Colorado Pikeminnow and Razorback Sucker larval fish survey in the San Juan River during 2014

FINAL REPORT

Michael A. Farrington[1], Dr. Robert K. Dudley[1], Jennifer L. Kennedy[1], Steven P. Platania[1] and Dr. Gary C. White[2]

[1]American Southwest Ichthyological Researchers L.L.C. 800 Encino Place NE
Albuquerque, New Mexico 87102-2606
&
[2]Department of Fish, Wildlife, and Conservation Biology; 239 Wagar,
Colorado State University, Fort Collins, Colorado 80523-1474

SAN JUAN RIVER BASIN RECOVERY IMPLEMENTATION PROGRAM
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prepared by:

Michael A. Farrington[1], Dr. Robert K. Dudley[1], Jennifer L. Kennedy[1],
Steven P. Platania[1] and Dr. Gary C. White[2]
[1]American Southwest Ichthyological Researchers L.L.C.
800 Encino Place NE Albuquerque, New Mexico 87102-2606
&
[2]Department of Fish, Wildlife, and Conservation Biology; 239 Wagar,
Colorado State University, Fort Collins, Colorado 80523-1474

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Executive Summary

From 21 April to 31 July 2014 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 1,373 cfs (225–4,110 cfs) and mean temperature was 20.5 °C (12.2–27.4 °C). A total of 290 collections were made encompassing 8,623 m^2 of low velocity habitat. The 290 collections contained 19,288 age-0 and 1,220 age-1+ fish representing six families and 14 species.

There were 312 age-0 Colorado Pikeminnow collected in 2014 between river miles 116.9 and 3.2. Colorado Pikeminnow ranged from 8.5 to 20.8 mm (total length) and specimens included ontogenetic stages ranging from mesolarvae to juvenile. Back-calculated spawning dates encompassed an 18-day period between 15 June and 2 July 2014. A total of 98 age-1+ Colorado Pikeminnow were also collected in 2014. 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 (δ (Year) μ(Monitor 450+(*R*)) received most (0.49) of the AIC_C weight (w_i). Cumulatively, the top ten models received > 99.0% of the AIC_C weight with the top two models (both with fall monitoring capture data covariates for Delta) receiving > 65.0% of the AIC_C weight. The estimated densities ($E(x)$) of age-0 Colorado Pikeminnow in 2014, using sampling-site density data, were significantly higher ($P < 0.05$) than any of the previous years (2003–2013).

Within the habitat types, estimated densities ($E(x)$) for Colorado Pikeminnow were higher in backwaters and embayments ($P < 0.05$) than in low velocity, zero velocity, or run type habitats. Estimated densities in the terminus of backwaters and embayments were higher ($P < 0.05$) than those associated with the shoreline.

Between the April and mid-July sampling trips, 612 larval Razorback Sucker were collected between river miles 147.1 and 3.2. Ontogenetic stages of age-0 Razorback Sucker ranged from protolarvae to juvenile and back-calculated spawning dates ranged from 13 March to 30 June 2014. Spawning by Razorback Sucker in the San Juan River has been documented for each of the last 17 years. General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(cumulative#stocked+*R*) μ(cumulative#stocked+*R*)) model received most (0.72) of the AIC_C weight (w_i) Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2014), were highest in 2011 (16.5) and 2014 (16.2) and lowest in 1999 (0.17) and 2005 (0.21). The estimated densities of Razorback Sucker were significantly higher ($P < 0.05$) in 2011–2014 as compared with 1999–2001 and 2004–2009.

Within the habitat types, estimated densities ($E(x)$) for larval Razorback Sucker were significantly higher in backwaters ($P < 0.05$) when compared to low and zero velocity habitat types. Estimated densities were also higher ($P < 0.05$) in embayments compared with low velocity habitats.

For the second consecutive year, monitoring sites had a low level of connectivity to the river. Among the five trips, there were 64 visitations to the monitoring sites. A backwater habitat was only encountered 26 times. Between April and the mid-July survey, 126 age-0 Razorback Sucker were collected from monitoring sites; this represents 20.6% of the 2014 yearly total. A single age-0 Colorado Pikeminnow was also collected at the river mile 116.9 (Cowboy Wash) monitoring site during the mid-July survey. This collection was the farthest upstream documentation of age-0 Colorado Pikeminnow during 2014.

During the 2014 larval survey the phase I 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 within the RERI sites was similar to comparable river sites, but RERI sites were found to have a higher proportion of native species.

Elevated levels of opercular deformities continue to be observed in age-0 Razorback Sucker. Of the 85 specimens rated in 2014, 34.1% 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 nonnative 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 20ºC and 25ºC (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 14ºC (Tyus and Karp, 1990). Razorback Sucker larvae have been collected from Lake Mohave at 9.5–15.0ºC, 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 notable 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).

Early investigations into the reproductive success of Colorado Pikeminnow on the San Juan River, using larval drift nets were conducted 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. Razorback Sucker larvae have been documented every year since 1998 (Table A-2).

Objectives

This work was conducted as required by the San Juan River Basin Implementation Program (2014) 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.

4.1.7.2 Provide annual updates of the rate of opercular deformities found in Razorback Sucker.

4.2.3.2 Document and track trends in the use of specific mesohabitat types by larval Colorado Pikeminnow and Razorback Sucker.

4.2.4.1 Identify principal river reaches and habitats used by various life stages of endangered fish.

4.3.2.1 Monitor TNC's restoration sites.

5.1.1.3 Provide detailed analysis of data collected to determine progress towards endangered species recovery in the San Juan River.

Study Area

The San Juan River is a major tributary of the Colorado River and drains 38,300 mi.^{2} (99,198 km.^{2}) in Colorado, New Mexico, Utah, and Arizona (Figure 1). 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 (360 km) 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, (1.9 m/km) but can be as high as 21.2 ft/mi. (4.0 m/km) 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. Convective storm-induced flow spikes frequently punctuate summer and early autumn base flows. 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 historically unregulated storm induced flow spikes were 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 50% of pre-dam values. Conversely, post-dam base flow increased over pre-dam base flows. Since 1992, efforts have been made to operate Navajo Dam to mimic a "natural" annual flow regime.

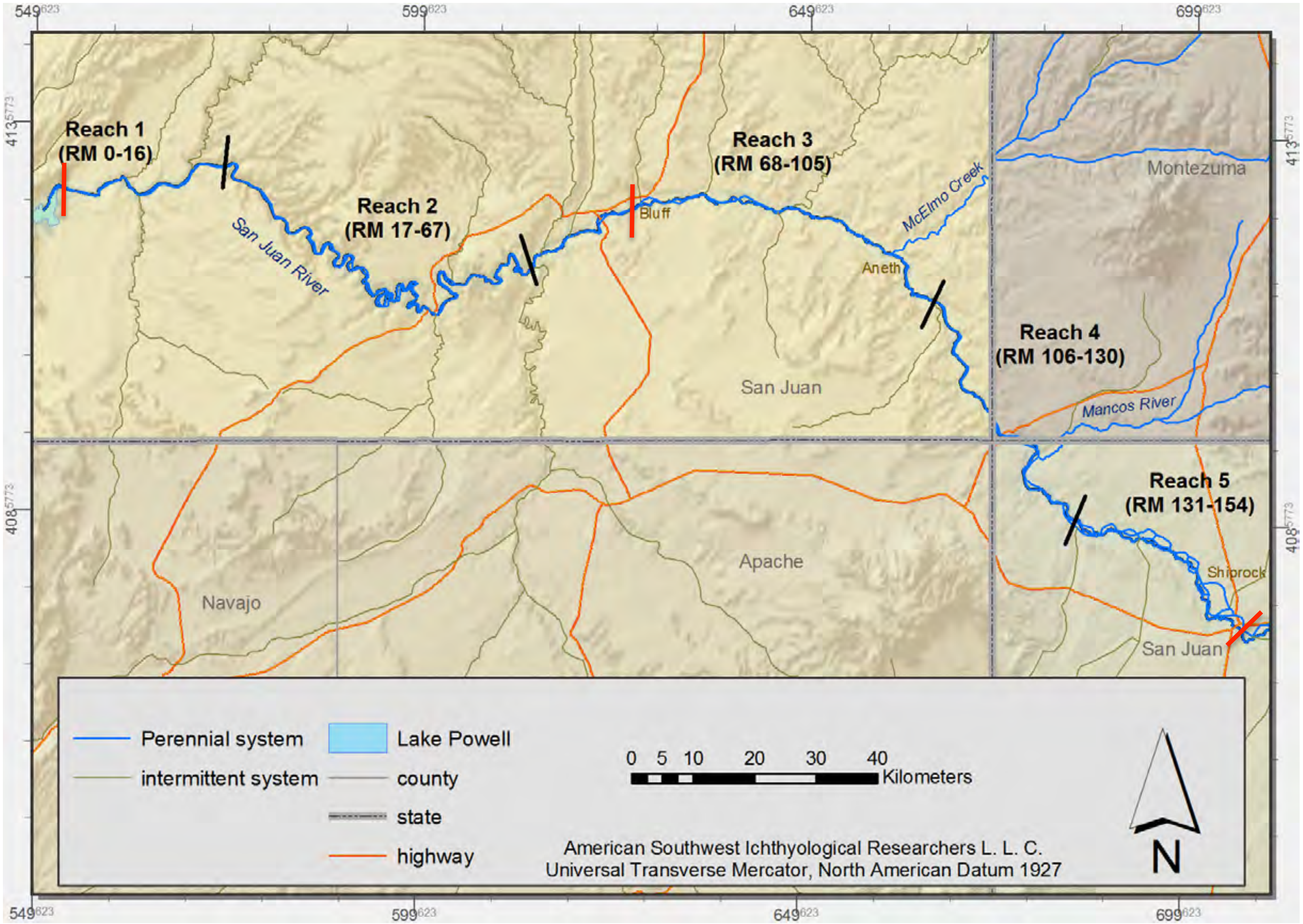


Figure 1. Map of the 2014 study area. Red bars denote upper (Shiprock, NM), middle (Sand Island, UT) and lower (Clay Hills, UT) boundaries.

Methods

Access to the river and collection localities was gained through the use of 16' (4.9 m) and 12’ (3.7 m) inflatable rafts that transported both personnel and collecting gear. There were 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.

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 backwater 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 (e.g. too deep or swift), photos were taken and no collection was made.

All retained specimens were placed in plastic bags (Whirl-Paks) containing a solution of 95% ethyl alcohol and a tag inscribed with a unique 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 follows conventions established 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.

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 (1999–2014) Colorado Pikeminnow, and ichtyofaunal community (2003–2014) sampling-site density data were analyzed using PROC NLMIXED (SAS, 2014), a numerical optimization procedure, by fitting a mixture model using 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 four parameter estimates for each year (δ = probability of occurrence, μ = mean of the lognormal distribution, σ = standard deviation of the lognormal distribution, and $E(x)$ = estimated density).

General linear models were used to incorporate covariates to model δ, μ, and σ. Covariates considered to model annual sampling-site density data for Razorback Sucker (1999–2014) were year, reach, mean April flow and temperature, mean May flow and temperature, annual number stocked, cumulative number stocked, and fall monitoring captures (1+ overwinter periods) For example, if 175 individuals were collected during fall 2013 it was assumed that these individuals would be available to spawn in spring 2014 (Table A-7). Covariates considered to model annual sampling-site density data for Colorado Pikeminnow

(2003–2014) were year, reach, mean June flow and temperature, mean July flow and temperature, and fall monitoring captures in two size categories (450+ mm TL and 300-449 mm TL). The same overwinter criteria applied to Razorback Sucker were used for Colorado Pikeminnow (Table A-8).

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 (April through 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). All AIC tables present the top models (5-10) that account for > 99.0% of the AIC_C weight (w_i). Differences among null and alternative models were assessed using a log-likelihood ratio goodness-of-fit test (Zar, 2010). For nested models, an analysis of deviance (ANODEV) was used to determine the proportion of deviance explained by the covariates for both the δ and μ models and to assess the significance ($P < 0.05$) of those values based on an *F*-test (Skalski et al., 1993).

Additional samples were taken in 2013 and 2014 to increase the overall sample size and provide supplemental information on habitats (i.e., habitat type, habitat location, and cover type). Field sampling efforts occurred in nine habitat types (backwater [BW], cobble shoal [CS], eddy [ED], embayment [EM], pool [PO], pocketwater [PW], run [RU], sand shoal [SS], and slackwater [SW]). Additionally, 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., providing information on habitat type, 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. Habitat-specific density data were also analyzed using PROC NLMIXED (SAS, 2014), using the same methods outlined previously, to assess differences among models. A simplified list of five habitats (BW, EM, RU, LV [combining CS, PW, SS, and SW], and NZV [combining ED and PO]) was used for the purpose of statistical analysis since several habitats shared nearly identical low velocity (LV) or near zero velocity (NZV) conditions. 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. General linear models were used to incorporate covariates to model δ, μ, and σ. Covariates considered to model habitat-specific density data were year, reach, habitat type, habitat location, and cover type. Random effects models were used with the joint binomial and lognormal likelihood to provide random errors for the Site*Year combinations. Bivariate normal errors with mean zero and covariance were assumed for each Site*Year combination. A random error was added to the logit of the binomial parameter δ, and a second random error was added to the log of the μ lognormal parameter. Adaptive Gaussian quadrature as described in Pinheiro and Bates (1995) was used to integrate out these random effects in fitting the model using the SAS NLMIXED procedure. Goodness-of-fit statistics (logLike and AIC_C) were generated to assess the relative fit of data to various models.

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^{o}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). Spawning dates for Razorback Sucker are then calculated once hatching dates have been established using the negative exponential equation $y = 1440.3e^{\mathbf{-0.109x}}$ (Bestgen et. al., 2011) where y is the temperature dependent incubation time (in hours), *e* is the base of the natural logarithm, and x is the mean daily temperature on the hatching date.

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, maximum, minimum) were taken at the state highway 160 bridge crossing in Colorado (river mile 119.2) and near Bluff, UT (river mile 52.0).

Results

2014 Summary

The 2014 San Juan River larval fish survey encompassed a four-month period from 21 April to 31 July 2014. 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 1,373 cfs (225–4,110 cfs) and 20.5 ^{o}C (12.2–27.4^{o}C). There were no large spring releases out of Navajo Dam in 2014 and discharge in the San Juan River exceeded 4,000 cfs for three consecutive days (1-3 June). Discharge was less than 1,000 cfs for the majority of 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.

During the 2014 larval fish survey, 290 collections were made in zero and low velocity habitats encompassing an area of 8,623 m^2. Collections resulted in the capture of 20,508 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–late July) and accounted for 94.1% of the overall catch (*n* = 19,288).

Low discharge (225 cfs) during the late July survey (27 and 28 July 2014) precluded sampling below Mexican Hat, UT. The lower canyon bound reaches (particularly Reach 1) are not navigable at the discharge levels encountered. Therefore, there is no capture data for the study area below Mexican Hat for this final sampling trip.

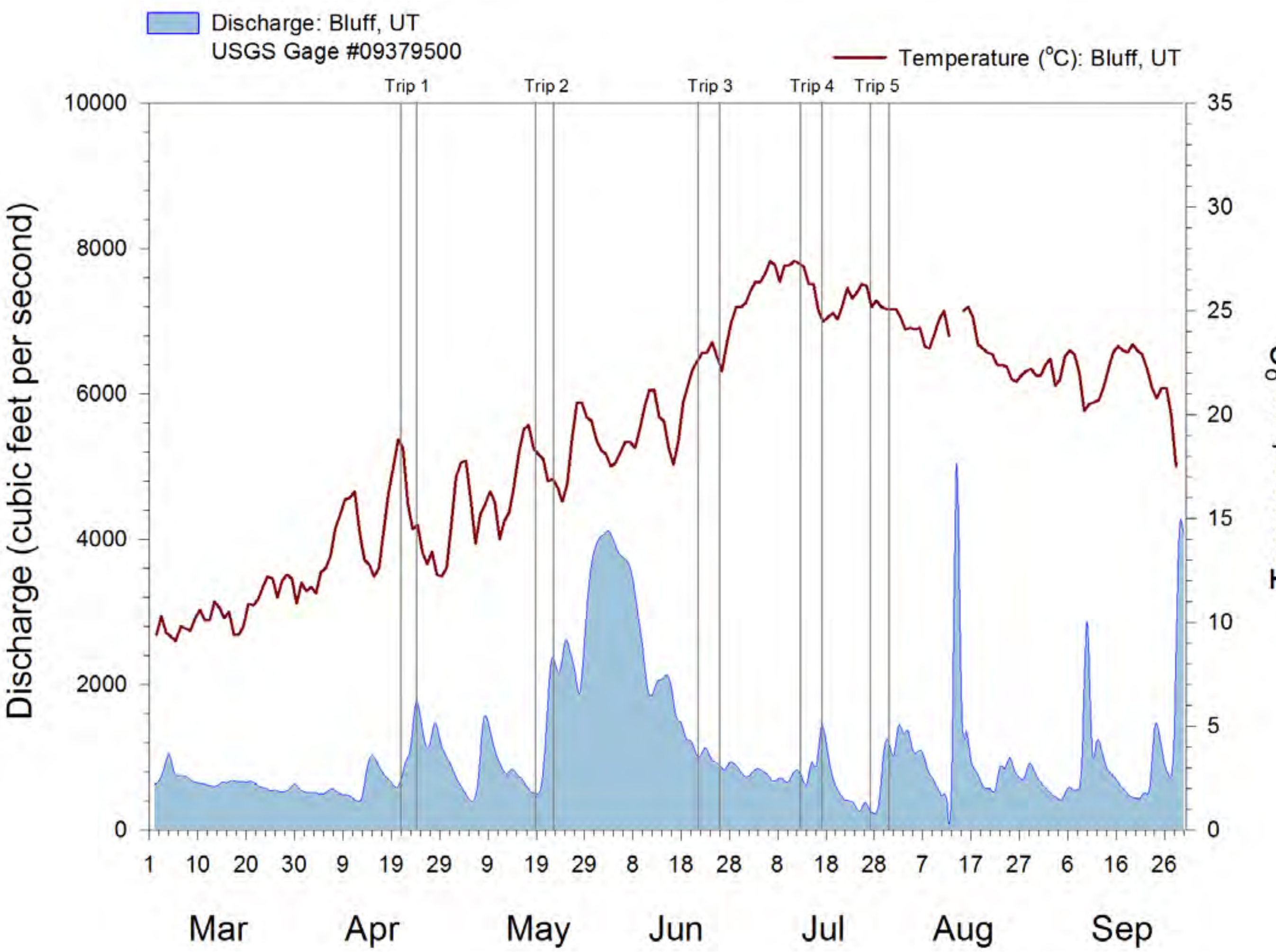


Figure 2. Discharge (cfs) and temperature (^{o}C) in the San Juan River during the 2014 sampling period. Grey vertical bars denote individual collecting trips.

Colorado Pikeminnow

2014 Summary

There were 312 larval Colorado Pikeminnow collected in 2014 between river miles 116.9 and 3.2. Colorado Pikeminnow was collected during the mid and late July surveys at 34 discrete localities (Figure 3). Prior to 2014, only 58 larval Colorado Pikeminnow had been collected in the 20 year period between 1993 and 2013 (Table A-1). Spawning by Colorado Pikeminnow has been documented in seven of the last 12 years, and four of the last five, in the San Juan River. Colorado Pikeminnow ranged in size from 8.5 to 20.8 mm TL and specimens included ontogenetic stages ranging from mesolarvae to juvenile (Table A-9). Back-calculated spawning dates encompassed a two and a half week (18 day) period between 15 June and 2

July 2014 (Figure 4). Mean temperature and discharge during this period were 20.8 ^oC (17.1–23.9 ^oC) and 1,233 cfs (807–2,680 cfs). A total of 98 age-1+ Colorado Pikeminnow were also collected in 2014. It is assumed these fish were the results of augmentation efforts.

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 (δ (Year) μ(Monitor 450+(*R*)) received the most AIC_C weight (w_i) (Table 1). Cumulatively, the top ten models received > 99.0% of the AIC_C weight with the top two models (both with fall monitoring capture data covariates for Mu (μ) receiving > 65.0% of the AIC_C weight.

