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ARTICLE

Barriers Impede Upstream Spawning Migration of Flathead Chub

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Abstract
Many native cyprinids are declining throughout the North American Great Plains. Some of these species require long reaches of contiguous, flowing riverine habitat for drifting eggs or 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 populations of species with passively drifting eggs or larvae, and prior researchers have suggested that these fishes 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, Colorado. We measured CPUE, spawning readiness (percent of Flathead Chub expressing milt), and fish movement relative to a channel-spanning dam. Multiple lines of evidence indicate that Flathead Chub migrate upstream to spawn during summer. The CPUE was much higher at the base of the dam than at downstream sites; the seasonal increases in CPUE at the dam 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 dam. The CPUE of Flathead Chub was much lower upstream of the OHDD than at downstream sites, and <0.2% of fish marked at the dam were recaptured upstream. This study provides the first direct evidence of spawning migration for Flathead Chub and supports the general hypothesis that barriers limit adult dispersal of these and other plains fishes.

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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 USA and the Great Plains are highly fragmented by dams, other diversion structures, and dewatered channels. These barriers to dispersal have been implicated in the shrinking ranges and declining abundances of plains fishes (Cross et al. 1985; Bestgen and Platania 1990, 1991; Winston et al. 1991; Fausch and Bestgen 1997; Luttrell et al. 1999; Matthews and Marsh-Matthews 2007). Consequently, improving and restoring the hydrologic connectivity of plains river systems has become a cornerstone strategy in the conservation of plains fishes (Fausch et al. 2002; Dodds et al. 2004; Hoagstrom et al. 2011, Perkin and Gido 2011). However, large-scale movements, particularly for small-bodied plains fishes, remain largely unknown (Fausch et al. 2002).

One such species is the 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 (Kucas 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 River and the Rio Grande basins (Alves 1997; Nesler et al. 1999), where based on historical records, their range has shrunk (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; Pflieger and Grace 1987; Bonner and Wilde 2000; Hoagstrom et al. 2007; Gido et al. 2010; Perkin and Gido 2011).

Flathead Chub occupy large, turbid river systems (Quist et al. 2004; 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, 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; Pflieger and Grace 1987; Winston et al. 1991; Luttrell et al. 1999; Gido et al. 2010). Larval Flathead Chub are known to drift (Smith and Hubert 1989; Durham and Wilde 2008). However, empirical evidence of semibuoyant, passively drifting eggs is lacking, leading some to question their inclusion in the pelagic spawning cyprinid guild (K. Bestgen, C. Hoagstrom, and G. Wilde personal communication). For example, millions of drifting eggs collected in the Rio Grande River, where Flathead Chub occur, were reared as part of recovery efforts for Rio Grande Silvery Minnow *Hybognathus amarus*. None of these hatched eggs have given rise to a Flathead Chub (C. Hoagstrom, personal communication). None the less, large-scale extirpations of Flathead Chub, known pelagic-spawning cyprinids, and other plains fishes are attributed to a common factor, habitat fragmentation (e.g., Gido et al. 2010, Perkin and Gido 2011), even if the mechanisms (e.g., interruption of spawning migrations and insufficient egg or larval drifting distance) remain unclear.

Upstream dispersal is presumed to be a critical mechanism by which plains fishes with drifting eggs or larvae, repopulate upstream reaches (Fausch and Bestgen 1997; Cross et al. 1985; Luttrell et al. 1999). Such species 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 provide adequate development time for drifting eggs or larvae (Durham and Wilde 2008). Direct support for the upstream dispersal hypothesis is lacking, in part due to the logistical challenges of measuring the movement of small fishes in large streams and rivers. However, indirect evidence in support of this hypothesis has been provided for Flathead Chub and other plains cyprinids. Olund and Cross (1961) and Scott and Crossman (1973) suggested that Flathead Chub move upstream into tributaries to spawn. We have also observed large aggregations of Flathead Chub below dams in Colorado during the summer spawning season (J. F. Bruce, unpublished data), suggesting an upstream migration impeded by barriers. Among the known pelagic spawning cyprinids, Rio Grande Silvery Minnow swam the equivalent of 50 km upstream in less than 72 h under laboratory conditions (Bestgen et al. 2010), and Arkansas River Shiners *Notropis girardi* are thought to migrate upstream to spawn, based on longitudinal distributions of adults (Durham and Wilde 2008) and drifting larvae (Bonner and Wilde 2000) during the spawning season.

