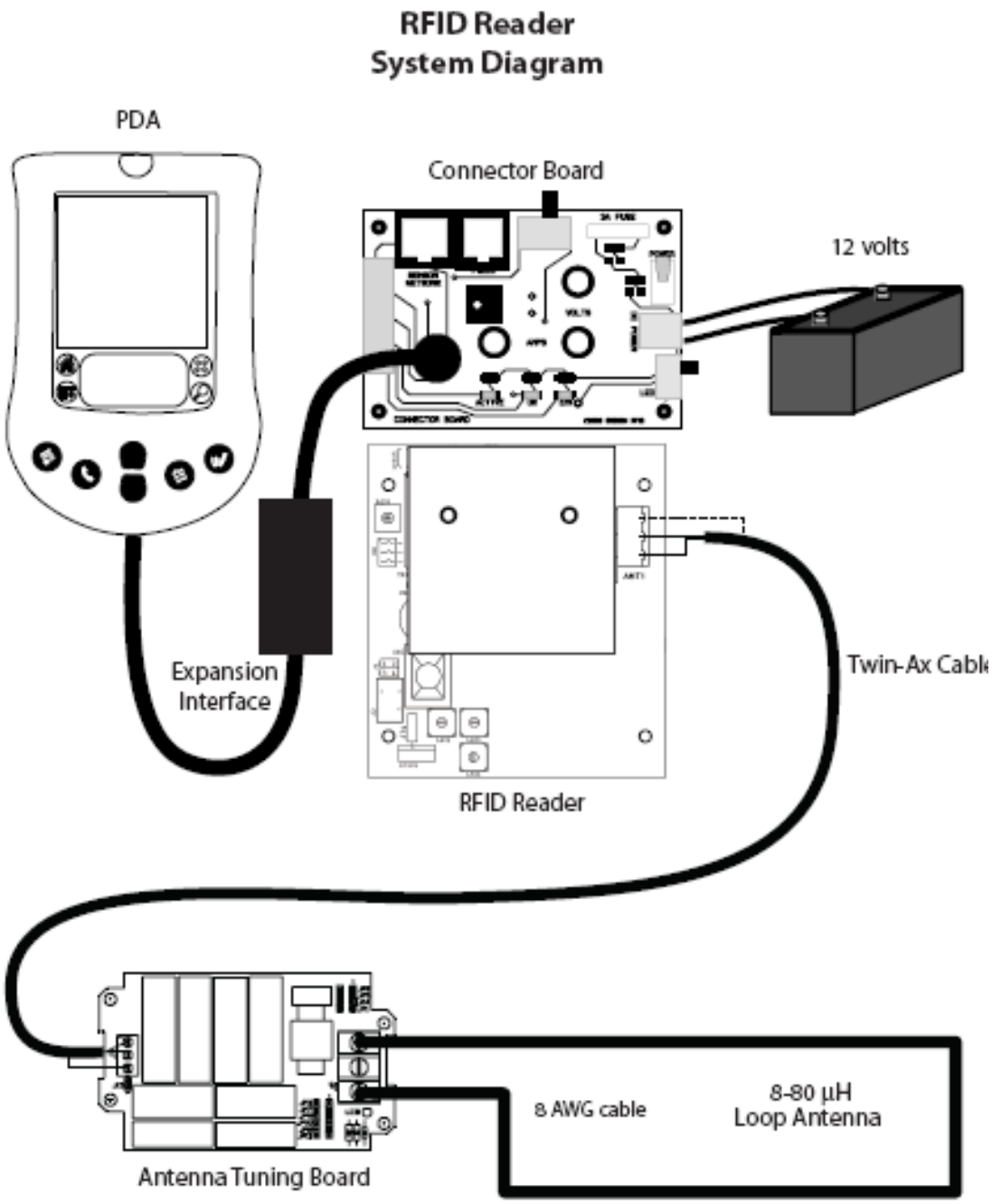
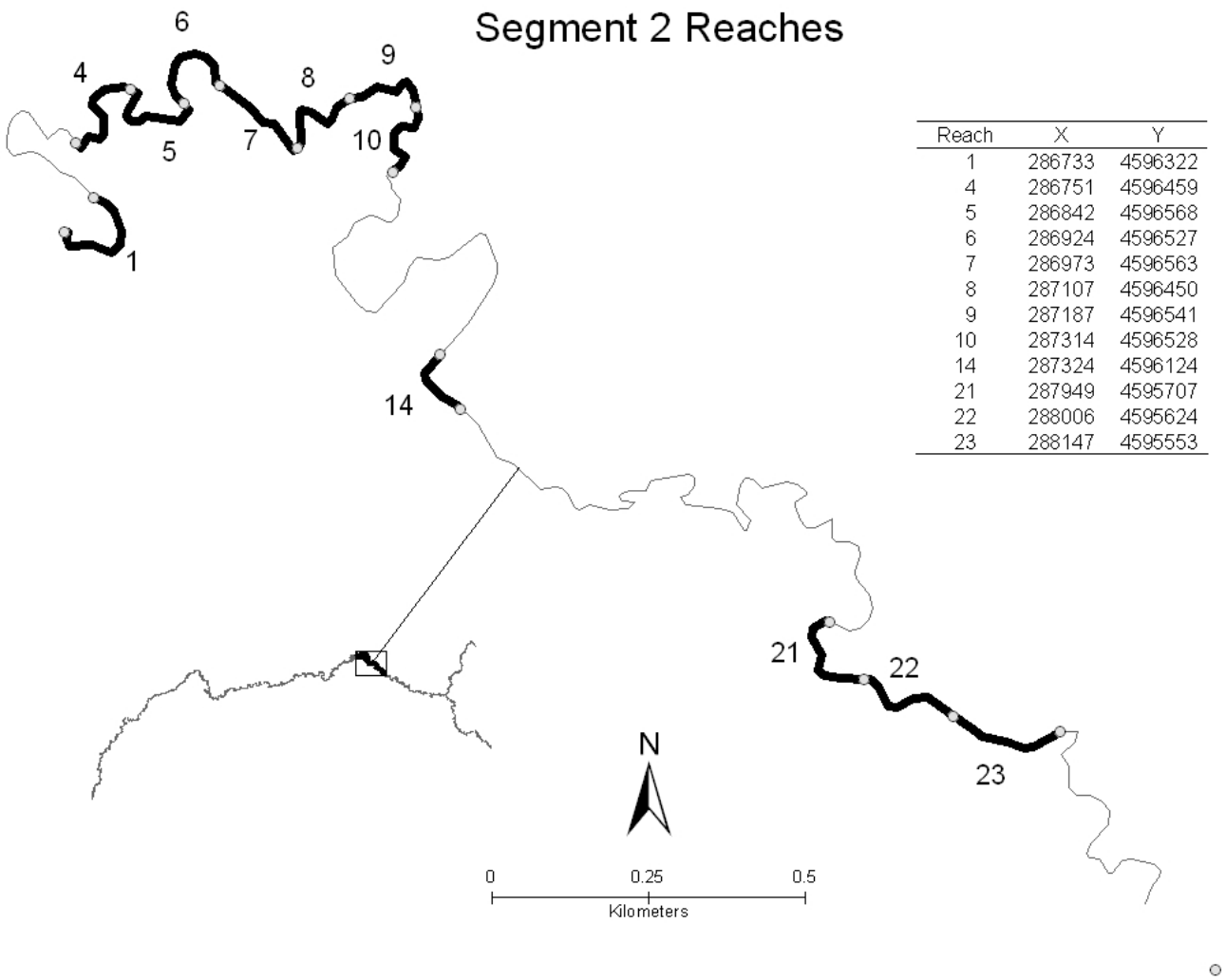


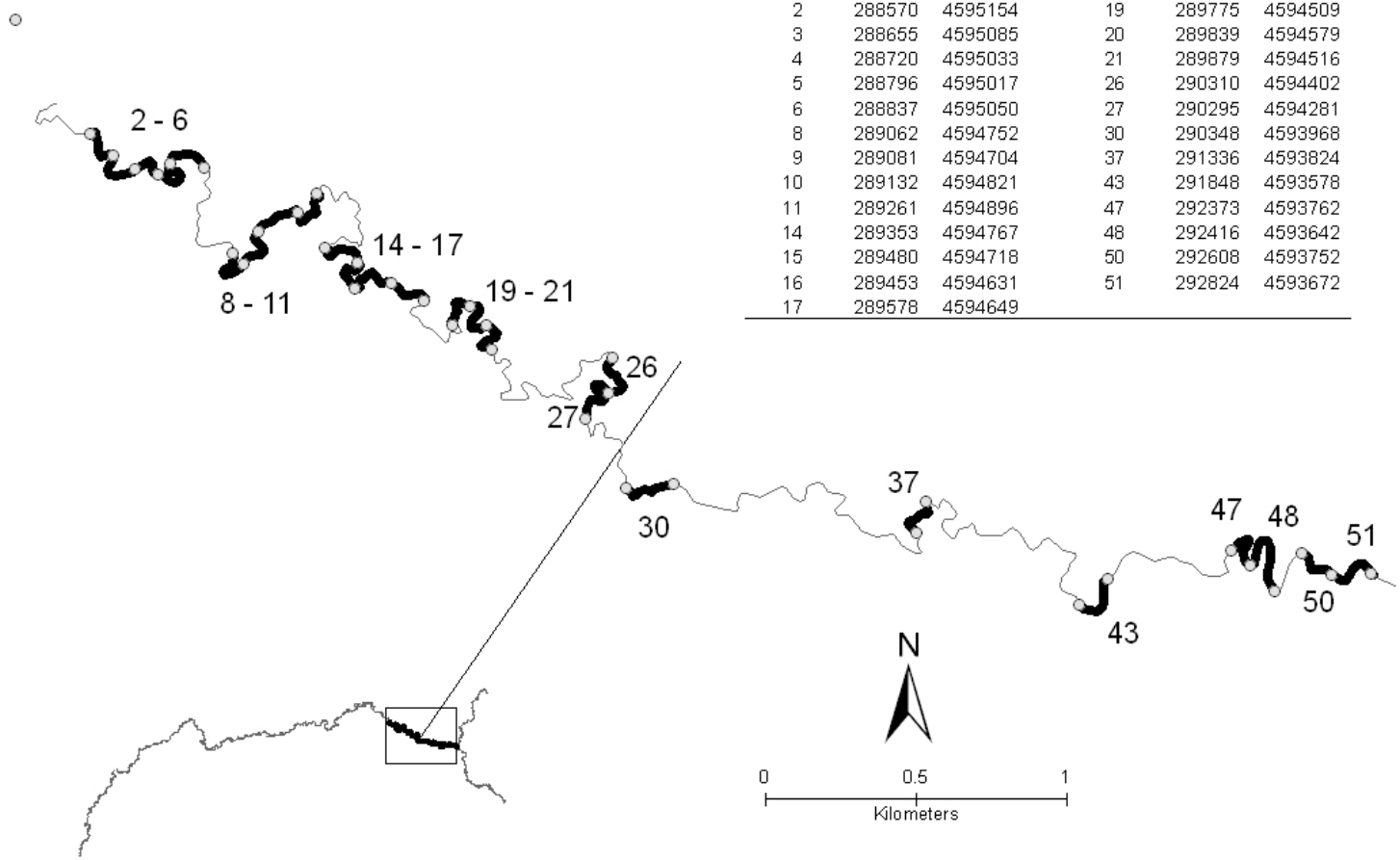
Figure 6. Antenna design configuration. Image created by Oregon RFID, Portland, Oregon.



Reach	X	Y
1	286733	4596322
4	286751	4596459
5	286842	4596568
6	286924	4596527
7	286973	4596563
8	287107	4596450
9	287187	4596541
10	287314	4596528
14	287324	4596124
21	287949	4595707
22	288006	4595624
23	288147	4595553

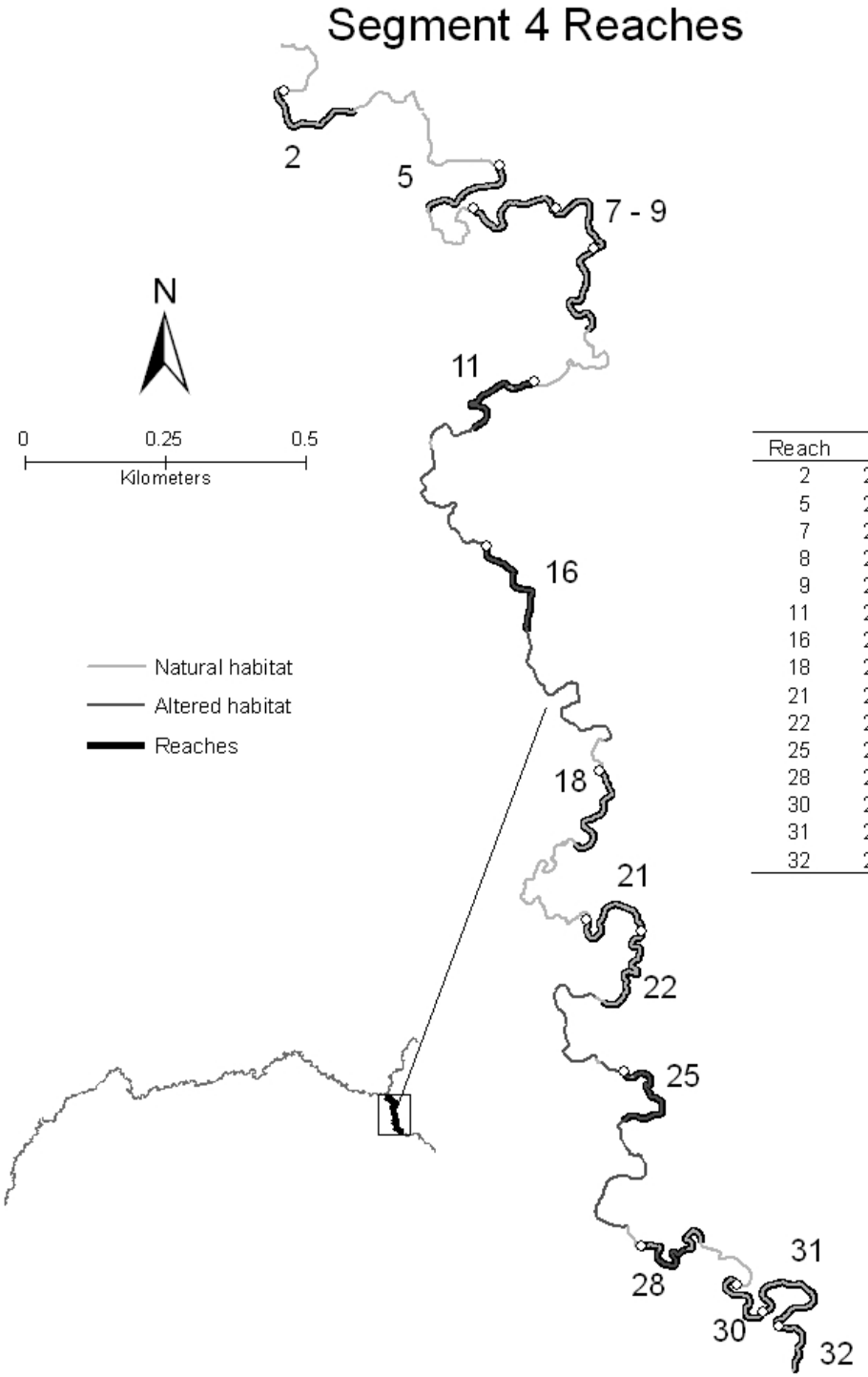
Figure 7. Reaches sampled within segment 2, 2006. The coordinates (UTM projection, NAD 83, Zone 13) corresponds to the downstream end of each reach and are reported in the table.