The estimated densities ($E(x)$) of Colorado Pikeminnow in 2014 using sampling-site density data (2003–2014) were significantly higher ($P < 0.05$) than any of the preceding years (Figure 5). Estimated density, with 95% confidence intervals, could not be computed in 2009 since there was only a single non-zero value recorded which precluded mixture-model estimation of σ. Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities over time. Estimated densities in 2014 were an order of magnitude higher than the second highest estimated density (2011).

Habitat

Within the habitats sampled in 2014, the general linear model showed that the (δ(Year) μ (Year) random Station received nearly all of the AIC_C weight (w_i) (Table 2). Within the habitat types, estimated densities ($E(x)$) were significantly higher in backwaters and embayments ($P < 0.05$) than in condensed low velocity, zero velocity, or run type habitats (Figure 6). Estimated density, with 95% confidence intervals, could not be computed for run habitats since there was only a single non-zero value, which precluded mixture-model estimation of σ. Within backwaters and embayments, there was little difference in estimated densities within the location sampled. However, estimated densities in the terminus of backwaters and embayments were significantly higher ($P < 0.05$) than those associated with the shoreline (Figure 6).

Trip and reach

Larval Colorado Pikeminnow were first collected during the mid-July survey, and were present again two weeks later during the late July survey (Figure 7). Nearly all (99.0%) of larval Colorado Pikeminnow were collected during the mid-July survey and were found in Reaches 4-1 (Figure 7). During this trip, larval Colorado Pikeminnow was found in nearly half (45.1%) of all collections. During the late July survey, three larval Colorado Pikeminnow were collected at two localities between Bluff and Mexican Hat, UT. Due to low discharge (225 cfs) during this final trip, no sampling occurred downstream of Mexican Hat.

Among reaches, Reach 2 had the highest densities (13.6 fish per $100m^2$) with the largest single collection of 91 individuals also being in this reach. While densities were lowest in Reach 4 (0.27 fish per $100m^2$) 2014 was the third year in which Colorado Pikeminnow larvae were collected in this reach.

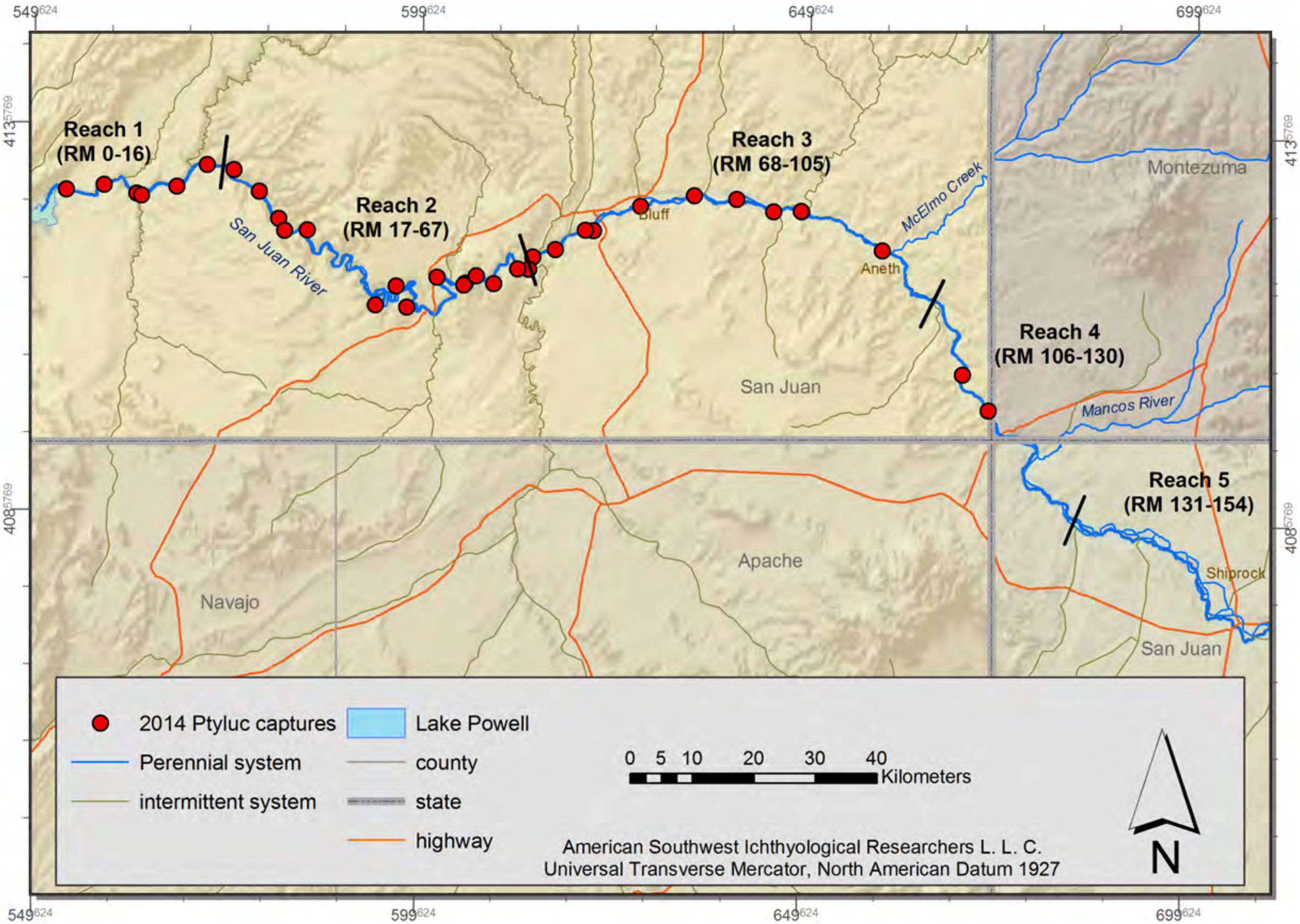


Figure 3. Map of the 2014 age-0 Colorado Pikeminnow collection localities.

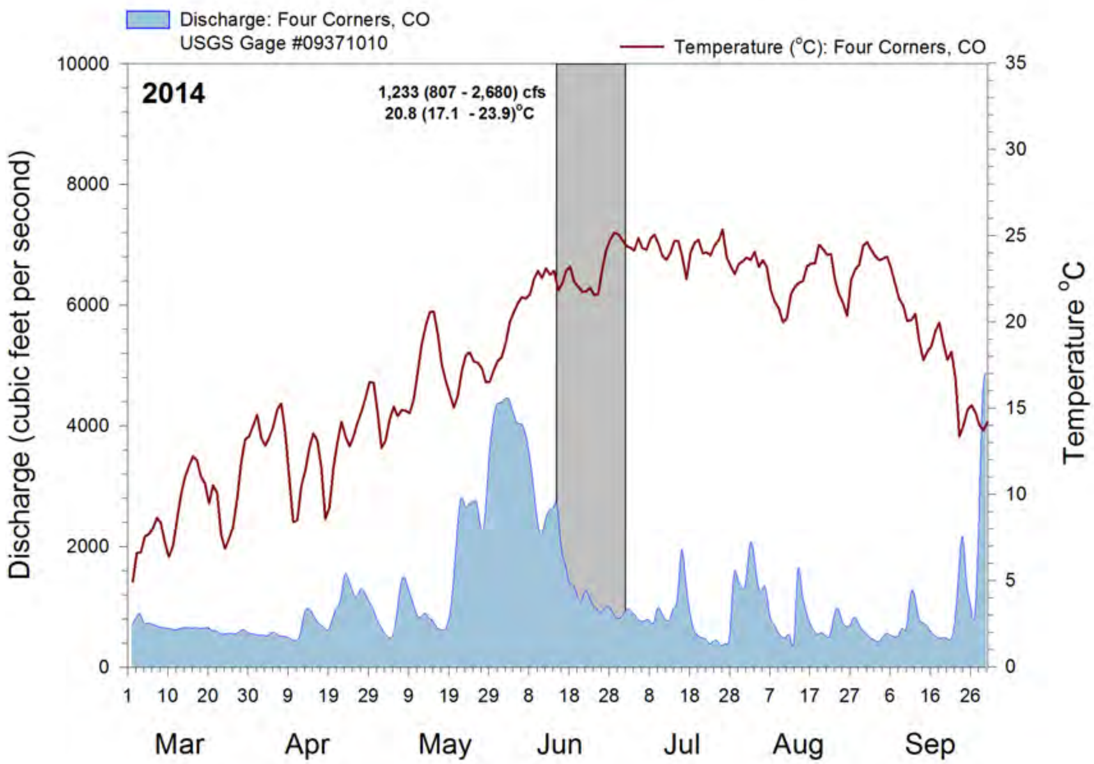


Figure 4. Back-calculated spawning dates for Colorado Pikeminnow plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported.

Ontogenetic stages

Three ontogenetic stages of Colorado Pikeminnow were collected in 2014. During the mid-July survey, mesolarvae and metalarvae were found in similar densities and distributed in a similar pattern within the study area (Figure 8). During the late July survey, metalarvae and a single juvenile fish were collected. The juvenile fish was found at river mile 62.4 (Figure 8) and was recently transformed from the metalarval stage. There is no collection data below river mile 53.3 (Mexican Hat, UT) for this final survey.

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 year model (δ (Year) μ(Year)) received essentially all of the AIC_C weight (w_i) despite having the most parameters (Table 3). 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)).

The estimated densities (*E*(x)) of age-1+ Colorado Pikeminnow, using sampling-site density data (2003–2014), were highest in 2009 (2.63) and lowest in 2011 (0.28). The estimated densities of Colorado Pikeminnow differed significantly ($P > 0.05$) across years, with 2011, and 2013 being years with lower densities (Figure 9). Estimated densities for 2014 were similar to all previous years except 2011. Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities over time.

Table 1. General linear models of Colorado Pikeminnow (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and covariates, allowing for random effects (*R*). Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Monitor 450+mm TL)	16	382.22	414.61	0.491
δ(Year) μ(Monitor 300-449 mm TL)	16	384.44	416.82	0.163
δ(Year) μ(.)	14	389.16	417.46	0.118
δ(Year) μ(June flow)	16	386.67	419.06	0.053
δ(Year) μ(July temp.+*R*)	17	385.14	419.57	0.041
δ(Year) μ(June flow+*R*)	17	385.28	419.71	0.038
δ(Year) μ(Monitor 450+mm TL+*R*)	17	385.44	419.87	0.035
δ(Year) μ(Monitor 300-449 mm TL+*R*)	17	385.48	419.92	0.035
δ(Year) μ(July temp.)	16	388.21	420.60	0.025
δ(Monitor 450+mm TL+*R*) μ(Monitor 450+ mm TL+*R*)	9	409.64	427.76	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, mean June flow and temperature, mean July flow and temperature, and fall monitoring captures in two size categories (450+mm TL and 300-449 mm TL).
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

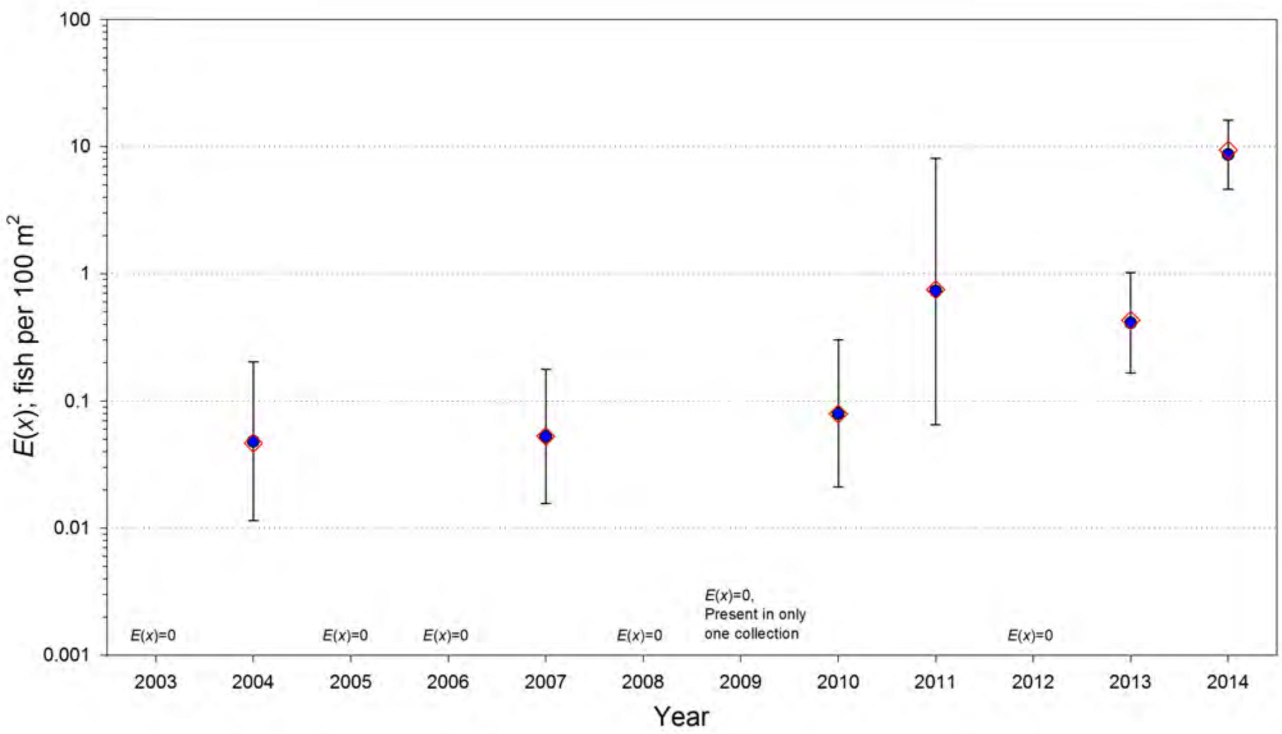


Figure 5. Colorado Pikeminnow (age-0) mixture-model estimates (*E*(*x*)) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 2. General linear models of Colorado Pikeminnow (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2013 and 2014) and spatial covariates with random station (i.e. sampling locality) effects. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year) random Station	9	414.42	432.67	0.998
δ(Reach) μ(.) random Station	10	426.34	446.64	0.001
δ(Year) μ(.) random Station	7	433.15	447.31	0.001
δ(Reach) μ(Reach) random Station	18	412.20	449.14	<0.001
δ(.) μ(Year) random Station	8	441.35	457.54	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, and habitat types.
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

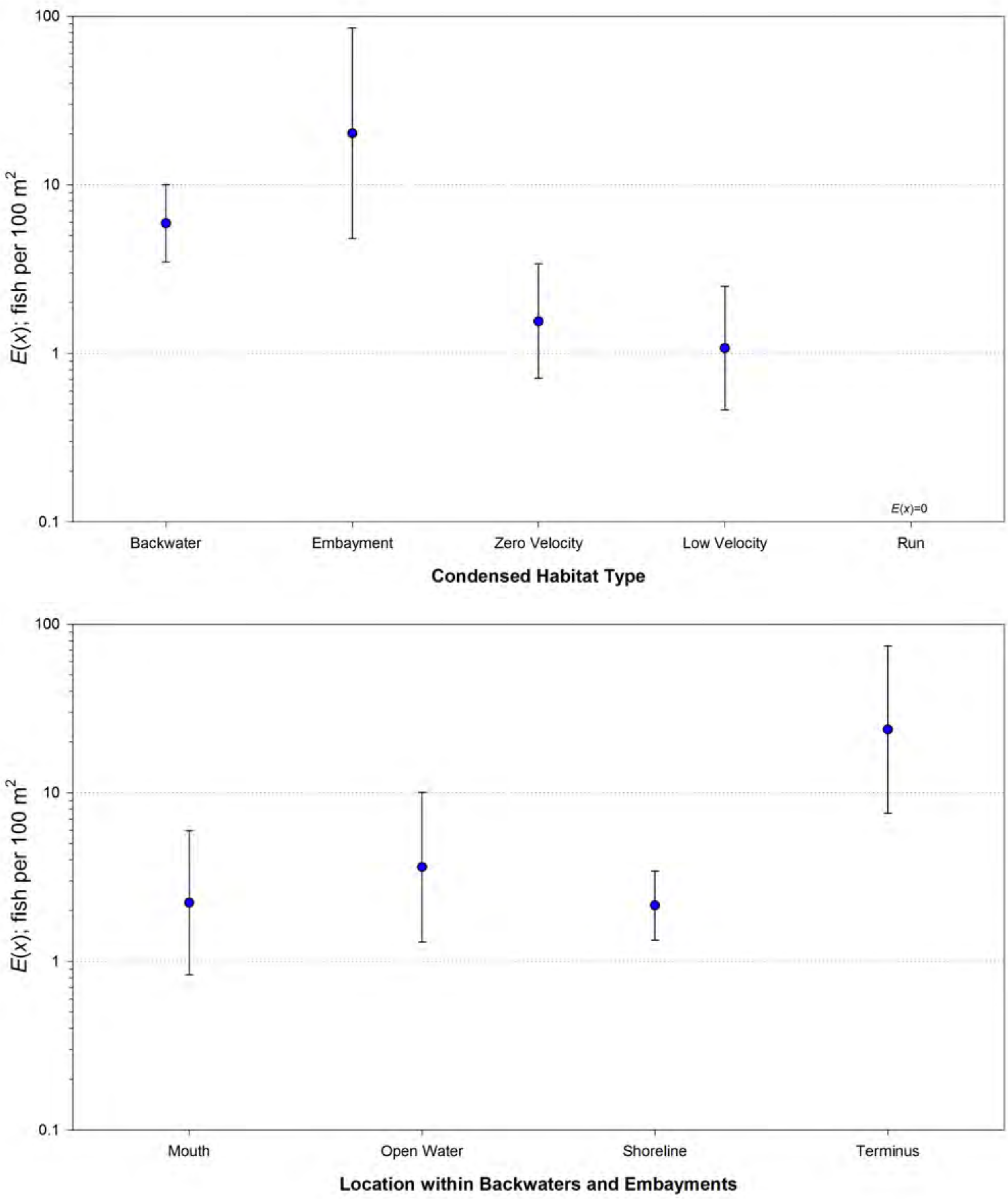
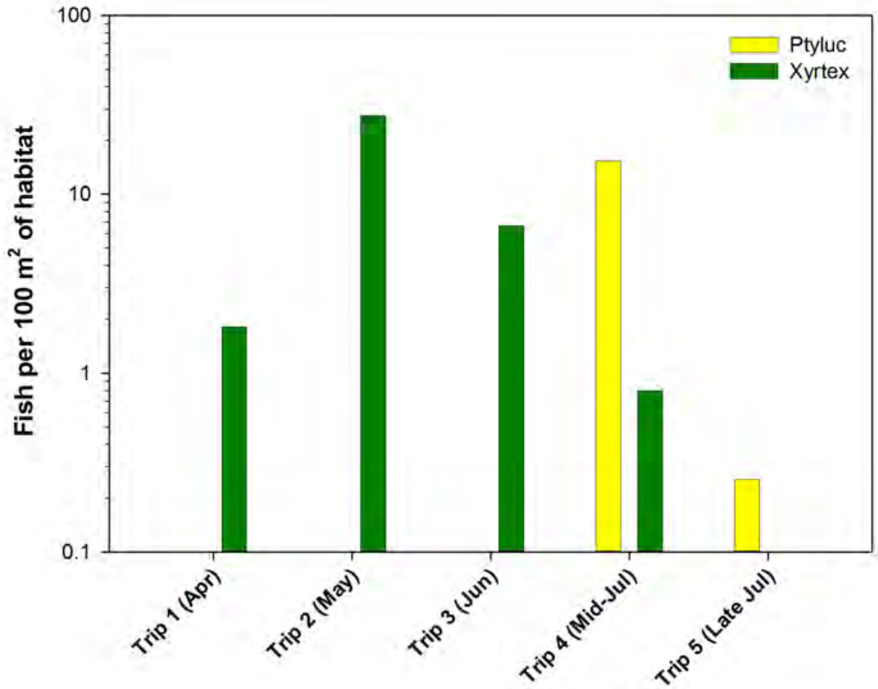


Figure 6. Colorado Pikeminnow (age-0) mixture-model estimates (δ and μ), using sampling-site density data (2013 and 2014) and habitat covariates, for habitat type (top graph) and location within backwaters and embayments (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals.



