Upper Colorado River basin young-of-year Colorado pikeminnow (*Ptychocheilus lucius*) monitoring: Summary report 1986–2009

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LIST OF KEY WORDS

Young-of-year, Green River, Colorado River, Colorado pikeminnow, Ptychocheilus lucius, backwater habitat, seine, Interagency Standardized Monitoring Program (ISMP).

EXECUTIVE SUMMARY

Young-of-year (YOY) Colorado pikeminnow (*Ptychocheilus lucius*) sampling in the upper Colorado River Basin (Basin) has been ongoing for over 20 years. Although this research was initiated to monitor Colorado pikeminnow, it is also an important tool for monitoring abundance, distribution, catch rates, and trends of all native fishes as well as small-bodied non-native fishes.

To monitor YOY fishes in the Basin, backwaters were seined during late September or early October each year from 1986–2009 within three designated reaches; the lower Colorado River (Reach 1), the lower Green River (Reach 3), and the middle Green River (Reach 4). The resulting data was examined for trends in species abundance over time with our primary focus on defining periods of significant change. The data were as also reviewed and analyzed for within-year patterns that might indicate habitat preferences or other abiotic or biotic associations for YOY Colorado pikeminnow.

Over the entire study period each reach experienced similar annual trends in YOY catch rates, where catches were highly variable and generally declining between the mid-80's and the mid-90's, to catches which were much less variable and typically 75% lower than observed in the previous period. In addition, all three reaches had catch rates that were positively correlated with annual peak flows between 1986 and 1994, but not for the entire project period. Relative percent catch of YOY Colorado pikeminnow was positively correlated with catch rates of red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), and fathead minnow (*Pimephales promelas*) in all three reaches, suggesting that YOY Colorado pikeminnow are selecting the same habitats as the non-native cyprinids. In the lower Colorado River and lower Green River, YOY Colorado pikeminnow selected for larger, deeper backwaters that were warmer than the main channel and had mid-range mud depths between two and 25 cm. Also, fall mean total length was positively correlated in the lower Colorado River and lower Green River to the number of days between the spring peak and fall sampling which we use as a surrogate measure for the length of the growing season. The middle Green River reach differed from the other reaches in that YOY Colorado pikeminnow did not seem to select for specific characteristics of backwaters, and there was no correlation between fall mean total length and the growing season.

Summarizing this dataset has shed light on a few primary points that will likely help researchers determine more specific causes for recruitment declines. The first is the apparent breakpoint occurring in each reach somewhere between 1994 and 1997; this appears to be a turning point which is being assessed in relation to adult and larval pikeminnow databases as well as hydrologic and habitat datasets by K. Bestgen and J. Hayes in their data integration report (2011). This turning point not only marks the onset of suppressed levels of fall YOY catches, it also marks the end of several apparent correlations between hydrologic factors and fall pikeminnow numbers. The final point is brought to light by the occurrence of highly successful years typically occurring only once every five to ten years. With only one data point each year it is impossible to extrapolate cause.

INTRODUCTION

The Upper Colorado River Basin (Basin), including the Green and Colorado rivers and their tributaries, is home to 14 native fish species (Vanicek 1970). Native fish species that inhabit the mainstems of the Green and Colorado rivers represent a unique "big-river" assemblage adapted to a highly variable flow regime including low base flows and extremely high spring runoff flows capable of inundating large expanses of floodplain (Heitmeyer and Frederickson 2005). In recent years, water development for municipal, industrial, and agricultural purposes (i.e, dams and diversions) has altered natural flow regimes and habitat conditions that native fishes are not well adapted to in terms of their life histories (Muth et al. 2000; USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d; Valdez and Muth 2005). Changes in flow regimes have also made rivers in the Upper Colorado River Basin more amenable to non-native fishes (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d; Valdez and Muth 2005). Negative interactions between native and non-native species include both direct competition (i.e., for food or space; Minckley et al. 2003; Lentsch et al. 1996) and predation (Hawkins and Nesler 1991; Tyus and Beard 1990; Lentsch et al. 1996). By the 1960's and 1970's, the preceding factors in addition to impacts from disease and other habitat alterations caused a noticeable decline in native species populations (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d).

As a result of major population declines, many of the "big-river" fishes native to the basin are now federally protected. The Colorado pikeminnow, razorback sucker (*Xyrauchen texanus*), bonytail (*Gila elegans*), and humpback chub (*Gila cypha*) are currently listed as endangered on the federal Endangered Species List (USFWS 2009). Colorado pikeminnow and humpback chub were first included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967. Colorado pikeminnow and humpback chub were later listed under the Endangered Species Act (ESA) of 1973 (USFWS 2002b; USFWS 2002c) and were joined by bonytail in 1980 and razorback sucker in 1991 (USFWS 2002a; USFWS 2002d). Conservation and recovery needs for these species have been addressed through the Upper Colorado River Endangered Fish Recovery Program (Recovery Program), which has developed both Recovery Plans (USFWS 1990a; USFWS 1990b; USFWS 1991; USFWS 1998) and Recovery Goals (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d) that describe potential explanations for observed declines in each species' range and recommend actions that can be taken to improve their status.

The Recovery Program has been working to identify life history needs and habitat requirements of its focal species. Over the past 20 years, researchers for the Recovery Program have identified a handful of Colorado pikeminnow spawning locations around the basin, including Yampa (Tyus and McAda 1984) and Gray canyons (Tyus 1985) in the Green River Basin and Grand Valley, Loma, Professor Valley, and Cataract Canyon in the Colorado River Basin (Archer et al. 1985). Upon hatching, swim-up larval Colorado pikeminnow drift for miles in the main channel before finding adequate backwater areas they can use as rearing habitats (Tyus and Haines 1991). Backwater habitats are also known to be important for early life stages of bonytail and razorback sucker (Wydoski and Wick 1998), as well as for the other species of concern in the Basin including roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*), which are all occasionally observed in backwater habitat in alluvial reaches within the Basin (McAda et al. 1994).

In an effort to monitor survival of larval fish into the fall when these young-of-year (YOY) fish are larger and more easily identified, partners to the Recovery Program initiated the Interagency Standardized Monitoring Program (ISMP). The ISMP was developed by Recovery Program representatives serving on the Biological Subcommittee of the Upper Colorado River Basin Coordinating Committee (McAda et al. 1994). The YOY monitoring portion of the ISMP, in its current protocol, was initiated in 1986 and was intended to provide predictive capabilities for future adult Colorado pikeminnow population estimates.

Since its inception, ISMP data has become a valuable source of information on long-term trends for all species in the Basin, especially early life stages of YOY Colorado pikeminnow (Ploskey and Jenkins 1982). To this end, the ISMP dataset has been used as a vital cornerstone in concert with additional studies to examine more specific questions about Colorado pikeminnow such as; nursery habitat availability and use in the Colorado and Green Rivers (Trammell & Chart 1999b-c; Day et al. 1999), downstream larval transport relationships to spatial variation in abundance and juvenile recruitment (Bestgen et al. 1998), and overwinter survival of age-0 pikeminnow in the Green River 1987-1995 (Valdez et al. 1999). Currently, Bestgen and Hayse (2011) are completing a comprehensive synthesis of physical and biological data collected in the Green River. The Synthesis report will integrate available information to determine relationships of changes in backwater fish communities (with emphasis on age-0 Colorado pikeminnow) to flow and temperature conditions that create and maintain backwaters.

GOALS AND OBJECTIVES

This project was implemented from 1986–2009 to monitor abundance and distribution of YOY Colorado pikeminnow each fall in the Basin.

Goals[1]:

- Determine status and trends of fishes native to the Basin.
- Explain the relationships between physical and biological parameters and the relative abundance of YOY Colorado pikeminnow (USFWS 1987).

Objectives:

1. Determine size and relative numbers of YOY Colorado pikeminnow at the end of their first growing season to complement larval and juvenile sampling data collected by other researchers in the Basin.
2. Determine relationships between YOY Colorado pikeminnow catch-per-unit-effort (CPUE) and flow and temperature regimes for each year surveyed.

[1] Because this project has been ongoing for over 20 years, many versions of the scope of work exist for this project. The goals were honed from the original ISMP handbook and the objectives included herein were taken from the FY04-05 scope of work.

STUDY AREA

The U.S. Fish and Wildlife Service was the first agency to systematically inventory the abundance of YOY Colorado pikeminnow in the Green and Colorado rivers in 1979 (Archer et al. 1985; Jones and Tyus 1985; Tyus et al. 1982b; Valdez et al. 1982). Initially, there were four river reaches sampled: two in the Colorado River (reaches 1 and 2) and two in the Green River (reaches 3 and 4). Designated reaches were chosen because they contained the majority of the YOY Colorado pikeminnow collected during previous research activities (Archer et al. 1985; Jones and Tyus 1985; Tyus et al. 1982a; Valdez et al. 1982). Reaches 1, 3, and 4 continue to be sampled and will be discussed in depth in this report.

- *Reach 1* - starting at Fish Ford (Colorado River River Mile (RM) 110) proceeding downstream to the confluence of the Green River (RM 0; Figure 1). The upper 45 miles of this reach is high gradient with mostly gravel and cobble substrate. The lower 65 miles is lower gradient with predominantly sand and silt substrates.
- *Reach 2* - starting near Grand Junction (RM 170) and ending downstream at RM 140 (Figure 1). Substrate in this reach consists mainly of cobble and rubble. This reach is no longer sampled for this study.
- *Reach 3* - starting at the town of Green River, UT (RM 120) and ending downstream at the confluence of the Green and Colorado rivers (RM 0; Figure 1). The upper part of this reach is high gradient with predominately gravel and cobble substrate. The lower portion is lower gradient and is predominately sand and silt substrate.
- *Reach 4* - starting at the Split Mountain boat ramp in Dinosaur National Monument (RM 319.3) and ending downstream at the Sand Wash boat ramp (RM 215; Figure 1). High gradient and an abundance of cobble and gravel substrates characterize the uppermost 10 miles of the reach within Dinosaur National Monument (DNM). The sub-reach within DNM has fewer and smaller backwaters than the remainder of this reach. From Jensen to Sand Wash boat ramp, gradient decreases and the number and size of backwaters increase. Substrate shifts from cobble and gravel to primarily silt and/or sand substrates (McAda et al. 1994).

METHODS

Field sampling

According to the Interagency Standardized Monitoring Program Handbook (USFWS 1987), sampling occurred on an annual basis between 20 September and 10 October. Each river reach (as discussed in the preceding section) is divided into adjacent five-mile segments; the first two suitable backwaters in each five-mile segment were sampled. A suitable backwater is defined as at least 30 m^2 and at least 30.5 cm deep at its maximum (USFWS 1987).

As detailed in the YOY ISMP protocol, each backwater was sampled with at least two non-overlapping seine hauls using a 0.32 cm mesh seine net measuring 1.2 m tall and 4.6 m long. Seine hauls were evenly spaced across the backwater and preferably parallel to one another. When possible, they avoided both the interface between the backwater and main channel and the shallow end of the backwater and covered approximately 25% of the entire backwater. Hauls also crossed the backwater perpendicular to the long axis; however, backwaters that were too deep to cross with a seine were sampled along the shoreline with parallel seine hauls. In the first seine haul, all fish were counted, and all endangered and native fish measured for total length (TL) to the nearest 1 mm and returned alive to the habitat. Ray counts were completed for all chubs (*Gila* spp.) captured to aid in a species determination. If chubs were not able to be identified to species, they were left in the *Gila* spp. category. In the second seine haul and any subsequent seine hauls, only native fish and the less numerous non-natives (i.e., any non-native except red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), or fathead minnows (*Pimephales promelas*)) were counted. All native fish captured in this seine haul were also measured to the nearest 1 mm and released (USFWS 1987). Beginning in 1997, the described protocol applies to both the primary (the first backwater encountered in each 5 mi reach) and secondary (the second backwater encountered within the same 5 mi reach) backwaters. Before 1997, only Colorado pikeminnow were counted in the second seine haul of the primary backwater and in all seine hauls in the secondary backwater. In all years, any fish in “counted” seine hauls that were not readily identified in the field were preserved for later identification.

In addition to fish measurements, overall lengths (m) and widths of backwaters (m) were measured as well as maximum overall depth (m) and backwater temperature (ºC). Main channel temperature (ºC) was also recorded. Each seine haul was measured for length (m) and width (m). Depth of each seine haul (m) was recorded at three locations, one at the maximum depth and two others across the seine haul. Substrate was characterized based on particle size (silt, sand, gravel, rubble, or boulder) at each point where depth was measured. Especially where substrate was predominantly silt or mud, the approximate depth of the substrate was recorded as a means to recognize how difficult the location was to sample. River mile and UTM coordinates were taken for each backwater as was the time of day the backwater was sampled (USFWS 1987). All flow measurements used for analyses were taken from the United States Geological Survey (USGS) gage at either Jensen, Utah (#09261000), Green River, Utah (#09315000), or Cisco, Utah (#09180500).

Data analysis

Though monitoring for trends in species abundance is the main goal of the study, the data were as also reviewed and analyzed for within-year patterns that might indicate habitat preferences or habitat associations of YOY Colorado pikeminnow. Total catch-per-unit-effort (CPUE) was used to evaluate inter-annual trends in YOY Colorado pikeminnow fall abundance and correlations to peak spring flows, days between instantaneous peak flows and sampling, and total length of YOY Colorado pikeminnow during the study period. We calculated CPUE as the number of fish per 100 m^2 sampled. All YOY Colorado pikeminnow CPUE figures were calculated from the totals of first and second hauls in both primary and secondary backwaters combined.

Trend analysis of annual pikeminnow CPUE (y) through time (x) was preformed with simple linear regression and piecewise linear regression. Piecewise linear regression allows two linear models to be fit to the data for different ranges of x with the two segments separated by a breakpoint (c) where the slope of the response variable changes (Ryan and Porth 2007). The least squares method is applied separately to each segment, by which the two regression lines are made to fit the data set as closely as possible while minimizing the sum of squares of the differences (SSD) between observed y and calculated (Y_r) values of the dependent variable, this results in the following two equations:

$$Y_r = a_1x + b_1 \quad \text{for } x \leq c$$
$$Y_r = a_2x + b_2 \quad \text{for } x > c$$

Where Yr is the predicted value of y for a certain value of x; a_1 and a_2 are regression coefficients (slope); b_1 and b_2 are regression constants (y-intercept). To evaluate this as a piecewise regression for the entire data range the regression function needs to be continuous at the breakpoint so the two equations for Y_r need to be equal at the breakpoint when x = c:

$$a_1 + b_1c = a_2 + b_2c.$$

Solve for one of the parameters in terms of the others by rearranging the equation above:

$$a_2 = a_1 + c(b_1 - b_2).$$

Then by replacing a_2 with the equation above, the result is a piecewise regression model that is continuous at $x = c$:

$$Yr = a_1 + b_1x \quad \text{for } x \leq c$$
$$Yr = \{a_1 + c(b_1 - b_2)\} + b_2x \quad \text{for } x > c.$$

Nonlinear least squares regression techniques, such as PROC NLIN in SAS, can be used to fit this model to the data.

Inter-annual relationships between catch metrics and biotic or abiotic factors were assessed using Spearman's Rank Order Correlation to describe the strength (r_S) and probability (p) of association. The nonparametric Spearman's Correlation was used throughout our analysis primarily because CPUE and other catch metrics were not normally distributed; in addition, the test does not require linear relationships or that any variable be assigned as dependent or independent.

To assess inter-annual associations between YOY Colorado pikeminnow and red shiner fall catches we applied a Spearman's Correlation to the log of total catch of both species from the first haul of primary backwaters within each reach. Overall, in some reaches, a positive but non-significant relationship was observed with what appeared to be multiple one to three year exceptions, where the association was strongly negative. Post hoc examination showed that those years could be typified as drought years by a low instantaneous spring peak, below average summer base flows, and higher than average summer main channel temperatures. Spearman's

Correlations were therefore run both with and without drought year data to show the response of each species in typical versus drought years.