Segment 3 Reaches



Reach	X	Y	Reach	X	Y
2	288570	4595154	19	289775	4594509
3	288655	4595085	20	289839	4594579
4	288720	4595033	21	289879	4594516
5	288796	4595017	26	290310	4594402
6	288837	4595050	27	290295	4594281
8	289062	4594752	30	290348	4593968
9	289081	4594704	37	291336	4593824
10	289132	4594821	43	291848	4593578
11	289261	4594896	47	292373	4593762
14	289353	4594767	48	292416	4593642
15	289480	4594718	50	292608	4593752
16	289453	4594631	51	292824	4593672
17	289578	4594649			

Figure 8. Reaches sampled within segment 3, 2006. The coordinates (UTM projection, NAD 83, Zone 13) corresponds to the downstream end of each reach and are reported in the table.



Reach	X	Y
2	292972	4593443
5	293355	4593308
7	293310	4593231
8	293455	4593231
9	293522	4593158
11	293417	4592921
16	293331	4592624
18	293533	4592219
21	293511	4591953
22	293608	4591932
25	293577	4591680
28	293607	4591366
30	293778	4591297
31	293823	4591248
32	293855	4591190

Figure 9. Reaches sampled within segment 4, 2006. The coordinates (UTM projection, NAD 83, Zone 13) corresponds to the downstream end of each reach and are reported in the table.

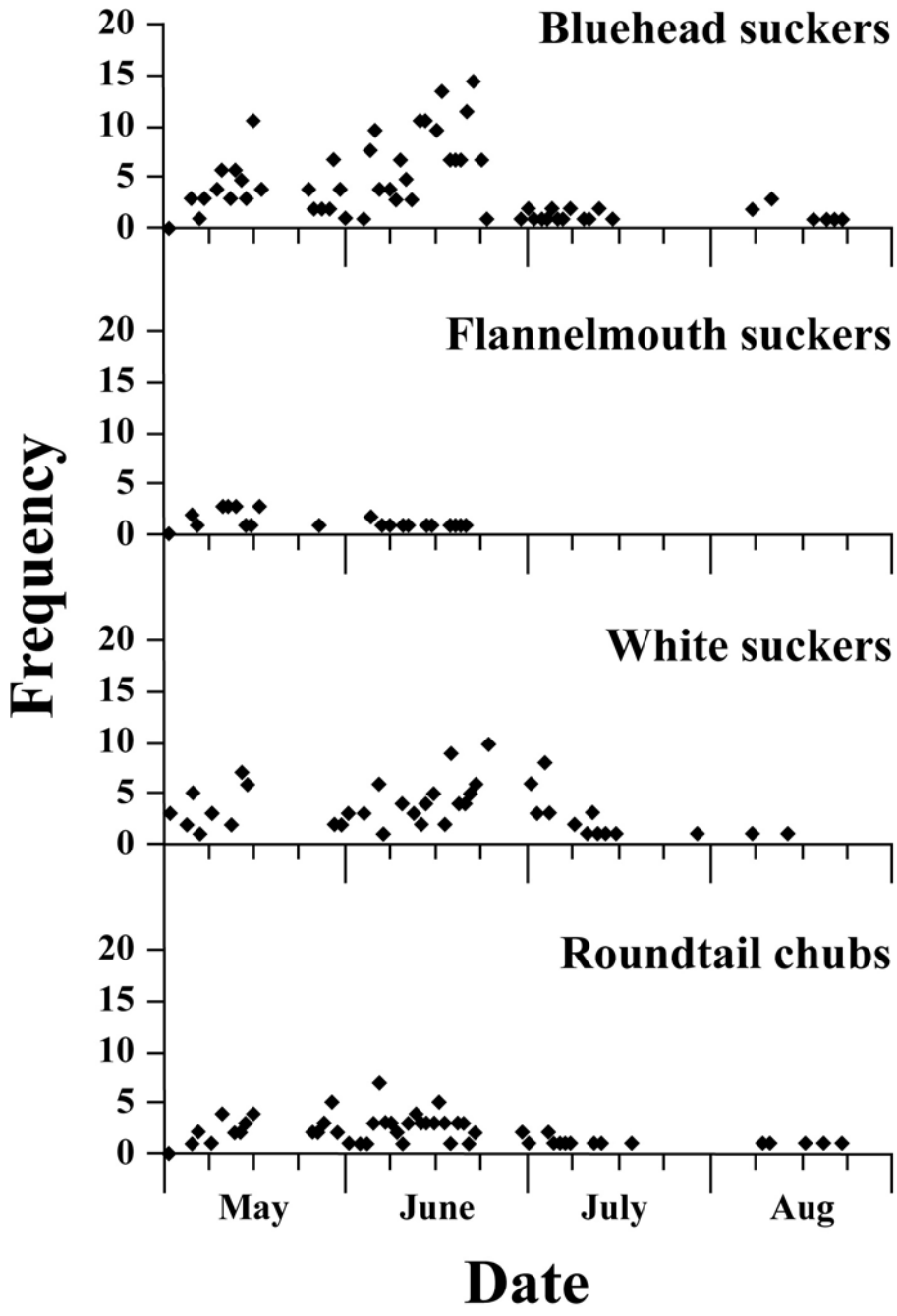


Figure 10. The number of PIT tagged fish detected per day (frequency) at the passive monitoring station in McKinney Creek in 2005.

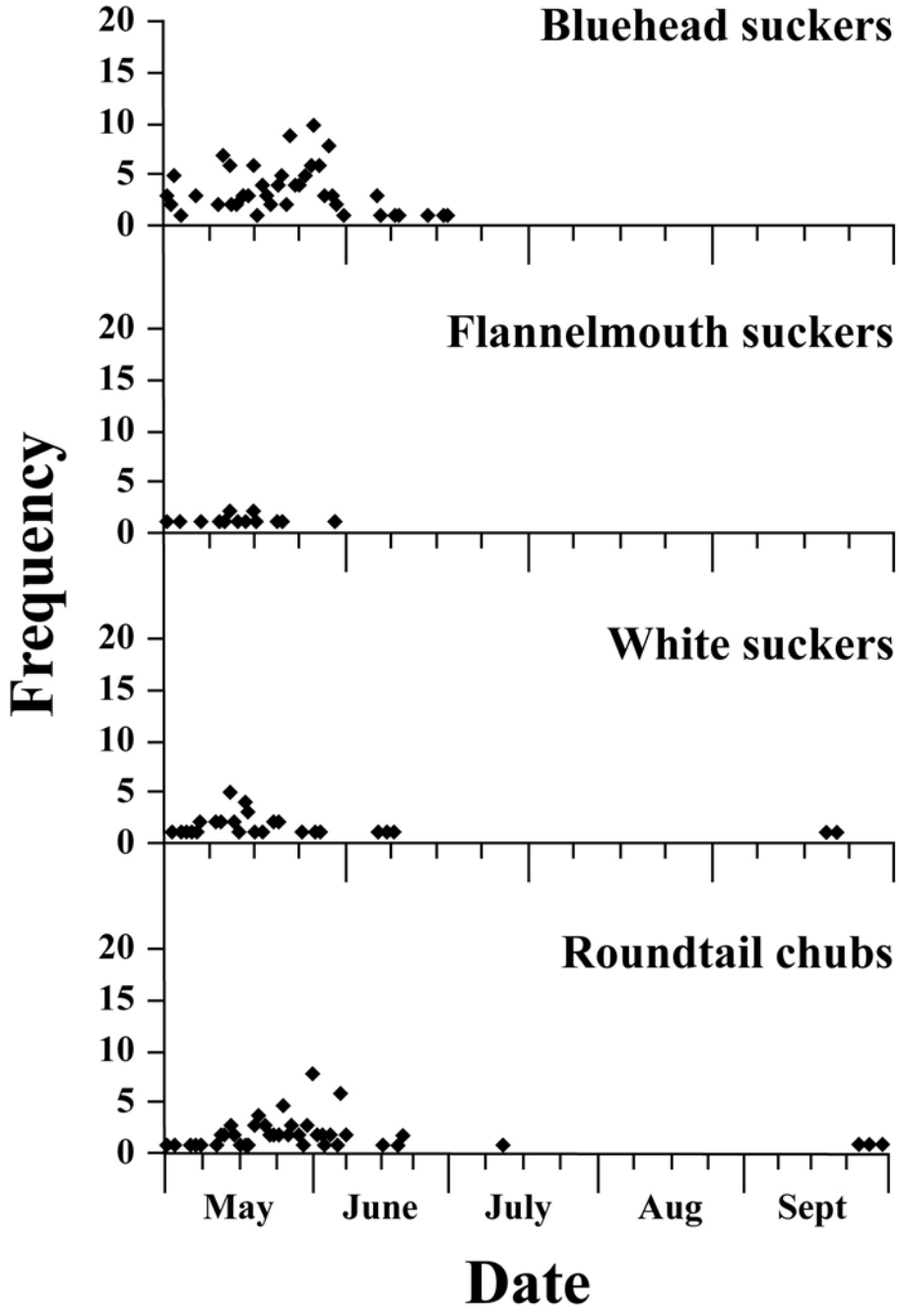


Figure 11. The number of PIT tagged fish detected per day (frequency) at the passive monitoring station in McKinney Creek in 2006.

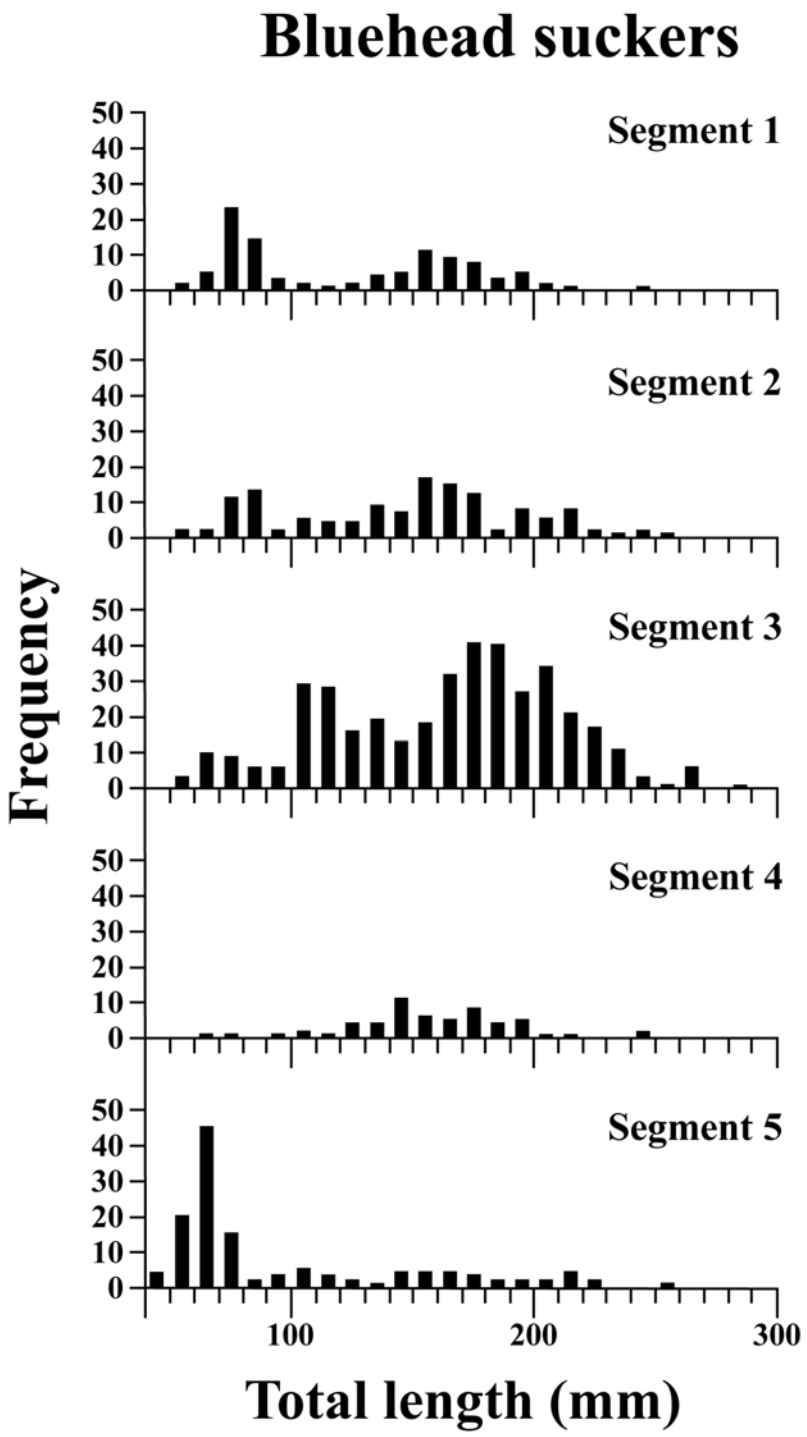


Figure 12. Length frequency (total length, mm) of bluehead suckers collected within each segment in 2005.