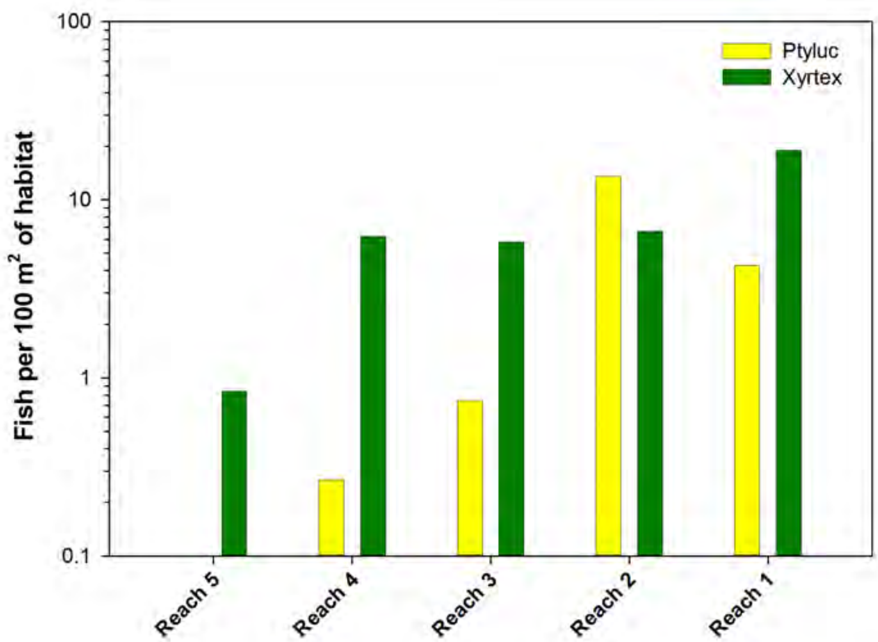


Figure 7. Density (fish per 100 m^2 of area sampled) of age-0 Colorado Pikeminnow (Ptyluc) and Razorback Sucker (Xyrtex) by trip (top graph) and reach (bottom graph) during the 2014 survey.

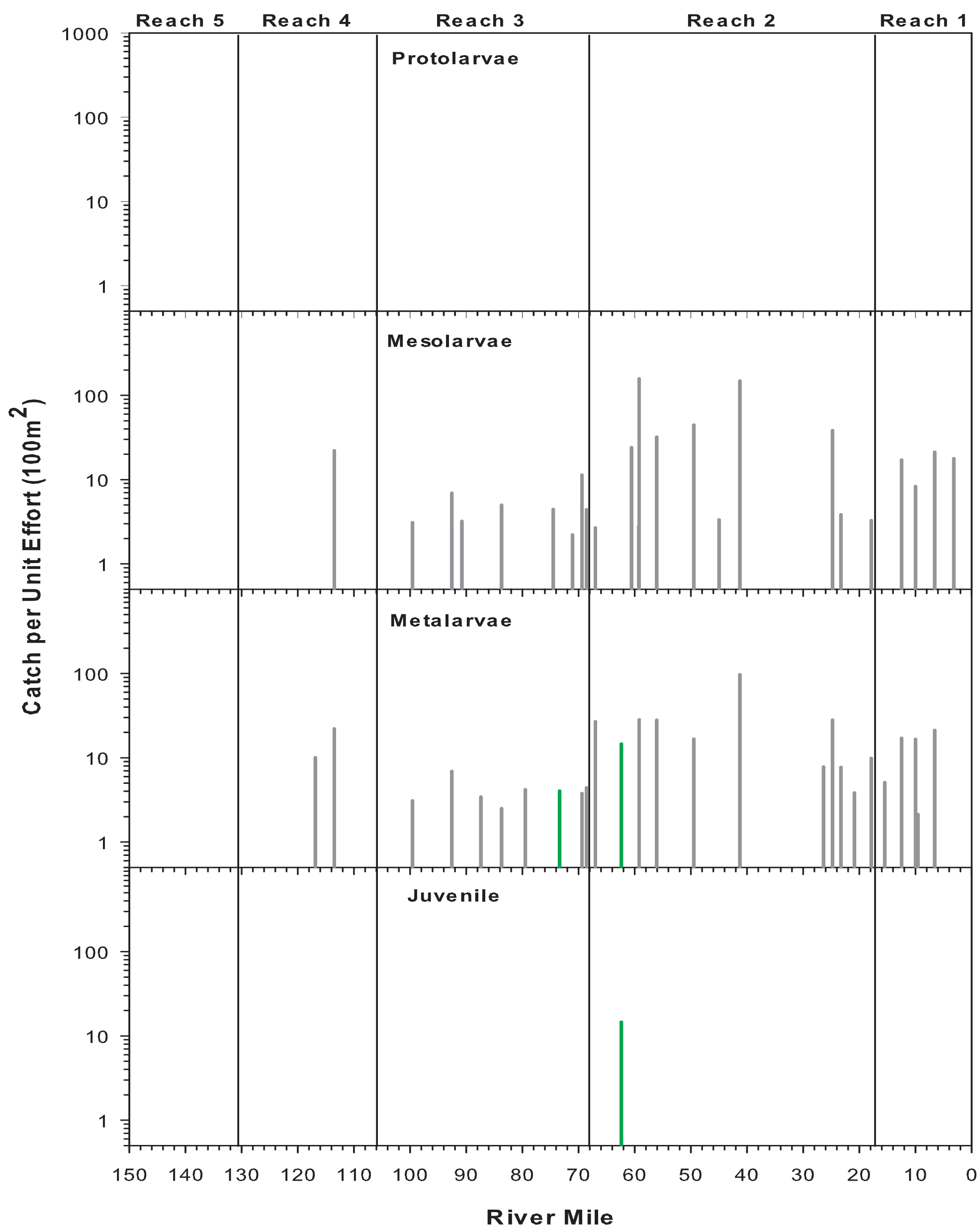


Figure 8. Catch per unit effort /100 m^2 of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of Colorado Pikeminnow by sample locality during the 2014 survey. Gray bars represent mid-July collections, and green bars late July collections.

Table 3. General linear models of Colorado Pikeminnow (age-1+) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and reach. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	36	2,787.26	2,860.20	0.886
δ(Year) μ(.)	14	2,836.15	2,864.30	0.114
δ(Reach) μ(Reach)	15	2,852.51	2,882.67	<0.001
δ(Reach) μ(.)	7	2,873.79	2,887.83	<0.001
δ(.) μ(Reach)	11	2,899.43	2,921.52	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year and reach.
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

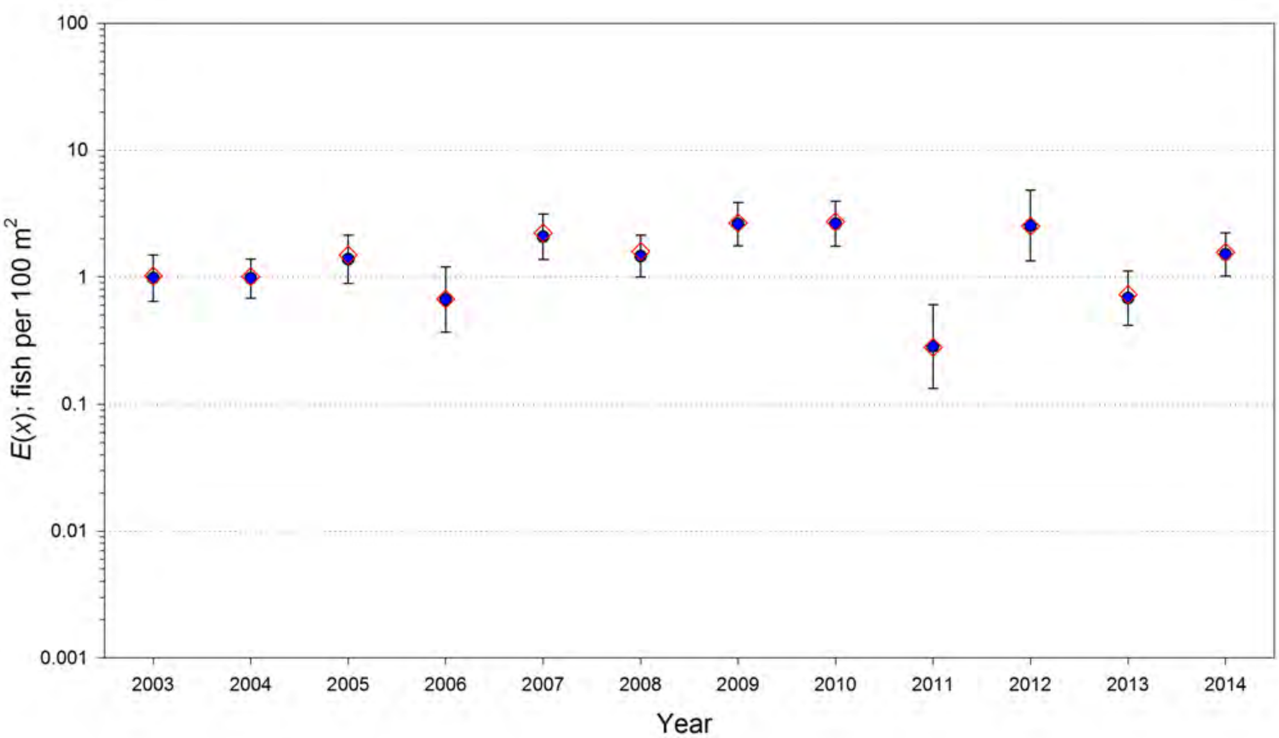


Figure 9. Colorado Pikeminnow (age-1+) mixture-model estimates (*E*(*x*)) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Razorback Sucker (age-0)

2014 Summary

For the seventeenth 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 ontogenetic stages from protolarvae to juveniles (size range = 8.8–57.6 mm TL [Table A-10]). Razorback Sucker was collected throughout the study area and was present in 85 of the 292 collections (Figure 10). During 2014, Razorback Sucker larvae were collected between river miles 147.1 and 3.2. Back-calculated hatching dates were from 31 March to 4 July 2014 (Figure 11). Mean temperature and discharge during this period was 17.5 ^{o}C (10.9–26.4) and 1,397 cfs (394–4,110). Back-calculated spawning dates for Razorback Sucker were 13 March to 30 June 2014 (Figure 12). Mean temperature and discharge during this period was 16.1 ^{o}C (9.4–25.2) and 1,290 cfs (394–4,110).

Trip and reach

Larval Razorback Sucker was first collected during the April survey, and was present in the three subsequent sampling trips (Figure 7). Between 1998 and 2014 larval Razorback Sucker have been collected during April in four different years (2002, 2006, 2007, and 2014). The 31 fish collected during the April 2014 survey represent 40.8% of all fish collected in April. Similar to previous years, the majority (68.9%) of larval Razorback Sucker were collected during the May survey and were found in all 5 reaches of the study area (Figure 7). During this trip, larval Razorback Sucker was found in 72.7% of all collections.

Densities of larval Razorback Sucker were highest in Reach 1 (18.9 fish per 100m^2), lowest in Reach 5 (0.8 fish per 100m^2), and similar between Reaches 4–2 [(5.8–6.7 fish per 100m^2) Figure 7]. The largest single collection (n = 79) of larval Razorback Sucker was in Reach 1 during the May Survey. During this month, 7 of the 8 collections made in this Reach contained larval Razorback Sucker.

Sampling-site density data

General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(cumulative#stocked+R) μ(cumulative#stocked+R)) model received most of the AIC$_C$ weight (w_i) (Table 4). The covariate (cumulative#stocked) accounted for 26.2% of the deviance explained by the μ(Year) over the null μ(.) model (P = 0.04). Cumulatively, the top ten models received >99.0% of the AIC$_C$ weight.

Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2014), were highest in 2011 (16.5) and 2014 (16.2) and lowest in 1999 (0.17) and 2005 (0.21). The estimated densities of Razorback Sucker were significantly higher (P < 0.05) in 2011–2014 compared to 1999–2001 and 2004–2009 (Figure 13). Simple estimates of mean densities, using the method of moments, were similar to estimated densities for most the years plotted. The greatest deviation occurred in 2009 and 2012. Simple estimates were higher than estimated densities for both 2009 and 2012.

Habitat

Within the habitats sampled in 2013 and 2014, the general linear model showed that the (δ(Habitat) μ(Habitat) random Station received most of the AIC$_C$ weight (w_i) (Table 5). Within the habitat types, estimated densities ($E(x)$) were significantly higher in backwaters (P < 0.05) when compared to low and zero velocity habitat types (Figure 14). Estimated densities were also significantly higher ($P < 0.05$) in embayments compared to low velocity habitats. Estimated density, with 95% confidence intervals, could not be computed for run habitats since there was only a single non-zero value, which precluded mixture-model estimation of σ. Within backwaters and embayments, there was no statistical difference of estimated densities for sampling location within those two habitat types (Figure 14).

Ontogenetic stages

Four ontogenetic stages (protolarvae, mesolarvae, metalarvae and juvenile) of Razorback Sucker were collected in 2014. During the April survey protolarvae and mesolarvae were found in Reaches 3-1, with these two ontogenetic stages also present throughout the study area during the May survey (Figure 15). During the June survey, mesolarvae were present in all five reaches with metalarvae and juveniles found at seven discrete localities within Reaches 4-1 (Figure 16). By the mid-July survey (the last survey in which age-0 Razorback Sucker was captured), mesolarvae, metalarvae and juvenile fish were collected in Reaches 3-1.

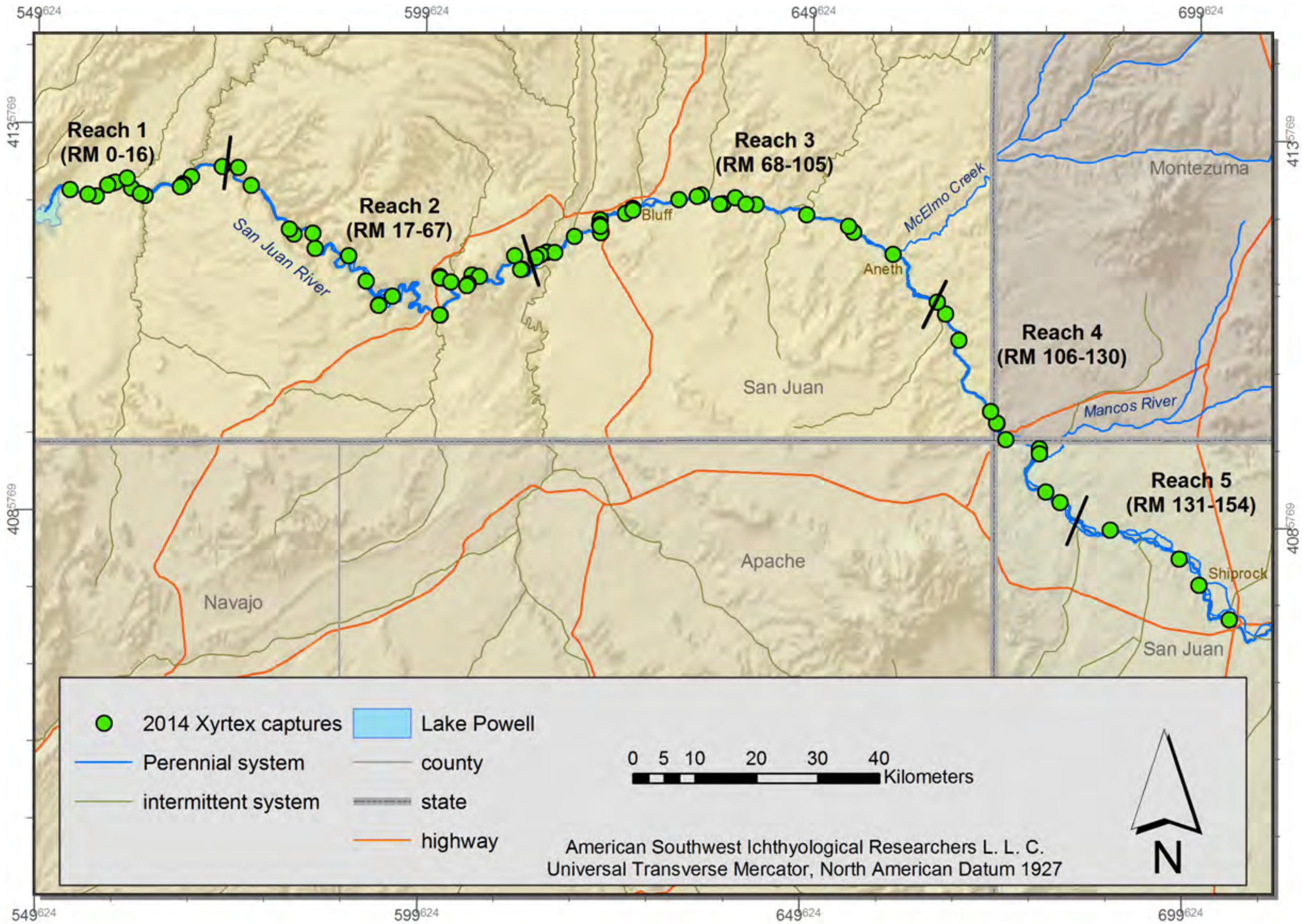


Figure 10. Map of the 2014 age-0 Razorback Sucker collection localities.

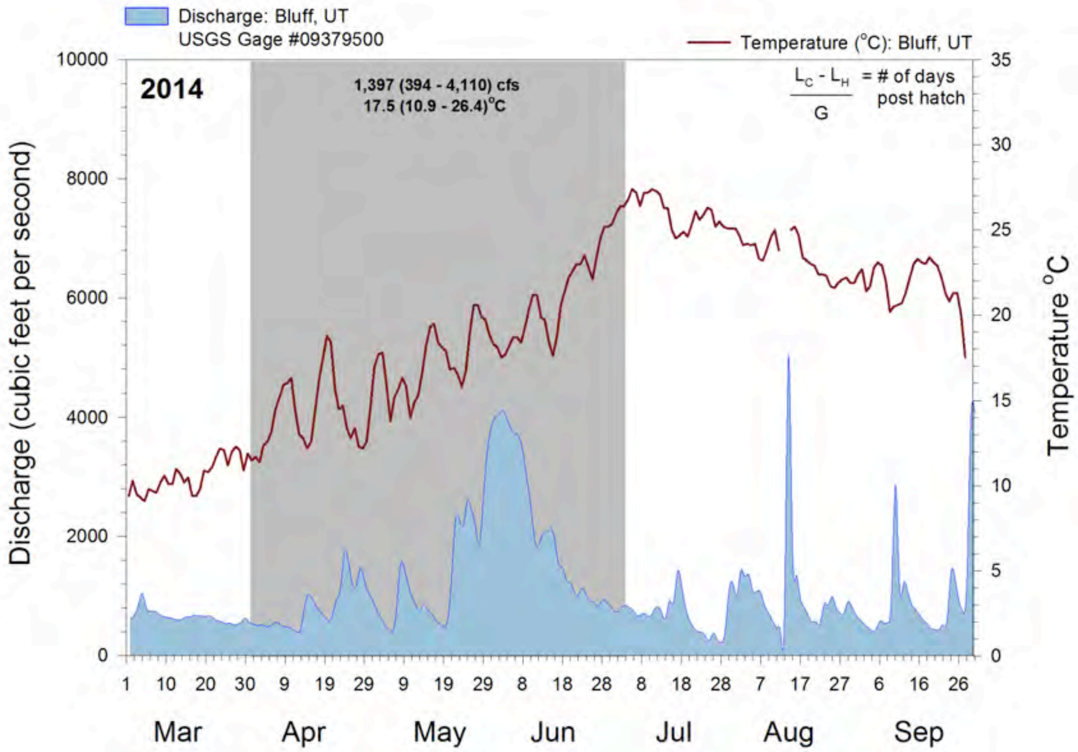


Figure 11. Back-calculated hatching dates for Razorback Sucker plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported.