We also examined how various biotic (non-native red shiner) and abiotic (backwater area, mud depth, backwater maximum depth, seine haul maximum depth, backwater temperature, difference between backwater and main channel temperature, and annual instantaneous peak flow) factors may have affected habitat selection and distribution of YOY Colorado pikeminnow regardless of cohort strength in any given year. To do this we converted each individual seine haul in a specific reach into a relative percent catch (RPC) frequency, as follows:

$$RPC = (SC_{RiYi} / TC_{RiYi})*100$$

Where SC_{RiYi} is the sample catch in reach *Ri* and year *Yi* and TC_{RiYi} is the species total catch in reach *Ri* and year *Yi.* Relationship strength was tested for all years (N=24) combined within each reach using Spearman's (r_S) Correlation Coefficient for input variables: Colorado pikeminnow RPC, river mile (RM), habitat area, habitat maximum depth, seine haul maximum depth, habitat temperature, main channel temperature, and the difference between habitat and main channel temperature (Table 3). Spearman's Correlation was also used to test association between YOY Colorado pikeminnow RPC and red shiner CPUE. For this test we only used captures of each species from the first seine haul in primary backwaters because those are the only samples in which non-natives were enumerated. Comparisons between Colorado pikeminnow RPC and mud depth category were analyzed with a one-way ANOVA and specific pairwise comparisons were made using Tukey's Test.

RESULTS

Lower Colorado River (Reach 1)

Native species collected in most years in the lower Colorado River include Colorado pikeminnow, *Gila* spp., bluehead sucker, flannelmouth sucker, and speckled dace (*Rhinichthys osculus*) (Table 1). The occurrence of speckled dace captures has become rare since 1999, and the frequency of capture of *Gila* has also declined since 2003 (Table 1). Razorback sucker have not been captured during this sampling (Table 1). The number of non-native species found in fall seining has grown over the study period from seven or eight in the early 1980's to ten or eleven in the last five years (Table 2). Recent additions to the species list in the last five years include gizzard shad (*Dorosoma cepedianum*), yellow bullhead (*Ameiurus natalis*) and one isolated capture of smallmouth bass (*Micropterus dolomieu*) in the lower Colorado River (Table 2). In every year of the study, small-bodied cyprinids (red shiner, sand shiner, and fathead minnow) were the most abundant species captured.

Trend analysis of annual CPUE of YOY Colorado pikeminnow showed a significant linear decline (R^2 = 0.21, $F(2,22)$ = 5.67, p = 0.026) over the twenty-three year study period (Figure 2). Piecewise regression analysis showed catch rates declining significantly from 1986–2004 (p=0.032) followed by a slight increase in rates from 2004–2009 (Figure 2). Although the piecewise regression showed a significant trend breakpoint in 2004, high CPUE rates in 2009, 1996, and 1986 greatly affected the models predictive ability for this data set. Comparing mean CPUE for multiple periods of the entire data set showed the largest declines occurred after 1996; when mean CPUE declined significantly ($t(14)$ = 2.89, p= 0.011) from 7.5 fish/100m^2 (1986–1996) to 1.8 fish/100m^2 (1997–2009). Over the entire sample period, the highest catch rates were observed in 1996 at 20.82 fish/100m^2 and the lowest in 2003 and 2008 when no YOY Colorado pikeminnow were collected.

Annual YOY Colorado pikeminnow catch rates were first compared to instantaneous annual peak flows (Figure 3), and observed a positive relationship between 1986 and 1994 in the lower Colorado River (r_S =0.733, p =0.020); however, after 1994, this was not observed. No correlation was observed between annual YOY Colorado pikeminnow catch rates and mean fall total length (TL) of YOY Colorado pikeminnow (Figure 4).

Fall mean TL was negatively correlated to the magnitude of the spring peak flow (r_S =-0.780, p <0.001, Figure 5). The years with the greatest mean TL were 2007 (73.33 mm), 1994 (63.33 mm), and 2002 (54.94 mm; Figure 5). These years also had some of the lowest peak flows (4,580 cubic feet per second [cfs], 14,900 cfs, and 15,300 cfs, respectively) during the study period (Figure 5). No correlation was found between the mean TL and the number of days between spring peak flows and the sample date.

Although YOY Colorado pikeminnow were found throughout the entire reach, the densities increased downstream of RM 70 (Figure 6). The increase in the RPC of YOY Colorado pikeminnow closely follows the downstream decline in channel velocity, increase in sinuosity, and the switch from gravel and cobble to alluvial substrates, which is likely a result of YOY Colorado pikeminnow settling out into slackwater habitats as river velocity declines. Young-of-year Colorado pikeminnow were most consistently found near river miles 20 and 50.

Several correlations were observed between YOY Colorado pikeminnow RPC and various biotic and abiotic characteristics of backwater and main channel habitats. Relative percent catch of YOY Colorado pikeminnow was positively correlated with backwater area, maximum backwater depth, the difference between backwater and main channel temperature, and CPUE of non-native cyprinids (Table 3). An ANOVA showed that mean RPC was significantly different among the four mud depth categories (p = 0.02). Relative percent catch was higher in mud depth of >2 to 5 cm. (2.54 %) and >5 to 25 cm. (2.64 %) than in habitats with mud depths of zero to 2 cm. (0. 99 %) or >25 cm. (1.98 %). There was a negative association between RPC and main channel temperature (Table 3). No correlation was observed between RPC and backwater temperature (Table 3).

A comparison of total catch of YOY Colorado pikeminnow and red shiner by year shows an overall positive correlation (r_S =0.550, p=0.050), with a few single year exceptions (1989, 1992, and 2000) showing strong negative or no correlations (Figure 7).

Lower Green River (Reach 3)

Young-of-year Colorado pikeminnow were the only native species in this reach consistently captured every year. Young-of-year bluehead sucker, flannelmouth sucker, *Gila* spp. and speckled dace (adult and YOY) captures have been sporadic and declining in the last ten years (Table 4). Razorback sucker have not been captured during this sampling (Table 4). The number of non-native species found in fall seining has increased over the study period from seven or eight in the early 1980's to ten or eleven in the last five years (Table 5). Recent additions to the species list in the last five years include gizzard shad, yellow bullhead and largemouth bass (*Micropterus salmoides*) in the lower Green River (Table 5). In every year of the study small-bodied cyprinids (red shiner, sand shiner, and fathead minnow) were the most abundant non-native species captured.

Trend analysis of annual CPUE of YOY Colorado pikeminnow in reach 3 was best described by piecewise linear regression; showing a linear decline from 1986–1994 followed by a flat trend through 2009 (R^2 = 0.46, F(2,22) = 19.44, p < 0.001, Figure 8). For periods before and after the 1994 breakpoint, mean CPUE declined 78% from 35.7 fish/100m^2 (1986–1993) to 7.58 fish/100m^2 through 2009 (t(14) = 2.89, p= 0.011). The highest observed CPUE in reach 3 occurred in 1988 at 89.95 fish/100m^2 and lowest in 2001 at 0.29 fish/100m^2 (Figure 8).

A comparison of annual YOY Colorado pikeminnow catch rates to annual peak flows followed a similar pattern to that observed in the lower Colorado River (Figure 9), with a positive relationship between 1986 and 1994 (r_S =0.650, p=0.050), and no relationship to peak flow observed after 1994. A negative correlation was observed between annual YOY catch rates and fall mean TL of YOY Colorado pikeminnow (Table 3, Figure 10).

Fall mean TL was again negatively correlated to the spring peak flow (r_S =-0.657, p<0.001, Figure 11). The year (2002) with the greatest mean TL (64.29 mm) also had the lowest annual peak flow (7670 cfs) during the study period (Figure 11). A positive but nonsignificant (p=0.148) correlation was found between the mean TL and the number of days between spring peak flows and the sample date.

Young-of-year Colorado pikeminnow were distributed fairly even throughout the entire reach with the RPC increasing slightly downstream (Figure 12). Relative percent catch is highest near river mile 30 (2.33 %) and lowest around river mile 110 (0.12 %; Figure 12). Channel morphology in this reach is primarily meandering and depositional with slightly higher velocities and more riffle habitat in the upper 20 miles. Although the upper 20 miles contains fewer typical backwaters formed by sand deposition than downstream reaches, a substantial number of large, stable, low-velocity habitats are formed in flooded tributary mouths and abandoned side channels.

In terms of habitat selection and use, YOY Colorado pikeminnow RPC and various biotic and abiotic characteristics of backwater and main channel habitats were found to be correlated. Relative percent catch was positively correlated with backwater area, maximum backwater depth, the difference between backwater and main channel temperature, and CPUE of non-native cyprinids (Table 3). There was a negative association between RPC and main channel temperature (Table 3). No correlation was observed between RPC and backwater temperature (Table 3). Mean RPC was significantly different in habitats with mud depths of >2 to 5 cm (2.28 %) than in habitats with mud depths of zero to 2 cm. (1.42 %), >5 to 25 cm. (1.99 %) or >25 cm. (2.08 %).

A comparison of total catch of YOY Colorado pikeminnow and red shiner by year shows a positive, nonsignificant correlation (r_S =0.350, p=0.058) when drought periods were removed (1989–1990, and 2001–2003). However, the relationship was strongly negative during drought periods (Figure 13).

Middle Green River (Reach 4)

Native species collected in most years in the middle Green River include Colorado pikeminnow, bluehead sucker, *Gila* spp., flannelmouth sucker, and speckled dace, although speckled dace have only sporadically been captured in the last 10 years (Table 6). Razorback sucker were captured in backwater sampling in 1997, 1998, and 2000, but have not been observed since then (Table 6). The number of non-native species found in fall seining has grown since 1986 from eight species to 11 species in 2009 (Table 7). In each year of the study, the small-bodied cyprinids (red shiner, sand shiner, and fathead minnow) were the most abundant species.

Trend analysis of YOY Colorado pikeminnow annual CPUE in the middle Green River was best described by piecewise linear regression; showing a linear decline from 1986–1997 followed by a flat trend through 2009 (R^2 = 0.49, $F(2,22)$ = 21.48, p < 0.001, Figure 14). For periods before and after the 1997 breakpoint, mean CPUE declined from 6.74 fish/100m^2 (1986–1996) to 0.82 fish/100m^2 through 2009 ($t(14)$ = 2.45, p= 0.034). In 2009, Colorado pikeminnow catch rates finally rebounded to pre-1994 levels. Young-of-year Colorado pikeminnow numbers were at the all time low in 2002, when no Colorado pikeminnow were observed in fall backwater sampling; the highest catch rates occurred in 1988 (21.45 fish/100 m^2).

Young-of-year Colorado pikeminnow CPUE was not significantly correlated with annual peak flow in the middle Green River (Figure 15). However, during the 1986–1994 period, when CPUE was relative high (pre-1994), a significant relationship was observed between these two variables (r_S = 0.881, p < 0.001). Annual peak flows did not correlate with mean TL of YOY Colorado pikeminnow in this reach (Figure 16), nor did mean TL correlate significantly with the number of days between peak flow and the start of sampling (Figure 17). While, the years 1994, 2000, and 2007 had the highest mean TL during the study period, these years did not also correspond to the lowest peak flow years. These years did experience low flows, but other lower flow years also saw relatively high mean TL, thus reducing the correlation between the two variables. Mean TL and YOY Colorado pikeminnow CPUE were negatively correlated over the study period in the middle Green River (Table 3; Figure 18).

As in the other reaches, backwater area and non-native cyprinid CPUE were positively correlated with YOY Colorado pikeminnow RPC in the middle Green River (Table 3). Unlike the other reaches, backwater depth and seine haul depth were negatively correlated with relative percent catch (Table 3). Also, there was no correlation between temperature (backwater, main channel, or the difference between) and RPC in this reach (Table 3). However, when backwater temperatures were rounded to integer values (to increase the number of values within each "compartment"), the relationship between RPC of YOY Colorado pikeminnow and backwater temperature was positively correlated ($r_s = 0.554$, $p = 0.0137$). However, neither main channel temperature nor the difference between main channel and backwater temperature showed a positive relationship upon rounding. A one-way ANOVA on ranks showed that YOY Colorado pikeminnow are more often found in backwaters with mud depths < 5 cm (5.42 %) versus backwaters with mud depths of > 25 cm (0.21 %; F=20.951; $p < 0.001$).

In the middle Green River, YOY Colorado pikeminnow are found in the highest concentrations between RM 215 and RM 220 and in the lowest concentrations between RMs 245–250 and RMs 300–320 (Figure 19). The 30 miles between the White River confluence (RM 246) and Sand Wash (RM 215) contained the most important nursery habitat sampled in the middle Green River during the study period. The reach between Red Wash (RM 298) and the Ouray National Wildlife Refuge (RMs 249.5–263) also contained important YOY Colorado pikeminnow nursery habitat. Backwaters in these reaches tend to be larger than those in Split Mountain (RMs 300–320) or immediately around the Duchesne River (RM 247.9). In fact, YOY Colorado pikeminnow RPC by river mile correlated positively with backwater area by river mile ($r_S = 0.488$, $p = 0.0246$; Figure 20).

We observed no correlation between total annual catch of red shiner and total annual catch of YOY Colorado pikeminnow in the middle Green River (Figure 21). Also, no correlation was observed when drought years or years with no pikeminnow caught in the first seine haul of the sub-reach were removed from the analysis.

DISCUSSION

Lower Colorado River (Reach 1)

No consistent relationship between any biotic or abiotic factor and fall YOY Colorado pikeminnow catch rates was observed over the study period. Mean CPUE in this reach varied annually, but within a fairly tight range; however, the mean of the annual range dropped by 76% after 1996. No biotic or abiotic factors measured during fall surveys varied to a degree that would suggest a direct response.

Total YOY Colorado pikeminnow catch declines coincided with significant drought events in 1989–1990 and 2001–2003, typified by summer base flows below 3,000 cfs, spring peaks near or below 10,000 cfs, and high summer water temperatures. When examining total annual catches of Colorado pikeminnow and red shiner, we observed that during years of significant drought conditions, not only did YOY Colorado pikeminnow decline, but red shiners increased significantly (Figure 7). The extent of this relationship is somewhat incomplete in the lower Colorado River due to only presence/absence of non-natives being recorded in 2001, a year in which red shiners were believed to have been numerous.

Trammell and Chart (1999a) compared larval driftnet catch rates (sites in Loma, Westwater, and near Moab) with fall YOY seining catch rates below Westwater Canyon from 1992 to 1996. They found that fall cohort strength in the lower Colorado River was related only to Moab area drift rates. They also concluded that peak discharge was not correlated to larval production levels. In general, Trammell and Chart (1999b) concluded that moderate flow scenarios were most conducive to successful reproduction and recruitment, a conclusion shared by McAda and Ryel (1999).

Young-of-year Colorado pikeminnow were found progressively more often with distance downstream suggesting that velocity, geomorphic characteristics, spawning location, and the drifting nature of YOY Colorado pikeminnow fry, all play a role in determining where Colorado pikeminnow are found in the fall. Trammell and Chart (1999a) reported that larval drift in this reach was primarily a result of spawning within the lower Colorado River, likely within the 30 river miles above Moab. Colorado pikeminnow appear to drift from sites at the top of this reach to low velocity portions of the reach further downstream where they are retained.

We did not find a relationship between fall mean TL and fall catch rates, suggesting that good or poor growing conditions did not consistently translate into corresponding higher or lower YOY fall catches. The fall mean TL of YOY Colorado pikeminnow was negatively correlated with spring peak flows, but not with the number of days between the peak and sample date; suggesting that the timing of the spring peak is not indicative of when spawning may occur, nor is the number of days after the peak predictive of summer growing conditions. The fall total length of Colorado pikeminnow should be a result of when spawning occurred, the corresponding number of accumulated degree days, and availability and condition of habitat and forage (McAda et al. 1994; Trammell and Chart 1999b).

