Colorado Pikeminnow and Razorback Sucker larval fish survey in the San Juan River during 2013

FINAL REPORT

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prepared by:

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Executive Summary

From 15 April to 2 August 2013 five larval fish survey trips were conducted between river miles 147.9 (Shiprock, NM) and 2.9 (Clay Hills Crossing, UT) on the San Juan River. During the study period mean discharge was 791 cfs (309–2,190 cfs) and mean temperature was 21.6°C (10.3–27.1 °C). A total of 292 collections were made encompassing 9,750m^2 of low velocity habitat. The 292 collections contained 25,127 age-0 and 715 age-1+ fish representing six families and 14 species.

There were 12 age-0 Colorado Pikeminnow collected in 2013 between river miles 107.6 and 10.0. Colorado Pikeminnow ranged from 14.1 to 28.7 mm (total length) and all specimens were either metalarvae or juveniles. Back-calculated spawning dates encompassed a six week period between 23 May and 3 July 2013. A total of 48 age-1+ Colorado Pikeminnow were also collected in 2013. It is assumed these fish were the results of stocking efforts. The analysis of Colorado Pikeminnow (age-0) sampling-site density data, using general linear models based on mixture-model estimates (Delta (δ) and Mu (μ)), showed that the global model (δ(Year) μ(Year)) received essentially all of the AIC_C weight (w_i). Estimates of μ indicated a significantly higher ($P < 0.05$) abundance of Colorado Pikeminnow in 2013 as compared to either 2004 or 2007; there were no significant differences in estimates of δ over time The estimated densities ($E(x)$) of age-0 Colorado Pikeminnow, using sampling-site density data (2003–2013), were highest in 2011 (0.72) and 2013 (0.35) and lowest in 2004 and 2007 (0.05). The estimated densities of Colorado Pikeminnow did not differ significantly ($P > 0.05$) among any of the years

Between the May and July sampling trips, 979 larval Razorback Sucker were collected between river miles 147.5 and 3.3. Ontogenic stages of age-0 razorback sucker ranged from protolarvae to juvenile with back-calculated hatching dates ranging from 10 April to 7 June 2013. Spawning by razorback sucker in the San Juan River has been documented for each of the last 16 years. General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the global model (δ(Year) μ(Year)) received essentially all of the AIC_C weight (w_i). Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2013), were highest in 2011 (24.19) and 2013 (18.53) and lowest in 1999 (0.23) and 2005 (0.32). The estimated densities of Razorback Sucker were significantly higher ($P <$ 0.05) in 2011–2013 as compared with 2004–2009.

Mixture-model estimates (Delta (δ) and Mu (μ)), generated from general linear models of habitat-specific density data, revealed that the mesohabitat model (δ(Habitat) μ(Habitat)) received essentially all of the AIC_C weight (w_i). The estimated densities ($E(x)$) of Razorback Sucker, using habitat-specific density data (2013), were highest in backwaters (31.78), pools (16.76), and embayments (11.66) but lowest in sand shoals (1.90) and slackwaters (1.67). Razorback Sucker estimated densities were significantly higher ($P < 0.05$) in backwaters and pools as compared with sand shoals and slackwaters.

Despite an overall low level of connectivity to the river in 2013, the 14 monitoring sites contained a high percentage (38.1%) of the larval Razorback Sucker collected in 2013. For the first time during this study, no monitoring site was connected to the main channel during the June survey. Connectivity improved in the subsequent months as a result of summer rain events.

For the second consecutive year, the RERI sites provided nursery habitat for larval fishes. Both Razorback Sucker (age-0) and Colorado Pikeminnow (Age-1+) were found in these restored habitats. Species composition, and the proportion of native to non-native species within the RERI site was nearly identical to comparable river sites.

Elevated levels of opercular deformities continue to be observed in age-0 Razorback Sucker. Of the 216 specimens rated in 2013, 34.0% were found to have some level of deformity.

Introduction

Colorado Pikeminnow, *Ptychocheilus lucius*, and Razorback Sucker, *Xyrauchen texanus,* are two endangered species of cypriniform fishes native to the San Juan River, a large tributary of the Colorado River. The decline of these and other native fishes in the San Juan River has been attributed to flow modifications, instream barriers, changes to the thermal regime and channel simplification. In addition, the introduction of non-native fishes may have altered predation dynamics and competition for habitat and resources.

Colorado Pikeminnow (family Cyprinidae) was listed as an endangered species by the U.S. Department of the Interior in 1974. It is endemic to the Colorado River Basin where it was once abundant and widespread (Tyus, 1991). Currently this species occupies only about 20% of its historical range (Behnke and Benson, 1983; Tyus, 1990), with the majority of the remaining Upper Basin individuals occurring in the Green River (Holden and Wick, 1982; Bestgen et al., 1998). No Colorado Pikeminnow have been reported in the Lower Basin since the 1960's (Minckley and Deacon, 1968; Minckley, 1973; Moyle, 2002).

Studies in the Upper Colorado River Basin (Yampa and Green Rivers) demonstrated that Colorado Pikeminnow spawn on the descending limb of the summer hydrograph at water temperatures between 20^{o}C and 25^{o}C (Haynes et al., 1984; Nesler et al., 1988). Larval Colorado Pikeminnow drift down river as a dispersal mechanism and appear to begin this passive movement approximately five days after hatching. The five-day time frame corresponds with the swim-up period of this fish as reported by Hamman (1981, 1986). Drift of the newly hatched larval fish counteracts upstream migrations of the adults and disperses offspring to favorable nursery habitats downstream.

Razorback Sucker (family Catostomidae) was listed as an endangered species in 1991. There are few historical San Juan River records of Razorback Sucker despite the fact that this is one of three endemic Colorado River Basin catostomids. There are anecdotal reports from the late 1800's of Razorback Sucker occurring in the Animas River as far upstream as Durango, Colorado (Jordan, 1891). There are no specimens to substantiate this claim. The first verified record of razorback sucker in the San Juan River was in 1976 when two adult specimens were collected in an irrigation pond near Bluff, Utah (VTN Consolidated, Inc., and Museum of Northern Arizona, 1978).

Spawning of Razorback Sucker has been associated with the ascending limb of the spring hydrograph, peak spring discharge, and warming river temperatures. Adults congregate in riffles with cobble, gravel, and sand substrates. Spawning has been documented from mid-April to early June in the Green River at mean water temperatures of 14^{o}C (Tyus and Karp, 1990). Razorback Sucker larvae have been collected from Lake Mohave at 9.5–15.0^{o}C, indicating successful incubation of eggs at these temperatures (Bozek et al., 1990). Spawning of Razorback Sucker coincides with spawning of other native catostomids. Hybridization between Flannelmouth Sucker and Razorback Sucker has been documented where these two species co- occur (Tyus and Karp, 1990; Douglas and Marsh, 1998).

Mortality rates are substantial in the early ontogeny of fishes (Harvey,1991; Jennings and Philipp, 1994). Biotic and abiotic factors often operate simultaneously and affect the survival rates of larval fishes. Starvation, the presence and duration of important environmental conditions, and biotic interactions such as competition and predation all affect the survival of larvae (Bestgen, 1996). Early-life mortality can be especially significant in populations of slow growing fishes (Kaeding and Osmundson, 1988) such as Colorado Pikeminnow and Razorback Sucker. Abiotic factors, such as water temperature and discharge, act as cues for spawning of adult fishes but also affect growth rates, available food supplies, and mortality rates, for their offspring (Miller et al., 1988).

Food production, competition for food resources, and predation, especially in limited nursery habitats, result in high mortality rates of larval fishes (Houde, 1987). These factors are compounded in modified systems with large numbers of non-native fishes. For example, non-native Red Shiner, *Cyprinella lutrensis*, preys on cypriniform larvae (Brandenburg and Gido, 1999; Bestgen and Beyers, 2006). Red Shiner can compose up to 80% of the ichthyofaunal community in nursery habitats in the San Juan River (Propst et al., 2003; Brandenburg and Farrington, 2010) and may have significant impacts on native fish populations.

To mitigate these negative effects, attempts to mimic natural flow regimes in regulated systems are used to maintain cues for activities such as spawning and migration of native fishes, create and maintain nursery habitat for larval fishes, and suppress non-native fish populations (Poff et al., 1998). Natural flow regimes also favor the downstream displacement or drifting behavior of larval fishes and exploitation of the most advantageous feeding and rearing areas (Muth and Schmulbach, 1984; Pavlov, 1994). In many western river systems, higher spring and early summer flows increase sediment transport and turbidity and have been shown to reduce predation of larvae (Johnson and Hines, 1999). Sediment transport during high spring flows also scours substrates providing critical spawning habitat to native catostomids (Osmundson et al., 2002).

Investigations into the reproductive success of Colorado Pikeminnow began on the San Juan River using larval drift net surveys from 1991 to 2001. During that period of passive sampling only six larval Colorado Pikeminnow were collected (Appendix A, Table A-1).

Beginning in 2002, the sampling protocol was switched to active collection of larval fishes using larval seines and a raft to navigate the San Juan River. Using this active approach a total of 40 larval Colorado pikeminnow were collected between 2004 and 2011 (Table A-1).

Larval surveys using the same active sampling methods as that for the larval Colorado Pikeminnow survey began in 1998 on the San Juan River in an attempt to document reproduction of stocked Razorback Sucker. The 1998 survey produced the first documentation of reproduction by stocked Razorback Sucker. Larval Razorback Sucker have been documented every year since (Table A-2).

Objectives:

This work was conducted as required by the San Juan River Basin Implementation Program (2013) Long Range Plan. The goals and objectives of this specific monitoring project are identified in the aforementioned document and listed below:

4.1.1.1	Develop and revise a Standardized Fish Monitoring Plan to assess presence, status, and trends of Colorado Pikeminnow, Razorback Sucker and fish community.
4.1.1.2	Analyze and evaluate monitoring data and produce Annual Fish Monitoring. Reports to ensure that the best sampling design and strategies are employed.
4.1.2.1	Conduct larval fish sampling to determine if reproduction is occurring, locate spawning and nursery areas, and gauge the extent of annual reproduction.
4.2.3.1	Quantify attributes of habitats important to each life-stage of endangered fish.
4.2.3.2	Document and track trends in the use of specific mesohabitat types by larval Colorado Pikeminnow and Razorback Sucker.
4.2.3.3	Identify principal river reaches and habitats used by various life stages of endangered fish.

Study Area

The San Juan River is a major tributary of the Colorado River and drains 38,300 $mi.^2$ in Colorado, New Mexico, Utah, and Arizona. The major perennial tributaries to the San Juan River are (from upstream to downstream) Navajo, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers, and McElmo Creek. In addition there are numerous ephemeral arroyos and washes that contribute relatively little flow annually but input large sediment loads during rain events.

The San Juan River is currently a 224 mile lotic system bounded by two reservoirs (Navajo Reservoir near its head and Lake Powell at its mouth). From Navajo Dam to Lake Powell, the mean gradient of the San Juan River is 10.1 ft/mi, but can be as high as 21.2 ft/mi. Except in canyon-bound reaches, the river is bordered by non-native salt cedar, *Tamarix chinensis*, Russian olive, *Elaeagnus angustifolia*, native cottonwood, *Populus fremontii*, and willow, *Salix sp*. Non-native woody plants dominate nearly all sites and result in heavily stabilized banks. Cottonwood and willow compose a small portion of the riparian vegetation.

The characteristic annual hydrographic pattern in the San Juan River is typical of rivers in the American Southwest, with large flows during spring snowmelt followed by low summer, autumn, and winter base flows. Summer and early autumn base flows are frequently punctuated by convective storm-induced flow spikes. Prior to operation of Navajo Dam, about 73% of the total annual San Juan River drainage discharge (based on USGS Gage # 09379500; near Bluff, Utah) occurred during spring runoff (1 March through 31 July). Mean daily peak discharge during spring runoff was 10,400 cfs (range = 3,810 to 33,800 cfs). Although flows resulting from summer and autumn storms contributed a comparatively small volume to the total annual discharge, the magnitude of storm-induced flows exceeded the peak snowmelt discharge in about 30% of the years, occasionally exceeding 40,000 cfs (mean daily discharge). Both the magnitude and frequency of these storm induced flow spikes are greater than those recorded in the Green or Colorado Rivers.

Operation of Navajo Dam altered the annual discharge pattern of the San Juan River. The natural flow of the Animas River ameliorated some aspects of regulated discharge by augmenting spring discharge. Regulation resulted in reduced magnitude and increased duration of spring runoff in wet years and substantially reduced magnitude and duration of spring flow during dry years. Overall, flow regulation by operation of Navajo Dam has resulted in post-dam peak spring discharge averaging about 54% of pre-dam values. Conversely, post-dam base flow increased markedly over pre-dam base flows. Since 1992 efforts have been made to operate Navajo Dam to mimic a “natural” annual flow regime.

Methods

Access to the river and collection localities was gained through the use of 16' inflatable rafts that transported both personnel and collecting gear. There was not a predetermined number of collections per river mile or geomorphic reach for this study. Instead, collections were made in as many suitable larval fish habitats as possible within the river reach being sampled. Previous San Juan River investigations clearly demonstrated that larval fish most frequently occur and are most abundant in low velocity habitats such as pools and backwaters (Lashmett, 1993). Sampling of the entire study area was accomplished during a one week period in which the study area is divided into an “upper” section (Shiprock, NM to Sand Island, UT) and a “lower” section [Sand Island, UT to Clay Hills, UT (Figure 1)]. Sampling trips for both portions of the study area were initiated on the same day of each month whenever possible.

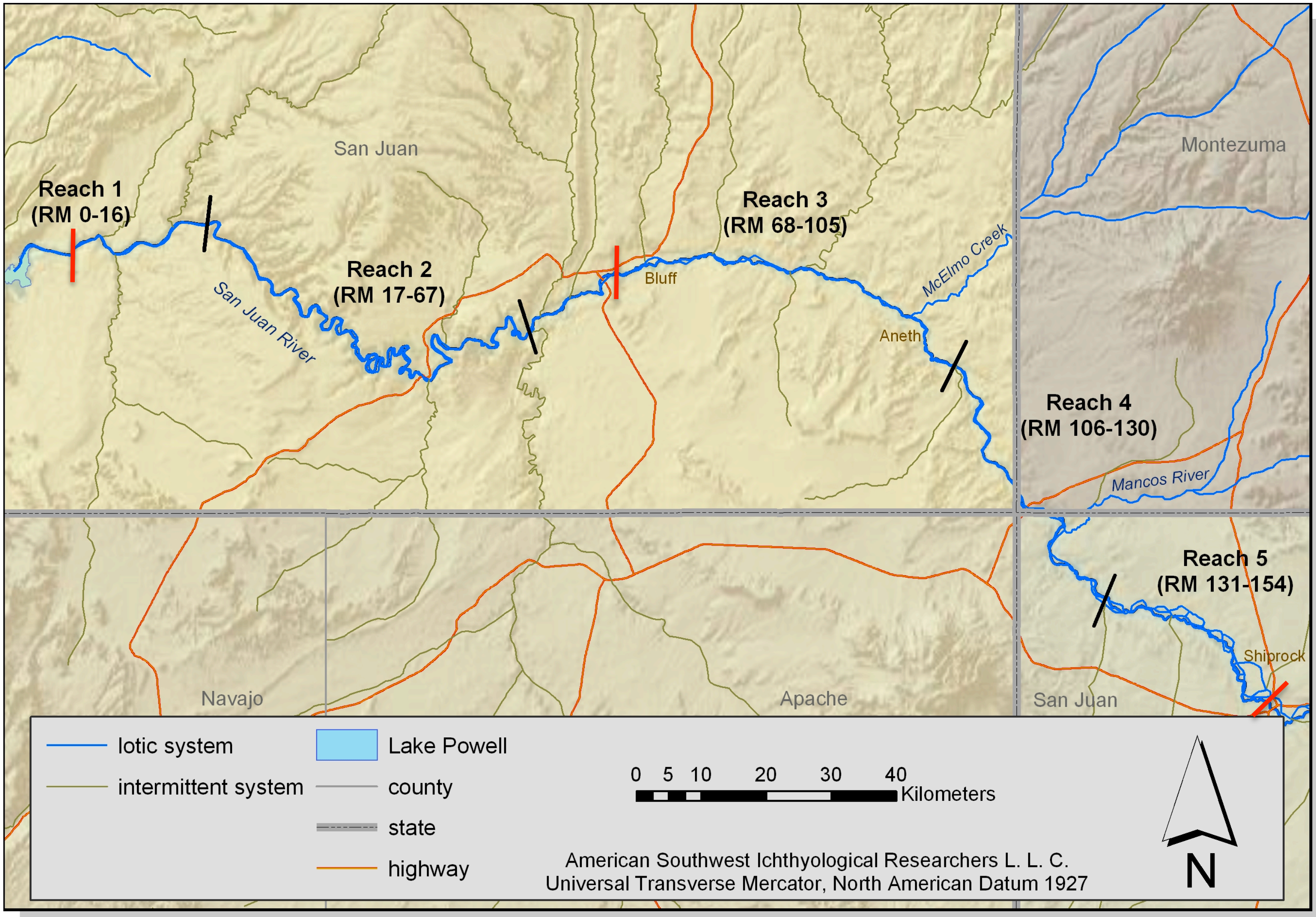


Figure 1. Map of the 2013 study area. Red bars denote upper (Shiprock, NM), middle (Sand Island, UT) and lower (Clay Hills, UT) boundaries.

Collecting efforts for larval fishes were concentrated in low velocity habitats using a fine mesh larval fish seine (1 m x 1 m x 0.8 mm). Several seine hauls (between two and six) were made through an individual mesohabitat depending on the size of that habitat. Beginning in 2013, fishes collected within an individual mesohabitat were preserved by individual seine haul (as opposed to all fish preserved as a single sample). For each site sampled, the length (in meters) of each seine haul was determined in addition to the number of seine hauls per site. Mesohabitat type, length, maximum and minimum depth, substrate, and turbidity (using a Secchi disk) were recorded in the field data sheet for the particular collecting site (Figure A-1). Water quality measurements (dissolved oxygen, conductivity, specific conductance, pH, salinity, and temperature) were also obtained using a multiparameter water quality meter. Habitat designations used in this report were developed for the San Juan River Basin Recovery Implementation Program's (SJRBRIP) monitoring projects (Bliesner et al., 2008). A minimum of one digital photograph was recorded at each collection site.

River mile was determined to the nearest tenth of a mile using the 2009 standardized aerial maps produced for the SJRBRIP and used to designate the location of collecting sites. In addition, geographic coordinates were determined at each site with a Garmin Geographic Positioning System (GPS) unit and were recorded in Universal Transverse Mercator (UTM) Zone 12 (NAD27). In instances where coordinates could not be obtained due to poor GPS satellite signal, coordinates were determined in the laboratory using a Geographic Information System based on the recorded river mile.

Beginning in 2011, ASIR researchers defined 20 monitoring sites throughout the study area in an attempt to assess persistence of backwaters habitats. All but three sites were geomorphically similar and were characterized as lateral washes or canyons which form backwaters during increased river discharge. In 2012 the three monitoring sites not located in lateral washes or canyons were excluded from analysis. In addition, two sites designated in Reach 5 were also excluded because one was fed by irrigation return water and the other was inaccessible at most discharge levels (Table A-3). Because these sites do not have perennial flow, the only habitat types encountered were either backwaters, or, after river levels have subsided, isolated pools. Due to a change in the physical characteristics, the site at river mile 24.5 (John's Canyon) was removed from the monitoring site list in 2013. Scour at the mouth of the site has led to the formation of a pool or eddy type habitat, depending on discharge; there was no backwater type habitat encountered in 2013. The 14 remaining monitoring sites were visited in each monthly survey. If suitable nursery habitats had formed in them at the time of visitation they were sampled. If they were dry or isolated, photographs were taken and field notes written detailing condition of the habitat. Conditions of monitoring sites were then related back to discharge at time of visitation.

Each of the six River Ecosystem Restoration Initiative (RERI) sites located between river miles 132.2 and 127.2 were also the subject of repeated monthly monitoring. Unlike the monitoring sites, these areas were only sampled if suitable nursery habitat was available. The goal of these collections was to detect the presence of fishes, regardless of age class. If a site could not be effectively sampled (either because of depth, or high water velocity), photos were taken and no collection made.

All retained specimens were placed in plastic bags (Whirl-Paks) containing a solution of 95% ethyl alcohol and a tag inscribed with unique a alpha-numeric code that was also recorded on the field data sheet. Samples were returned to the laboratory where they were sorted and identified to species. Specimens were identified by personnel with expertise in San Juan River Basin larval fish identification. Stereo-microscopes with transmitted light bases and polarized light filters were used to aid in identification of larval individuals. Age-0 specimens were separated from age-1+ specimens using published literature that define growth and development rates for individual species (Auer, 1982; Snyder, 1981; Snyder and Muth, 2004).

Both age classes were enumerated, measured (minimum and maximum size [mm standard length] for each species at each site), and cataloged in the Museum of Southwestern Biology (MSB), Division of Fishes at the University of New Mexico (UNM).

Results reported in this document pertain primarily to age-0 fishes. Raw numbers of age-1+ and age-0 fishes are presented in Appendix A (Tables A-4 and A-5). Scientific and common names of fishes used in this report follow Page et al. (2013) and six letter codes for species are those adopted by the San Juan River Basin Biology Committee (Table A-6). Total length (TL) and standard length (SL) were measured on all Colorado Pikeminnow and Razorback Sucker to be consistent with information gathered by the San Juan River Basin and Upper Colorado River Basin programs (Tables A-4 and A-5). Within this report, lengths of these species are given as TL.

The term young-of-year (YOY) can include both larval and juvenile fishes. It refers to any fish, regardless of developmental stage, between hatching or parturition and the date (1 January) that they reach age 1 (i.e., YOY = age-0 fish). Larval fish is a specific developmental (morphogenetic) period between the time of hatching and when larval fish transform to juvenile stage. The larval fish terminology used in this report is defined by Snyder (1981). There are three distinct sequential larval developmental stages: protolarva, mesolarva, and metalarva. Fishes in any of these developmental stages are referred to as larvae or larval fishes. Juvenile fishes are those that have progressed beyond the metalarva stage and no longer retain traits characteristic of larval fishes. Juveniles were classified as individuals that 1) had completely absorbed their fin folds, and 2) had developed the full adult complement of rays and spines.