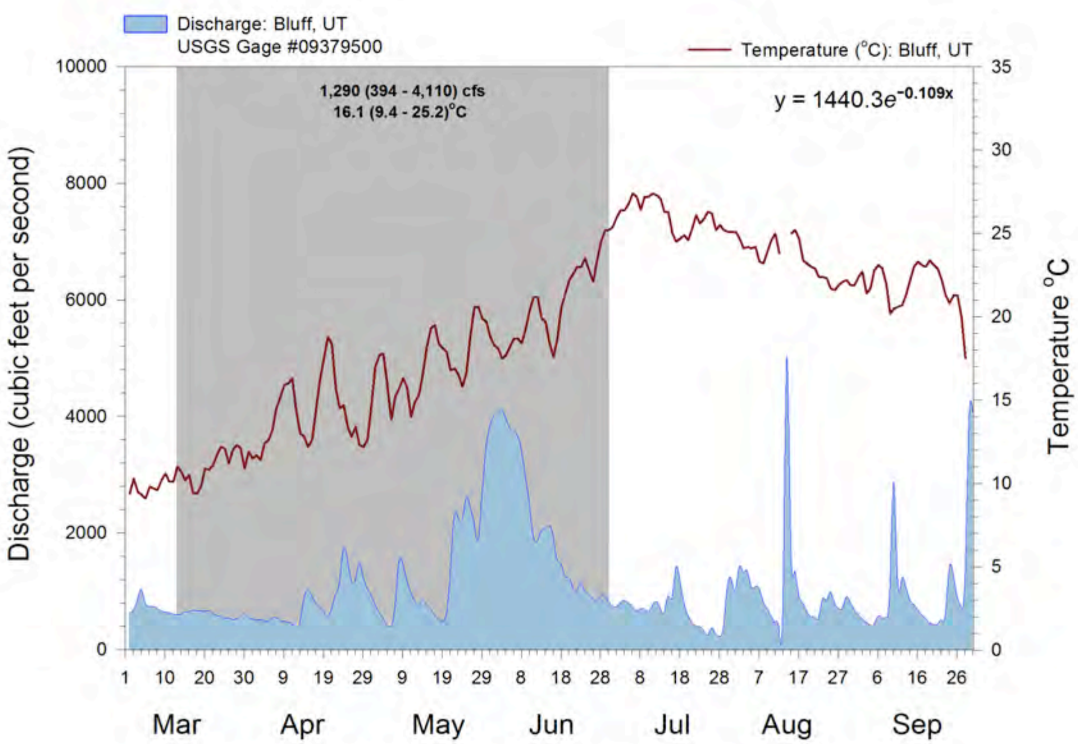


Figure 12. Back-calculated spawning dates for Razorback Sucker plotted against discharge and water temperature. Grey box delineates spawning period with mean (min max) discharge and water temperature reported.

Table 4. General linear models of Razorback Sucker (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (1999–2014) and covariates allowing for random effects (*R*). Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Cum.Stock+*R*) μ(Cum.Stock+*R*)	9	3,249.27	3,267.34	0.720
δ(May flow+*R*) μ(May flow+*R*)	9	3,252.56	3,270.63	0.139
δ(Monitor+*R*) μ(Monitor+*R*)	9	3,253.41	3,271.47	0.091
δ(Cum.Stock+*R*) μ(Year)	35	3,202.41	3,273.34	0.036
δ(Monitor+*R*) μ(Year)	35	3,205.87	3,276.81	0.006
δ(May flow+*R*) μ(Year)	35	3,207.30	3,278.24	0.003
δ(Year) μ(May flow+*R*)	21	3,236.76	3,279.10	0.002
δ(Year) μ(May flow)	20	3,238.86	3,279.18	0.002
δ(Year) μ(Year)	48	3,182.80	3,280.56	0.001
δ(April flow+*R*) μ(April flow+*R*)	9	3264.57	3,282.64	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, mean April flow and temperature, mean May flow and temperature, annual number stocked, cumulative number stocked (Cum.Stock), and fall monitoring captures (Monitor)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

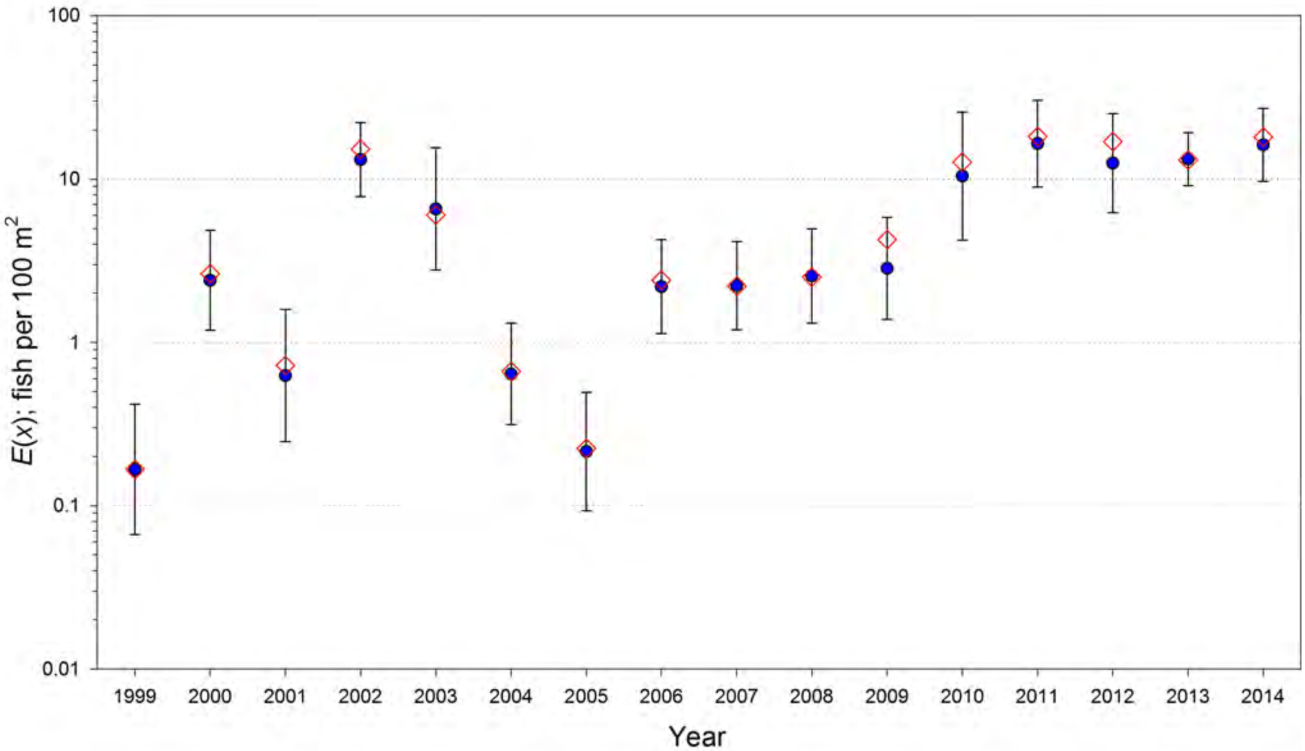


Figure 13. Razorback Sucker (age-0) mixture-model estimates (*E*(*x*)) using sampling-site density data (1999–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 5. General linear models of Razorback Sucker (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2013 and 2014) and spatial covariates with random station (i.e. sampling locality) effects. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Habitat) μ(Habitat) random Station	18	1,384.48	1421.08	0.855
δ(Habitat) μ(.) random Station	10	1,404.45	1424.64	0.144
δ(Location) μ(.) random Station	10	1,419.23	1437.23	<0.001
δ(Year) μ(.) random Station	7	1,427.18	1441.18	<0.001
δ(.) μ(.)	6	1,430.94	1443.01	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, and habitat types.
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

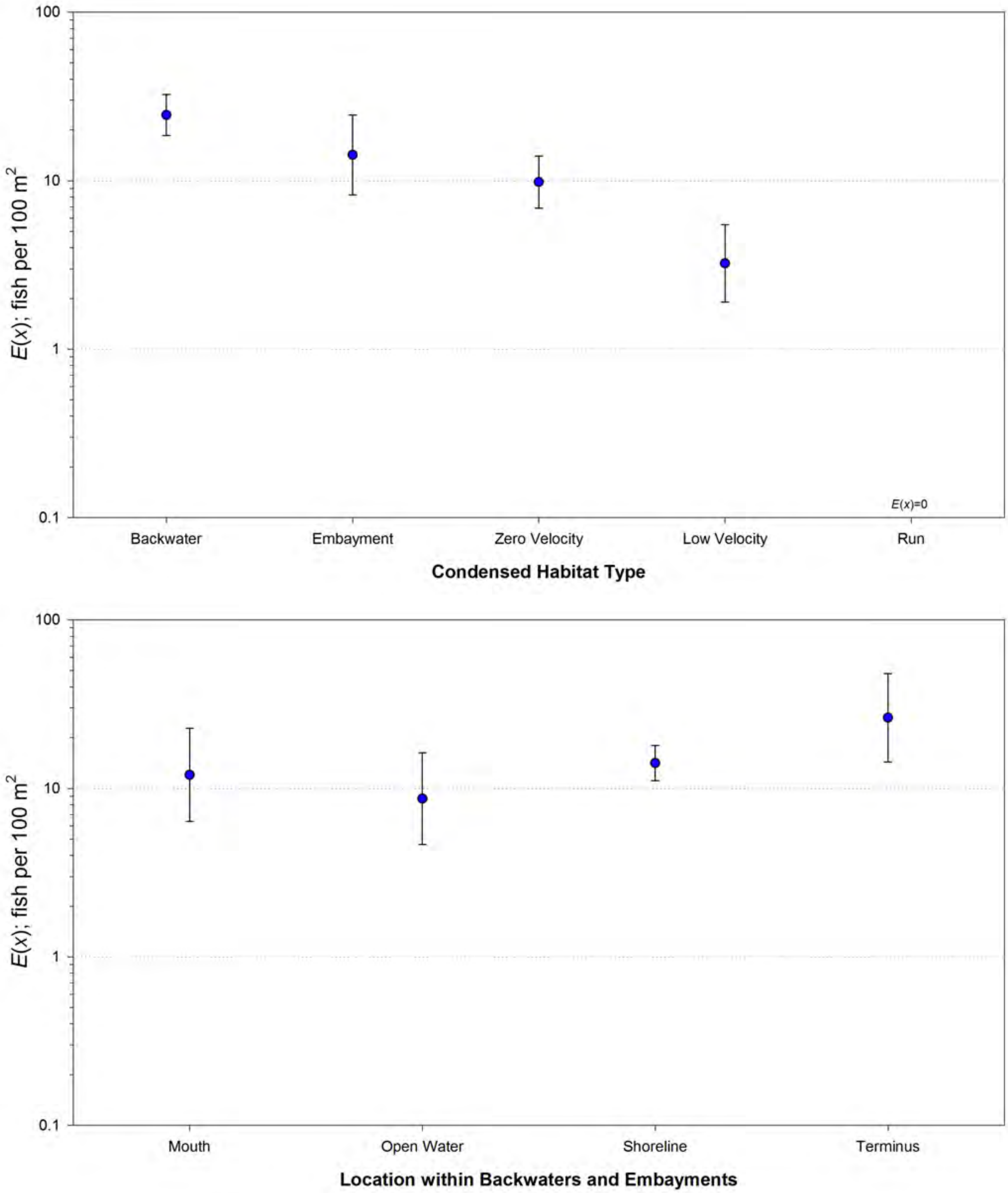


Figure 14. Razorback Sucker (age-0) mixture-model estimates (δ and μ), using sampling-site density data (2013 and 2014) and habitat covariates, for habitat type (top graph) and location within backwaters and embayments (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals.

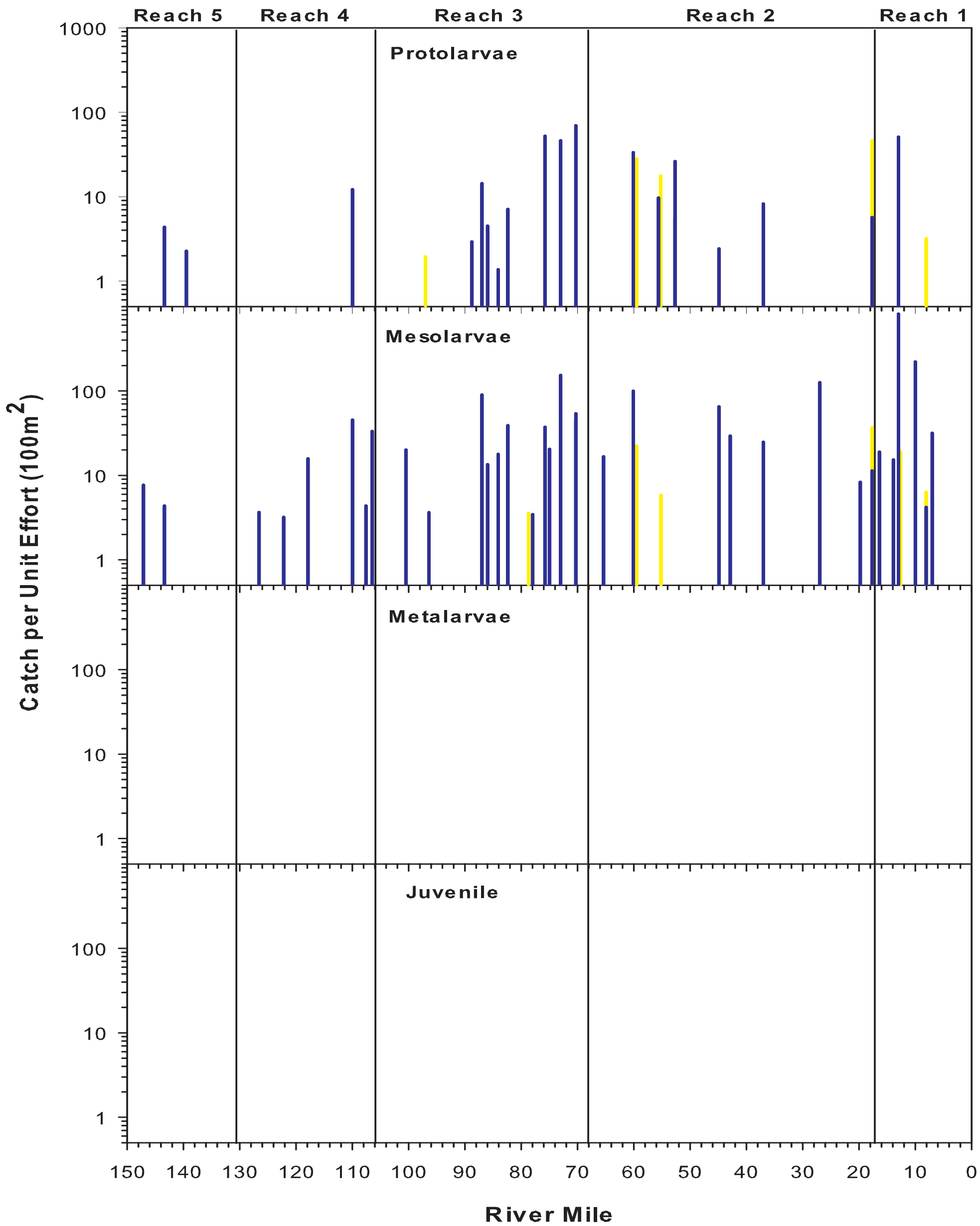


Figure 15. Catch per unit effort /100 m^2 of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of Razorback Sucker by sample locality during the 2014 survey. Yellow bars represent April collections, and blue bars May collections.

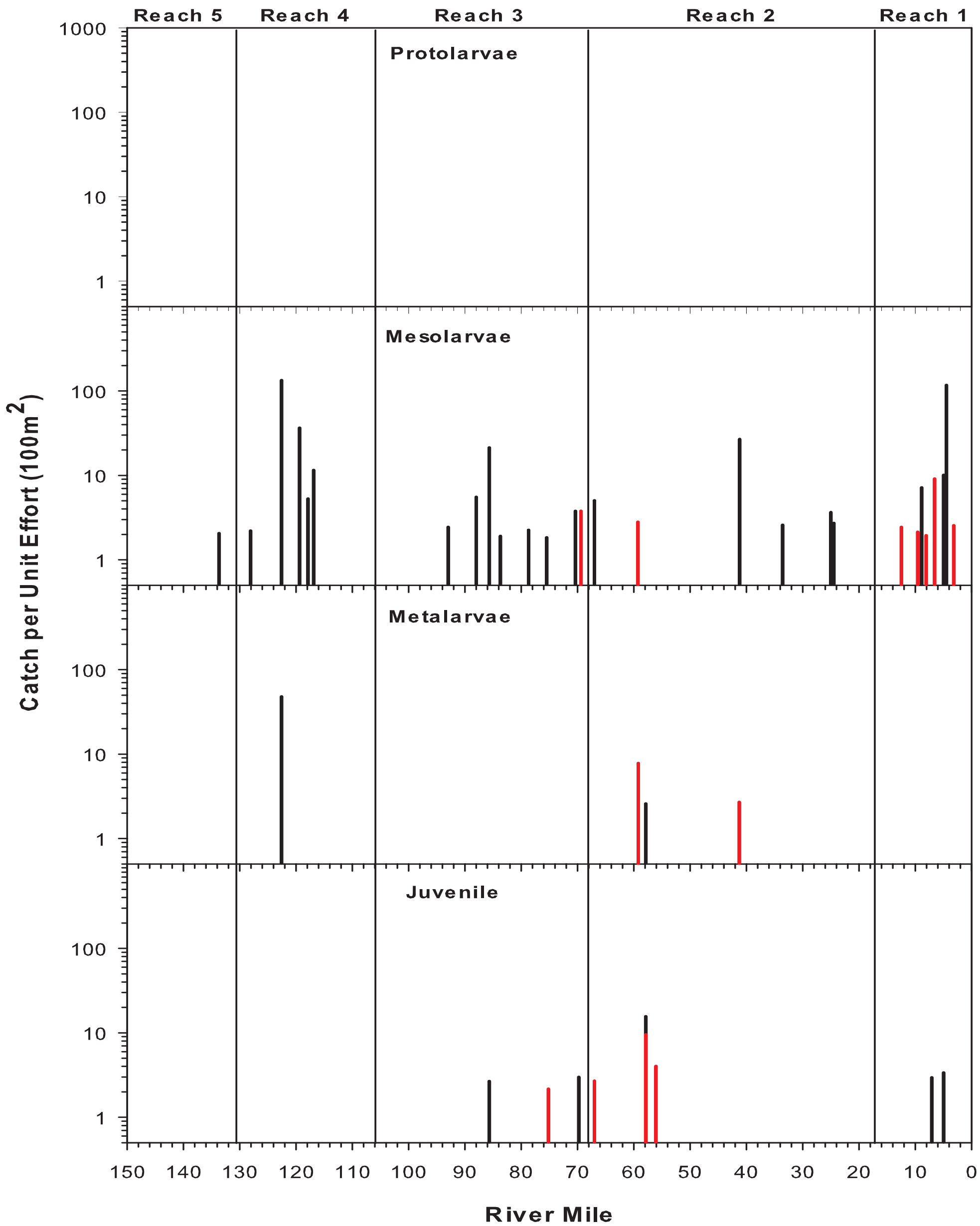


Figure 16. Catch per unit effort /100 m^2 of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of Razorback Sucker by sample locality during the 2014 survey. Black bars represent June collections, and red bars mid-July collections.

Common species

Bluehead Sucker. General linear models of Bluehead Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(Reach) μ(Reach)) model received nearly all of the AIC_C weight (w_i) (Table 6). Bluehead Sucker was one of two species for which the (δ(Reach) μ(Reach)) model was ranked the highest. Among years, estimated densities (*E*(*x*)) were highest in 2013 (111.8) and lowest in 2009 [7.8 (Figure 17)]. Estimated densities in 2014 were significantly higher ($P < 0.05$) than 2003, 2008–2010 and not significantly lower than any preceding year. The 3,024 age-0 specimens collected accounted for 15.6% of the 2014 catch and Bluehead Sucker was found in 43.4% of all collections. For only the second time during the tenure of this study, larval Bluehead Sucker (n = 1) was first collected during the April survey (Figure 18). Densities of Bluehead Sucker were highest two months later during the June survey. Within reaches, densities were highest in Reach 5 (Figure 18) and steadily declined in each of the subsequent downstream reaches.

Table 6. General linear models of Bluehead Sucker (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Reach) μ(Reach)	15	7,029.81	7,102.75	0.999
δ(.) μ(Reach)	11	7,132.12	7,162.28	<0.001
δ(Reach) μ(.)	7	7,119.39	7,169.84	<0.001
δ(Year) μ(Year)	36	7,161.30	7,189.44	<0.001
δ(.) μ(Year)	25	7,184.51	7,206.60	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (n = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

Flannelmouth Sucker. Mixture-model estimates (Delta (δ) and Mu (μ)) for Flannelmouth Sucker revealed that the (δ(Year) μ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 7). Estimated densities (*E*(*x*)) were highest in 2008 (358.7) and lowest in 2009 [22.9 (Figure 19)]. Estimated densities in 2014 were significantly lower ($P < 0.05$) than 2006–2008, 2011, and 2012 and not significantly higher than any of the preceding years (Figure 19). Densities of age-0 Flannelmouth Sucker were highest in April and declined in each of the subsequent survey trips (Figure 18). Densities were highest in Reach 3, lowest in Reach 1, and similar among Reaches 5, 4, and 2 (Figure 18). Larval Flannelmouth Sucker accounted for 10.1% of the total catch in 2014 and was found in nearly half (48.6%) of all collections.

