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2013 INTEGRATED PIT TAG DATABASE SUMMARY OF COLORADO PIKEMINNOW AND RAZORBACK SUCKER IN THE SAN JUAN RIVER

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To Bureau of Reclamation

From

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ABSTRACT

I integrated and summarized the PIT tag data for endangered Colorado pikeminnow and razorback sucker from all of the San Juan River Basin Recovery Implementation Program's management and monitoring efforts. Most Colorado pikeminnow encountered in 2013 were stocked without PIT tags and like past years, relatively few pikeminnow were encountered in the San Juan River after three years post-stocking. While the total numbers of Colorado pikeminnow individuals detected in 2013 declined compared to previous years, abundance estimates by size class have exhibited substantial temporal variation. Annual growth rates for Colorado pikeminnow averaged 72.2 mm/year but varied by size class and year. Smaller Colorado pikeminnow grew faster than larger fish, but there was no relationship between prey, temperature, and flow on annual growth rates. The total number of razorback sucker individuals detected has generally increased since 2008, consistent with patterns in razorback sucker abundance estimates. Although the return rate of stocked razorback suckers has varied through time, numerous individuals were detected three or more years post-stocking in 2013. The proportion of razorback suckers captured in 2013 without PIT tags was half that observed for 2010-2012, perhaps due to changes in PIT tagging protocol for fish stocked from the NAPI ponds. Capture of untagged razorback suckers in the San Juan River does not suggest widespread wild recruitment. The San Juan Recovery Implementation Program should continue to integrate PIT tag data across all projects in order to inform the adaptive management process and evaluate the status of the species' progress toward recovery.

INTRODUCTION

The San Juan River Basin Recovery Implementation Program (Program) conducts efforts in the San Juan River Basin to recover endangered Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*). These efforts include management actions such as the stocking of hatchery-reared endangered fish, non-native fish removal, increased range expansion through removal of fish passage barriers, and managed releases of peak and base flows from Navajo Dam. Annual monitoring provides information on the fish community response to management actions. Endangered fishes are handled during management (non-native fish removal and PNM Fish Passage) and monitoring activities (larval, small-bodied, and large-bodied fish monitoring). Information on individual fish is gathered through the reading of uniquely identified passive integrated transponder (PIT) tags implanted in these individuals. In addition to the PIT tag number, river mile (RM) location, length, weight, breeding condition and other observations are recorded for each endangered fish captured. Colorado pikeminnow are currently stocked into the San Juan River at a size too small (~50 mm TL) to be implanted with a PIT tag (Furr 2013a), but these fish are implanted with a PIT tag when they are first recaptured ≥ 150 mm TL. Age-1+ Colorado pikeminnow were previously stocked into the San Juan River (Furr 2013a) but this augmentation effort ceased in 2011 (Durst 2009). Razorback suckers have typically been stocked into the San Juan River with a PIT tag implanted (Furr 2013b) but in 2006 and 2007 approximately 10,000 untagged fish were stocked as part of an effort to start a single cohort strategy at the Navajo Agricultural Production Industry (NAPI) Ponds (Ryden 2008, Morel 2011). Recaptures of PIT tagged individuals across the Program's monitoring and management efforts form the basis of a database that can be used to create encounter histories of each individual and produce the summaries and analyses presented herein.

The information that can be produced from this database includes summaries detailing the recapture rate of stocked individuals to inform the Program's adaptive management process, mark-recapture analyses to estimate annual survival of stocked individuals (Bestgen et al. 2009), and population estimates that can be used to evaluate the Program's progress toward recovery for both species (Duran et al. 2011, Gerig and Hines 2013). I used the integrated PIT tag databases to examine patterns across all management and monitoring projects that collect PIT tag information to present a broader view of the status of each species. The objectives of this PIT tag summary report are to: (1) describe and summarize the recaptures of stocked Colorado pikeminnow and razorback sucker, (2) examine Colorado pikeminnow annual growth rates, (3) evaluate recapture of razorback suckers by stocking source, (4) investigate patterns in captures of razorback sucker without PIT tags, and (5) use existing data to develop capture-recapture abundance estimates for Colorado pikeminnow and razorback sucker.

METHODS

Field methods

All management and monitoring efforts in the San Juan River that collect PIT tag data contributed to this report. Data were provided by the Southwestern Native Aquatic Resources and Recovery Center (SNARRC; formerly Dexter National Fish Hatchery and Technology Center), Uvalde National Fish Hatchery (Uvalde), Horsethief Canyon Native Fish Facility (Horsethief), NAPI Ponds; larval, small-bodied, and adult monitoring; Lake Powell razorback sucker survey; upper, middle, and lower San Juan non-native fish removal; the fish passage at PNM Weir; and other studies funded outside the Program. These activities primarily covered the San Juan River from upstream of the Animas River confluence (RM 180.2) to Clay Hills Crossing (RM 2.9) but also included data from the lower Animas River, the San Juan River arm of Lake Powell, and some tributaries of the San Juan River (Figure 1).

Colorado pikeminnow stocked at age-0 were too small to be implanted with a PIT tag. All pikeminnow recaptured in the San Juan River without a PIT tag are thought to be the result of the Program's age-0 stocking efforts. Too few larval Colorado pikeminnow have been detected to assume there is any recruitment of wild-produced individuals (Farrington et al. 2013). Only pikeminnow ≥ 150 mm TL captured in the San Juan River are typically implanted with a PIT tag (and entered in to the FIRST_ENC table as TAG records). The numerous pikeminnow < 150 mm TL that are captured without PIT tags during management and monitoring efforts are not included in this study. I assigned pikeminnow TAG records a year class based on their size and the month when they were first encountered in the San Juan River (D. Ryden, personal communication; Table 1). This allowed me to assign TAG records to a year class and stocking year to evaluate recaptures of untagged Colorado pikeminnow from a given stocking year. Typically, pikeminnow > 400 mm TL captured without a PIT tag could not be reliably assigned to an age class because of variation in growth rates for fish of that size. However, these cases are relatively rare (only 130 of 9,734 Colorado pikeminnow TAG records through 2013 could not be assigned to a year class).

Database methods

I received most source files in Excel formats. I confirmed all fields were in the same format as the integrated PIT tag databases, removed duplicate data, and ensured imported data did not violate the integrated databases' validation rules. Records in source files with duplicate or inappropriate PIT tag numbers I could not reconcile were not imported. I imported the proofed PIT tag data for Colorado pikeminnow and razorback sucker into two separate MS Access files for each species (Microsoft Office 2010; Appendix 1). Each database contains a table recording each individual's unique first encounter in the San Juan River (FIRST_ENC). The FIRST_ENC table contains records of individuals stocked with a PIT tag, noted as "STOCK" in the CONTACT_TYPE field and individuals encountered in the San Juan River and implanted with a PIT tag, noted as "TAG" in the CONTACT_TYPE field. All records of individuals' subsequent recaptures are in a corresponding CAPTURE table. The PIT tag numbers between the two tables are linked via a one-to-many relationship that is referentially enforced, meaning that no record can appear in the CAPTURE table without a corresponding PIT tag number in the FIRST_ENC table (i.e., PIT tag numbers are unique in the FIRST_ENC table but not in the CAPTURE table). I created a series of queries within and between the FIRST_ENC and CAPTURE tables to produce the raw data and summary tables used for all subsequent analyses.

Data analysis

I summarized the total number of individuals captured by year from particular stocking classes for Colorado pikeminnow stocked with and without PIT tags and for razorback sucker stocked with PIT tags. Total numbers of individuals captured by year were not adjusted for annual sampling effort or numbers stocked in previous years. For Colorado pikeminnow stocked without and with PIT tags, I reviewed recaptures from stocking classes since 2002 and 2003, respectively. Because not all Colorado pikeminnow were stocked with PIT tags, I retroactively assigned an age to untagged fish based on the month and length they were initially captured (Table 1). I assigned these fish to a year class and stocking class based on their age but I did not attempt to assign an age to Colorado pikeminnow > 400 mm TL. For razorback sucker, I summarized recaptures from stocking classes since 2000.

