Retention, Growth, and Habitat Use of Colorado Pikeminnow Stocked as Age-0 Fish in the San Juan River

2005–2006 Draft Annual Report



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EXECUTIVE SUMMARY

The San Juan River Basin Recovery Implementation Program (SJRIP) began a multi-year augmentation program for Colorado pikeminnow (*Ptychocheilus lucius*) in 2002. The SJRIP's *Colorado Pikeminnow Augmentation Plan* (Augmentation Plan) calls for 200,000–300,000 young-of-year (YOY) Colorado pikeminnow to be stocked annually from 2002–2009 (Ryden 2003). The objective of the Augmentation Plan is to meet the Recovery Goals, which indicate the need for a population of greater than 800 adult Colorado pikeminnow throughout critical habitat in the San Juan River (USFWS 2002). The SJRIP funded this study to monitor the stocked YOY Colorado pikeminnow throughout the first few years of life. Because retention in the first year of the study appeared low, various changes in stocking protocols have been incorporated and experiments designed to test the efficacy of various release protocols in increasing retention. Additional objectives of this study were to review data from existing research and monitoring programs and collect additional data from 2002–2006.

In 2005–2006 BIO-WEST conducted monitoring efforts in the same time periods as in previous years; including shortly after stocking in November 2005, March 2006, and in July–August 2006. We analyzed all data collected through this study, as well as data provided by cooperators working on other SJRIP-funded projects. Spring runoff in 2006 was not as high as it was in 2005, but a peak of high flow in October 2006 was much higher than any conditions observed during autumn in any previous monitoring year (2002–2005). Water temperatures in 2005–2006 were also closer to conditions experienced in 2002–2004 than those observed in 2005. Temperatures between October and December 2006 (during and immediately after stocking) were also within the range of conditions experienced during 2002–2005.

The number of YOY stocked Colorado pikeminnow in 2005 was approximately 320,270 and all analyses of first year retention of these fish were scaled to account for the difference between this number and the number of fish in previous stockings. We found that scaled catch rates in 2005–2006 were similar to previous years, although a lower rate observed in March 2006 may have been related to environmental conditions during the sample effort. There was a deviation in methodology in July 2006 to attempt to increase the number of "marked" fish captured during mark-recapture efforts for a population estimate, but this change did not noticeably affect catch rates. The growth rates of these fish differed from those observed in previous years. Growth was minimal between November 2005 and March 2006 (as in previous years), but these fish had grown to an average size that was larger than any previous year in July monitoring. By autumn, however, electrofishing captures showed an average length of age-1 fish that was smaller than any previous year.

Efforts to produce a population estimate in 2006 were again limited by too few recaptures to generate a useful estimate. The increased effort throughout the river, including increasing the number of larger (> 150 mm) fish that were marked did not substantially increase the number of recaptures (4 in 2006 compared with 2 in 2005). This result indicates that a river-wide estimate will be difficult to generate, particularly when attempting to use existing studies to collect the necessary data. An alternative may be to focus on smaller reaches and generate a series of population estimates for individual areas that can be used to formulate a more comprehensive estimate river wide.

Acclimation efforts were successful in 2005–2006. Acclimation in 2004 was plagued with breached nets, but both sites chosen for acclimation in 2005 remained intact for the full, 7-day acclimation period. As a result we found that acclimated Colorado pikeminnow were recaptured in higher proportion than would be expected overall based on stocking rates of acclimated vs. non-acclimated fish. The higher proportion of acclimated fish was statistically significant (chi-square analysis) for all samples combined in November 2005 and March 2006 and in the areas where acclimation occurred in both of these sample periods. These results suggest that when fish are maintained in these sites for the full acclimation period, there is higher survival overall and greater retention in the upstream areas where stocking and acclimation takes place. These efforts provide an opportunity to test the hypothesis that developing a population of 800 adult fish requires establishing fish use of the area upstream of the PNM Weir where native forage fish are abundant (Miller and Lamarra 2000).

An evaluation of all monitoring data collected to date suggested that Colorado pikeminnow stocked as YOY fish are recaptured as age-2 to age-3 fish in a similar proportion to fish stocked at age-1 or age-2 and later. Because more YOY fish can be stocked for the same cost and effort as larger fish, these similar recapture rates result in higher estimated numbers of recaptured YOY fish in later years. These numbers, however, are based on very low returns and have a great deal of uncertainty. Slight adjustments to the recapture percentages in either direction could affect the estimates of anticipated recaptures. In addition, we do not yet have information on the long-term contribution of each of these year classes to the adult population. Additional monitoring will help continue the evaluation of relative success of stocking each year class.

These monitoring data continue to show that Colorado pikeminnow primarily use low-velocity habitats and those with some sort of cover during the first 6 months after stocking. The age-1 fish are found in shoal habitats in much higher numbers by July. The data also show that side channel habitats are used in much higher frequency than main channel habitats during November and March, but the fish have been more equally distributed between main and side channel habitats (or more common in the main channel) by July. As in previous years, it was difficult to correlate the broad scale habitat changes noted in other studies to changes in Colorado pikeminnow population dynamics. Increased interaction between studies (or compilation into a single study) would likely improve the ability to relate habitat changes to Colorado pikeminnow habitat use and frequency of occurrence in particular reaches.