Speckled Dace. General linear models of Speckled Dace mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(Reach) μ(Reach)) model received nearly all of the AIC_C weight (w_i) (Table 8). Speckled Dace and Bluehead Sucker were the two species for which the (δ(Reach) μ(Reach)) model was ranked the highest. Estimated densities (*E*(*x*)) for larval Speckled Dace were highest in 2004 (177.4) and lowest in 2003 [13.4 (Figure 20)]. In 2014 Speckled Dace

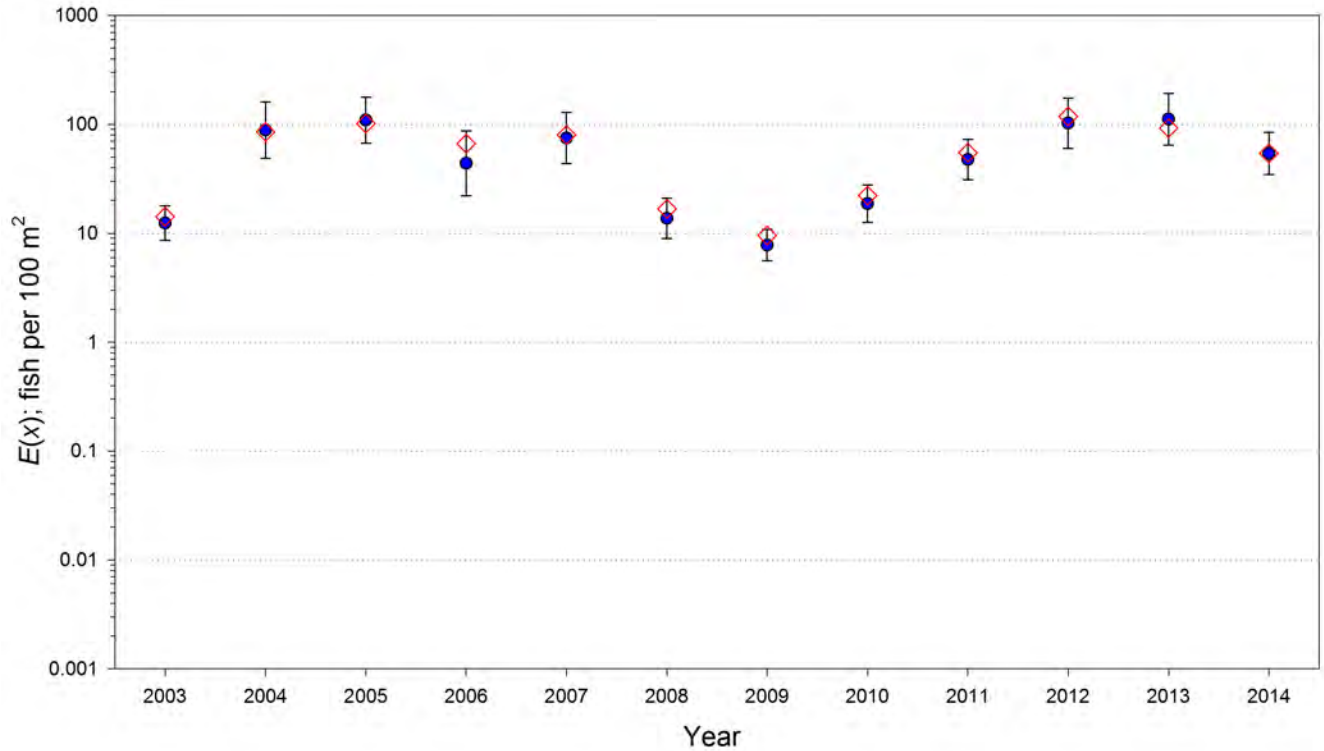


Figure 17. Bluehead Sucker (age-0) mixture-model estimates (*E*(*x*)) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

estimated densities were significantly higher ($P < 0.05$) than 2003, 2009, 2010, and 2012 and not significantly lower than any of the preceding years (Figure 20). Larval Speckled Dace were first collected during the May survey, and densities were highest during the mid-July survey (Figure 21). Similar to Bluehead Sucker, densities of larval Speckled Dace were highest in Reach 5 and declined in each of the subsequent downstream reaches (Figure 21). Speckled Dace was the numerically dominant native species collected in 2014 accounting for 25.3% of the total catch occurring in 46.9% of all samples.

Red Shiner. Mixture-model estimates (Delta (δ) and Mu (μ)) for Red Shiner revealed that the (δ(Year) μ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 9). Estimated densities (*E*(*x*)) were highest in 2005 (3,725.1) and lowest in 2008 [108.7 (Figure 22)]. Red Shiner estimated densities in 2014 were not significantly lower than any year but were significantly higher ($P < 0.05$) than during 2003–2005, 2009, and 2010 (Figure 22). Red Shiner larvae were first collected during the May survey, with the highest densities occurring during the mid-July survey (Figure 21). Among reaches, densities were highest in Reaches 4, 3, and 1, and lowest in Reaches 5 and 2 (Figure 21). Larval Red Shiner larvae accounted for 32.5% of the total 2014 catch and were found in 34.8% of the collections.

Fathead Minnow. Fathead Minnow mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(Year) μ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 10). Estimated densities (*E*(*x*)) were highest in 2003 (168.8) and lowest in 2009 [0.7 (Figure 23)]. In 2014 estimated densities were significantly lower than 2003–2006 ($P < 0.05$) but were significantly higher than 2009 (Figure 23).

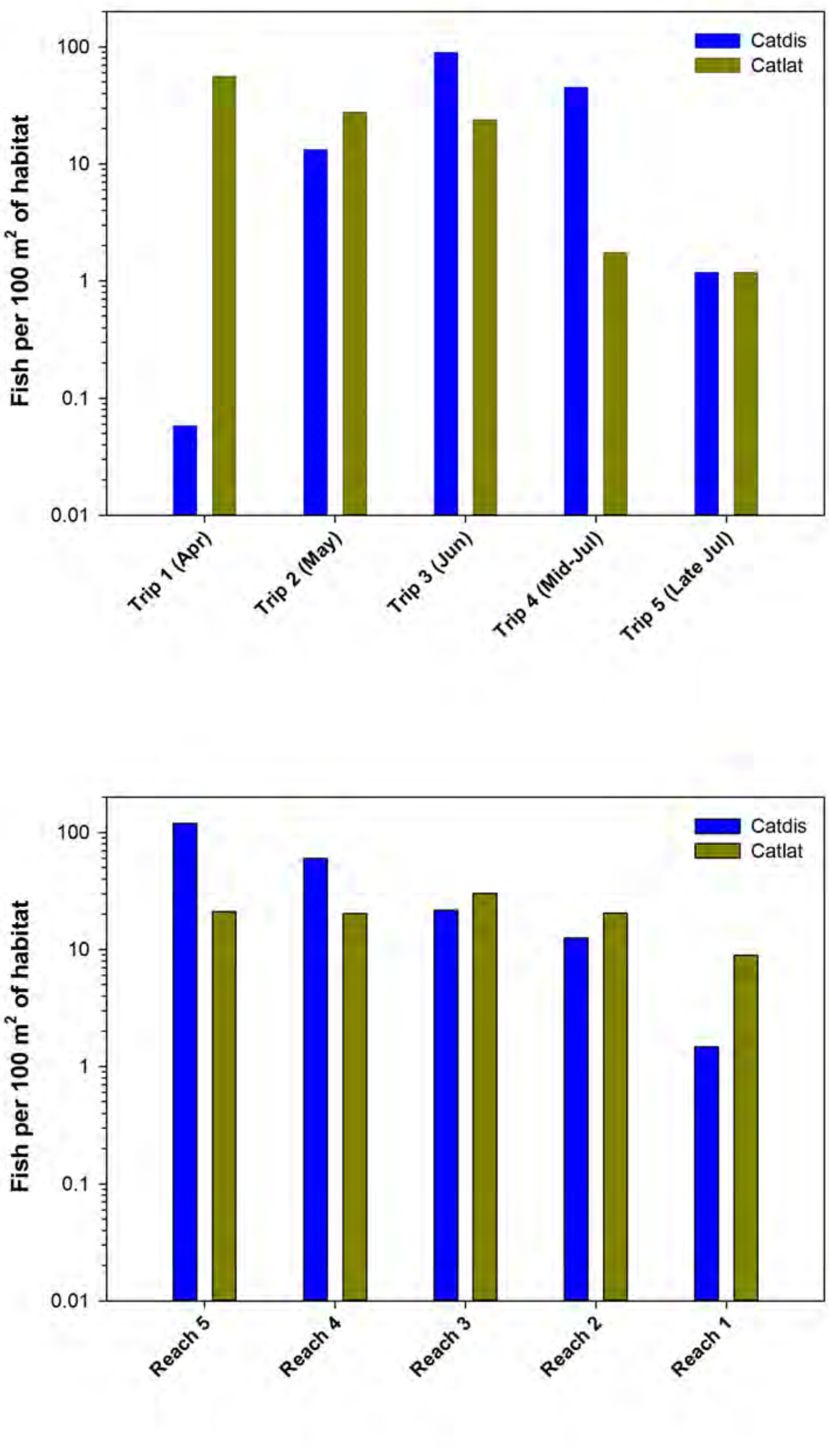


Figure 18. Density (fish per 100 m^2 of area sampled) of age-0 Bluehead Sucker (Catdis) and Flannelmouth Sucker (Catlat) by trip (top graph) and reach (bottom graph) during the 2014 survey.

Table 7. General linear models of Flannelmouth Sucker (age-0) mixture-model estimates (Delta (δ) and Mu (μ)), using sampling-site density data (2003–2014) 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)	36	7,029.81	7,102.75	0.999
δ(Reach) μ(Reach)	15	7,132.12	7,162.28	<0.001
δ(.) μ(Year)	25	7,119.39	7,169.84	<0.001
δ(Year) μ(.)	14	7,161.30	7,189.44	<0.001
δ(.) μ(Reach)	11	7,184.51	7,206.60	<0.001

[1] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model
[4]δ = probability of occurrence
[5]μ = mean of the lognormal distribution

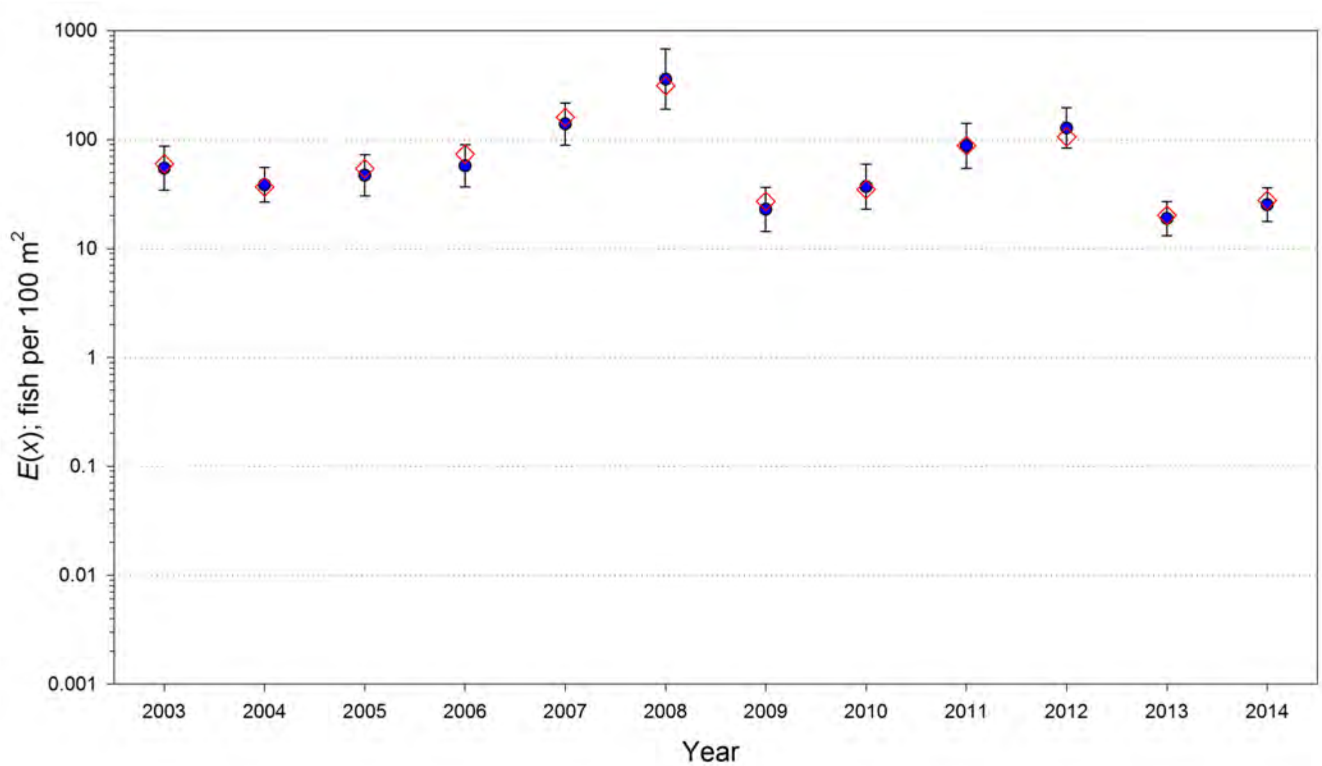


Figure 19. Flannelmouth Sucker (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 8. General linear models of Speckled Dace (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Reach) μ(Reach)	15	5,217.37	5,247.59	0.999
δ(Reach) μ(.)	7	5,381.06	5,395.12	<0.001
δ(.) μ(Reach)	11	5,374.31	5,396.43	<0.001
δ(Year) μ(Year)	36	5,328.37	5,401.64	<0.001
δ(.) μ(Year)	25	5,419.60	5,470.22	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

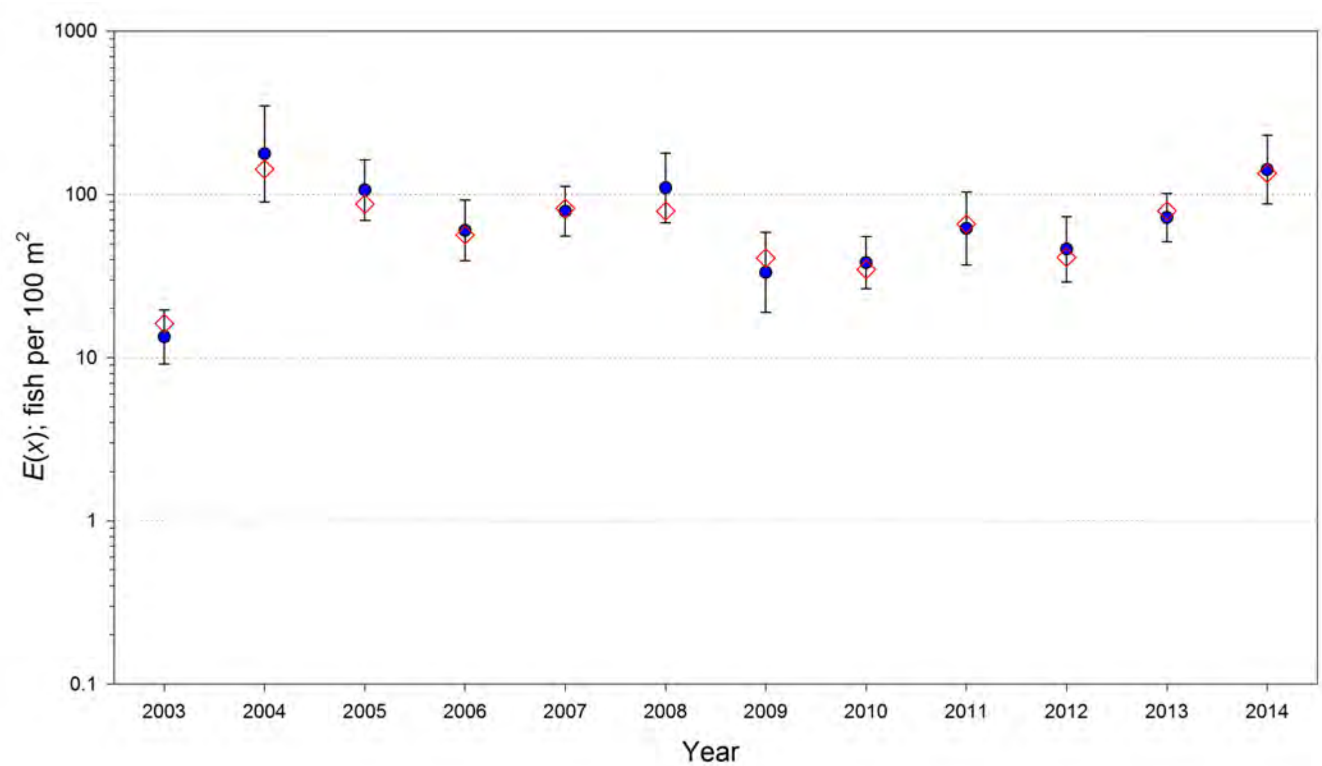
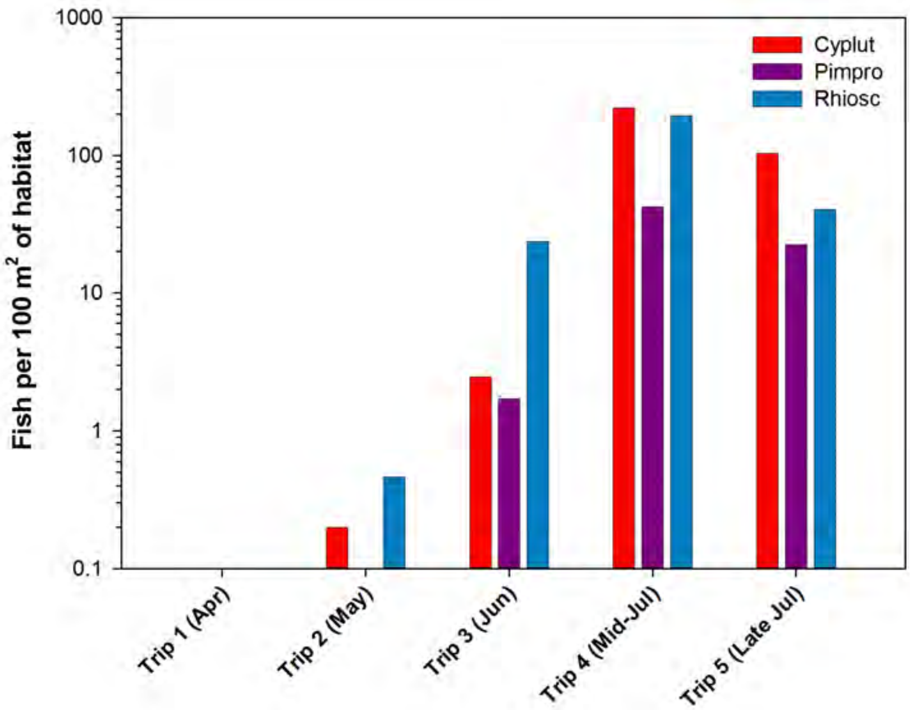


Figure 20. Speckled Dace (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.



