Barriers impede upstream spawning migration of flathead chub, a pelagic spawning cyprinid

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Running Head: Flathead chub spawning migration

Abstract

Pelagic spawning cyprinids are declining throughout the North American Great Plains. These species require long reaches of contiguous, flowing riverine habitat for drifting eggs and larvae to develop, and their declining populations have been attributed to habitat fragmentation or barriers (e.g., dams, dewatered channels, and reservoirs) that restrict fish movement. Upstream dispersal is also needed to maintain their populations, and prior researchers have suggested that members of this reproductive guild migrate upstream to spawn. To test this hypothesis, we conducted a mark-recapture study of flathead chub *Platygobio gracilis* within a 91 km reach of continuous riverine habitat in Fountain Creek, CO (USA). We measured catch per unit effort (CPUE), spawning readiness (percent of flathead chub expressing milt), and fish movement relative to a channel-spanning dam (Owens Hall Diversion Dam, OHDD). Multiple lines of evidence indicate that flathead chub migrate upstream to spawn during summer. CPUE was much higher at the base of the OHDD than at downstream sites, the seasonal increases in CPUE at the OHDD closely tracked seasonal increases in spawning readiness, and marked fish moved upstream as far as 33 km during the spawning run. The upstream migration was effectively blocked by the OHDD. CPUE of flathead chub was much lower upstream of the OHDD when compared to downstream sites and <0.2% of fish marked at the OHDD were recaptured upstream. This study provides the first direct evidence of spawning migration for pelagic spawning cyprinids and supports the general hypothesis that barriers to dispersal may disrupt the source-sink dynamics necessary to maintain populations of flathead chub and other pelagic spawning cyprinids.

Fishes depend upon unrestricted movement between various habitat types over their life-history (Schlosser and Angermeier 1995). Dams and diversion structures that restrict such movement can be detrimental to migratory species, especially when spawning habitats are isolated from downstream populations (Fullerton et al. 2010). Most prior work on the effects of migration barriers has focused on commercially important diadromous species such as salmonids, anguillids, and clupeids (Kemp and O'Hanley 2010), while barrier effects on small-bodied, potadromous fishes are poorly understood (Ficke and Myrick 2009). Streams of the semiarid western U.S. and the Great Plains are highly fragmented by dams and other diversion structures, and habitat fragmentation associated with these structures has been implicated in the shrinking ranges and declining abundances of several plains fishes (Cross et al. 1985; Winston et al. 1991; Fausch and Bestgen 1997; Luttrell et al. 1999; Matthews and Marsh-Mathews 2007). Consequently, improving and restoring the hydrologic connectivity of plains river systems has become a cornerstone of plains fish conservation efforts (Fausch et al. 2002; Dodds et al. 2004; Hoagstrom 2011, Perkin and Gido 2011). However, large-scale movements, particularly for small-bodied plains species, remain poorly understood (Fausch et al. 2002).

One such species is flathead chub *Platygobio gracilis*, a plains river cyprinid that is widely distributed from the Northwest Territory of Canada south to New Mexico, Texas, and Louisiana (Lee et al. 1980). In spite of its vast distribution, extirpations throughout its range have resulted in it being added to imperiled species lists in Colorado, Arkansas, Illinois, Kansas, Kentucky, Mississippi, Missouri, Oklahoma, and Texas (Rahel and Thel 2004). In Colorado, flathead chub occur mostly in plains portions of the Arkansas and the Rio Grande River basins (Alves 1997; Nesler et al. 1999), where their range has shrunk based on historical records (Woodling 1985). Barriers (e.g., dams, reservoirs, and dewatered channels) that limit dispersal are thought to be a key factor in flathead chub declines in Colorado and elsewhere (Woodling 1985; Cross and Moss 1987; Pfliegler and Grace 1987; Bonner and Wilde 2000; Hoagstrum et al. 2007; Gido et al. 2010; Perkin and Gido 2011). Flathead chub occupy large, turbid river systems (Rahel and Thel 2004) and are thought to belong to a guild of pelagic spawning cyprinids that produce passively drifting eggs and larvae (Smith and Hubert 1989; Durham and Wilde 2006, Durham and Wilde 2008; Perkin and Gido 2011). Pelagic spawners require long reaches of free flowing habit for drifting eggs and larvae to develop, and river fragmentation leads to extirpation of these species via reduced recruitment (Cross et al. 1985; Cross and Moss 1987; Pfliegler and Grace 1987; Winston et al. 1991; Luttrell et al. 1999; Gido et al. 2010).