Within this reach of the Colorado River, correlations between RPC of YOY Colorado pikeminnow and various biotic and abiotic habitat characteristics suggest YOY Colorado pikeminnow show an affinity for large deep backwaters, which are warmer than adjacent main channel habitats and moderate mud depths. Although YOY Colorado pikeminnow were more likely to be found in backwaters with moderate mud depths; it is possible that the actual level of selection for mud depths > 25 cm is masked by poor seining efficiency in those conditions. Trammell and Chart (2008) demonstrated through efficiency evaluations that mud depth did reduce efficiency, but the reduction in efficiency did not explain lower capture rates in habitats with high mud depths. The positive correlation between non-native cyprinid and YOY Colorado pikeminnow catch rates within specific habitats is likely related to both species selecting similar habitat characteristics.

Lower Green River (Reach 3)

Over the last 23 years, the lower Green River has typically had the highest Colorado pikeminnow YOY fall catch rates in the upper Colorado River Basin. Catch rate declines in this reach were most apparent from 1986–1994, after which catches were relatively low and much less variable. As in the Colorado River reach, no biotic or abiotic factors measured during fall surveys varied to a degree that would suggest a direct response.

The lowest catches observed in reach 3 occurred during the deepest drought of the study period in 2001–2003, typified by summer base flows below 1,500 cfs, and spring peaks near or below 10,000 cfs. The possible mechanisms effecting fall recruitment during this severe drought period include: low larval production, increased non-native cyprinid production, reduced forage production, and reduced habitat availability. Of all these mechanisms, only fall cyprinid abundance was measured and the total catch for red shiners increased greatly during years of significant drought, in addition, these were also the only years in which pikeminnow RPC was negatively correlated to red shiner catch rates. Larval production, forage abundance, and habitat availability were not examined during this sampling; however, habitat availability and its relationship to fall catches was examined by Trammell and Chart (1999c) between 1992–1996 and found to have no correlation.

Within the lower Green River, we again observed no relationship between fall mean TL of YOY Colorado pikeminnow and CPUE, suggesting that conditions which provide for greater growth in a season do not translate to greater fall densities.

Selection of specific backwater habitat qualities appeared to be minimal within this reach. Although several factors such as maximum depth and area were positively correlated to RPC, the strength of the correlations was weak. The strongest correlation was a positive relationship between YOY Colorado pikeminnow and red shiner CPUE in any given backwater. The link between YOY Colorado pikeminnow and sympatric cyprinids suggests that they select similar habitat types. Valdez et al. (1999) also found that overwinter survival of first year Colorado pikeminnow was related to backwater depth and total length, but not to non-native cyprinid densities, winter flow variability, or water temperature.

Middle Green River (Reach 4)

Between 1986 and 1998, YOY Colorado pikeminnow were regularly captured in the first seine haul of primary backwaters; however, after 1998, they were only captured in primary backwaters in six of 11 years. Similar to the other reaches, catch rates for YOY Colorado pikeminnow in the middle Green River were positively correlated with annual peak flow prior to 1994. However, once the fall population of YOY Colorado pikeminnow dropped precipitously in 1994, this relationship was no longer observed. The low to nonexistence catches of pikeminnow after the mid-90’s reduced our ability to measure any correlations between biotic or abiotic factors and annual variation in fall catch rates.

Within the middle Green River, we found significant correlations between backwater habitat variables and fish assemblage. First, we saw a positive relationship between RPC of YOY Colorado pikeminnow and backwater area suggesting that in reaches where YOY Colorado pikeminnow are found, the highest concentrations are in larger backwaters. Second, we found a positive relationship between RPC of YOY Colorado pikeminnow and non-native cyprinid CPUE. Although past studies have shown non-native cyprinids demonstrate aggressive behavior toward YOY Colorado pikeminnow (Bestgen et al. 2006), both groups of fish appear to be selecting for similar habitats within a reach. Third, we found a negative relationship between RPC of YOY Colorado pikeminnow and maximum depth of both the backwater and the seine haul. Finally, YOY Colorado pikeminnow tend to be found in backwaters with firm bottoms as evidenced by the significantly different results between mud depths < 5 cm and > 25 cm. These results may indicate a habitat preference. The correlations of YOY Colorado pikeminnow RPC with habitat depth may be affected by sampling effectiveness, with increased total depths > 1.5 meters hindering our seining ability and requiring a change in sampling strategy (parallel v. perpendicular for deeper backwaters).

The highest catch rates in this reach were found within the Red Wash to Ouray National Wildlife Refuge reach and below the White River. Backwaters in these reaches tend to be larger than those in or near Split Mountain or around the Duchesne River, where YOY Colorado pikeminnow were not often found.

Fall recruitment trends

For all three reaches, the most consistent pattern observed was the decline in mean CPUE for YOY Colorado pikeminnow following the mid-90's, with annual catch rates significantly declining in both the number of pikeminnow captured as well as intra-annual variability. In turn, no biotic or abiotic factors measured during fall surveys varied to a degree that would suggest a direct response or correlation. The first step in determining what factors may be impacting YOY recruitment is to determine if it is actually larval production or spawning adult availability at the root of the declines; this is being addressed by Bestgen and Hayes (2011). If production appears to be consistent over the last two decades, then a thorough review of habitat availability for both larval and YOY life stages is the next step; this is also being addressed by Bestgen and Hayes (2011). Continuing to pair the data collected for this project with other biotic and abiotic data sets will allow researchers to focus in on specific factors and time periods impairing pikeminnow recruitment.

Previous studies by Bestgen et al. (1998) examined relationships between larval abundance and juvenile recruitment between 1990–1996 in the middle and lower Green River. In general, Bestgen concluded that variation in larval abundance did not explain high intra-annual recruitment variation of pikeminnow. Instead, they hypothesized that predation by non-native cyprinids interacting with pikeminnow hatch timing and early-life growth rates was responsible for regulating juvenile recruitment in most years. It is important to note that this study period did not include the years with the most significant and sustained declines in fall juvenile recruitment. It will be important to see if this hypothesis is supported with the inclusion of thirteen additional years of data.

Total length achieved by a pikeminnow in the fall was not correlated to that years catch rates; suggesting indirectly, that growing conditions and the length of the growing season did not appear to affect fall recruitment. Water temperatures and flows play an important roll in the timing of pikeminnow spawning (Bestgen et al. 1998) which in turn determines the length of the growing season and in part affects the growth achieved by pikeminnow. Unfortunately, for our study period temperature data is only available from the Jensen gauge (#09261000) found at the top of reach 4; for this reason we used the length of time from peak flow to sampling as a proxy for growing season or accumulated degree days.

Past studies have primarily focused on the relationship between mean fall TL and its relationship to overwinter survival (McAda and Ryel 1999; Valdez and Cowdell 1999; and Trammell and Chart 1999b). These studies generally concluded that pikeminnow total length was a strong factor in overwinter survival only when a fall total length threshold of 30–21 mm was not achieved. Given the annual mean TL in each of these reaches over the study period, small size going into winter should not be a concern for managers.

Habitat selection

The ISMP monitoring provides some measure of habitat characteristics and species associations which may be selected for during the fall. Typically, pikeminnow were more likely to associate with larger, deeper backwaters and those which were warmer than the main channel. The fall habitat selection patterns reported here are generally the same reported by past studies (Tyus and Haines 1991; McAda et al. 1994; Trammell and Chart 1999b&c; Day et al. 1999). Some variables that were significant in reaches 1 and 3 were not significant in the middle Green River. A probable explanation is that reach 3 suffered the largest declines in CPUE after the mid-90's resulting in many zero data points over a sustained period. Hence, low sample size may have precluded significant correlations.

A consistent biotic association observed was the positive correlation between non-native cyprinids and YOY pikeminnow. This finding was consistent with McAda et al. (1994), in which the authors state, "Colorado squawfish are not avoiding backwaters utilized by these species." Based on our results, YOY Colorado pikeminnow may be selecting for the same habitat characteristics as non-native cyprinids even though red shiner have been shown to harass and prey upon larval Colorado pikeminnow up to a certain size.

Obstacles to juvenile recruitment

Our review of the fall ISMP data and past studies (Bestgen et al. 1998, Bestgen et al. 2006, Mcada and Ryel 1999, Trammell and Chart 1999 a&b) suggest that factors occurring during early life stages of Colorado pikeminnow are having the strongest affects in regulating fall juvenile recruitment. Bestgen et al. (2006) suggested that abiotic variables interacting with predator-prey dynamics were strongest controls on fall recruitment. Other potential constraints include food abundance and starvation, intra- and interspecific competition, habitat availability, and stochastic events.

Aside from the ubiquitous red shiner, an increasingly diverse non-native community is likely continuing to change the trophic structure of the system. The addition of new species like gizzard shad may be directly and indirectly affecting the flow of energy through the system. Stable isotope studies could be used to estimate the trophic niche space of native and non-native species to investigate the potential for competition. Evaluating the overlap of trophic niche spaces could help determine if competitive effects are also constraining pikeminnow recruitment.

CONCLUSIONS

- Young-of-year Colorado pikeminnow catch rates in the lower Colorado and middle and lower Green rivers have declined on average 75% between 1986–1995 and have remained at the reduced average through 2009.

- Catch rates for YOY Colorado pikeminnow were positively correlated with annual peak flows in all reaches between 1986 and 1994; however, this relationship was not observed in years after 1994.

- In the lower Colorado and lower Green Rivers, YOY Colorado pikeminnow total annual catch was positively correlated with red shiner total annual catch in all years except drought years. During droughts, YOY Colorado pikeminnow total annual catch declined and red shiner total annual catch increased.

- Mean total length of YOY Colorado pikeminnow was negatively correlated with annual peak flow in the lower Colorado River and lower Green River, but was not correlated with annual peak flow in the middle Green River.

- Relatively high catch rates of YOY Colorado pikeminnow were found in the lower Colorado River from Monument Creek (RM 15) to Coffee Pot Ruin (RM 20) and from Shafer Basin (RM 45) to Long Canyon (RM51); on the lower Green River from Deadhorse Canyon (RM 20) to Anderson Bottom (RM 31); and in the middle Green River from the White River confluence (RM 246) to Sand Wash (RM 215).

- Relative percent catch of YOY Colorado pikeminnow was positively correlated with backwater area, backwater depth, the difference between backwater and main channel temperature, and CPUE of non-native cyprinids in the lower Colorado and lower Green Rivers.

- Relative percent catch of YOY Colorado pikeminnow was positively correlated with backwater area and non-native cyprinid CPUE and negatively correlated with backwater and seine haul depth in the middle Green River.

- Relative percent catch of YOY Colorado pikeminnow was negatively correlated with main channel temperature in the lower Colorado and lower Green Rivers, but not correlated with temperatures in the middle Green River.

- The value of and ongoing 23 plus-year dataset cannot be overstated. This data will continue to be a cornerstone for analysis and synthesis of biotic and abiotic factors that effect Colorado pikeminnow status.

RECOMMENDATIONS

- Continue fall YOY Colorado pikeminnow monitoring with current sampling protocols. Any changes made to this project should be in addition to current methods and collections.

- Adjust the goals and objectives of the project to reflect realistic outcomes for work assigned and budgeted. This includes removing the goals and objectives to create predictive models or develop relationships to habitat availability, larval production, or adult abundance. These are very important objectives, but they must be addressed by separate projects developed and funded to synthesize historical data from multiple sources. The synthesis being completed by Bestgen & Hayse (2011) is an excellent example.

- Collect instantaneous water temperature data year-round at the Green River USGS Gauging Station (09315000). Currently Green River temperature data from 1998 to present is only available from the Jensen Gauge (09261000) nearly 200 miles upstream of reach 3. Year-round temperature data for the Colorado River has been collected at the Cisco gauge (9180500) since 2007.

- If analysis of combined life history and habitat data for Colorado pikeminnow demonstrate that early-life mortality is a significant constraint on juvenile recruitment, specific research during that time frame (July-August) will be needed to define predator species population dynamics, life history, and predatory potential to determine possible management actions.

- The introduction and establishment of non-native species can fundamentally alter the flow of energy and trophic structure in lotic systems. Examining effects of the non-native fishes on the food web in the lower Green River using stable isotope analysis (C and N, e.g. convex hulls technique) is recommended to estimate the trophic niche space of species in the river and backwaters to investigate the potential for competition and the implications of longer food chains as new species (e.g. gizzard shad) become more widespread and abundant.

LITERATURE CITED

Archer, D.L., L.R. Kaeding, B.D. Burdick, and C.W. McAda. 1985. A study of the endangered fishes of the upper Colorado River. Final Report. U.S. Fish and Wildlife Service, Colorado River Fishery Project. Grand Junction, Colorado.

Bestgen, K. R., and R. T. Muth. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Final report of Colorado State University Larval Fish Laboratory to Recovery Implementation Program for the Endangered Fishes in the Upper Colorado River Basin, Denver, Colorado.

Bestgen, K.R., D.W. Beyers, J.A. Rice, and G.B. Haines. 2006. Factors affecting recruitment of young Colorado pikeminnow: Synthesis of predation experiments, field studies, and individual-based modeling. Transactions of the American Fisheries Society 135:1722–1742.

Bestgen, K.R., and J.Hayse. 2011. Data Integration: Historical assessment of factors affecting young Colorado pikeminnow abundance and physical habitat availability in the Green River. 2009-11 Scope of Work for Upper Colorado River Recovery Program, Project FR-BW Synth.

Day, K. S., K. D. Christopherson, and C. Crosby. 1999. An assessment of young-of-the-year Colorado pikeminnow (Ptychocheilus lucius) use of backwater habitats in the Green River, Utah. Report B in Flaming Gorge Studies: assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Hawkins, J.A., and T.P. Nesler. 1991. Non-native Fishes of the Upper Colorado River Basin: An Issue Paper.

Heitmeyer, M.E. and L.H. Frederickson. 2005. An evaluation of ecosystem restoration and management options for the Ouray National Wildlife Refuge, Utah. Prepared for the U.S. Fish and Wildlife Service, Denver, CO.

Jones, R.L., and H.M. Tyus. 1985. Recruitment of Colorado squawfish in the Green River Basin, Colorado and Utah, 1979 – 1984. U.S. Fish and Wildlife Service, Colorado River Fishery Project, Vernal, Utah.

Lentsch, L.D., R.T. Muth, P.D. Thompson, B.G. Hoskins, and T.A. Crowl. 1996. Options for Selective Control of Non-native Fishes in the Upper Colorado River Basin. Utah Division of Wildlife Resources, Colorado River Fishery Project, Salt Lake City, Utah.

McAda , C.W., and R.J. Ryel. 1999. Distribution, relative abundance, and environmental correlates for age-0 Colorado pikeminnow and sympatric fishes in the Colorado River. Final Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado.

McAda, C.W., J.W. Bates, J.S. Cranney, T.E.Chart, W.R. Elmblad, and T.P. Nesler. 1994. Interagency Standardized Monitoring Program: Summery of Results, 1986 – 1992. Final Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado

Minckley, W.L., P.C. Marsh, J.E. Deacon, T.E. Dowling, P.W. Hedrick, W.J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. Bioscience 53(3):219–234.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, R.A. Valdez. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final Report to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Ploskey, G.R. and R.M. Jenkins. 1982. Biomass model of reservoir fish and fish-food interactions with implications for management. North American Journal of Fisheries Management 2:105–121.

Ryan, Sandra E. and Porth, Laurie S. 2007. A tutorial on the piecewise regression approach applied to bedload transport data. Gen. Tech. Rep. RMRS-GTR-189. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 41 p.

Trammell, M. and T. Chart 1998. Evaluation of Sampling Efficiency in the Interagency Standardized Monitoring Program (ISMP) for YOY Colorado Squawfish. Moab, Utah, Utah Division of Wildlife Resources: Report D in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Trammell, M. A. and T.E. Chart. 1999a. Aspinall Studies: Annual Assessment of Colorado Pikeminnow Larval Production in the Colorado River, Utah 1992-1996 Final Report: 52.