Only larval specimens (protolarva, mesolarva, and metalarva) were used to generate the larval occurrence graph. The period of larval occurrence was determined by recording the first collection of larval fish within a given year for each species as the initial occurrence. The cessation of larval occurrence was developed using the mean standard length of transformation from metalarva to juvenile as a cut off (Snyder, 1981; Snyder and Muth, 2004).

Modeling ecological data with multiple zeros can be particularly effective when using mixture models (e.g., combining a binomial distribution with a lognormal distribution) to estimate occurrence and abundance separately (White, 1978; Welsh et al., 1996; Fletcher et al., 2005; Martin et al., 2005). Long-term Razorback Sucker (1999–2013) and Colorado Pikeminnow (2003–2013) sampling-site density data were analyzed using a mixture model in PROC NLMIXED (SAS, 2014), a numerical optimization procedure, following the methods outlined in White (1978). Logistic regression was used to model the probability a site was occupied, and the lognormal model was used to model the distribution of abundance given that the site was occupied. Models provided estimates of Delta (δ = probability of occurrence), Mu (μ = mean of the lognormal distribution), Sigma (σ = standard deviation of the lognormal distribution), and $E(x)$ (estimated density of fish).

General linear models were used to incorporate covariates to model d, m, and s. Covariates considered to model annual sampling-site density data for both Razorback Sucker (1999–2013) and Colorado Pikeminnow (2003–2013) were year, reach, and habitat. Isolated pool habitats were excluded from analysis since fish densities in confined habitats were not comparable to densities in freely accessible habitats. Similarly, habitats that were dry or not sampled were excluded from further analysis. Also, one habitat type (combined) was added to account for instances where multiple habitats were sampled but where fish were combined into a single collection. There were a total of five sampling reaches included in the analysis along with ten habitat types (backwater [BW], combined [CO], cobble shoal [CS], eddy [ED], embayment [EM], pool [PO], pocketwater [PW], run [RU], sand shoal [SS], and slackwater [SW]). To facilitate a valid comparison among years and minimize excessive zeros in the model, months that produced a negligible number of specimens (< 1% of the total) were excluded from further analysis. The months considered for age-0 Razorback Sucker occurred earlier in the year (May and June) compared with the months considered for age-0 Colorado Pikeminnow (July and August). In contrast, stocked age-1+ Colorado Pikeminnow occurred throughout the typical sampling season (April–August) and so those months were included in the analysis for that life stage. Fixed effects models for each covariate were linear models ($b_0 + b_1 \times$ covariate) with the corresponding link function. These fixed effects assume that variation in the data is explained by the covariate. That is, for δ, there is no over-dispersion or extra-binomial variation, and for μ, no extra variation provided beyond the constant σ model. Random effects models were also considered for δ and μ to provide additional variation around the fitted line where a normally distributed random error with mean zero and non-zero standard deviation is used to explain deviations around the fitted covariate. Adaptive Gaussian quadrature as described in Pinheiro and Bates (1995) was used to integrate out these random effects in fitting the model.

The relative fit of data to various models was assessed using goodness-of-fit statistics (logLike = -2[log-likelihood] and AIC_C = Akaike's Information Criterion [Akaike, 1973; Burnham and Anderson, 2002] for finite sample sizes). Lower values of AIC_C indicate a better fit of the data to the model. Models were ranked by AIC_C values and included AIC_C weight (w_i). Differences among null and alternative models were assessed using a log-likelihood ratio goodness-of-fit test (Zar, 2010).

Additional samples were taken in 2013 to increase the overall sample size and provide additional information on specific habitat features (i.e., habitat location and cover type). Four categories were assigned to habitat depending on where the sample was taken. Shoreline (SH) indicated all samples taken along the land-water interface, open-water (OP) indicated samples taken away from the shoreline, and mouth (MO) or terminus (TR) indicated samples taken from those locations within a backwater or embayment. Three categories were assigned to habitat depending on the type of cover encountered. Type 1 indicated the presence of inundated vegetation, type 2 indicated the presence of submerged woody debris, and type 3 indicated the presence of overhead cover (i.e., shade).

Habitat-specific density data (i.e., using information on habitat location and cover type) have only been available since 2013. These data provide information on the specific habitat features used by Razorback Sucker and Colorado Pikeminnow and may eventually allow for more precise estimates of annual population trends. Habitat-specific density data were also analyzed using PROC NLMIXED (SAS, 2014), using the same methods outlined previously, to generate larval fish density estimates ($E(x)$). As there were not enough data to provide robust estimates of density among habitats for age-0 Colorado Pikeminnow, this age-class was not included in the analysis. No analyses were conducted for age-1+ Colorado Pikeminnow since the specific habitat preferences of recently stocked individuals was not a primary research concern. For Razorback Sucker, a simplified list of habitats (BW, EM, PO, SS, and SW) was used for the purpose of statistical analysis since some habitats (CS, PW, and RU) contained very few data and other habitats were not sampled (CO and ED). General linear models were used to incorporate covariates to model d, m, and s. Covariates considered to model habitat-specific density data were reach, habitat, habitat location, and cover type. Goodness-of-fit statistics (logLike and AIC_C) were generated to assess the relative fit of data to various models and differences among models (i.e. p-values) were assessed using a log-likelihood ratio goodness-of-fit test.

For species other than Colorado Pikeminnow and Razorback Sucker, differences in mean CPUE were determined by species among years, trips, and reaches using a one-way Analysis of Variance (ANOVA). Samples collected in isolated pools were not included in yearly or between year trend analysis. A variety of transformations (e.g., logarithmic, reciprocal, square root) were applied to the mean CPUE data for between year comparisons. A natural log-transformation yielded the best variance-stabilizing qualities and produced a relatively normal distribution. Pair-wise comparisons between years (2003 – 2013), trips and reaches were made for each species and significance (i.e., $p < 0.05$) was determined using the Tukey-Kramer HSD test. Finally, a nonparametric Analysis of Variance (Kruskal–Wallis test) was run for the various data sets to compare results to the parametric analysis.

Although both ANOVA and Kruskal-Wallis were used to analyze data, data transformations enabled use of parametric analysis in all cases. The assumption of homogeneity of variances was assessed using the more conservative variance ratio criterion of <3:1 (Box, 1954), as opposed to <4:1 (Moore, 1995), among years. All species data sets met this more rigorous criterion and in most cases the variance ratio was <2:1 among years. Additionally, the significance values between parametric and nonparametric techniques were nearly identical and so only the parametric analysis are presented.

Hatching dates were calculated for larval Colorado Pikeminnow using the formula: $-76.7105+17.4949(L)-1.0555(L)^2+0.0221(L)^3$ for larvae under 22 mm TL, where L = length (mm TL). For specimens 22 - 47mm TL the formula A= -26.6421+2.7798L is used. Spawning dates were then calculated by adding five days to the post-hatch ages to account for incubation time at 20 – 22°C (Nesler et al., 1988). Hatch dates of razorback sucker larvae were calculated by subtracting the average length of larvae at hatching (8.0 mm TL) from the total length at capture divided by 0.3 mm (Bestgen et al., 2002), which was the average daily growth rate of wild larvae observed by Muth et al. (1998) in the Green River UT. The back-calculated hatching formula was only applied to proto- and mesolarvae as growth rates become much more variable at later developmental stages (Bestgen, 2008).

This study was initiated prior to spring runoff and completed in the middle of the summer season (early August). Daily mean discharge during the study period was acquired from U.S. Geological Survey Gages near Four Corners, CO (#09371010) and near Bluff, UT (#09379500). Near Bluff discharge and temperature were used for all data analysis in this report except for back-calculated spawning dates of Colorado Pikeminnow in which Four Corners discharge and temperature were used. Temperature data (mean, max, min) were taken at the state highway 160 bridge crossing in Colorado (river mile 119.2) and near Bluff, UT (river mile 52.0).

Results

2013 Summary

The 2013 San Juan River larval fish survey encompassed a five-month period from 15 April to 2 August 2013. Five trips were conducted from river mile 147.9 (Shiprock, New Mexico) to river mile 2.9 (Clay Hills Crossing, Utah). During the study period, mean daily discharge and water temperature were 791 cfs (309–2,190 cfs) and 21.6 °C (10.3–27.1°C). There were no large Spring releases out of Navajo Dam in 2013 and discharge in the San Juan River rarely exceeded 1,000 cfs during the study period (Figure 2). Fluctuations in discharge in the San Juan River during the study period were a result of spring runoff in the Animas River and North American Monsoonal driven rain events. Spring runoff in the Animas River was minimal and only exceeded 2,000 cfs for a single day (18 May 2013; USGS gage 09364500). Discharge exceeded 15,000 cfs during the study period due to rain events (16 July 2013, USGS gage 09379500). Overall, the 2013 San Juan River water year was the second lowest ever recorded.

During the 2013 larval fish survey, 292 collections were made in zero and low velocity habitats encompassing an area of 9,750 m^2. Collections resulted in the capture of 25,842 age-0 and age-1+ fishes representing six families and 14 species (Tables A-4 and A-5). Age-0 fish were collected in each of the five surveys (April–August) and accounted for 97.2% of the overall catch (n=25,127).

The rain events encountered during the July survey (16 July 2013) caused a significant flash flood below Mexican Hat, Utah. Researchers camped below Mexican Hat during this event had the river run through camp which resulted in the loss of the samples and all sampling gear. Therefore, there is no age-0 capture data for the lower section of the study area for this month.

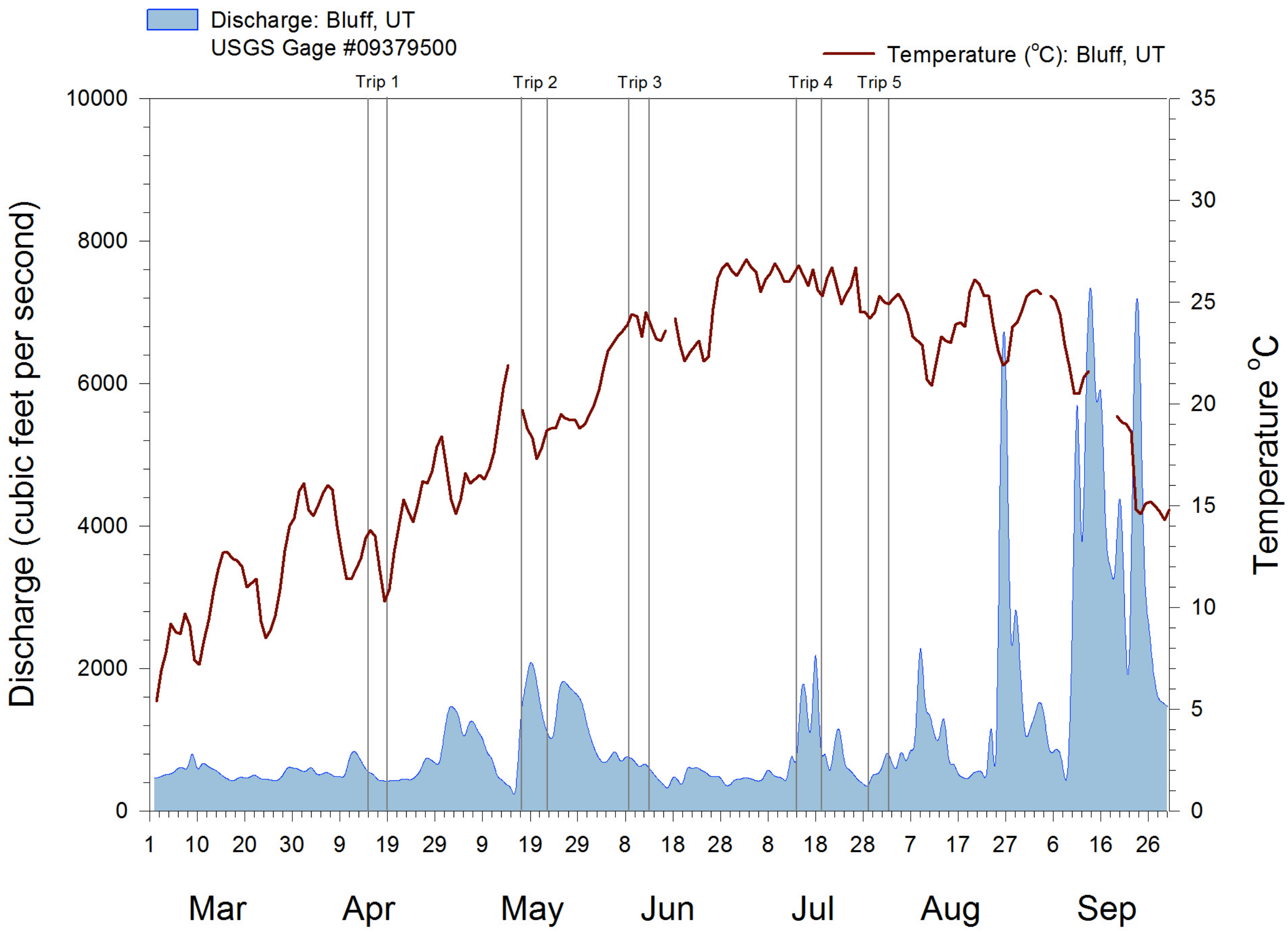


Figure 2. Discharge (cfs) and temperature (°C) in the San Juan River during the 2013 sampling period. Grey vertical bars denote individual collecting trips.

Endangered Species

Colorado Pikeminnow

Summary

There were 12 larval Colorado pikeminnow collected in 2013 between river miles 107.6 and 10.0. Spawning by Colorado Pikeminnow has been documented in six of the last 12 years in the San Juan River. Colorado Pikeminnow were collected during the July and August surveys at seven discrete localities (Figure 3). Colorado Pikeminnow ranged in size from 14.1 to 28.7 mm TL and all specimens were either metalarvae or juveniles (Table A-7). Back-calculated spawning dates encompassed a six week period between 23 May and 3 July 2013 (Figure 4). Mean temperature and discharge during this period were 21.3 °C (16.5–25.2 °C) and 832 cfs (449–1,790 cfs). A total of 48 age-1+ Colorado Pikeminnow were also collected in 2013. It is assumed these fish were the results of stocking efforts.

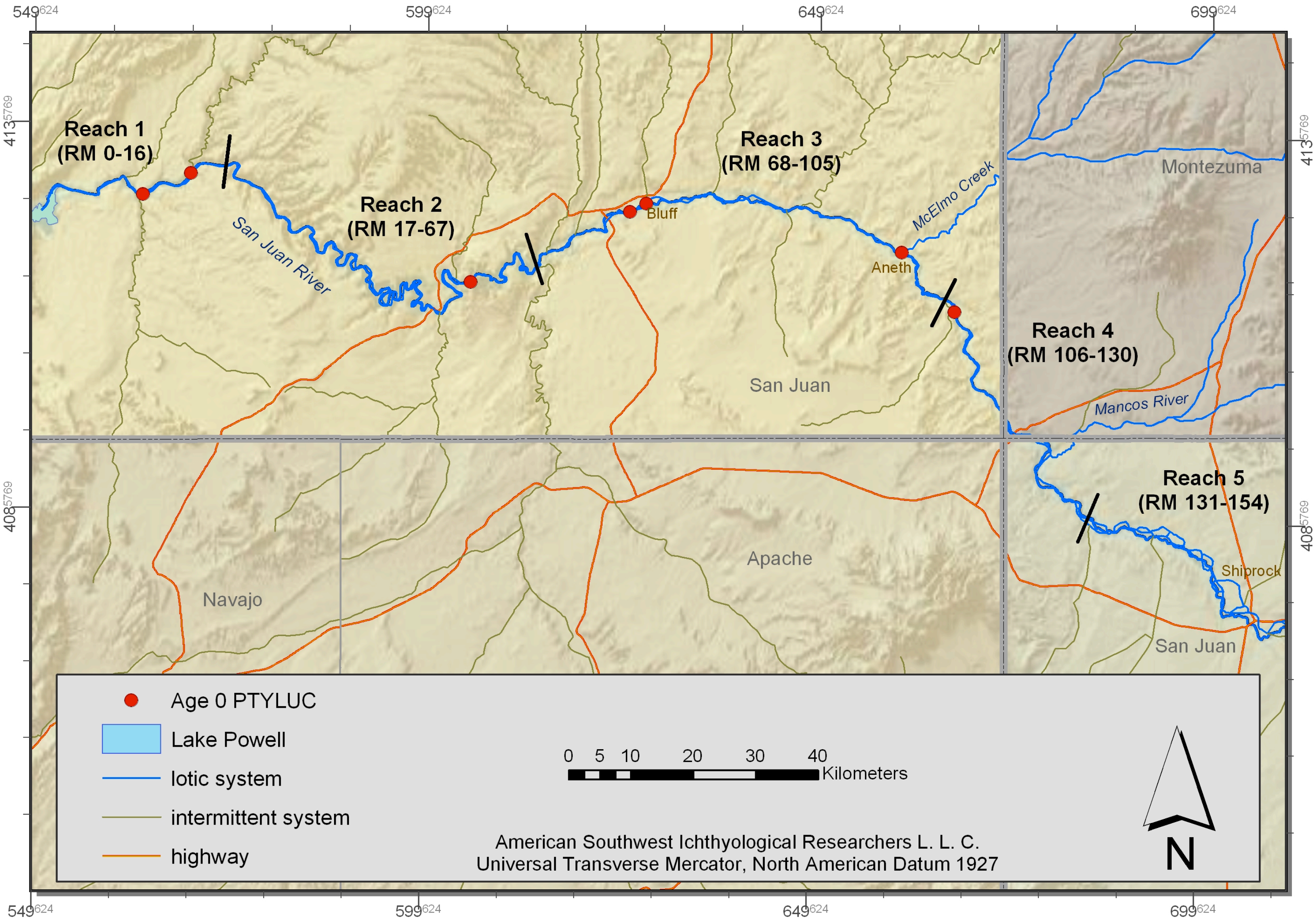


Figure 3. Map of the 2013 age-0 Colorado Pikeminnow collection localities.

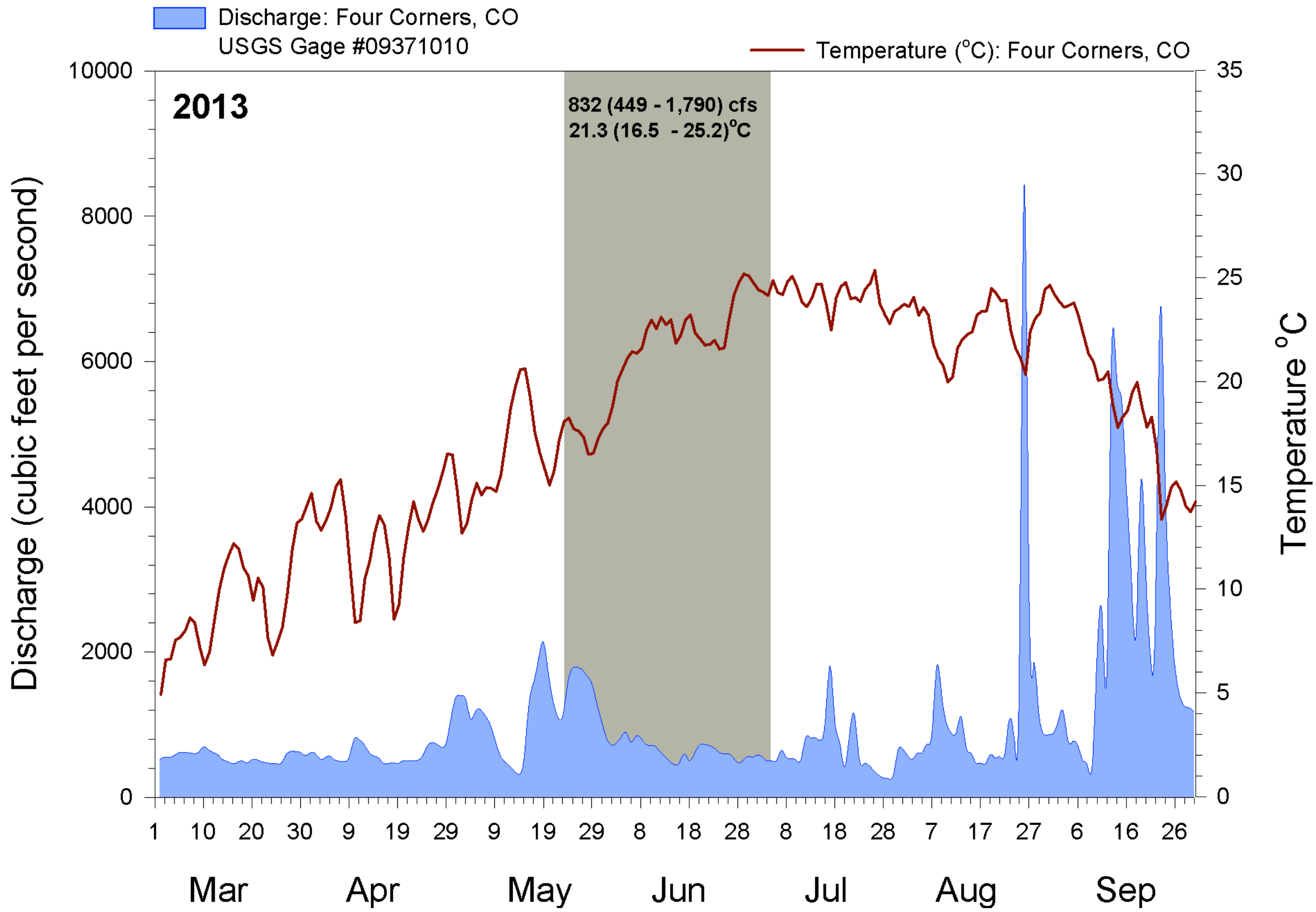


Figure 4. Back-calculated hatching dates for Colorado Pikeminnow plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported.