To examine variation in Colorado pikeminnow annual growth rates, I calculated the growth between successive recaptures that occurred in successive years but at least 300 days apart for fish initially captured in 2006-2012. I limited this dataset so all fish experienced a similar length in growing season. Because not all successive recaptures spanned the same number of days, I calculated a daily growth rate based on the number of days between encounters and standardized growth to annual (365 days) growth. I grouped Colorado pikeminnow into three size classes based on TL at initial capture (< 200 mm, 200-299 mm, and ≥ 300 mm). To assess how year and size class influenced annual growth rates, I used a general linear model (GLM) with annual growth rate as the dependent variable and Year (of initial capture), Size class, and their interaction as fixed factors. The interaction was only retained in the final model if it was significant. I used multiple linear regressions to assess how growth rates of Colorado pikeminnow by size class was related to annual variation. I modeled the effects of catch per unit effort (CPUE) of prey species based on small-bodied fish monitoring (flannelmouth sucker, bluehead sucker, speckled dace, red shiner, fathead minnow, and western mosquito fish), temperature based on the mean number of days >21°C at Four Corners, and flow based on mean spring daily discharge (March-June) at Four Corners on Colorado pikeminnow growth rates.

To evaluate the success of hatcheries and grow-out facilities used by the Program, I examined recaptures of razorback suckers stocked from NAPI, SNARCC, and Uvalde from 2006-2012. I calculated a return rate for each source-year combination based on the number of individuals recaptured through 2013 sampling. Because the capture of untagged razorback suckers could be an indicator of wild recruitment, I examined the percent of fish captured without PIT tags 2004-2013 and the length-frequency histogram of untagged fish in 2013.

Although the Program does not have a sampling regime in-place (multiple river-wide passes in close temporal proximity) to specifically estimate abundance, I used all capture-recapture data to estimate annual abundance of Colorado pikeminnow and razorback sucker for each year independently, 2008-2013. While this ad hoc approach may not produce estimates as reliable as those that would be derived from an effort designed to explicitly conduct population estimates, this approach does not require a dedicated field study, it can produce trend estimates that could be compared to other monitoring efforts, it can be used to guide the Program when there is a need to conduct more formal estimates, and it can be used to inform the Program's progress toward recovery. In order to use all available data, I categorized captures each year into four passes. Each year sampling typically spanned March-October, and each pass covered two months (i.e., captures from March and April were group into pass 1, May and June in pass 2, etc.). Each pass included sampling from the PNM Weir (RM 166.6) downstream to Clay Hills Crossing (RM 2.9). Thus encounter histories for each year were based on four occasions (i.e., the four passes). I used closed capture models with full likelihood parameterization of p (probability of initial capture), c (probability of recapture), and N (abundance) (Otis et al. 1978) in Program MARK (White and Burnham 1999) to estimate the abundance of Colorado pikeminnow and razorback sucker from 2008-2013. Because Colorado pikeminnow are typically stocked without a PIT tag at ~50-70 mm TL, I grouped them into five size classes (<200 mm TL, 200-299 mm TL, 300-399 mm TL, 400-449 mm TL, and ≥450 mm TL). Since razorback suckers are stocked into the San Juan River at nearly adult sizes, I grouped them into five groups based on years post-stocking (1-, 2-, 3-, 4-years post-stocking and ≥5 years post-stocking). These groupings should allow me to examine the abundance of recently stocked fish and the abundance of fish that have persisted multiple years post-stocking. I modeled each year independently with pass varying detection probability (M_t) and constant detection probability (M_0) for each group. For simplicity sake and because I was primarily interested in estimating abundance (N), in both M_t and M_0 models I constrained p = c.

All raw data were based on queries of the Colorado pikeminnow and razorback sucker MS Access databases (Microsoft Office 2010). I used MS Excel (Microsoft Office 2010) to summarize data and create tables; I conducted statistical analyses in JMP 8.0 (SAS Institute Inc. 2008) and all figures were produced in SigmaPlot 12 (Systat Software Inc. 2012).

RESULTS AND DISCUSSION

Following the 2013 update, the Colorado pikeminnow and razorback sucker PIT tag databases contained 55,398 and 147,630 records, respectively. The FIRST_ENC tables, containing both STOCK and TAG records, had a total of 50,090 Colorado pikeminnow records and 136,659 razorback sucker records. The CAPTURE tables had 5,308 and 10,971 records for Colorado pikeminnow and razorback sucker, respectively. Because I considered recaptures of individual PIT tagged Colorado pikeminnow and razorback sucker in this report, the number of encounters presented here likely differ from other San Juan River Basin Recovery Implementation Program reports.

Recapture summaries

Across all management and monitoring efforts, a total of 909 individual Colorado pikeminnow were captured in 2013 (Figure 2). Over 99% of these individuals were originally stocked without PIT tags (typically as age-0). Two age classes of Colorado pikeminnow were stocked without PIT tags in 2011. In May 2011, 214,720 age-1 Colorado pikeminnow were stocked into the San Juan without PIT tags (Table 2). These fish were 2010 year class held at SNARRC through 2010 due to quarantine issues at the hatchery. Since these fish were stocked without PIT tags, I considered them together with age-0 for analysis purposes. This stocking class was available for recapture through summer and fall 2011. Typically Colorado pikeminnow stocked as age-0 in the fall are not available for recapture until the subsequent year's sampling efforts. Additionally, SNARCC fulfilled its Colorado pikeminnow age-0 stocking obligations in 2011 with 426,588 untagged fish stocked in November 2011. The first opportunity to recapture the age-0 Colorado pikeminnow from that stocking event was 2012.

There were 903 individual Colorado pikeminnow captured in 2013 that were stocked without PIT tags (Table 2). Most of these fish were assigned to the 2011 and 2012 year classes, i.e., age-1 and age-2. Note that the total number of individuals captured in 2013 includes 22 Colorado pikeminnow TAG records that could not reliably be assigned to a year class, but these were fish initially encountered > 400 mm TL and thus represented individuals over age-3. The number of recaptured Colorado pikeminnow that were stocked without PIT tags increased from 665 in 2008; to 2,271 in 2010; and declined to 1,210 in 2012 and further to 903 in 2013 (Table 2). In 2011 approximately 21% of Colorado pikeminnow previously stocked without PIT tags were age-3+. In 2012 fish in these older age classes represented only 7% of the total captured and over 12% of individuals were age-3+ in 2013. The abundant age-3+ Colorado pikeminnow documented in 2011 may have been the result of unidentified environmental conditions unique to that year since that high proportion of older pikeminnow has not been observed in other years. Although the number of age-3+ and older Colorado pikeminnow captured (stocked without PIT tags) represents only a small portion of the total number of pikeminnow captured, some individuals from stocking classes as old as 2002 continue to persist in the San Juan River, suggesting that these stocked individuals could form a group of reproducing adult Colorado pikeminnow.

Only six Colorado pikeminnow stocked with PIT tags were recaptured in 2013 (Table 3). This was 2% of the number recaptured in 2011. The decline in the number of recaptures of Colorado pikeminnow stocked with PIT tags is due to ending age-1+ stocking in 2011. From 2009-2011, more than 83% of Colorado pikeminnow stocked with PIT tags were only recaptured in the same year that they were stocked. The Program ceased production and stocking of age-1+ Colorado pikeminnow in 2011 based on their relatively higher cost and limited return rate compared to fish stocked as age-0 (Durst 2009). As more time passes between the age-1+ Colorado pikeminnow stocking events and future monitoring efforts, fewer fish from these stockings should be detected.

A total of 1,875 individual razorback sucker were captured in 2013 across all management and monitoring efforts (Figure 3). Total razorback sucker captures have generally increased since 2000. Of razorback suckers stocked with PIT tags, 68% of recaptures in 2013 were from the 2010-2012 stocking classes and 15% of recaptures were from stocking events prior to 2010 (Table 4). The pattern of razorback suckers regularly being captured from multiple stocking classes has persisted for many years. The presence of razorback suckers in a variety of adult age classes has resulted in spawning for 15 consecutive years in the San Juan River (Farrington et al. 2013). This diverse age-structure of reproducing adults is an important step to establish a self-sustaining population of razorback suckers within the San Juan River Basin.

