Entrainment of Native Fish in Maybell Ditch, Northwestern Colorado, 2011-2012

by

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April 2014

Draft Final Report for the
Upper Colorado River Endangered
Fish Recovery Program
U. S. Department of Interior, Fish and Wildlife Service
Lakewood, Colorado 80225

Recovery Program Project No. 146

Contribution 184 of the Larval Fish Laboratory, Colorado State University

Acknowledgements

Funding for this project was provided by the U.S. Bureau of Reclamation though the Upper Colorado River Endangered Fish Recovery Program (Recovery Program). The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, National Park Service, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, and the Colorado River Energy Distributors Association. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the authors, the Fish and Wildlife Service, U.S. Department of Interior, or members of the Recovery Implementation Program.

We thank Mr. Darryl Steele of Maybell, Colorado for access to his property to conduct this study, and Mike Camblin of the Maybell Ditch Association for updates on ditch operations and helpful advice. We also thank Tom Chart and Tom Pitts of the Recovery Program for brokering a memorandum of agreement with Mr. Steele which allowed this work to proceed. Thanks also to Bill Kohler and Kevin Rudolph for their help during PIA installation and assistance with PIA operation and maintenance during the two irrigation seasons.

Key words: Colorado Pikeminnow, Roundtail Chub, Maybell Ditch, Yampa River, irrigation ditch, entrainment, passive interrogation array, PIT tags

Table of Contents

List of Figures

Executive Summary

We assessed potential for entrainment of Colorado Pikeminnow *Ptychocheilus lucius* into Maybell Ditch, a gravity-fed irrigation ditch on the Yampa River near Maybell, Colorado during the 2011 and 2012 irrigation seasons (late April through October of each year). We installed a solar-powered passive interrogation array (PIA) about 2.6 km below the ditch head gates in April 2011 to detect entrained fish implanted with 134.2 kHz passive integrated transponder tags. Based on system diagnostics, successful tag readability tests under ambient noise levels, performance of the equipment in other settings, and use of two antenna loops for increased detection probability, we feel that the PIA as a whole afforded a high likelihood of detecting fish on at least one of the two antenna loops. High levels of ambient electrical interference probably caused occasional lapses in detection efficiency of individual antenna loops. Average Yampa River discharge during the irrigation season was the greatest on record (1916-2012) in 2011 but the fourth lowest on record in 2012 (97% exceedence). We detected no fish entrainment during the 2011 irrigation season but detected entrainment of one Roundtail Chub in July 2012 and one Colorado Pikeminnow in August 2012. Considering all available data, entrainment of large-bodied (450 – 500 mm TL) native fish in Maybell Ditch can occur over a range of river flows during or immediately following the peak flow period and during the late summer base flow period. The Colorado Pikeminnow entrained in 2012 potentially represented between 0.3 and 1.3% (0.7% of the point estimate) of the Yampa River population of Colorado Pikeminnow, which was estimated to be 140 individuals (95% confidence interval 75 – 297 individuals) in 2008. A number of factors (e.g., uncertainties about detection efficiency, recent population data, and potential entrainment of untagged fish) indicate that this figure should be considered a minimum estimate. A better perspective on observed entrainment rates of Colorado Pikeminnow in relation to population size may be gained when 2011 and 2012 abundance estimates become available.

Introduction

Maybell Ditch is a gravity-fed irrigation canal on the Yampa River located near the town of Maybell, Moffat County, northwestern Colorado. Because the ditch intake is unscreened and can divert a relatively large proportion of the Yampa River during low flow periods, it constitutes a potential entrainment hazard for endangered Colorado Pikeminnow *Ptychocheilus lucius* and other fishes that occupy the Yampa River. Evaluation of entrainment potential of Yampa River diversion structures was recommended in the Management Plan for Endangered Fishes in the Yampa River Basin (Roehm 2004) and is a reasonable and prudent measure of the Final Programmatic Biological Opinion of that plan (PBO; U.S. Fish and Wildlife Service [USFWS] 2005).

Hawkins (2009) used an electric seine and hoop nets to evaluate entrainment of fish into Maybell Ditch in 2007 and 2008. Although eight species of fish (including two native species) were captured during the study, no endangered fish were captured. However, adult Roundtail Chub *Gila robusta* were entrained and captured in hoop nets in Maybell Ditch in 2008 during the migration period of Colorado Pikeminnow. Both Roundtail Chub and Colorado Pikeminnow are large-bodied cyprinid species, share a common morphology, and occupy similar habitat. Therefore, occurrence of large adult Roundtail Chub in Maybell Ditch suggested that the presumptively less abundant Colorado Pikeminnow could also become entrained in the ditch.

Hawkins (2009) determined that the results of his study were not conclusive regarding entrainment of endangered fish in Maybell Ditch because the ability to detect the presence of large fish (i.e., Colorado Pikeminnow) was low due to the limited time of sampling and poor sampling efficiency of hoop nets. He recommended a more rigorous approach to obtain less ambiguous results on entrainment of Colorado Pikeminnow during their migration period. The USFWS concurred with this recommendation as a means of complying with the PBO (USFWS 2005). Based on recommendations from the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) Biology Committee to obtain more conclusive results on entrainment of endangered fish, the Program Director's Office recommended use of a passive interrogation array (PIA) to monitor entrainment of Colorado Pikeminnow and other native fishes marked with passive integrated transponder (PIT) tags (Chart 2009).

The goal of this study was to determine likelihood of PIT-tagged Colorado Pikeminnow entrainment in Maybell Ditch. Specific objectives included:

1) Work with a private landowner and the Maybell Irrigation District to obtain access to Maybell Ditch to evaluate entrainment.
2) Construct, operate and maintain a PIA detection system in Maybell Ditch during the 2011 and 2012 irrigation seasons.
3) Dismantle and remove PIA system at the end of the second irrigation season.
4) Based on monitoring results, assess the potential for entrainment of Colorado Pikeminnow in Maybell Ditch and estimate the size range of Colorado Pikeminnow that might be entrained.

Study Area

Maybell Ditch (Figure 1) is maintained and operated by the Maybell Ditch Association and is structure number 694 in Water Division 6, Lower Yampa River, District 44 of the Colorado Division of Water Resources (CDSS 2006). It has a decreed capacity of 129 cubic feet per second (cfs), but average maximum discharge is 80 to 90 cfs (Kathy Bower, Colorado Division of Water Resources [CDWR], personal communication). The ditch is typically operated from late April through the end of October in any given year, and the diversion is closed and the ditch dewatered at all other times.

The ditch inlet structure is located on the north bank of the Yampa River in Juniper Canyon at river mile (RM) 90.3 and consists of an earthen and rock berm with two adjustable head gate valves set over two 1.2-m culverts that control inflow into an earthen channel. The diversion dam consists of boulders piled across the river channel which impound water upstream into Juniper Canyon and create a class II-III rapid at runoff flows. From the head gates, the ditch follows the river for approximately 1.4 km and then crosses to the south side of the river in a steel flume. Between the head gates and the flume, there are at least two culverts which function as “waste gates” that expel excess water back to the Yampa River channel. Downstream of the flume, the ditch parallels the river for another 1.2 km before leaving Juniper Canyon and continuing through several ranches along Colorado highways 40 and 318. Unused water returns to the Yampa River near RM 74.5.