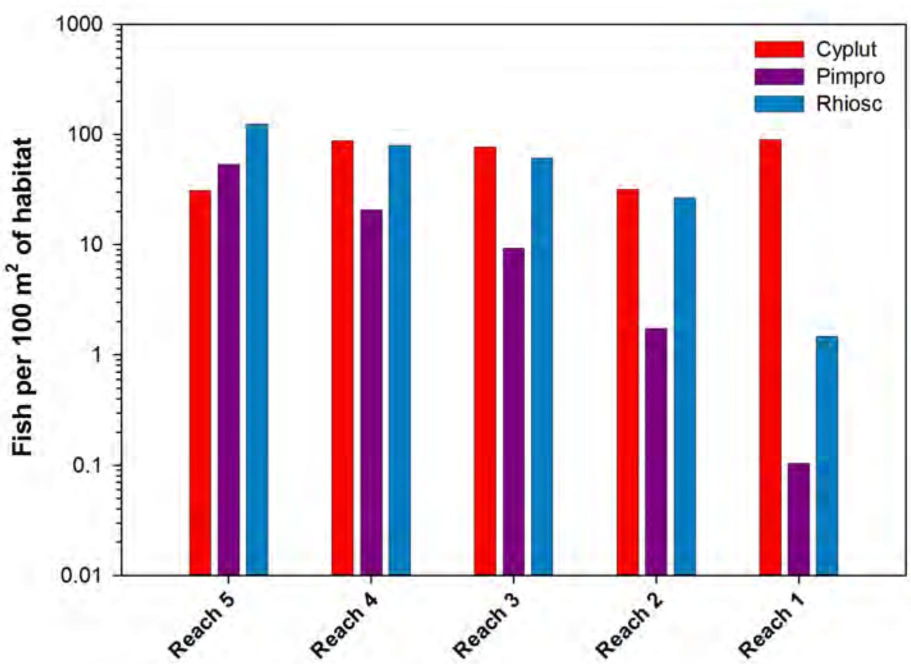


Figure 21. Density (fish per 100 m^2 of area sampled) of age-0 small-bodied cyprinids: Red Shiner (Cyplut), Fathead Minnow (Pimpro) and Speckled Dace (Rhiosc) by trip (top graph) and reach (bottom graph) during the 2014 survey.

Table 9. General linear models of Red Shiner (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	36	3,751.82	3,825.74	0.999
δ(.) μ(Year)	25	3,842.45	3,893.37	<0.001
δ(Reach) μ(Reach)	15	4,010.34	4,040.68	<0.001
δ(Year) μ(.)	14	4,032.72	4,061.02	<0.001
δ(.) μ(Reach)	11	4,058.49	4,080.67	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

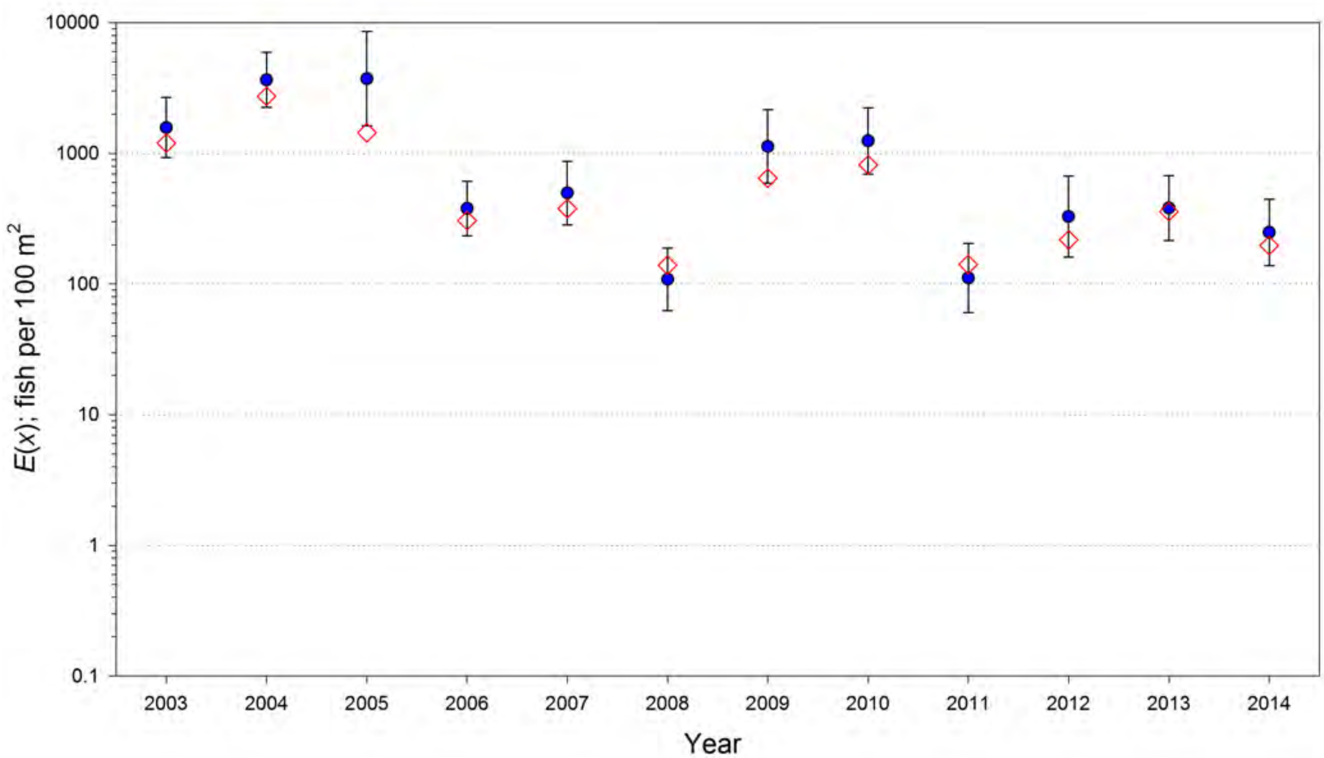


Figure 22. Red Shiner (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 10. General linear models of Fathead Minnow (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	36	5,507.16	5,580.11	0.999
δ(Year) μ(.)	14	5,677.10	5,705.25	<0.001
δ(Reach) μ(Reach)	15	5,688.10	5,718.27	<0.001
δ(Reach) μ(.)	7	5,778.81	5,792.85	<0.001
δ(.) μ(Year)	25	5,753.62	5,804.08	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

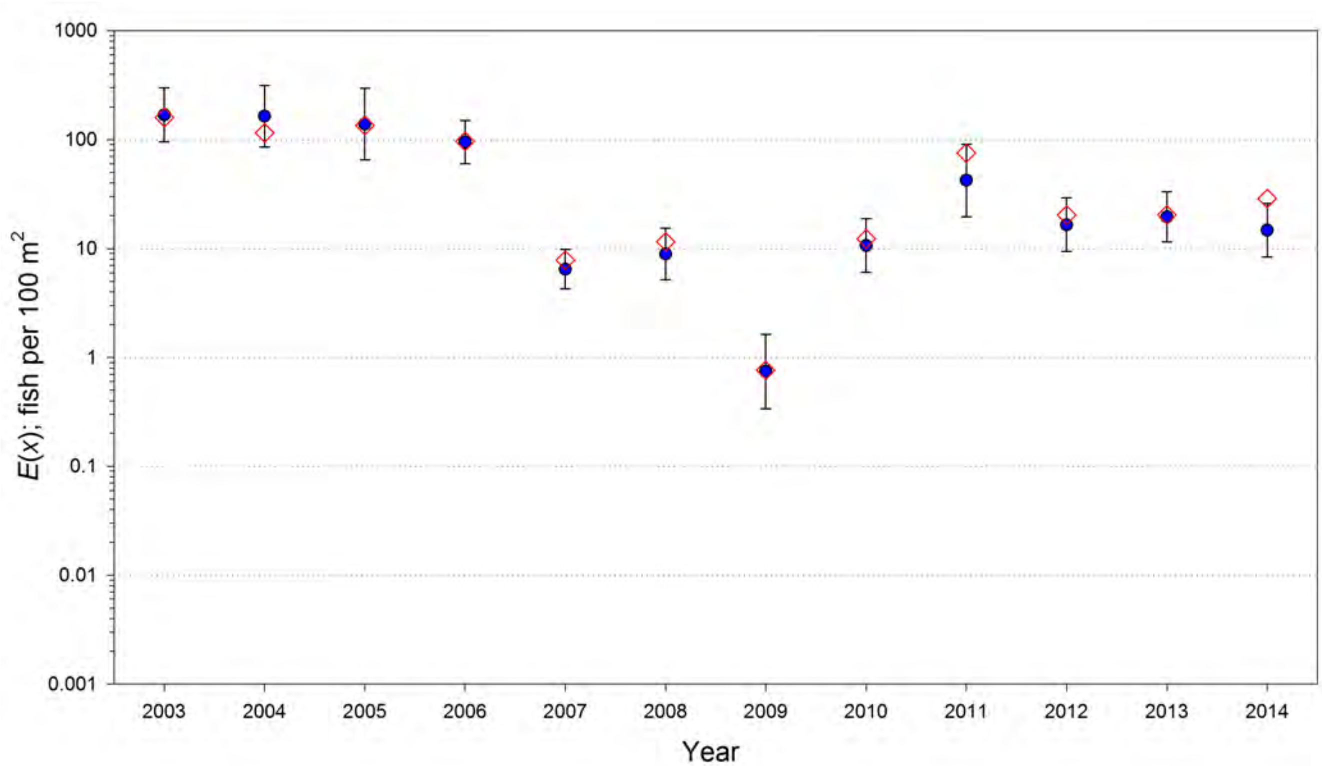


Figure 23. Fathead Minnow (age-0) mixture-model estimates (*E*(*x*)) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Larval Fathead Minnow were first encountered during the June survey, with densities being highest during the mid-July survey (Figure 21). Within reaches, densities were highest in Reach 5 and declined in each of the downstream reaches.

Common Carp. Mixture-model estimates (Delta (δ) and Mu (μ)) for larval Common Carp revealed that the (δ(Year) μ(null)) model received nearly all of the AIC_C weight (w_i) (Table 11). This was the only common species in which the Mu (null) was part of the top model. Estimated densities (*E*(*x*)) were highest in 2004 (2.3) and lowest in 2010 [0.1 (Figure 24)]. Estimated density, with 95% confidence intervals, could not be computed for 2003 and 2006 since there was only a single non-zero value, which precluded mixture-model estimation of σ. Estimated densities in 2014 were not significantly higher than any previous year but were lower ($P < 0.05$) than 2004 and 2005 (Figure 24). Larval Common Carp were first collected during the May survey, absent in June, and again present in both of the July surveys (Figure 25). Densities were highest in Reach 5, declined in Reaches in 4, 3 and 2, with no Common Carp collected in Reach 1 (Figure 25).

Channel Catfish. Channel Catfish mixture-model estimates (Delta(δ) and Mu(μ)) revealed that the (δ(Year) μ(year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 12). Estimated densities (*E*(*x*)) were highest in 2007 (36.9) and lowest in 2009 [3.1 (Figure 26)]. Estimated densities in 2014 were not significantly lower than any preceding year, but were significantly higher ($P < 0.05$) than all years except 2005, 2007, and 2008 (Figure 26). Larval Channel Catfish were first collected during the mid-July survey with densities being highest during that survey (Figure 25). Channel Catfish were collected throughout the study area with densities highest in Reach 2 and lowest in Reach 5 (Figure 25).

Table 11. General linear models of Common Carp (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(.)	14	1,543.53	1,571.68	0.999
δ(Year) μ(Year)	36	1,515.44	1,588.40	<0.001
δ(Reach) μ(Reach)	15	1,608.26	1,638.43	<0.001
δ(Reach) μ(.)	7	1,636.25	1,650.25	<0.001
δ(.) μ(Reach)	11	1,644.37	1,666.37	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

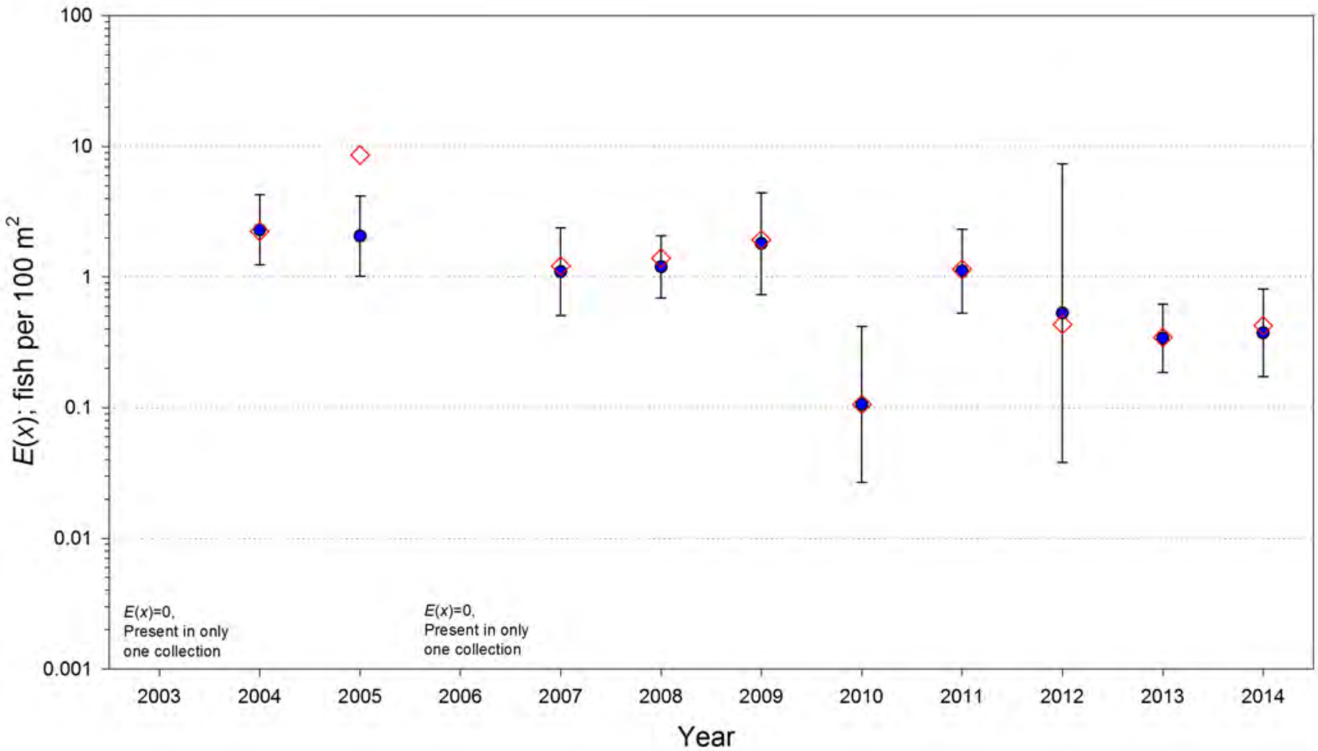
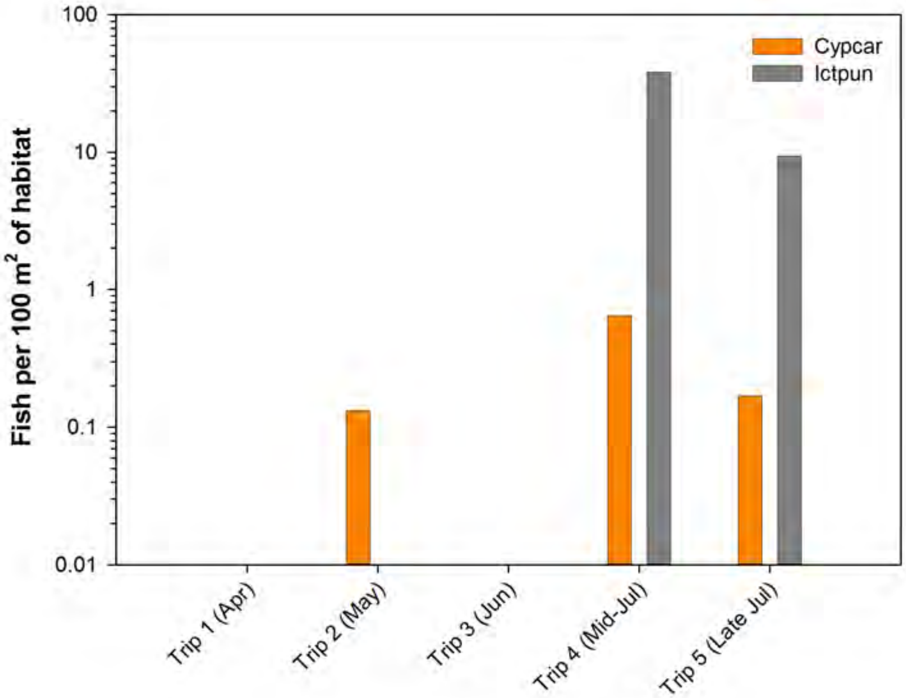


Figure 24. Common Carp (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

2014 Razorback Sucker opercular deformities.

In 2014, 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). Between 1998 and 2012, 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 2014 Razorback Sucker individuals (>15 mm TL) were rated bilaterally for deformed opercula on a scale of 0 (none), 1 (slight shortening), and 2 [severe shortening (Figure 27)].

A total of 85 specimens were rated with 29 (34.1%) exhibiting deformed opercula (Figure 28). Of the 85 fish rated most were larvae (*n* = 73) and 12 fish were juveniles. There were no deformities among the juvenile fish. Fish were rated from 4 geomorphic reaches (1-4) within the study area. Reach 3 had the highest percentage of deformities (66.7%) however only 3 fish from this reach were large enough to rate. Reach 4 had the highest number of deformed fish (*n* = 21 of 42 fish rated) and the second highest percentage of deformities (50.0%). Deformities were found bilaterally (62.1%, *n* = 18) and unilaterally (37.9%, *n* = 11). Severe deformities (a rating of 2) were found in 11 fish, with most of those (81.8% *n* = 9) having bilateral deformities.



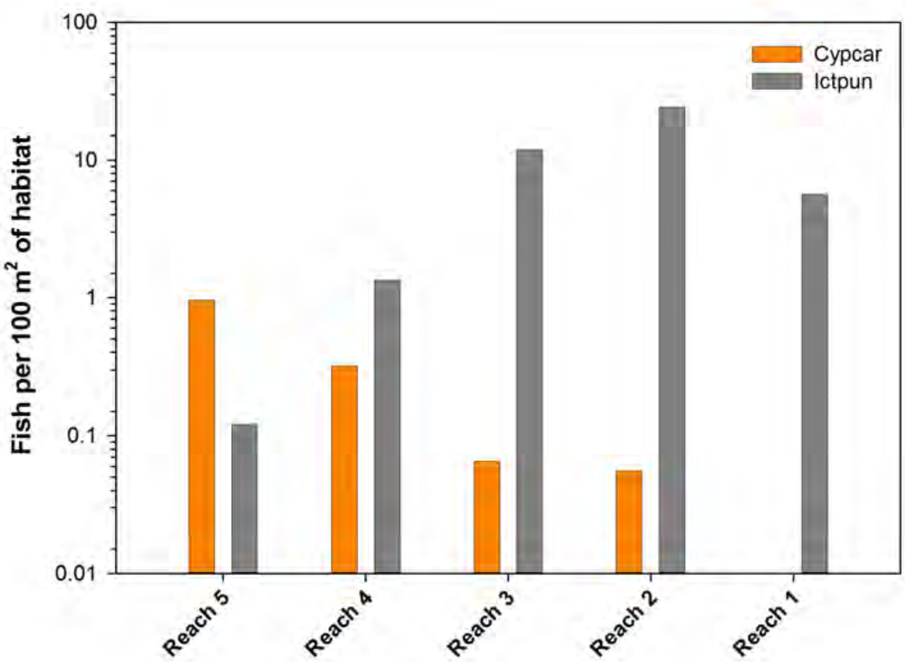


Figure 25. Density (fish per 100 m^2 of area sampled) of age-0 Common Carp (Cypcar) and Channel Catfish (Ictpun) by trip (top graph) and reach (bottom graph) during the 2014 survey.