Colorado pikeminnow growth

I examined 379 paired Colorado pikeminnow recaptures that spanned one year and were > 300 days apart. Colorado pikeminnow annual growth rates varied by size class ($F = 72.1$, $p < 0.001$)

and year ($F = 3.4$, $p = 0.002$; Figure 4). Annual growth rates declined with increasing size class, 93.2 mm/year, 69.8 mm/year, and 39.8 mm/year for Colorado pikeminnow < 200 mm TL, 200-299 mm TL, and ≥ 300 mm TL, respectively. This pattern has been observed in Colorado pikeminnow populations in the Colorado and Green Rivers (Osmundson et al. 1997, Osmundson 2006) and demonstrates the typical pattern that fish grow fastest when they are young and growth slows as individuals reach sexual maturity (Ricker 1975, Chen et al. 1992). Annual growth rates in the Upper Colorado River Basin averaged 32.2 mm/year to 82.0 mm/year for age-6 to age-3 individuals, respectively (Osmundson et al. 1997). Hawkins (2003) reported mean monthly growth rates of Colorado pikeminnow of 2.74-3.84 mm/month. Although Colorado pikeminnow growth rates in the San Juan River appear similar to those in other rivers in the Upper Colorado River Basin, caution should be exercised statistically comparing these growth rates because Osmundson et al. (1997) reported growth rates based on both scale and recapture data and many fish in Hawkins (2003) were > 500 mm TL.

There was no significant effect of CPUE of small-bodied prey species, number of days > 21°C at Four Corners, and mean daily spring discharge at Four Corners on the annual growth rate of Colorado pikeminnow < 200 mm TL ($R^2 = 0.671$, $F_{3,3} = 2.0$, $p = 0.286$), 200-299 mm TL ($R^2 = 0.292$, $F_{3,3} = 0.4$, $p = 0.757$), or ≥ 300 mm TL ($R^2 = 0.814$, $F_{3,3} = 4.4$, $p = 0.129$) using multiple regression (Figure 5). I was unable to detect any effect likely due to the limited (7 years) sample size used in this analysis and narrow range of variation in the predictor variables.

Razorback sucker recaptures by source

From 2006-2012 razorback suckers were stocked into the San Juan River from SNARCC, Uvalde, and NAPI Ponds (Table 5). I did not include 2013 stocking data in this summary because of the limited monitoring effort that occurred after these stocking events. I calculated return rates based on recaptures occurring through 2013, so fish stocked in earlier years have been subject to more sampling effort than those stocked in later years. There were five stocking events that to date have yielded < 0.5% recapture rates; Uvalde 2006, Uvalde 2007, Uvalde 2009, Uvalde 2010, and Uvalde 2012 (Table 5). Alternatively, some stocking events have yielded relatively high return rates; SNARCC 2007 (24%), NAPI 2009 (18%), NAPI 2010

(17%), and SNARCC 2012 (31%). Many factors, including length at stocking, season, and hatchery source have been identified as important for the post-stocking survival of hatchery-reared razorback suckers (Bestgen et al. 2009). In 2011 Uvalde revised management actions, primarily hauling fish in smaller batches, in an effort to improve return rates. Based on recaptures through 2013, it appears that these efforts have increased the return rate of razorback suckers stocked from Uvalde in 2011; however, the 2.9% return rate of the 11,391 razorback suckers stocked from Uvalde in 2011 is still lower than typical return rates of razorback suckers stocked from other sources (Table 5). If return rates of razorback sucker stocked from Uvalde matched those from NAPI Ponds each year, nearly 6,000 additional razorback suckers would have been detected in the San Juan River since 2007. The last razorback suckers from Uvalde were stocked in 2013 as the Program shifted to obtaining fish from Horsethief. Efforts to evaluate the Program's augmentation efforts are on-going and these results will be used to inform the Program's adaptive management process.

<u>Capture of razorback sucker without PIT tags</u>

Because almost all razorback sucker stocked prior to 2006 were implanted with PIT tags (Furr 2013b), and because of limited evidence of natural recruitment (Golden et al. 2006, Farrington et al. 2013), the untagged razorback suckers detected prior to 2006 were probably the result of tag loss. The high proportion (> 30%) of razorback suckers captured from 2006-2008 without PIT tags was likely the result of stocking approximately 10,000 untagged fish from NAPI ponds in 2006 and 2007 as part of the effort to start a single cohort harvest strategy at NAPI (Ryden 2008, Morel 2011). The proportion of untagged razorback suckers declined toward the presumed baseline PIT tag loss levels as fewer untagged razorback suckers were available for capture from those stocking events from NAPI and remained relatively constant from 2010-2012 (Table 6). The percent of razorback suckers captured without PIT tags from 2010-2012 declined by half in 2013, possibly due to a change in PIT tagging protocol for fish stocked from NAPI. Prior to 2013 SNARCC delivered razorback suckers to NAPI for grow-out in spring each year and these fish were PIT tagged during passive and active harvest when they were stocked into the San Juan River. In 2013 razorback suckers were PIT tagged at SNARCC prior to being delivered to NAPI for grow-out. Because > 90% of the 134 razorback suckers captured in 2013 without PIT tags exceeded 400 mm TL (Figure 6), it is unlikely that any of these fish recruited from wild-hatched fish.

Abundance estimates

Time varying detection probability models (M_t) received overwhelmingly greater support than constant detection probability models (M_0) for both Colorado pikeminnow and razorback sucker abundance estimates. Colorado pikeminnow abundance varied substantially by year, and abundance of Colorado pikeminnow <300 mm TL was likely influenced by the short-term retention from recent stocking events as most Colorado pikeminnow are recaptured one or two years post-stocking (Figure 7a). Abundance for Colorado pikeminnow < 400 mm TL decreased with increasing size class each year. Abundance estimates for recruiting sub-adults (400-449 mm TL) and adults (≥450 mm TL) could not be calculated in all years and had high standard error (SE) in other years, likely due to limited numbers of within-year recaptures (Figure 7b).

Razorback sucker abundance varied substantially among stocking classes by year and generally increased over time (Figure 8a and 8b). The abundance of razorback suckers 1- and 2-years post stocking was likely heavily influenced by short-term retention from recent stocking events (Figure 8a). Interestingly, the variation in abundance for 3- 4- and ≥ 5-years post-stocking does not seem to indicate a pattern of year-to-year recruitment among these age-classes (i.e., high abundance of a younger age class resulting in a high abundance of the next older age class in the subsequent year); this is possibly due to sampling inefficiency, low detection probability, or limited within year recaptures (Figure 8b).

Although M_t models were best supported, detection probability (p) varied by pass, I summarized p by year and size class for simplicity using the M_0 models. For Colorado pikeminnow annual p ranged from 0.022-0.053 for < 200 mm TL; 0.026-0.084 for 200-299 mm TL; 0.006-0.066 for 300-399 mm TL; 0.016-0.116 for 400-449 mm TL; and 0.002-0.109 for ≥ 450 mm TL (Table 7). For razorback sucker annual p ranged from 0.054-0.082 for 1-year post-stocking; 0.035-0.077 for 2-years post-stocking; 0.044-0.130 for 3-years post-stocking; 0.027-0.151 for 4-years post-stocking; and 0.034-0.109 for ≥ 5-years post-stocking (Table 7). In both M_t and M_0 models initial capture probability (p) was set equal to recapture probability (c). Models that evaluated p and c independently were not evaluated for simplicities sake. Testing p and c independently would be important to determine if fish are more or less susceptible to recapture following their initial encounter and could possibly be used to infer avoidance to electrofishing (Grabowski et al. 2009).