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, Colorado, 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 fishway for the OHDD. Our objectives were to determine (1) if Flathead Chub migrate upstream to during the reproductive season, (2) if they are able to pass the OHDD under its present configuration, and (3) how far they move within our survey reach. We conducted a large-scale (10 sites in 43 river kilometers [rkm]) survey and mark–recapture study of Flathead Chub upstream and downstream of the OHDD to achieve these objectives. Based on prior fish collections in Fountain Creek (J. F. Bruce and H. J. Crockett, unpublished data), we expected that Flathead Chub would migrate upstream during the spawning season and that this migration would be blocked by the OHDD. If so, then Flathead

Chub catch rate at the OHDD would be higher than downstream sites and the catch rates at the OHDD would track seasonal changes in spawning condition of Flathead Chub. Likewise, catch rates would be greatly reduced upstream of the OHDD, and few downstream fish would be recaptured upstream of the dam. Quantitative movement studies are lacking (Rahel and Thel 2004), so we had no a priori expectations regarding the distance that Flathead Chub would move.

METHODS

Study area.—Fountain Creek is a 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 in the study section, and streambed material is predominated by sand and small gravel. Average daily stream discharge is 3.47 m^3/s (range, 1.84–14.19 m^3/s), and average annual peak flow, which typically occurs in July, is 177.16m^3/s (range, 1.35–569.23 m^3/s; USGS gauge 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 1985). Flathead Chub are considered extirpated from the mainstem Arkansas River upstream of Florence, Colorado (Woodling 1985), and have not been collected in the system despite repeated sampling since 1985 (H. J. Crockett, unpublished data). They are also thought to be extirpated from the Arkansas River downstream of John Martin Reservoir (Las Animas, Colorado) in eastern Colorado and Kansas (Gido et al. 2010; Perkin and Gido 2011), but they were collected in Colorado in this section of the Arkansas River and its tributaries as recently as 2001 (Bestgen et al. 2003).

Sample sites.—We sampled 100-m reaches at 10 sites along 43 rkm in Fountain Creek near Fountain, Colorado (Figure 1). The study section is part of a larger 91-rkm contiguous fragment of riverine habitat extending from the OHDD downstream into the Arkansas River (Figure 1). One site was located at the base of the OHDD, and eight additional sites were distributed downstream. To detect both smaller and larger scale movements, distance was approximately doubled between sites downstream from the OHDD, the farthest site being 32 rkm downstream of 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 (5–17 sampling events per site) between April and October 2010 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-L buckets and instream live wells. All collected fishes were identified to species, counted, and then measured (total length; mm) in the field.

Fish marking and spawning readiness.— Using elastic fluorescent polymer (Northwest Marine Technology, Seattle, Washington), Flathead Chub were batch-marked subcutaneously with site-specific color and body position combinations and returned to the stream. We only marked adult fish ($\geq$80 mm TL based on age-length studies summarized by Rahel and Thel 2004) because these were the 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, and marked 10,320 adults (range = 80–195 mm, mean = 105 mm). We marked 30 fish in April and maintained them in aquaria through October. Mark retention for these fish was 100% with no mortalities.

We assessed spawning condition of adults by applying light pressure to the abdomen and recording the presence or 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 because we could not consistently determine if swollen abdomens were related to ripe ovaries or full stomachs.

Data analysis.—We calculated the Flathead Chub CPUE (number/min of electrofishing) using first pass data only. We used ANOVA to determine if variability in mean CPUE values was associated with site and used Bonferroni-adjusted posthoc tests to test for mean differences between sites (α = 0.05). Flathead Chub spawn during summer (Rahel and Thel, 2004), and we used a Welch's *t*-test to determine whether mean CPUE at the OHDD was different from other sites (α = 0.05) during summer (June, July, and August) and nonsummer months. 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 analyses of the timing and directionality of fish movements was beyond the scope of this paper, but it 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 calculation