Upstream dispersal is presumed to be a critical mechanism by which pelagic spawning cyprinids repopulate upstream reaches (Fausch and Bestgen 1997, Cross et al. 1985, Lutrell et al. 1999). These cyprinids are thought to migrate upstream to spawn (e.g., Cross et al. 1985; Durham and Wilde 2008), where migrations serve to recolonize upstream reaches and to provide adequate development time for drifting eggs and larvae (Durham and Wilde 2008). However, support for this upstream spawning hypothesis is limited to indirect evidence (Rahel and Thel 2004). For example, Arkansas River shiner (*Notropis girardi*) are thought to migrate upstream to spawn based on longitudinal distributions of adults (Durham and Wilde 2008) and drifting larvae (Bonner 2000) during the spawning season. In addition, anecdotal evidence suggests that flathead chub migrate upstream into tributaries to spawn in Wyoming streams (Rahel and Thel 2004). We have also observed large aggregations of flathead chub below dams in Colorado during the summer spawning season (J. Bruce, unpublished data), suggesting an upstream migration impeded by barriers.

These factors, combined with recent efforts in Colorado to improve fish passage in Plains river networks, prompted a 2010 study to evaluate spawning related movement of flathead chub in Fountain Creek, CO relative to a channel-spanning dam (Owens-Hall diversion dam, OHDD). Our goal was to provide managers with information on flathead chub movement in order to optimize the operation of a planned fish way for the OHDD. Our objectives were to determine 1) if and when flathead chub migrate upstream to spawn 2); how far they move; and 3) if they are able to pass the OHDD under its present configuration. We conducted a large-scale survey and mark-recapture study of flathead chub up- and downstream of the OHDD to achieve these objectives. We hypothesized that flathead chub migrate upstream to spawn and that this migration is blocked by the OHDD. If so, we expect that flathead chub catch rate at the OHDD will be higher than at downstream sites and that flathead chub catch rate at the OHDD will be highest during the spawning season. Quantitative movement studies are lacking (Rahel and Thel 2004), so we did not develop *a priori* expectations regarding the distance that flathead chub would move. Additionally, we hypothesized that the OHDD has low barrier passability. If so, we expect that flathead chub catch rate would be greatly reduced upstream of OHDD and that few fish marked downstream would be recaptured upstream of the dam.

Methods

Study area.- Fountain Creek is a large tributary (basin area 2,398 km^2) of the Arkansas River in south-central Colorado (Figure 1). Basin elevation ranges from 1,432 m at the confluence with the Arkansas River to 4,300 m at the summit of Pikes Peak (Hansen and Crosby 1982). Channel form alternates between braided reaches and meandering, single-thread reaches. Wetted width is typically between 12 and 40 m within the study section. Streambed material is dominated by sand and small gravel with unstable large woody debris piles in the channel and along the banks. Fountain Creek hydrology is strongly influenced by agricultural, urban, and industrial water use and management (Stogner 2000; Edelmann et al. 2002). Average daily stream discharge is 3.47 m^3/s (range 1.84-14.19 m^3/s), and average peak flow is 177.16m^3/s (range 1.35-569.23m^3/s; USGS gage 07106000, discontinuous period of record from 1941 to 2010, 39 years of complete record). The lower reaches of Fountain Creek (Figure 1) maintain one of the last populations of flathead chub within the Arkansas River basin (Woodling et al. 1985). Flathead chub have been extirpated from the mainstem Arkansas River upstream of Florence, CO and downstream of John Martin Reservoir (Las Animas, CO) in eastern Colorado and Kansas (Woodling 1985, Gido et al. 2010, Perkin and Gido 2011).

Sample Sites.- We sampled 100 m reaches at 10 sites along 43 river kilometers (rkm) in Fountain Creek near Fountain, CO (Figure 1). The study section is part of a larger 91 rkm fragment of contiguous riverine habitat extending from the OHDD downstream into the Arkansas River (Figure 1). One site was located at the base of the OHDD with eight additional sites distributed downstream of the OHDD. In order to detect both smaller scale and larger scale movements, distance was approximately doubled between sites downstream from the OHDD. We also sampled at the base of the next upstream barrier from the OHDD (Chilcotte Diversion, Site 0).

Fish sampling. – We sampled each site multiple times between April and October 2010 (Table 1) using backpack electrofishers (Smith-Root Model LR-24). We sampled in an upstream direction along each stream bank without block nets for two complete passes. We used two electrofishers simultaneously followed by multiple netters in most cases, but occasionally a single unit was used. Fish from each pass were held separately in 20-liter buckets and/or in-stream live wells. All flathead chub were identified, enumerated, and measured (total length) to the nearest millimeter in the field.