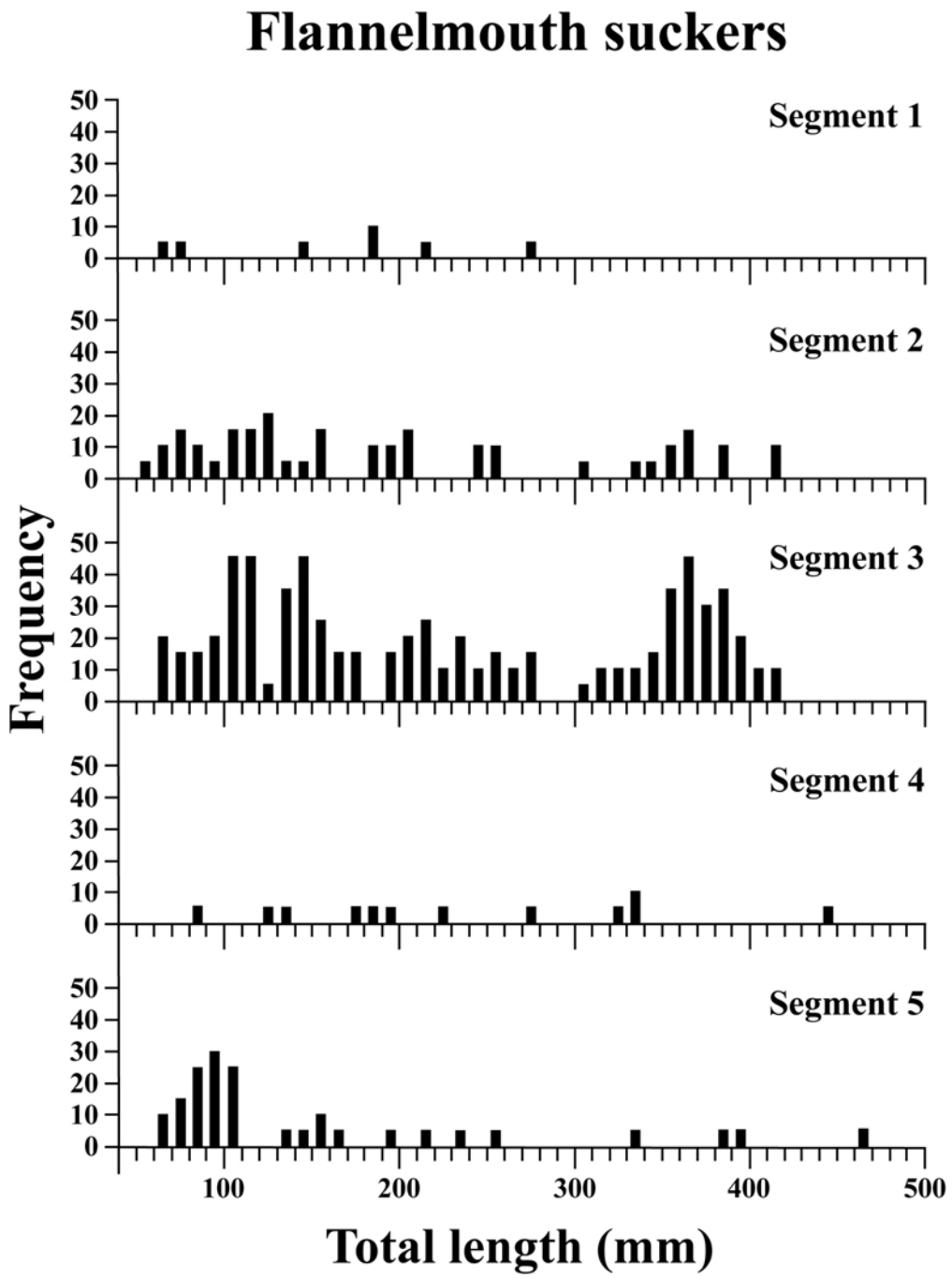


Figure 13. Length frequency (total length, mm) of flannelmouth suckers collected within each segment in 2005.

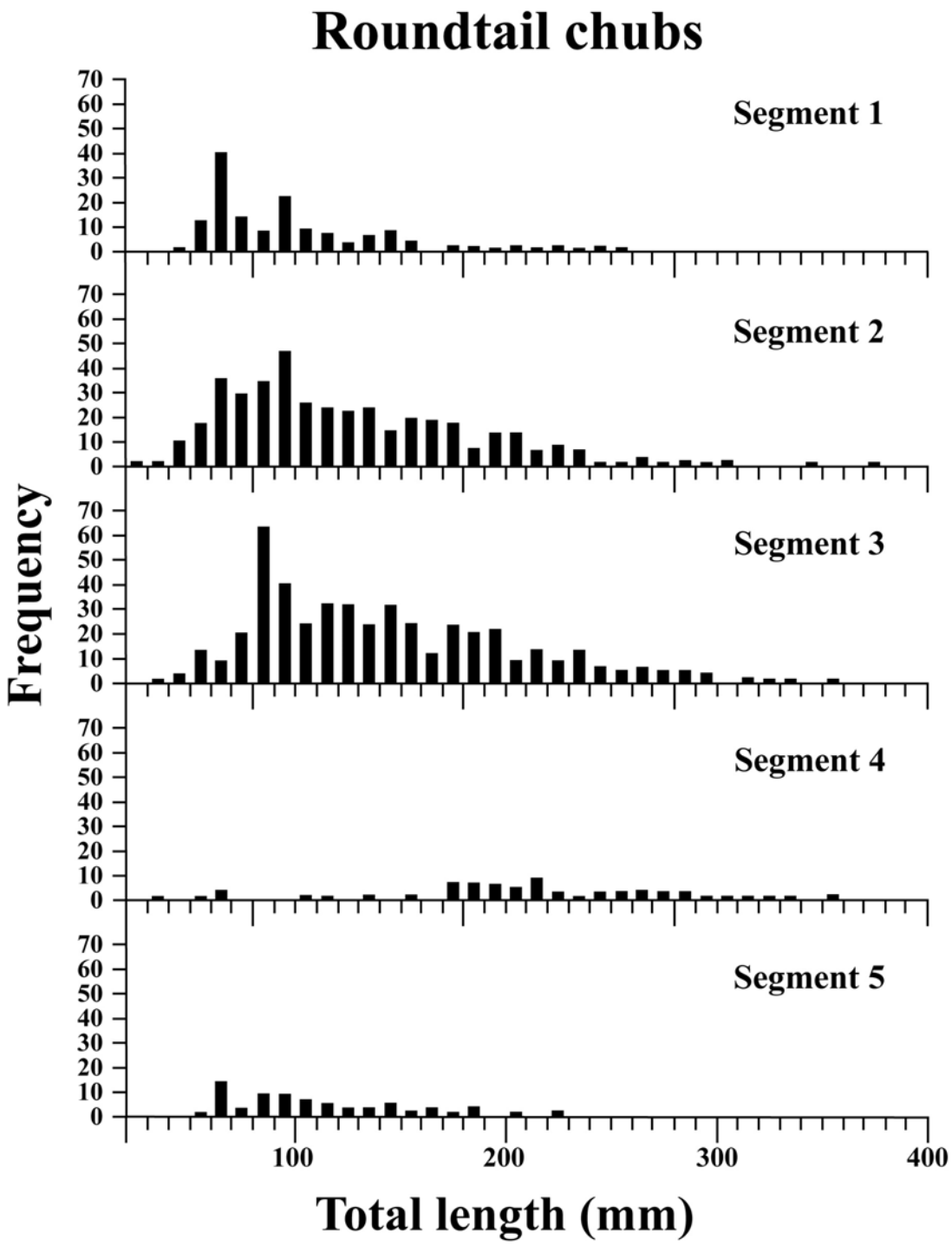


Figure 14. Length frequency (total length, mm) of roundtail chubs collected within each segment in 2005.

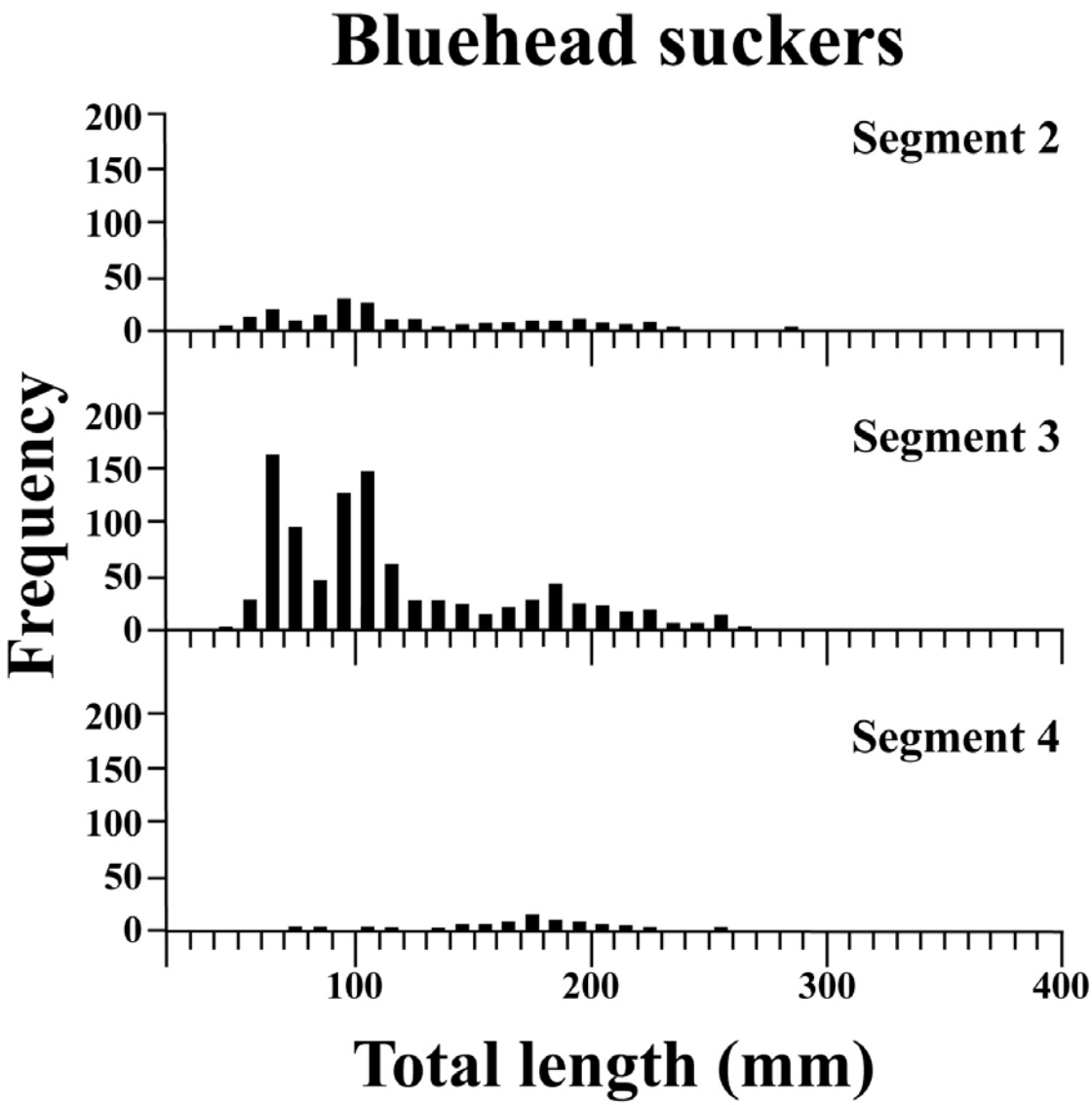


Figure 15. Length frequency (total length, mm) of bluehead suckers collected within each segment in 2006.

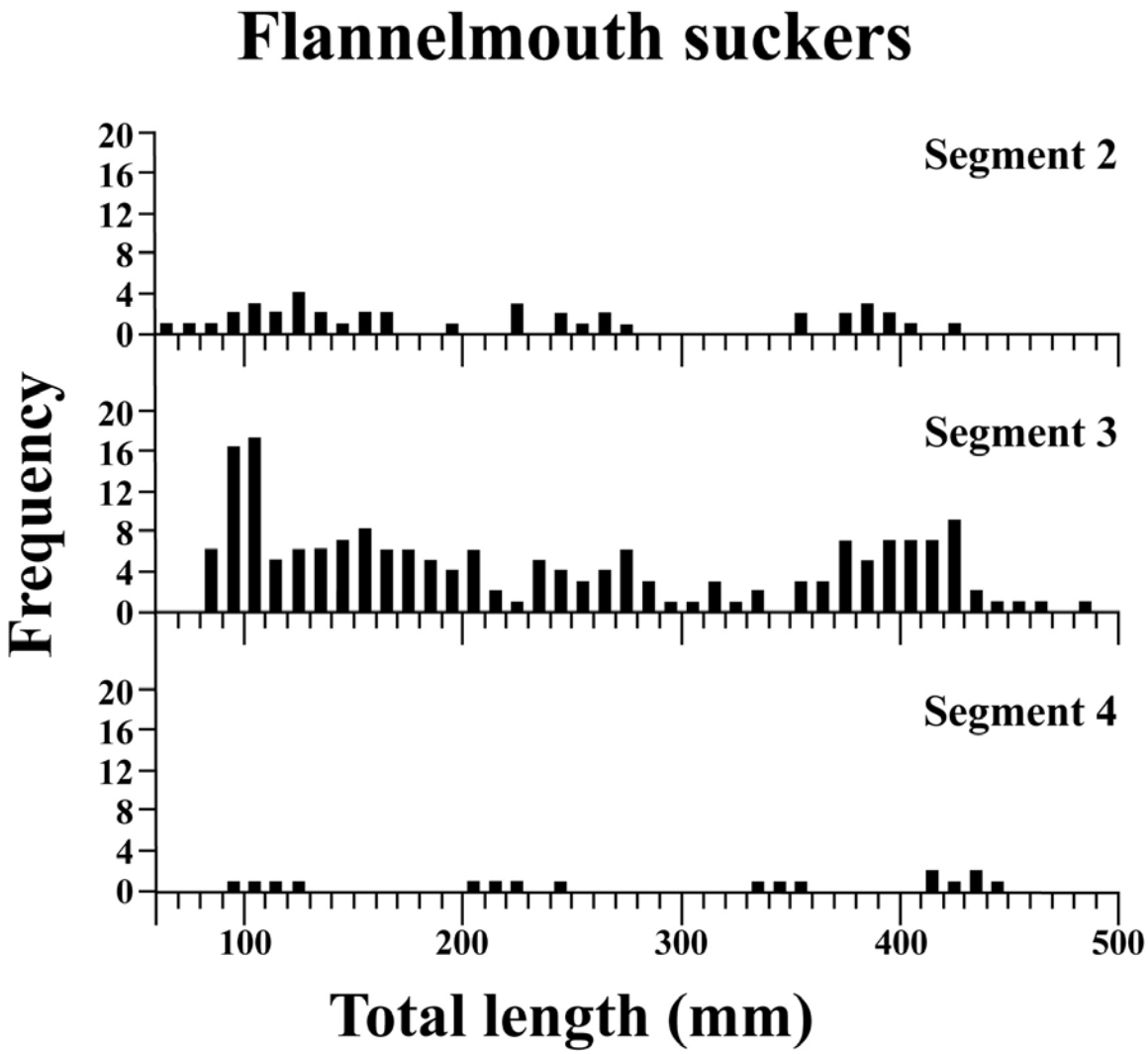


Figure 16. Length frequency (total length, mm) of flannelmouth suckers collected within each segment in 2006.