To avoid potential for vandalism of the PIA on public lands, we obtained permission to install the system on private land about 2.6 km downstream from the head gates (Figure 1). At the PIA location, the ditch channel was approximately 4.5 m wide with a flat bed and steeply sloped earthen banks. Substrate was sand and silt with occasional cobbles, small boulders, and concrete rubble. Overhanging grasses, junipers, and sagebrush occurred along most of the ditch. The PIA was located just upstream of the first lateral ditch head gates, which ensured that entrained PIT-tagged fish could be detected before being diverted into irrigated fields.

Methods

Through a memorandum of understanding between the Recovery Program and the Maybell Irrigation District (Recovery Program 2011), we agreed to install and operate a PIA in Maybell Ditch during the 2011 and 2012 irrigation seasons. We installed a PIA in Maybell Ditch on April 20-21, 2011. The system consisted of two rectangular antenna loops housed in schedule 80 PVC pipes (inside loop dimensions 1.2 m x 4.9 m) installed in a vertical position[1] in the canal (Figure 2). The antenna loops spanned the entire width of the canal and were spaced about 4-5 m apart. Both loops were anchored to the canal bed with duck-bill anchors and to the canal banks with t-posts and nylon webbing straps. A second antenna loop provided system redundancy, increased probability of detecting PIT-tagged fish, and provided some ability to monitor direction of movement. Any fish moving through the canal water column would pass through one or both antenna loops, and we considered fish to be entrained if they were detected at either loop.

The PIA was designed to detect PIT tags operating at a frequency of 134.2 kHz which is the type and frequency of tag implanted in Colorado Pikeminnow and Roundtail Chub captured in the Yampa River by field biologists since 2005. Tags implanted in fish prior to 2005 operated at a frequency of 400 kHz and were not detectable by the PIA. The antenna loops were operated with a Destron-Fearing® FS1001M multiplexing PIT-tag reader, and the system was powered by two 160-watt solar panels with a 256-ampere-hour battery bank. This configuration afforded continuous operation for five days without solar input. The system was monitored remotely by satellite uplink, which allowed periodic downloads of data and system diagnostics. All electronics were enclosed in a locked steel box which, together with the solar panels, was fenced with barbed wire to exclude cattle.

We optimized the PIA operation so that PIT tags were readable when tagged fish passed

[1] We had originally installed the antennas in a "hybrid" or pass-through/pass-by configuration, but this design captured too much floating debris.

through any given point in the rectangle formed by the antenna loops. We performed readability tests by passing a floating or partially-submerged test PIT tag embedded in a four-inch plastic "fish" through both antenna loops from both upstream and downstream directions. Test tags were attached to a fishing line and floated downstream through the antenna loops and then retrieved back upstream at roughly the same velocity of the canal (about 25 cm/sec). We conducted a total of 40 trials (20 on each antenna) in April 2011 following installation and an additional 12 trials (six on each antenna) in May 2012, and all tags were detected on both loops on all trials. The tests were conducted at the same average ambient electrical interference ("noise") levels that the system operated under during the study. Due to proximity to high voltage power lines, average noise levels near the PIA were 20-25% (arbitrary measurement) during the study which is slightly higher than optimal levels (0-15%). The multiplexer was programmed to automatically "self-tune" itself in relation to changing environmental conditions (water level, temperature, conductivity) to optimize system performance (Connolly et al. 2008). Canal water depth was less than 48 cm throughout the study, so any fish passing through an antenna would have been within the estimated read range (i.e., approximately 60 cm in any direction).

We evaluated entrainment data in relation to endangered fish population parameters (including mark/recapture information), life-history characteristics, and magnitude of canal flows relative to Yampa River flow during the two study periods. We obtained Yampa River discharge from the USGS gauge near Maybell (09251000) located 6.4 km downstream of the diversion head gates and upstream of the diversion return. We obtained Maybell Ditch discharge estimates during the 2011 and 2012 irrigation seasons from the CDWR, which periodically monitored ditch flows at the flume upstream of the PIA during both seasons. Ditch flows were estimated through a flume stage-discharge relationship developed by CDWR (Kathy Bower, CDWR, personal communication). We estimated the proportion of Yampa River discharge diverted by Maybell Ditch by dividing the latter by the sum of Yampa River discharge and ditch discharge and multiplied by 100.

We used abundance estimates and capture records of Colorado Pikeminnow that were PIT-tagged in the Yampa River during other studies (Bestgen et al. 2005, 2007, 2010) from 2000 to 2012 to determine frequency of their entrainment into Maybell Ditch. In those studies, Colorado Pikeminnow were tagged in the Yampa River upstream of Yampa Canyon (RM 46.0;

Figure 1) during multi-pass tag-recapture sampling for estimating abundance. We excluded fish captured or tagged downstream of RM 46.0 because that is a spawning area visited by migrant Colorado Pikeminnow from other rivers that are not necessarily winter occupants of the Yampa River (Tyus and McAda 1984; Tyus 1990; Irving and Modde 2000). Additionally, we determined how many Colorado Pikeminnow were present near or upstream of Maybell Ditch to estimate the proportion of the Yampa River population that were resident upstream of the diversion and therefore most susceptible to entrainment during their spawning migration. We reasoned that since Colorado Pikeminnow adults (usually the only life stage to occupy the Yampa River study area; Bestgen et al. 2007) occupy distinct home ranges (e.g., Tyus and McAda 1984; Tyus 1990; Irving and Modde 2000), and understanding locations of home ranges of individual fish would allow us to ascertain which fish may pass by Maybell Ditch head gates going to or from the lower Yampa River spawning area in Yampa Canyon. This would also allow us to calculate the proportion of the population that occupied the area upstream of the diversion and were therefore most susceptible to entrainment. Fish residing downstream of the diversion would presumably be less susceptible to entrainment than upstream residents because they would not pass by the diversion head gates as often, if at all.

To determine the proportion of Colorado Pikeminnow in the Yampa River that occupy home ranges upstream of the Maybell Ditch inlet, we examined records of Colorado Pikeminnow captured and tagged in the Yampa River upstream of Yampa Canyon (RM 46.0) from 2010 through 2012. Pikeminnow with 50% or more of their total Yampa River captures between 2000 and 2012 upstream of the Maybell Ditch inlet (RM 90.3) were defined as "upstream residents". Colorado Pikeminnow with greater than 50% of their captures between 2000 and 2012 that were downstream of the diversion inlet to RM 46.0 were defined as "downstream residents". This provided a conservative estimate of the number of upstream residents by excluding some upstream residents that might be captured occasionally as migrants while moving through the downstream section. Additional fish susceptible to entrainment would be downstream residents that made occasional forays upstream of Maybell Ditch when it was operating, but the number of those fish is difficult to estimate and likely low based on evidence for home range affinity (Tyus 1990; Irving and Modde 2000).