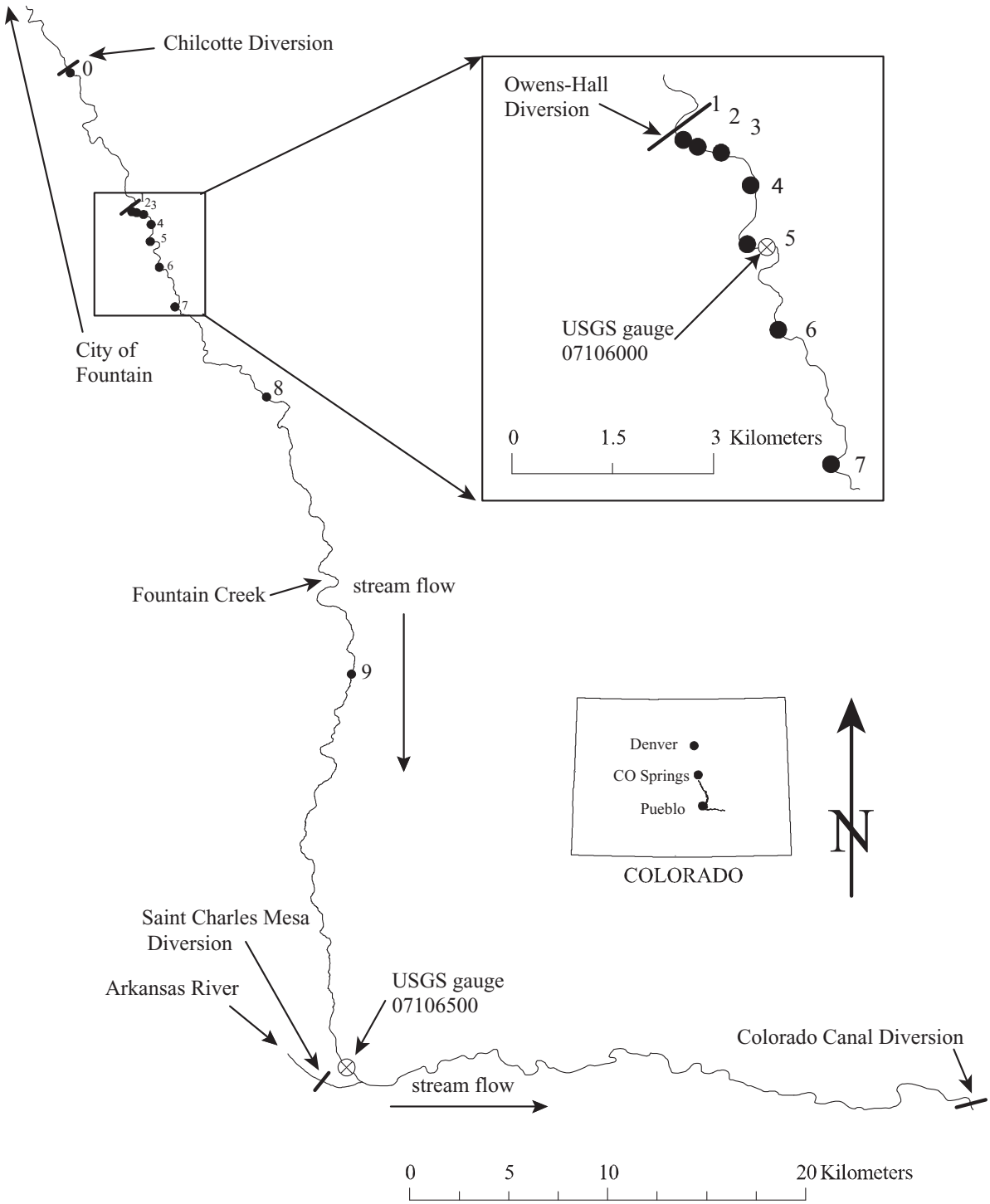

FIGURE 1. The Fountain Creek, Colorado, study area for Flathead Chub dispersal showing approximate locations and distances between 10 sampling locations and upstream dispersal barriers (diversion structures) within the study reach. Numbers next to site locations (closed circles) are site numbers in Table 1.

could underestimate passage rate because it 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 CPUE

Flathead Chub CPUE was significantly higher at OHDD (site 1) than at other sites in most cases ($F_{9,74} = 7.14$, $P < 0.0001$),