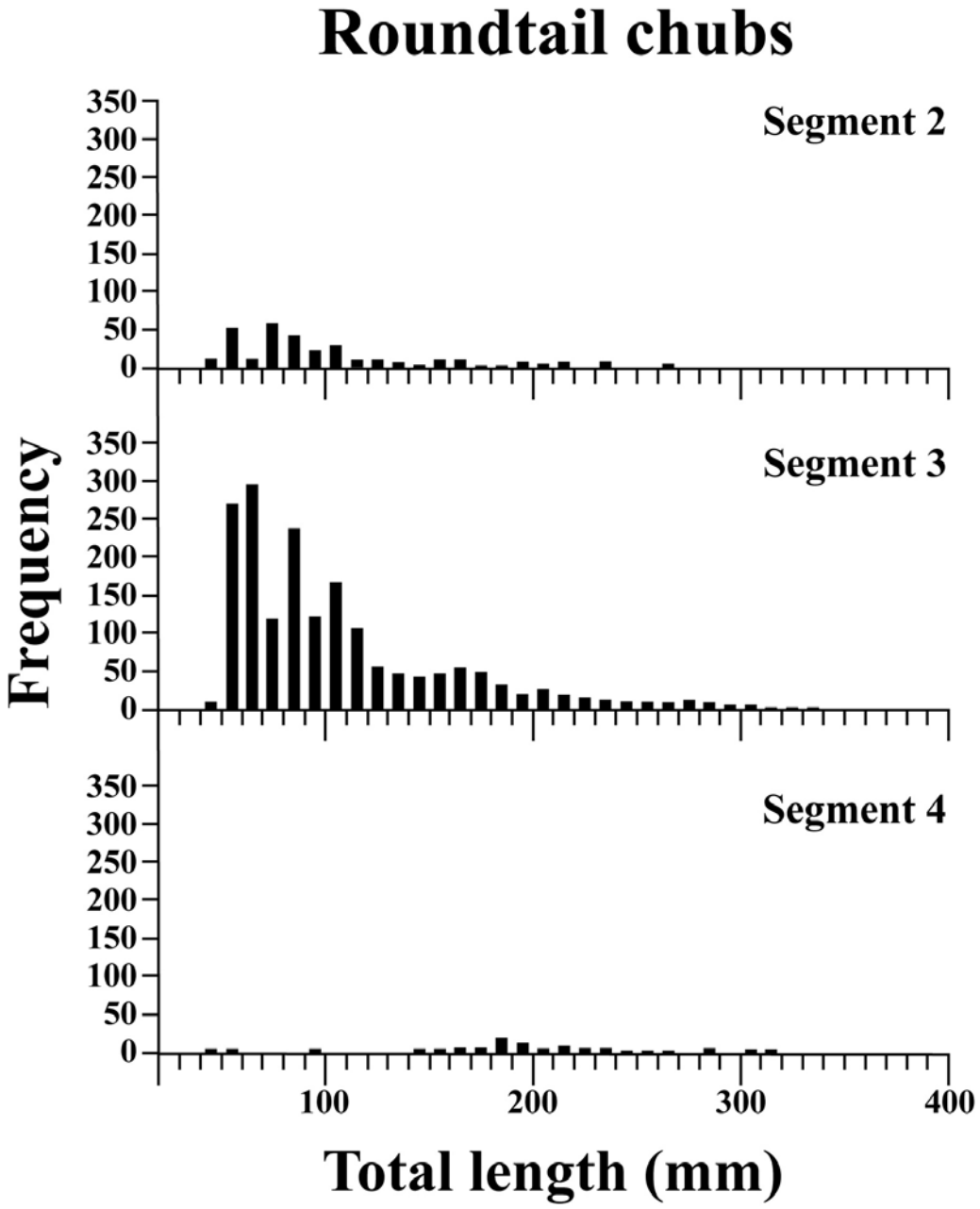


Figure 17. Length frequency (total length, mm) of roundtail chubs collected within each segment in 2006.

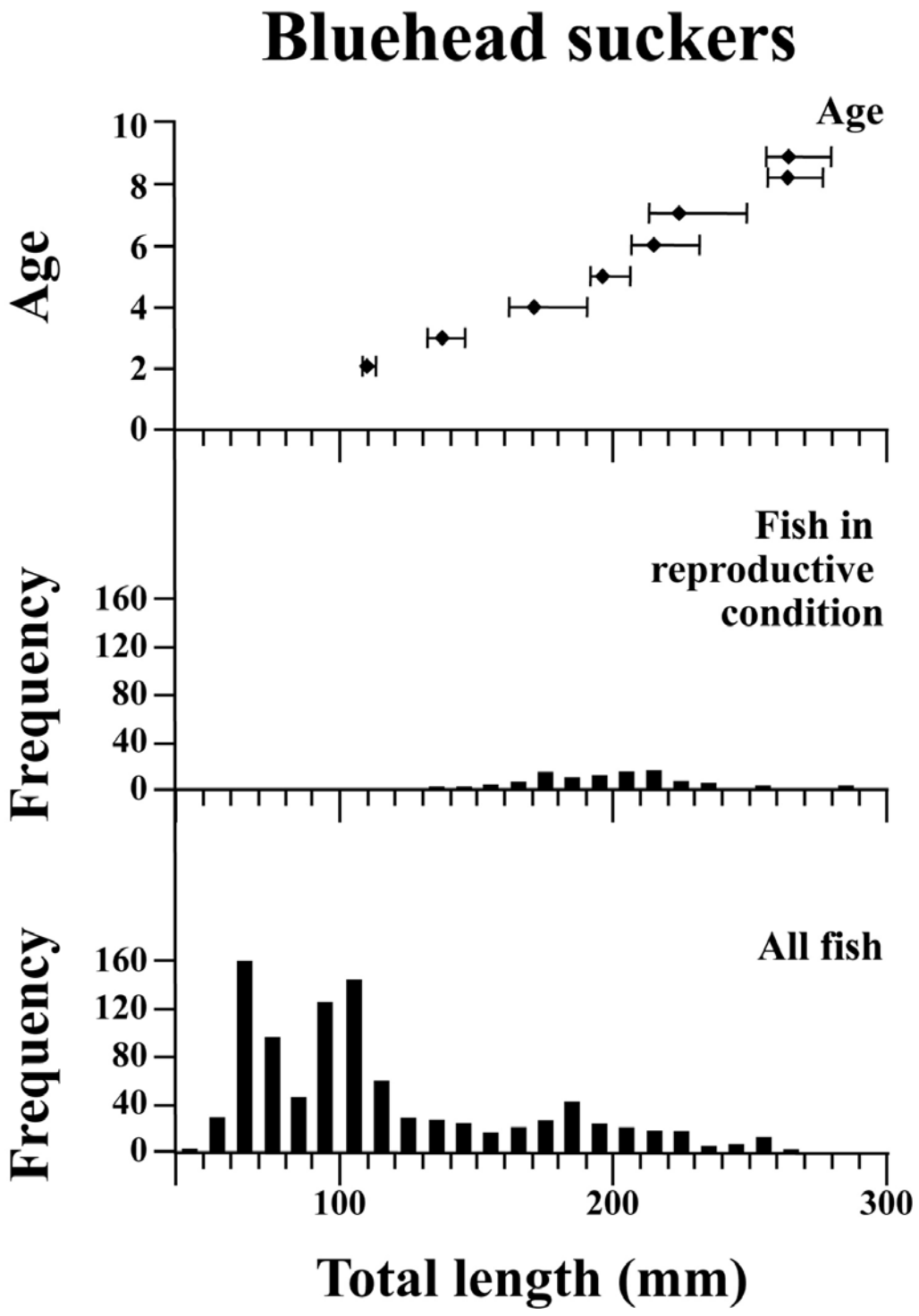


Figure 18. Bluehead sucker ages bounded by 95% confidence intervals, length ranges of fish with reproductive characteristics, and length frequencies in segment three, 2006.

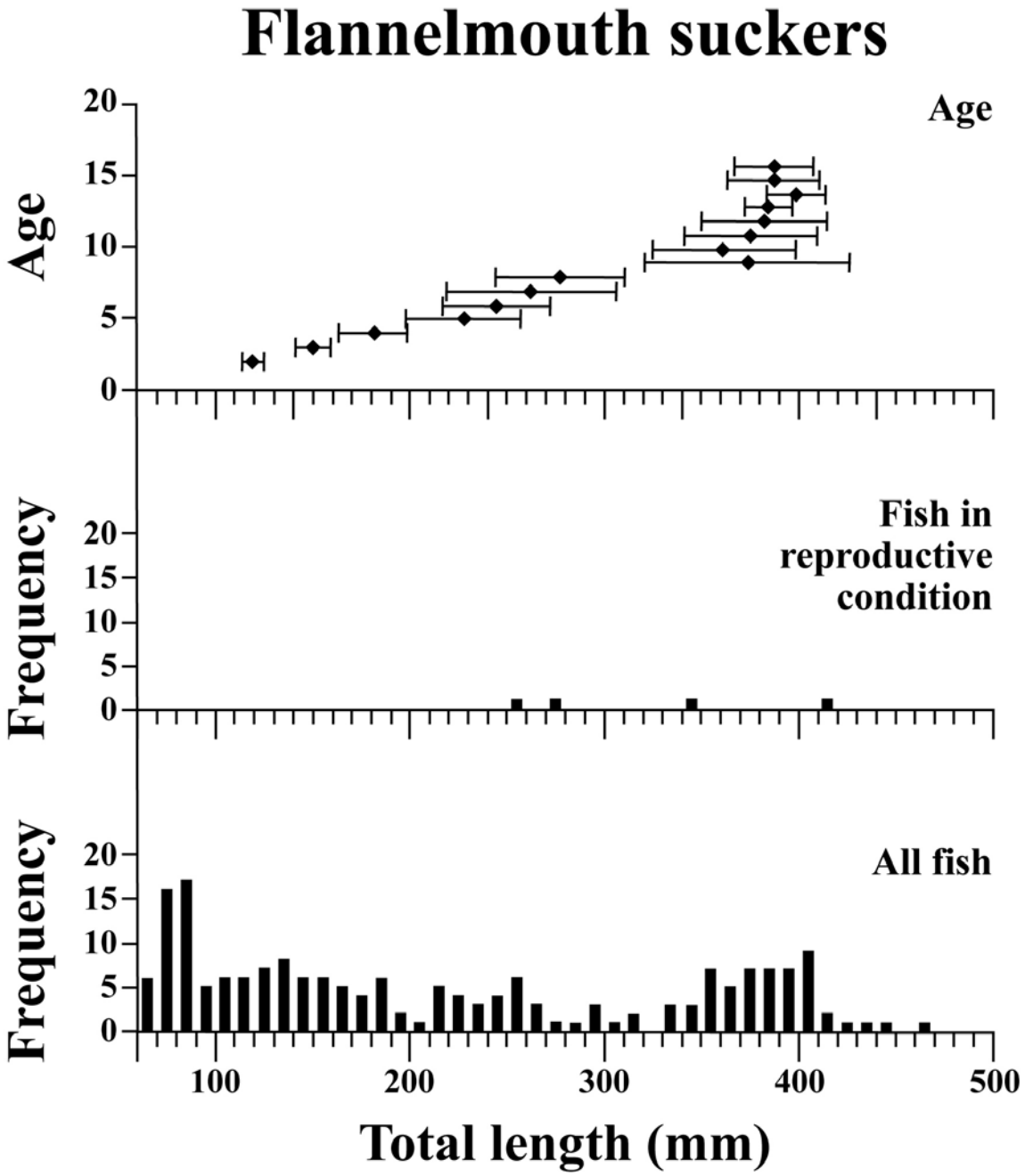


Figure 19. Flannelmouth sucker ages bounded by 95% confidence intervals, length ranges of fish with reproductive characteristics, and length frequencies in segment three, 2006.

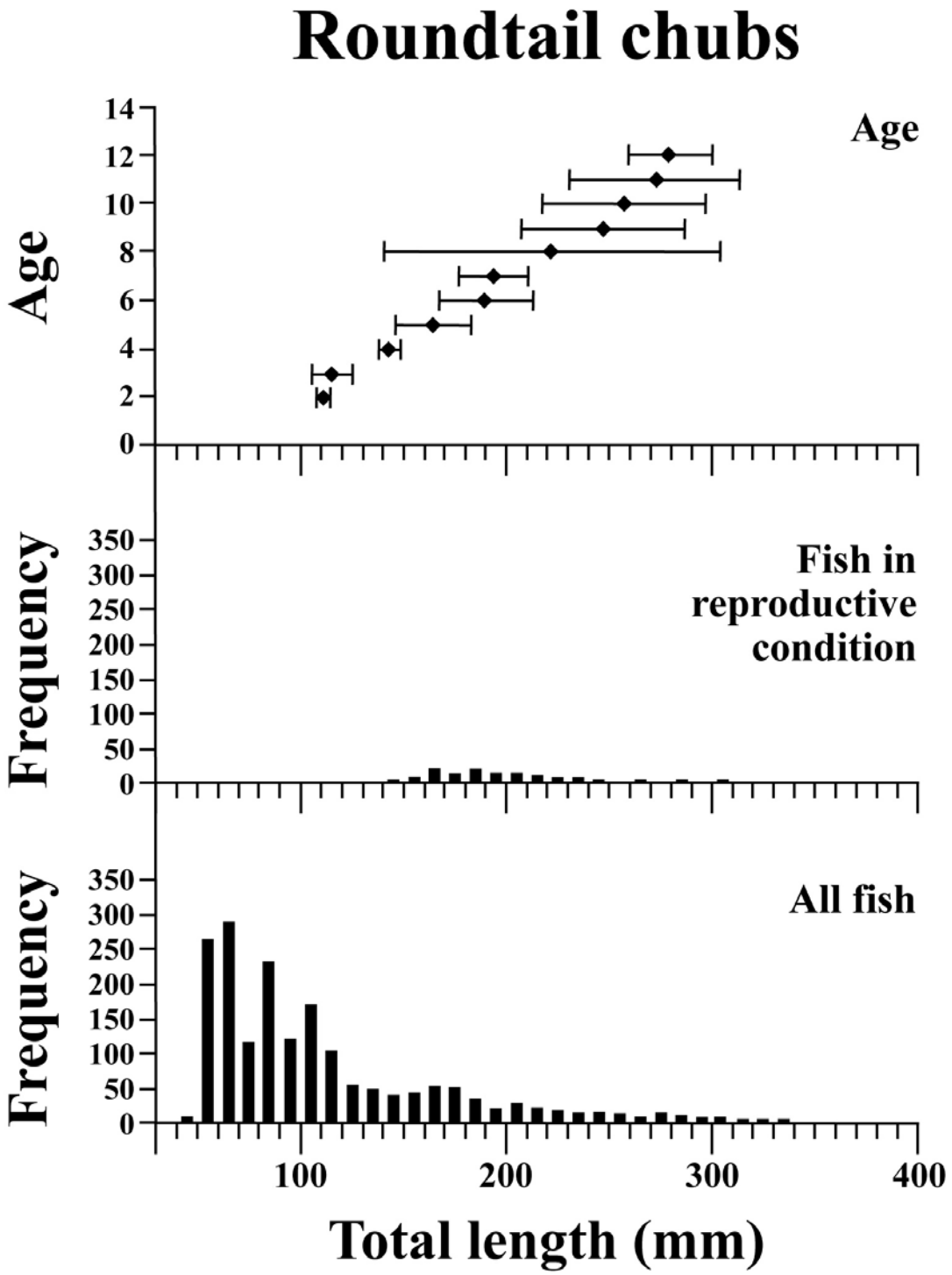


Figure 20. Roundtail chub ages bounded by 95% confidence intervals, length ranges of fish with reproductive characteristics, and length frequencies in segment three, 2006.