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Colorado pikeminnow population trends in the San Juan River are difficult to discern. Since 2010, the number of individual Colorado pikeminnow captured has declined. However, number of captures is heavily influenced by sampling effort and conditions. Also CPUE metrics reported in the Program's Adult Monitoring (Schleicher and Ryden 2013) and Non-native Fish Removal (Duran et al. 2013, Gerig and Hines 2013) do not account for detection probability. Although the Program does not have a dedicated capture-recapture population estimate effort, the river-wide sampling efforts produce equivalent data although it was not collected with the assumptions of a closed capture population estimate in mind (White et al. 1982). These closed capture models resulted in annually variable abundance estimates for Colorado pikeminnow in each size class. Limited within year recaptures resulted in low detection probability and large error estimates around abundance point estimates. The Program is planning to install remote PIT tag readers that span the entire San Juan River at the PNM Weir (RM 166.6) and just upstream of Mexican Hat (RM 52.9). The passive detection of PIT tagged individuals should result in higher detection probabilities and more robust demographic parameter estimates (Hewitt et al. 2010). Even if the reliability of the current estimates is unclear given the ad hoc nature of the analysis, they do not seem unreasonable compared to other abundance estimates of Colorado pikeminnow in the San Juan River (Duran et al. 2009, Gerig and Hines 2013, Schleicher and Ryden 2013). In the meantime, without a dedicated capture-recapture population estimate, these abundance estimates could serve as a benchmark to evaluate the Program's progress toward recovery.

Colorado pikeminnow in all size classes exhibited variation in annual growth rates, but the source of this variation remains unclear. Perhaps because only seven years were investigated, I was unable to detect a relationship between Colorado pikeminnow annual growth rates and prey density, temperature, and flow. Clearly, prey density and temperature play an important role affecting growth of a piscivorous fish like the Colorado pikeminnow (Fox 1989, Olson 1996, Graeb et al. 2004, Durst and Franssen 2014). Because seasonal variation in growth rates suggests warmer water contributes to faster growth (Durst and Franssen 2014), perhaps temperature can be experimentally manipulated based on managed releases from Navajo Dam to benefit growth and survival of Colorado pikeminnow. Additionally, because density of small-bodied prey varied with flow conditions (Gido and Propst 2012), it might be possible to use managed flows from Navajo Dam to increase the density of Colorado pikeminnow prey, and thus their growth and survival.

Despite the lack of clarity provided by the Colorado pikeminnow abundance estimates, persistence of individuals into the near future is doubtful without continued stocking of hatchery-reared fish. The few individuals recaptured three or more years post-stocking could be caused by Colorado pikeminnow eluding sampling efforts. In addition to evading capture, some Colorado pikeminnow are lost from the San Juan River by passing over the waterfall into Lake Powell (Francis et al. 2013) making them unavailable for recapture in the San Juan River. The magnitude of fish lost to Lake Powell is unknown, but because the waterfall is only infrequently inundated these fish can rarely return to the San Juan River unless they are physically transported upstream of the waterfall (Francis et al. 2013). A selective passage similar to the one at PNM could be infeasible due to the remoteness and underlying geology of the waterfall. Understanding age-specific survival rates may provide insight as to how Colorado pikeminnow are being lost from the San Juan River and what factors would lead to the persistence of hatchery-reared fish and their eventual recovery within the San Juan River.

The razorback sucker augmentation program has resulted in multiple adult age-classes in the San Juan River that have spawned for 15 consecutive years (Farrington et al. 2013). Abundance estimates, captures of individuals, and CPUE data (Schleicher and Ryden 2013, Duran et al. 2013) reveal consistent increasing temporal trends for razorback suckers in the San Juan River. Increasing detection probability with the installation of river-wide remote PIT tag readers would improve the precision of demographic parameter estimates, possibly allowing age- and stocking-classes to be tracked over time. Although the razorback sucker adult population is apparently robust and regularly reproducing in the San Juan River, documentation of wild recruitment remains elusive despite the detection of some juvenile individuals (Farrington et al. 2013, Hines 2014). Until wild recruitment replaces adult mortality, augmentation with hatchery-reared fish will be necessary to sustain the razorback sucker population in the San Juan River.

Previous experiments to understand important factors influencing survival of hatchery-reared razorback suckers (Bestgen et al. 2009) were not successful due to the limited recaptures of fish stocked from Uvalde. Because of the low apparent survival of razorback suckers stocked from Uvalde, 2013 was the last year the Program used it as a source for hatchery-reared fish. Also starting in 2013, the Program obtained razorback suckers from Horsethief in an effort to improve the overall retention of razorback suckers in the San Juan River. Efforts are on-going to evaluate the Program's razorback sucker augmentation efforts. Program MARK is being used to understand variation in razorback sucker survival based on stocking season, stocking location, and TL based on fish stocked from NAPI in order to guide augmentation efforts and improve the survival of hatchery-reared fish.

The change in PIT tagging protocol for razorback suckers stocked from NAPI appeared to improve PIT tag retention. Prior to 2013 when razorback suckers were PIT tagged at NAPI during passive and active harvest, processing and stocking these fish into the San Juan River as rapidly and efficiently as possible may have contributed to the capture of untagged razorback suckers in the San Juan River in the range of 14-15% because of PIT tag loss. In 2013 razorback suckers were PIT tagged at SNARCC prior to delivery to NAPI. In addition to determining short-term (4-6 month) PIT tag retention while these fish grew-out in the NAPI ponds (Cheek 2014), it appears the reduced rate of untagged razorback suckers captured in the San Juan River could be attributed to this revised protocol. Perhaps anesthetizing fish and tagging them under controlled hatchery conditions resulted in improved long-term (post six months) PIT tag retention for razorback suckers. Once wild recruitment becomes more widespread, a minimized rate of PIT tag loss will improve the Program's ability to distinguish between untagged fish resulting from wild recruitment and PIT tag loss. Reliable documentation of wild recruitment will be an important step in the recovery of razorback sucker in the San Juan River.

It is important to periodically summarize and analyze the Program's monitoring data to determine the biological response to management actions and inform adaptive management decisions. Analyses utilizing the integrated PIT tag database could be informative in refining and revising Colorado pikeminnow and razorback sucker demographic parameters like abundance and survival that would be beneficial to the Program's adaptive management process and ultimately, species recovery. Additionally, because the integrated PIT tag database details the capture history of individuals over time, it could be utilized to track growth and condition. Information on growth rates and condition may be useful in evaluating and revising the flow recommendations if particular flow regimes can be tied to growth, condition, and survival of endangered fishes. Maintenance of this integrated PIT tag database will be essential to evaluate the Program's progress toward recovery in reaching Colorado pikeminnow and razorback sucker demographic criteria in the San Juan River Basin for downlisting and delisting.

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TABLES

Table 1. Age matrix for untagged Colorado pikeminnow based on size of fish and month of capture. Fish > 400mm TL without a PIT tag could not be reliably aged. The breakdown of age based on size at capture and month of capture was based on personal communication with D. Ryden.

<table>
<tr><th></th><th colspan="12">Month of capture</th></tr>
<tr><th>Size at capture (TL)</th><th>Jan</th><th>Feb</th><th>Mar</th><th>April</th><th>May</th><th>June</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>150-190mm</td><td colspan="12">Age-1</td></tr>
<tr><td>191-240mm</td><td colspan="8">Age-2</td><td colspan="4">Age-1</td></tr>
<tr><td>241-300mm</td><td colspan="12">Age-2</td></tr>
<tr><td>301-350mm</td><td colspan="6">Age-3</td><td colspan="6">Age-2</td></tr>
<tr><td>351-400mm</td><td colspan="12">Age-3</td></tr>
</table>

Table 2. Number of Colorado pikeminnow stocked at age-0 from 2002-2012 and recaptured from 2003-2013. The number of recaptures is based only on individuals large enough to be implanted with a PIT tag during their TAG record (≥ 150 mm TL). The total number of individuals recaptured may be less than the sum of the number of individuals recaptured by year because some individuals are recaptured in multiple years. The number of individuals from a particular stocking class can be examined looking across rows. The number of individuals captured by year from different stocking classes can be examined looking across columns. Note that the total number of pikeminnow captured in any year includes those fish that could not be assigned to a particular year class. The 2010 year class pikeminnow stocked in May 2011 without PIT tags were age-1 fish that should have been stocked in 2010 as age-0. For the purpose of this report, all pikeminnow stocked into the San Juan River without PIT tags are considered age-0.