Colorado Pikeminnow (age-0)

Sampling-site density data

The analysis of Colorado Pikeminnow (age-0) sampling-site density data, using general linear models based on mixture-model estimates (Delta (δ) and Mu (μ)), showed that the global model (δ(Year) μ(Year)) received essentially all of the AIC_C weight despite having the most parameters (Table 1). This model was significantly different ($P < 0.001$) from the null model (δ(.) μ(.)). The habitat model (δ(Habitat) μ(Habitat)) also differed significantly ($P < 0.01$) from the null model but the reach model (δ(Reach) μ(Reach)) did not ($P = 0.07$). Estimates of μ indicated a significantly higher ($P < 0.05$) abundance of Colorado Pikeminnow in 2013 as compared to either 2004 or 2007; there were no significant differences in estimates of δ over time (Figure 5). The estimated densities ($E(x)$) of age-0 Colorado Pikeminnow, using sampling-site density data (2003–2013), were highest in 2011 (0.72) and 2013 (0.35) and lowest in 2004 and 2007 (0.05).

The estimated densities of Colorado Pikeminnow did not differ significantly ($P > 0.05$) among any of the years (Figure 6). Estimated density, with 95% confidence intervals, could not be computed in 2009 since there was only a single non-zero value recorded out of 126 sampling sites, which precluded mixture-model estimation of σ. Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities ($E(x)$) over time. Estimates of log-transformed densities followed a similar pattern over time as compared with density estimates generated using the method of moments and the mixture model approach, with the exception of 2013. Inferences based on mixture-model vs. log-transformed estimates were similar, but the log-transformed method indicated that 2009 (based on a single non-zero data point) was significantly lower ($P < 0.05$) compared with 2013.

Colorado Pikeminnow (age-1+)

Sampling-site density data

General linear models based on mixture-model estimates (Delta (δ) and Mu (μ)) of Colorado Pikeminnow (age-1+) sampling-site density data, showed that the habitat model (δ(Habitat) μ(Habitat)) received essentially all of the AIC_C weight (Table 2). This model was significantly different ($P < 0.001$) from the null model (δ(.) μ(.)). The other eight candidate models also differed significantly ($P < 0.001$) from the null model. All of the δ-only models had lower AIC_C values as compared to the μ-only models (e.g., δ(Year) μ(.) vs. δ(.) μ(Year)), which indicated that δ was explaining most of the variation in the combined models (e.g., δ(Year) μ(Year)). Estimates of δ and μ illustrated the differences among years for both the occurrence and abundance of Colorado Pikeminnow, respectively (Figure 7). While estimates of δ were quite different among years (i.e., many pair-wise significant differences based on non-overlapping confidence intervals), estimates of μ were more similar over time and had broader confidence intervals.

The estimated densities ($E(x)$) of age-1+ Colorado Pikeminnow, using sampling-site density data (2003–2013), were highest in 2012 (2.04) and lowest in 2011 (0.23). The estimated densities of Colorado Pikeminnow differed significantly ($P > 0.05$) among several years, with 2006, 2011, and 2013 being years with lower densities (Figure 8). Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities ($E(x)$) over time. Estimates of log-transformed densities followed a generally similar pattern over time as compared with density estimates generated using the method of moments and the mixture model approach. However, the relative precision of estimates was lower when using log-transformed densities as opposed to densities derived from the mixture model. Also, inferences based on mixture-model vs. log-transformed estimates were notably different in some cases (e.g., significant decrease from 2012 to 2013 based on mixture-model estimates but no difference based on log-transformed estimates).

Table 1. General linear models of Colorado Pikeminnow (age-0) mixture-model estimates (Delta (δ) and Mu (μ)), using sampling-site density data (2003–2013) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[1]	K[2]	logLike[3]	AIC_C	w_i
δ(Year) μ(Year)	33	146.57	214.25	0.973
δ(.) μ(Year)	23	175.39	222.20	0.018
δ(Year) μ(.)	12	197.64	223.90	0.008
δ(.) μ(Habitat)	21	188.06	230.74	<0.001
δ(Reach) μ(.)	6	218.37	232.45	<0.001
δ(.) μ(.)	3	226.45	232.47	<0.001
δ(.) μ(Reach)	11	214.44	236.64	<0.001
δ(Reach) μ(Reach)	15	206.36	236.71	<0.001
δ(Habitat) μ(Habitat)	30	176.20	237.59	<0.001
δ(Habitat) μ(.)	12	214.59	238.82	<0.001

[1] = Model variables included year (2003–2013), reach (n = five reaches), and mesohabitat (habitat = BW, CO, CS, ED, EM, PO, PW, RU, SS, and SW)
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model

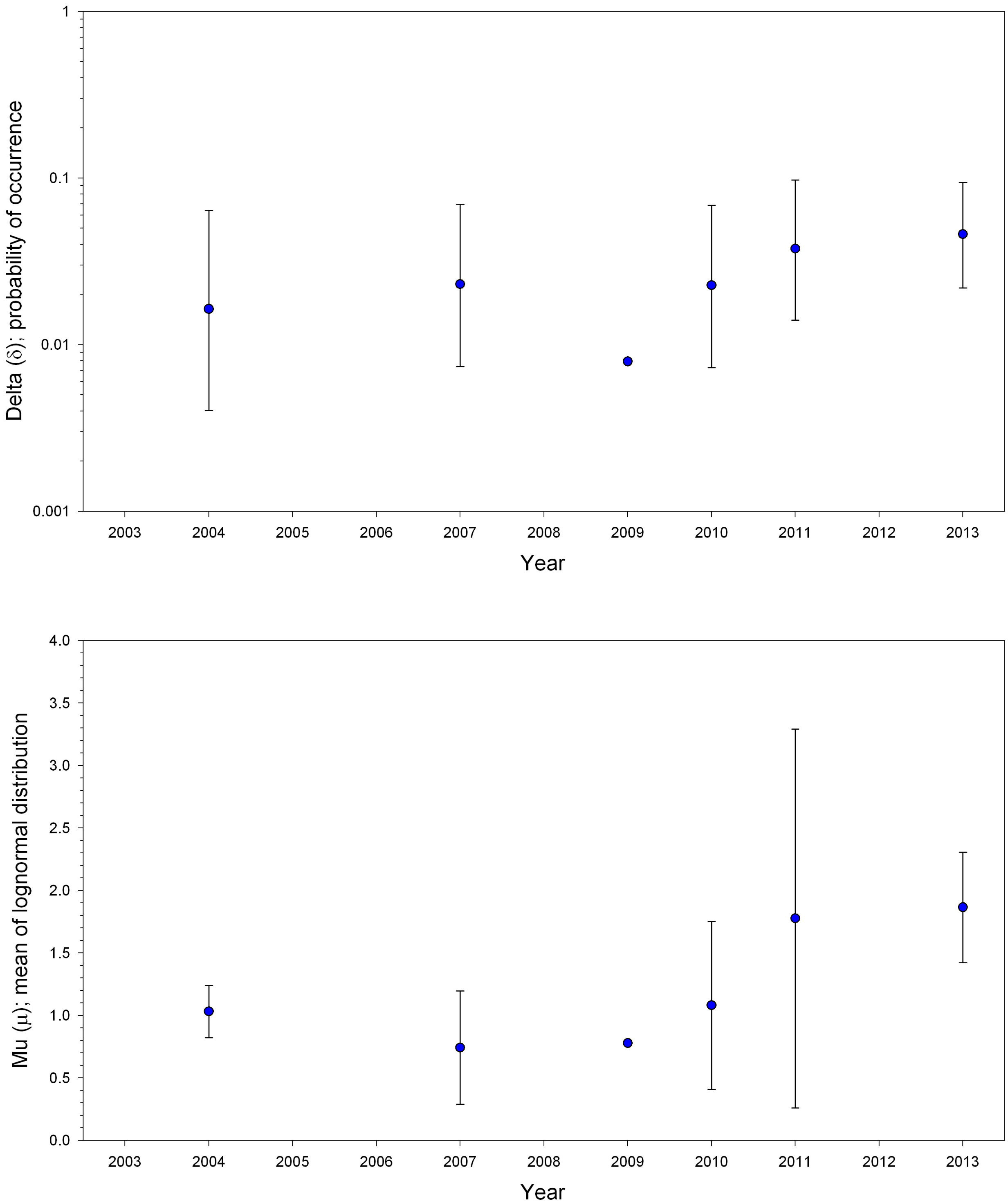


Figure 5. Colorado Pikeminnow (age-0) mixture-model estimates (δ and μ), using sampling-site density data (2003–2013). Delta estimates shown on log-scale because of extremely low values. Solid circles indicate estimates and bars represent 95% confidence intervals.

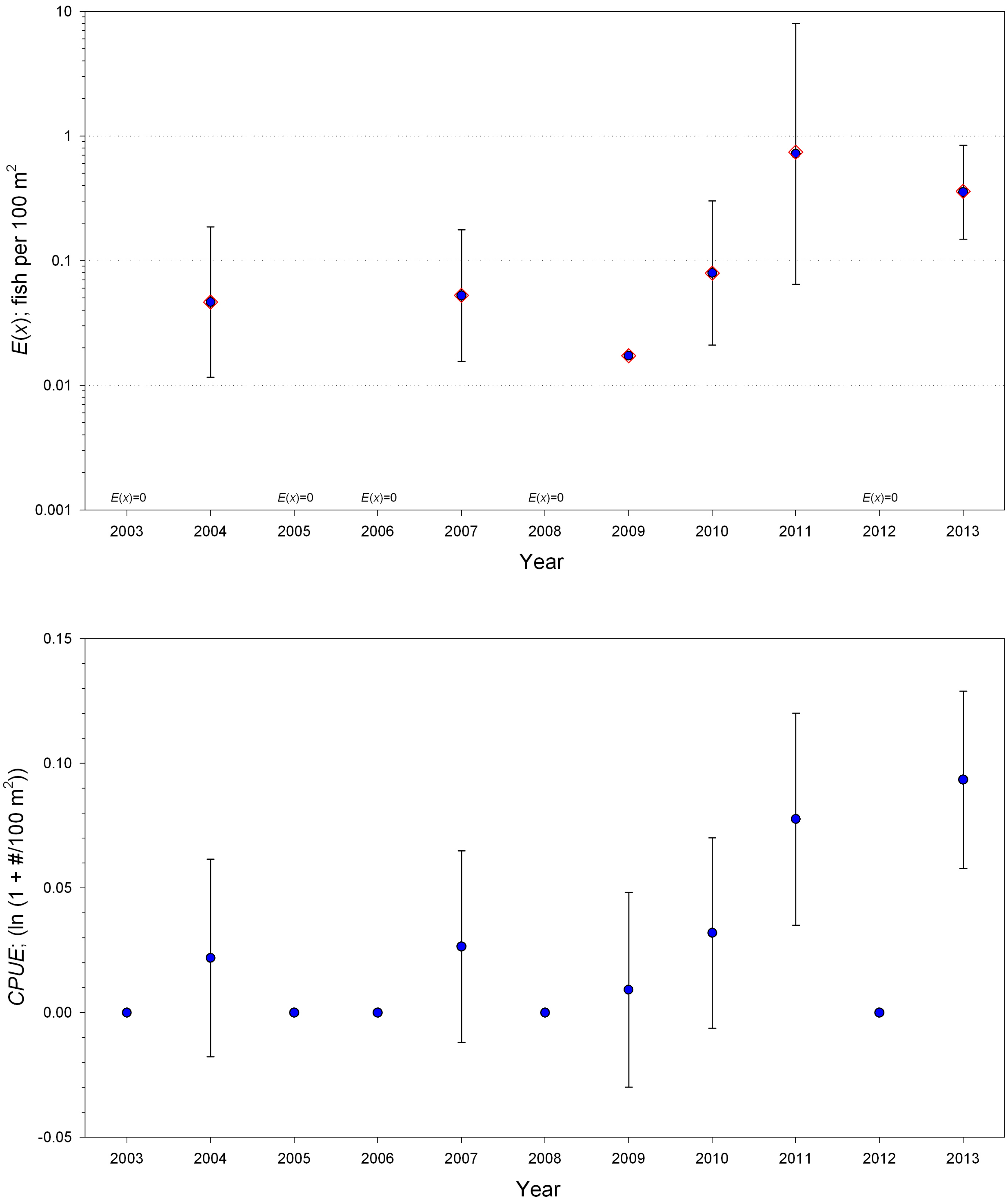


Figure 6. Colorado Pikeminnow (age-0) mixture-model estimates (*E*(*x*)) and log-transformed estimates (*CPUE*), using sampling-site density data (2003–2013). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 2. General linear models of Colorado Pikeminnow (age-1+) mixture-model estimates (Delta (δ) and Mu (μ)), using sampling-site density data (2003–2013) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[1]	K[2]	logLike[3]	AIC_C	w_i
δ(Habitat) μ(Habitat)	30	2,776.35	2,838.95	0.999
δ(Year) μ(Year)	33	2,786.04	2,852.73	0.001
δ(Year) μ(.)	12	2,831.72	2,857.83	<0.001
δ(Habitat) μ(.)	12	2,845.81	2,869.90	<0.001
δ(Reach) μ(Reach)	11	2,853.38	2,883.53	<0.001
δ(Reach) μ(.)	6	2,876.74	2,890.78	<0.001
δ(.) μ(Habitat)	21	2,849.96	2,894.27	<0.001
δ(.) μ(Reach)	11	2,896.06	2,918.14	<0.001
δ(.) μ(Year)	23	2,873.75	2,920.08	<0.001
δ(.) μ(.)	3	2,919.43	2,925.43	<0.001

[1] = Model variables included year (2003–2013), reach (n = five reaches), and mesohabitat (habitat = BW, CO, CS, ED, EM, PO, PW, RU, SS, and SW)
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model

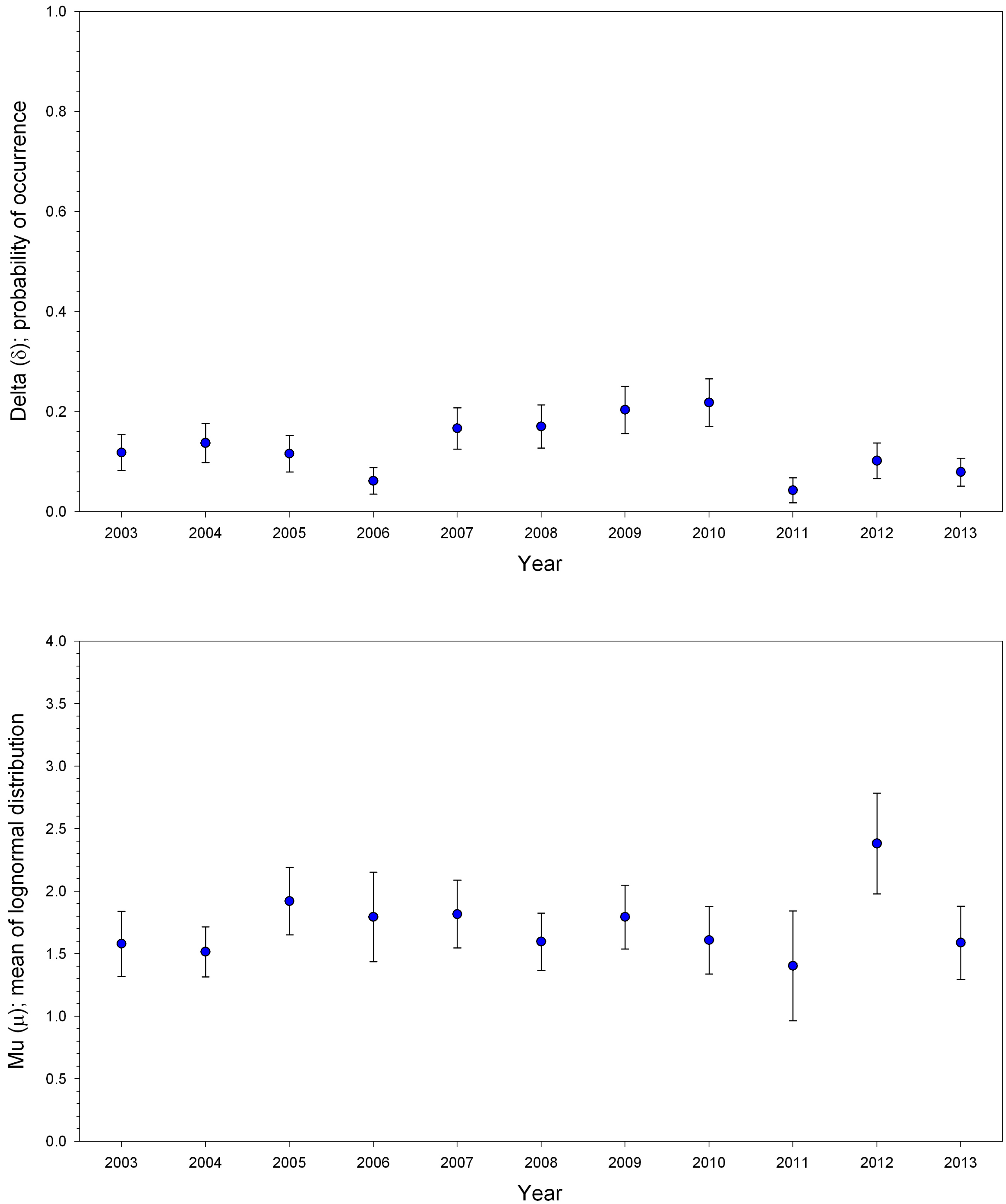


Figure 7. Colorado Pikeminnow (age-1+) mixture-model estimates (δ and μ), using sampling-site density data (2003–2013). Solid circles indicate estimates and bars represent 95% confidence intervals.

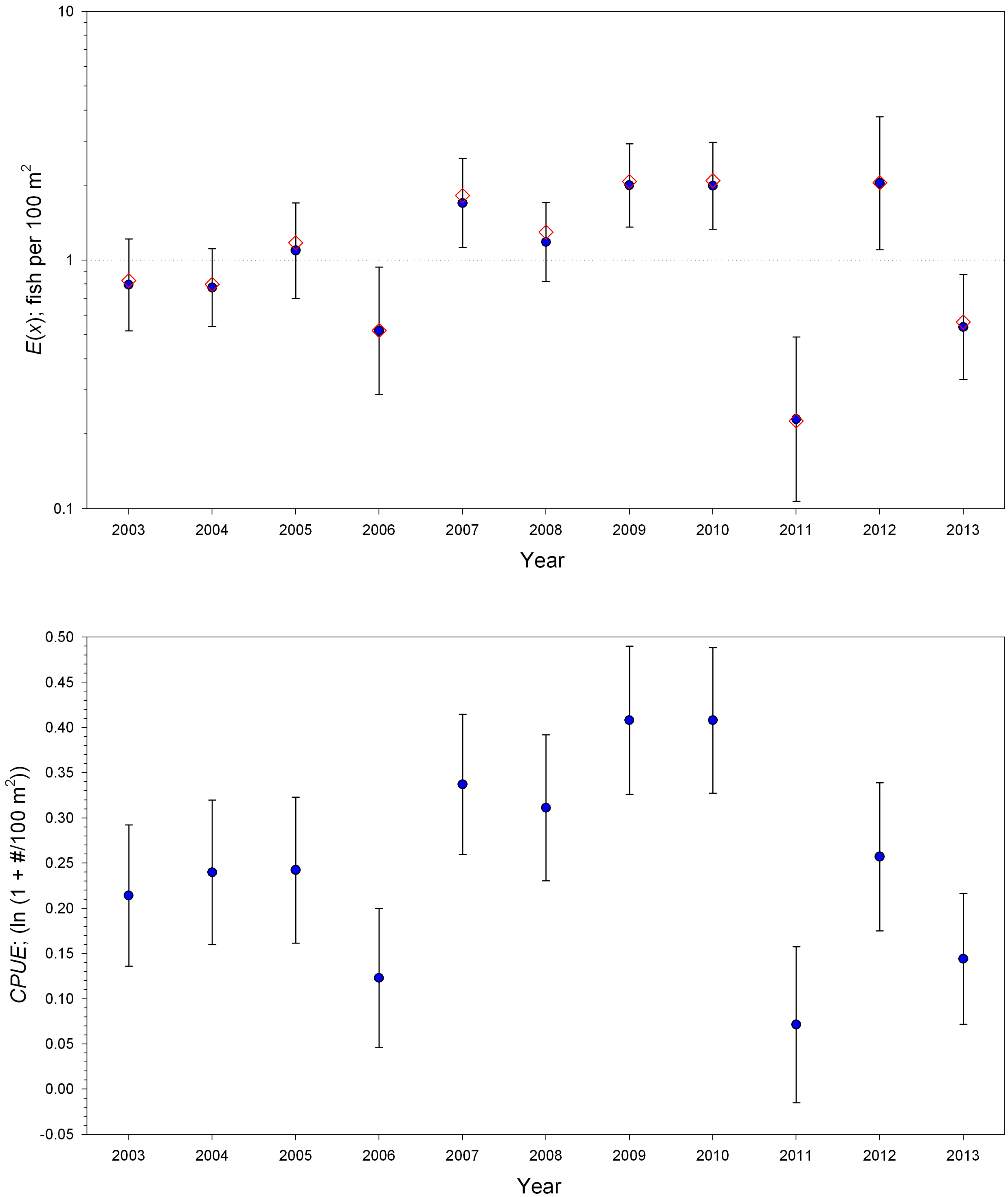


Figure 8. Colorado Pikeminnow (age-1+) mixture-model estimates ($E(x)$) and log-transformed estimates (*CPUE*), using sampling-site density data (2003–2013). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Razorback Sucker (age-0)

Summary

For the sixteenth consecutive year, spawning by Razorback Sucker was documented in the San Juan River. Age-0 Razorback Sucker were collected in three consecutive months (May – July) and included all ontogenic stages from protolarvae to juveniles (size range= 9.5–70.0 mm TL [Figure 9, Table A-8]). Razorback sucker were collected throughout the study area and were present in 91 of the 292 collections (Figure 10). The upstream distribution of larval Razorback Sucker continues to increase. During 2013, larvae were collected 3.6 miles (rivermile 147.5) farther upstream than any previous survey year. Back-calculated hatching dates were from 10 April to 7 June 2013 (Figure 11). Mean temperature and discharge during this period were 17.0 ^{o}C (range= 10.3–23.6) and 931 cfs (range= 309–2,080).