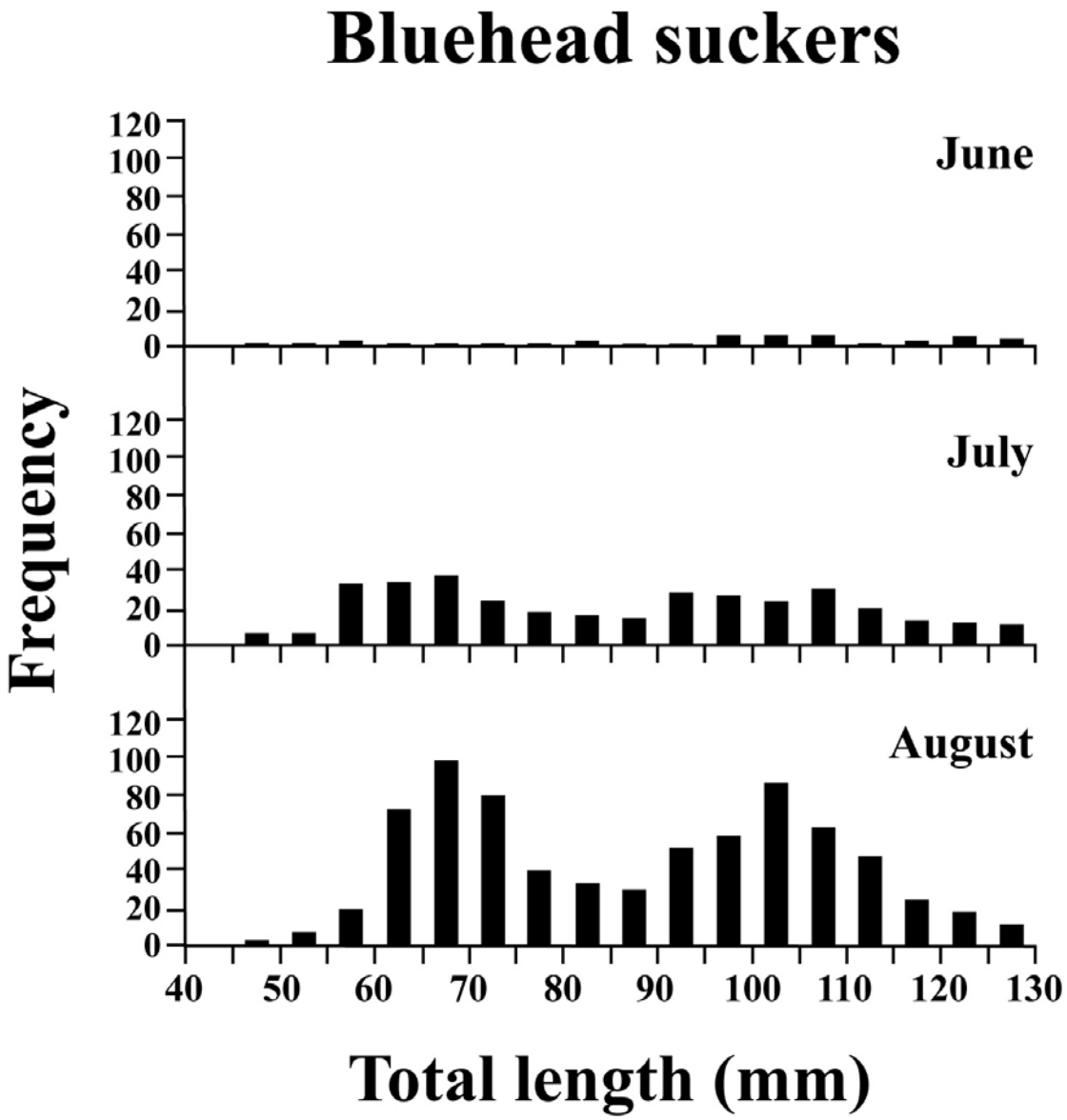


Figure 21. Length frequency (total length, mm) of bluehead suckers less than 130 mm collected in June, July, and August, 2006.

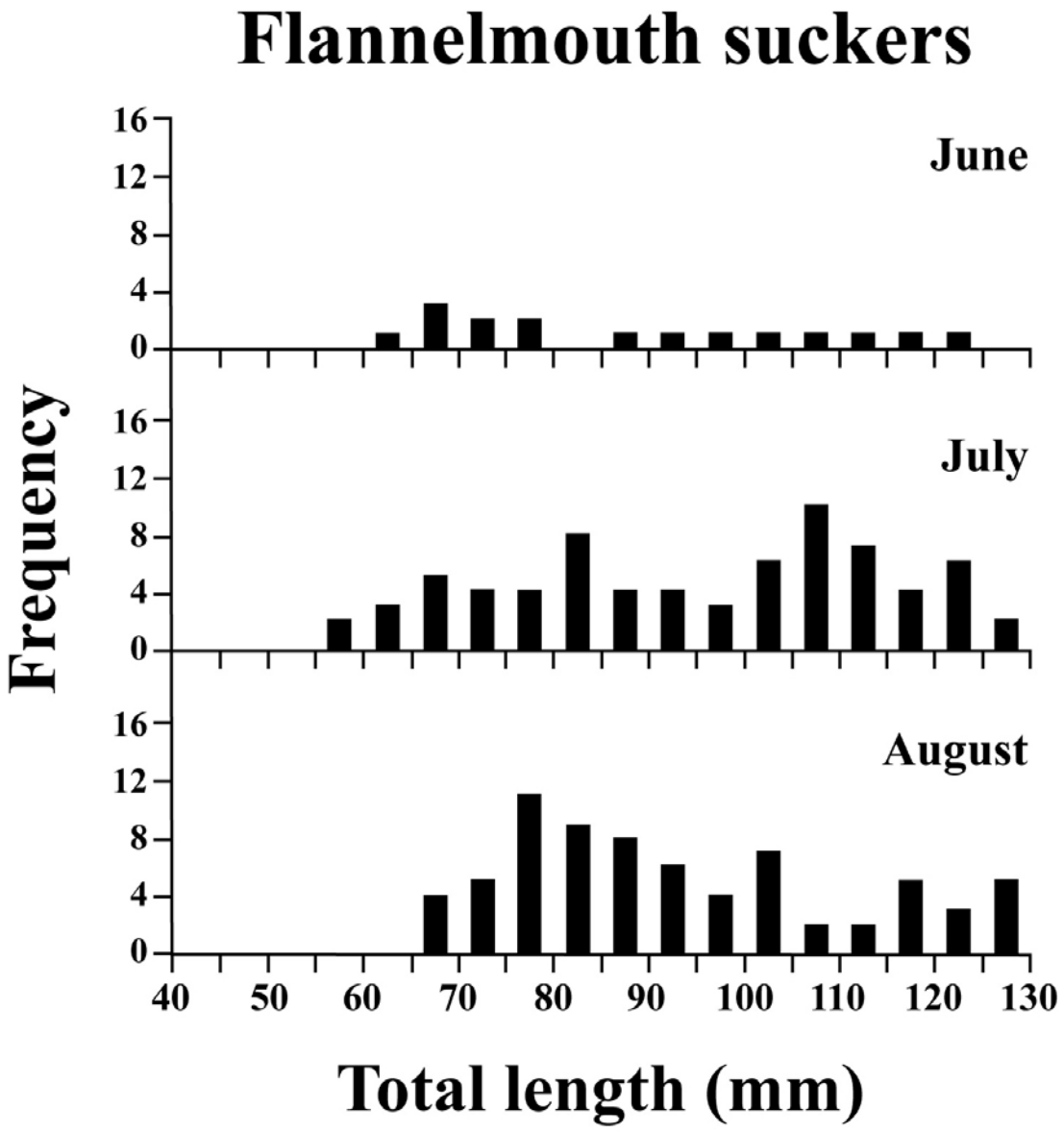


Figure 22. Length frequency (total length, mm) of flannelmouth suckers less than 130 mm collected in June, July, and August, 2006.

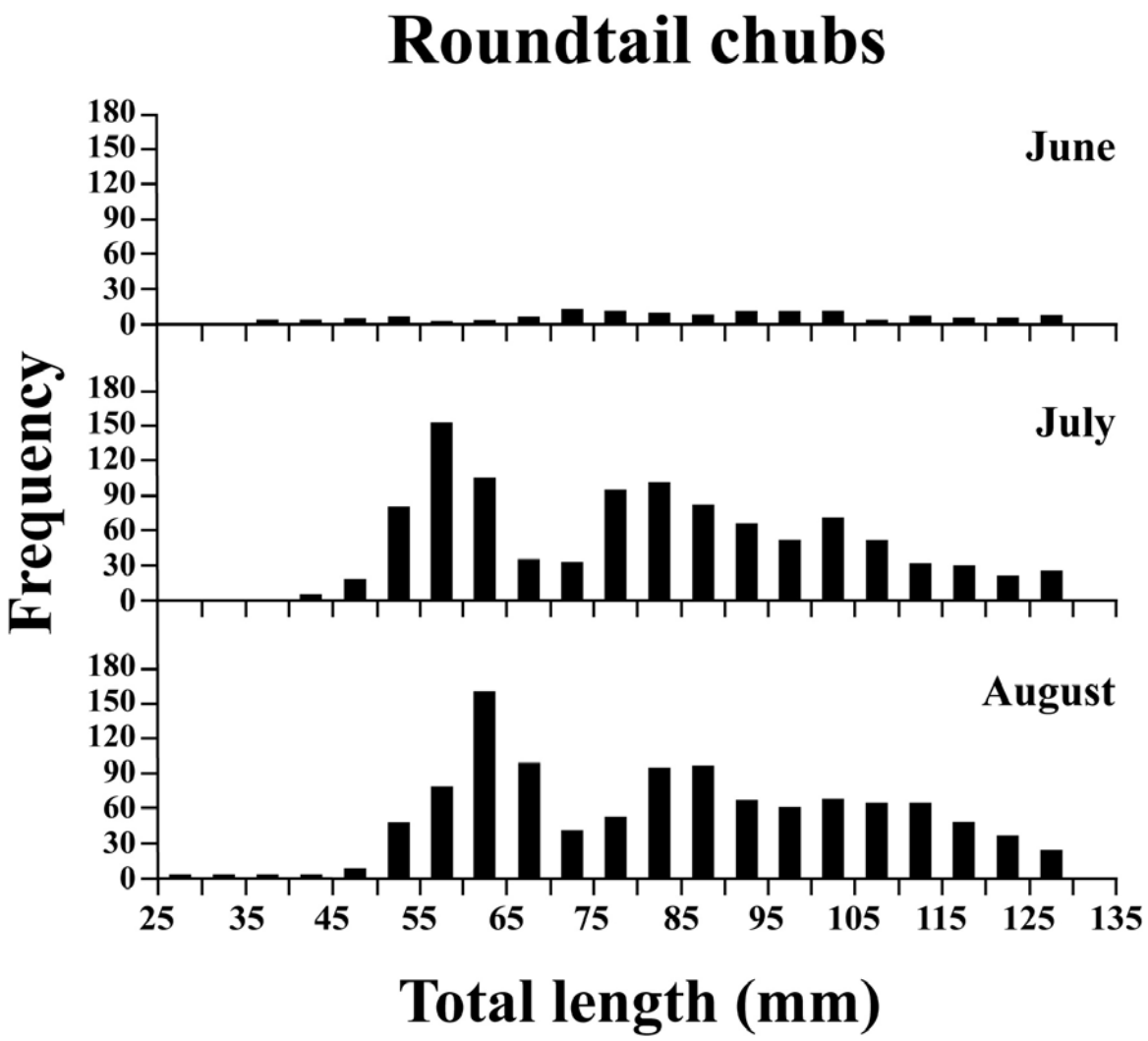


Figure 23. Length frequency (total length, mm) of roundtail chubs less than 130 mm collected in June, July, and August, 2006.