Year stocked	Year class	Number stocked	Total captured	Individuals captured by year										
				2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	UNKNOWN		90	3	1	2	15	7	4	12	19	27	19	22
2002	2002	210,418	211	73	132	11	0	1	0	0	0	0	0	1
2003	2003	175,928	446	-	190	233	33	2	0	0	0	0	0	0
2004	2004	280,000	341	-	-	155	183	22	5	4	2	0	2	1
2005	2005	302,270	547	-	-	-	393	138	37	11	1	4	1	0
2006	2006	313,854	507	-	-	-	-	270	224	80	7	3	1	0
2007	2007	475,970	872	-	-	-	-	1	395	476	76	20	6	5
2008	2008	270,234	2,108	-	-	-	-	-	-	899	1124	353	8	3
2009	2009	468,000	1,921	-	-	-	-	-	-	-	1042	962	48	6
2011	2010	214,720	985	-	-	-	-	-	-	-	-	555	456	74
2011	2011	426,588	666	-	-	-	-	-	-	-	-	-	667	371
2012	2012	395,640	420	-	-	-	-	-	-	-	-	-	-	420
Total individuals captured				76	323	401	624	441	665	1,482	2,271	1,924	1,210	903

Table 3. Number of Colorado pikeminnow stocked as age-1+ and recaptured by year, 2003-2013. The total number of individuals recaptured may be less than the sum of the number of individuals recaptured by year because some individuals are recaptured in multiple years. The number of individuals from a particular stocking class can be examined looking across rows. The number of individuals captured by year from different stocking classes can be examined looking across columns. Note that the relatively small number of age-1+ Colorado pikeminnow stocked in 2010 was due to the detection of largemouth bass virus at SNARCC resulting in a quarantine of fish held at that hatchery. Those fish held over from 2010 were stocked in 2011. Also, 2011 was the last year that age-1+ Colorado pikeminnow were stocked into the San Juan River.

Year stocked	Number stocked	Total captured	Individuals captured by year										
			2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2003	1002	3	3	0	0	0	0	0	0	0	0	0	0
2004	1217	79	-	66	13	1	0	0	0	0	0	0	0
2005	4119	89	-	-	84	5	0	0	0	0	0	0	0
2006	12661	357	-	-	-	294	53	6	6	2	2	1	1
2007	3250	232	-	-	-	-	141	79	16	1	3	0	0
2008	4848	628	-	-	-	-	-	203	439	16	2	1	0
2009	8942	565	-	-	-	-	-	-	470	108	14	4	1
2010	353	41	-	-	-	-	-	-	-	35	8	0	3
2011	3724	292	-	-	-	-	-	-	-	-	269	25	1
Total individuals captured			11	68	99	300	194	288	931	162	298	31	6

Table 4. Number of razorback sucker stocked and recaptured by year, 2000-2013. The total number of individuals recaptured may be less than the sum of the number of individuals recaptured by year because some individuals are recaptured in multiple years. The number of individuals from a particular stocking class can be examined looking across rows. The number of individuals captured by year from different stocking classes can be examined looking across columns. The total number of individuals captured in any year also includes individuals stocked before 2000.

			Individuals captured by year													
Year stocked	Total stocked	Total captured	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000	1044	62	0	26	7	9	8	12	7	7	5	7	5	4	2	1
2001	688	233	-	0	43	73	61	43	32	34	26	19	18	13	13	10
2002	140	36	-	-	5	13	12	3	6	2	3	2	3	4	1	2
2003	887	71	-	-	-	54	11	5	1	2	3	1	2	2	0	0
2004	2979	591	-	-	-	-	288	174	113	65	48	56	33	55	46	26
2005	1993	146	-	-	-	-	-	68	42	25	24	15	16	20	12	13
2006	13764	251	-	-	-	-	-	-	133	72	38	38	24	33	28	15
2007	16906	799	-	-	-	-	-	-	-	499	188	115	90	74	55	45
2008	4424	241	-	-	-	-	-	-	-	-	46	144	46	31	29	16
2009	8316	783	-	-	-	-	-	-	-	-	-	43	526	186	132	114
2010	28419	1466	-	-	-	-	-	-	-	-	-	-	108	862	479	373
2011	18807	1078	-	-	-	-	-	-	-	-	-	-	-	93	750	361
2012	15822	575	-	-	-	-	-	-	-	-	-	-	-	-	248	368
2013	15341	271	-	-	-	-	-	-	-	-	-	-	-	-	-	271
Total individuals recaptured			14	43	68	156	381	307	338	708	382	440	873	1379	1797	1616

Table 5. Razorback sucker recaptures by stocking year and source from 2006-2012. Return rate and recapture number are based on fish collected through the 2013 monitoring effort, thus there have been more opportunities to sample the fish stocked in earlier years.

	Stock		Recapture	
Year	**Source**	**Number**	**Number**	**Percent**
2006	NAPI	12635	242	1.9
	SNARCC	1129	0	0.0
2007	SNARCC	1344	328	24.4
	NAPI	10717	449	4.2
	Uvalde	4845	0	0.0
2008	SNARCC	2051	77	3.8
	NAPI	2373	162	6.8
2009	NAPI	4350	782	18.0
	Uvalde	3966	1	0.0
2010	NAPI	8170	1415	17.3
	Uvalde	20249	49	0.2
2011	NAPI	7416	697	9.4
	Uvalde	11391	333	2.9
2012	SNARCC	815	254	31.2
	NAPI	4329	311	7.2
	Uvalde	10667	9	0.1

Table 6. Number of individual razorback sucker captured with and without PIT tags, 2004-2013. Percent without PIT tags represents the percent of razorback sucker captured without PIT tags out of total number of razorback sucker individuals captured.

	Individuals captured				Percent without PIT tags
Year	Total	with PIT tags (STOCK)	with PIT tags (TAG)	without PIT tags	
2004	415	381	0	34	8.2
2005	345	307	4	34	9.9
2006	559	338	8	213	38.1
2007	1105	708	40	357	32.3
2008	605	382	39	184	30.4
2009	699	440	75	184	26.3
2010	1117	873	80	164	14.7
2011	1717	1379	84	254	14.8
2012	2207	1797	92	318	14.4
2013	1875	1616	125	134	7.1

Table 7. Detection probability summarized by year for Colorado pikeminnow by size class (left-side of table) and razorback sucker by years post-stocking (right-side of table). Detection probabilities are based on M_0 for each year.

	Colorado pikeminnow (TL)					Razorback sucker (years post-stocking)				
Year	<200 mm	200-299 mm	300-399 mm	400-449 mm	>=450 mm	1 year	2 years	3 years	4 years	>=5 years
2008	0.037	0.042	0.066	-	-	0.067	0.035	0.082	0.151	0.035
2009	0.022	0.057	0.037	-	-	0.087	0.077	0.130	0.130	0.053
2010	0.053	0.070	0.051	0.116	-	0.082	0.052	0.080	0.130	0.034
2011	0.044	0.084	0.056	0.016	0.023	0.060	0.049	0.121	0.027	0.049
2012	0.035	0.026	0.006	-	0.002	0.054	0.066	0.044	0.068	0.049
2013	0.022	0.046	0.045	0.096	0.109	0.064	0.062	0.085	0.083	0.109

FIGURES

Figure 1. Map of San Juan River including river mile (RM) and Reach designations. Top panel (A) shows the lower San Juan River and the bottom panel (B) shows the upper San Juan River.