Results

The PIA operated continuously from April 21 through November 3, 2011, and from April 18 through November 1, 2012. We visited the PIA twice each year during the irrigation season to remove accumulated debris and maintain equipment. We did not encounter any problems with the system during visits. Continuous system diagnostics indicated no problems with PIA functionality as an electronic system and average noise levels remained in the range of 20-25% throughout the study period.

Yampa River flows at the Maybell gauge during PIA operations in 2011 ranged from 312 to 19,590 cfs and averaged 5,941 cfs, which was the greatest on record for this time period (i.e., 0% exceedance, period of record 1916 - 2012; Figure 3). No tagged fish were detected by the PIA during the 2011 irrigation season (May 1 through November 3). In 2011, Maybell Ditch flows ranged from 55 to 69 cfs (CDWR, unpublished; Figure 3) and up to 15% of the river flow was diverted into the ditch, with the greatest percent diversion taking place between mid-July and November (Figure 4). The canal did not flow from June 6-14 while repairs necessitated by flood damage were made to the head gates and ditch.

Yampa River flows at the Maybell gauge during PIA operation in 2012 ranged from 38 to 4,222 cfs and averaged 851 cfs (97% exceedence; Figure 5). Flows in the Maybell Ditch during 2012 ranged from 18 to 88 cfs (CDWR, unpublished). Maybell Ditch diversions were less than 10% of the Yampa River flow prior to June 13 but thereafter increased to an average of 44% (range 12 – 88%; Figure 6) through the end of the irrigation season on November 3.

During the 2012 irrigation season (April 15 through November 3), the PIA detected two PIT-tagged fish. On July 11, 2012, a Roundtail Chub (460-mm total length [TL], 900 g when tagged; tag code 3D9.1C2D152229) was detected at 0601 h first on the downstream antenna and a second time on the upstream antenna about 20 seconds later. This fish was originally captured, tagged, and released at RM 72.7 of the Yampa River (about 28 km below Maybell Ditch) on April 20, 2010 by Colorado Parks and Wildlife personnel. On August 20 at 0131 h, a Colorado Pikeminnow (479-mm TL, 799 g when tagged; tag code 3D9.1C2D04C993) was detected on the upstream antenna but not the downstream antenna. This fish was originally captured by USFWS on June 6, 2012 between RM 25.2 and 24.5 and was tagged and released at RM 24.5 of the Yampa River. Percent of Yampa River flows diverted was 32% and 69% at the time of detections on July 11 (Roundtail Chub) and August 20 (Colorado Pikeminnow), respectively.

In a database of tag recaptures from other studies, there were 82 individual Colorado Pikeminnow captured 111 times in the Yampa River upstream of Yampa Canyon from 2010 through 2012. Thirty-four percent (n=28) of these fish were residents of the reaches upstream of the diversion inlet and 66% (n=54) were downstream residents. Of the 28 tagged upstream residents, 26 had 134.2-kHz PIT tags readable by the PIA and two had 400 kHz tags which were not detectable by the PIA.

Discussion

In this study, we documented no entrainment of PIT-tagged native fish in Maybell Ditch in 2011 but entrainment of one Roundtail Chub and one Colorado Pikeminnow in 2012. Since only one Colorado Pikeminnow was documented, we could not provide a size range for entrained individuals of this species based solely on data from the present study. However, it is clear from this study and Hawkins (2009) that entrainment of large (i.e., 450 – 500-mm TL) cyprinid native fish can occur in Maybell Ditch. Hawkins (2009) also demonstrated that large numbers of small-bodied fish (both native and non-native species) can also become entrained.

Data on entrained fish in this investigation are sparse, most likely due to the study's limited duration as well as limited numbers of tagged fish in the Yampa River. Tagged Colorado Pikeminnow and Roundtail Chub were the fish most likely to be detected by the PIA in this study, and neither species are abundant in the Yampa River in the vicinity of Maybell Ditch (Hawkins 2009). Sparseness of data and the fact that observations were made during extreme hydrologic conditions (high and low water years) limits our interpretation of entrainment rates as they relate to controlling variables (e.g., river flow or canal operations, especially during average hydrologic conditions) or impacts to fish populations. However, we can discuss results within the context of sampling assumptions, efficiency and limitations, incidental take criteria described in the PBO (USFWS 2005), Colorado Pikeminnow population dynamics and life history in the Yampa River, other studies, and hydrologic conditions during the 2011 and 2012 irrigation seasons.

Due to a host of factors which include uncertainties about PIA detection efficiency, spatial coverage, and proportions of PIT-tagged fish in the Yampa River system, we feel that results of the present study should be viewed as minimum estimates of entrainment. Pass-through systems deployed in narrow, low velocity environments such as Maybell Ditch are thought to be among the most efficient applications of PIT-tag detection equipment (Connolly et al. 2008). Based on observations of system operational diagnostics, successful readability tests under ambient noise levels, and use of two antenna loops for increased detection probability, we feel that the PIA as a whole afforded a high likelihood of detecting fish on at least one of the two antenna loops and thus fulfilling our criterion for entrainment. We feel that there were too few observations to determine credible sampling efficiencies of individual antenna loops, but comparison to the system's performance in other settings may be informative. After being removed from Maybell Ditch, PIA components were installed in Green River Canal near Green River, Utah in April 2013 detected 695 PIT-tagged fish during the irrigation season (K. McAbee and J. Stahli, USFWS, unpublished data). Based on preliminary estimates, detection efficiencies of the two antenna loops were 86% and 90%, but overall efficiency (i.e., likelihood of being detected on at least one antenna loop) was estimated to be almost 99%. Average noise levels at the Green River PIA are 18%.

While entrainment was documented twice in this study according to the criterion of detection on at least one antenna loop, it is apparent from the data that individual antenna loops were at times operating at efficiencies below 100%. The Roundtail Chub was detected first on the downstream loop and second on the upstream loop, which means that as the fish moved downstream it evaded detection on the upstream loop and was first detected on the downstream loop. The fish could not have originated from points below the PIA as there is no access to the ditch downstream of the PIA, and the fish could not have overwintered in the canal as it was dewatered during those months. The fact that the Colorado Pikeminnow was only detected on one antenna loop also suggests that individual antenna loops may not have been operating at 100% efficiency at all times. While PIA readability tests were successful despite less than optimal ambient noise levels, we cannot discount noise as a contributing factor to inefficiency of individual antenna loops. Other factors which may impede detection efficiency include fish orientation in relation to the antenna, fish swimming speed, presence of more than one tag in the antenna field at one time, or a combination of these factors. Due to these uncertainties and the general lack of detections, we did not attempt to draw conclusions on direction of fish movement.

Limited of spatial coverage is another factor that which suggests that our results should be considered minimum estimates of entrainment. The PIA was positioned 2.6 km downstream of the head gates and relied on fish moving downstream to the PIA for detection. Thus, we may have underestimated total entrainment if tagged fish remained in the upper portion of the canal near the head gates or other cover (e.g., flumes, culverts, etc.; Clothier 1954; Roberts and Rahel 2008). For example, Hawkins (2009) documented entrainment by capturing adult Roundtail Chub in hoop nets in the uppermost mile of Maybell Ditch in 2008. If such fish were present in our study but failed to move downstream or escaped to the river through the waste gates, then they would not be detected by the PIA.