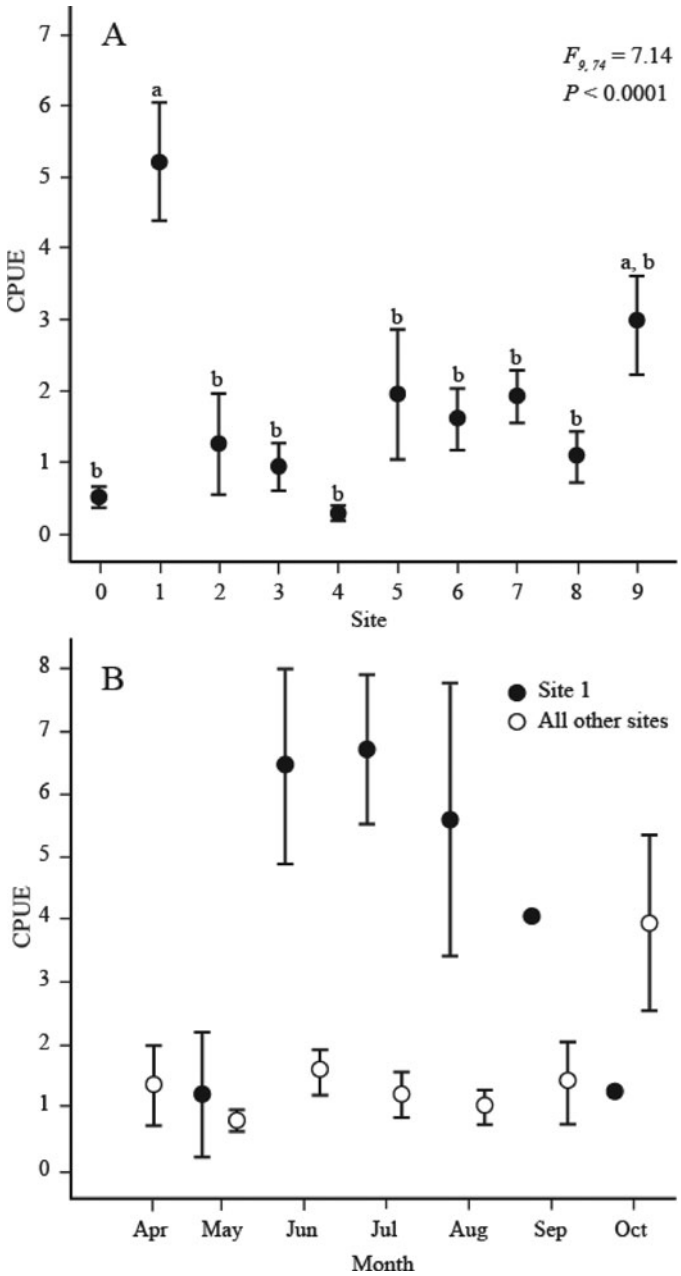

FIGURE 2. Mean (± SE) CPUE (fish/min of electrofishing) of Flathead Chub **(A)** at each of the 10 sites between April and October 2010 combined, and **(B)** at site 1 compared with all other sites for each month. Means with different letters indicate significant differences ($P \leq 0.05$, Bonferroni adjusted).

and the largest differences occurred during June, July, and August (Figure 2). Mean CPUE was higher at OHDD than all other sites except site 9, where CPUE was indistinguishable from either OHDD or the other sites (Figure 2*A*). At OHDD the CPUE (fish/min) increased approximately sixfold from May (1.13) to June (6.44), July (6.71), and August (5.60). In contrast, mean monthly CPUE was low and invariant (around 1.5) at the other sites until October, when it increased (3.92; Figure 2*B*). At OHDD mean CPUE was around fivefold higher than at

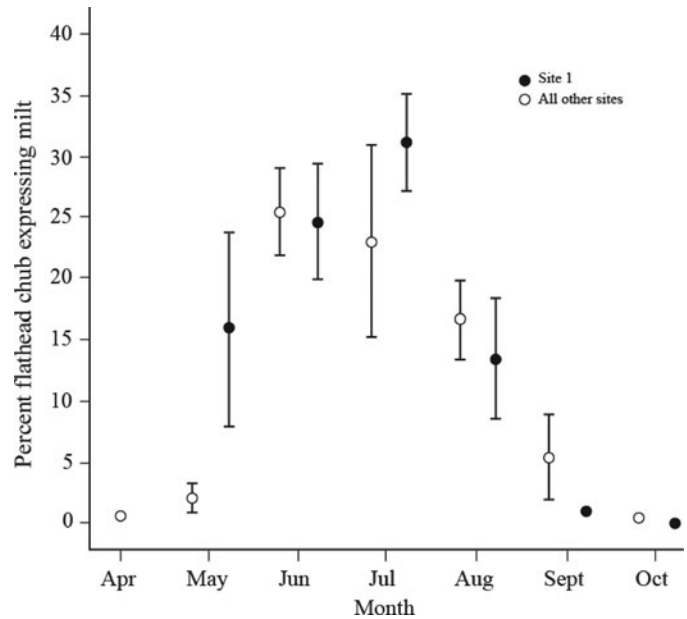

FIGURE 3. Mean percent (± SE) of adult Flathead Chub (≥80 mm TL) that expressed milt captured at site 1 versus all other Fountain Creek sites, April–October 2010.

other sites during summer ($t_{12.43} = 5.97$, $P < 0.0001$) but was similar to other sites during nonsummer months ($t_{4.13} = 0.47$, $P < 0.66$; Figure 2B).