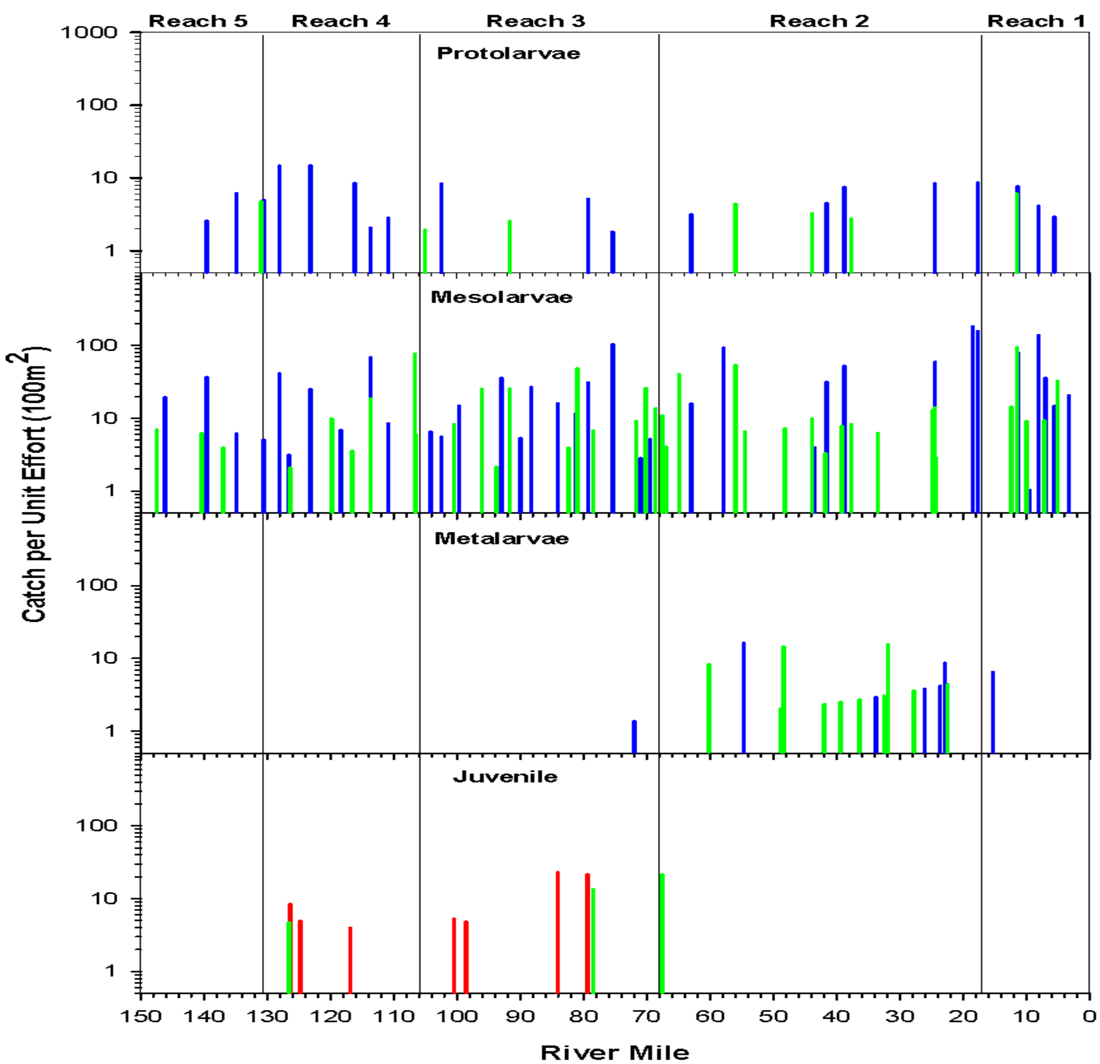


Figure 9. Catch per unit effort /100 m^2 of discrete ontogenic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of razorback sucker by sample locality during the 2013 survey. Blue bars represent May collections, green bars June collections and red bars July collections.

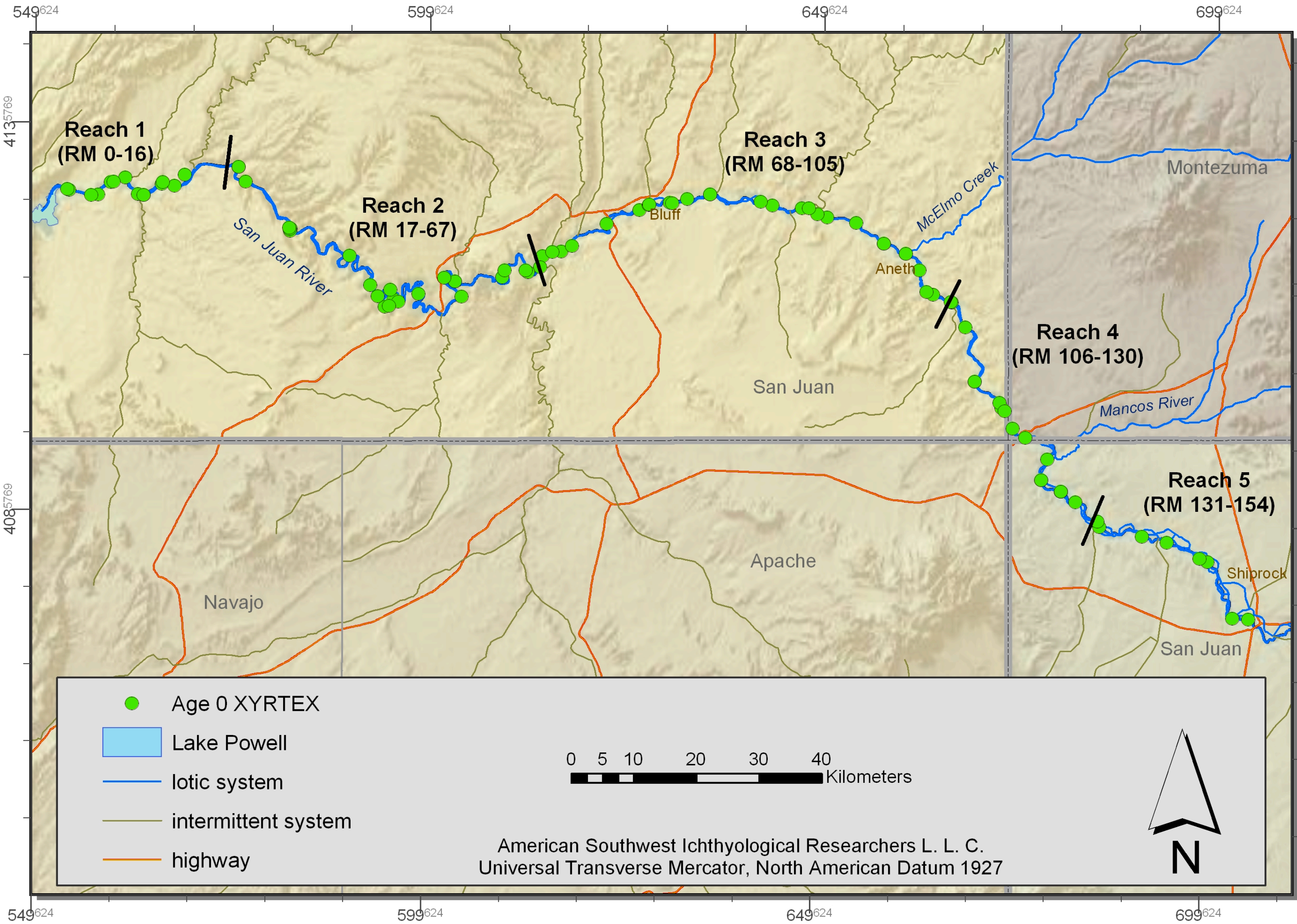


Figure 10. Map of the 2013 age-0 Razorback Sucker collection localities.

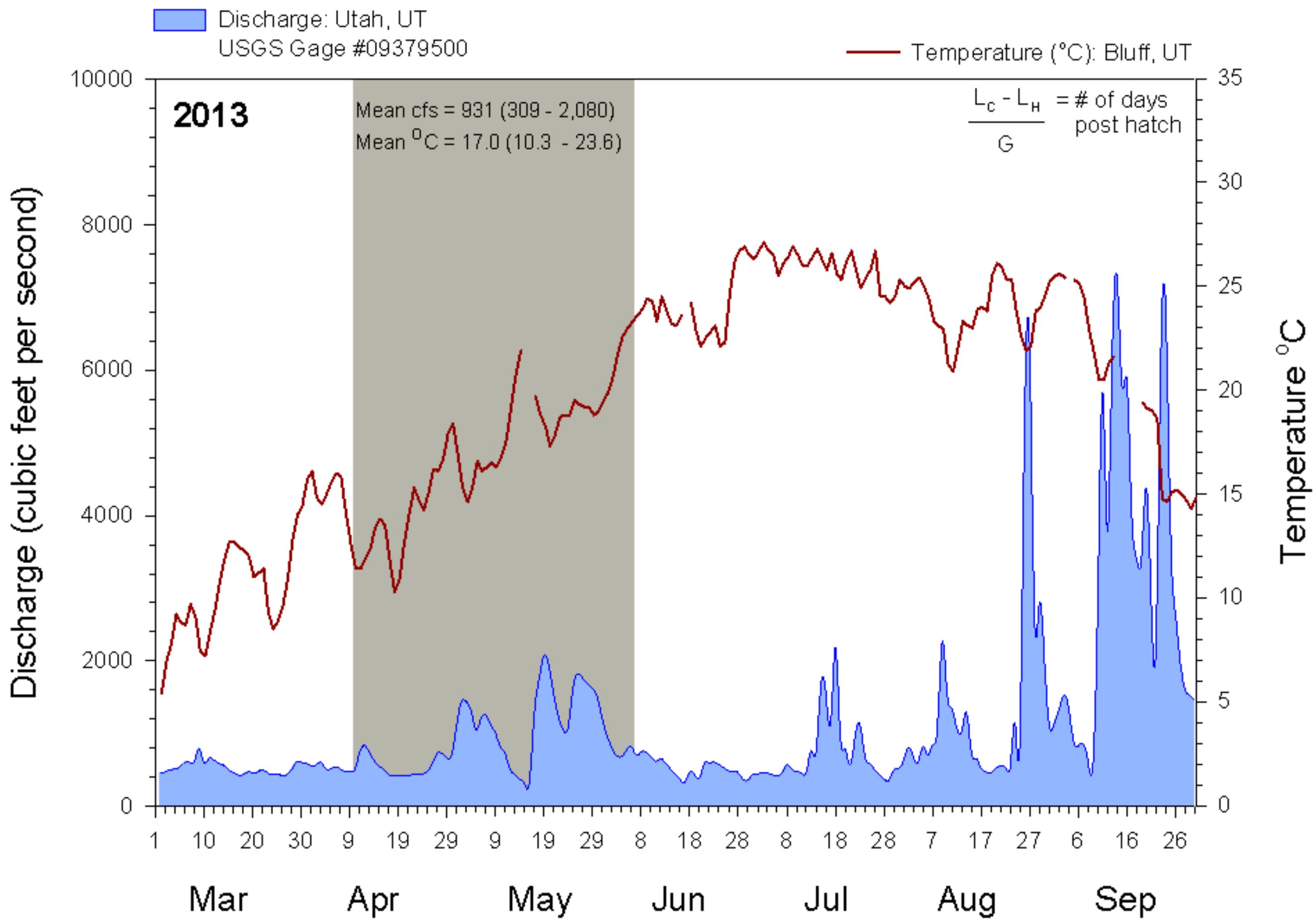


Figure 11. Back-calculated hatching dates for Razorback Sucker plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported.

Sampling-site density data

General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the global model (δ(Year) μ(Year)) received essentially all of the AIC_C weight (w_i) despite having the most parameters (Table 3). This model was significantly different ($P < 0.001$) from the null model (δ(.) μ(.)). The other nine models also differed significantly ($P < 0.01$) from the null model with the simplified reach model (δ(.) μ(Reach)) receiving the lowest w_i value. All of the δ-only models had lower AIC_C values as compared to the μ-only models (e.g., δ(Year) μ(.) vs. δ(.) μ(Year)), indicating that δ was explaining most of the variation in the combined models (e.g., δ(Year) μ(Year)). This relationship was clearly illustrated for the global model by plotting estimates of both δ and μ over time (Figure 12). While estimates of δ were quite different among years (i.e., many pair-wise significant differences based on non-overlapping confidence intervals), estimates of μ were more similar over time and had broader confidence intervals.

Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2013), were highest in 2011 (24.19) and 2013 (18.53) and lowest in 1999 (0.23) and 2005 (0.32). The estimated densities of Razorback Sucker were significantly higher ($P < 0.05$) in 2011–2013 as compared with 2004–2009 (Figure 13). Simple estimates of mean densities, using the method of moments, illustrated their similarity with estimated densities ($E(x)$) over time. In contrast, estimates of log-transformed densities (aka *CPUE*) illustrated an abundance pattern over time that was only superficially similar to density estimates generated using either the mixture model or the method of moments. The general pattern was most similar to that generated for the estimates of δ over time but showed almost no resemblance to the estimates of μ over time. Inferences based on mixture-model vs. log-transformed estimates were notably different in some cases (e.g., significant increase from 2012 to 2013 based on log-transformed estimates but no difference based on mixture-model estimates).

Habitat-specific density data

Mixture-model estimates (Delta (δ) and Mu (μ)), generated from general linear models of habitat-specific density data, revealed that the mesohabitat model (δ(Habitat) μ(Habitat)) received essentially all of the AIC_C weight despite having the most parameters (Table 4). This model was significantly different ($P < 0.001$) from the null model (δ(.) μ(.)). The simplified habitat models (δ(Habitat) μ(.) and (δ(.) μ(Habitat)) received a negligible amount of weight but were both significantly different ($P < 0.001$) from the null model. None of the other nine candidate models differed significantly ($P < 0.05$) from the null model, although the location model (δ(Location) μ(Location)) had a P-value of 0.06. All of the δ-only models had lower AIC_C values as compared to the μ-only models (e.g., δ(Habitat) μ(.) vs. δ(.) μ(Habitat)), which indicated that δ was explaining most of the variation in the combined models (e.g., δ(Habitat) μ(Habitat)). Estimates of δ and μ illustrated the differences among mesohabitats for both the occurrence and abundance of Razorback Sucker, respectively (Figure 14).

The estimated densities ($E(x)$) of Razorback Sucker, using habitat-specific density data (2013), were highest in backwaters (31.78), pools (16.76), and embayments (11.66) but lowest in sand shoals (1.90) and slackwaters (1.67). Razorback Sucker estimated densities were significantly higher ($P < 0.05$) in backwaters and pools as compared with sand shoals and slackwaters (Figure 15). Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities ($E(x)$) across mesohabitats. Estimates of log-transformed densities illustrated an abundance pattern across mesohabitats that was quite similar to density estimates generated using the mixture model and the method of moments. However, the relative precision of estimates was notably lower when using log-transformed densities as opposed to densities derived from the mixture model. Inferences based on mixture-model vs. log-transformed estimates were different in some cases (e.g., significant difference between pools and sand shoals based on mixture-model estimates but no difference based on log-transformed estimates).

Table 3. General linear models of Razorback Sucker (age-0) mixture-model estimates (Delta (δ) and Mu (μ)), using sampling-site density data (1999–2013) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[1]	K[2]	logLike[3]	AIC_C	w_i
δ(Year) μ(Year)	45	2,428.82	2,521.30	1.000
δ(Year) μ(.)	17	2,513.36	2,547.72	<0.001
δ(Reach) μ(Reach)	15	2,644.38	2,674.66	<0.001
δ(Reach) μ(.)	6	2,666.13	2,680.20	<0.001
δ(Habitat) μ(Habitat)	30	2,630.25	2,691.35	<0.001
δ(Habitat) μ(.)	12	2,675.82	2,700.00	<0.001
δ(.) μ(Year)	31	2,659.37	2,722.55	<0.001
δ(.) μ(Habitat)	21	2,698.34	2,740.88	<0.001
δ(.) μ(Reach)	11	2,722.15	2,744.30	<0.001
δ(.) μ(.)	3	2,743.91	2,749.92	<0.001

[1] = Model variables included year (1999–2013), reach (n = five reaches), and mesohabitat (habitat = BW, CO, CS, ED, EM, PO, PW, RU, SS, and SW)
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model

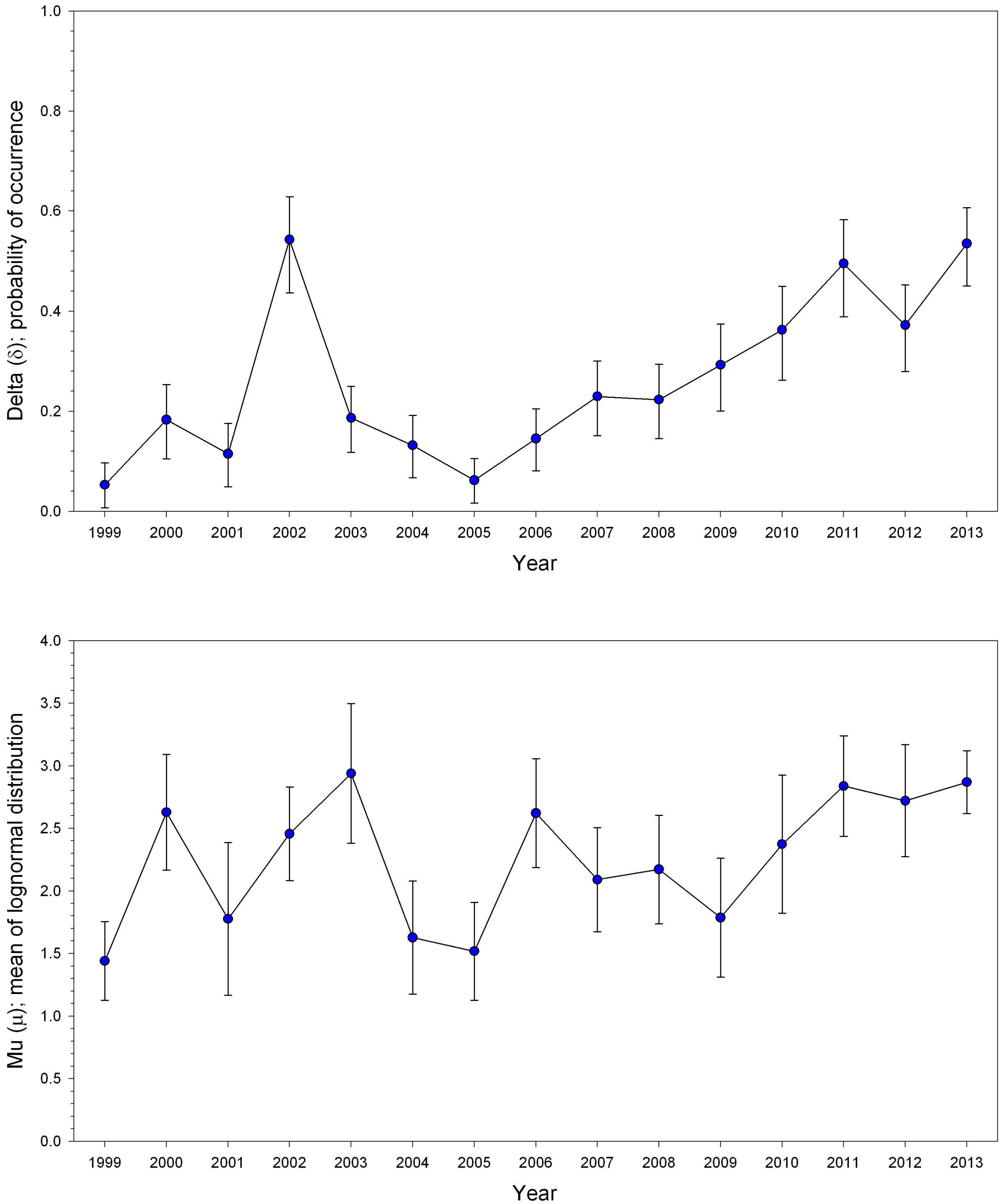


Figure 12. Razorback Sucker (age-0) mixture-model estimates (δ and μ), using sampling-site density data (1999–2013). Solid blue circles indicate estimates and bars represent 95% confidence intervals.