There are at least three routes by which fish could escape back to the Yampa River once they enter the diversion: through the ditch head gates, through waste gates or through return flows at the bottom of the canal. None of these areas were monitored in our study, so the fate of the two entrained fish is not known. Proximity of the PIA to the ditch head gates (2.6 km) make it somewhat unlikely (but not impossible) that detected fish would swim the distance upstream back to the head gates and escape to the Yampa River. The potential for entrained fish to escape to the Yampa River and survive through waste gates or return flows at the bottom of the ditch is debatable but likely low. Water returning to the river through waste gates typically flows over shallow, rocky gradients that are probably difficult for adult fish to negotiate. At least one gate near the flume involves a 2-3 m vertical drop to rocky substrates in river. At the bottom of the ditch, unused water is typically minimal and returns to the river by cascading down a steep, rocky slope that would be too shallow for large-bodied fish to negotiate safely. While it is possible for fish to return to the river alive after being entrained, doing so would probably subject fish to harsh conditions and perhaps high levels of stress. Thus, if fate of entrained fish is a high priority information need in future studies, investigators should consider deployment of antennas in all areas where safe return to the adjacent river is likely (i.e., head gates, return flow structures, etc.).

The third and final reason why our results should be considered minimum estimates of entrainment stems from the fact that a certain fraction of Colorado Pikeminnow in the Yampa River population were undetectable (i.e., fish without PIT tags or with PIT tags operating at 400 kHz) during the study period. During 2010 through 2012, percentages of undetectable Colorado Pikeminnow in electrofishing samples collected above Maybell Ditch ranged from 23 to 50% and were as high as 69% in samples collected below Maybell Ditch. Thus, it is possible that additional, undetectable Colorado Pikeminnow were entrained in Maybell Ditch during PIA operations 2011 and 2012. Because of these factors and lapses in detection efficiency, results from this study (0-1 Colorado Pikeminnow entrained per year or 0-2 large-bodied native fish per year) should be regarded as minimum estimates of entrainment.

Estimates of Colorado Pikeminnow population size during the study period are forthcoming, so it is not yet possible to directly compare entrainment rates with peer-reviewed 2011 and 2012 population estimates. This direct comparison may be needed to interpret entrainment results in terms of incidental take during those years. According to the Yampa River PBO (USFWS 2005),

> …the Service anticipates an annual incidental take of less than one percent of the current adult Colorado Pikeminnow population below Craig. Recent preliminary population estimates for Colorado Pikeminnow in the Yampa River below Craig are 253 adults…Therefore, the current level of anticipated incidental take is less than 3 adult Colorado Pikeminnow per year. As population estimates change (either up or down), the level of anticipated incidental take would change proportionately.

To place the estimates of entrainment from the present study into some perspective, it is helpful to consider trends in Yampa River Colorado Pikeminnow population size over the last decade. The Colorado Pikeminnow population has been in decline since abundance estimation began in 2000 (Figure 7), and the most recent estimate by Bestgen et al. (2010) was 140 adults (95% confidence interval [CI] 75-297 adults) in 2008. If we relax the assumption that entrainment rates vary according to population size as outlined in the PBO and apply our entrainment estimates to the 2008 population estimate, 0% of the 2008 adult population would have been entrained in 2011 and the single fish entrained in 2012 would represent 0.7% of the point estimate (Bestgen et al. 2010), or between 0.3% to 1.3% of the 95% confidence interval around the adult population. More recent information suggests that the population has declined to less than 100 fish (K. Bestgen, unpublished data), which if true during 2012 would indicate an entrainment rate greater than 1% of the population that year. Abundance estimates from 2011 to 2013 may add more perspective to population size, entrainment rates, and incidental take.

Entrainment of large-bodied fish expressed as a fraction of riverine “donor” populations varies with a host of biotic (movement, habitat preference, life stage, etc.) and abiotic factors (hydrology, canal size and configuration, and canal operations; Der Hovanisian 1995; Earle and

Post 2001). Carlson and Rahel (2007) reported entrainment of 2.6% to 7.1% of sub-adult and adult Bonneville Cutthroat Trout *Oncorhynchus clarkii utah* and 1.7% to 5.0% of Brown Trout *Salmo trutta* populations in canal systems of the Smiths Fork, WY. Megargle (1999) found that 7.9% of large Rainbow Trout *Oncorhynchus mykiss* inhabiting the Big Wood River (Idaho) were entrained in irrigation canals. Among other factors, impacts of fish entrainment on riverine populations can vary depending on the geographic scale over which populations are considered (Carlson and Rahel 2007) but are generally believed to be significant if populations are at or near recruitment thresholds that determine population growth or decline (Earle and Post 2001; Roberts and Rahel 2008). Thus, while entrainment rates of large, mature or nearly mature Colorado Pikeminnow observed in our study seem low compared to other studies, any loss can constitute a threat to population stability if the population is comparatively small. Loss of fish by entrainment into the ditch could have a significant impact on the population, but it should be noted that the Maybell Ditch has been in operation for over 100 years and is not likely the cause of recent declines in Colorado Pikeminnow. Also, impacts due to entrainment should be considered alongside all other factors threatening persistence of the population (Der Hovanisian 1995; Earle and Post 2001). For example, Bestgen et al. (2010) noted that the Yampa River population of Colorado Pikeminnow has declined while populations in other rivers have stabilized or increased because the Yampa River population is under constant predation pressure and competition from Northern Pike *Esox lucius* and Smallmouth Bass *Micropterus dolomieu.*

An understanding of Colorado Pikeminnow life history in the Yampa River assists our understanding of their entrainment. Colorado Pikeminnow undergo an annual migration from their winter home range in the upper Yampa River to the lower 18 miles of Yampa Canyon in Dinosaur National Monument in late June or early July where they gather with fish from the lower Yampa, Green, and White rivers to spawn (Tyus 1990). After spawning, Colorado Pikeminnow return to their home range occupied during non-reproductive months (Tyus and McAda 1984; Tyus 1990). Hawkins (1991) aged Colorado Pikeminnow in the Yampa River up to 18 years old. Therefore, older individuals living upstream of Maybell Ditch could migrate past the head gates twice annually over a 13-year period (i.e., as reproductively mature fish) while the ditch is in operation.