Temporal and Spatial Variation in Spawning Readiness

Spawning readiness was high from May through August, peaking in June and July (Figure 3). High spawning readiness corresponded with peak Flathead Chub catch rates at OHDD (June– August; Figure 2). 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 upstream and downstream 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 predominated 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 two individuals that moved 33 km (one upstream and one downstream).

Barrier Passability of the OHDD

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

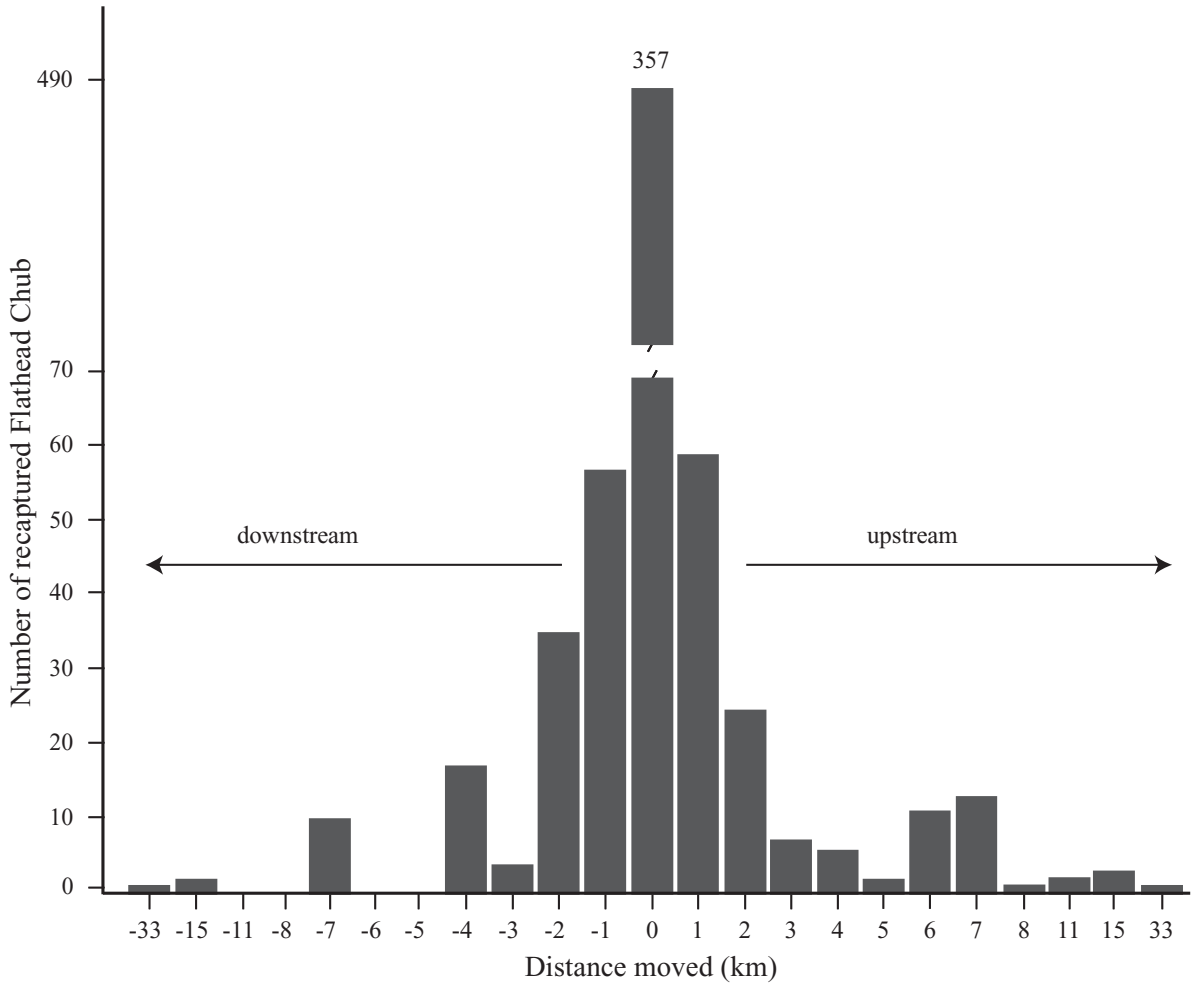

FIGURE 4. Number of recaptured Flathead Chub (≥80 mm TL) and the upstream and downstream distances moved from where they were originally marked in Fountain Creek, April to October 2010. Number above the zero bar indicates the number of Flathead Chub that were marked and recaptured at the Ownes-Hall Diversion structure (site 1).