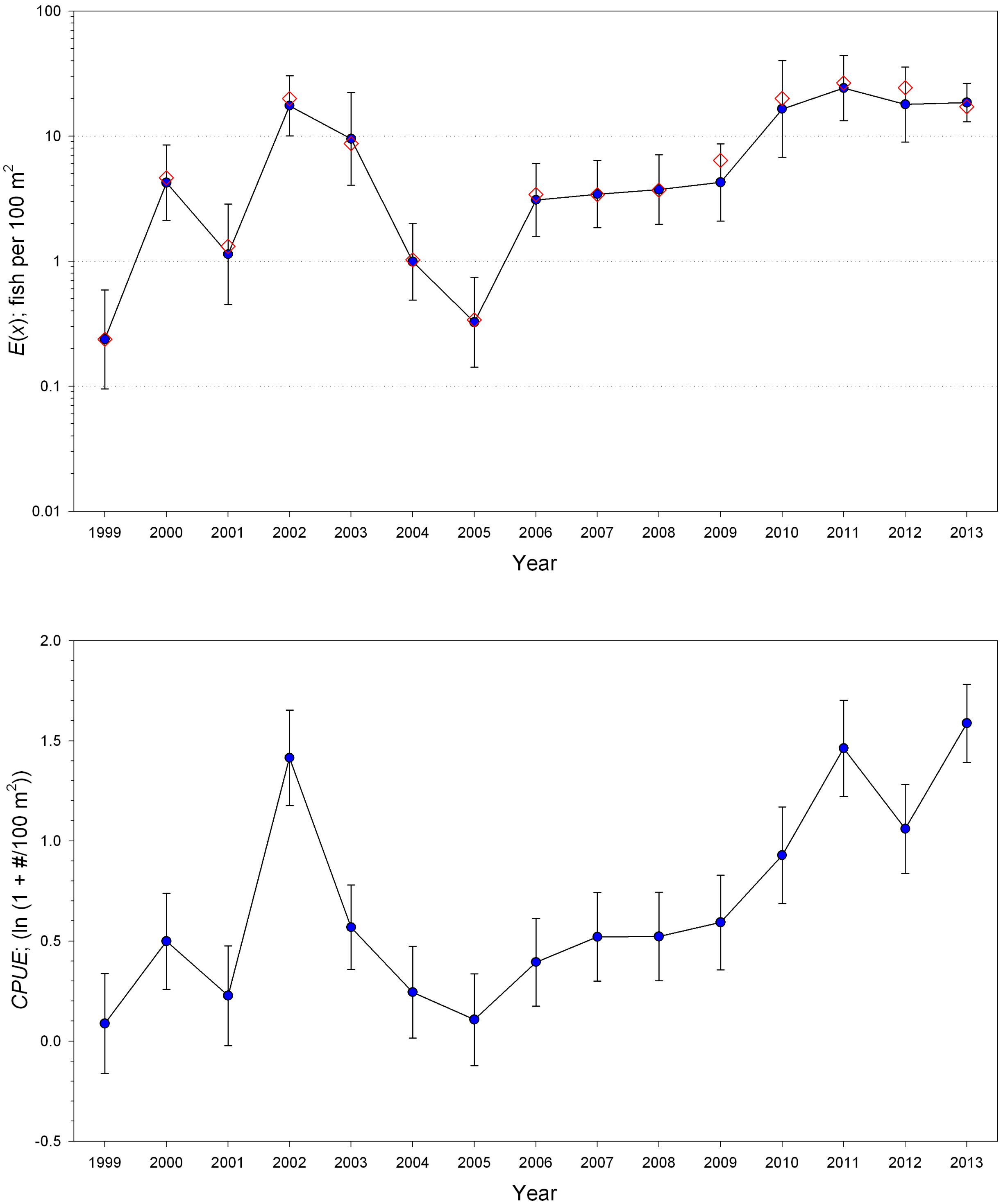


Figure 13. Razorback Sucker (age-0) mixture-model estimates (*E*(*x*)) and log-transformed estimates (*CPUE*), using sampling-site density data (1999–2013). Solid blue circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 4. General linear models of Razorback Sucker (age-0) mixture-model estimates (Delta (δ) and Mu (μ)), using habitat-specific density data (2013) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[1]	K[2]	logLike[3]	AIC_C	w_i
δ(Habitat) μ(Habitat)	15	682.96	714.07	0.997
δ(Habitat) μ(.)	7	711.57	725.83	0.003
δ(.) μ(Habitat)	11	712.33	734.94	<0.001
δ(Reach) μ(.)	7	731.53	745.78	<0.001
δ(Location) μ(.)	6	733.71	745.90	<0.001
δ(.) μ(.)	3	740.95	747.00	<0.001
δ(Location) μ(Location)	12	724.40	749.12	<0.001
δ(.) μ(Location)	9	731.64	750.05	<0.001
δ(Cover) μ(.)	6	739.54	751.73	<0.001
δ(.) μ(Cover)	9	734.64	753.05	<0.001
δ(Reach) μ(Reach)	15	722.37	753.49	<0.001
δ(.) μ(Reach)	11	731.79	754.40	<0.001
δ(Cover) μ(Cover)	12	733.23	757.95	<0.001

[1] = Model variables included reach (n = five reaches), mesohabitat (habitat = BW, EM, PO, SS, and SW), mesohabitat location (location = SH, OP, MO, and TR), and cover (types 1–3)
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model

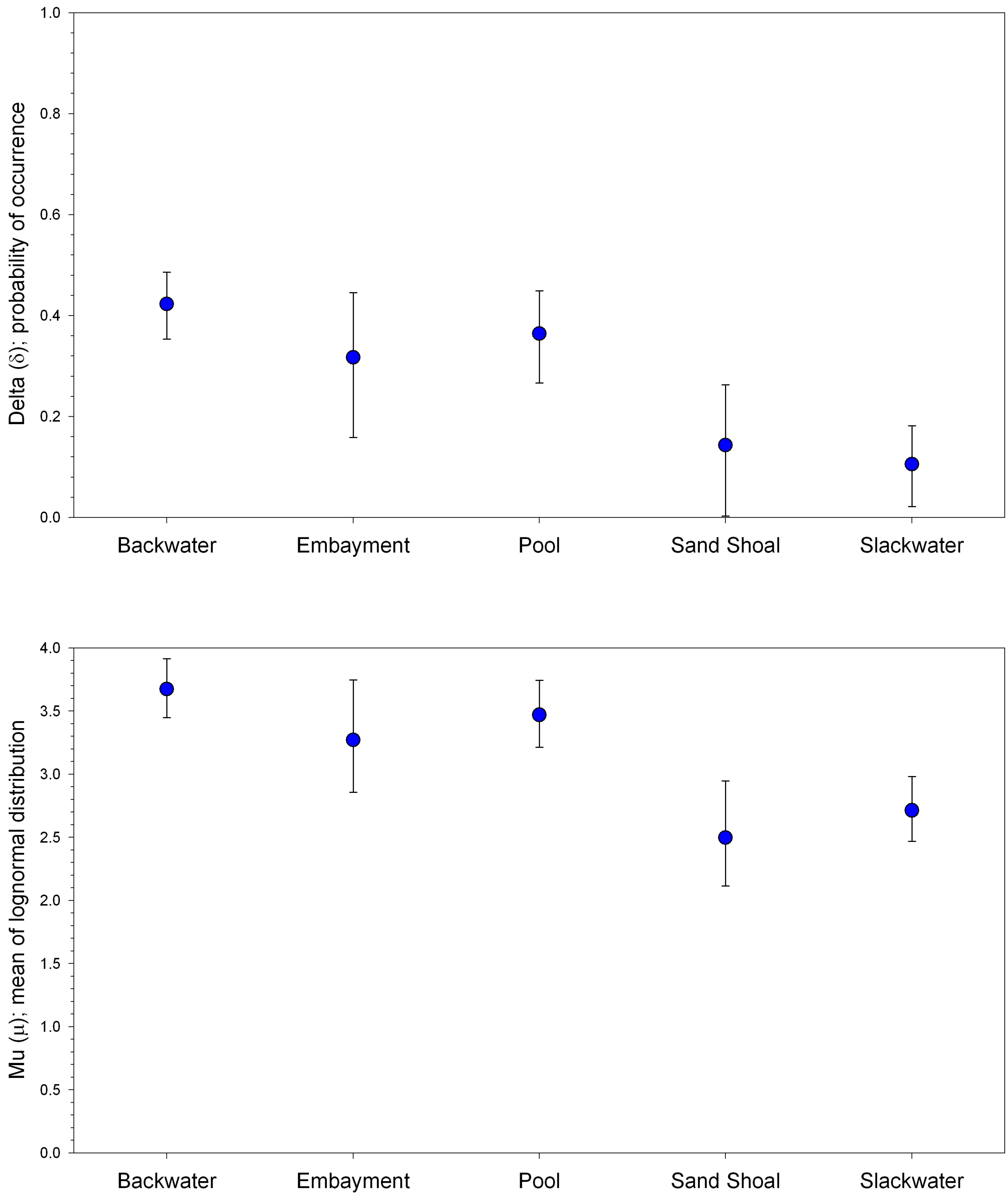
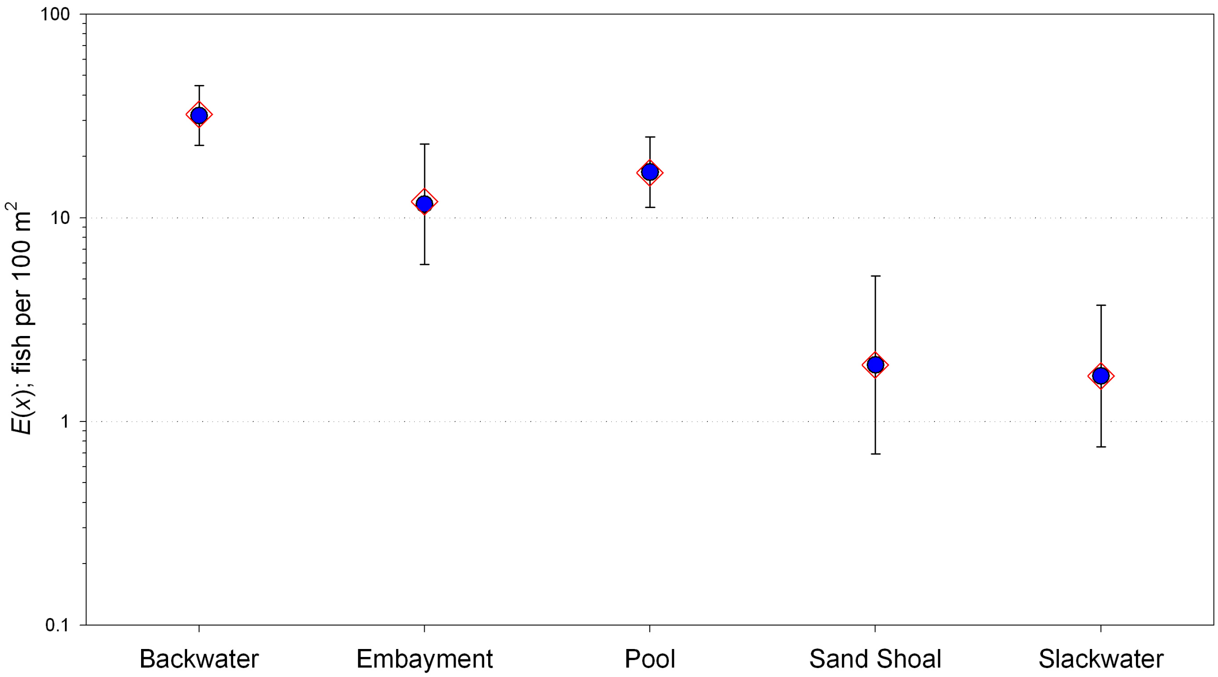


Figure 14. Razorback Sucker (age-0) mixture-model estimates (δ and μ), using habitat-specific density data (2013). Solid blue circles indicate estimates and bars represent 95% confidence intervals.



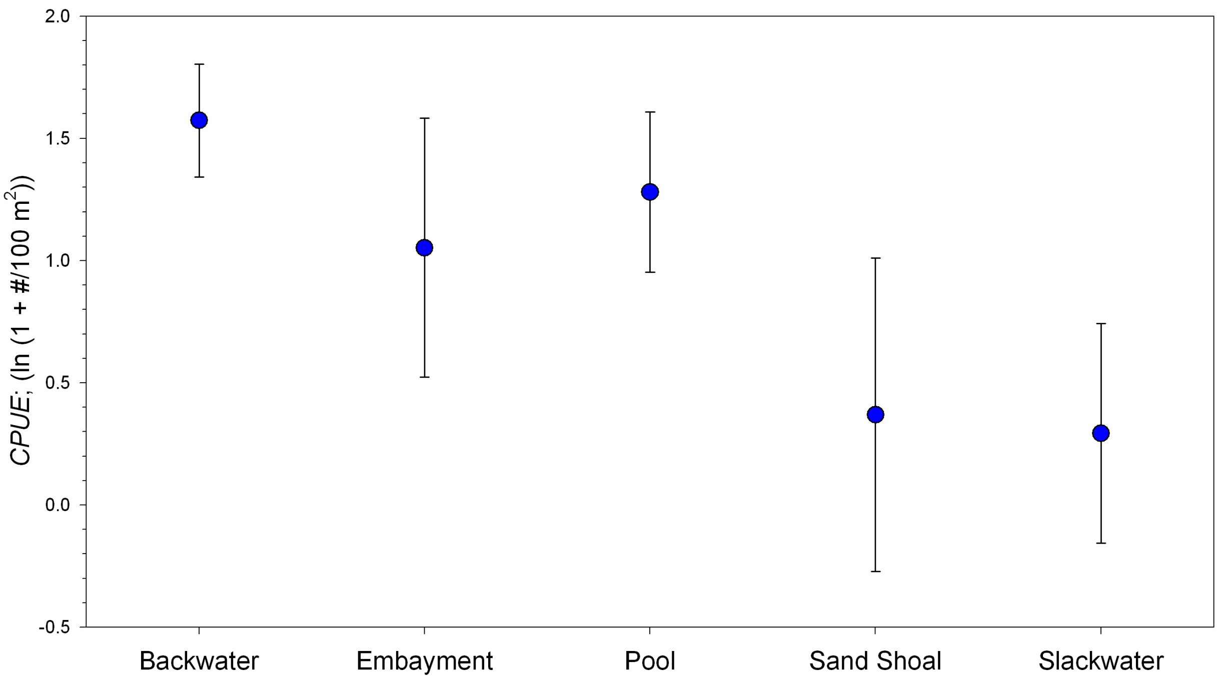


Figure 15. Razorback Sucker (age-0) mixture-model estimates ($E(x)$) and log-transformed estimates (*CPUE*), using habitat-specific density data (2013). Solid blue circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments

Fish Community

Native Species

Speckled Dace. Larval Speckled Dace were first collected during the May survey. Catch rates for this species peaked two months later during the July survey (F = 75.4, P < 0.0001 [Figure 16]). Speckled Dace was collected in 53.8% of the 2013 collections making it the most frequently encountered species. There was little statistical difference among reaches, with catch rates in Reaches 5, 4 and 3 higher than those of Reaches 2 and 1 (F = 12.0, P < 0.0001 [Figure 16]). Among years, catch rates during 2013 were significantly higher than those of 2003, 2009, and 2010 but not lower than any year between 2003 and 2012 (F = 7.7, P < 0.0001 [Figure 17]).

Bluehead Sucker. For the second consecutive year, Bluehead Sucker was the numerically dominant native species collected. The 6,637 age-0 specimens collected accounted for 26.4% of the 2013 catch and Bluehead Sucker was the second most frequently encountered species. Similar to Speckled Dace, the first captures of larval Bluehead Sucker occurred during the May survey, with catch rates highest during the July survey (F = 74.4, P < 0.0001 [Figure 18]). The July survey accounted for 66.3% (n=4,406) of the 2013 catch. Among reaches, catch rates declined from upstream to downstream, with Reach 5 having significantly higher catch rates than all other reaches (F = 28.3, P < 0.0001 [Figure 18]). The 2013 catch rate was significantly higher than five of the preceeding years and no different than the other five (F = 9.8, P < 0.0001 [Figure 19]).

Flannelmouth sucker. As is often the case, Flannelmouth Sucker was the first age-0 species collected during the larval fish survey. Larval Flannelmouth Sucker were collected during the April survey in Reaches 2 and 1. Catch rates of age-0 Flannelmouth Sucker were highest in May and July (F = 13.0, P <.0001 [Figure 20]). Similar to Bluehead Sucker, catch rates of Flannelmouth Sucker declined from upstream to downstream with Reach 1 catch rates significantly lower than all other reaches. (F = 15.6, P < 0.0001 [Figure 20]). The catch rate in 2013 was significantly lower than all of the preceding years except for 2003, 2009, and 2010 (F = 12.1, P < 0.0001 [Figure 21]). Larval Flannelmouth Sucker accounted for just 7.3% of the total catch in 2013; a low percentage for this species.

Non-Native Species

Red Shiner. Red Shiner was the numerically dominant species in 2013 accounting for 37.9% of the total catch. Red Shiner was first captured during the May survey with catch rates highest in July and August (F = 198.9, P < 0.0001 [Figure 22]). Among reaches catch rates were generally higher in the three upstream reaches. Densities in Reach 2 were significantly lower than each of the three upstream reaches and Reach 1 densities were lower than those of Reach 3 (F = 7.8, P < 0.0001 [Figure 22]): The 2013 catch rate was lower than 2004, and no different than any other preceding year (F = 11.5, P < 0.0001 [Figure 23]).

Common Carp. This species represented just 0.1% of the total 2013 catch (n=27). Larval Common Carp were first collected in June, with catch rates highest during the July survey (F = 12.7 P < 0.0001 [Figure 24]). There was little difference in catch rates among reaches. Densities in Reach 4 were higher than those of Reaches 3 and 2; however larval Common Carp were not collected in Reach 2 (F = 4.1, P = 0.0031 [Figure 24]). Similar to Red Shiner, 2013 catch rates were lower than 2004, and no different than any other preceding year (F = 8.7, P < 0.0001 [Figure 25]).

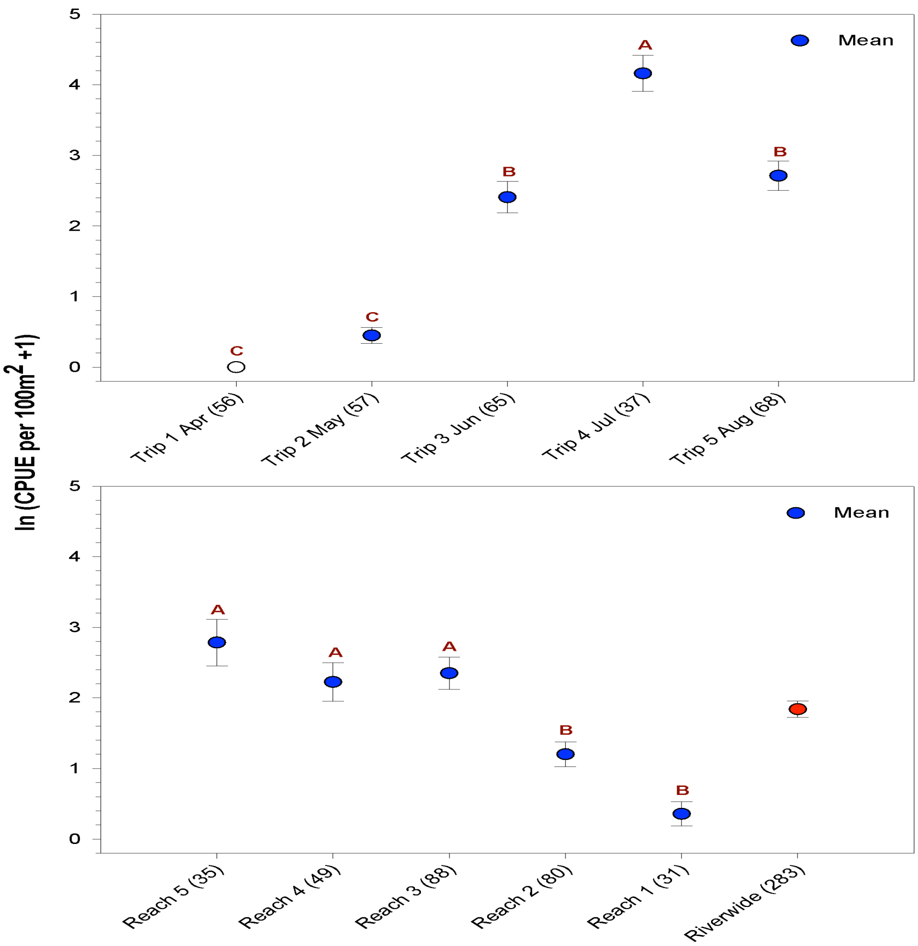


Figure 16. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Speckled Dace by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

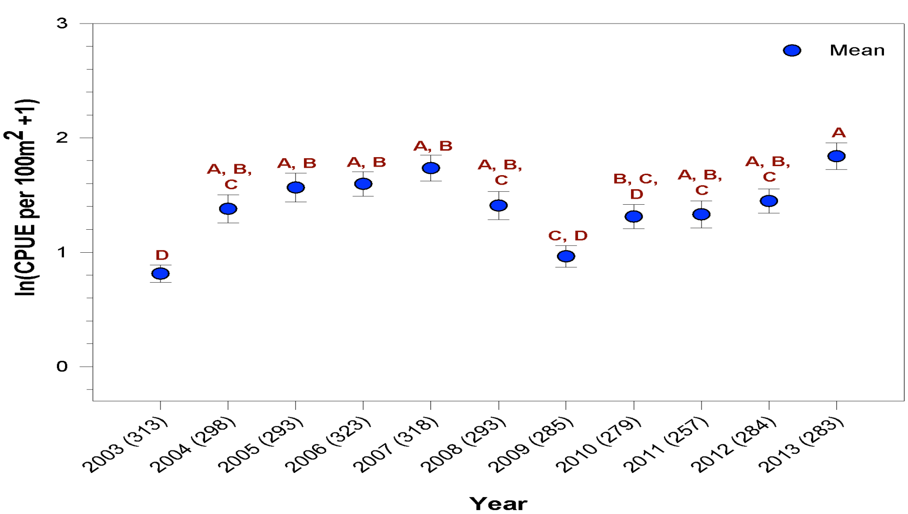


Figure 17. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Speckled Dace by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

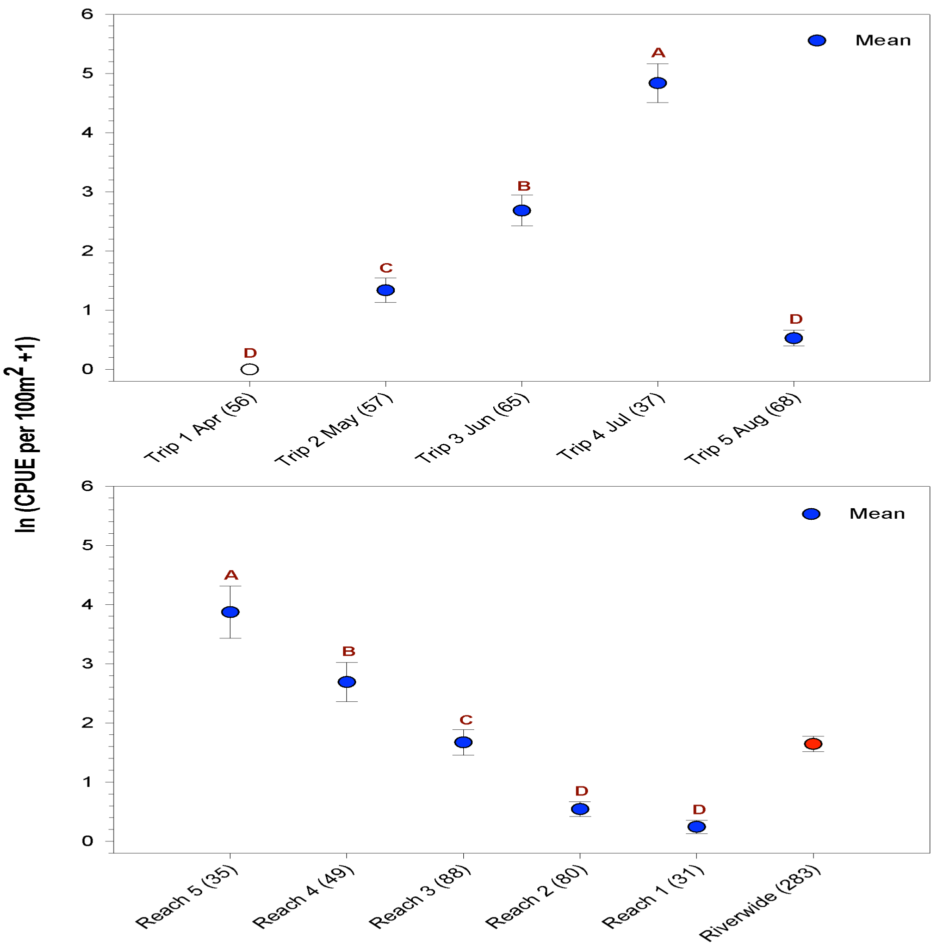


Figure 18. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Bluehead Sucker by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