The length of the Colorado Pikeminnow entrained in the ditch in 2012 (479 mm TL when tagged) suggests that when this fish was originally captured and tagged two months prior, it was either a young Yampa River spawner or a young recruit that was moving from the Green River to the Yampa River upstream of Yampa Canyon. Previous studies with radio-tagged Colorado Pikeminnow that reside in the reach upstream of Maybell Ditch revealed that they can successfully migrate past the head gates without being entrained (Tyus 1990). However, the present study indicates that entrainment occurs occasionally. Tag recapture data suggests the portion of Colorado Pikeminnow residing upstream of Maybell Ditch are most susceptible to entrainment because of their annual movements past the point of diversion. Based on the criteria that we used to define residency of tagged fish, 34% (28 individuals) of Colorado Pikeminnow captured during 2010-2012 were considered residents of the reach upstream of Maybell Ditch inlet and 66% (54 individuals) were considered residents of the reach downstream of the inlet. Extrapolation from the most recent (2008) abundance estimate of 140 individuals living in the Yampa River shows that assuming numbers of fish above and below the diversion inlet vary over time in equal proportions, 48 individuals (34% of the population) reside upstream of the inlet to Maybell Ditch. Therefore, a single entrained Colorado Pikeminnow represents 2% of upstream residents which must migrate past the Maybell Ditch inlet twice annually to spawn in the lower Yampa River and return upstream afterwards.

River discharge and canal diversion rates probably play a role in entrainment, but large-bodied cyprinids have been entrained in Maybell Ditch at both high (2008; Hawkins 2009) and low river discharge (2012) and under variable rates of diversion. In our study, fish entrainment occurred during July and August 2012 when percentages of the Yampa River diverted into Maybell Ditch ranged from 28 to 88% and averaged 54% over the two months (Figure 6), suggesting that entrainment is likely to occur during low flow periods (i.e., late summer base flow periods) when diversion rates are high. However, when we consider other instances of fish entrainment on record for Maybell Ditch, it is apparent that fish can enter the canal under a much wider range of water diversion rates than those occurring during low water periods (Figure 8). The Roundtail Chub entrained in 2012 was a 460-mm adult when it was tagged two years prior to being detected in the Maybell Ditch. Two other large Roundtail Chub (482- and 498-mm TL) were captured by hoop nets in June 2008 when Yampa River flows at the Maybell gauge were 6,470 and 8,620 cfs (Hawkins 2009). All three Roundtail Chub were similar in size to adult Colorado Pikeminnow and were captured at flows that ranged from 908 cfs in 2012 to 8,620 cfs in 2008. Entrainment of large numbers of mostly small-bodied, non-native fish and two large adult Roundtail Chub during June 2008 (Hawkins 2009) suggests that entrainment can also occur at relatively low rates of water diversion, as average percentage of the Yampa River diverted during that irrigation season was 1.6%, about five times less than rates observed in 2012 (8.5%; Figure 8). Thus, fish entrainment (including large-bodied native fish) in the Maybell Ditch can occur over a relatively wide range of river flow levels.

At least two different mechanisms of entrainment are probably at work in Maybell Ditch, one operating during the Yampa River peak flow period and one during the base flow period. As evidenced by Hawkins (2009), fish can apparently enter Maybell Ditch during the peak flow period, either through the head or waste gates. Flows of about 8,000 cfs can inundate the ditch through the regulatory waste gates near the main head gates (Mike Camblin, Maybell Ditch Association, personal communication). Thus, fish may be able to access the canal at these elevations even if the head gates are closed. Based on observations made during the peak flow period of 2011, flows in excess of approximately 16,000 cfs can overtop the canal levee near the head gates, providing a more direct route into the canal. Likewise, peak flows during 2008 reached a maximum of 16,000 cfs, which may have enhanced access to the ditch. Earle and Post (2001) postulate that consistent or low-velocity flows commonly found in canals can provide a refuge for fish from high spring flows, which is consistent with results from a number of studies involving salmonids (Mathur et al. 1977; Helwig and Fernet 1993; Reiland 1997). This mechanism may be enhanced if fish migrate during the peak flow period, as migrating fish are thought to be especially vulnerable to entrainment (Earle and Post 2001 and references therein).

Entrainment of fish during low flow periods when a high proportion of river water is diverted into canals has also been fairly well documented in the literature (Spindler 1955; Thurow 1990; Megargle 1999; Earle and Post 2001; Post and van Poorten 2006; Baumgartner et al. 2007). During the base flow period, fish may be attracted to Maybell Ditch as it often diverts over half of the Yampa River flow. Under such conditions, depth and velocity in the ditch or areas immediately adjacent to the head gates may be more favorable for fish than other areas in main channel, especially if competition for habitat under low flow conditions is significant (Clothier 1953; Megargle 1999; Earle and Post 2001). The positive relationship between proportion of diverted flows and entrainment can be further exacerbated if canal head gates are positioned on the outside of river bends (Spindler 1955; Megargle 1999), as is the case with the Maybell Ditch head gates (Figure 1).

Conclusions

- Based on observations of system operational diagnostics, successful readability tests under ambient noise levels, performance of the system in other settings, and use of two antenna loops to increase detection probability, we feel that the PIA as a whole afforded a high likelihood of detecting fish on at least one of the two antenna loops to document entrainment.
- Ambient electrical noise was above optimum levels and probably reduced efficiency of individual antenna loops.
- In 2011, the PIA detected no PIT-tagged fish in Maybell Ditch.
- In 2012, the PIA detected entrainment of one PIT-tagged Colorado Pikeminnow and one PIT-tagged Roundtail Chub in Maybell Ditch.
- All available length data (Hawkins 2009; present study) on entrained Colorado Pikeminnow and Roundtail Chub indicate that large (i.e., 450 – 500 mm TL) native cyprinids are entrained in Maybell Ditch.
- The Colorado Pikeminnow entrained in 2012 represents between 0.3 and 1.3% (0.7% of the point estimate) of the most recent (2008) estimate of population size in the Yampa River (140 individuals; 95% CI 75 – 297), although forthcoming population estimates for the years 2011 and 2012 will aid in interpreting observed entrainment rates in relation to population size.
- A number of factors (uncertain efficiency of individual antenna loops, limited spatial scale, potential entrainment of untagged fish or fish containing unreadable tags) indicate that estimates of entrainment from the present study (0-1 Colorado Pikeminnow/year) should be considered minimum estimates.
- Considering all available data (Hawkins 2009; present study), entrainment of large-bodied native fish in Maybell Ditch can occur over a range of flows during or immediately following the peak flow period or during the late summer low flow period.

Recommendations

- Consider use of PIAs to investigate endangered fish entrainment in other canal systems according to Recovery Program needs.
- PIAs should be located in areas of low ambient electrical interference whenever possible.

- PIAs should consist of at least two antenna loops to maximize detection probability.
- If fate of entrained fish is a high priority information need in future studies using PIAs, investigators should consider deployment of antennas in all areas where safe return to the adjacent river is likely (i.e., head gates, waste gates, other return flow structures, etc.).
- Mark/recapture information on main channel Colorado Pikeminnow populations during 2011 and 2012 should be used to maximize knowledge on entrainment in relation to population size and to evaluate incidental take.