Table 12. General linear models of Channel Catfish (age-0) mixture-model estimates (Delta (δ)[1] and Mu (m)[2]), using sampling-site density data (2003–2014) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	36	2,605.21	2,679.13	0.999
δ(Year) μ(.)	14	2,687.13	2,715.42	<0.001
δ(Reach) μ(Reach)	15	2,688.83	2,719.17	<0.001
δ(Reach) μ(.)	7	2,730.56	2,744.64	<0.001
δ(.) μ(Year)	25	2,777.60	2,828.53	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year (2003–2014), and reach (*n* = five reaches)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

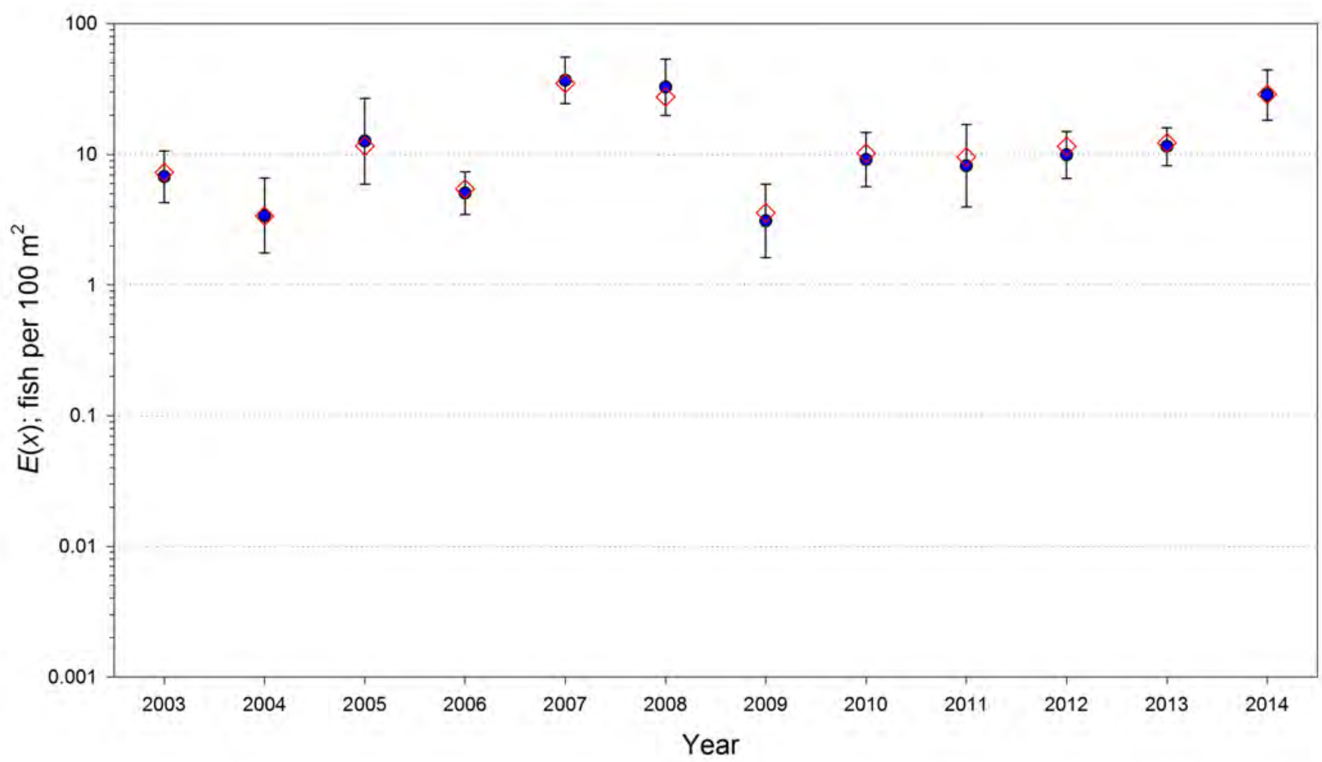


Figure 26. Channel Catfish (age-0) mixture-model estimates (*E*(*x*)) using sampling-site density data (2003–2014). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Figure 27. 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").

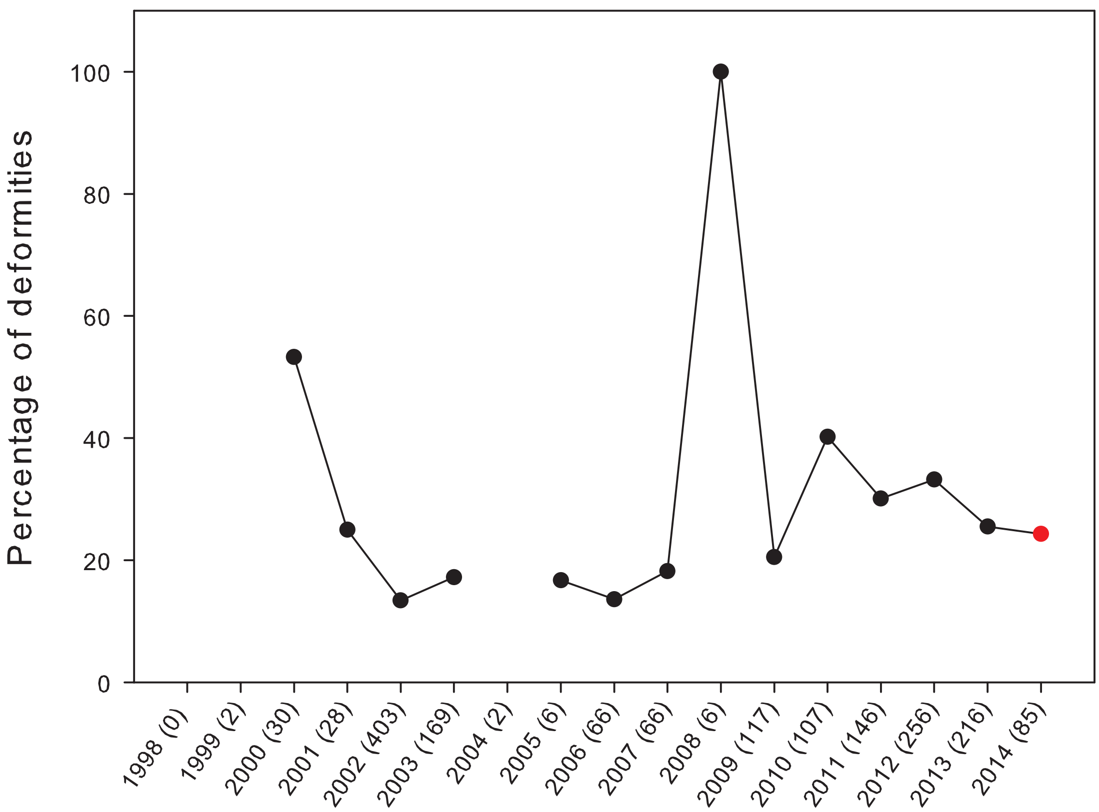


Figure 28. Percentage of Razorback Sucker with opercular deformities by year. The number of fish examined is reported in parentheses. Years with no associated value are due to insufficient sample sizes. Sample size reported in parentheses.

Monitoring sites

During the 2014 survey, a total of 64 visitations were made to the 14 monitoring sites within the study area (Table A-3). The site was sampled if suitable nursery habitat was available, otherwise photographs were taken and conditions noted on a field data sheet. During 64 visitations to the monitoring sites, backwater habitats were encountered 26 times, isolated pools were found 9 times, with the remaining 29 visitations being to dry sites. Typically 70 visitations are reported (14 sites x five trips) each year. The six monitoring sites downstream of Mexican Hat, UT were not visited during the last sampling trip because of insufficient discharge and the inability to sample that portion of the study area.

During the April survey, 12 of the 14 sites were connected to the main channel and contained a backwater habitat. This was the highest level of connectivity observed during 2014 (Figure 29). The following month, connectivity remained high with nine of the 14 sites containing a backwater habitat. For the remainder of the study period (three additional sampling trips) a backwater habitat was found in five of the 36 site visitations. Between April and the mid-July surveys, 126 age-0 Razorback Sucker were collected from monitoring sites; this represents 20.6% of the 2014 yearly total. A single age-0 Colorado Pikeminnow was also collected at the river mile 116.9 (Cowboy Wash) monitoring site during the mid-July survey. This collection was the farthest upstream documentation of age-0 Colorado Pikeminnow during 2014.

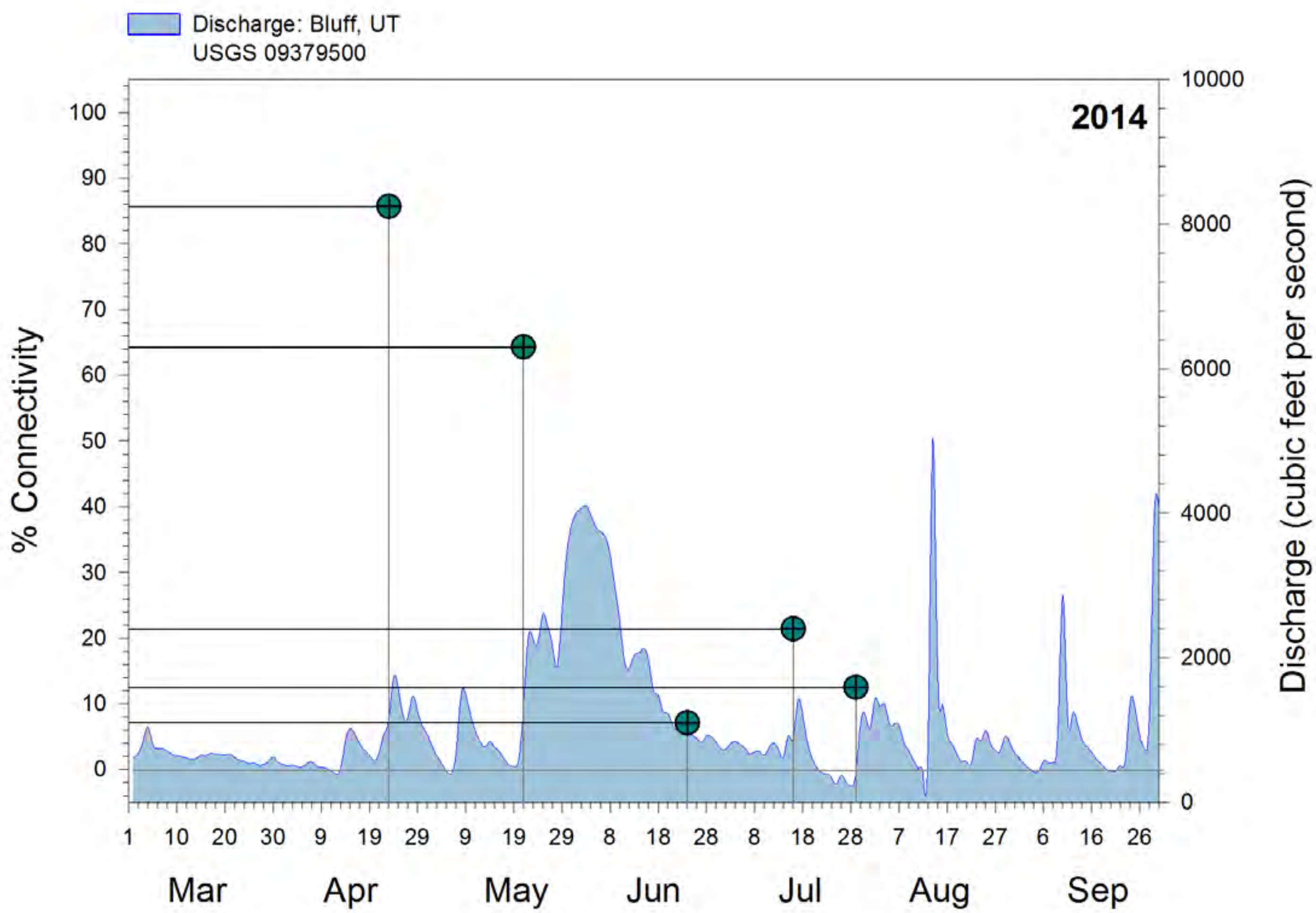


Figure 29. Mean connectivity of the 14 monitoring sites during the five survey trips.

RERI sites

During the 30 RERI site visitations (six sites x five monthly surveys), 16 collections yielded nine species and a total of 970 age-0 specimens (Table 13).
Two of the RERI sites contained age-0 Razorback Sucker. Three Razorback Sucker were captured between May and June at the river miles 126.8 (n = 1) and 127.2 (n = 2) sites. Four age-1+ Colorado Pikeminnow were also collected in the RERI sites during 2014. Three age-1+ Colorado Pikeminnow were collected at the river mile 130.7 site in April and one at the river mile 126.6 site in May.

An effort was made to compare the six RERI sites to other, similar sites sampled in 2014. 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 (RM 137.2–122.2). Within this pool of sites, all habitats associated with washes, arroyos, or tributaries were excluded from analysis. The remaining sites (n = 17) were all habitats that were directly associated with either the main or a secondary channel. Similar to the 16 collections made within the RERI sites, not all of these 17 sites contained fish at the time of visitation. These 17 sites will be considered the “control” sites.

Age-0 species composition was similar between the RERI and control sites. The native species composition was the same for the RERI and control sites and each group of sites contained Common Carp, Fathead Minnow and Red Shiner. Other non-native species found within the RERI sites include Channel Catfish and Plains Killifish; these species were not in the control sites. Conversely, the controls sites contained Western Mosquitofish, which was not found in the RERI sites. The proportion of native to non-native species found between the RERI and control sites was different. Of the 970 specimens collected in the RERI sites, 74.0% were native species and 26.0% were non-native. Control sites yielded 1,634 specimens, with 60.5% of those fish being native species and 39.5% being non-native. The RERI sites yielded a higher proportion of the native Speckled Dace, while the control sites were found to have a higher proportion of the two non-natives Fathead Minnow and Red Shiner.

Table 13. Species composition and habitat type of the six RERI sites sampled in 2014. Six letter species codes are defined in Table A-6.

RERI	Survey Month	Water Descriptor	Q (cfs)		PTYLUC	RHIOSC	CATDIS	CATLAT	XYRTEX	CYPCAR	CYPLUT	PIMPRO
132.2	April	site dry	978									
	May	site dry	798									
	June	embayment	1,160			11	14	2				
	Mid-July	backwaters (n=2)	973			117	71				12	9
	Late July	site dry	542									
				Total	**0**	**128**	**85**	**2**	**0**	**0**	**12**	**9**
132	April	run, not sampled	978									
	May	run, not sampled	798									
	June	run, not sampled	1,160									
	Mid-July	slackwater at outlet	973			6	2					
	Late July	run, not sampled	542									
				Total	**0**	**6**	**2**	**0**	**0**	**0**	**0**	**0**
130.7 A	April	pool	1,120									
	May	run, not sampled	1,320									
	June	pool	1,160			16	29	4				
	Mid-July	pool	973			40	9				4	2
	Late July	backwater	542			3					153	1
				Total	**0**	**59**	**38**	**4**	**0**	**0**	**157**	**3**
130.7 B	April	sand shoal	1,120									
	May	sand shoal	1,320									
	June	run, not sampled	1,160									
	Mid-July	slackwater	973			16						1
	Late July	slackwater	542			4					24	4
				Total	**0**	**20**	**0**	**0**	**0**	**0**	**24**	**5**
126.8	April	site dry	1,120									
	May	sand shoal	1,320									
	June	sand shoal	1,160			13	15	12	1			
	Mid-July	? site was missed	973									
	Late July	site dry	542									
				Total	**0**	**13**	**15**	**12**	**1**	**0**	**0**	**0**
127.2	April	run, not sampled	1,120									
	May	pool	1,320				1	11	2		1	
	June	slackwater & sand shoal	1,160			1	13	9				
	Mid-July	slackwater	973			248	51	1			26	8
	Late July	site dry	542									
				Total	**0**	**249**	**65**	**21**	**2**	**0**	**27**	**8**

Discussion

General linear models that included multiple environmental covariates were used to elucidate changes in the occurrence and density of endangered species over time. Initial analyses in 2013 that included only a few general covariates (e.g., reach and habitat) indicated that most of the variation in density was explained by the year model (δ(Year) μ(Year)). While the year models illustrated the importance of annual changes, a more complete understanding of the underlying processes remained unclear. Environmental covariates included in the 2014 models included mean discharge and temperature during the back-calculated spawning period for both Colorado Pikeminnow and Razorback Sucker. Fall monitoring capture data (for Razorback Sucker and Colorado Pikeminnow) and augmentation data (for Razorback Sucker only) was also included. Models that included these additional covariates generally received a substantial amount of the AIC_C weight, indicating their importance in explaining variation in population parameter estimates over the study period.

The two top models for age-0 Colorado Pikeminnow both had the year covariate for delta(δ) (i.e., probability of occurrence) and some element of the fall monitoring capture data for mu(μ) (i.e., density). Fall monitoring captures were divided into two size-classes; fish > 450 mm TL (i.e. adults) and fish that were 300-449 mm TL. It was assumed that fish > 450 mm TL were fully capable of spawning, and that fish in the 300-449 mm TL range had some potential to spawn. The smaller size-class comprised fish that would spend 8-10 months in the river between the time of capture in the fall and the subsequent onset of summer spawning. The top model included the 450+ mm TL covariate for mu, and the second model contained the 300-449 mm TL covariate for mu. Together these models received 65.4% of the AIC_C weight. While augmentation data were not considered for Colorado Pikeminnow (since stocked fish require several years to reach maturity), the fall monitoring capture data could be viewed as a proxy for augmentation efforts. Given the extremely low numbers of larval Colorado Pikeminnow collected prior to 2014, it is highly likely that most adult fish in the San Juan River are a result of augmentation.

The collection of 312 larval Colorado Pikeminnow in 2014 resulted in estimated densities using sampling-site data that were significantly higher than any preceding year. While this is a positive indication of successful spawning and early larval recruitment in the wild, the lack of sampling data in the lower canyon below Mexican Hat, UT introduces uncertainty into the interpretation of the 2014 survey. During the tenure of this study, that section of river during that time of year has been one of the most productive for larval Colorado Pikeminnow. While there is no way to know what would have been collected, the dramatic increase in the number of larvae found in 2014 coupled with the fact that Colorado Pikeminnow were collected immediately upstream of Mexican Hat during the final survey suggests that some additional number of larvae would likely have been collected.

The continued collection of larval Razorback Sucker throughout the entire study area and the documentation of seventeen consecutive years of spawning suggest that an established adult population resides within the San Juan River. Mixture-model estimates using sampling-site data suggests that the cumulative number of Razorback Sucker stocked in the San Juan River since 1998 is a key factor in explaining larval fish captures. The top model incorporated cumulative stocking as a covariate for both delta and mu. This model received 72.0% of the AIC_C weight. The second top model showed that May discharge explained some variability (13.9% of the AIC_C weight) in larval fish captures. This spring flow covariate was included for both the delta and mu model parameters. While there was some variability among years, estimated densities were generally higher in years with lower values for May discharge. It should be noted that the model only speaks to larval fish captures, and does not address life-history characteristics of adult Razorback Sucker, creation and maintenance of nursery habitats, or growth and survivorship of larvae.

Estimated densities for Razorback Sucker were significantly higher in 2011–2014 than all preceding years except 2002 and 2003. During this time period, several metrics suggest that recovery efforts are having a positive impact. Increased upstream distribution of larvae, higher frequencies of occurrence, broad back-calculated hatching and spawning dates, and the increased frequency of the juvenile life stage all have positive implications. The 2014 survey was the second consecutive year in which age-0 juvenile Razorback Sucker were large enough to positively identify in the field and release back into the river. Between 1998 and 2010, this life stage was collected in five of the 13 annual surveys but has been collected in each of the annual surveys between 2011 and 2014.

Unlike Colorado Pikeminnow, the absence of collection data in the lower portion of the study area during the final July survey trip does not complicate interpretation of the 2014 survey results. Razorback Sucker is rarely collected during that time year, and the few that have been collected are typically juvenile fish; a life stage that was documented in 2014 during previous survey trips. Because the back-calculated hatching and spawning dates are done using only proto- and mesolarvae, it is unlikely those dates would have been influenced by the missing capture data. Furthermore, mixture-model estimates only incorporate months that have produced at least 1.0% of larval captures during the tenure of this study. For Razorback Sucker that time period is April through June.

For both Colorado Pikeminnow and Razorback Sucker, habitat data that incorporates specific spatial components such as location of individual (i.e. seine haul) sampling efforts have only been available since 2013. For both species estimated densities were highest in backwater and embayment habitat types. These results were similar to previously reported habitat analysis done for Razorback Sucker (Farrington et al., 2013) with 2014 being the first time this type of analysis was done for Colorado Pikeminnow. Within backwaters and embayments, the terminal portion of the habitat had the highest estimated densities of Colorado Pikeminnow. This supports the anecdotal observations of several researchers over the years; that during the summer months larval densities are highest in the terminal portion of these two mesohabitat types. Because backwaters and embayments are the only two habitat types to have a terminal end, management actions (i.e. habitat creation, environmental flows etc.) that maintain these habitats become particularly important. The continued collection of detailed habitat information should further elucidate habitat and fish use relationships.