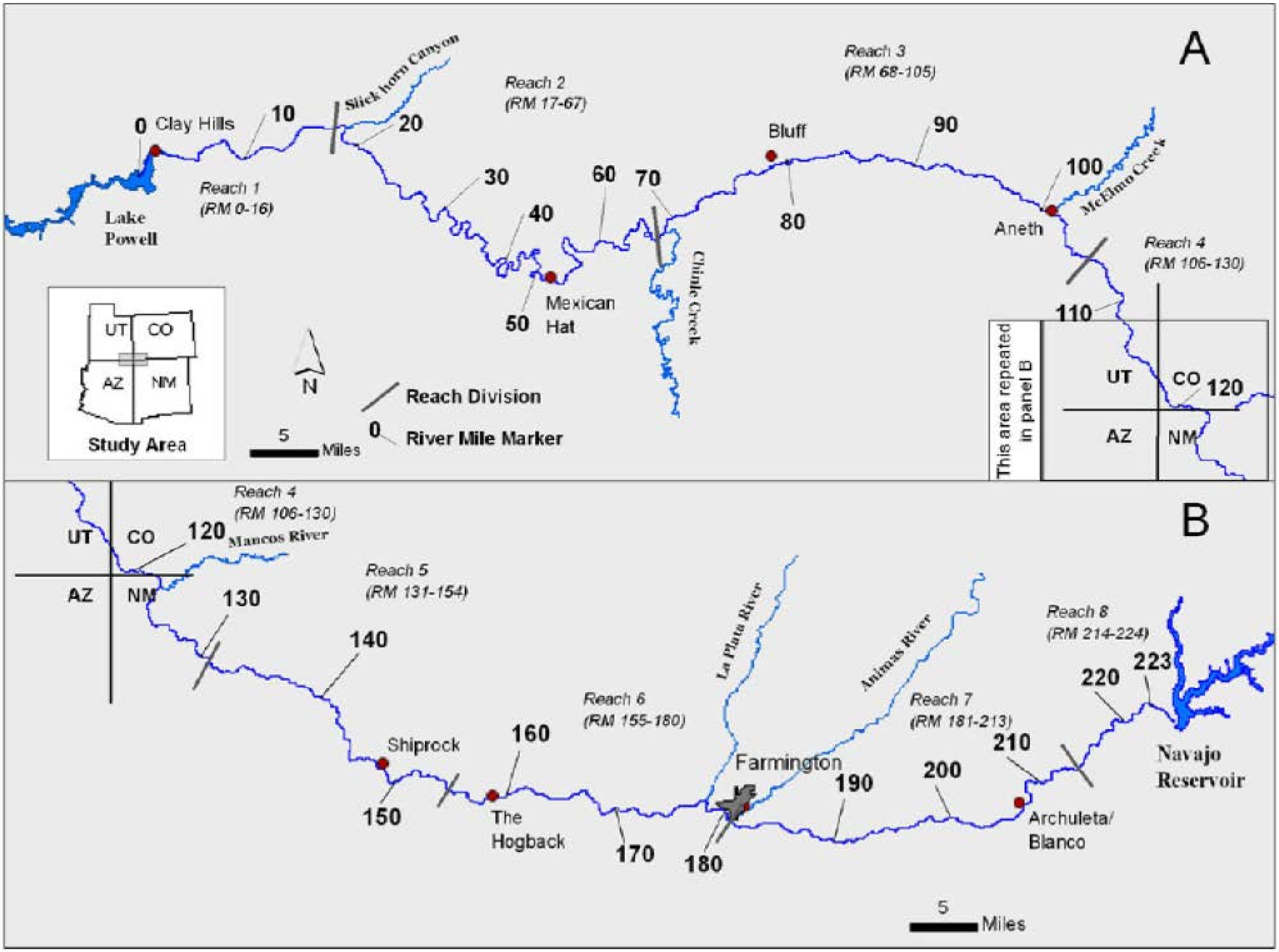


Figure 2. Total number of individual PIT tagged Colorado pikeminnow captured by year across all Program projects.

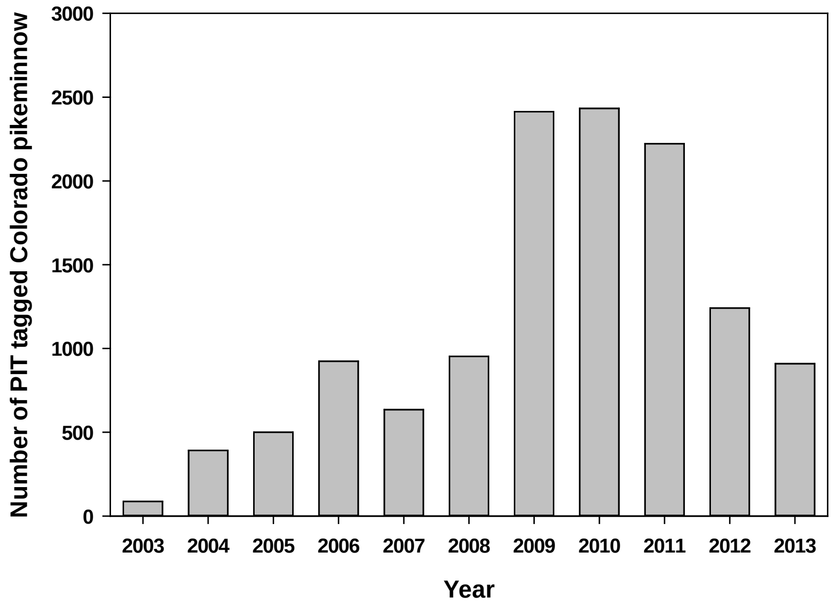


Figure 3. Total number of individual PIT tagged razorback sucker captured by year across all Program projects.

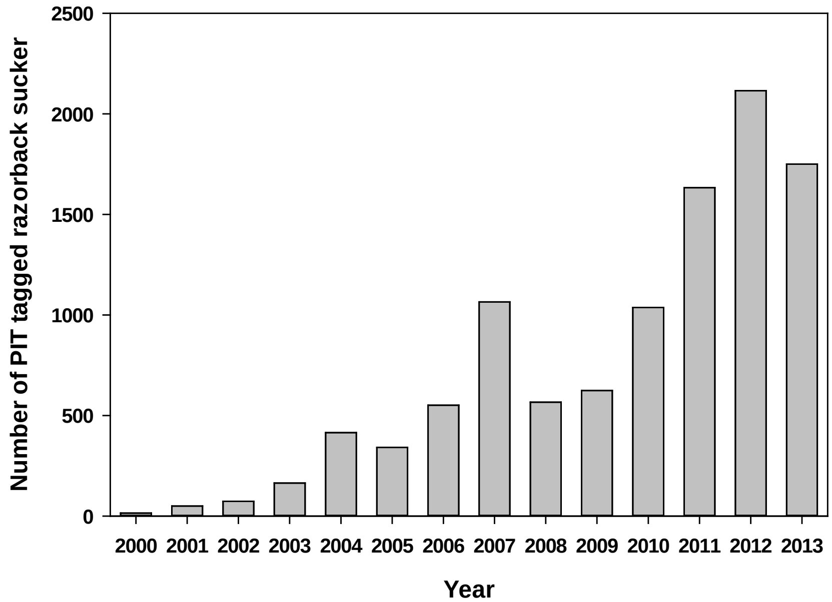


Figure 4. Annual growth rate of Colorado pikeminnow <200 mm TL, 200-299 mm TL, and ≥300 mm TL by year. Error bars present ± 1 SE.

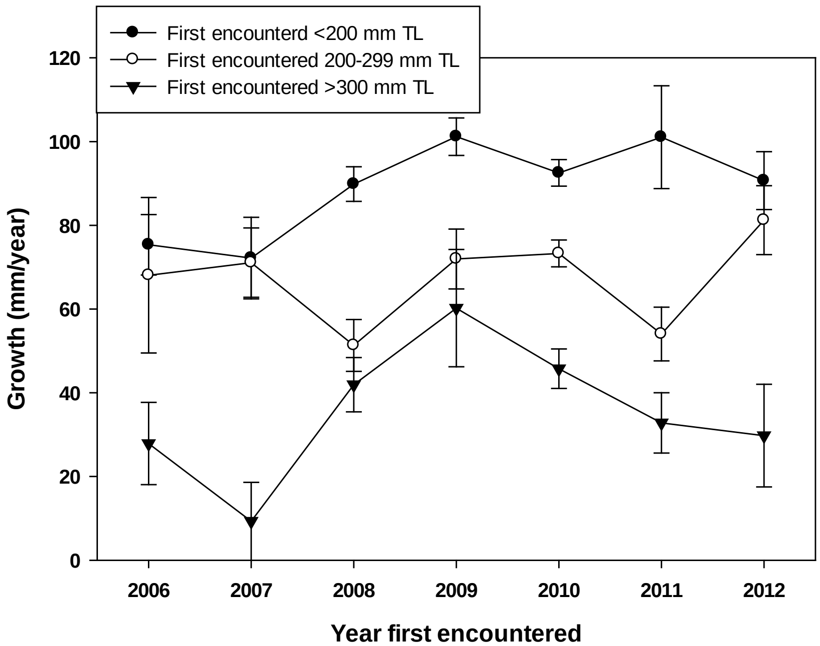


Figure 5. Annual growth rate Colorado pikeminnow <200 mm TL, 200-299 mm TL, and ≥300 mm TL versus total CPUE of small bodied prey (flannelmouth sucker, bluehead sucker, speckled dace, red shiner, fathead minnow, and western mosquito fish), temperature based on the mean number of days >21°C at Four Corners, and flow based on mean spring daily discharge (March-June) at Four Corners.