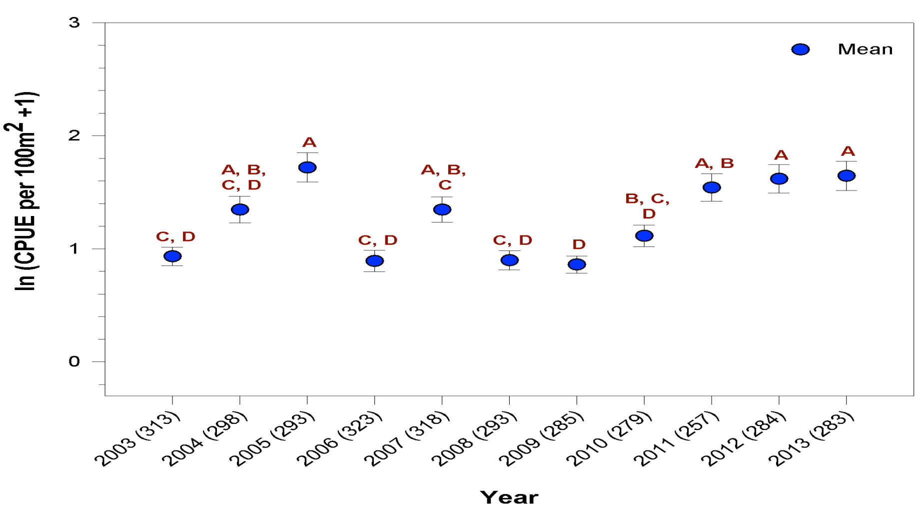


Figure 19. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Bluehead Sucker by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

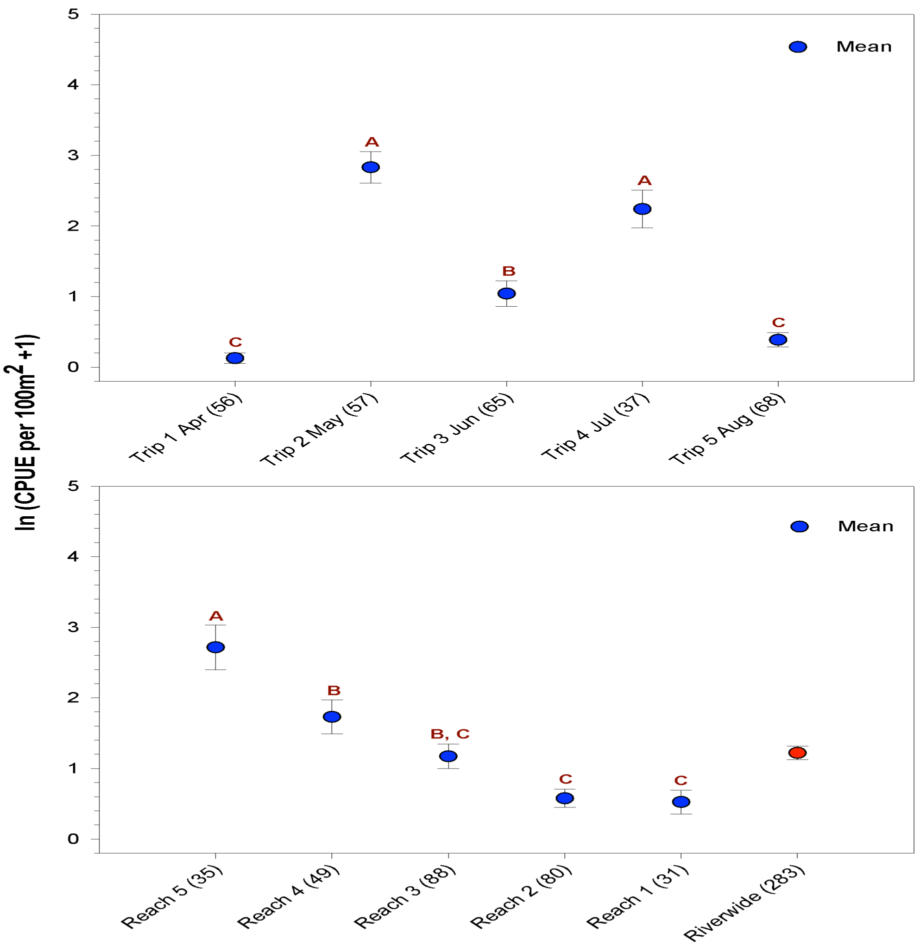


Figure 20. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Flannelmouth Sucker by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

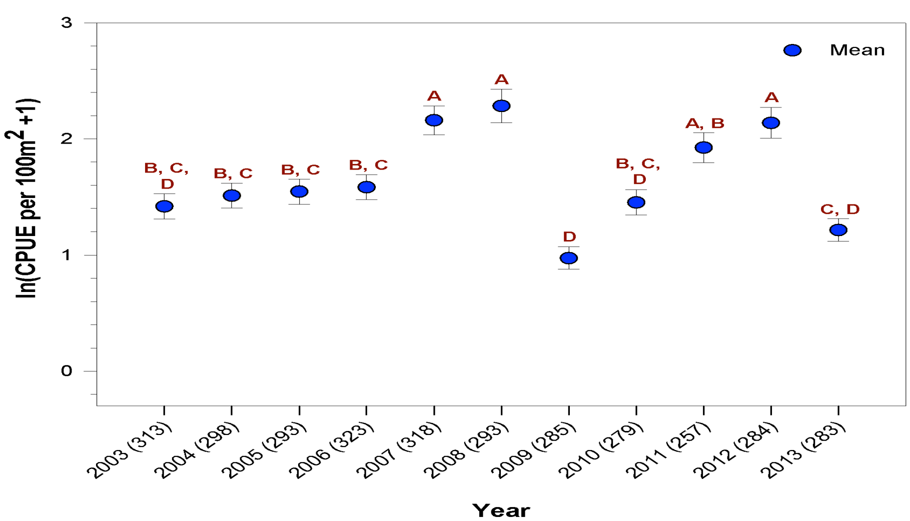


Figure 21. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Flannelmouth Sucker by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

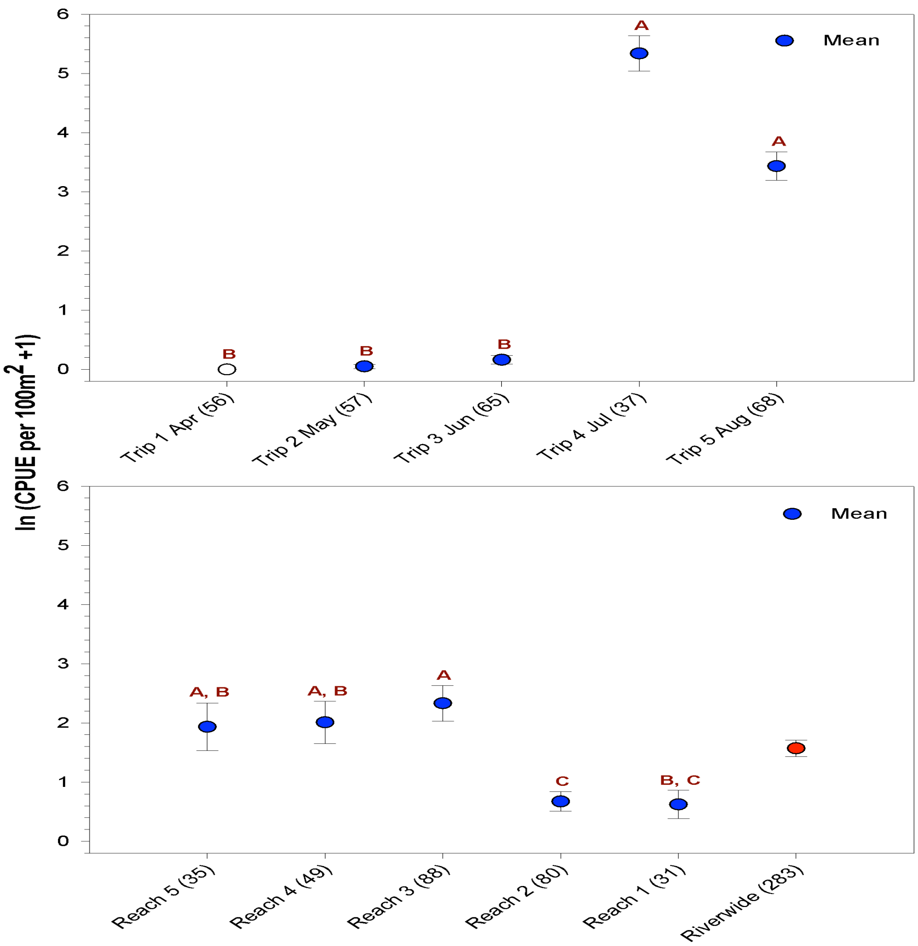


Figure 22. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Red Shiner by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

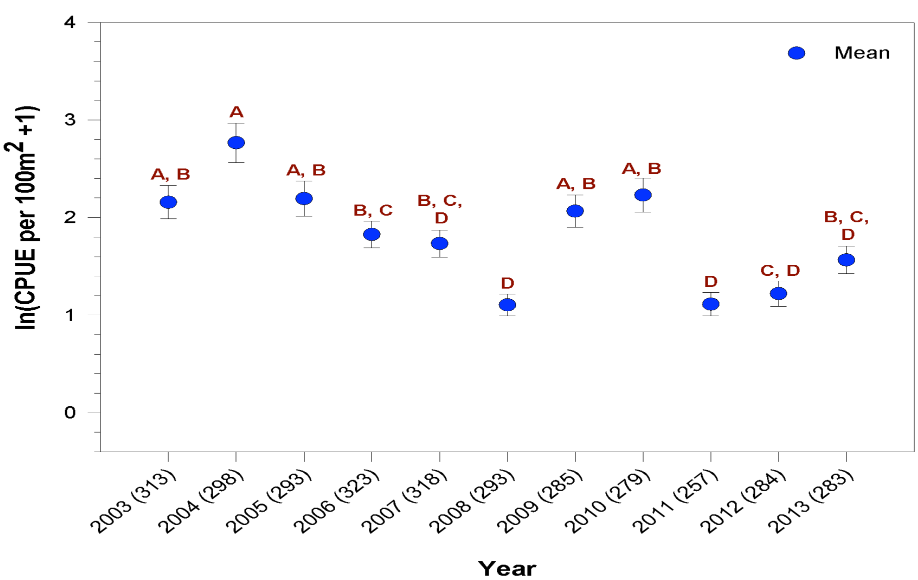


Figure 23. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Red Shiner by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

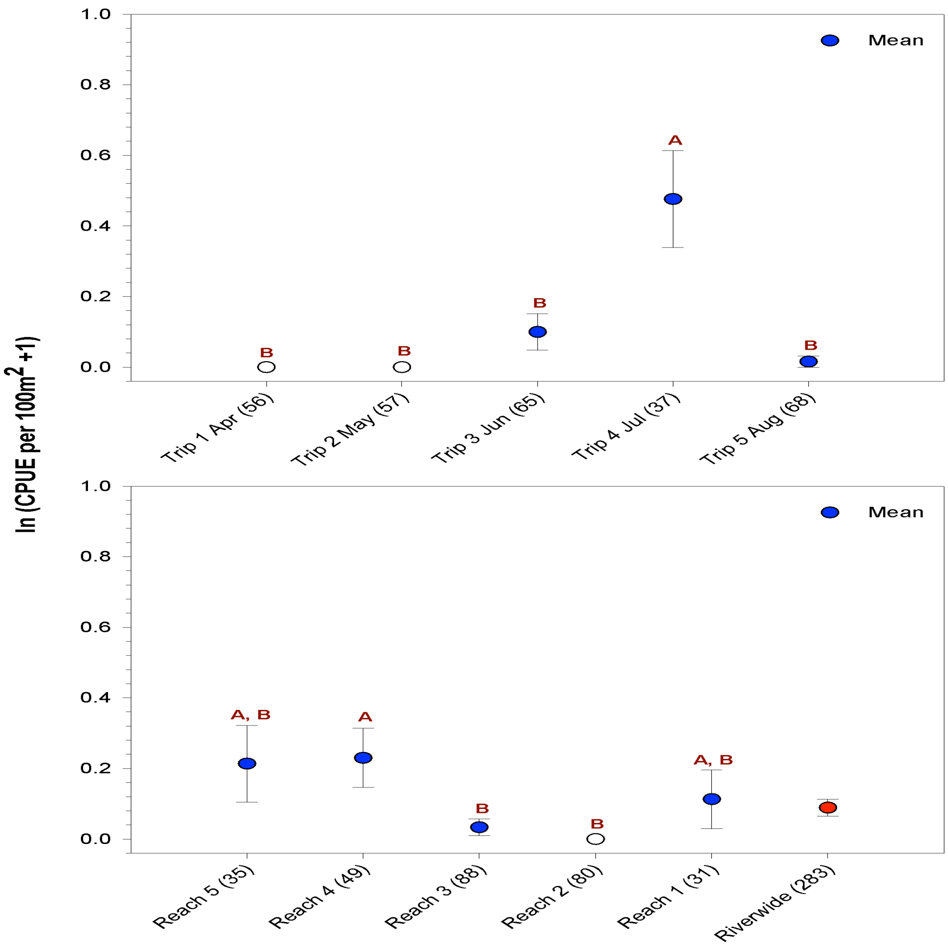


Figure 24. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Common Carp by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

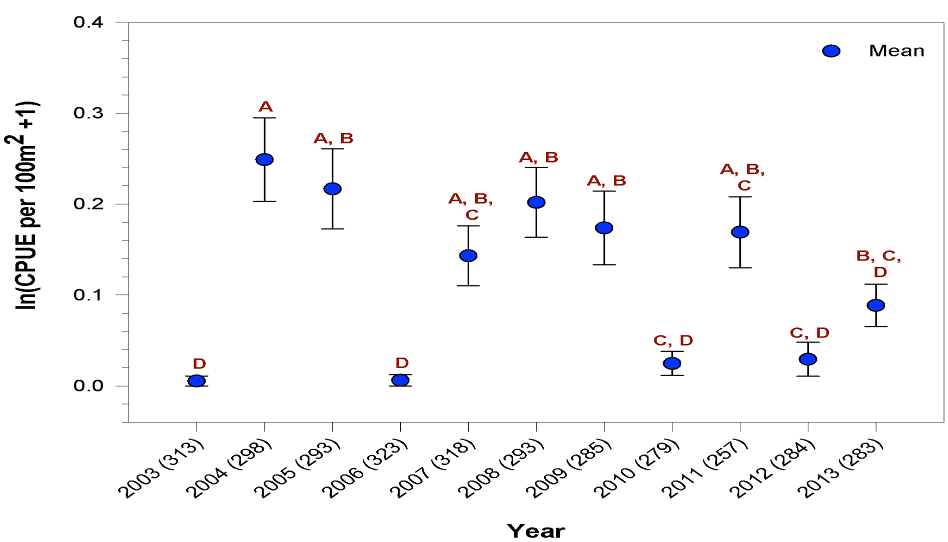


Figure 25. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Common Carp by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

Fathead Minnow. While larval Fathead Minnow remain the second most abundant non-native species in the San Juan River, in 2013 this species was less common than any of the three common natives (Speckled Dace, Bluehead and Flannelmouth sucker) The 1,502 specimens collected accounted for 6.0% of the total catch. Fathead Minnow were first collected during the May survey with catch rates peaking during the July survey (F =35.5, P < 0.0001 [Figure 26]). Densities of Fathead Minnow generally decline from upstream to downstream, with little significant difference between any two adjoining reaches (F =14.7, P < 0.0001 [Figure 26]). The 2013 catch rate is significantly lower than 2003, 2004, and 2006 (F = 28.0, P < 0.0001), and only significantly higher than 2009 (Figure 27).

Channel Catfish. As is often the case, this species was only collected during the July and August surveys (Figure 28). There was no statistical difference in catch rates between these two months (F = 55.1, P < 0.0001) There was little statistical difference among reaches with catch rates in Reach 3 higher than those of Reach 1(F = 3.2, P = 0.0129 [Figure 28]). Among years, the 2013 catch rate was significantly higher than 2004, and 2009, and lower that 2007 (F = 12.3, P < 0.0001 [Figure 29]).

Monitoring Sites

During the 2013 survey, each of the monitoring sites (Table A-1) was visited each month. The site was sampled if suitable nursery habitat was available, otherwise photographs were taken and conditions noted on a field data sheet. During 70 visitations to the monitoring sites (14 sites x five monthly surveys), a backwater habitat was encountered 26 times, isolated pools were found 11 times, pools were found three times (due to flow input from the site into the river), with the remaining 30 visitations being to dry sites.

During the May survey, eight of the 14 sites were connected to the main channel and contained a backwater habitat; all of these were sampled. Six of those collections contained larval fish, and each also contained larval Razorback Sucker. Those six collections produced 38.1% (n = 217) of the 2013 Razorback Sucker total.

For the first time since the monitoring sites were established for this project, none of the sites were connected to the river during the June survey. Connectivity was highest the following month as a result of summer rain events (Figure 30). The rain events that led to the greater connectivity in July seemed to remove sediment from the mouths of many of these sites, without a subsequent re-deposition on the descending limb of the rain driven flow spike. Following the July survey, half of the monitoring sites were connected to the river during the August survey. Mean discharge was less during this trip (619 cfs) than during the June trip (652 cfs) when none of the monitoring sites were connected to the river (Figure 30).

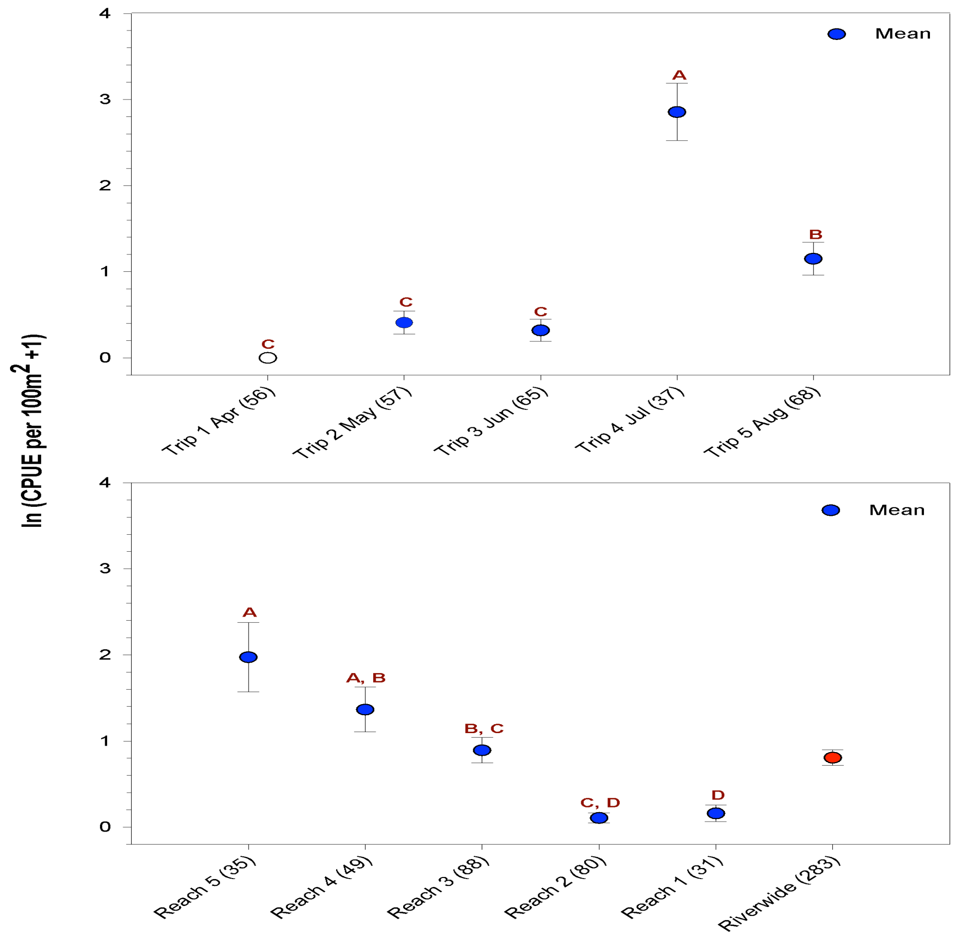


Figure 26. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Fathead Minnow by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

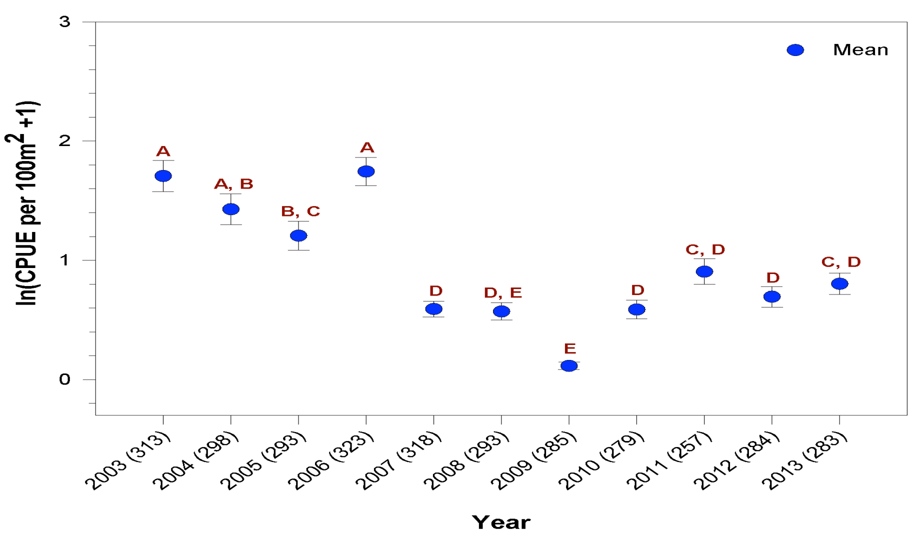


Figure 27. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Fathead Minnow by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