Mixture-model estimates were done for some of the common species for the first time in 2014. Currently, the two covariates analyzed were year and reach. For many species, the model runs in 2014 indicated that most of the variation in density was explained by the year model (δ(Year) μ(Year)). The two exceptions to this were Speckled Dace and Bluehead Sucker. For both of these species the (δ(Reach) μ(Reach)) model received most of the AIC_C weight (w_i). Densities for these species are highest in upstream reaches of the study area and decrease in the downstream reaches.

While there is considerable variation in estimated densities among years, many of the common species analyzed for this report exhibit overall long term stability. The two exceptions to this are Red Shiner and Fathead Minnow. Both of these small-bodied cyprinids show a declining trend due primarily to very high densities recorded during the first few years of this study, which have not been observed in more recent years.

Opercular deformities continue to be observed in young-of-year Razorback Sucker. While the number of fish examined in 2014 (n = 85) was fewer than the number examined in 2013 (n = 216) in 2013, the percentage of fish with deformities was nearly identical. Assuming that severely deformed fish are subjected to higher mortality rates, it is possible that the percentage of deformed fish is underestimated in this study. Elevated levels of mortality, or reduced condition factor may also be inhibiting recruitment of young Razorback Sucker to later life stages. An examination of hatchery reared Razorback Sucker larvae revealed opercular deformities occurred at a lower rate (2.9%) than wild spawned fish. This suggest the causative mechanism is environmental (vs. genetic). During the opercular deformity study done for the SJRBRIP (see Barkstedt et al., 2014), the U.S. Bureau of Reclamation requested specimens be set aside for both histological and toxicological analyses. Specimens were sent to Dr. Wolfgang K. Vogelbein (Virginia Institute of

Marine Science, College of William and Mary) for histological analyses and Dr. Sharon K. Taylor (U.S. Bureau of Reclamation) for toxicological analyses. The results of these two pilot investigations will be provided to the SJRBRIP by the U.S. Bureau of Reclamation when available.

The monitoring sites established for this study have provided some insight into the dynamic nature of habitats in the San Juan River. These sites were established strictly to monitor backwater formation in lateral washes and canyons. An examination of the four-year database for these sites illustrates the stochastic nature of inundation of sites that have a degree of physical stability not associated with other backwater habitats, such as those formed at the downstream end of secondary channels or cut into exposed cobble and sand bars. Despite this degree of stability, there is no clear pattern in site inundation and river stage. For example, the monitoring site located at river mile 16.4 is located in a large lateral canyon in Reach 1. This site has contained a backwater at flows as low as 449 cfs and been completely dry at flows of 1,140 cfs. Similar patterns of inundation exist for all of the monitoring sites. This suggests that the antecedent conditions that deposit or remove sand from the mouth of these sites potentially dictates inundation more than discharge. Most of the monitoring sites have inundated at flows above 1,500 cfs and all have inundated at flows above 2,000 cfs.

Habitat types encountered during 2014 in the six RERI sites included backwaters, pools, sand and cobble shoals, slackwaters and runs. Most of the sites were not dry at the time of visitation. The final trip saw dry sites at river mile sites 132.2, 128.6, and 127.2 when mean discharge was 542 cfs at time of visitation. The site at 132.2 was also dry during the April and May surveys. These restored secondary channels again provided nursery habitat during a several month period over a range of discharge levels.

Future modeling efforts will include the addition of more environmental and biological covariates for all species analyzed. While things such as augmentation obviously do not apply to the common species, temperature and flow metrics, small and large-bodied monitoring data, and non-native removal data all could potentially be used as covariates. This new modeling framework, should lead to a more robust understanding of the dynamic ecological processes in the San Juan River. This understanding will be essential in ensuring the persistence of native species and in the development of successful management plans for the recovery of endangered fish species.

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Appendix A

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

Field No.: MAF14-137

Date: 17 July 2014 / Acc. No.: 2014-IV:21

State/Country: Utah/USA Locality: San Juan River @ RM 12.5

County: San Juan Drainage: San Juan Quad.: Slickhorn Canyon West

Coordinate System: UTM Datum: NAD27 Zone: 12S

Start (E)/W: 568000 (N)/S: 4127585 Stop: E/W: N/S:

Shore Description: Sand bank Air Temp.: 25.5 °C

Water Description: Sand shoal

Substrate: Sand & silt Water Depth: ≤ 20 m

Aquatic Vegetation / Cover: none / none

Water Temp.: 24.2 °C Velocity (est.): ≤ 1 m/s Width (est.): 6 m Secchi Depth: 1 cm

D.O.: 5.82 mg/l Conductivity (µS): C 616 / Sc 625 Salinity: 0.30 ppt pH: 8.08

Method of Capture: Larval Seine / 1m x 1m x 0.8mm

Hauls: 4 Area: 407 m² Shocking Sec.: Volts: Amps:

Collectors: WH Brandenburg, SL Durst, C Cheek

Time: (start) 0758 h (stop) 0810 h Notes taken by: WHB

Orig. Preservative: 95% EtOH Photographs: 0411, 0412

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

We worked a variety of low velocity areas associated with an exposed mid channel island. Larval fishes were captured in all hauls. Flows in the river seem unchanged from yesterday

✓ ① SSSH 12.3 m ✓ Catlat 62 mm SL

✓ ② SSSH 12.0 m ✓

✓ ③ SSSH 6.1 m ✓

✓ ④ SSSH 10.3 m ✓ Ptyluc 92 mm SL / 112 mm TL

Table A-1. Summary of larval Colorado Pikeminnow in the San Juan River (1993-2013) 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
WHB13-135	86309	1	16.7	17 Jul 13	17 Jun 13	107.6	larval seine
WHB13-140	86561	1	14.1	18 Jul 13	20 Jun 13	100.6	larval seine
WHB13-152	86573	4	15.8-17.6	19 Jul 13	19-20 Jun 13	78	larval seine
WHB13-187	86656	3	15.8-23.6	1 Aug 13	18 Jun-3 Jul 13	14	larval seine
WHB13-151	86411	1	28	19 Jul 13	23 May 13	79.4	larval seine
WHB13-163	86656	1	28.7	30 Jul 13	1 Jun 13	59.3	larval seine
WHB13-189	86411	1	28.7	2 Aug 13	4 June 13	10	larval seine
TOTAL		**58**					

Table A-2. Summary of larval and age-0 Razorback Sucker collected during the San Juan River larval fish survey 1998-2013.

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
2013	147.9 - 2.9	21 Apr - 2 Aug	9,750.0	979	larval seine
TOTAL				**7,408**	

Table A-3. Locality and description of the 14 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 2014 larval fish survey. Effort =8,623.0 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	6,287	32.5	72.9	101	34.8
Common Carp	I	17	0.1	0.2	12	4.1
Roundtail Chub	N	1	*	*	1	0.3
Fathead Minnow	I	1,155	6.0	13.4	72	24.8
Colorado Pikeminnow	N	312	1.6	3.6	34	11.7
Speckled Dace	N	4,897	25.3	56.8	136	46.9
SUCKERS						
Flannelmouth Sucker	N	1,945	10.1	22.6	141	48.6
Bluehead Sucker	N	3,024	15.6	35.1	126	43.4
Razorback Sucker	N	612	3.2	7.1	85	29.3
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	15	0.1	0.2	5	1.7
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	881	4.6	10.2	64	22.1
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	25	0.1	0.3	8	2.8
LIVEBEARERS						
Western Mosquitofish	I	79	0.4	0.9	24	8.3
SUNFISHES						
Green Sunfish	I	-	-	-	-	-
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	38	0.2	0.4	20	6.9
TOTAL		19,288		223.7		

[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* = 290 samples.
* Value is less than 0.05%

Table A-5. Summary of age-1+ fishes collected in the San Juan River during the 2014 larval fish survey. Effort =8,623.0 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	889	75.1	9.9	101	34.8
Common Carp	I	-	-	-	-	-
Roundtail Chub	N	-	-	-	-	-
Fathead Minnow	I	86	7.3	1.0	20	6.9
Colorado Pikeminnow	N	98	8.3	1.1	45	15.5
Speckled Dace	N	109	9.2	1.3	27	9.3
SUCKERS						
Flannelmouth Sucker	N	3	0.3	0.0	2	0.7
Bluehead Sucker	N	2	0.2	*	2	0.7
Razorback Sucker	N	-	-	-	-	-
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	-	-	-	-	-
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	3	0.3	*	1	0.3
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	2	0.2	*	2	0.7
LIVEBEARERS						
Western Mosquitofish	I	27	2.3	0.3	11	3.8
SUNFISHES						
Green Sunfish	I	-	-	-	-	-
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	1	0.1	*	1	0.3
-						
TOTAL		1220		13.7		

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* = 290 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 2014 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)

Covariate	Description
Year	The calendar year in which the larval survey took place.
Reach	Each of the 5 geomorphic reaches (5–1) within the study area.
Mean April and May temperature.	Daily mean temperature data was taken from USGS gage #09379500 near Bluff, Utah.
Mean April and May discharge.	Daily mean discharge data (cfs) was taken from USGS gage #09379500 near Bluff, Utah.
Annual # stocked.	The number of Razorback Sucker stocked within a calendar year. Fish stocked in a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).
Cumulative # stocked	The number of Razorback Sucker stocked during the time period between 1998 and the year prior to the larval survey year. (e.g. 5,000 fish stocked between 1998–2000 would be used as a covariate for 2001 larval capture data).
Fall monitoring captures.	All fall monitoring captures of adult Razorback Sucker. Fish collected during a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).

Table A-7. Covariates used in mixture models for Razorback Sucker.

Covariate	Description
Year	The calendar year in which the larval survey took place.
Reach	Each of the 5 geomorphic reaches (5–1) within the study area.
Mean June and July temperature.	Daily mean temperature data was taken from USGS gage #09379500 near Bluff, Utah.
Mean June and July discharge.	Daily mean discharge data (cfs) was taken from USGS gage #09379500 near Bluff, Utah.
Fall monitoring captures 300–449 mm TL.	All fall monitoring captures of Colorado Pikeminnow between 300-449 mm TL. Fish collected during a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).
Fall monitoring captures 450+ mm TL.	All fall monitoring captures of Colorado Pikeminnow 450+ mm TL. Fish collected during a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).

Table A-8. Covariates used in mixture models for Colorado Pikeminnow.

Table A-9. Summary of the age-0 Colorado Pikeminnow collected in the San Juan River during the 2014 larval fish survey.

Field Number	**N=**	**Length (mm TL)**	**Ontogeneic Stage**	**Date Collected**	**Rivermile**
JLK14-120	1	14.4	metalarva	15-July-14	116.9
JLK14-122	4	9 -15	meso - metalarvae	15-July-14	113.5
JLK14-129	2	11, 15.4	meso - metalarvae	16-July-14	99.6
JLK14-132	1	13.1	mesolarva	16-July-14	92.6
JLK14-133	2	11.8, 14	meso - metalarvae	16-July-14	92.6
JLK14-135	1	12.9	mesolarva	16-July-14	90.8
JLK14-136	1	17.1	metalarva	16-July-14	87.4
JLK14-138	3	12.4 -15.2	meso - metalarvae	17-July-14	83.7
JLK14-139	1	13.9	metalarva	17-July-14	79.5
MAF14-105	2	10.4, 11.7	mesolarvae	13-July-14	74.5
MAF14-106	1	13.5	metalarva	13-July-14	71.1
MAF14-107	4	12.2 -14.3	meso - metalarvae	14-July-14	69.4
MAF14-108	4	12.6 -14.4	meso - metalarvae	14-July-14	68.6
MAF14-109	11	11.9 -15.9	meso - metalarvae	14-July-14	67
MAF14-112	3	8.7 -11.8	mesolarvae	14-July-14	60.6
MAF14-113	1	N/A	mesolarva	14-July-14	59.3
MAF14-114	72	8.7 -15.2	meso - metalarvae	14-July-14	59.2
MAF14-116	15	10.4 -15.5	meso - metalarvae	14-July-14	56.1
MAF14-119	11	10 -16	meso - metalarvae	14-July-14	49.5
MAF14-120	1	13.1	mesolarva	15-July-14	45
MAF14-123	91	8.5 -17.2	meso - metalarvae	15-July-14	41.3
MAF14-128	2	15, 15.8	metalarvae	16-July-14	26.4
MAF14-129	26	9.8 -16.2	meso - metalarvae	16-July-14	24.8
MAF14-130	3	12 -16.2	meso - metalarvae	16-July-14	23.3
MAF14-132	1	14.6	metalarva	16-July-14	20.9
MAF14-133	4	13.2 -14.5	meso - metalarvae	16-July-14	17.9
MAF14-135	2	13.7, 14.1	metalarvae	16-July-14	15.5
MAF14-137	14	8.6 -17.8	meso - metalarvae	17-July-14	12.5
MAF14-139	3	10.8 -16.4	meso - metalarvae	17-July-14	10
MAF14-141	1	14	metalarva	17-July-14	9.6
MAF14-143	14	9 -15.8	meso - metalarvae	17-July-14	6.6
MAF14-145	7	9.4 -12.8	mesolarvae	17-July-14	3.2
JLK14-145	1	17.7	metalarva	27-July-14	73.4
JLK14-148	2	18.8, 20.8	meta - juvenile	28-July-14	62.4
Total	**312**				

Table A-10. Summary of the age-0 Razorback Sucker collected in the San Juan River during the 2014 larval fish survey.

Field Number	N=	Length (mm TL)	Ontogeneic Stage	Date Collected	Rivermile
MAF14-022	1	10.9	protolarva	23-April-14	97
MAF14-031	2	13.5, 13.6	mesolarvae	24-April-14	78.7
JLK14-008	9	10 -14.4	proto - mesolarvae	22-April-14	59.8
JLK14-010	4	9.5 -12.7	proto - mesolarvae	22-April-14	55.2
JLK14-018	1	11.3	mesolarva	23-April-14	27
JLK14-023	9	10.8 -11.8	proto - mesolarvae	24-April-14	17.7
JLK14-026	2	11.4, 11.4	mesolarvae	24-April-14	12.9
JLK14-030	3	10.7 -13.7	proto - mesolarvae	24-April-14	8.1
MAF14-033	3	11 -12.4	mesolarvae	19-May-14	147.1
MAF14-035	2	11.3, 11.5	proto - mesolarvae	19-May-14	143.4
MAF14-036	1	10.9	protolarva	19-May-14	139.5
MAF14-044	2	11.4, 11.5	mesolarvae	20-May-14	126.6
MAF14-046	1	11.1	mesolarva	20-May-14	122.2
MAF14-049	7	10.7 -13.5	mesolarvae	20-May-14	117.9
MAF14-053	19	10.1 -14.2	proto - mesolarvae	20-May-14	110
MAF14-054	2	11.2, 11.3	mesolarvae	20-May-14	107.6
MAF14-055	2	11.3, 11.5	mesolarvae	21-May-14	106.5
MAF14-057	11	10.7 -13.9	mesolarvae	21-May-14	100.5
MAF14-058	1	12	mesolarva	21-May-14	96.4
MAF14-061	1	10.7	protolarva	21-May-14	88.8
MAF14-062	29	10.3 -14.2	proto - mesolarvae	22-May-14	87
MAF14-063	8	10 -12.2	proto - mesolarvae	22-May-14	86
MAF14-064	14	10.7 -13.6	proto - mesolarvae	22-May-14	84.1
MAF14-065	13	10.5 -13.9	proto - mesolarvae	22-May-14	82.4
MAF14-067	1	15.9	mesolarva	22-May-14	78
JLK14-033	24	10 -11.7	proto - mesolarvae	19-May-14	75.8
JLK14-034	2	11.4, 11.5	mesolarvae	19-May-14	75
JLK14-035	26	10 -12.9	proto - mesolarvae	19-May-14	73
JLK14-036	11	10.7 -12.9	mesolarvae	20-May-14	70.3
JLK14-037	16	9 -12	proto - mesolarvae	20-May-14	70.3
JLK14-038	2	11.5, 13.5	mesolarvae	20-May-14	65.4
JLK14-040	20	10.2 -12.5	proto - mesolarvae	20-May-14	60
JLK14-042	1	10.7	protolarva	20-May-14	55.6
JLK14-043	2	8.8, 9.7	protolarvae	20-May-14	52.7
JLK14-044	1	10.1	protolarva	20-May-14	52.7
JLK14-046	28	10.7 -16.2	proto - mesolarvae	21-May-14	44.9
JLK14-047	2	11.5, 12	mesolarvae	21-May-14	42.9
JLK14-048	4	10.9 -12	proto - mesolarvae	21-May-14	37
JLK14-049	12	9.9 -12.4	mesolarvae	21-May-14	27
JLK14-051	1	12.1	mesolarva	21-May-14	19.8
JLK14-052	3	11.1 -17	proto - mesolarvae	22-May-14	17.7

JLK14-053	2	15.6, 17	mesolarvae	22-May-14	16.4
JLK14-054	3	11 -15.7	mesolarvae	22-May-14	13.9
JLK14-055	14	9.9 -15.9	mesolarvae	22-May-14	13
JLK14-056	34	10.3 -16.3	proto - mesolarvae	22-May-14	13
JLK14-057	79	10.3 -17.9	mesolarvae	22-May-14	10
JLK14-058	1	14.1	mesolarva	22-May-14	8.1
JLK14-059	10	10.8 -14.5	mesolarvae	22-May-14	7
JLK14-070	1	11.8	mesolarva	23-Jun-14	133.7
JLK14-073	1	12.6	mesolarva	23-Jun-14	128.1
JLK14-076	68	12.1 -23.9	meso - metalarvae	23-Jun-14	122.6
JLK14-078	8	11.1 -14.2	mesolarvae	23-Jun-14	119.4
JLK14-080	2	13.1, 13.2	mesolarvae	24-Jun-14	117.9
JLK14-081	4	12.5 -14.2	mesolarvae	24-Jun-14	116.9
JLK14-094	1	20.5	mesolarva	25-Jun-14	93
JLK14-097	2	12.7, 13.6	mesolarvae	25-Jun-14	88
JLK14-098	9	11.3 -41	meso - juvenile	26-Jun-14	85.7
JLK14-100	1	13.4	mesolarva	26-Jun-14	83.7
JLK14-102	1	10.6	mesolarva	26-Jun-14	78.7
MAF14-068	1	12.3	mesolarva	22-Jun-14	75.5
MAF14-070	1	10.1	mesolarva	22-Jun-14	70.4
MAF14-071	1	28.5	juvenile	22-Jun-14	69.8
MAF14-073	1	10.4	mesolarva	23-Jun-14	67
MAF14-075	7	25.2 -34.4	meta - juvenile	23-Jun-14	57.9
MAF14-083	8	10 -12.2	mesolarvae	24-Jun-14	41.2
MAF14-085	2	11.3, 11.7	mesolarvae	24-Jun-14	33.6
MAF14-087	1	13.9	mesolarva	25-Jun-14	25
MAF14-088	1	13.2	mesolarva	25-Jun-14	24.5
MAF14-097	4	11.5 -11.8	mesolarvae	26-Jun-14	8.9
MAF14-099	1	31.2	juvenile	26-Jun-14	7.1
MAF14-101	4	11.1 -35.3	meso - juvenile	26-Jun-14	5
MAF14-102	17	10.7 -13.8	mesolarvae	26-Jun-14	4.5
MAF14-104	1	28.7	juvenile	13-Jul-14	75.2
MAF14-107	1	N/A	mesolarva	14-Jul-14	69.4
MAF14-109	1	24.9	juvenile	14-Jul-14	67
MAF14-113	1	11	mesolarva	14-Jul-14	59.3
MAF14-114	3	21.5 -25.2	metalarvae	14-Jul-14	59.2
MAF14-115	3	25.5 -57.6	juvenile	14-Jul-14	57.9
MAF14-116	1	28.4	juvenile	14-Jul-14	56.1
MAF14-123	1	17.1	metalarva	15-Jul-14	41.3
MAF14-137	1	12.1	mesolarva	17-Jul-14	12.5
MAF14-141	1	16.5	mesolarva	17-Jul-14	9.6
MAF14-142	1	15.2	mesolarva	17-Jul-14	8.1
MAF14-143	3	12.8 -14.2	mesolarvae	17-Jul-14	6.6
MAF14-145	1	15.2	mesolarva	17-Jul-14	3.2
2014 Total	**612**				