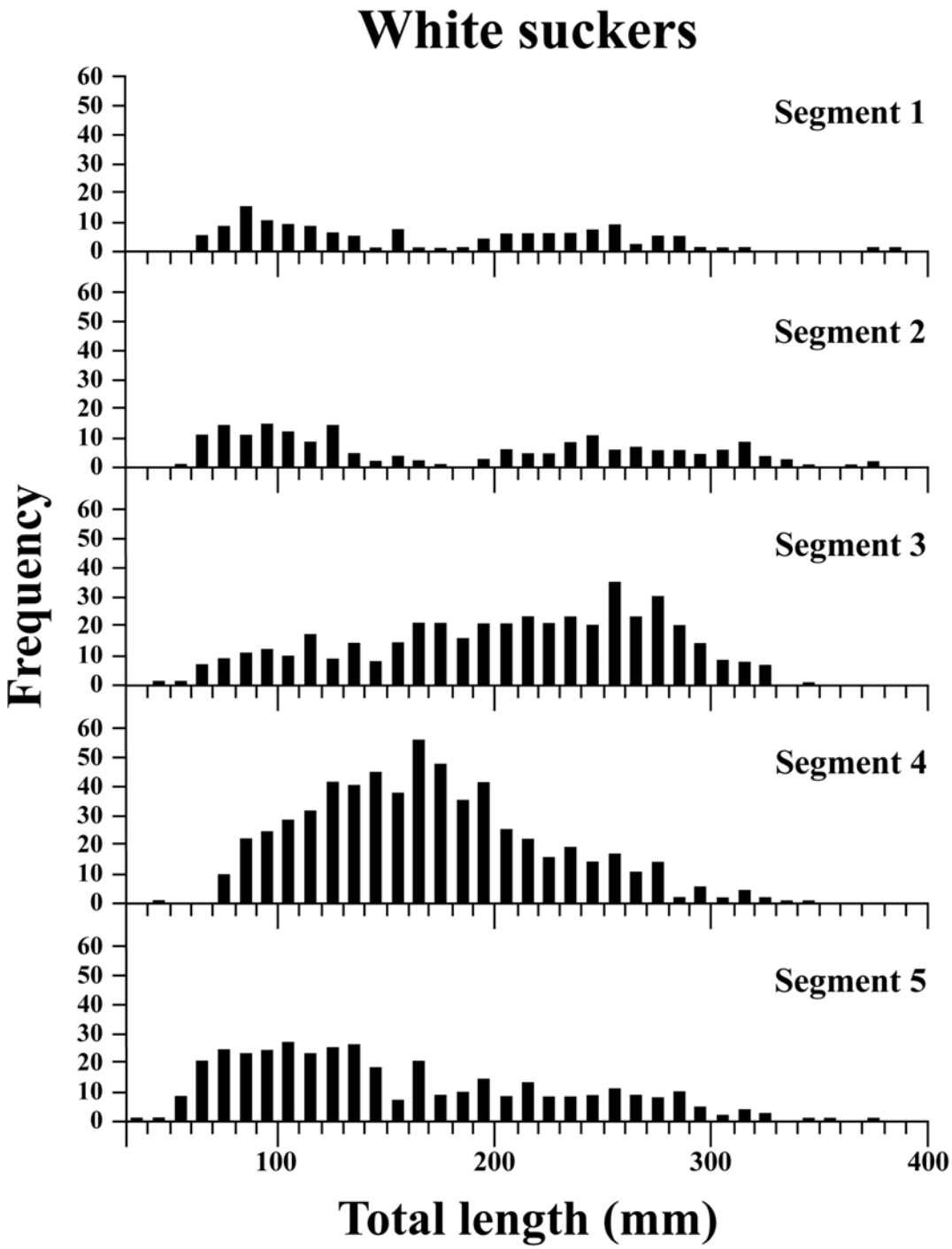


Figure 24. Length frequency (total length, mm) of white suckers collected within each segment in 2005.

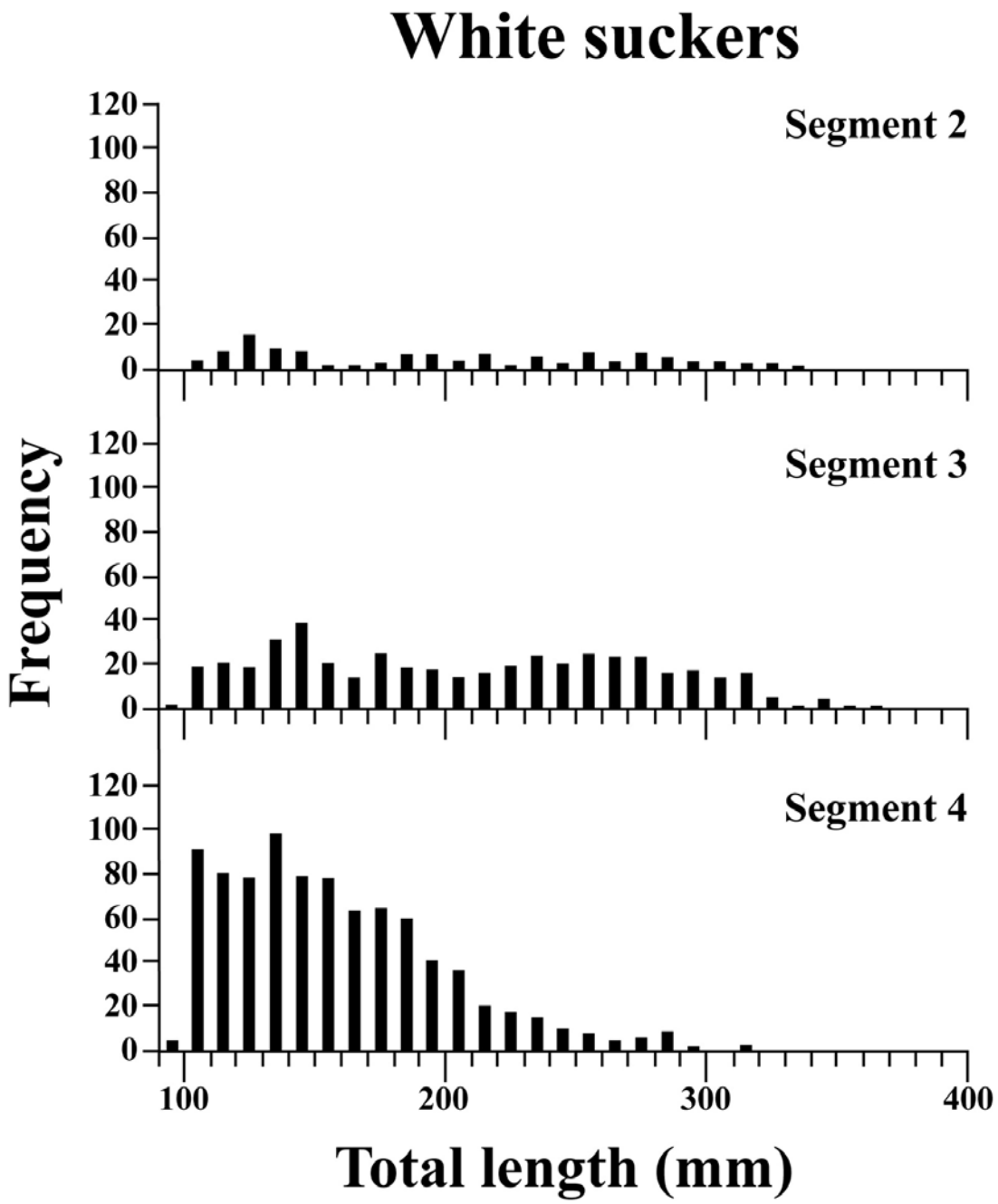


Figure 25. Length frequency (total length, mm) of white suckers collected within each segment in 2006.

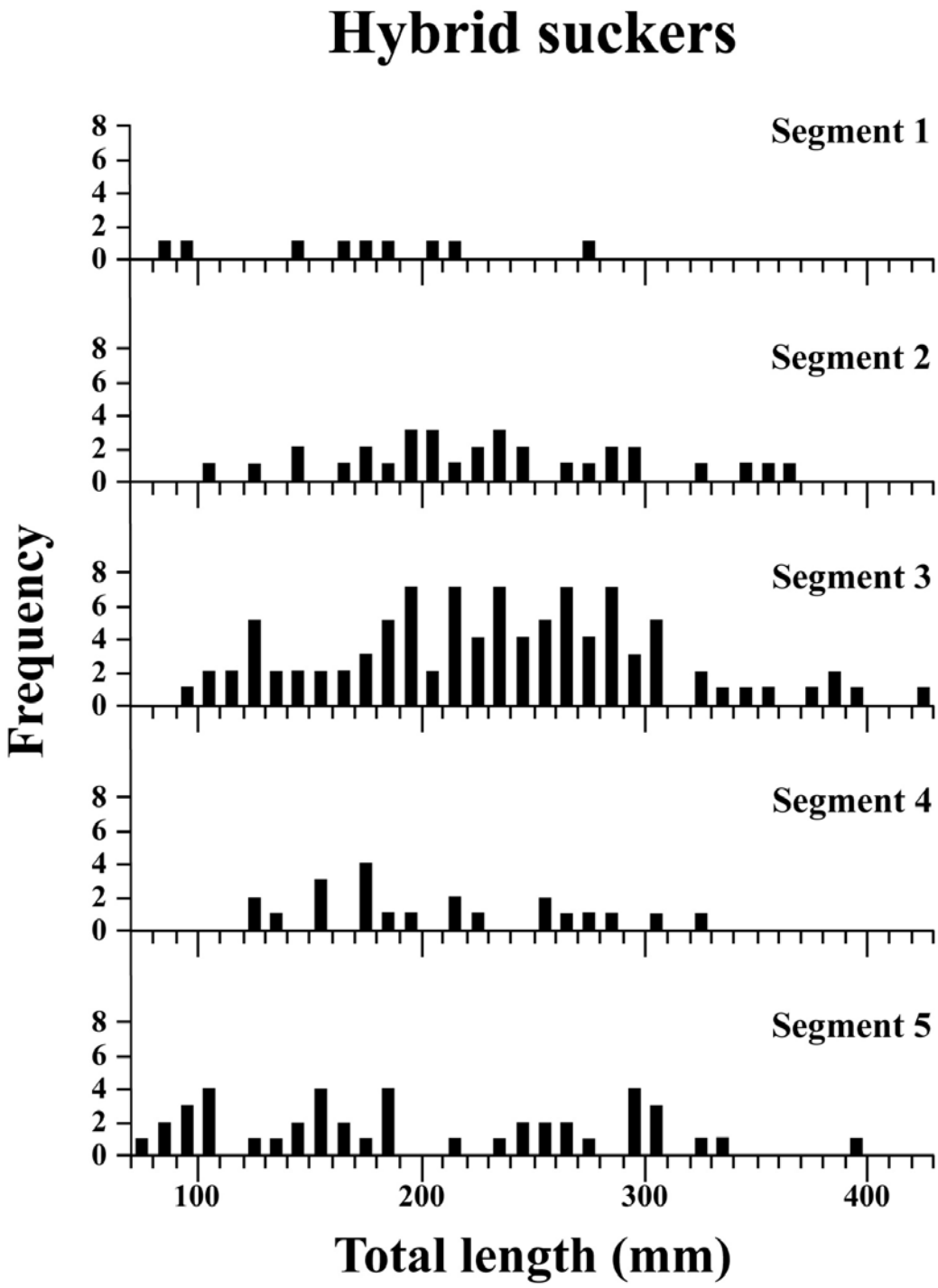


Figure 26. Length frequency (total length, mm) of hybrid catostomids collected within each segment in 2005.

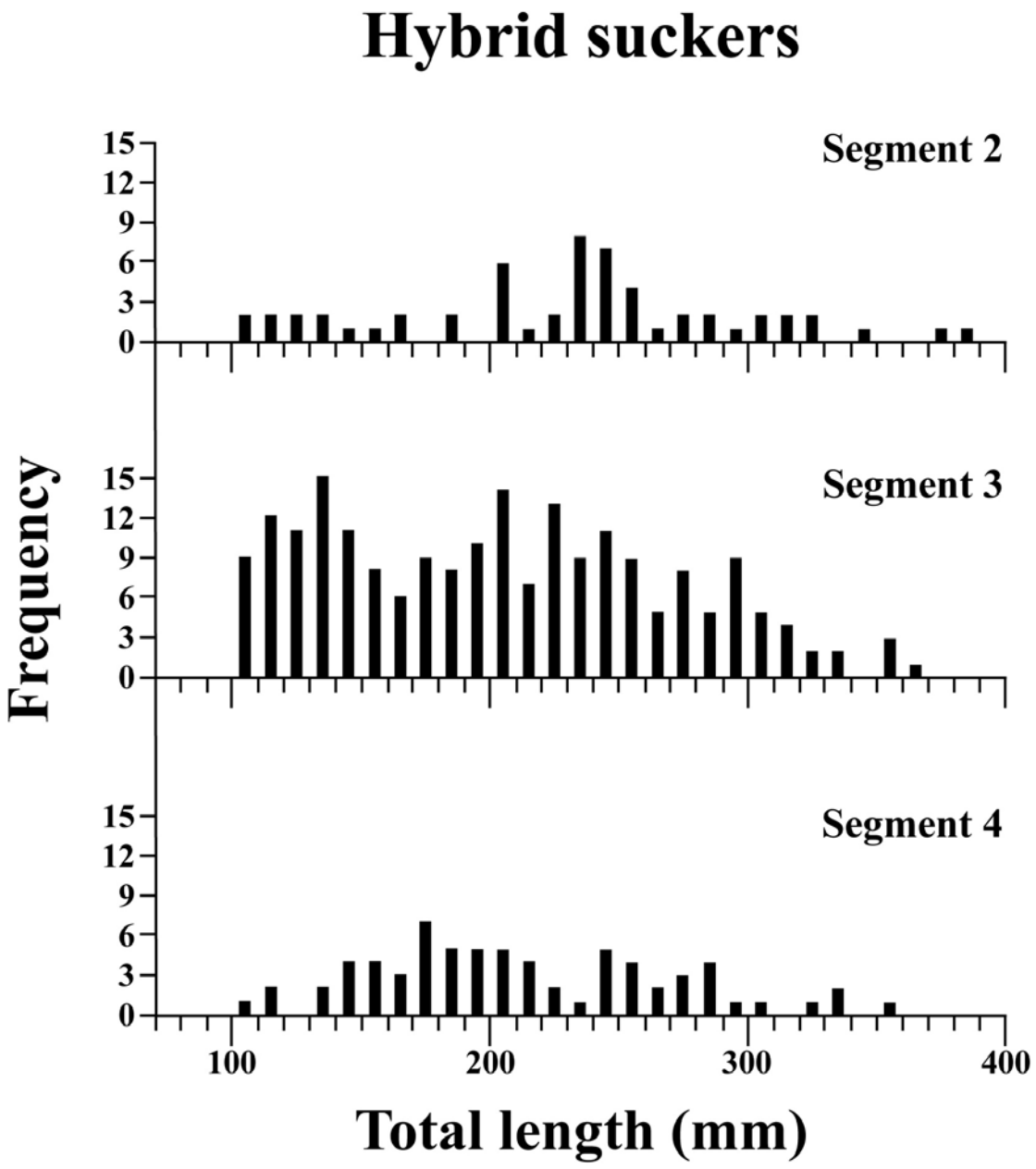


Figure 27. Length frequency (total length, mm) of hybrid catostomids collected within each segment in 2006.