Trammell, M. A., and T. E. Chart. 1999b. Aspinall Unit Studies: evaluation of nursery habitat availability and Colorado pikeminnow young-of-the-year habitat use in the Colorado River, Utah, 1992–1996. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Trammell, M. A., and T. E. Chart. 1999c. Colorado pikeminnow young-of-the-year habitat use, Green River, Utah, 1992–1996. Report C in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Tyus, H.M. 1985. Homing behavior noted for Colorado squawfish. Copeia 1985:213–215.

Tyus, H.M., and Beard, J.M., 1990. *Esox lucius* (Esocidae) and *Stizostedion vitreum* (Percidae) in the Green River basin, Colorado and Utah. Great Basin Naturalist 50(1): 33–39.

Tyus, H.M. and C.W. McAda. 1984. Migration, movements, and habitat preferences of Colorado squawfish, *Ptychocheilus lucius*, in the Green, White, and Yampa rivers, Colorado and Utah. Southwestern Naturalist 29:289–299.

Tyus, H.M., C.W. McAda, and B.D. Burdick. 1982b. Green River fishery investigations: 1979–1981. Pages 1–99 in W.H. Miller, J.J. Valentine, D.L. Archer, H.M. Tyus, R.A. Valdez, and L. Kaeding. Colorado River Fishery Project, final report, field investigations. Part 2. U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation, Salt Lake City, UT. 365 pp.

Tyus, H.M. and G.B. Haines. 1991. Distribution, habitat use, and growth of Age-0 Colorado squawfish in the Green River Basin, Colorado and Utah. Transactions of the American Fisheries Society 120:79–89.

USFWS (U.S. Fish and Wildlife Service). 1987. Interagency Standardized Monitoring Program Handbook. Grand Junction, Colorado

USFWS (U.S. Fish and Wildlife Service). 1990a. Bonytail Chub Recovery Plan. U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS (U. S. Fish and Wildlife Service). 1990b. Humpback chub recovery plan, 2nd revision. Report of Colorado River Fishes Recovery Team to U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 1991. Colorado Squawfish Revised Recovery Plan. 2nd revision. Report of the Colorado River Fishes Recovery Team to U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 1998. Razorback Sucker (*Xyrauchen texanus*) Recovery Plan. Report prepared for U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2002a. Bonytail (*Gila elegans*) Recovery Goals: amendment and supplement to the Bonytail Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2002b. Colorado pikeminnow (*Ptychocheilus lucius*) Recovery Goals: amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado

USFWS (U.S. Fish and Wildlife Service). 2002c. Humpback chub (*Gila cypha*) Recovery Goals: amendment and supplement to the Humpback Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2002d. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2009. Species Reports. http://ecos.fws.gov/tess_public/SpeciesReport.do?groups=E&listingType=L&mapstatus=1. Updated July 17, 2009.

Valdez, R., P. Mangan, R, Smith, and B. Nilson. 1982. Upper Colorado River Investigation (Rifle, Colorado to Lake Powell, Utah). Pages 101 – 279 in W.H. Miller, J.J. Valentine, D.L. Archer, H.M. Tyus, R.A. Valdez, and L. Kaeding. Colorado River Fishery Project, final report, field investigations. Part 2. U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation, Salt Lake City, UT.

Valdez, R.A., B.R. Cowdell, and L.D. Lentsch. 1999. Overwinter survival of age-0 Colorado pikeminnow in the Green River, Utah, 1987–1995. Final Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado.

Valdez, R.A. and R.T. Muth. 2005. Ecology and Conservation of Native Fishes if the Upper Colorado River Basin. American Fisheries Society Symposium 45:157–204.

Vanicek D. C. 2007. Distribution of Green River Fishes in Utah and Colorado Following Closure of Flaming Gorge Dam. The Southwestern Naturalist, 14: 297–315.

Wydoski, R.S. and E.J. Wick. 1998. Ecological value of floodplain habitats to razorback suckers in the Upper Colorado River Basin. Final Report submitted to the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, CO. 55 pp.

Table 1. Presence/absence of bluehead sucker (BH), *Gila* spp. (CH), Colorado pikeminnow (CS), flannelmouth sucker (FM), razorback sucker (RZ), and speckled dace (SD) in backwaters in the lower Colorado River.

Year	CH	CS	RZ	FM	BH	SD
1986	X	X				X
1987	X	X		X	X	X
1988	X	X		X		
1989	X	X		X	X	X
1990	X	X		X	X	
1991	X	X		X		X
1992	X	X		X	X	X
1993	X	X		X	X	X
1994	X	X			X	X
1995	X	X		X	X	X
1996	X	X		X	X	X
1997	X	X		X	X	X
1998	X	X		X	X	X
1999	X	X			X	
2000	X	X		X	X	
2001	X	X				X
2002	X	X			X	
2003						
2004	X	X		X	X	
2005		X				
2006		X		X	X	X
2007		X		X		
2008				X	X	
2009		X		X	X	X

Table 2. Lower Colorado River, presence/absence of black bullhead (BB), black crappie (BC), bluegill (BG), channel catfish (CC), common carp (CP), fathead minnow (FH), mosquitofish (GA), green sunfish (GS), gizzard shad (GZ), largemouth bass (LG), northern pike (NP), plains killifish (PK), red shiner (RS), smallmouth bass (SM), sand shiner (SS), walleye (WE), white sucker (WS), and yellow bullhead (YB) in backwaters.

YEAR	**RS**	**FH**	**SS**	**CC**	**GA**	**PK**	**LG**	**CP**	**BB**	**GS**	**WS**	**BG**	**BC**	**YB**	**GZ**	**SM**
1986	X	X	X	X	X	X	X									
1987	X	X	X	X	X			X	X							
1988	X	X	X			X		X		X						
1989	X	X	X	X		X		X	X	X	X					
1990	X	X	X	X	X	X	X	X	X	X		X				
1991	X	X	X	X		X		X	X		X					
1992	X	X	X		X	X		X	X	X	X					
1993	X	X	X	X	X			X	X	X	X					
1994	X	X	X	X	X			X	X	X	X					
1995	X	X	X	X	X		X	X	X	X						
1996	X	X	X	X	X	X	X			X		X				
1997	X	X	X	X	X		X	X								
1998	X	X	X	X	X	X				X						
1999	X	X	X	X	X	X		X		X		X	X			
2000	X	X	X		X		X	X	X	X	X					
2001	X	X	X	X	X			X	X							
2002	X	X	X	X	X	X		X	X							
2003	X	X	X		X	X		X	X							
2004	X	X	X					X								
2005	X	X	X	X				X								
2006	X	X	X	X	X	X	X	X	X	X			X	X		
2007	X	X		X	X			X	X		X				X	X
2008	X	X	X	X	X		X	X			X			X	X	
2009	X	X	X		X			X	X				X		X	

Table 3. Spearman correlation coefficients for YOY Colorado pikeminnow RPC (unless otherwise noted) and biotic and abiotic characteristics of backwater and main channel habitats in the middle Green, lower Green, and lower Colorado rivers. Data from 1986–2009 were analyzed and only significant relationships ($p < 0.05$) are listed.

	Reach 1	**Reach 3**	**Reach 4**
Backwater area (m^2)	r_s = 0.0120	r_s = 0.172	r_s = 0.109
Max. backwater depth (m)	r_s = 0.0775	r_s = 0.0506	r_s = -0.218
Seine haul max depth (m)			r_s = -0.456
Backwater temp. (°C)			
Main channel temp. (°C)	r_s = -0.0763	r_s = -0.124	
Backwater-main channel temp. difference (°C)	r_s = 0.106	r_s = 0.0850	
Non-native cyprinid CPUE	r_s = 0.244	r_s = 0.195	r_s = 0.114

Table 4. Presence/absence of bluehead sucker (BH), *Gila* spp. (CH), Colorado pikeminnow (CS), flannelmouth sucker (FM), bonytail (BT), humpback chub (HB), razorback sucker (RZ), and speckled dace (SD) in backwaters in the lower Green River.

Year	**CH**	**CS**	**BT**	**HB**	**FM**	**BH**	**SD**
1986	X	X					X
1987	X	X			X	X	
1988		X			X		X
1989	X	X			X		
1990		X					X
1991		X				X	X
1992	X	X			X	X	X
1993		X			X	X	X
1994	X	X		X		X	X
1995	X	X			X	X	X
1996		X			X	X	X
1997	X	X				X	X
1998		X				X	X
1999	X	X			X	X	X
2000	X	X					X
2001		X					X
2002	X	X			X		X
2003	X	X					X
2004		X			X	X	
2005		X					
2006	X	X					
2007	X	X	X				
2008		X			X		X
2009	X	X					X

Table 5. Lower Green River, presence/absence of black bullhead (BB), black crappie (BC), bluegill (BG), channel catfish (CC), common carp (CP), fathead minnow (FH), mosquitofish (GA), green sunfish (GS), gizzard shad (GZ), largemouth bass (LG), northern pike (NP), plains killifish (PK), red shiner (RS), smallmouth bass (SM), sand shiner (SS), white sucker (WS), and yellow bullhead (YB) in backwaters.

YEAR	RS	FH	SS	CC	CP	GS	BB	GA	BC	WS	LG	GZ	YB	BG	SM	NP	PK
1986	X	X	X	X	X	X	X										
1987	X	X	X	X		X											
1988	X	X	X	X	X	X	X	X									
1989	X	X	X	X	X	X	X										
1990	X	X	X	X	X		X										
1991	X	X	X	X	X	X											
1992	X	X	X	X	X		X										
1993	X	X	X	X	X		X										
1994	X	X	X	X	X	X		X									
1995	X	X	X	X	X	X	X										
1996	X	X	X			X		X									
1997	X	X	X	X	X	X		X		X							
1998	X	X	X		X			X	X								
1999	X	X	X	X	X			X	X								
2000	X	X	X	X	X	X	X			X							
2001	X	X	X	X	X												
2002	X	X	X	X	X	X											
2003	X	X	X	X	X	X	X										
2004	X	X	X	X		X	X										
2005	X	X	X	X	X	X											
2006	X	X	X	X	X	X	X	X	X		X						
2007	X	X	X	X							X	X					
2008	X	X	X	X	X				X		X	X	X				
2009	X	X	X	X								X					

Table 6. Presence/absence of bluehead sucker (BH), *Gila* spp. (CH), Colorado pikeminnow (CS), flannelmouth sucker (FM), razorback sucker (RZ), and speckled dace (SD) in backwaters in the middle Green River.

Year	BH	CH	CS	FM	RZ	SD
1986	X	X	X	X		X
1987	X	X	X	X		X
1988	X	X	X	X		X
1989	X	X	X	X		X
1990	X	X	X			X
1991		X	X			
1992	X	X	X	X		X
1993	X	X	X	X		X
1994	X	X	X	X		X
1995	X	X	X	X		X
1996	X	X	X	X		X
1997	X	X	X	X	X	X
1998	X	X	X	X	X	X
1999	X	X	X	X		X
2000	X	X	X	X	X	X
2001		X	X	X		
2002		X		X		X
2003	X	X	X	X		
2004	X	X	X	X		X
2005	X	X	X	X		X
2006	X		X	X		
2007	X	X	X	X		
2008	X	X	X	X		
2009	X	X	X	X		X

Table 7. Presence/absence of fathead minnow (FH), red shiner (RS), sand shiner (SS), black bullhead (BB), channel catfish (CC), common carp (CP), green sunfish (GS), northern pike (NP), black crappie (BC), white sucker (WS), smallmouth bass (SM), redside shiner (RD), gizzard shad (GZ), bluegill (BG), and plains killifish (PK) in backwaters in the middle Green River.

Year	FH	RS	SS	BB	CC	CP	GS	NP	BC	WS	SM	RD	GZ	BG	PK
1986	X	X	X	X	X	X	X	X							
1987	X	X	X	X	X	X									
1988	X	X	X	X	X	X	X								
1989	X	X	X		X	X	X								
1990	X	X	X		X	X									
1991	X	X			X	X	X								
1992	X	X	X	X	X	X	X								
1993	X	X	X		X	X	X								
1994	X	X	X			X	X		X	X					
1995	X	X	X		X	X	X				X				
1996	X	X	X		X	X	X								
1997	X	X	X	X		X	X		X	X	X				
1998	X	X	X	X	X	X	X	X		X		X			
1999	X	X	X	X		X	X	X	X		X	X			
2000	X	X	X	X		X	X		X						
2001	X	X	X	X	X	X			X		X				
2002	X	X	X			X	X		X	X					
2003	X	X	X			X			X						
2004	X	X	X		X	X	X		X	X	X				
2005	X	X	X	X	X	X	X		X	X	X				
2006	X	X	X	X		X	X		X	X	X		X	X	
2007	X	X	X	X	X	X	X		X	X	X		X	X	
2008	X	X	X	X	X	X	X		X	X	X		X		X
2009	X	X	X	X	X	X	X		X	X	X		X		