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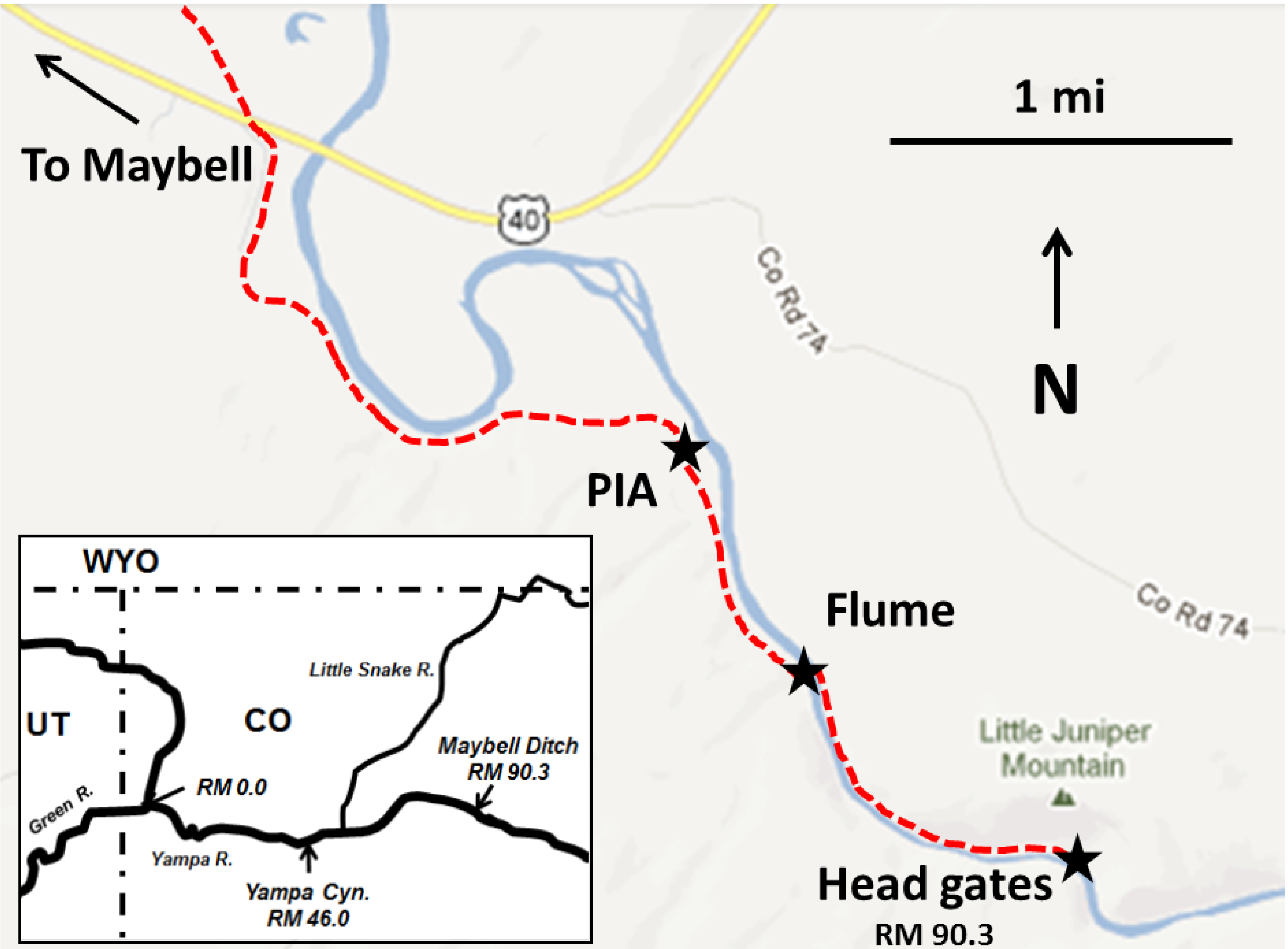

Figure 1. Study area showing Yampa River (blue) and Maybell Ditch (red dashed line) near Maybell, Colorado; river and canal flow is toward the northwest (inset: greater Yampa River area showing river miles [RM]). Key physical features of Maybell Ditch including the passive interrogation array (PIA) locations are indicated by stars. At least two waste gates are located between the head gates and the flume.

Figure 2. Passive interrogation array in Maybell Ditch near Maybell, CO immediately following installation on April 21, 2011.

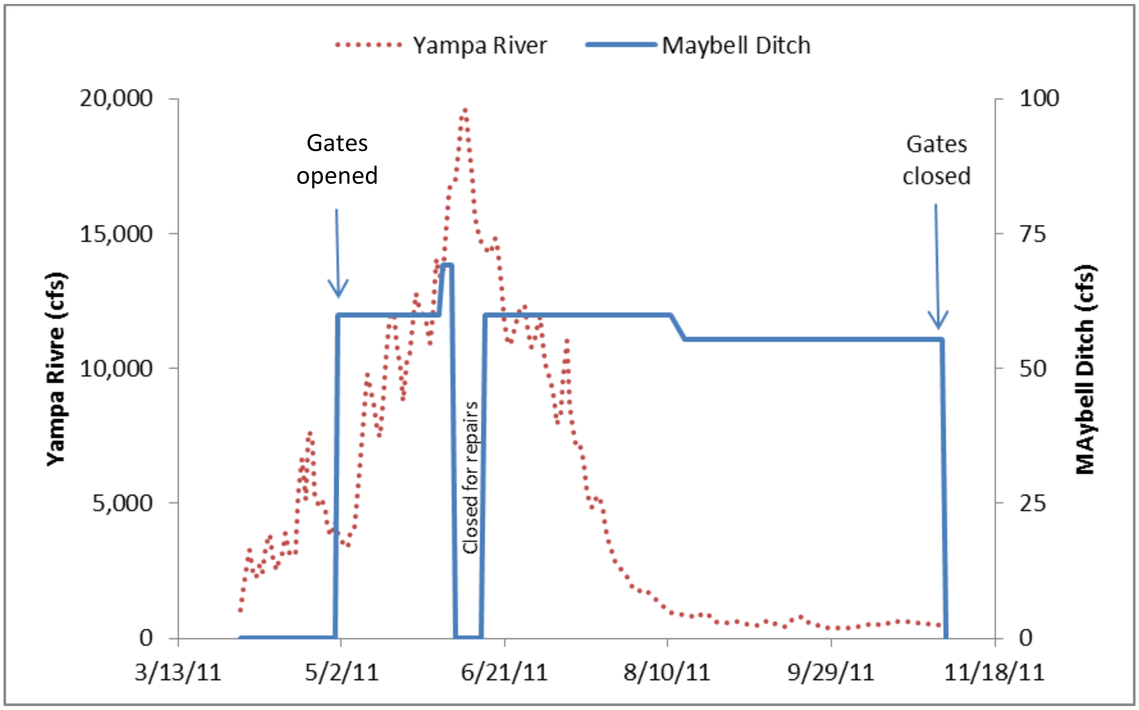

Figure 3. Discharge (cubic feet/second; cfs; left axis) of the Yampa River near Maybell, CO and estimated discharge of Maybell Ditch(cfs; right axis) during the 2011 irrigation season.