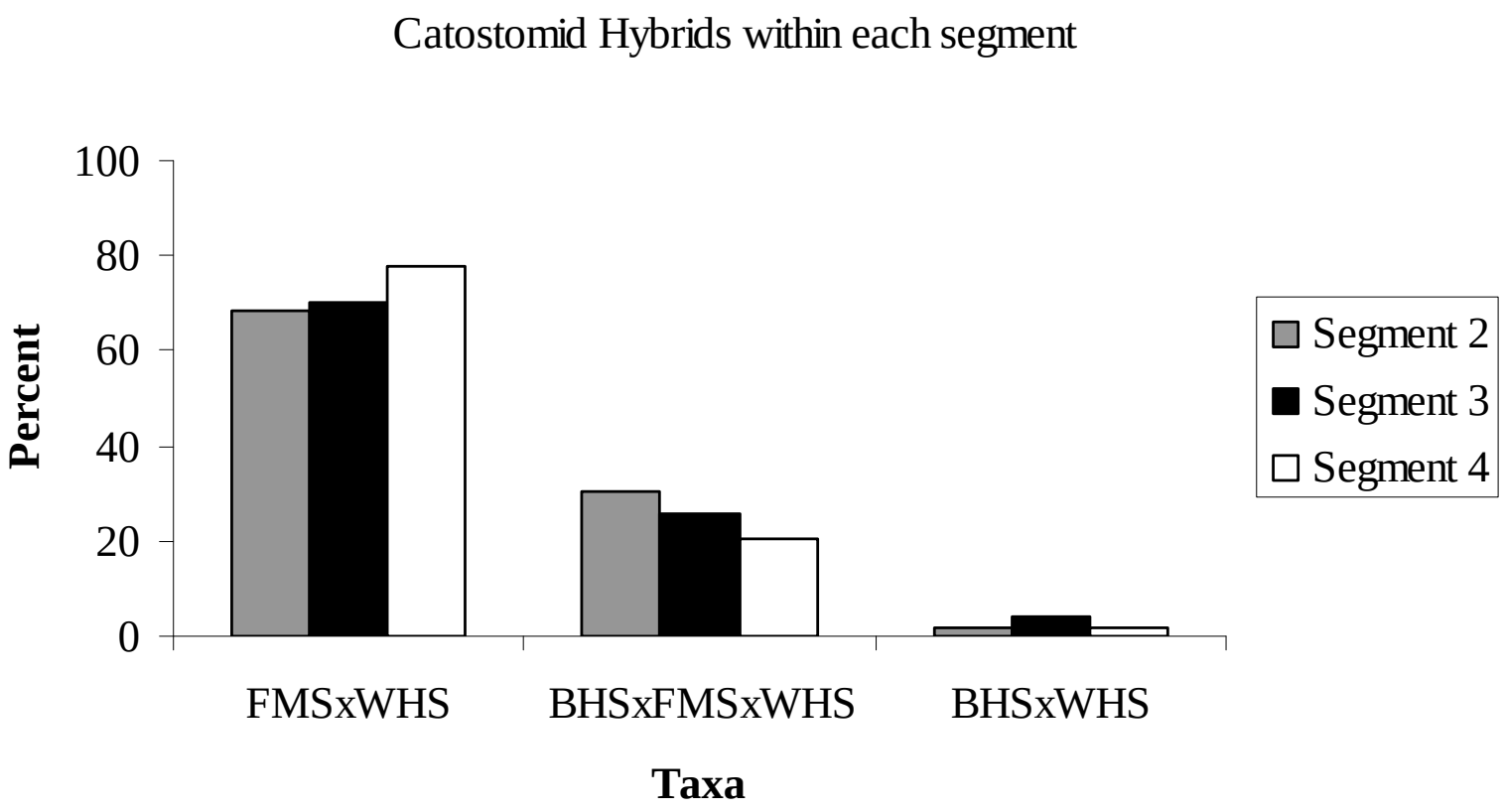


Figure 28. Percent of flannelmouth sucker x white sucker (FMSxWHS), bluehead sucker x flannelmouth sucker x white sucker (BHSxFMSxWHS), and bluehead sucker x white sucker (BHSxWHS) within each segment in 2006.

Appendix A. Instream structure UTM localities. UTM coordinates were projected in NAD 83, Zone 13.

Instream structure	X	Y
Headcut stabilization structure	271660	4592961
Irrigation diversion dam	288506	4595034
Fish barrier	293010	4593320
Gully plug	293467	4592710
Gully plug	293424	4592710
Gully plug	293395	4592707
Gully plug	293338	4592626
Gully plug	293286	4592589
Gully plug	293571	4591598
Gully plug	293539	4591594
Gully plug	293590	4591498
Gully plug	294258	4590722
Gully plug	294274	4590722
Gully plug	294388	4590735
Gully plug	294377	4590750
Culvert at BLM Road 3304	296140	4589665

Appendix B. Downstream UTM localities for 2005 reaches. UTM coordinates were Projected in NAD 83, Zone 13.

Segment	Reach	X	Y
1	1	271709	4592710
	2	271157	4592100
	3	270583	4591760
	4	270271	4591479
	5	269935	4590824
	6	269300	4590145
	7	268925	4589728
	8	268607	4589072
	9	268214	4588222
	10	268354	4587720
	11	268057	4587039
	12	267914	4586292
2	1	288380	4595253
	2	287119	4596275
	3	286178	4595907
	4	284815	4594946
	5	283987	4595011
	6	282315	4594869
	7	280768	4594100
	8	279254	4594074
	9	277554	4593888
	10	276196	4593387
	11	275698	4594726
	12	274611	4594680
	13	272568	4593409
3	1	292734	4593481
	2	292375	4593468
	3	291866	4593489
	4	291441	4593712
	5	291053	4593765
	6	290424	4593735
	7	290354	4594137
	8	290011	4594105
	9	289789	4594249
	10	289431	4594549
	11	289264	4594670
	12	289011	4594733

Appendix B. Continued.

Segment	Reach	X	Y
4	1	296008	4589864
	2	295617	4590208
	3	295281	4590613
	4	295014	4590806
	5	294632	4590790
	6	294210	4590737
	7	293911	4591008
	8	293647	4591331
	9	293557	4591738
	10	293474	4592199
	11	293500	4592720
	12	293284	4593003
5	1	295352	4596541
	2	294909	4597091
	3	294491	4597032
	4	294317	4596569
	5	294028	4596185
	6	294120	4595679
	7	293942	4595181
	8	293532	4594974
	9	293243	4594676
	10	293337	4594267
	11	293165	4594027
	12	293008	4593633

Appendix C. Description of removal and mark-recapture estimation trials and results used to determine sampling methodology for 2006.

Introduction

A main objective of my research was to estimate abundance of bluehead suckers, flannelmouth suckers, and roundtail chubs in upper Muddy Creek. Abundance estimates had not been performed on the target species residing in headwater streams in Wyoming and no methodology had been developed. Removal and mark-recapture estimate trails were completed in 2005, and the results and feasibility of each technique were evaluated.

Methods

Four removal and multiple mark-recapture estimation trials were completed in July and August 2005. Abundance estimates were computed for bluehead suckers, flannelmouth suckers, white suckers, and roundtail chubs. Each 200-m trial reach was closed by placing fine mesh block nets at the downstream and upstream end. Electrofishing was conducted by a two-person team, one person operated a backpack electrofishing unit using pulsed DC current and another person netted fish. After the first electrofishing pass, bluehead suckers, flannelmouth suckers, white suckers, and roundtail chubs greater than 100 mm total length (TL) were measured. Once all fish were processed, they were uniquely marked with right pectoral fin punches and equally distributed back into the isolated reach. The reach was left undisturbed for 1 h and was resampled in the exact method of pass one. Fish were processed again, and recaptured fish with fin clips were noted. Fish not captured on the first pass were marked by

punching the left pectoral fin. Fish were released back into the reach, a 1h undisturbed period followed, and the same process remained constant for pass three. The only change that occurred on each pass was fin punch selection. The assumptions of the estimates were met by closing the reach at both ends with block nets to prevent fish from entering or leaving before all passes were completed and a constant sampling effort during each elelectrofishing pass was performed (Carter and Hubert 1995; Thompson and Rahel 1996).

The software program CAPTURE (White et al. 1982) was used to compute abundance estimates (N), standard errors (SEs), and 95% confidence intervals (CI) of each species or grouping. Model M_{bh} and a generalized jackknife modification of model M_{bh} developed by Pollock and Otto (1983) were used to calculate the three-pass removal method; these models account for varying capture probability of individual animals and behavioral response to first capture. Model M_t (Darroch) was used to calculate the mark-recapture method; this model accounts for varying capture probability of individual animals over time (White et al. 1982).

Results

Some differences in abundance estimates were observed among the two removal models (M_{bh} and Pollock and Otto Biometrics) and mark-recapture model M_t (Darroch mark-recapture estimator, Table. Abundance estimates are reported in Table 1A. The Pollock and Otto Biometrics model abundance estimates were often larger than the M_{bh} model, but this model was able to compute an estimate when a fish was not caught on the first pass. The lack of estimates for bluehead suckers in the first trial and roundtail chubs

in the second trial reflected this problem. The Darroch mark-recapture estimator had the lowest estimates and SEs of the three models. Individual trial abundance estimates were combined to compare overall results. The M_{bh} model estimates for bluehead suckers and roundtail chubs were lower because estimates were not generated in trial one (bluehead suckers) and trial two (roundtail chubs). When comparing the combined estimates for the removal Pollock and Otto Biometrics model and the mark-recapture model M_t, the difference was 13 bluehead suckers, 24 flannelmouth suckers, 10 white suckers, and 26 roundtail chubs.

Conclusions

The removal estimator developed by Pollock and Otto (a modification of model M_{bh}) was selected for estimating abundance of fishes in upper Muddy Creek during 2006 because all model abundance estimates, standard errors, and 95% confidence intervals were similar. Field efficiency and the probability of electrofishing injury were weighted in selecting the proper abundance estimate method.

In evaluating mark-recapture and removal estimates using field efficiency as an important variable, the time needed to complete a reach was less with the removal method. Mark-recapture methodology required measuring, marking, and identifying previously marked fish on each pass. In addition, fish were hauled and evenly distributed throughout the reach. These activities required additional time. Finally, it was difficult to complete a reach in one day by allowing for one hour non-sampling periods between passes. If non-sampling periods were removed, fish may not have fully recovered and re-

distributed and the assumption of equal capture probability and distribution on each pass would not have been met.

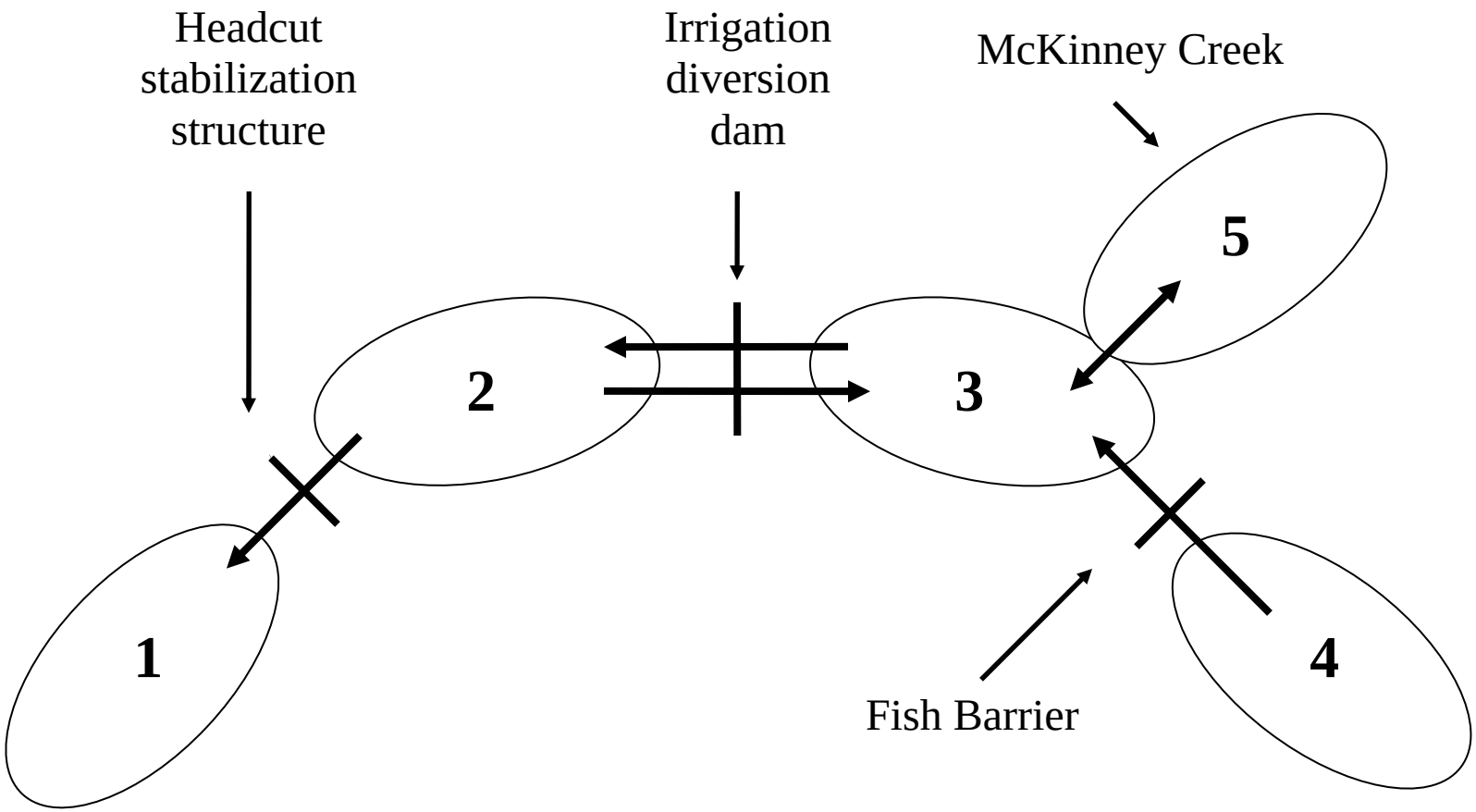
Fish were shocked and handled up to three times if recaptured on the second and third pass; therefore, potential electrofishing injuries and handling stress may have been increased with each additional pass. In order to reduce electrofishing injury and handling stress, and increase field efficiency, three-pass removal was selected as the preferred method.

Table 1A. Abundance estimates (N), standard errors (SE), and 95% confidence intervals (CI) for bluehead suckers, flannelmouth suckers, white suckers using removal estimators (model M_{bh} and Pollock and Otto Biometrics) and mark-recapture estimator M_t.