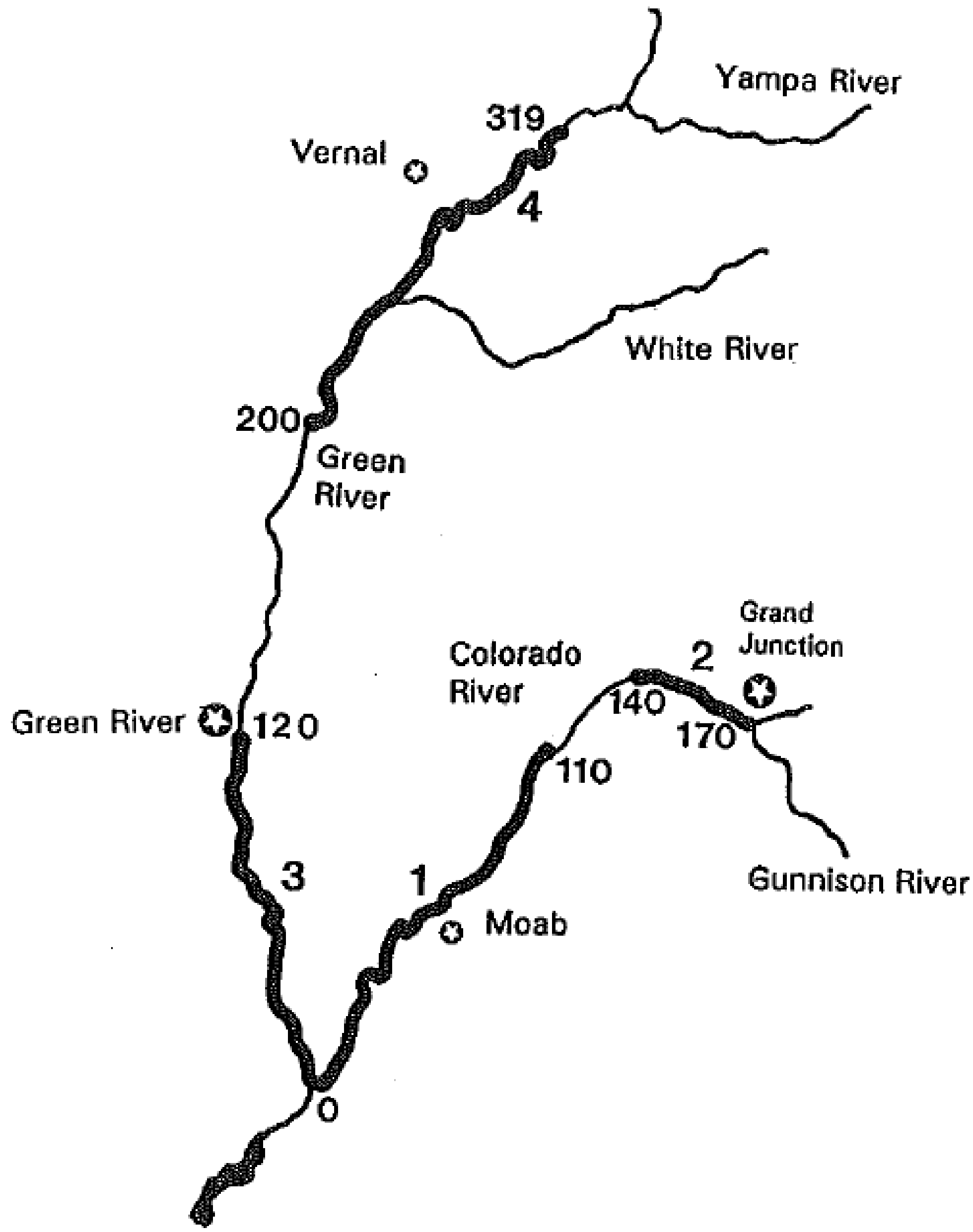
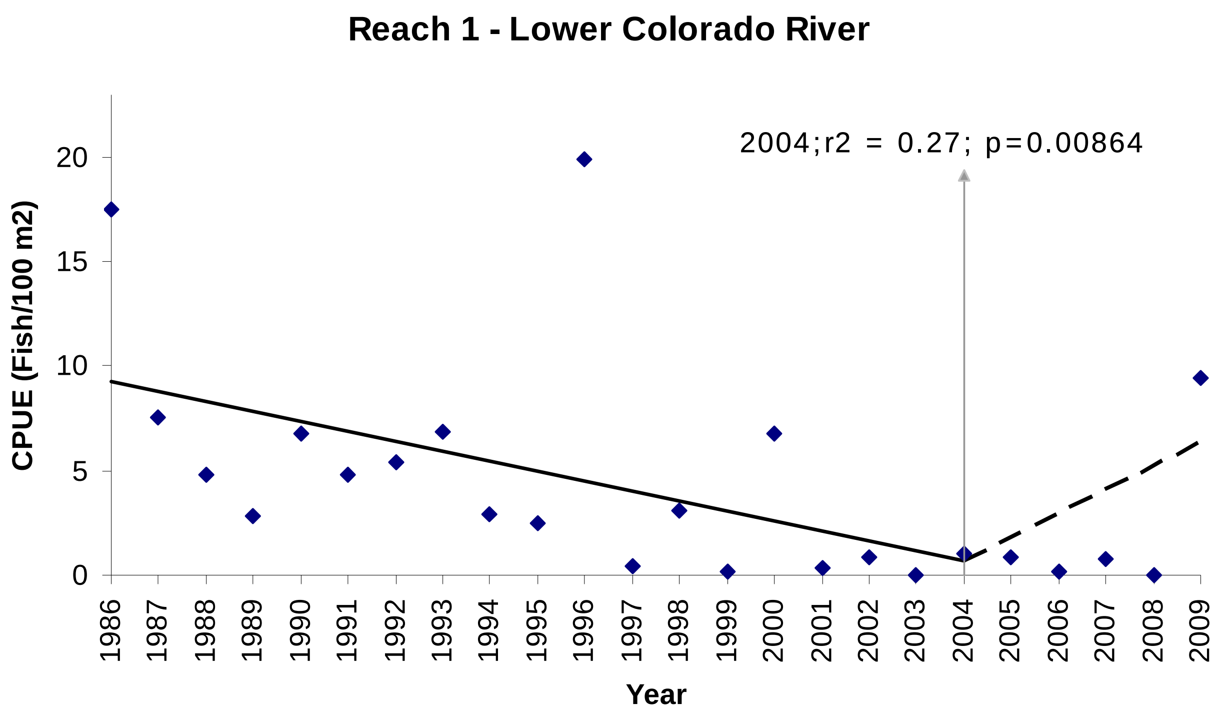


Figure 1. Backwater sampling reaches within the Green and Colorado rivers. In the text, Reach 1 is referred to as the lower Colorado River reach, Reach 3 is referred to as the lower Green River reach, and Reach 4 is referred to as the middle Green River reach. Reach 2 is no longer sampled.



Parameter	Piecewise Regression Results 1986-2009	1986-2004	2004-2009	PW Regr
Intercept - a	676.12	960.81	-2286.57	
Slope - b	-0.336	-0.479	1.141	
r^2	0.2048	0.2426	0.3417	0.2742
d*f*	22	17	4	22
F	5.67	5.44	2.08	8.31
p	0.026	0.032	0.223	0.0086

Figure 2. Mean Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured from backwaters in the lower Colorado River (Reach 1) 1986–2009. The Solid line represents a linear trend regression from 1986–2004 and the dashed line represents a linear regression from 2004–2009. The piecewise regression is represented by both lines combined and the break point indicated by the grey arrow. All regression results and parameters are summarized in the above table for: all data combined (1986–2009), individual periods (1986–2004 and 2004–2009), and as a piecewise regression for all sample periods combined (PW Regr).

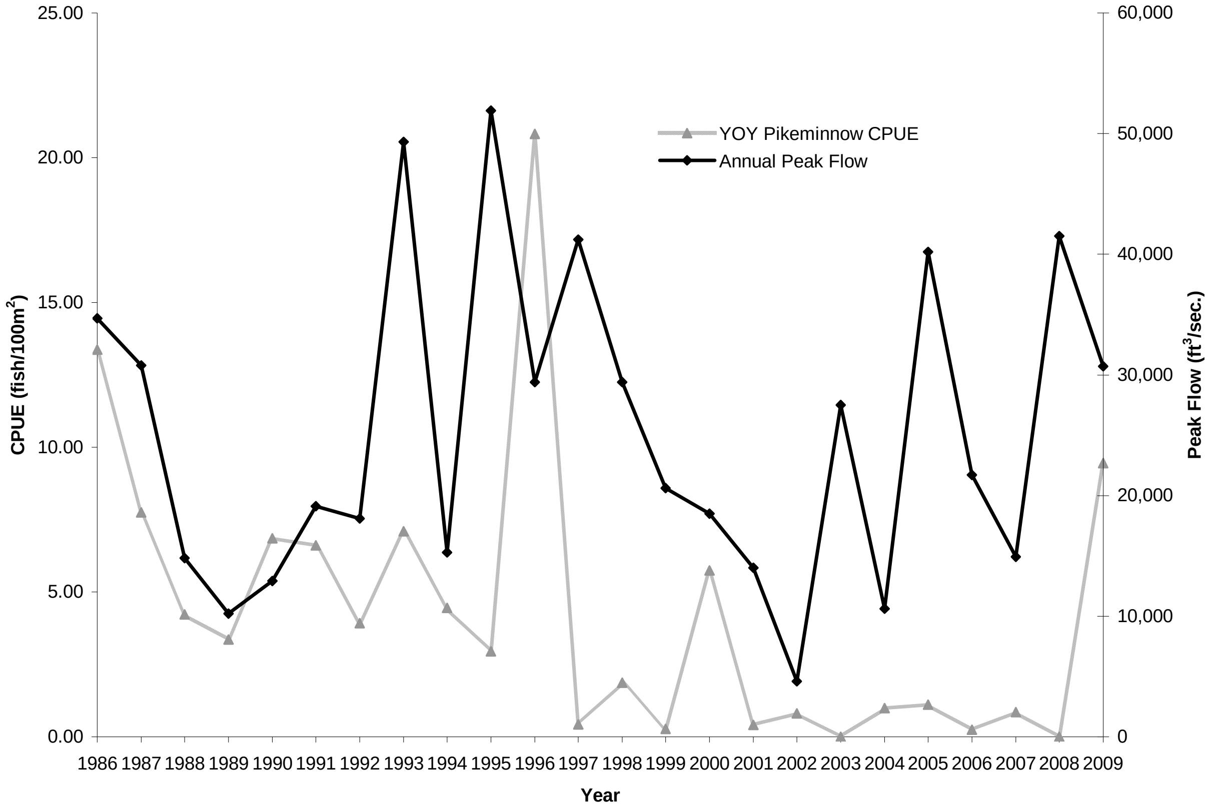


Figure 3. Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters and annual peak flows in the lower Colorado River (Reach 1). All discharge data were obtained from the United States Geological Survey (gage #09180500; Cisco, UT; 2002 and 2007 data are for the daily mean).

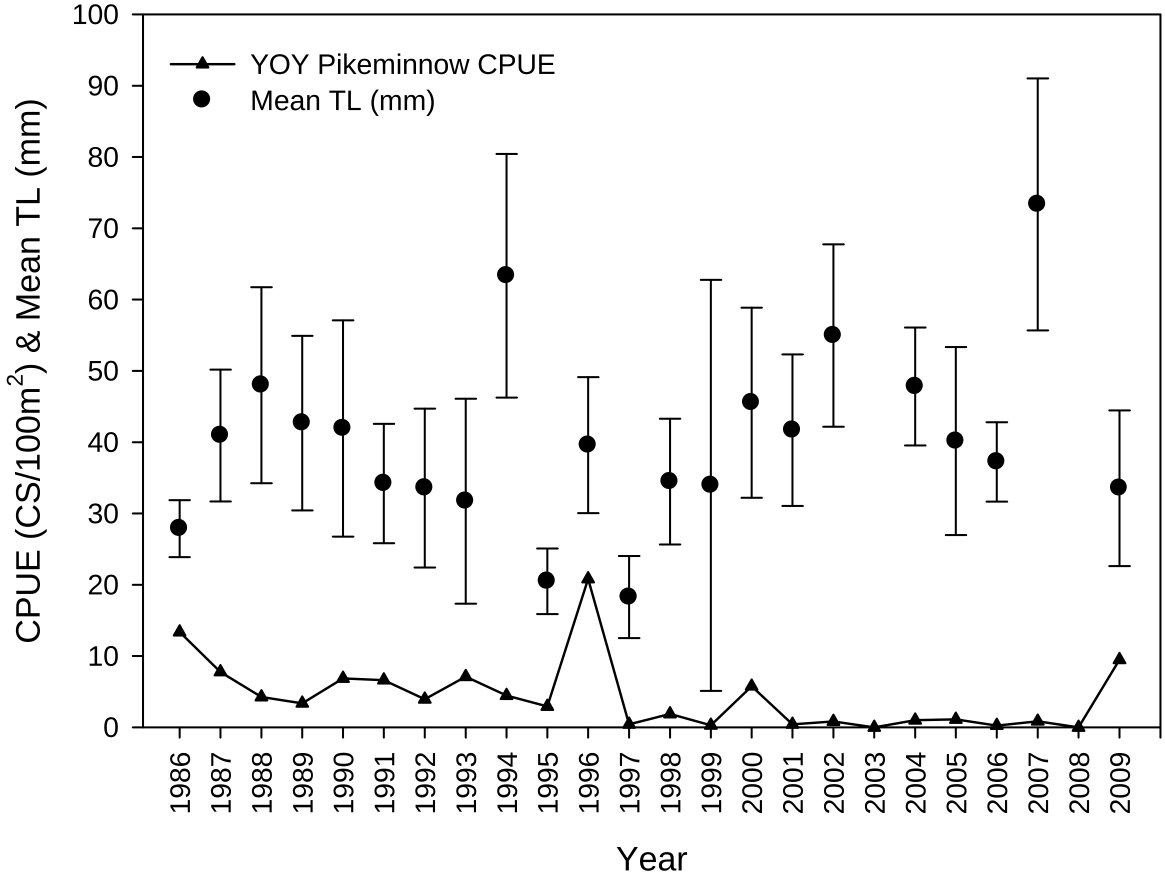


Figure 4. Mean total length (TL) and catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters in the lower Colorado River (Reach 1). Error bars represent one standard error.

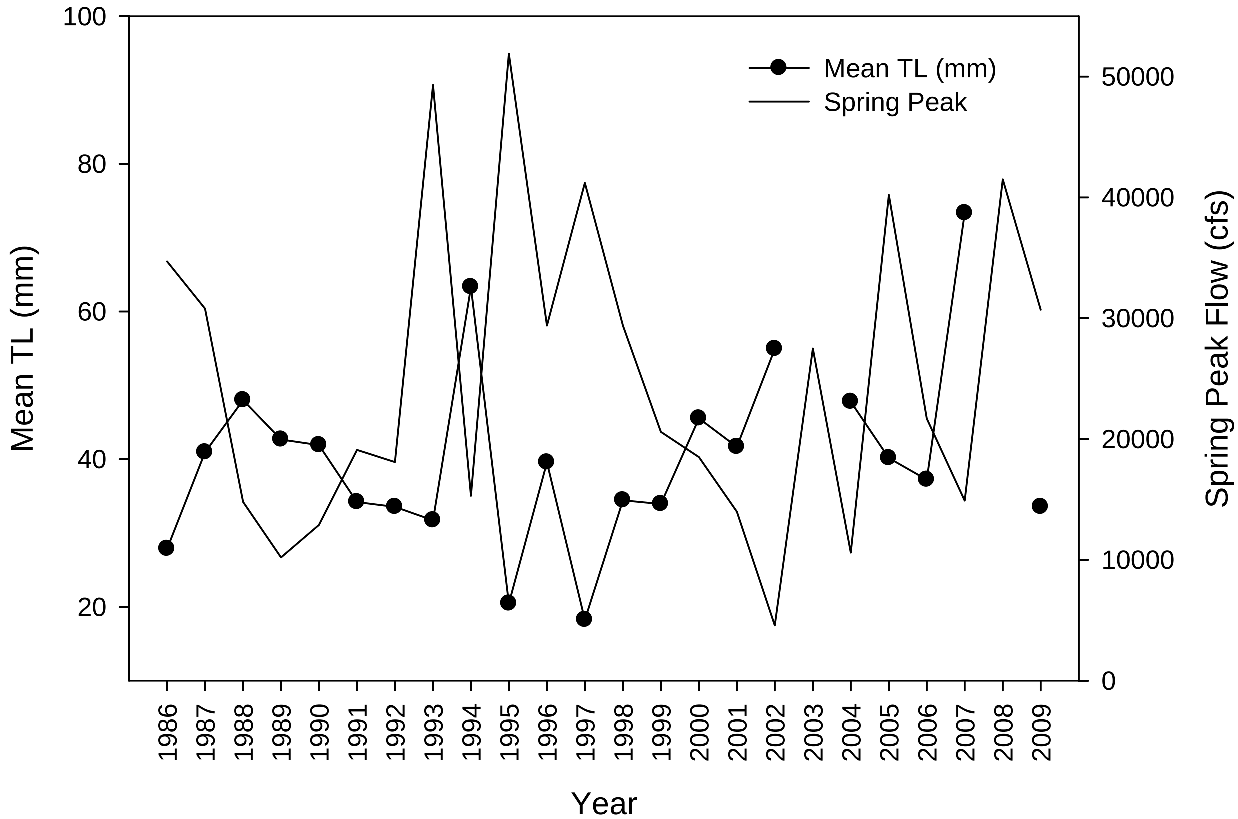


Figure 5. Mean total length (TL) of YOY Colorado pikeminnow captured in backwaters and the annual instantaneous peak flow in the lower Colorado River (Reach 1). All discharge data was obtained from the United States Geological Survey (gage #09180500; Cisco, UT; 2002 and 2007 data are for the daily mean on the day of the peak as no daily maximum data were found).