Fish marking and spawning readiness. – Flathead chub were batch marked subcutaneously with site-specific color and body position combinations using elastic fluorescent polymer (Northwest Marine Technology, Seattle, Washington, USA) and returned to the stream. We only marked adult fish (≥ 80 mm TL based on age-length studies summarized by Rahel and Thel 2004) as these are most likely to undertake spawning migrations. After the first sampling event, we inspected all adult flathead chub for marks using long-wave ultraviolet light. Newly encountered flathead chub were marked, and any recaptures were recorded and remarked if previously captured at another site. We collected 21,245 flathead chub, of which 10,320 were marked. We maintained 30 marked individuals in aquaria over the course of the study. Mark retention for these fish was 100% with 0 mortalities.

We assessed spawning condition of adult flathead chub by applying light pressure to the abdomen and recording the presence/absence of milt. We used these data to calculate spawning readiness as the percent of flathead chub expressing milt. We used percent of total catch because flathead chub lack sexually dimorphic traits (Rahel and Thel 2004), and we could not reliably determine sex unless fish extruded gametes. We did not record data on extruded eggs or note gravid females since we could not consistently determine if swollen abdomens were related to ripe ovaries or full stomachs.

Data analysis. – We calculated catch per unit effort (CPUE; number of flathead chub/min of electrofishing) using first pass data to control for differences among sites, sampling events, and sampling time. We used analysis of variance (ANOVA) to determine if variability in mean CPUE values was associated with site, and used Bonferroni-adjusted post-hoc tests to test for mean differences between sites ($P \leq 0.05$). We used a student's t-test to determine if mean CPUE at the OHDD was different from the remaining sites ($P \leq 0.05$) during the summer spawning months of June, July, and August. Data were pooled across the remaining sites because we were unable to sample all sites multiple times per month and because preliminary analysis indicated that CPUE at the OHDD was consistently much higher than all other sites during summer.

All remaining analyses relied on sample data combined from both passes. We compared the percent of total flathead chub expressing milt at the OHDD (site 1) to all other sites, and data were pooled as described above. We also calculated the distance and direction fish moved using individual recapture data. Detailed analysis of the timing and directionality of fish movements is beyond the scope of this paper, but is the subject of ongoing modeling efforts. Additionally, we calculated barrier passability (the proportion of fish able to pass a barrier while migrating upstream, O'Hanley and Tomberlin 2005) as the percent of fish marked at the OHDD that were recaptured at the Chilcotte diversion dam (site 0, Figure 1). This assumes that all fish captured at the OHDD intended to pass upstream of the dam and that these fish would move upstream through the 9.7 km reach separating the two barriers.

Results

Spatial and temporal variation in flathead chub CPUE

Flathead chub CPUE was significantly higher at the OHDD (site 1) than at other sites in most cases, ($F_{9, 74} = 7.14$, $P < 0.0001$), and the largest differences occurred during June, July, and August (Figure 2). Mean CPUE was higher at the OHDD (site 1) than all other sites except site 9, where CPUE was indistinguishable from either OHDD or the other sites (Figure 2A). CPUE at the OHDD increased approximately 6-fold from May (1.13) to June, July, and August (6.44, 6.71, and 5.60, respectively). In contrast, mean monthly CPUE was low and invariant (around 1.5) at the other sites until October when CPUE increased (3.92; Figure 2B). CPUE was around 4-fold higher at the OHDD than at other sites during June, July, and August ($t_{12.43} = 5.97$, $P < 0.0001$; equal variances not assumed).

Temporal and spatial variation in spawning readiness

Temporal patterns in spawning readiness (the percent of male flathead chub expressing milt) indicate that flathead chub spawn in summer (Figure 3). Spawning readiness was high from May through August, and peaked in June and July. In contrast, few flathead chub (<3% of total catch) expressed milt during April, September, and October. Spawning readiness in May was much higher at the OHDD (mean 15.9%) than other sites (2.0%), but values were similar between the OHDD and other sites during the remainder of the study (Figure 3).

Movement distance

We recaptured 741 fish (7.2 % of fish marked) and detected up- and down-stream movements across the entire 33 km study section downstream of the OHDD (Figure 4). Most fish were recaptured at the same site, and these were dominated by individuals marked at the OHDD. Overall, nearly 82 % of marked fish were recaptured within 1 km of their initial marking site. The remainder moved between 2 and 15 km except for 2 individuals that moved 33 km (one upstream and one downstream).

Barrier passability of the Owens-Hall diversion dam

The OHDD blocked nearly all upstream movement of flathead chub. We marked or recaptured 6,032 fish at the OHDD structure during June, July, and August, but only 10 (0.17 %) were recaptured 9.7 km upstream at the Chilcotte Diversion dam (Figure 1). Mean monthly total catch was more than an order of magnitude lower at the Chilcotte Diversion (15 ± 8; 1 SD) than at the OHDD (505 ± 168) during the peak spawning months of June, July, and August (Table 1).