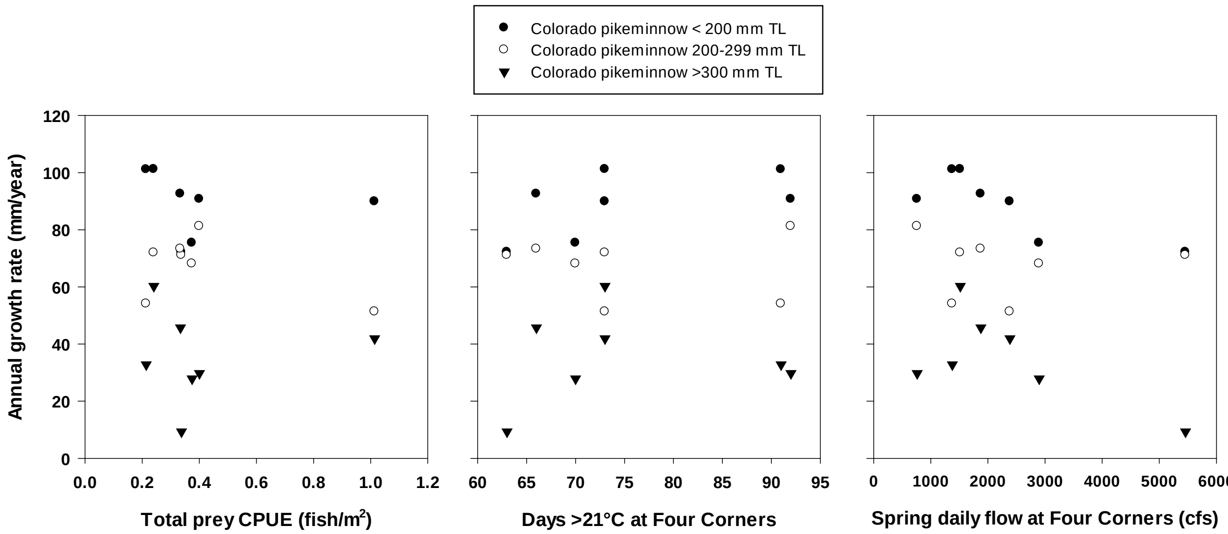


Figure 6. Length-frequency histogram of razorback suckers captured without PIT tags in 2013.

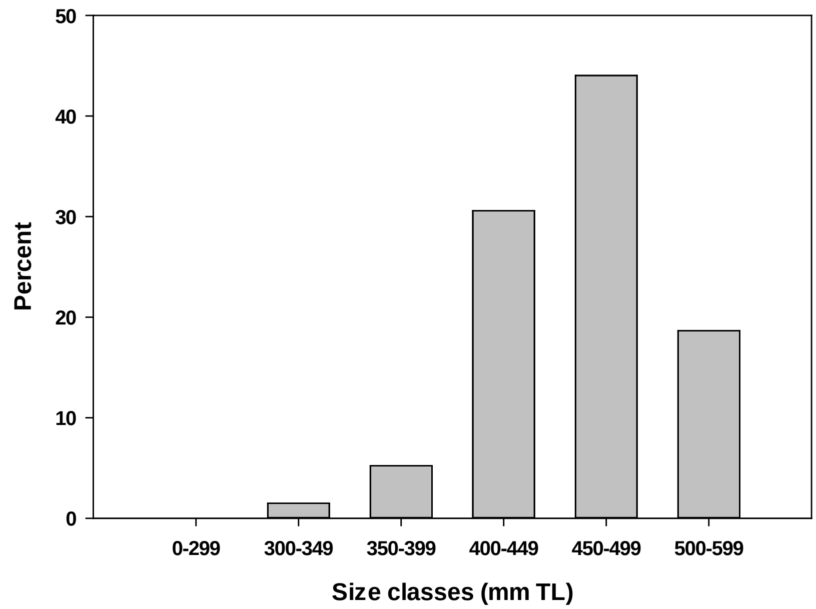
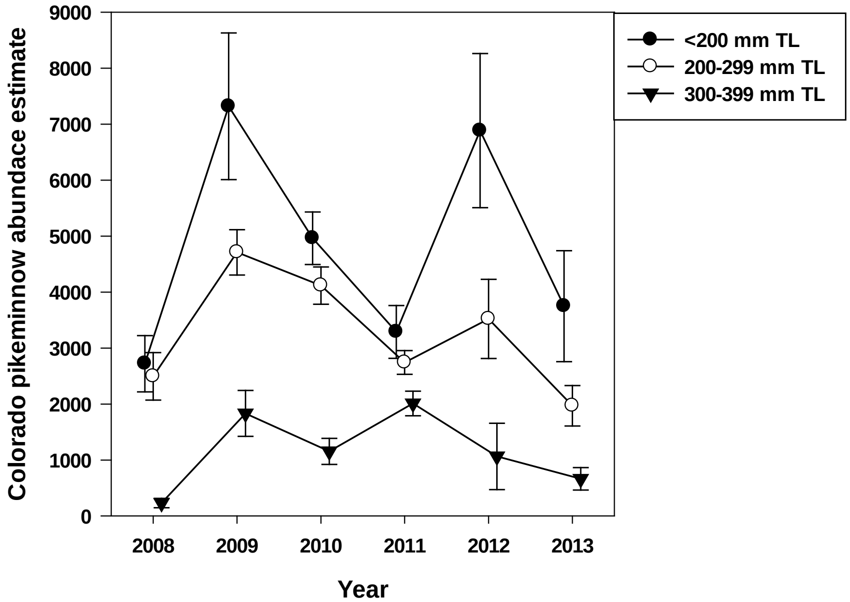


Figure 7. Closed capture abundance estimate of Colorado pikeminnow based on Mt model each year (A) <200 mm TL, 200-299 mm TL, 300-399 mm TL, (B) 400-339 mm TL, and ≥450 mm TL. Error bars represent ± 1 SE.