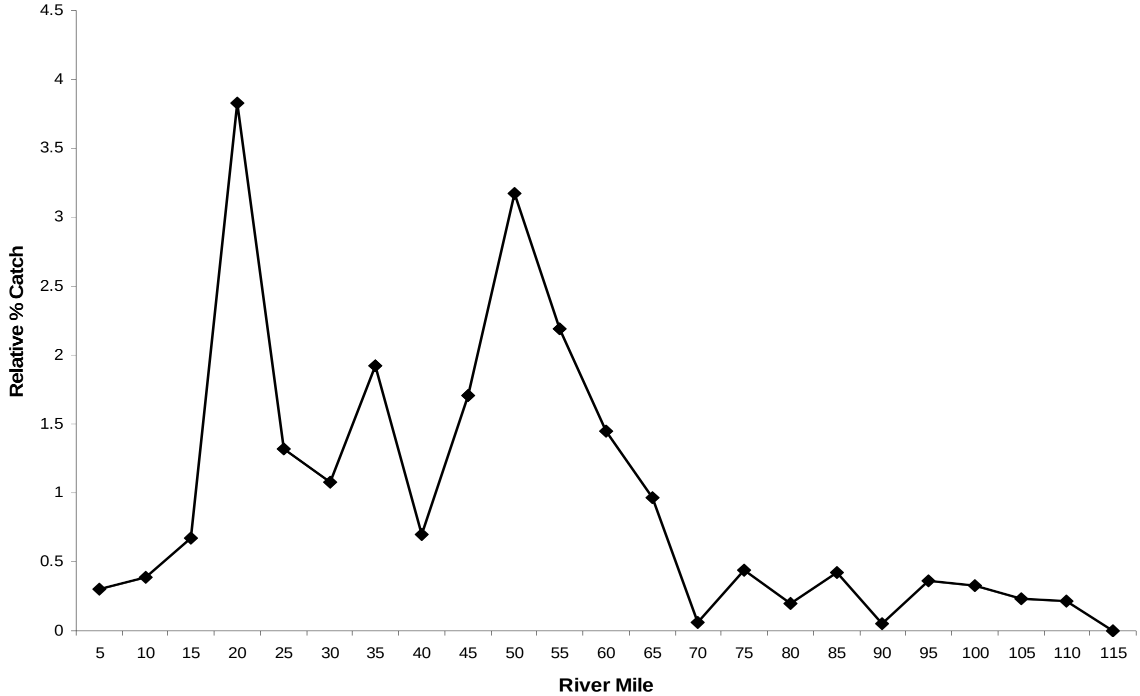


Figure 6. Relative percent catch of YOY Colorado pikeminnow captured in backwaters in the lower Colorado River from 1986–2009 (Reach 1). Data were compiled for all years combined in each five mile reach from Cisco Landing (RM 110) to the confluence of the Green River (RM 0).

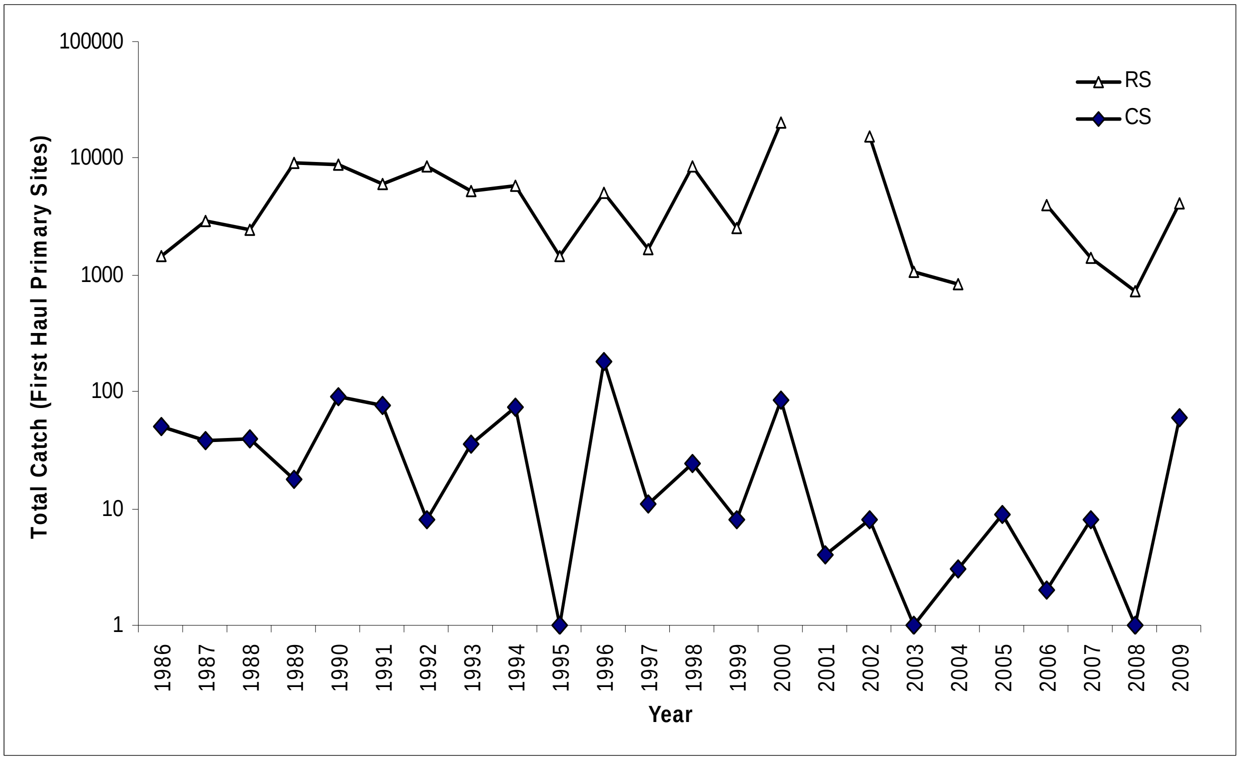
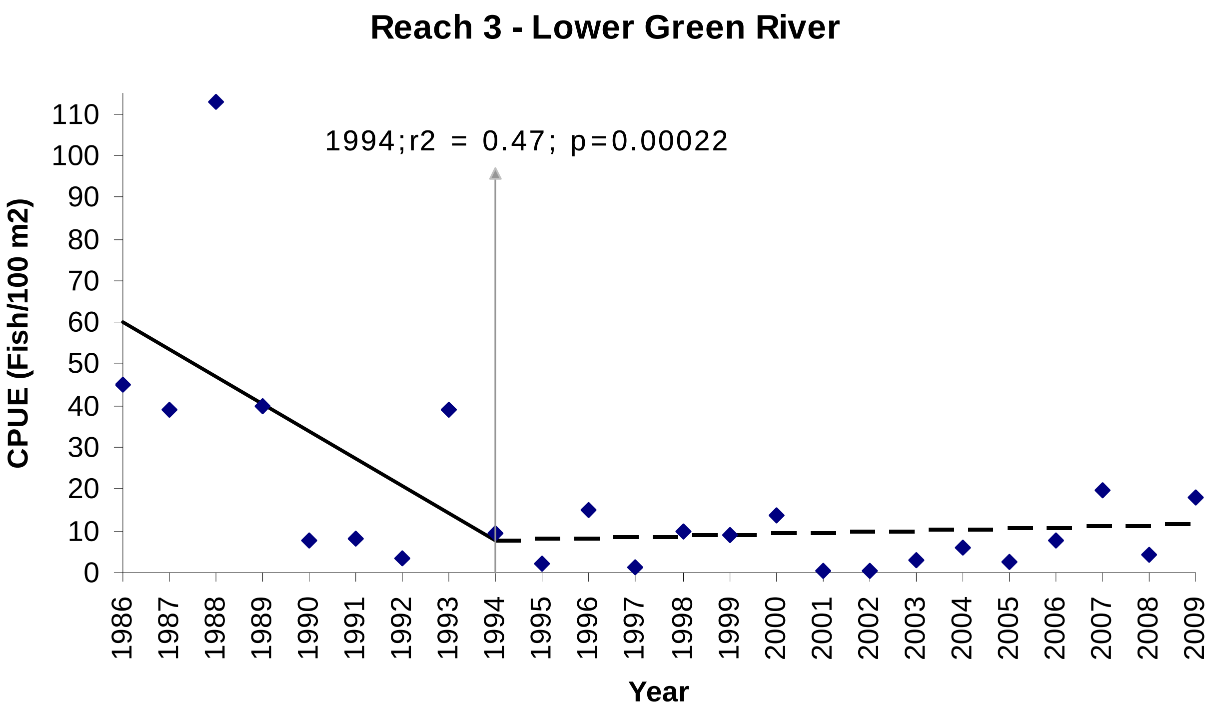


Figure 7. Lower Colorado River total annual catch for YOY Colorado pikeminnow (CS) and red shiner (RS) in the first seine haul of primary backwaters only (Reach 1). The Y-axis scale is logarithmic.



	Piecewise Regression Results			
Parameter	**1986-2009**	**1986-1994**	**1994-2009**	**PW Regr**
Intercept - a	3604.36	13066.39	374.51	
Slope - b	-1.796	-6.549	0.254	
r^2	0.2685	0.2756	0.0369	0.4691
df	22	7	14	22
F	8.08	2.66	0.54	19.44
p	0.00949	0.147	0.47612	0.00022

Figure 8. Mean Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured from backwaters in the lower Green River (Reach 3) 1986–2009. The Solid line represents a linear trend regression from 1986–1991 and the dashed line represents a linear regression from 1991–2009. The piecewise regression is represented by both lines combined and the break point indicated by the grey arrow. All regression results and parameters are summarized in the above table for: all data combined (1986–2009), individual periods (1986–1991 and 1991–2009), and as a piecewise regression for all sample periods combined (PW Regr).

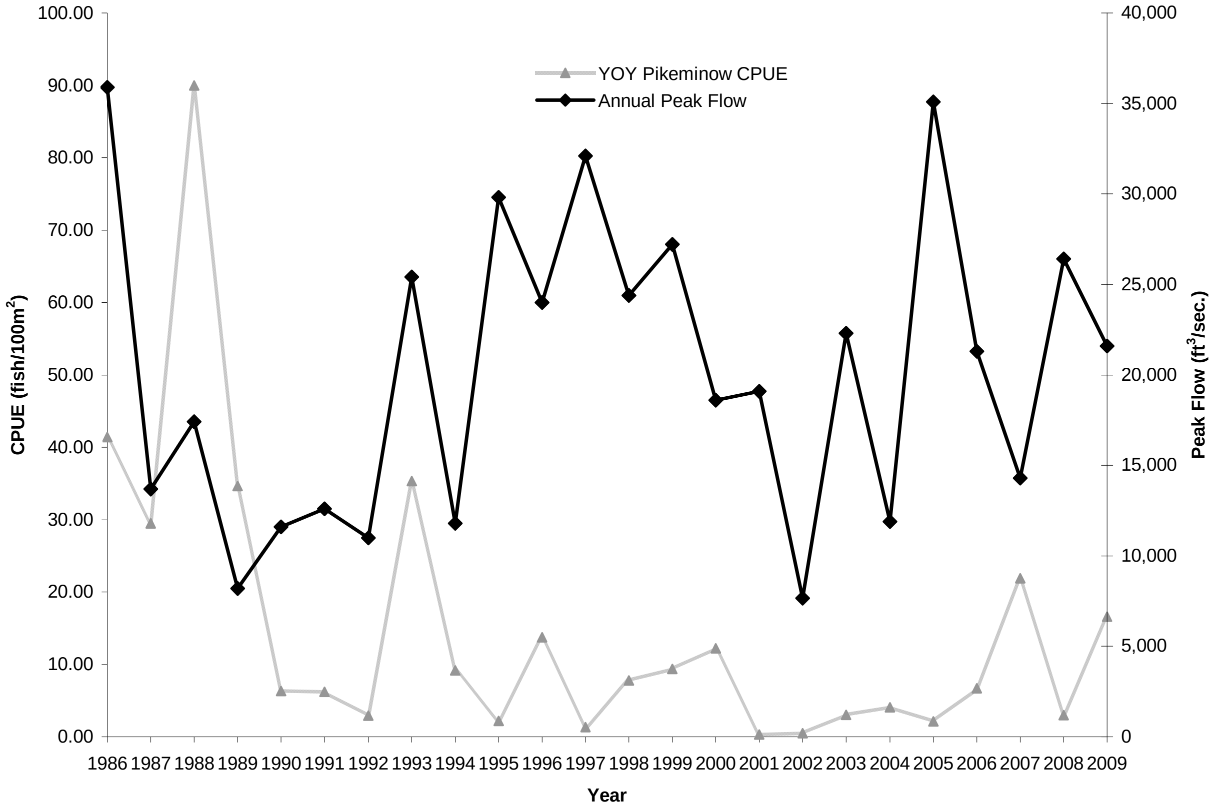


Figure 9. Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters and annual instantaneous peak flows in the lower Green River (Reach 3). All discharge data was obtained from the United States Geological Survey (gage #09315000; Green River, UT).

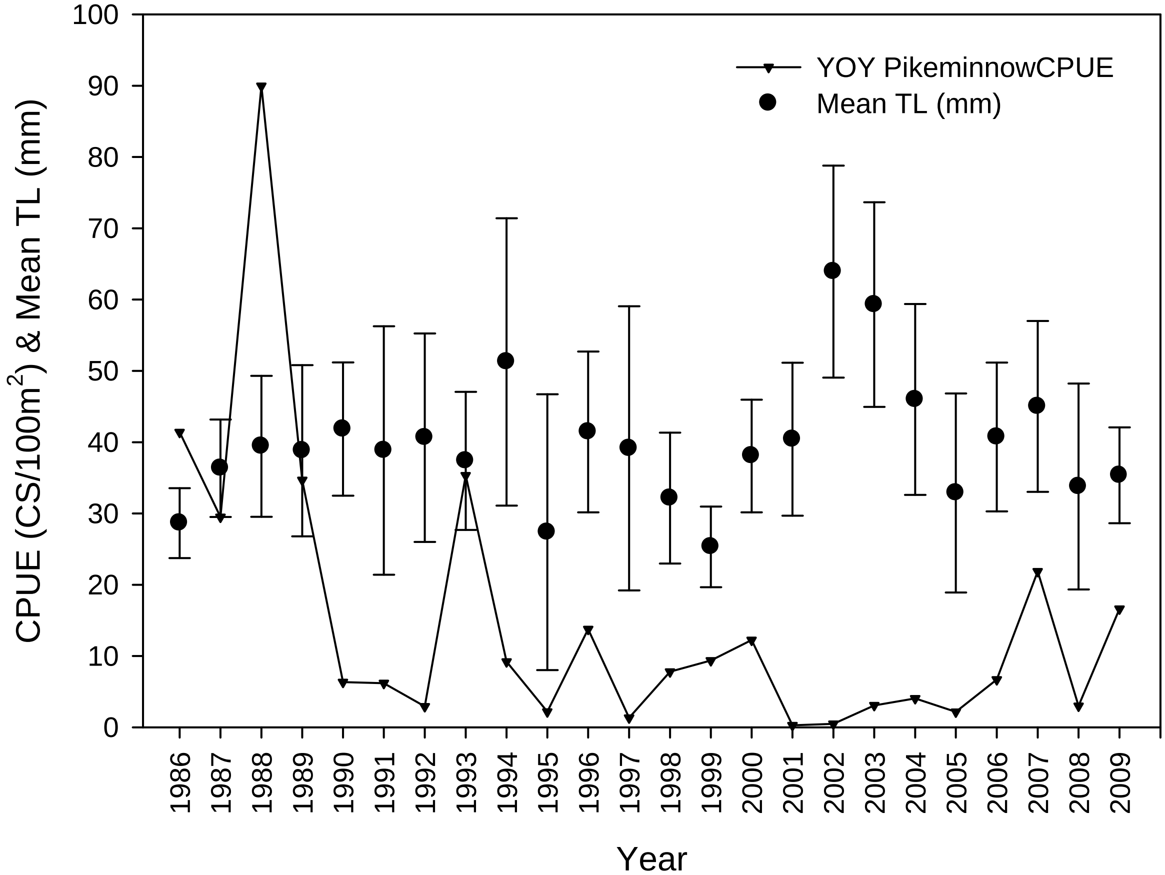


Figure 10. Mean total length (TL) and catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters in the lower Green River (Reach 3). Error bars represent one standard error.