Discussion

Extirpation of flathead chub and other pelagic spawning cyprinids is directly related to habitat fragmentation (Gido et al. 2010; Perkin and Gido 2011). Recruitment bottlenecks associated with drifting eggs and larvae are a key factor in these extirpations (Platania and Altenbach 1998; Dudley and Platania 2007), but upstream movement of juveniles and or adults must play an important, yet unproven, role in maintaining populations (Fausch and Bestgen1997; Luttrell et al. 1999). Testing this upstream movement hypothesis is challenging due to the logistical constraints of detecting small-bodied fish movements in large riverine habitats, but here we found strong support for the hypothesis that flathead chub migrate upstream to spawn. Catch rates were highest at the upstream barrier and tracked seasonal differences in male spawning readiness. We also measured movements of at least 33 rkm during the spawning season. To our knowledge, these findings are the first direct evidence of large-scale movements (10s of km) of North American adult pelagic spawning cyprinids.

Plains fishes thrive in harsh stream environments that are prone to drying, flash floods, and poor water quality (Matthews 1985; Fausch and Bestgen 1997; Dodds et al. 2004). Paradoxically, many of these tolerant species are increasingly in need of conservation efforts due to declining populations (Fausch and Bestgen 1997; Hoagstrum et al. 2011). Pelagic spawning minnows in particular suffer high rates of imperilment (Jelks et al. 2008) and are being systematically extirpated throughout the Great Plains (Fausch and Bestgen 1997; Gido et al. 2010; Perkin and Gido 2011). The case of the flathead chub epitomizes the declines seen across this reproductive guild of fishes. Formerly common and abundant over a vast area stretching from Northern Canada to Louisiana, they are now extirpated from large parts of their range (Woodling 1985; Cross and Moss 1987; Pfliegler and Grace 1987; Bonner and Wilde 2000; Hoagstrum et al. 2007; Gido et al. 2010) including most (61%) of the large stream fragments remaining in the Great Plains portion of the U.S. (Perkin and Gido 2011). Efforts to identify mechanisms of extirpation in pelagic spawning minnows have coalesced around two critical factors: 1) movement at multiple life stages is an important life history strategy for this guild and, 2) barriers restrict these movements, disrupting the source-sink dynamics necessary to maintain populations (Cross and Moss 1987; Winston et al. 1991; Fausch and Bestgen 1997; Platania and Altenbach 1998; Luttrell et al. 1999; Bonner and Wilde 2000; Gido et al. 2010). Our key findings that 1) adults migrated upstream to spawn and 2) their migration was effectively blocked by a dam support this general model of species decline. Likewise, these findings support calls to preserve large reaches of riverine habitat and to reconnect fragmented segments as a general strategy for conserving populations of flathead chub and other pelagic spawning cyprinids (Fausch and Bestgen 1997; Fullerton et al. 2010; Hoagstrum et al. 201; Perkin and Gido 2011).

The lower reaches of Fountain Creek support a large population of flathead chub (we marked >10,000 adults) even though it is part of a stream fragment that is only 91 rkm long. This is considerably shorter that the predicted minimum length of riverine habitat needed to sustain populations of flathead chub and other pelagic spawning cyprinids. Perkin and Gido (2011) modeled occurrences of 8 pelagic spawners in large stream fragments of the U.S. Great Plains and estimated that 183 rkm was the minimum fragment length for persistence of flathead chub and that all species suffered 100% extirpation in fragments <103 rkm. It is possible that flathead chub persist within this fragment because flowing water is maintained in the channel throughout the spawning season. Perkin and Gido (2011) noted that extirpations of pelagic spawning minnows occurred to the greatest extent in the south and central Great Plains where water withdrawals cause extensive stream drying during the summer spawning season. Stream discharge in Fountain Creek downstream of Colorado Springs is heavily augmented by treated wastewater effluent, and median daily stream discharge during spawning season (mid-May through August) typically range between 0.27 – 2.24m^3/s near its confluence with the Arkansas River (U.S. Geological Survey gage 07106500, discontinuous period of record from 1922 to 2010, 68 years of complete record).

Implications for management of the OHDD

The OHDD limits access of flathead chub to upstream reaches as it is currently operated. Catch rate and abundance were much lower upstream of the OHDD, and passability of the OHDD was low. Less than 0.2% of flathead marked at the OHDD were recaptured upstream. Approximately 6.0 % (10) of the adult fish captured at the Chilcotte Diversion (site 0; Table 1) were originally marked downstream of the OHDD structure (site 1). It is unclear if the remaining 94% (170) were resident fish between the two diversion structures or if fish captured at the Chilcotte Diversion had successfully passed the OHDD in 2010. We observed flathead chub repeatedly and unsuccessfully attempt to swim up the thin sheet of water spilling over the face of OHDD, suggesting that individuals would have continued upstream were their progress not impeded by the dam. The OHDD has a head gate that is opened periodically (mostly weekly) to flush accumulated sediments, and it is possible that flathead chub pass the barrier during these operations.