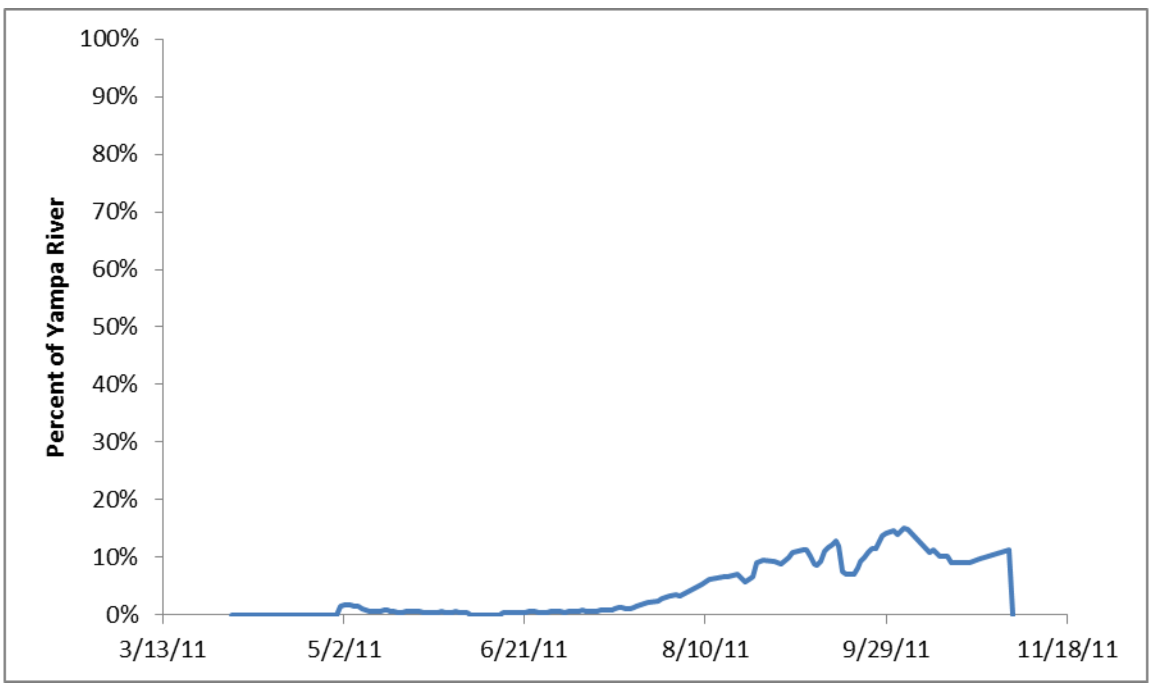

Figure 4. Percent of the Yampa River diverted by Maybell Ditch during the 2011 irrigation season.

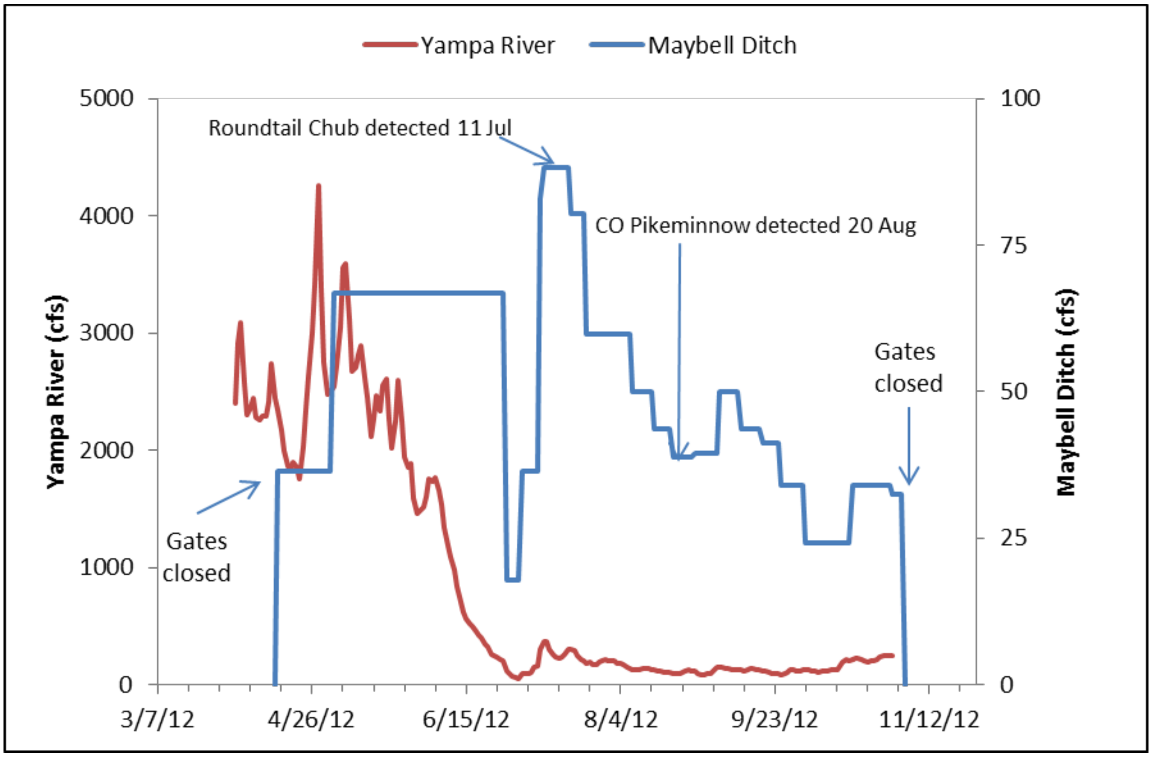

Figure 5. Discharge (cfs; left axis) of the Yampa River near Maybell, CO and estimated discharge of the Maybell Ditch during the 2012 irrigation season (cfs; right axis).