A



B

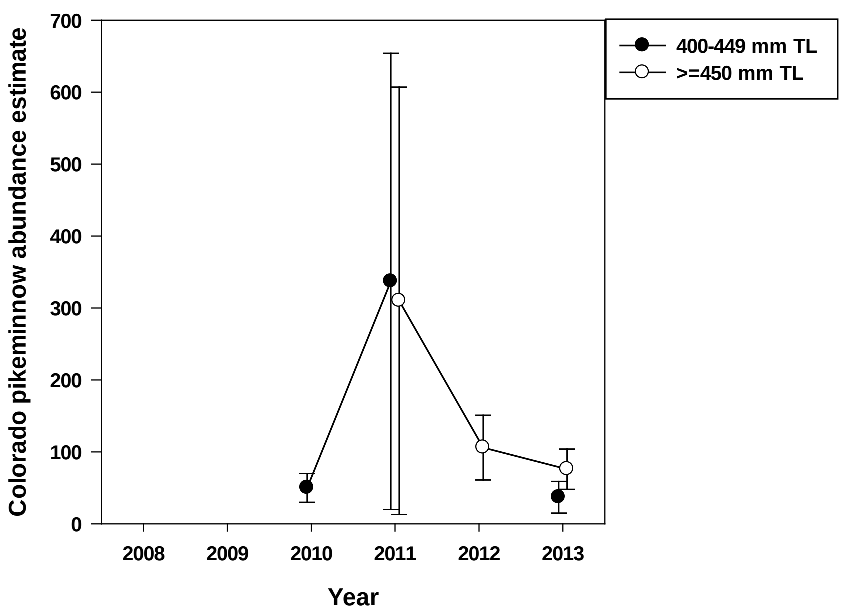
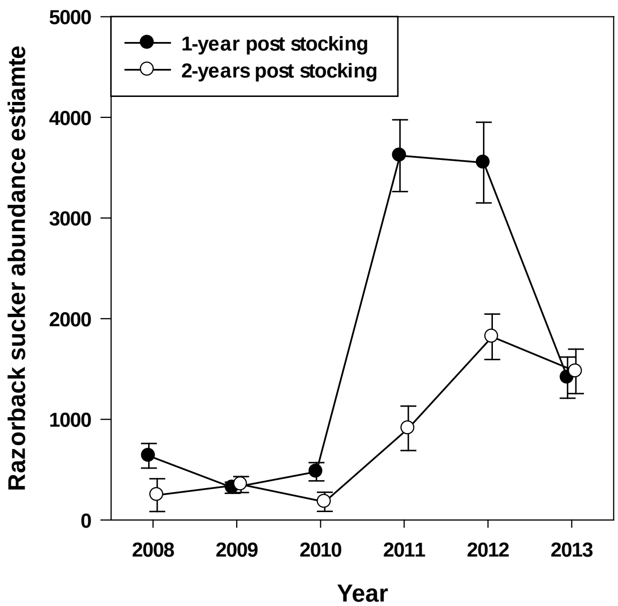
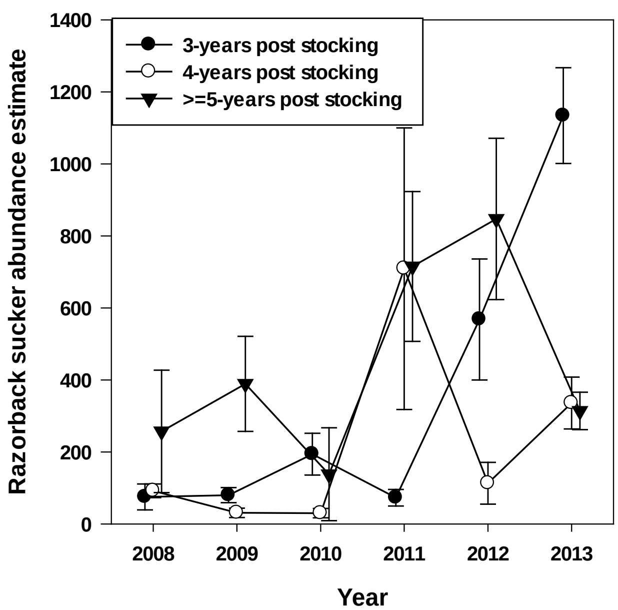


Figure 8. Closed capture abundance estimate of razorback sucker based on Mt model each year (A) 1-year post stocking, 2-years post-stocking, (B) 3-years post-stocking, 4-years post-stocking, and ≥5 5-years post-stocking. Error bars represent ± 1 SE.

A



B



Appendix 1. The following table and field definitions are the metadata document that describes the FIRST_ENC and CAPTURE tables in both the Colorado pikeminnow and razorback sucker databases. There is a one-to-many relationship on the MR_TAG field between the FIRST_ENC and CAPTURE tables.

Field name and data types for CAPTURE and FIRST_ENC Tables

Field Name	Data Type	Type	Size
MR_TAG	Text	Text	20
Species	Text	Text	6
Sample	Text	Text	50
Study	Text	Text	50
Date	Date/Time	Date/Time	
RIVER	Text	Text	50
RM	Number	Decimal	
Gear	Text	Text	50
PITIDNO_400khz	Text	Text	10
PITIDNO_134khz	Text	Text	13
Other_Tag	Text	Text	50
TL	Number	Decimal	
WT	Number	Decimal	
Sex	Text	Text	1
Tubercles	Text	Text	1
Ripe	Text	Text	1
YearClass	Number	Integer	
Source	Text	Text	50
ReCap_Number	Number	Integer	
Days_In_River	Number	Integer	
Contact_Type	Text	Text	10
Mortality	Text	Text	2
Harvest	Text	Text	1
Comments	Memo	Memo	

Field Descriptions:

MR_TAG = Most Recent Tag – If fish is implanted with 134 khz tag then this tag number appears here (superseding 400 khz tag if it is also present), if the fish has only been implanted with an older 400 khz tag then that number appears here. This field is used to link the CAPTURE and FIRST_ENC Tables. It is an indexed field in each table, duplicates are allowed in the CAPTURE Table but not the FIRST_ENC Table. I can update this field when I compile the data each January.

Species = Species – Fish species code: PYTLUC = *Ptychocheilus lucius* (Colorado pikeminnow); XYRTEX = *Xyrauchen texanus* (razorback sucker). This field is limited to 6 characters.

Sample = Sample – Sample number of collection or sighting.

Study = Study – The name of the study that encountered this fish.

Date = Date – Date of fish encounter, formatted: yyyy/mm/dd. Note that if the date field is in numeric format it needs to be changed to the appropriate date format. To change number to date in Excel use formula: =DATE(LEFT(A1,4),MID(A1,5,2),RIGHT(A1,2)).

RIVER = River – River where encounter occurred.

RM = River Mile – River mile where encounter occurred recorded to one decimal point.

Gear = Gear – Method used to encounter fish.

PITIDNO_400khz = PIT Tag Number (400khz) – Old PIT tag number (10 digits). This field is formatted to only accept 10 digit entries.

PITIDNO_134khz = PIT Tag Number (134khz) – New PIT tag number (13 digits). This field is formatted to accept only 13 digit entries

Other_Tag = Other Tag – Other indentify tag or number on fish. PIT tags that are not in a 10 or 13 digit format should also be entered here.

TL = Total Length – Total length of fish (mm). No decimal places.

WT = Weight – Weight of fish (g). No decimal places.

Sex = Sex – Sex of fish; F = Female, M = Male, I = Indeterminate. The field has formatted to only accept F, M, or I values.

Tubercles = Tubercles? – Did the fish have tubercles (Y = Yes, N = No). The field is formatted to only accept Y or N. Consider null field as "No."

Ripe = Ripe? – Was the fish freely expressing gametes (Y = Yes, N = No). The field is formatted to only accept Y or N. Consider null field as "No."

YearClass = Year Class – Year class that fish was grown from prior to stocking. Note that Colorado pikeminnow captured and tagged (TAG Contact Type) do not have a record of a stocking event and thus do not have a known year class. Based on conversation with Dale Ryden, these pikeminnow can be assigned a year class based on their size and the date of their first capture (TAG).

Source = Stocking Source – The source of stocked fish, including hatchery or grow-out pond.

ReCap_Number = Recapture Number – Number of times fish has been recaptured, stocked fish (STOCK) or new captures (TAG) have a recapture number of zero. I update this field using formula in Excel =COUNTIF(K2:K16,K2) with PIT tag number in first column and date in second column in order to get a count of number of records. PIT tags are arranged in alphabetical order and date is from newest to oldest.

Days_In_River = Days in river – Number of days between stocking (or initial capture) and this recapture. For TAG fish with estimated year class, this number is not back calculated to their estimated stocking date. It only reflects the difference in dates between a CAPTURE record and a FIRST ENCOUNTER record (TAG or STOCK). I use a query in Access to update this field.

Contact_Type = Contact type – How the fish was encountered; "STOCK" for initially stocked fish, "TAG" for an individual captured and implanted with a PIT tag (also includes individuals without stocking information), and "CAPTURE" for all subsequent encounters

Mortality = Mortality – Indicates a fish that was encountered dead or died during handling (M = Mortality, RA = Released alive). Any mortality should be detailed in the comments field. Consider null field as "RA."

Harvest = Harvest – Indicate that the fish was actively (A) or passively (P) harvested out of grow-out ponds.

Comments = Comments – Any notes related to fish encounter.