Plans are underway to install a fishway to improve passage of the OHDD. This fishway should be operated to maintain optimal flows for flathead chub passage in June, July, and August during the peak of the spawning run. If possible, fishway operations should be extended into May and September to accommodate early and late spawners. Spawning readiness (proportion of flathead chub expressing milt) was higher at the OHDD than downstream in May, suggesting an early onset of the spawning run. Likewise, catch rates remained high at the OHDD into September, even though we had inadequate temporal replication at the site to precisely determine the end of spawning run.

Improving passage of the OHDD is a sensible first step for conserving this remnant population of flathead chub. The OHDD is the lowest barrier on Fountain Creek (Figure 1) and intercepts fish from 10s of km downstream (Figure 1). We suspect that flathead chub migrate into Fountain Creek from the mainstream Arkansas River during spawning season, and additional mark-recapture studies are underway to address this possibility. If flathead chubs could move upstream of the OHDD to the Chilcotte Diversion, this would extend the reach an additional 10 km to 101 km, close to the minimum fragment length associated with persistence of pelagic spawning minnows (Perkin and Gido 2011). Upstream of the Chilcotte Diversion, Fountain Creek is highly fragmented with 29 potential barriers (diversion dams and grade control structures) located over the next 40 rkm. Considering the high degree of fragmentation in these upstream reaches, the greatest near-term ecological benefits for flathead chub will likely be gained by increasing passability of the downstream-most barriers in Fountain Creek.

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Table 1. Monthly total number of flathead chub $\geq$ 80 mm captured at each site using two-pass electrofishing, Fountain Creek, 2010. Standard deviation is in parenthesis followed by the number of samples collected that month. Total numbers without standard deviation were visited < three times and totals without an indicated number of samples were visited once. --- indicates site was not visited during that month.

Site	Apr	May	Jun	Jul	Aug	Sept	Oct
0	---	---	25, (13), 3	58, (10), 4	70, (21), 3	27, 2	---
1	---	148, (38), 3	2105, (301), 4	3306, (384), 5	980, (174), 3	191	114
2	---	54, 2	239, (119), 3	44	3	351	---
3	---	33	214, 2	128	28	39	---
4	---	123, 2	72, 2	22	16	32	---
5	54	63	168, 2	219	27	---	293
6	130, 2	71	358, 2	172	22	67	181
7	353, 2	193	326, 2	98	76	---	62
8	---	89	107, 2	10	131	67	---
9	---	201, 2	604, 2	162	106	---	247