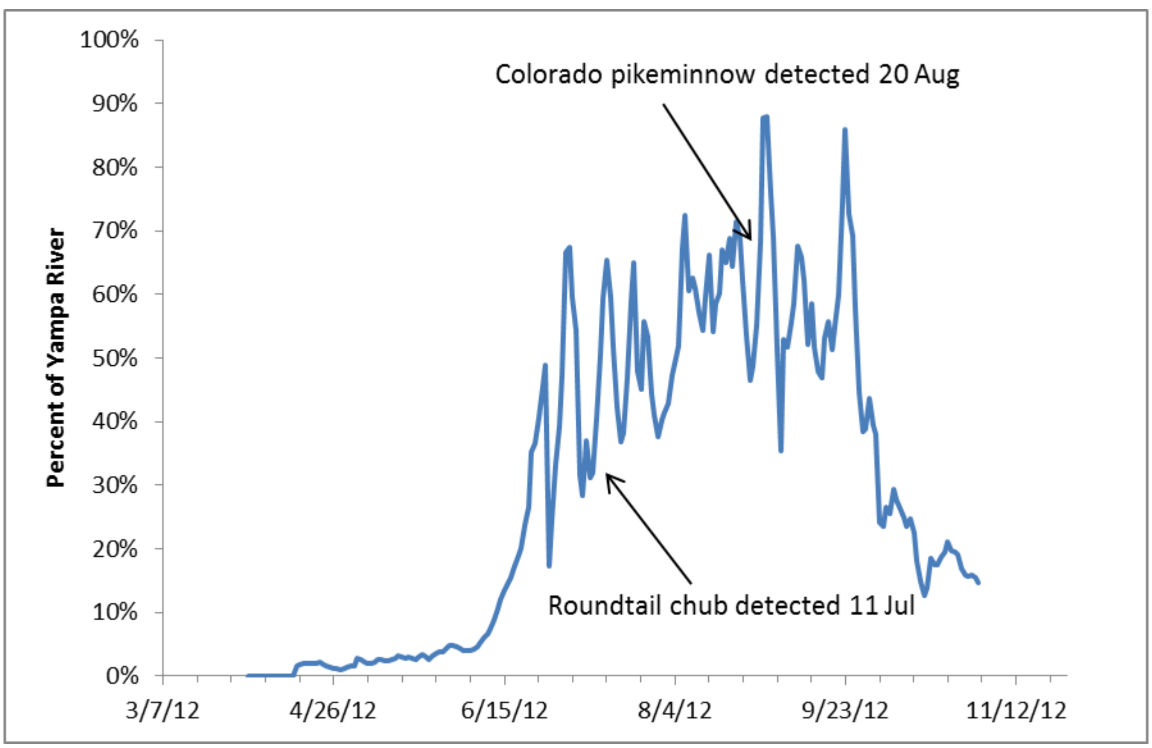

Figure 6. Percentage of the Yampa River diverted into Maybell Ditch during the 2012 irrigation season. Detections of tagged fish are indicated by arrows.

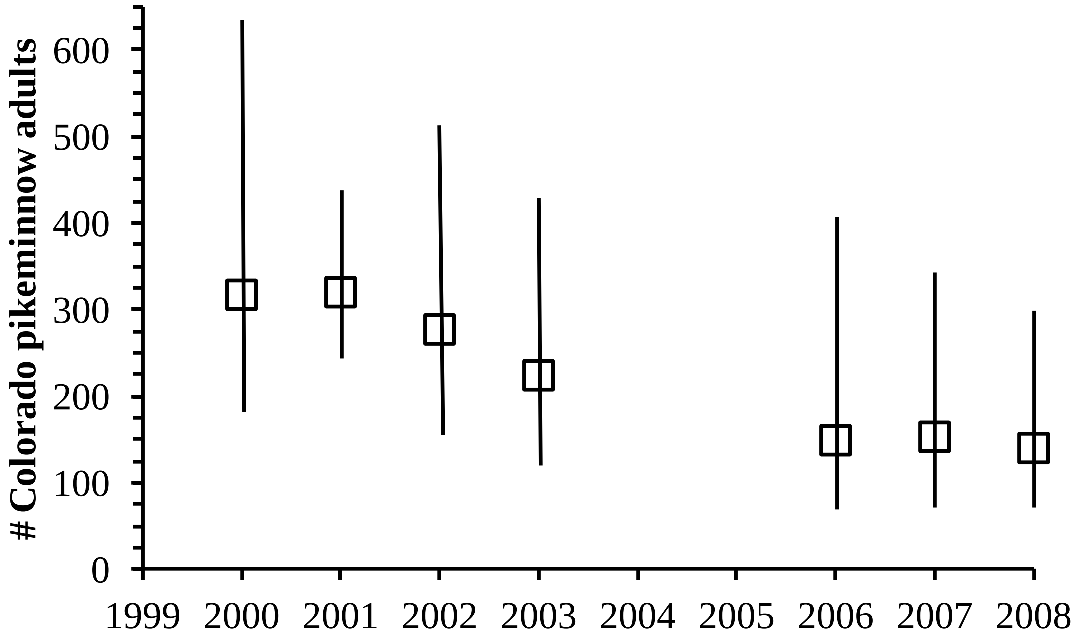

Figure 7. Abundance of Colorado Pikeminnow in the Yampa River, 2000-2003 and 2006-2008 (Bestgen et al. 2010). Box marker represents estimated abundance bounded by the 95% confidence interval.

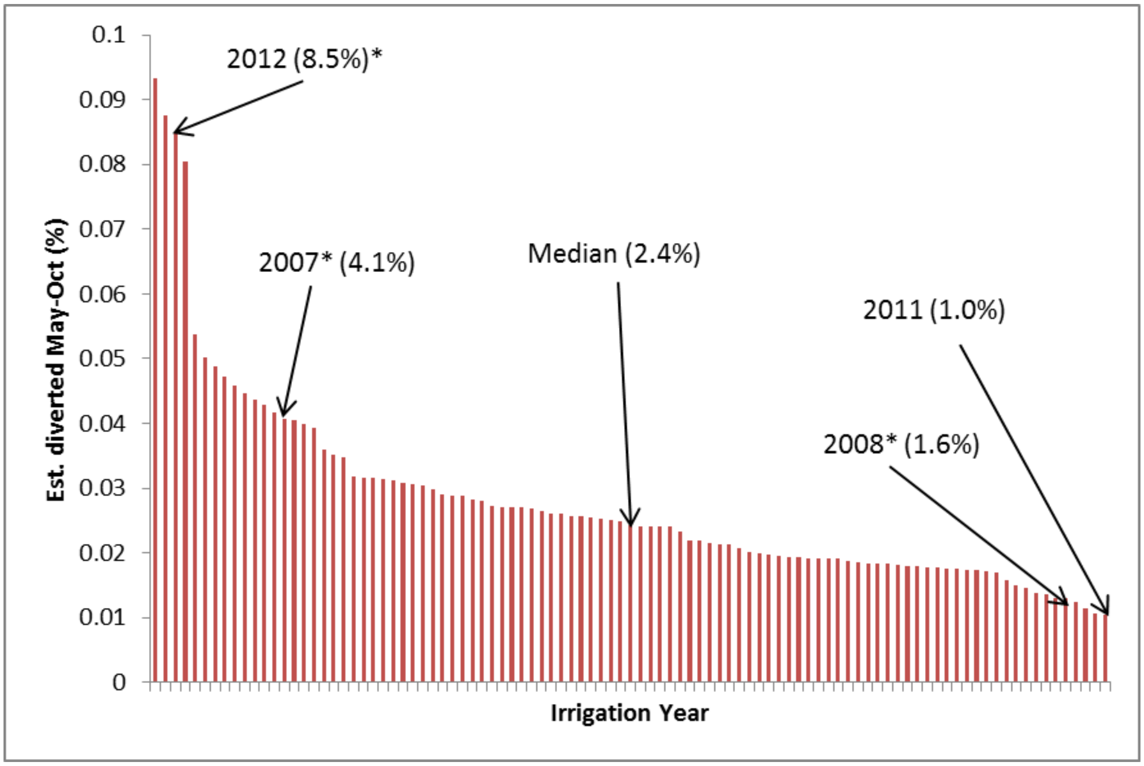

Figure 8. Estimated average percent of Yampa River flows diverted into Maybell Ditch during the irrigation season (May-October) for 96-year period of record (1916-2012) at the USGS gauge near Maybell, CO. Data were ranked along the x-axis from highest to lowest percent of flow diverted. Asterisks (*) indicate years in which non-listed native or endangered fish were documented as entrained in the ditch.