dam (Figure 1). Mean monthly total catch was more than an order of magnitude lower at the Chilcotte Diversion (15 fish, SD = 8) than at the OHDD (505 fish, SD = 168) during the peak spawning months of June, July, and August (Table 1).

DISCUSSION

Extirpation of Flathead Chub and other plains fishes, such as 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 Bestgen 1997; 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 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 of North American cyprinids of the Great Plains.

Other cyprinids are known to aggregate below diversion dams in arid, western rivers during extreme low flows (Bestgen and Platania 1990, 1991). If adult Flathead Chub were responding to low flows as opposed to spawning cues, then we would expect that (1) flows would be lowest during the spawning season, and (2) abundances of other fishes (juvenile Flathead Chub and other species) would increase along with adult Flathead Chub. Neither of these conditions occurred. Mean daily discharge in Fountain Creek during our study was typically higher during the spawning season compared to other months (U.S. Geological Survey gauge 07106500). Likewise, the abundances of juvenile

TABLE 1. Monthly total number of Flathead Chub (≥80 mm TL) captured at each site using two-pass electrofishing, Fountain Creek in 2010. Standard deviation of the mean number per sample is in parenthesis (na = <3 samples) followed by the number of samples collected that month (*n*; not shown if only 1 sample).Blank cells indicates site was not visited during that month. Site locations are shown in Figure 1.

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

Flathead Chub and adults of six other common species (Longnose Dace *Rhinichthys cataractae,* Fathead Minnow *Pimephales promelas*, Central Stoneroller *Campostoma anomalum*, Sand Shiner *Notropis stramineus*, White Sucker *Catostomus commersonii*, and Longnose Sucker *Catostomus catostomus*) did not increase at the dam during spawning season. For example, mean juvenile Flathead Chub abundance at the dam during spawning season (96, SD = 142) was similar to abundances measured at other sites and over time during the study (79, SD = 127). The relatively low and stable abundance of juvenile Flathead Chub and other fishes stands in stark contrast to the order of magnitude increase in adult Flathead Chub at the dam during spawning season (Table 1).

Many species of plains fishes are increasingly in need of conservation efforts due to declining populations (Fausch and Bestgen 1997; Hoagstrom et al. 2011). The case of the Flathead Chub epitomizes the declines seen for plains fishes whose recruitment is thought to depend upon unrestricted movement between habitats. For example, Perkin and Gido (2011) concluded that they had been extirpated from 61% of the large stream fragments remaining in the Great Plains portion of the USA. Efforts to identify mechanisms of extirpation for many plains fish species have coalesced around two critical factors: (1) movement at multiple life stages is an important life history strategy, 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 plains fishes (Fausch and Bestgen 1997; Fullerton et al. 2010; Falke et al. 2010; Hoagstrom et al. 2011; 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 183 rkm of riverine habitat needed to sustain populations of Flathead Chub (Perkin and Gido 2011). It is possible that Flathead Chub persist within this reach because flowing water is maintained in the channel throughout the spawning season. In their analysis of Flathead Chub and known pelagic spawning cyprinids, Perkin and Gido (2011) noted that extirpations occurred to the greatest extent in the south and central Great Plains where water withdrawals cause extensive stream drying during the summer spawning season. That is not the case in Fountain Creek where discharge is heavily augmented by treated wastewater effluent (Stogner 2000; Edelmann et al. 2002), and median daily stream discharge during spawning season (mid-May through August) typically ranges between 0.27 and 2.24 m^3/s near its confluence with the Arkansas River (U.S. Geological Survey gauge 07106500, discontinuous period of record from 1922 to 2010, 68 years of complete record). Another possibility is that Flathead Chub are able to persist in shorter river reaches because they do not have semibuoyant drifting eggs that require long, unfragmented river reaches to properly develop. This hypothesis is supported by additional Flathead Chub populations that persist in short reaches of the Rio Grande River and upper Pecos River in New Mexico (Sublette et al. 1990; Platania 1991). These rivers are highly fragmented by dams, many of which were closed in the early 20th century (Hoagstrom et al. 2008), yet Flathead Chub remain in short reaches where known pelagic spawning cyprinids (e.g., Speckled Chub *Macrhybopsis aestivalis*) have been extirpated (Platania 1991).