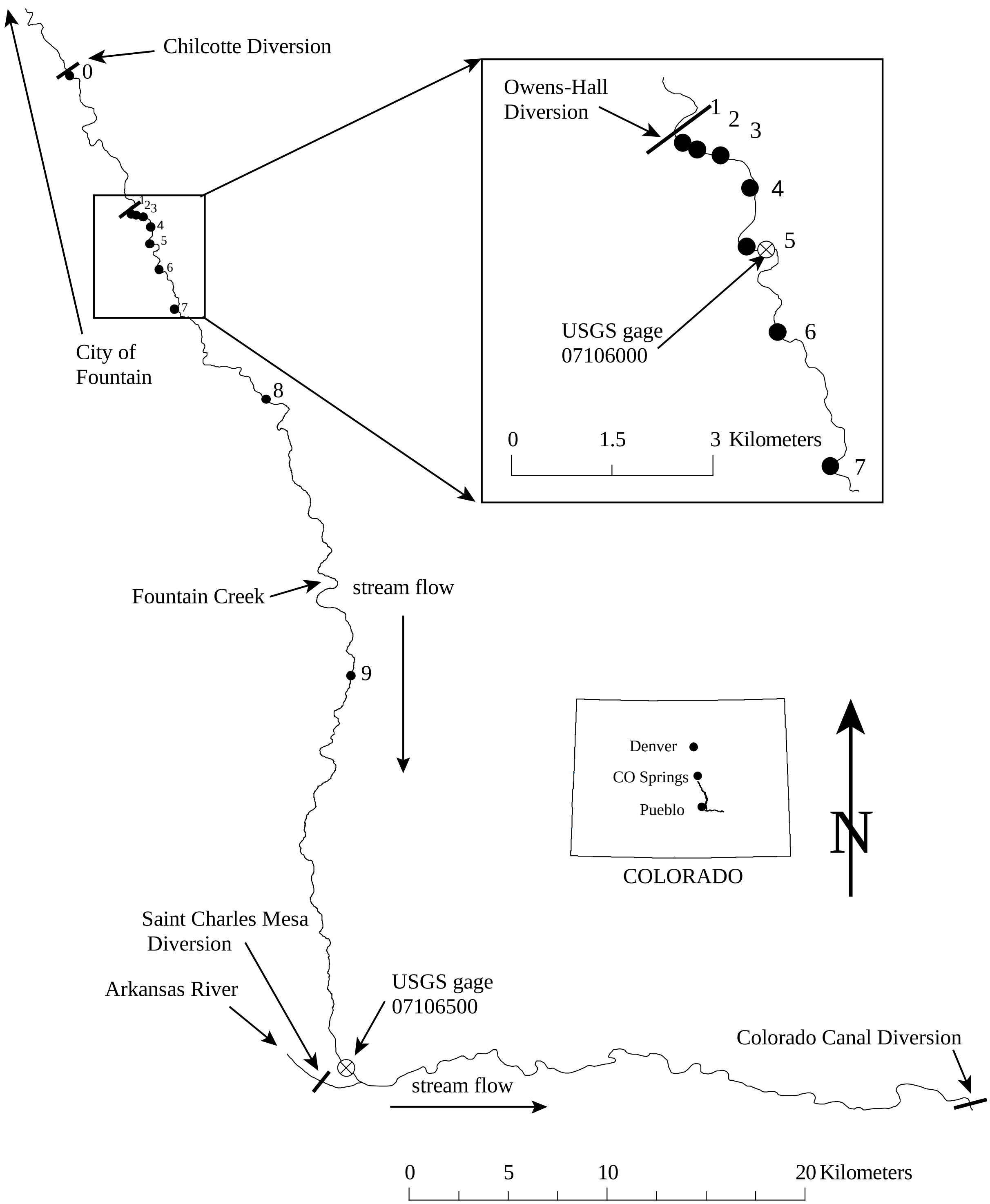

Figure 1. Study area showing approximate locations and distance between 10 sampling locations and upstream dispersal barriers (diversion structures) within the study reach. Numbers next to site locations (closed circles) are site numbers inTable 1.