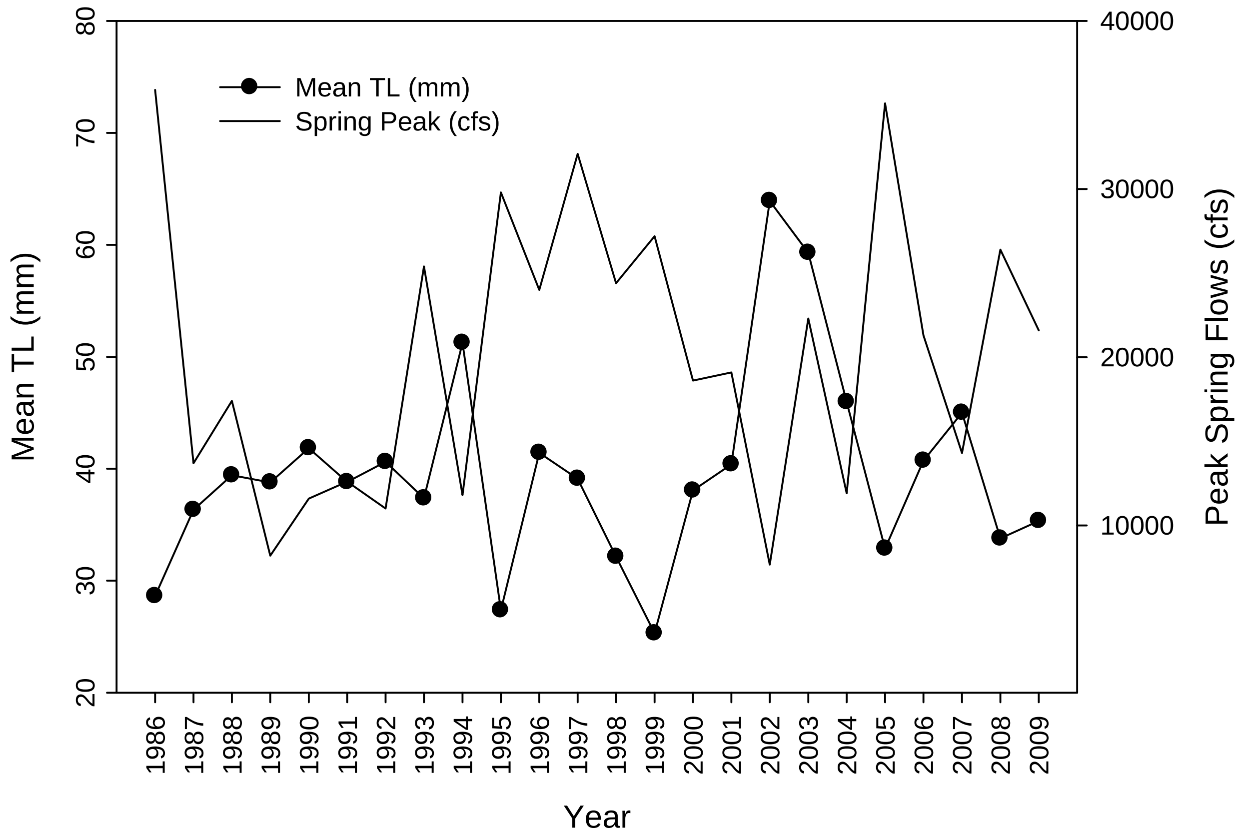


Figure 11. Mean total length (TL) of YOY Colorado pikeminnow captured in backwaters and annual instantaneous peak flow in the lower Green River (Reach 3). All discharge data were obtained from the United States Geological Survey (gage #09315000; Green River, UT).

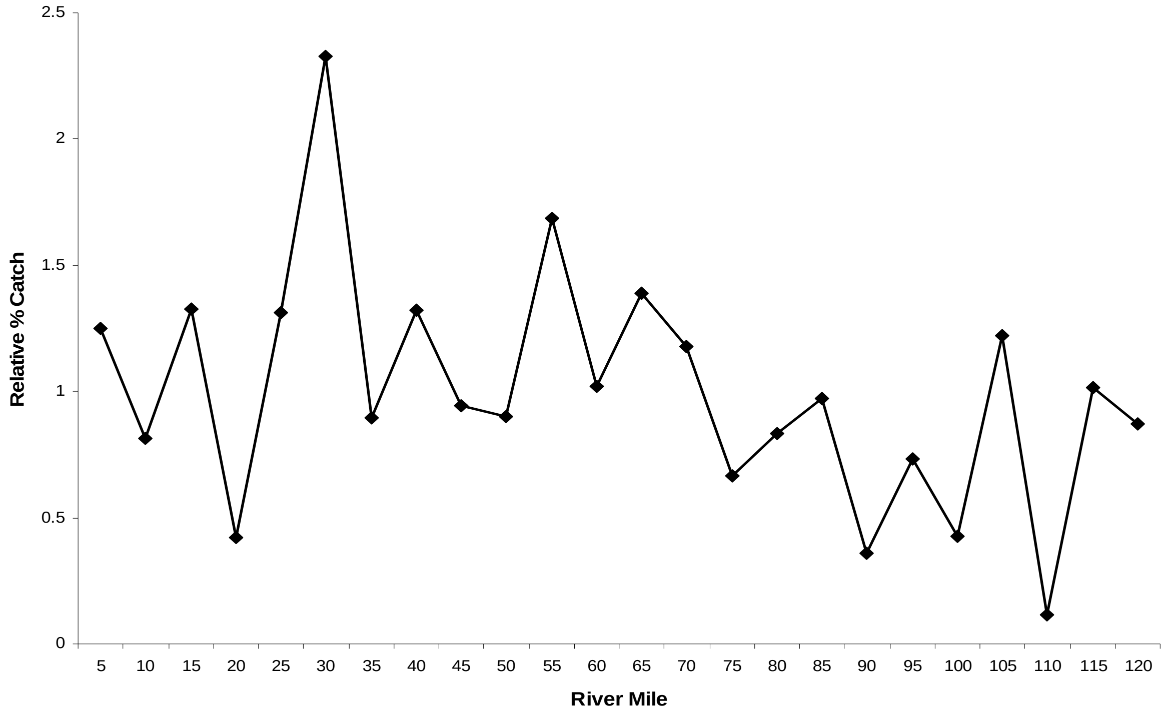


Figure 12. Relative percent catch of YOY Colorado pikeminnow captured in backwaters in the lower Green River from 1986–2009 (Reach 3). Data were compiled for all years combined in each five mile reach from the town of Green River (RM 120) to the confluence of the Colorado River (RM 0).

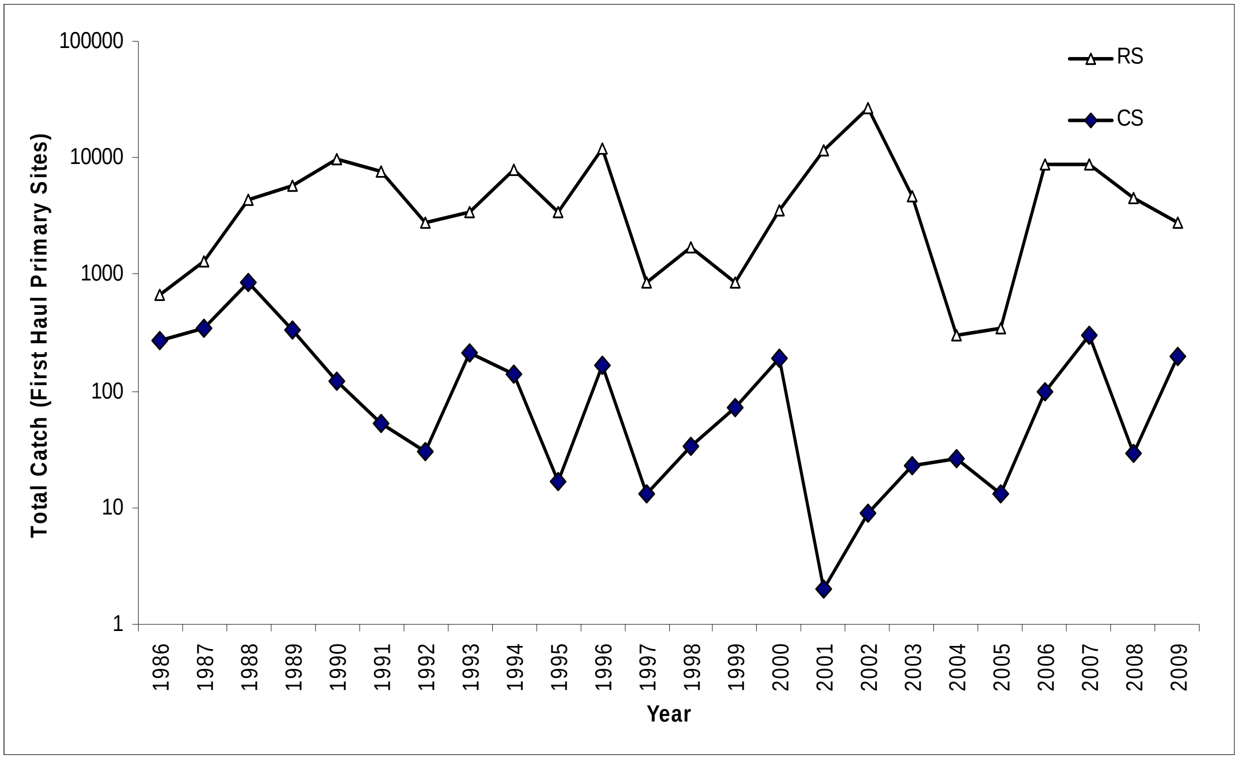
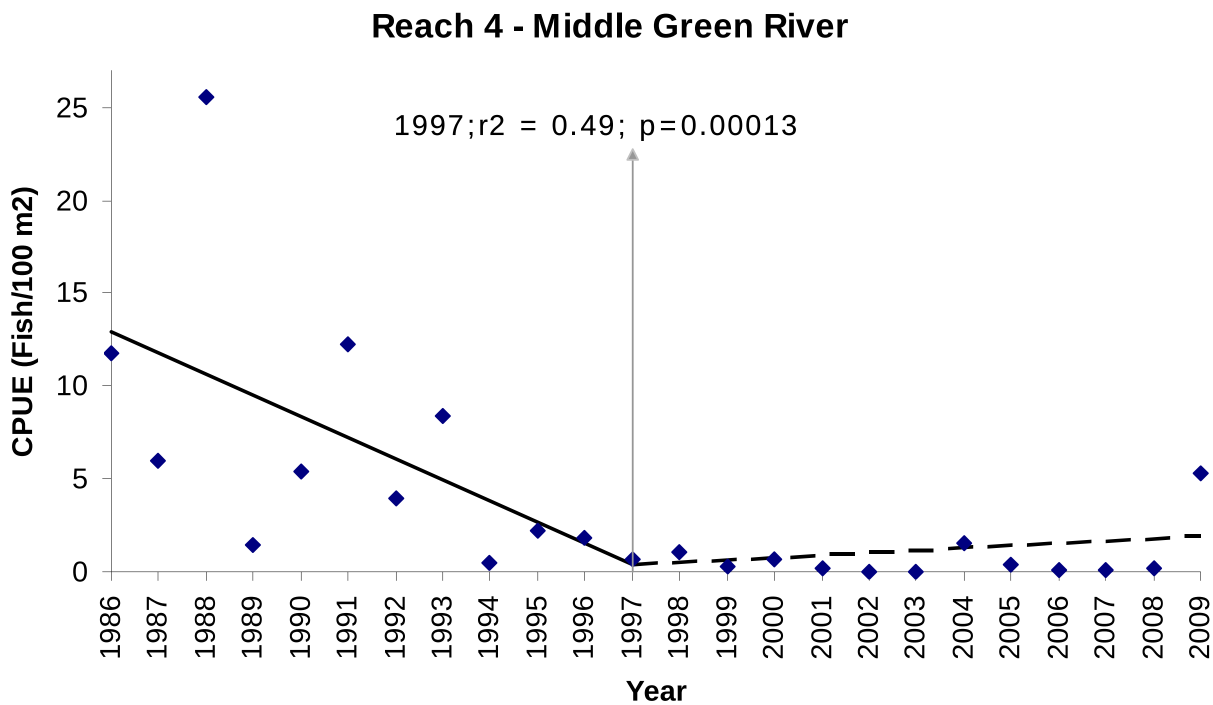


Figure 13. Lower Green River total annual catch for YOY Colorado pikeminnow (CS) and red shiner (RS) in the first seine haul of primary backwaters only (Reach 3). The Y-axis scale is logarithmic.



Piecewise Regression Results

Parameter	1986-2009	1986-1997	1997-2009	PW Regr
Intercept - a	979.16	2287.92	-254.78	
Slope - b	-0.488	-1.146	0.128	
r^2	0.3431	0.3286	0.1239	0.4940
d*f*	22	10	11	22
F	11.49	4.89	1.56	21.48
p	0.00263	0.051	0.2382	0.000128

Figure 14. Mean Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured from backwaters in the middle Green River (Reach 4) 1986–2009. The Solid line represents a linear trend regression from 1986–1997 and the dashed line represents a linear regression from 1997–2009. The piecewise regression is represented by both lines combined and the break point indicated by the grey arrow. All regression results and parameters are summarized in the above table for: all data combined (1986–2009), individual periods (1986–1997 and 1997–2009), and as a piecewise regression for all sample periods combined (PW Regr).

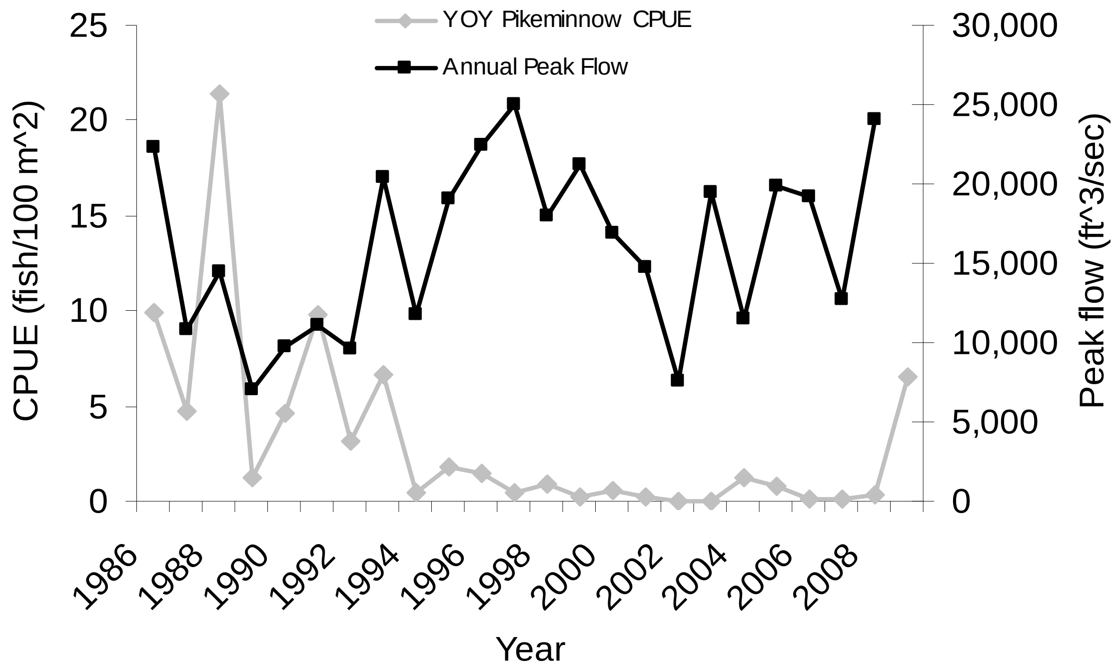


Figure 15. Catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters and annual peak flows in the middle Green River (Reach 4). All discharge data were obtained from the United States Geological Survey (gage #09261000; Jensen, UT; mean daily flow was used for 2009 as the peak flow statistics have not yet been posted for this year).