IMPLICATIONS FOR MANAGEMENT OF 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 Chub marked at the OHDD were recaptured upstream. Approximately 6.0% (10) of the adult fish captured at the Chilcotte Diversion were originally marked downstream of the OHDD structure. It is unclear if the remaining 94% (170 fish) occupied the area 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 likely 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 suitable 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 the spawning run.

Flathead Chub persist in Fountain Creek in reaches much shorter than predicted by Perkin and Gido (2011). This population thrives in the 91-rkm reach we studied, and other populations occur in the Fountain Creek systems upstream of the Chilcotte Diversion (Bruce, unpublished data). This section of Fountain Creek is highly dissected, with 29 potential barriers (diversion dams and grade control structures) located over the next 40 rkm. More research is needed to determine if other factors (e.g., augmented summer flows in streams receiving treated wastewater effluent) can mitigate the effects of stream fragmentation on Flathead Chub that has been documented in other river systems. However, improving passage of the OHDD remains a sensible first step for conserving this remnant population of Flathead Chub. The OHDD is the lowest barrier on Fountain Creek and intercepts fish from downstream (Figure 1). We suspect that Flathead Chub migrate into Fountain Creek from the main-stem Arkansas River during spawning season; additional mark–recapture studies are underway to address this possibility. 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 and reconnecting populations in the lower and upper reaches of this system.

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REFERENCES

Alves, J. 1997. Rio Grande 1. Colorado Division of Wildlife, Annual Fish Survey Project Report, Monte Vista.

Bestgen, K. R., B. Mefford, J. M. Bundy, C. D. Walford, and R. I. Compton. 2010. Swimming performance and fishway model passage success of Rio Grande Silvery Minnow. Transactions of the American Fisheries Society 139:433–448.

Bestgen, K. R., and S. P. Platania. 1990. Extirpation of *Notropis simus simus* (Cope) and *Notropis orca* Woolman (Pisces: Cyprinidae) from the Rio Grande in New Mexico, with notes on their life history. Occasional Papers the Museum of Southwestern Biology 6:1–8.

Bestgen, K. R., and S. P. Platania. 1991. Status and conservation of the Rio Grande Silvery Minnow, *Hybognathus amarus*. Southwestern Naturalist 36:225–232.

Bestgen, K. R., K. Zelasko, and R. Compton. 2003. Environmental factors limiting Suckermouth Minnow *Phenacobius mirabilis* populations in Colorado. Final Report to Colorado Division of Wildlife, Colorado State University, Fort Collins.

Bonner, T. H., and G. R. Wilde. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology 15:189–198.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155–165 *in* W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Cross, F. B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. Museum of Natural History, University of Kansas, Lawrence.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54:205–216.

Dudley, R. K., and S. P. Platania. 2007. Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. Ecological Applications 17:2074–2086.

Durham, B. W., and G. R. Wilde. 2006. Influence of stream discharge on reproductive success of a prairie stream fish assemblage. Transactions of the American Fisheries Society 135:1644–1653.

Durham, B. W., and G. R. Wilde. 2008. Composition and abundance of drifting fish larvae in the Canadian River, Texas. Journal of Freshwater Ecology 23:273–280.

Edelmann, P., S. A. Ferguson, R. W. Stogner Sr., M. August, W. F. Payne, and J. F. Bruce. 2002. Evaluation of water quality, suspended sediment, and stream morphology with an emphasis on effects of stormflow on Fountain and Monument Creek basins, Colorado Springs and vicinity, Colorado, 1981 through 2001. U.S. Geological Survey, Water-Resources Investigations Report 02-4104, Reston, Virginia.

Falke, J. A., K. R. Bestgen, and K. D. Fausch. 2010. Streamflow reductions and habitat drying affect growth, survival, and recruitment of Brassy Minnow

across a Great Plains riverscape. Transactions of the American Fisheries Society 139:1566–1583.

Fausch, K. D., and K. R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. Pages 131–166 *in* F. L. Knopf and F. B. Samson, editors. Ecology and conservation of Great Plains vertebrates. Springer-Verlag, New York.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483–498.

Ficke, A. D., and C. A. Myrick. 2009. A method for monitoring movements of small fishes in urban streams. North American Journal of Fisheries Management 29:1444–1453.