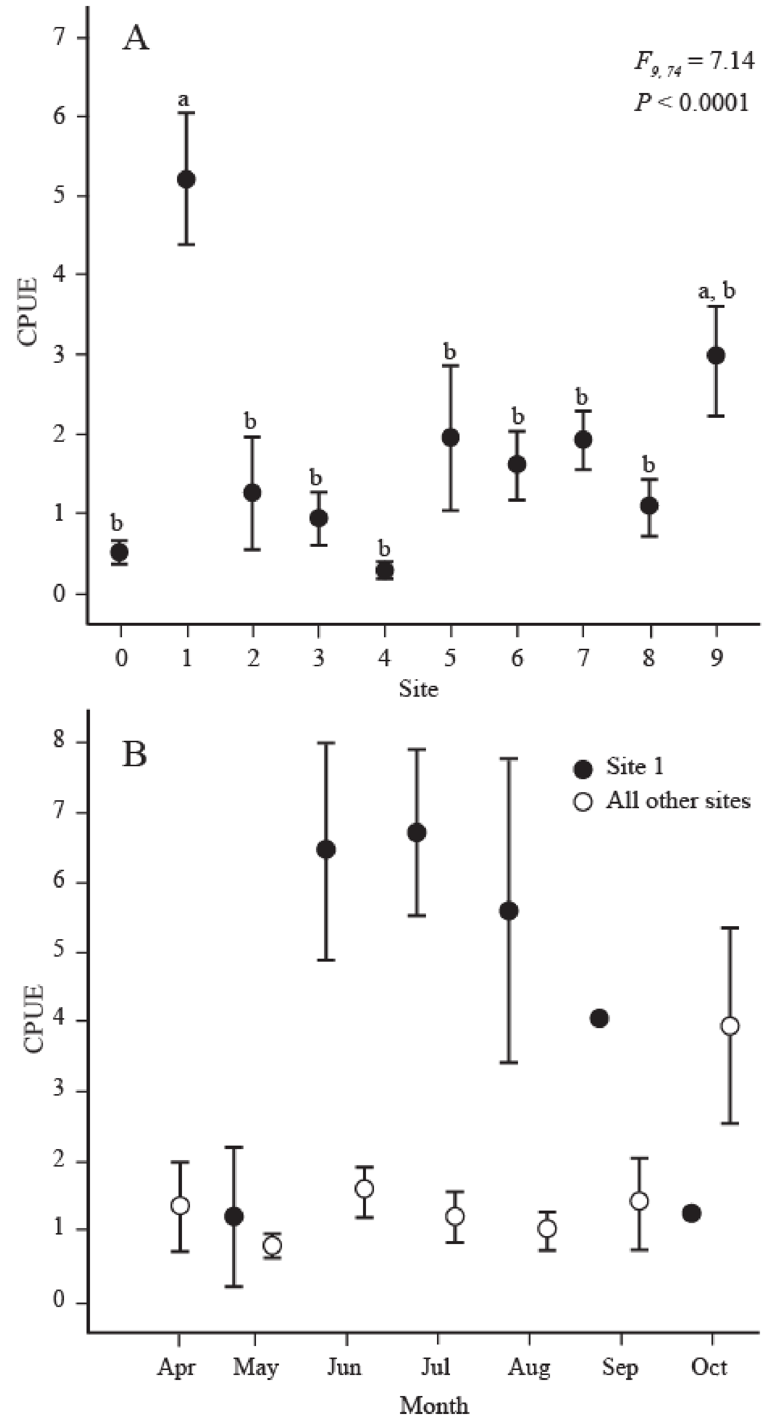

Figure 2. Mean (± SE) catch per unit effort (CPUE; number of flathead chub/min of electrofishing) of flathead chub at each site between April and October (A) and at site 1 relative to all other sites for each month (B), Fountain Creek, 2010. Letters indicate significant differences ($P \leq 0.05$, Bonferroni adjusted).

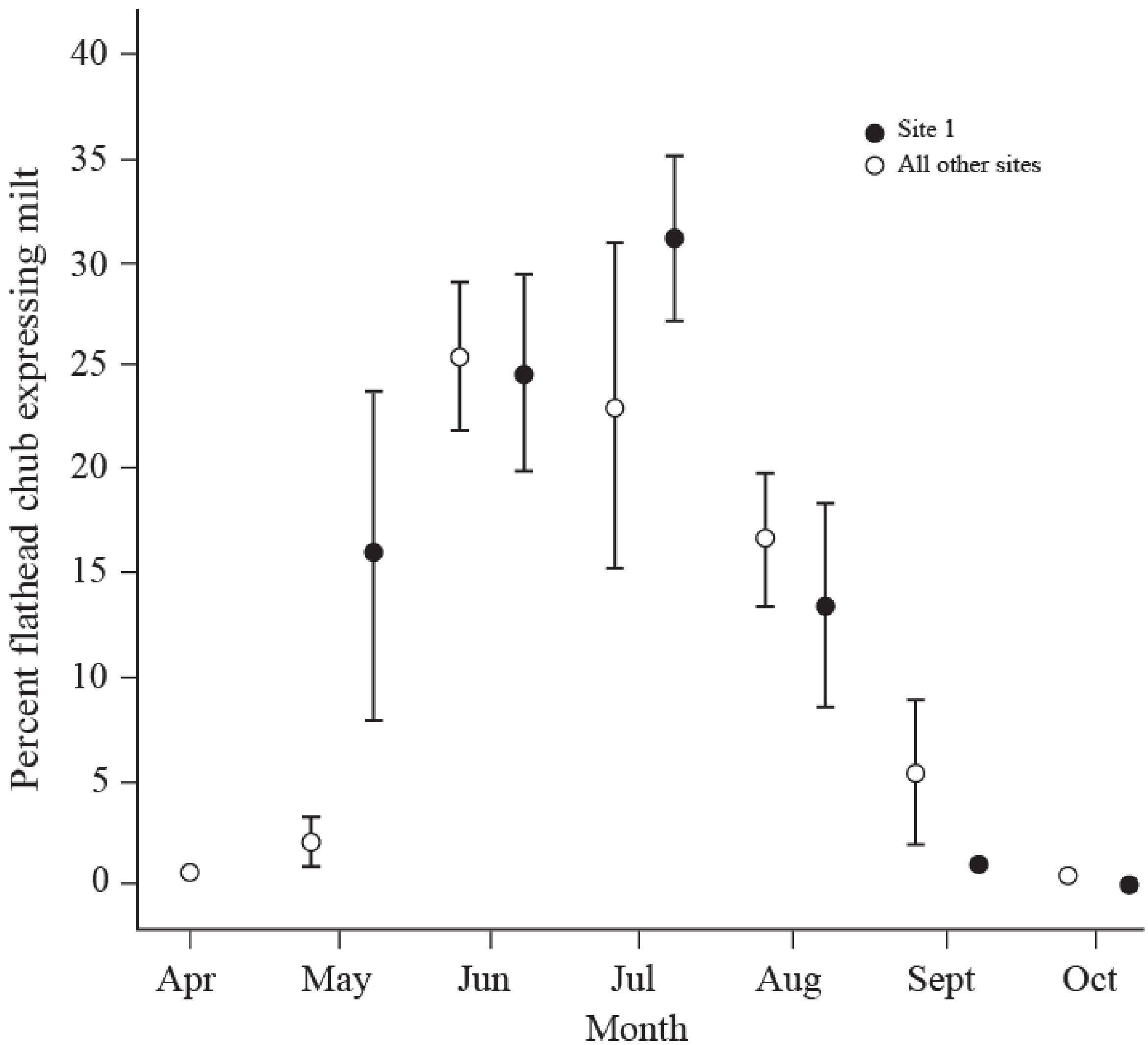

Figure 3. Percent (± SE) of adult flathead chub (≥ 80 mm) captured from Fountain Creek expressing milt between April and October, 2010 at site 1 and at all remaining sites.