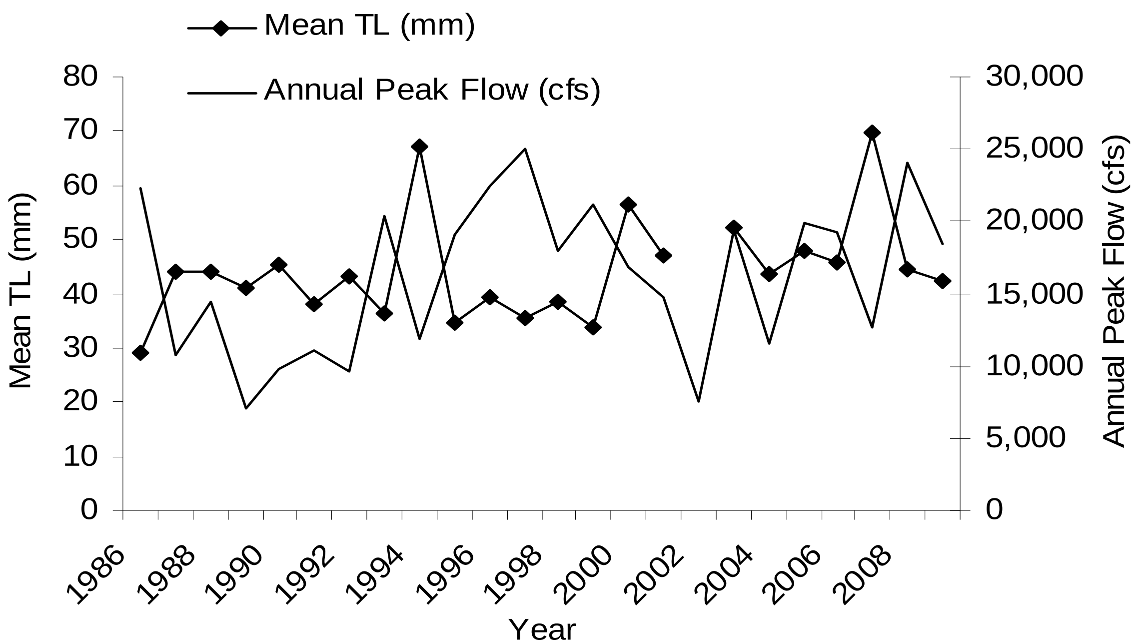


Figure 16. Mean total length (TL) of YOY Colorado pikeminnow captured in backwaters and annual instantaneous peak flows in the middle Green River (Reach 4). All discharge data were obtained from the United States Geological Survey (gage #09261000; Jensen, UT; mean daily flow was used for 2009 as the peak flow statistics have not yet been posted for this year).

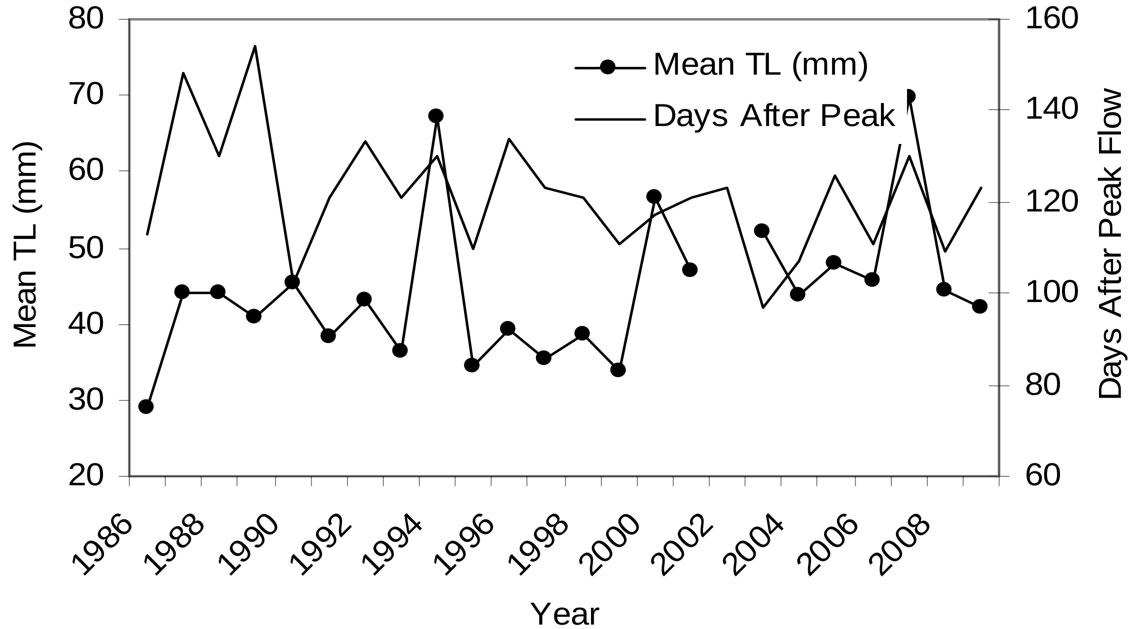


Figure 17. Mean total length (TL) of YOY Colorado pikeminnow captured in backwaters and the number of days after annual peak flows that the sampling occurred in the middle Green River (Reach 4). All discharge data were obtained from the United States Geological Survey (gage #09261000; Jensen, UT; mean daily flow was used for 2009 as the peak flow statistics have not yet been posted for this year).

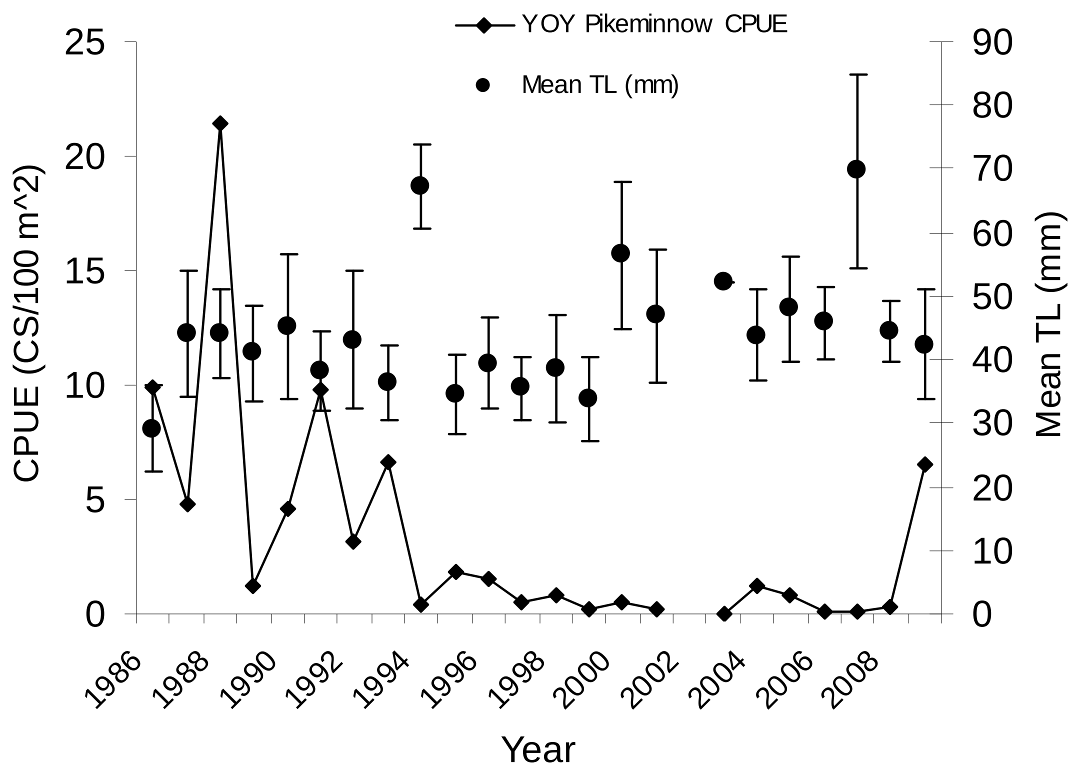


Figure 18. Mean total length (TL) and catch-per-unit effort (CPUE) of YOY Colorado pikeminnow captured in backwaters in the middle Green River (Reach 4). The error bars represent one standard error

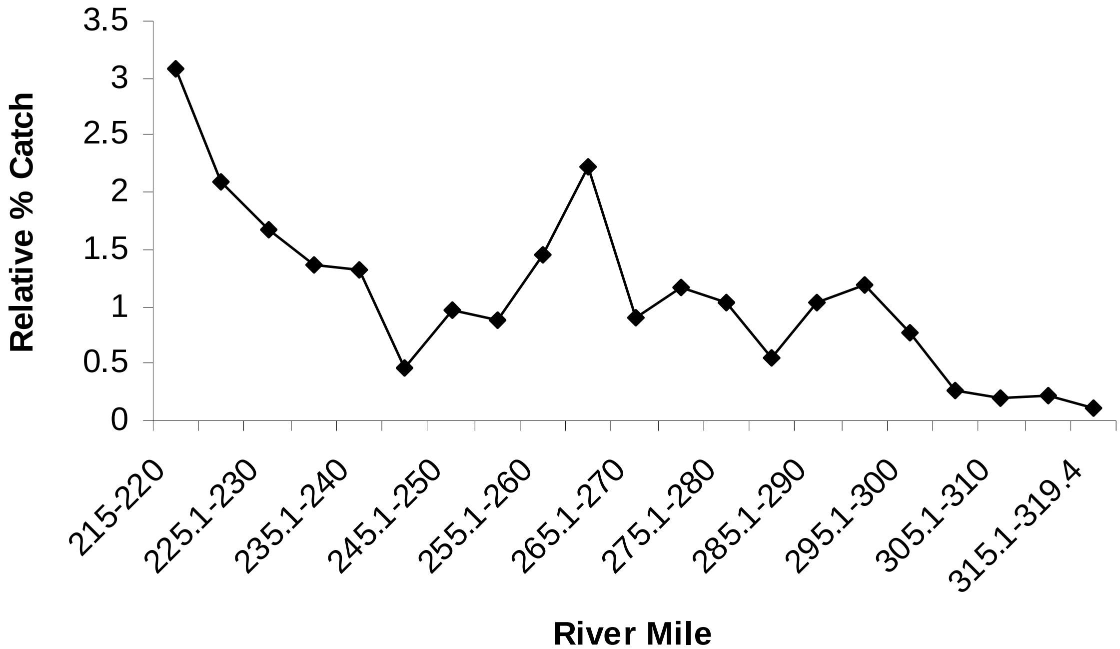


Figure 19. Relative percent catch of YOY Colorado pikeminnow captured in backwaters in the middle Green River (upstream is on the right side of the figure) from 1986–2009 (Reach 4). Data were compiled for all years combined in each five mile reach from Split Mountain (river mile 319.4) to the Sand Wash (river mile 215).

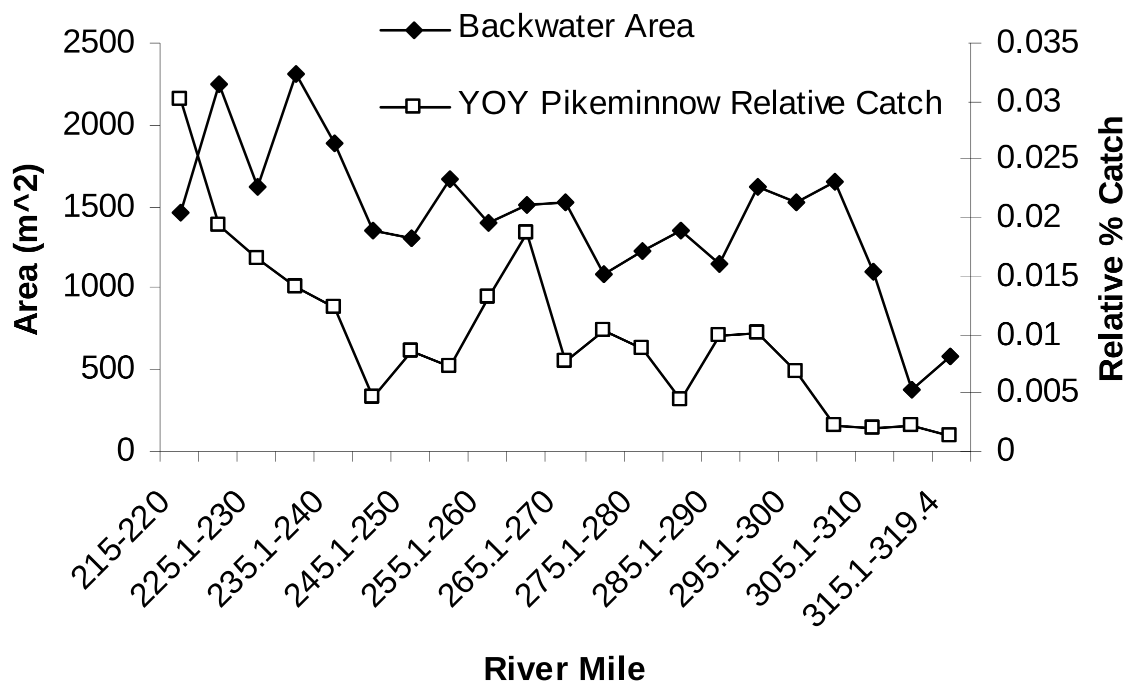


Figure 20. Relative percent catch of YOY Colorado pikeminnow and backwater area by 5 river mile segments in the middle Green River from 1986–2009 (Reach 4).

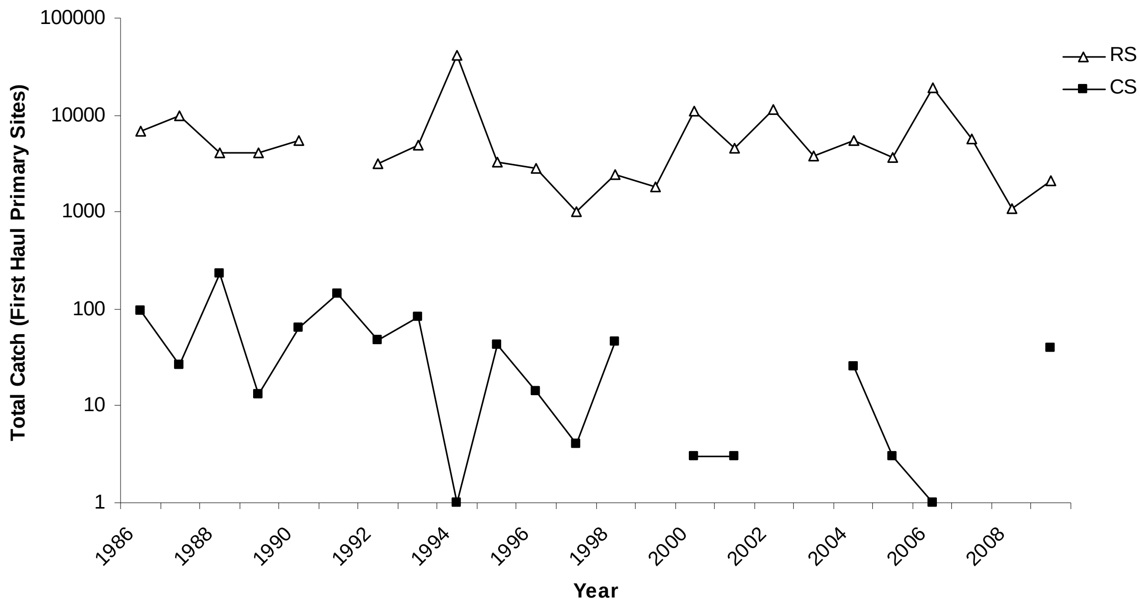


Figure 21. Middle Green River total annual catch for Colorado pikeminnow (CS) and red shiner (RS) in the first seine haul of primary backwaters only (Reach 4). The Y-axis scale is logarithmic.