Fullerton, A. H., K. M. Burnett, E. A. Steel, R. L. Flitcroft, G. R. Pess, B. E. Feist, C. E. Torgersen, D. J. Miller, and B. L. Sanderson. 2010. Hydrological connectivity for riverine fish: measurement challenges and research opportunities. Freshwater Biology 55:2215–2237.

Gido, K. B., W. K. Dodds, and M. E. Eberle. 2010. Retrospective analysis of fish community change during a half-century of landuse and streamflow changes. Journal of the North American Benthological Society 29:970–987.

Hansen, W. R., and E. J. Crosby. 1982. Environmental geology of the Front Range urban corridor and vicinity, Colorado with a specific section on physical properties and performance characteristics of surficial deposits and rock units in the greater Denver area. U.S. Geological Survey, Professional Paper 1230, Reston, Virginia.

Hoagstrom, C. W., J. E. Brooks, and S. R. Davenport. 2008. Recent habitat association and the historical decline of *Notropis simus pecosensis*. River Research and Applications 24:789–803.

Hoagstrom, C. W., J. E. Brooks, and S. R. Davenport. 2011. A large-scale conservation perspective considering endemic fishes of the North American plains. Biological Conservation 144:21–34.

Hoagstrom, C. W., A. C. DeWitte, N. J. C. Gosch, and C. R. Berry Jr. 2007. Historical fish assemblage flux in the Cheyenne River below Angostura Dam. Journal of Freshwater Ecology 22:219–229.

Kemp, P. S., and J. R. O'Hanley. 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. Fisheries Management and Ecology 17:297–322.

Kucas, S. T. 1980. *Hybopsis gracilis* (Richardson), Flathead Chub. Page 186 *in* D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer Jr., editors. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh.

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

Matthews, W. J., and E. Marsh-Matthews. 2007. Extirpation of Red Shiner in direct tributaries of Lake Texoma (Oklahoma–Texas): a cautionary case history from a fragmented river–reservoir system. Transactions of the American Fisheries Society 136:1041–1062.

Nesler, T. P., C. Bennett, J. Melby, G. Dowler, and M. Jones. 1999. Inventory and status of Arkansas River native fishes in Colorado. Colorado Division of Wildlife, Denver.

O'Hanley, J. R., and D. Tomberlin. 2005. Optimizing the removal of small fish passage barriers. Environmental Modeling and Assessment 10:85–98.

Olund, L. J., and F. B. Cross. 1961. Geographic variation in the North American cyprinid fish, *Hybopsis gracilis*. University of Kansas Publications of the Museum of Natural History 13:323–348.

Perkin, J. S., and K. B. Gido. 2011. Stream fragmentation thresholds for a reproductive guild of Great Plains fishes. Fisheries 36:371–383.

Pflieger, W. L., and T. B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940–1983. Pages 166–177 *in* W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Platania, S. P. 1991. Fishes of the Rio Chama and upper Rio Grande, New Mexico, with preliminary comments on their longitudinal distribution. Southwestern Naturalist 36:186–193.

Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande basin cyprinids. Copeia 1998:559–569.

Quist, M. C., W. A. Hubert, and F. J. Rahel. 2004. Relations among habitat characteristics, exotic species, and turbid-river cyprinids in the Missouri River drainage of Wyoming. Transactions of the American Fisheries Society 133:727–742.

Rahel, F. J., and L. A. Thel. 2004. Flathead Chub (*Platygobio gracilis*): a technical conservation assessment. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Species Conservation Project, Golden, Colorado. Available: www.fs.fed.us/r2/projects/scp/assessments/flatheadchub.pdf. (May 2011).

Schlosser, I. J., and P. L. Angermeier. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. Pages 392–401 *in* J. L. Nielsen and D. A. Powers, editors. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society, Symposium 17, Bethesda, Maryland.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184.

Smith, J. B., and W. A. Hubert. 1989. Use of a tributary stream by fishes in a Great Plains river system. Prairie Naturalist 21:27–38.

Stogner, R. W., Sr. 2000. Trends in precipitation and streamflow and changes in stream morphology in the Fountain Creek watershed, Colorado, 1939–99. U.S. Geological Survey, Water-Resources Investigations Report 00-4130, Denver.

Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque.

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

Woodling, J. 1985. Colorado's little fish: a guide to the minnows and other lesser known fishes in the state of Colorado. Colorado Division of Wildlife, Denver.