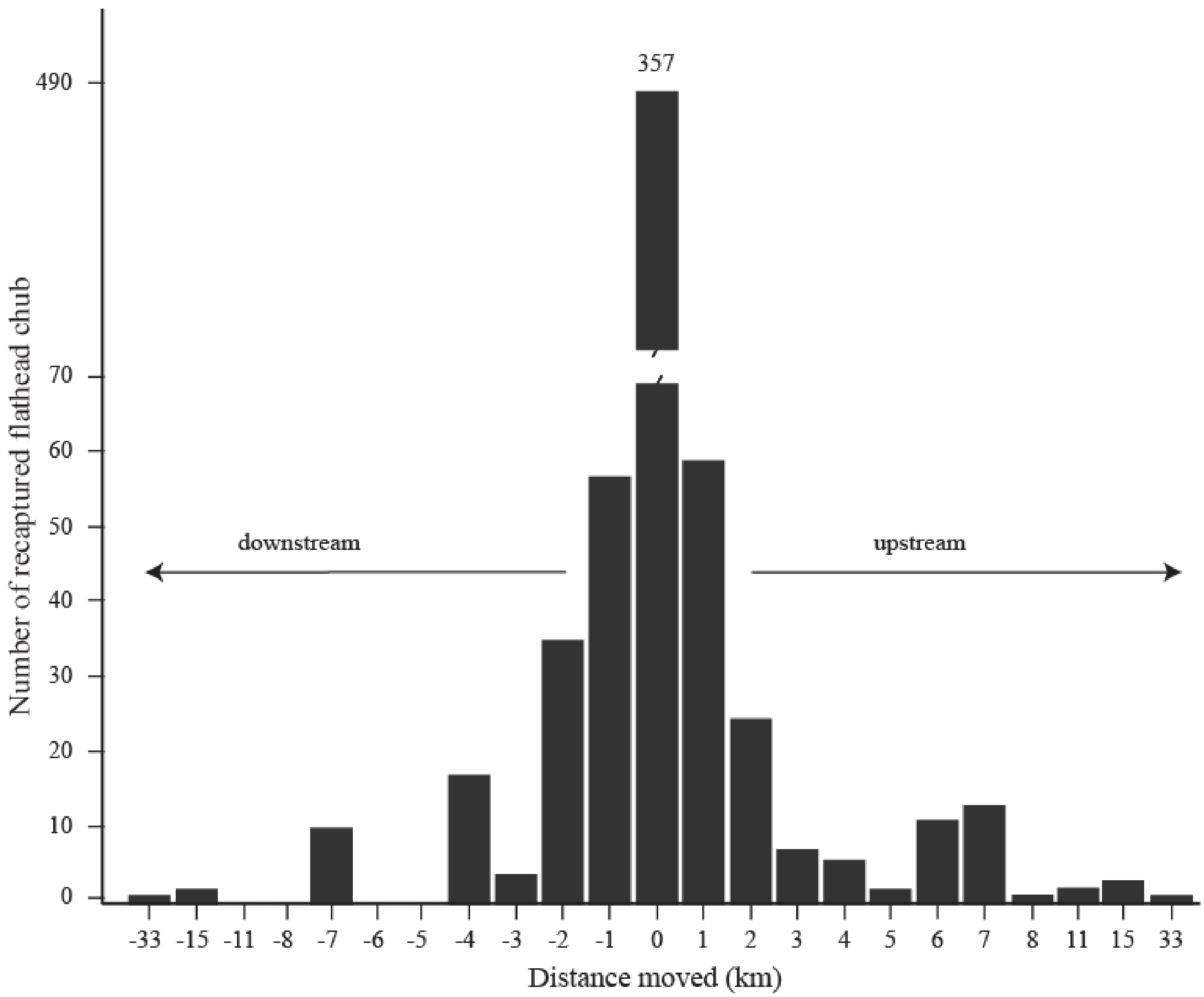

Figure 4. Number of recaptured flathead chub ≥ 80 mm and the upstream and downstream distances moved from where they were origianlly marked, Fountain Creek, April to October, 2010. Number above the zero bar indicates the number of flathead chub that were marked and recaptured at the Ownes-Hall Diversion structure (Site 1).