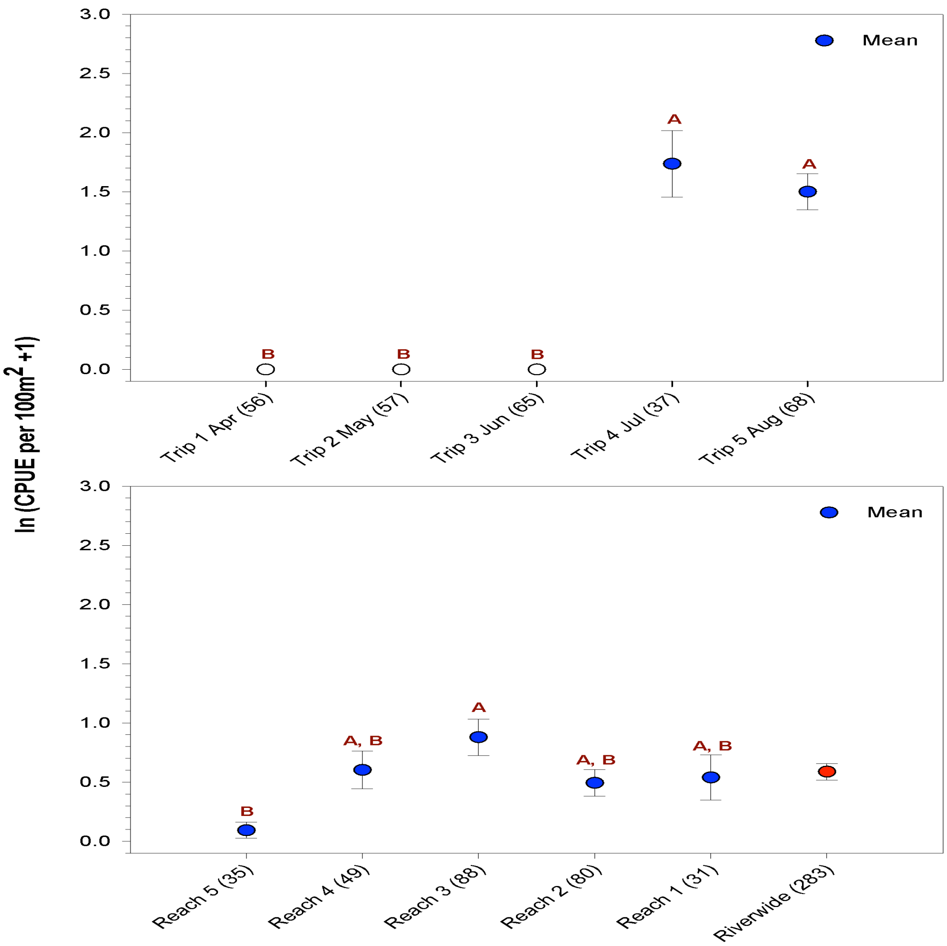


Figure 28. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Channel Catfish by trip (top graph), reach, and river wide (bottom graph) during the 2013 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

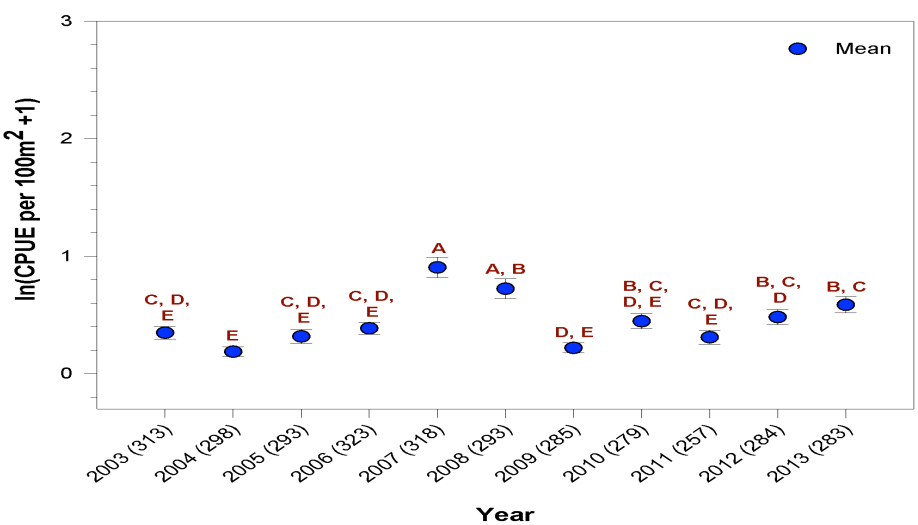


Figure 29. ln(CPUE per 100 m^2 +1) [+1 SE] for age-0 Channel Catfish by year (2003-2013). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

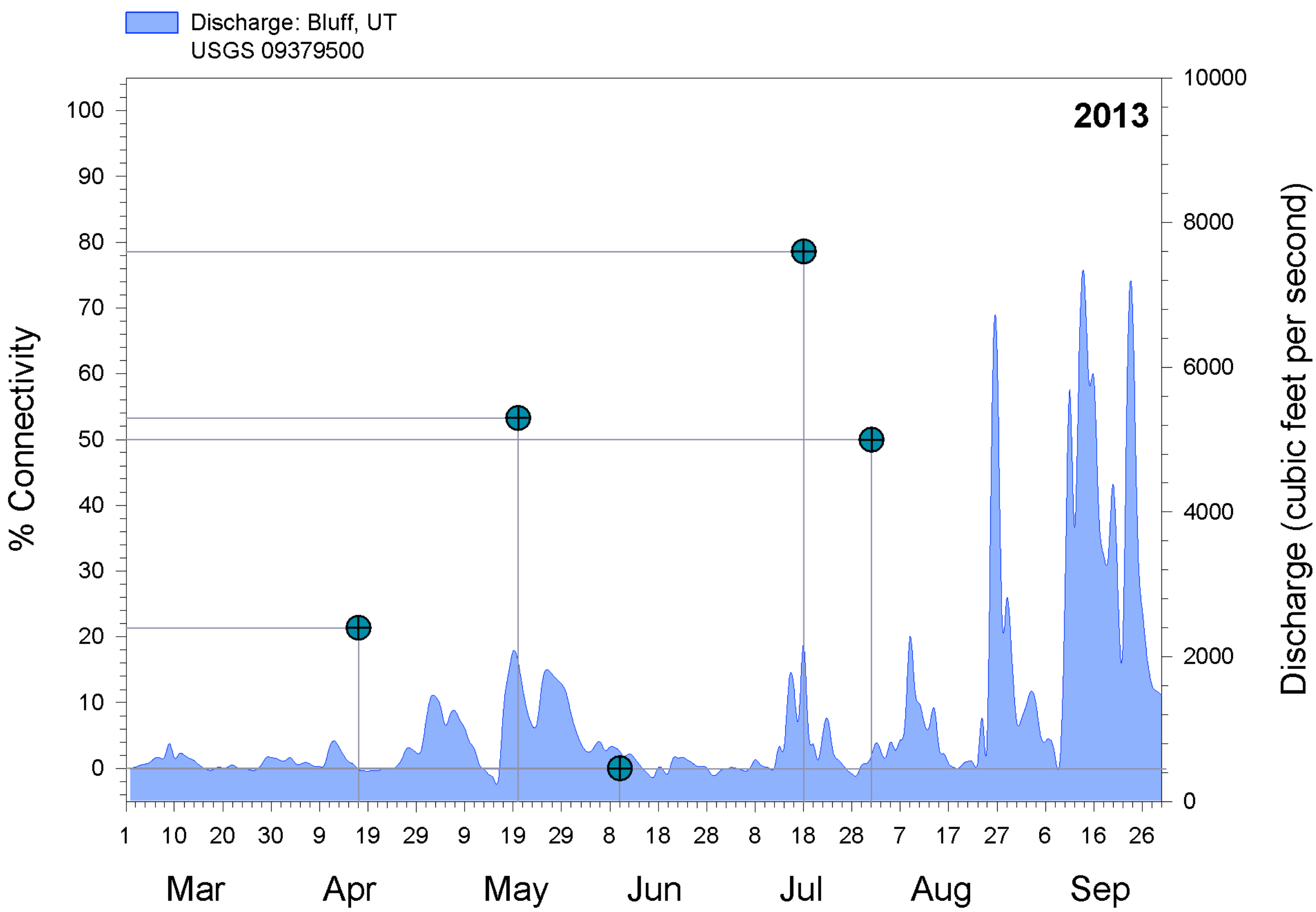


Figure 30. Mean connectivity of the 14 monitoring sites during the five survey trips.

RERI Sites

During the 30 RERI site visitations (six sites x five monthly surveys), 14 collections were made. A total of 2,079 age-0 specimens representing 11 species were collected (Table 5).

Two of the RERI sites contained age-0 Razorback Sucker. Five Razorback Sucker were captured between May and July at the river mile 127.2 site. Nineteen Razorback Sucker were collected in May at the river mile 128.6 site. Three age-1+ Colorado Pikeminnow were also collected in the RERI sites during 2013.

An effort was made to compare the six RERI sites to other, similar sites sampled in 2013. Capture data were separated for all sites located within the same five river miles as the RERI sites, and for all sites within five miles up or downstream of the RERI sites. Within this pool of sites, all habitats associated with washes, arroyos, or tributaries were cut out. The remaining sites (n=33) were all habitats that were directly associated with either the main or a secondary channel. Similar to the 14 collections made within the RERI sites, not all of these 33 sites contained fish at the time of visitation. These 33 sites will be considered the “control” sites.

Age-0 species composition was identical between the RERI and control sites with the same 11 species encountered. The proportion of native to non-native species found between the RERI and control sites was nearly identical. Of the 2,079 specimens collected in the RERI sites, 61.4% were native species and 38.6% were non-native. A total of 6,976 specimens were collected within the control sites with 65.6% of those fish being native species and 34.4% being non-native.

Table 5. Species composition and habitat type of the six RERI sites sampled in 2013.

RERI	Month	Water_Descriptor		PTYLUC	RHIOSC	CATDIS	CATLAT	XYRTEX	ICTPUN	AMEMEL	FUNZEB	GAMAFF	MICSAL	CYPCAR	CYPLUT	PIMPRO
127.2	April	Site dry														
	May	Pool					5	1								30
	June	Sand shoal			3	111	114	3								37
	July	Sand shoal			3	135	7	1		9		7	1	2	412	134
	August	Site dry														
			Total		**6**	**246**	**126**	**5**		**9**		**7**	**1**	**2**	**412**	**201**
128.6	April	Site dry														
	May	Pool			1	15	54	19								
	June	Isolated pool, not sampled														
	July	Slackwater, sand shoal			9	103	1						1		35	26
	August	Site dry														
			Total		**10**	**118**	**55**	**19**					**1**		**35**	**26**
130.7 A	April	Site dry														
	May	Run, not sampled														
	June	Pool			13	63	4									
	July	Slackwater			5	44	4		4					1	32	9
	August	Site dry														
			Total		**18**	**107**	**8**		**4**					**1**	**32**	**9**
130.7 B	April	Pool														
	May	Backwater ,Cobble Shoal			1	9	7	2								
	June	Run, not sampled														
	July	Run, not sampled														
	August	Site dry														
			Total		**1**	**9**	**7**	**2**								
132	April	Slackwater														
	May	Run, not sampled														
	June	Run, not sampled														
	July	Run, not sampled														
	August	Sand shoal			11		5								13	9
			Total		**11**		**5**								**13**	**9**
132.2	April	Site dry														
	May	Slackwater			1	2	12									
	June	Pool			3	114	23									
	July	Backwater, Sand Shoal			110	247	12		1						32	7
	August	Site dry														
			Total		**114**	**363**	**47**		**1**						**32**	

2013 Razorback Sucker Opercular Deformities.

In 2013, age-0 Razorback Sucker were rated for opercular deformities using the methods outlined in a previous investigation of opercular deformities in native suckers from 1998–2012 (Barkstedt et al. 2014). The opercular deformity study completed in 2013 rated all three native suckers from collections in 1998–2012 (n = 55,385). Across all years, opercular deformities were found in 4.3% of Bluehead Sucker (*n* = 8,565), 6.3% of Flannelmouth Sucker (*n* = 45,416), and 23.6% of Razorback Sucker (*n* = 1,404). In 2013 Razorback Sucker meeting a minimum size of 15 mm TL were rated bilaterally for deformed opercula on a scale of 0 (none), 1 (slight shortening), and 2 [severe shortening (Figure 31)].

A total of 216 specimens were rated with 55 (34.0%) exhibiting deformed opercula (Figure 32). Most fish were larvae (*n = 53*) and only two fish were juveniles, neither of which had deformities. Fish were rated from all 5 geomorphic reaches within the study area, with Reach 3 having the highest number of deformed fish (58.3%, *n* = 24 fish rated), followed by Reach 2 (21.0%, *n* = 124 fish rated). Deformities were found bilaterally (57.2%, *n* = 26) and unilaterally (47.3%, *n* = 29). Of unilateral deformities, more deformities were found on the left side of the fish (69.0%) than the right (31.0%).

Figure 31. Age-0 Flannelmouth Suckers from the San Juan River displaying opercular deformities. The top two fish would be rated as severely deformed ("2"), and the bottom fish would be rated as slight shortening ("1").

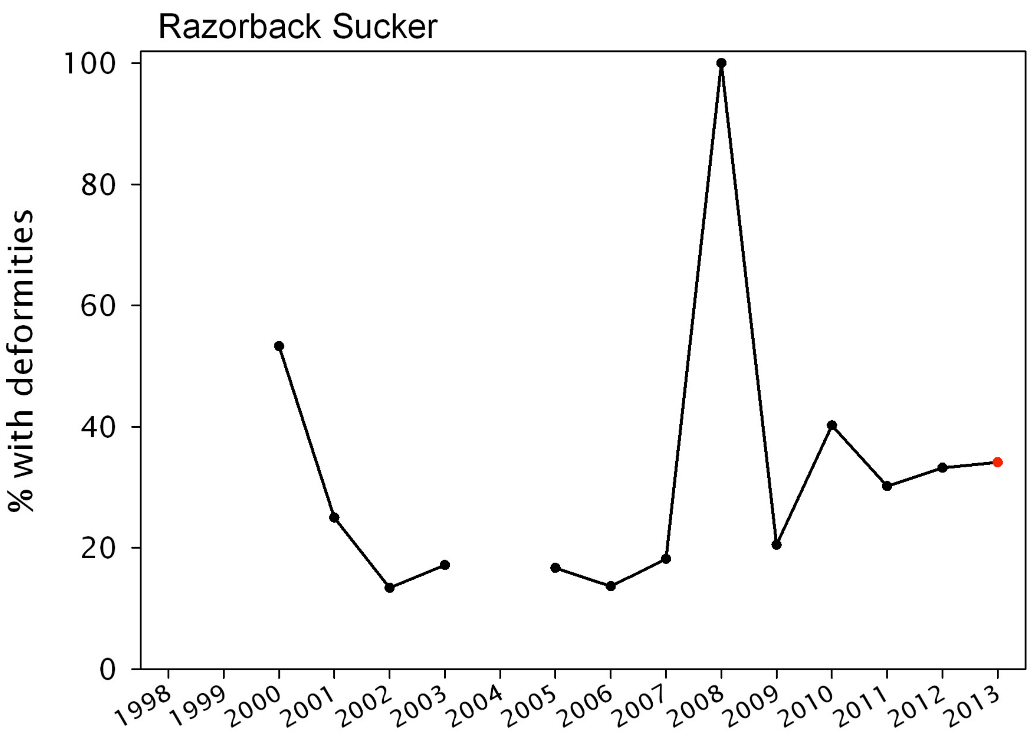


Figure 32. Percent of Razorback Sucker with opercular deformities by year. Years with no associated value are due to insufficient sample sizes.

Discussion

The mixture models used to estimate Razorback Sucker and Colorado Pikeminnow densities in this study utilized two separate components, an approach which has been shown to be particularly effective for modeling zero-inflated ecological data (White, 1978; Welsh et al., 1996; Fletcher et al., 2005; Martin et al., 2005). Logistic regression was used to model the probability that a site was occupied while a lognormal model was used to estimate fish densities at occupied sites. Although the estimated densities ($E(x)$) of Razorback Sucker and Colorado Pikeminnow were mostly similar to those calculated during previous years using means of log-transformed data (Farrington et al., 2013), the two processes (i.e., presence-absence vs. density) that generated $E(x)$ were clearly separated when using the mixture model approach. Further, it was unnecessary to make the arbitrary addition of some positive constant onto observations of zero density values as is commonly done for simple regression models using log-transformed data (e.g., ln (1 + # / 100 m^2)).

While density estimates using both mixture models and log-transformed means were presented, the assumptions required for parametric analysis (i.e., normality and homoscedasticity) were violated to some extent for the log-transformed data. Although parametric analyses are robust to deviations from these assumptions to some extent (Zar, 2010), even nonparametric analyses are inappropriate for datasets with markedly heterogeneous variances (McDonald, 2009). Mixture models are particularly robust to these statistical issues since the data are examined as two discrete components (i.e., occurrence vs. abundance), which made their use more appropriate for both the sampling-site and habitat-specific datasets. In contrast, log-transformed data were either somewhat problematic or simply inappropriate for the analysis of data. This was particularly true when the occurrence of endangered fish was particularly low relative to their non-zero abundance (e.g., Razorback Sucker (2003 and 2012) or age-0 Colorado Pikeminnow (all years). The log-transformed results also differed from simple method of moments estimates in several cases, making their utility in understanding ecological processes more questionable as compared to the mixture model results.

Additional effort was made in 2013 to characterize the specific habitat features (i.e., location and cover) within mesohabitats. The overall sample size was increased as a result of this new effort, which led to a notable increase in the percentage of zero data collected. The increased sample size obtained in 2013, using the habitat-specific data, may also be useful in the future for inferring occurrence/abundance differences among years since it results in increased precision of estimates. However, several years of habitat-specific data will need to be analyzed to ensure that there is not a strong within-habitat response (e.g., densities consistently high across location for specific mesohabitats), which would potentially invalidate the use of these data to infer differences among years (i.e., because of pseudoreplication concerns). Regardless of these issues, it is clear that habitat-specific data can be used to infer differences among mesohabitats and possibly among locations within mesohabitats as well. This type of detailed information about mesohabitats and habitat features could eventually be useful in efforts to restore suitable nursery habitats for both Razorback Sucker and Colorado Pikeminnow. For example, if the terminal ends of mesohabitats are shown to have consistently higher densities of endangered larval fishes, the specific conditions in these areas (e.g., shallow, clear, no velocity) could help better inform future restoration efforts.

General linear models for age-0 endangered fishes indicated that most of the variation in density was explained by the year model (δ(Year) μ(Year)) or habitat model (δ(Habitat) μ(Habitat)) based on the level of data analyzed (i.e., sample-site over time or habitat-specific for 2013). These models indicate that additional spatial covariates (e.g., reach, location, and cover) were not particularly informative in explaining differences based on either the long-term or short-term datasets. While many of these other candidate models were significantly different than the null models, their current utility in explaining spatial or temporal density differences appears limited.

In contrast, the age-1+ Colorado Pikeminnow mixture model results indicated that the habitat model (δ(Habitat) μ(Habitat)) explained nearly all of the variation in densities. This suggests that stocked Colorado Pikeminnow were utilizing habitats differentially but that overall population trends were remaining relatively constant over time. However, there was a notable decline in the occurrence of age-1+ Colorado Pikeminnow from 2009–2010 to 2011–2013. It is possible that dispersal following stocking was reduced during recent years or that there was a higher site affinity because of changing habitat conditions over time. However, the population dynamics and apparent habitat preferences of age-1+ Colorado Pikeminnow should be interpreted cautiously as all individuals were reared under hatchery conditions, possibly affecting their selection of habitat and distribution within the river following stocking. Also, there were varying levels of stocking effort at different stocking locations among years, which could be influencing some of the occurrence and abundance trends for age-1+ individuals as well.

Occurrence-based δ models show promise in furthering our understanding of the causative mechanisms driving changes in age-0 and age-1 fish densities over time or space. The occurrence of early life stages of Colorado Pikeminnow or Razorback Sucker is an important factor to consider in the management of these species in the San Juan River. Significant changes in the probability of occurrence among years are indicative of potentially large-scale differences in the reproductive effort and early recruitment of individuals into the population. As was seen most pointedly with Razorback Sucker mixture model results, these occurrence trends (δ) don't necessarily reflect the abundance trends (μ) and were sometimes notably different. These results suggest that both occurrence and abundance trends should be considered as potentially important management tools for insight to mechanistic processes that are impacting endangered fish populations over time.

Despite the promise of mixture model estimates and general linear models for elucidating patterns of ichthyofaunal change within the San Juan River, there is still a considerable amount of work remaining to gain a richer understanding of the ecological processes that are driving changes in the larval endangered fish populations. It is possible that there are multiple abiotic and biotic factors that could explain a substantially higher proportion of the variation in the existing datasets. While the year models illustrate the importance of annual changes, it remains unclear why these changes are occurring and what factors are most critical to understanding the underlying processes. Future work will include the addition of more environmental and biological covariates to assess the relative importance, using the new modeling framework, of potentially vital processes that haven't yet been considered. Increased knowledge, based on sound analytical techniques, should lead to a more sound understanding of the dynamic ecological processes in the San Juan River, which will ultimately be essential in developing successful management plans for the recovery of endangered fish species.