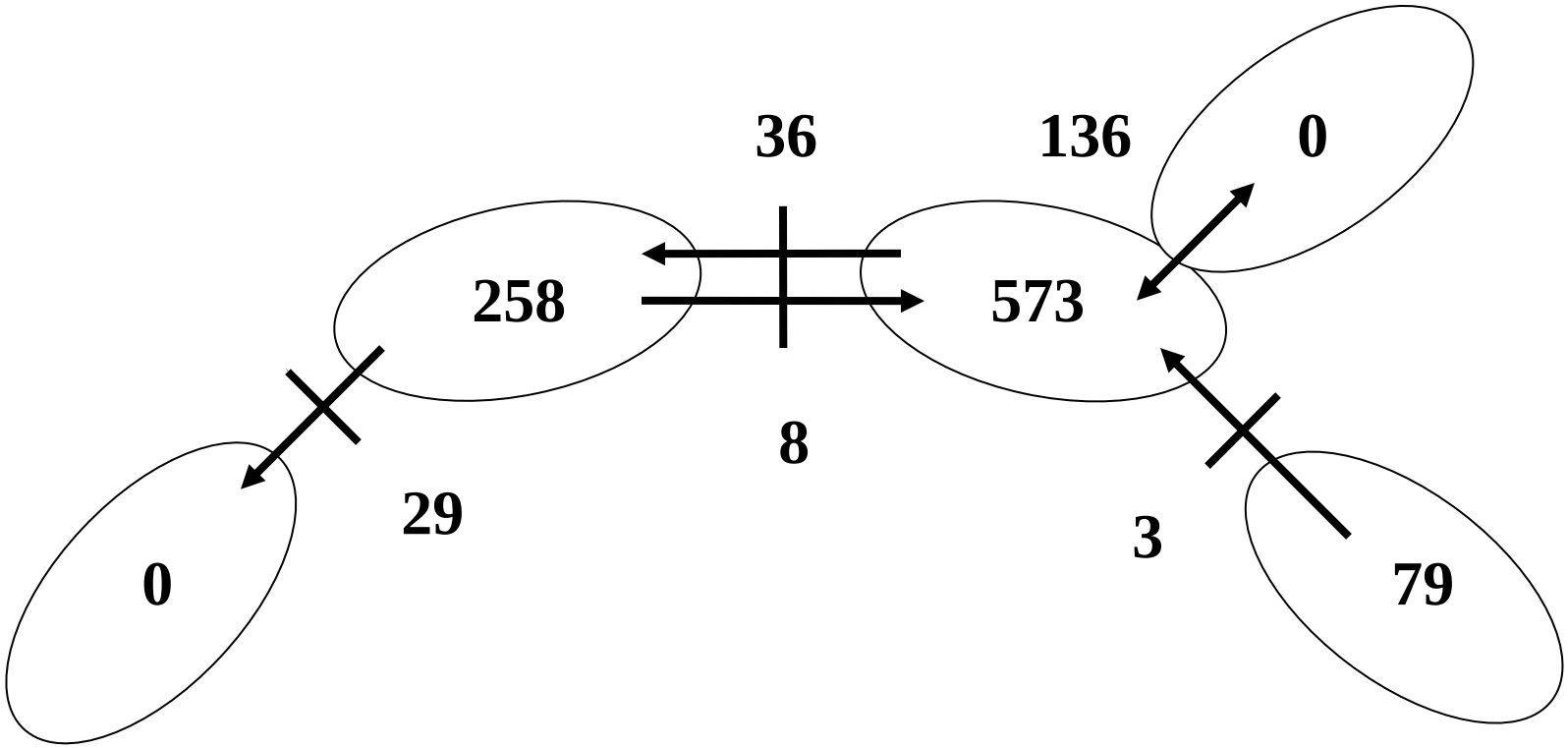
		Removal estimator						Mark-recapture estimator		
		M(bh)			Pollock and Otto Biometrics			M(t)		
Trial	Species	N	SE	95% CI	N	SE	95% CI	N	SE	95% CI
1	Bluehead sucker				9	3.46	6 - 22	8	3.42	6 - 23
	Flannelmouth sucker	3	0.71	3 - 3	5	2.45	4 - 16	3	0.00	3 - 3
	White sucker	9	0.46	9 - 9	11	2.45	10 - 22	9	0.01	9 - 9
	Roundtail chub				20	4.24	16 - 34	17	2.84	15 - 28
2	Bluehead sucker	11	0.58	11 - 11	13	2.45	12 - 24	11	0.71	11 - 15
	Flannelmouth sucker	7	0.12	7 - 7	7	0.00	7 - 7	7	0.00	7 - 7
	White sucker	9	0.26	9 - 9	9	0.00	9 - 9	9	0.38	9 - 11
	Roundtail chub				18	4.24	14 - 32	23	9.50	15 - 59
3	Bluehead sucker	43	1.41	43 - 50	48	4.24	44 - 62	48	3.65	45 - 60
	Flannelmouth sucker	14	1.50	14 - 24	18	3.46	15 - 31	14	0.35	14 - 16
	White sucker	63	1.96	62 - 71	71	5.48	65 - 88	68	3.74	64 - 79
	Roundtail chub	55	0.97	55 - 61	59	3.46	56 - 72	73	8.23	63 - 97
4	Bluehead sucker	128	20.11	106 - 193	132	10.68	117 - 159	122	9.00	109 - 145
	Flannelmouth sucker	56	49.60	30 - 309	46	7.75	36 - 67	28	1.94	27 - 35
	White sucker	38	1.47	38 - 46	43	4.24	39 - 57	38	0.80	38 - 41
	Roundtail chub	86	11.94	74 - 126	90	8.12	79 - 112	100	11.70	85 - 132

Appendix D. Amount of time antennas were installed, actually running, and proportion of time running in 2005 and 2006.

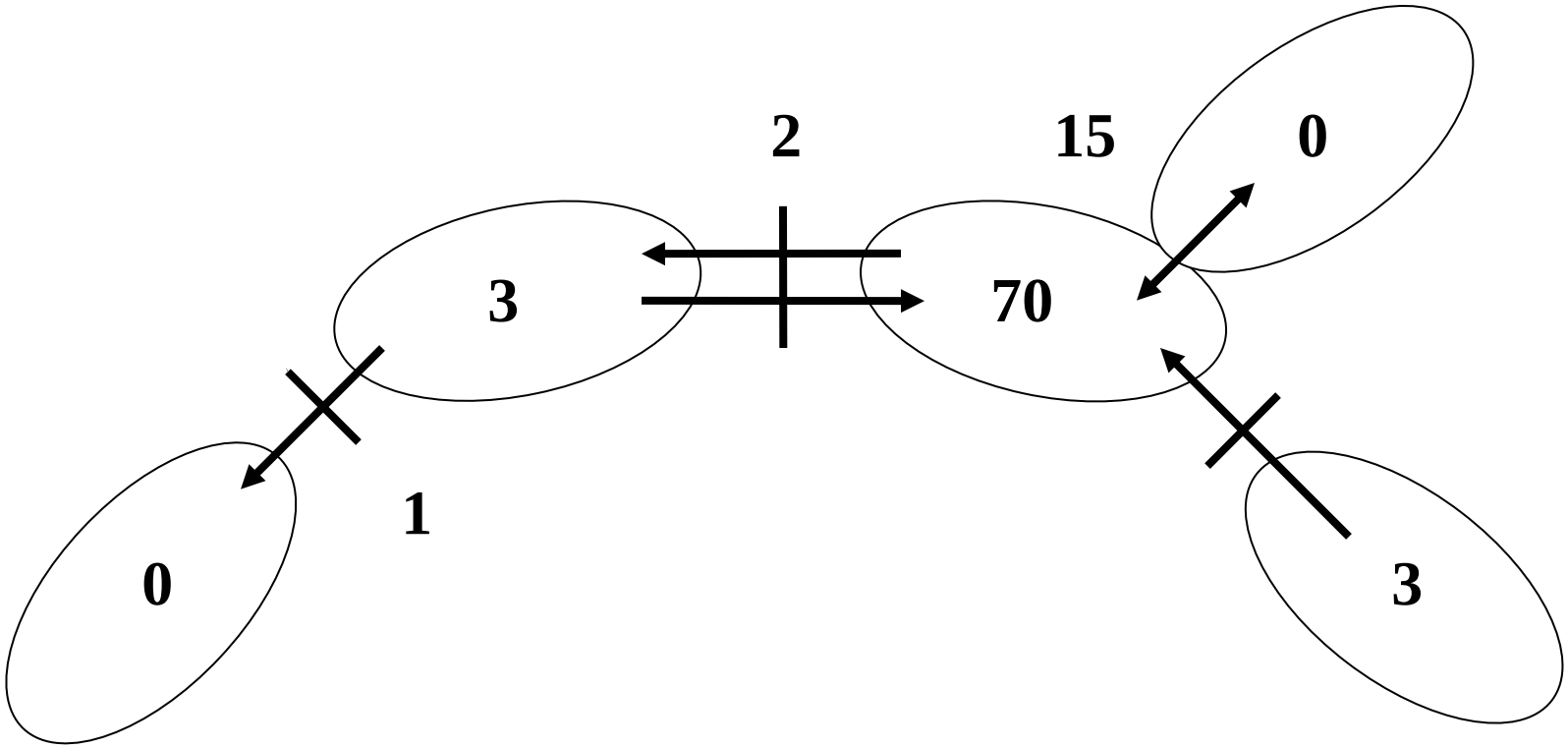
	2005			2006		
Station	Hours installed	Hours running	Proportion of time running	Hours installed	Hours running	Proportion of time Running
1	3,292	2,638	80.1	4,799	3,698	77.1
2	2,304	2,114	91.8			
3	2,634	2,583	98.1	3,939	2,907	73.8
4	2,876	2,426	84.4	3,947	3,508	88.9
5	2,854	2,162	75.8	3,947	2,270	57.5



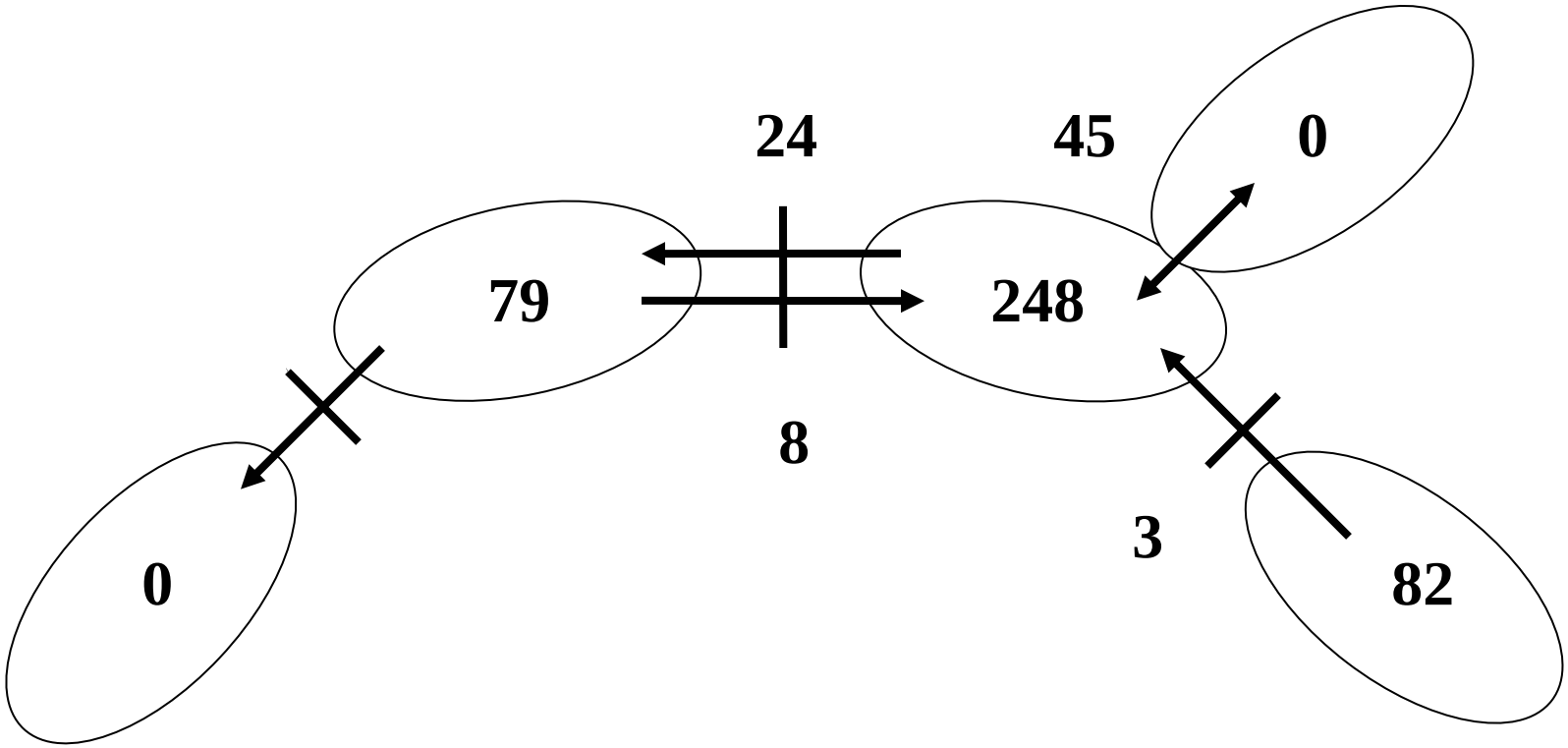
Appendix E. Explanation of diagram used to describe fish movements among segments, with ovals representing individual segments.



Appendix F. Diagram of bluehead sucker movements in 2005 and 2006 combined. Numbers inside the ovals represent the number of fish tagged within the segment, and numbers outside the ovals represent the number of fish that moved among segments.



Appendix G. Diagram of flannelmouth sucker movements in 2005 and 2006 combined. Numbers inside the ovals represent the number of fish tagged within the segment, and numbers outside the ovals represent the number of fish that moved among segments.



Appendix H. Diagram of roundtail chub movements in 2005 and 2006 combined. Numbers inside the ovals represent the number of fish tagged within the segment, and numbers outside the ovals represent the number of fish that moved among segments.

Appendix I. Counts of bluehead suckers, flannelmouth suckers, and roundtail chubs less than 100-mm total length sampled in 2006.

		Species		
Segment	Reach	Bluehead sucker	Flannelmouth sucker	Roundtail chub
2	1	0	1	7
	4	22	0	3
	5	3	0	20
	6	4	0	12
	7	2	3	28
	8	15	0	21
	9	20	0	31
	10	2	1	15
	14	3	0	7
	21	3	2	19
	22	5	0	27
	23	5	0	47
3	2	1	1	85
	3	5	2	40
	4	7	1	51
	5	4	0	67
	6	15	0	19
	8	54	2	47
	9	23	2	43
	10	6	0	34
	11	60	4	50
	14	14	0	42
	15	15	2	37
	16	34	4	87
	17	7	0	33
	19	57	0	23
	20	4	0	15
	21	18	0	41
	26	10	0	57
	27	7	6	62
	30	27	1	39
	37	38	3	20
	43	27	6	33
	47	5	3	13
	48	16	0	4
	50	21	2	15
	51	9	6	29

Appendix I. Continued.

		Species		
Segment	Reach	Bluehead sucker	Flannelmouth sucker	Roundtail chub
4	2	0	0	0
	5	1	2	0
	7	0	0	0
	8	0	0	0
	9	0	0	0
	11	0	0	1
	16	0	0	2
	18	0	0	4
	21	0	0	0
	22	0	1	1
	25	1	0	0
	28	2	0	0
	30	0	0	0
	31	0	0	0
	32	0	0	0