The continued increase in upstream distribution coupled with 16 consecutive years of documented reproduction suggest adult Razorback Sucker are well established in the San Juan River. Estimated densities ($E(x)$) were significantly higher in 2011-2013 as compared to 2004-2009, suggesting an increasing trend in Razorback Sucker reproduction over the last ten years. This trend is supported by the San Juan River adult monitoring program which has documented an increase in the number of adult Razorback Sucker captured over the same time period (Benjamin Schleicher, pers. comm.)

The monitoring sites established in 2010 continue to demonstrate the importance of these types of habitats to the early life stages of Razorback Sucker. While all habitat is ephemeral in nature, backwaters that form in lateral arroyos and canyons tend to be larger in size than a backwater habitat that is cut into a sand or cobble bar. These main channel associated backwaters also tend to be more sensitive to changes in river stage, with relatively small changes either inundating the habitat or causing it to dry out. When present, the backwater habitats found at the monitoring site locations have consistently contained good numbers of larval Razorback Sucker. While none of the monitoring sites were connected to the river during the June survey (a critical time period in the reproductive cycle of Razorback Sucker), the monitoring sites sampled during the May survey produced 38.1% of all larvae collected in 2013.

While the specific habitat type varied from month to month, the six RERI sites demonstrated for a second consecutive year that these mechanically restored habitats are providing good nursery type habitat. Nearly every collecting effort made in an RERI site resulted in the collection of larval fishes. The only collections not to contain larvae were those done in the month of April. During that month, larval fishes were first collected at rivermile 31.2; nearly 100 rivermiles downstream of any RERI site. The species composition within the RERI sites was identical to that encountered throughout the study area. The relative abundance of individual species, timing of occurrence, and proportion of native to non-native species within the RERI sites was nearly identical to similar sampling sites located nearby. As the SJRBRIP program moves forward with a second phase of mechanical restoration, biological monitoring of these sites will continue to play a critical role in determining the effectiveness of this management strategy, and its benefits to the recovery of Colorado Pikeminnow and Razorback Sucker in the San Juan River.

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Appendix A

Figure A-1. Example of field data recorded at each sampling locality.

Field No.: WHB13 - 181

Date: 1 Aug 2013 / Acc. No.: 2013 - IV : 15

State/Country: Utah USA Locality: San Juan River @ RM 20.0

County: San Juan Co Drainage: San Juan Quad.: Slickhorn Canyon East

Coordinate System: UTM Datum: NAD 27 Zone: 12S

Start E/W: 577386 N/S: 4127679 Stop: E/W: N/S:

Shore Description: sand and limestone bolders, willow Air Temp.: 32.4 °C

Water Description: shoreline pockets

Substrate: silt & sand Water Depth: ≤ 80 m

Aquatic Vegetation / Cover: None / bolders

Water Temp.: 24.9 °C Velocity (est.): ≤ 1 m/s Width (est.): 4 m

Secchi Depth: Ø cm D.O. 5.89 mg/l Conductivity (µS): C. 793 / Sc. 795 Salinity: 0.39 ppt pH:

Method of Capture: hand seine / 1m x 1m

No. Hauls: 5 Area: 34.9 m² Shocking Sec.: Volts: Amps:

Collectors: WHBrandenburg, JMBarkstedt

Time: (start) 14.50 h (stop) 15.11 h Notes taken by: WHB

Orig.Preservative: 95% EtOH Photographs: 5027

Released fishes: Yes / No (list separately): Larval fishes: Yes / No

A variety of deeper low velocity shoreline habitats dot the bank punctuated by limestone bolders. The habitat looked good however only juvenile *Ictalurus punctatus* was captured.

① POSH 5.4 ✓

② PO SH 5.3 ✓

③ SS SH 8.2 —

④ SW SH 9.8 —

⑤ PO SH 6.2 —

Made it past Government once more.... whew —

Table A-1. Summary of larval Colorado Pikeminnow in the San Juan River (1993-2012) and back-calculated dates of spawning.

Field Number	MSB Catalog Number	Number of Specimens	Total Length (mm)	Date Collected	Date Spawned	River Mile	Sample Method
MH72693-2	18098	1	9.2	26 Jul 93	08 Jul 93	53.0	drift netting
MH72793-2	18099	1	9.2	27 Jul 93	09 Jul 93	53.0	drift netting
JPS95-205	26187	1	9.2	02 Aug 95	15 Jul 95	53.0	drift netting
JPS95-207	26191	1	9.0	03 Aug 95	17 Jul 95	53.0	drift netting
WHB96-037	29717	1	8.6	02 Aug 96	18 Jul 96	128.0	drift netting
FC01-054	50194	1	8.5	01 Aug 01	17 Jul 01	128.0	drift netting
MAF04-046	53090	1	14.2	22 Jul 04	24 Jun 04	46.3	larval seine
MAF04-059	53130	1	18.1	26 Jul 04	25 Jun 04	17.0	larval seine
MAF07-139	70144	1	14.9	25 Jul 07	27 Jun 07	107.7	larval seine
MAF07-157	70145	1	17.5	27 Jul 07	27 Jun 07	74.9	larval seine
WHB07-078	64032	1	15.6	25 Jul 07	27 Jun 07	33.7	larval seine
MAF09-072	74264	1	25.2	29 Jul 09	10 Jun 09	24.7	larval seine
MAF10-140	82014	1	12.6	23 Jul 10	27 Jun 10	58.9	larval seine
WHB10-096	82040	3	19.7-21.4	20 Jul 10	15-18 Jun 10	41.5	larval seine
WHB10-106	82071	1	16.2	22 Jul 10	23 Jun 10	13.0	larval seine
MAF11-114	86309	3	10.6-11.8	20 Jul 11	23-25 Jun 11	87.4	larval seine
WHB11-122	86561	21	10.0-12.9	21 Jul 11	25-29 Jun 11	10.8	larval seine
WHB11-124	86573	3	11.8-15.2	21 Jul 11	29 Jun-1 Jul 11	10.0	larval seine
WHB11-153	86656	1	21.3	10 Aug 11	5 Jul 11	92.6	larval seine
MAF11-149	86411	1	17.3	11 Aug 11	12 Jul 11	7.0	larval seine
TOTAL		**46**					

Table A-2. Summary of larval and age-0 Razorback Sucker collected during the San Juan River larval fish survey 1998-2012.

Year	Study Area	Project Dates	Total Effort m^2	Xyrtex	Sample Method
1998	127.5 - 53.0	17 Apr - 6 Jun	-	2	larval seine/ light trap
1999	127.5 - 2.9	5 Apr - 10 Jun	2,713.5	7	larval seine/ light trap
2000	127.5 - 2.9	4 Apr - 23 Jun	2,924.6	129	larval seine/ light trap
2001	141.5 - 2.9	10 Apr - 14 Jun	5,733.1	50	larval seine/ light trap
2002	141.5 - 2.9	15 Apr - 12 Sep	9,647.5	815	larval seine/ light trap
2003	141.5 - 2.9	15 Apr - 19 Sep	13,564.6	472	larval seine
2004	141.5 - 2.9	19 Apr - 14 Sep	11,820.3	41	larval seine
2005	141.5 - 2.9	19 Apr - 14 Sep	10,368.6	19	larval seine
2006	141.5 - 2.9	17 Apr - 15 Sep	12,582.6	202	larval seine
2007	141.5 - 2.9	16 Apr - 19 Sep	13,436.0	200	larval seine
2008	141.5 - 2.9	14 Apr - 13 Sep	14,292.3	126	larval seine
2009	141.5 - 2.9	13 Apr - 26 Sep	15,860.3	272	larval seine
2010	141.5 - 2.9	19 Apr - 3 Sep	16,761.0	1,251	larval seine
2011	141.5 - 2.9	13 Apr - 26 Sep	9,387.9	1,065	larval seine
2012	147.9 - 2.9	16 Apr - 9 Aug	8,269.8	1,778	larval seine
TOTAL				**6,429**	

Table A-3. Locality and description of monitoring sites designated for habitat persistence.

River Mile	Reach	Easting	Northing	Locality description	
124.8	4	678281	4091267	lateral wash	river left
119.5	4	675632	4096476	lateral wash	river left
118.5	4	674456	4097745	lateral wash	river left
116.9	4	673442	4100108	lateral wash	Cowboy Wash
104.4	3	663008	4115111	lateral wash	river left
92.2	3	648003	4125824	lateral wash	Montezuma Creek
84.1	3	635458	4127339	lateral wash	Recapture Creek
57.9	2	603144	4115670	lateral wash	Lime Creek
52.4	2	601301	4111310	lateral wash	Gypsum Creek
17.7	2	575497	4130142	lateral canyon	Slickhorn Canyon
16.4	1	573427	4130259	lateral canyon	river right
10.0	1	563449	4126456	lateral canyon	Buckhorn Canyon
8.1	1	561124	4128666	lateral canyon	Steer Gulch
3.3	1	553978	4127054	lateral canyon	river right

Table A-4. Summary of age-0 fishes collected in the San Juan River during the 2013 larval fish survey. Effort =9,750.0m^2.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
Red Shiner	I	9,534	37.9	97.8	104	35.6
Common Carp	I	27	0.1	0.3	15	5.1
Roundtail Chub	N	-	-	-	-	-
Fathead Minnow	I	1,502	6.0	15.4	76	26.0
Colorado Pikeminnow	N	12	*	0.1	7	2.4
Speckled Dace	N	3,779	15.0	38.8	157	53.8
SUCKERS						
Flannelmouth Sucker	N	1,827	7.3	18.7	123	42.1
Bluehead Sucker	N	6,637	26.4	68.1	133	45.5
Razorback Sucker	N	979	3.9	10.0	91	31.2
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	21	0.1	0.2	8	2.7
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	342	1.4	3.5	66	22.6
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	37	0.1	0.4	7	2.4
LIVEBEARERS						
Western Mosquitofish	I	412	1.6	4.2	34	11.6
SUNFISHES						
Green Sunfish	I	-	-	-	-	-
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	18	0.1	0.2	10	3.4
TOTAL		25,127		257.7		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on n = 292 samples.
* Value is less than 0.05%

Table A-5. Summary of age-1+ fishes collected in the San Juan River during the 2013 larval fish survey. Effort =9,750.0 m^2

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
Red Shiner	I	237	33.1	2.4	68	23.2
Common Carp	I	1	0.1	*	1	0.3
Roundtail Chub	N	-	-	-	-	-
Fathead Minnow	I	48	6.7	0.5	23	8.9
Colorado Pikeminnow	N	48	6.7	0.5	23	8.9
Speckled Dace	N	197	27.6	2.0	57	19.5
SUCKERS						
Flannelmouth Sucker	N	40	5.6	0.4	18	6.1
Bluehead Sucker	N	1	0.1	*	1	0.3
Razorback Sucker	N	-	-	-	-	-
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	1	0.1	*	1	0.3
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	-	-	-	-	-
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	21	2.9	0.2	1	0.3
LIVEBEARERS						
Western Mosquitofish	I	119	16.6	1.2	21	7.2
SUNFISHES						
Green Sunfish	I	1	0.1	*	1	0.3
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	1	0.1	*	1	0.3
-						
TOTAL		715		7.3		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on n = 292 samples.
* Value is less than 0.05%

Table A-6. Scientific names, common names, and species codes of fishes collected in the San Juan River. Asterisk (*) indicates a species was collected in prior years surveys but not in the 2013 larval fish survey.

Scientific Name	Common Name	Code
Order Cypriniformes		
Family Cyprinidae	**carps and minnows**	
Cyprinella lutrensis	Red Shiner	(CYPLUT)
Cyprinus carpio	Common Carp	(CYPCAR)
*Gila robusta**	Roundtail Chub	(GILROB)
Pimephales promelas	Fathead Minnow	(PIMPRO)
Ptychocheilus lucius	Colorado Pikeminnow	(PTYLUC)
Rhinichthys osculus	Speckled Dace	(RHIOSC)
Family Catostomidae	**suckers**	
Catostomus (Pantosteus) discobolus	Bluehead sucker	(CATDIS)
Catostomus latipinnis	Flannelmouth sucker	(CATLAT)
Xyrauchen texanus	Razorback sucker	(XYRTEX)
Order Siluriformes		
Family Ictaluridae	**catfishes**	
Ameiurus melas	Black Bullhead	(AMEMEL)
*Ameiurus natalis**	Yellow Bullhead	(AMENAT)
Ictalurus punctatus	Channel Catfish	(ICTPUN)
Order Salmoniformes		
Family Salmonidae	**trouts**	
*Oncorhynchus nerka**	Kokanee Salmon	(ONCNER)
Order Cyprinodontiformes		
Family Fundulidae	**topminnows**	
Fundulus zebrinus	Plains Killifish	(FUNZEB)
Family Poeciliidae	**livebearers**	
Gambusia affinis	Western Mosquitofish	(GAMAFF)
Order Perciformes		
Family Centrarchidae	**sunfishes**	
Lepomis cyanellus	Green Sunfish	(LEPCYA)
*Lepomis macrochirus**	Bluegill	(LEPMAC)
Micropterus salmoides	Largemouth Bass	(MICSAL)

Table A-7. Summary of the age-0 Colorado Pikeminnow collected in the San Juan River during the July and August larval fish survey.

Field Number	N=	Length (mm TL)	Ontogeneic Stage	Date Collected	Rivermile
WHB13-135	1	16.7	metalarva	17-Jul-13	107.6
WHB13-140	1	14.1	metalarva	18-Jul-13	100.5
WHB13-151	1	28	juvenile	19-Jul-13	79.4
WHB13-152	4	15.8 - 17.6	metalarvae	19-Jul-13	78
WHB13-163	1	28.7	juvenile	30-Jul-13	59.3
WHB13-187	3	15.8 - 23.6	meta -juvenile	1-Aug-13	14
WHB13-189	1	28.7	juvenile	2-Aug-13	10
Total	**12**				

Table A-8. Summary of the age-0 Razorback Sucker collected in the San Juan River during the May larval fish survey.

Field Number	N=	Length (mm TL)	Ontogeneic Stage	Date Collected	Rivermile
WHB13-035	5	11.1 -12.7	mesolarvae	20-May-13	146.2
WHB13-038	15	11.6 -19.8	proto - mesolarvae	20-May-13	139.6
WHB13-039	2	11.5, 16.0	proto - mesolarvae	21-May-13	134.9
WHB13-044	2	10.9, 13.3	proto - mesolarvae	21-May-13	130.6
WHB13-045	19	10.5 -13.7	proto - mesolarvae	21-May-13	128.1
WHB13-046	1	12	mesolarvae	21-May-13	126.6
WHB13-047	43	10.3 -16.1	meso - metalarvae	21-May-13	124.8
WHB13-048	16	10.5 -15.9	proto - mesolarvae	21-May-13	123.2
WHB13-051	2	11.7, 14.8	mesolarvae	21-May-13	118.4
WHB13-052	3	10.5 -12.3	protolarvae	22-May-13	116.2
WHB13-053	34	10.1 -15.4	proto - mesolarvae	22-May-13	113.7
WHB13-054	4	10.5 -13.2	proto - mesolarvae	22-May-13	110.9
WHB13-056	3	11.8 -17.1	mesolarvae	22-May-13	104.2
WHB13-057	5	11.3 -14.7	proto - mesolarvae	22-May-13	102.5
WHB13-060	4	13.0 -15.7	mesolarvae	22-May-13	99.7
WHB13-062	11	12.0 -18.1	mesolarvae	22-May-13	93
WHB13-063	10	9.9 -16.3	proto - mesolarvae	22-May-13	92.2
WHB13-064	2	14.9 - N/A	mesolarvae	23-May-13	90
WHB13-065	9	13.0 -15.7	mesolarvae	23-May-13	88.3
WHB13-066	4	13.0 -15.2	mesolarvae	23-May-13	84.1
WHB13-067	5	9.9 -16.3	proto - mesolarvae	23-May-13	81.2
WHB13-068	14	10.9 -18.1	mesolarvae	23-May-13	79.3
MAF13-042	58	10.9 -18.8	proto - mesolarvae	17-May-13	75.4
MAF13-043	1	13.1	protolarva	17-May-13	71
MAF13-044	2	11.5, 13.3	mesolarvae	17-May-13	69.5
MAF13-047	6	10.5 -14.4	proto - mesolarvae	18-May-13	63
MAF13-049	60	11.0 -21.4	proto - metalarvae	18-May-13	57.9
MAF13-053	1	13.1	mesolarva	18-May-13	43.5
MAF13-054	16	10.4 -15.4	proto - mesolarvae	18-May-13	41.6
MAF13-055	32	9.6 -18.2	proto - mesolarvae	18-May-13	38.8
MAF13-057	16	9.5 -15.0	proto - mesolarvae	19-May-13	24.5
MAF13-060	29	11.8 -20.7	meso - metalarvae	19-May-13	18.5
MAF13-061	40	10.5 -21.2	proto - metalarvae	19-May-13	17.7
MAF13-063	1	21.1	metalarva	20-May-13	16.4
MAF13-064	24	10.8 -18.8	meso - metalarvae	20-May-13	11.4
MAF13-065	2	15.6, 17.7	mesolarvae	20-May-13	10
MAF13-066	1	14.2	mesolarvae	20-May-13	9.6
MAF13-067	104	9.7 -19.3	proto - metalarvae	20-May-13	8.1
MAF13-068	16	11.9 -18.8	mesolarvae	20-May-13	7
MAF13-069	6	9.6 -15.4	mesolarvae	20-May-13	5.6
MAF13-070	7	11.0 -17.4	mesolarvae	20-May-13	3.3
May Total	**635**				

Table A-8. Summary of the age-0 Razorback Sucker collected in the San Juan River during the June and July larval fish surveys.

Field Number	N=	Length (mm TL)	Ontogeneic Stage	Date Collected	Rivermile
MAF13-072	2	11.4, 12.1	mesolarvae	9-Jun-13	147.5
MAF13-074	3	14.6 -16.1	mesolarvae	9-Jun-13	144.8
MAF13-075	1	10.7	mesolarva	9-Jun-13	137
MAF13-079	2	10.0, 10.3	protolarvae	10-Jun-13	131
MAF13-082	3	17.7 -27.8	meso - juvenile	10-Jun-13	126.4
MAF13-085	11	10.0 -22.6	meso - metalarvae	10-Jun-13	119.8
MAF13-089	1	11.1	mesolarva	11-Jun-13	116.6
MAF13-090	11	13.1 -23.6	meso - metalarvae	11-Jun-13	113.7
MAF13-092	17	14.3 -25.4	meso - juvenile	11-Jun-13	106.7
MAF13-093	4	10.8 -24.6	meso - metalarvae	11-Jun-13	106.6
MAF13-094	1	9.8	protolarva	11-Jun-13	105.1
MAF13-097	11	12.8 -25.2	meso - metalarvae	11-Jun-13	100.5
MAF13-100	11	10.3 -19.8	meso - metalarvae	12-Jun-13	96.1
MAF13-101	1	11.4, 12.1	mesolarvae	12-Jun-13	93.8
MAF13-103	11	10.9 -19.2	mesolarvae	12-Jun-13	91.7
MAF13-108	1	11.3	mesolarva	13-Jun-13	82.4
MAF13-109	9	10.1 -16.9	protolarvae	13-Jun-13	81
MAF13-111	2	12.2 -28.0	meso - juvenile	13-Jun-13	78.5
WHB13-071	2	11.5, 11.9	mesolarvae	9-Jun-13	71.7
WHB13-074	12	11.8 -20.8	meso - metalarvae	10-Jun-13	70.2
WHB13-075	6	11.7 -29.0	meso - metalarvae	10-Jun-13	68.7
WHB13-076	7	12.9 -37.2	meso - juvenile	10-Jun-13	67.6
WHB13-077	1	11.8	mesolarva	10-Jun-13	67
WHB13-079	3	10.4 -11.0	mesolarva	10-Jun-13	64.9
WHB13-081	95	13.8 -37.3	proto - juvenile	10-Jun-13	57.9
WHB13-082	14	9.5 -23.4	proto - mesolarvae	10-Jun-13	56
WHB13-084	2	9.8, 11.2	mesolarvae	10-Jun-13	54.5
WHB13-087	2	10.4 -15.0	protolarvae	11-Jun-13	48.2
WHB13-089	4	10.8 -11.9	proto - mesolarvae	11-Jun-13	43.9
WHB13-090	1	12.2	mesolarvae	11-Jun-13	41.8
WHB13-091	4	11.4 -12.7	mesolarvae	11-Jun-13	39.2
WHB13-092	4	9.8 -10.7	proto - mesolarvae	11-Jun-13	37.7
WHB13-093	2	10.2, 11.6	mesolarvae	11-Jun-13	33.5
WHB13-097	5	11.3 -14.2	mesolarvae	12-Jun-13	24.8
WHB13-098	3	10.4 -14.3	mesolarvae	12-Jun-13	24.5
WHB13-099	1	12.4	mesolarva	12-Jun-13	24.4
WHB13-102	2	19.2, 37.8	meta - juvenile	12-Jun-13	17.7
WHB13-105	6	10.4 -15.4	mesolarvae	13-Jun-13	12.4
WHB13-106	34	9.8 -23.0	proto - metalarvae	13-Jun-13	11.4

Table A-8. (Con't). Summary of the age-0 Razorback Sucker collected in the San Juan River during the June and July larval fish surveys.

Field Number	N=	Length (mm TL)	Ontogeneic Stage	Date Collected	Rivermile
WHB13-107	3	13.2 -15.6	mesolarvae	13-Jun-13	10
WHB13-109	4	10.0 -16.6	mesolarvae	13-Jun-13	7.2
WHB13-110	15	10.0 -15.8	mesolarvae	13-Jun-13	5.1
WHB13-112	1	16.7	mesolarva	13-Jun-13	3.1
WHB13-126	1	38.5	juvenile	16-Jul-13	126.6
WHB13-127	1	68	juvenile	16-Jul-13	124.8
WHB13-132	1	70	juvenile	17-Jul-13	116.9
WHB13-140	1	33.4	juvenile	18-Jul-13	100.5
WHB13-142	1	26.2	juvenile	18-Jul-13	98.6
WHB13-148	1	54	juvenile	18-Jul-13	84.1
WHB13-151	3	26.8 -55.0	juvenile	19-Jul-13	79.4
June/July Total	**344**				
2013 Total	**979**				