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INTRODUCTION

In 1996 and again in 1997, the Utah Division of Wildlife Resources (UDWR) stocked approximately 100,000 young-of-year (YOY) Colorado pikeminnow (*Ptychocheilus lucius*) in the San Juan River to characterize Colorado pikeminnow growth and retention in the river, as well as to quantify and characterize the nursery habitat used by the stocked fish (Trammell and Archer 2000). They showed that habitat for YOY and juvenile Colorado pikeminnow was available and reasonably common in the San Juan River. The YOY Colorado pikeminnow stocked in 1996 and 1997 survived for at least 2 years and grew up to 250 mm total length (TL). Additionally, it appeared as though a large proportion of the stocked fish remained in the river rather than dispersing to Lake Powell. Trammell and Archer (2000) attributed the differences in survival and retention observed between sampling trips and years to storm events and flow patterns. Storm and runoff events reduced retention and moved the fish downstream. Colorado pikeminnow in the canyon section of the river below Bluff, Utah, seemed to be more susceptible to flow-induced changes in retention than those in the upper river between Bluff and Shiprock, New Mexico.

Based on the results and success of these experimental studies, the SJRIP drafted the *Colorado Pikeminnow Augmentation Plan* (Augmentation Plan), which calls for stocking 200,000–300,000 YOY Colorado pikeminnow annually between 2002 and 2009 (Ryden 2003). In 2002 implementation of the Augmentation Plan began when SJRIP cooperators stocked 105,000 YOY Colorado pikeminnow near the Animas River confluence with the San Juan River and an additional 105,000 YOY Colorado pikeminnow near the Shiprock bridge. The SJRIP funded this study to follow the progress of the stocked Colorado pikeminnow seasonally through 2002-2003. The initial objectives of this study were to characterize the retention of the stocked Colorado pikeminnow and what changes, if any, should be made to the stocking protocols to increase retention. The stocking experiments in 1996 and 1997 focused on the area downstream of Shiprock. However, the adult Colorado pikeminnow recovery goal of 800 adult fish (USFWS 2002) was based on the assumption that Colorado pikeminnow could be expanded into the area above Shiprock, especially upstream of the PNM Weir, to utilize the abundant available forage (Miller and Lamarra 2000). Therefore, determining whether these upstream areas could retain stocked Colorado pikeminnow was also an important objective of this study.

Following the apparently poor retention of the fish stocked in 2002, and using the principals of adaptive management, several changes were made to the study starting in 2003–2004 and new objectives were added (Golden et al. 2006, Golden and Holden 2005, Holden and Golden 2005). In addition, changes in stocking protocols were made by the U.S. Fish and Wildlife Service (USFWS) (Ryden 2004). A report summarizing the findings of this monitoring effort in 2002–2005, including recommendations for improving Colorado pikeminnow stocking and monitoring protocols to increase the success of future stocking and monitoring efforts was submitted in 2006 (Golden et al. 2006). The following report describes the results of the YOY Colorado pikeminnow monitoring project in 2005–2006.

OBJECTIVES

As described in Golden et al. (2006), several changes and additions were implemented over time during this study in an attempt to increase post-stocking retention and survival of stocked Colorado pikeminnow, as well as improve our ability to measure the success of the stocking program. Although study objectives have also changed over time (see Golden et al. 2006 for a summary) the objectives in 2005–2006 remained the same as in 2004–2005.

1. Characterize growth and retention of stocked YOY Colorado pikeminnow from all stockings as they reach age-1, age-2, and age-3.

2. Compare growth and retention of stocked fish from all stocking efforts and relate to changes in stocking protocol, river conditions, and habitat availability.

3. Compare growth and retention of stocked fish from all stocking efforts with historical stockings, and relate to changes in stocking protocol, river conditions, and habitat availability.

4. Experiment with augmentation protocols for Colorado pikeminnow to improve retention, especially in the upper river.

METHODS

Study Area

In November 2005 and March 2006, we sampled the six stations that have been sampled during each monitoring trip since 2002 (Table 1). In addition, we sampled all four reaches that were added in the second year of the study in 2005–2006 (Table 2). We also sampled the river between Clay Hills Crossing (River Mile [RM] 2.9) and the confluence of the San Juan River with Lake Powell in 2004–2005 and November 2005 to determine any Colorado pikeminnow use of the river below the waterfall barriers, but did not continue to sample this area in March or July 2006. In July 2006 we deviated from the protocol described above with the goal of increasing the number of Colorado pikeminnow captures throughout the river in conjunction with a population estimate. This modification included sampling every third mile from RM 178 to RM 49. Between RM 49 and RM 10, high flows reduced seining efficacy, so we sampled opportunistically in this section. Below RM 10 we resumed sampling every third mile to Clay Hills Crossing (RM 2.9).

Table 1. Stations sampled in each year of the monitoring effort.

STATION	RIVER MILES	GEOMORPHIC REACH
Below Fruitland Diversion	169.5–178.6	6
APS Weir to Hogback Diversion	159.2–163.7	6
Shiprock to Cudei	140.5–147.9	5
Four Corners	119.2–127.5	5
Aneth	96.4–104.1	3
Bluff	76.4–83.0	3

Table 2. Additional stations sampled since the second study year of monitoring.

STATION	RIVER MILES	GEOMORPHIC REACH
Below Mexican Hat	40.0–45.0	2
John's Canyon	20.0–25.0	2
Grand Gulch	8.0–13.0	1
Miscellaneous Canyon Samples	2.9–52.9	1 and 2

Stocking and Monitoring

Stocking

As described in Golden et al. (2006), stocking methodologies have evolved over the study period to try to increase the initial retention and survival of Colorado pikeminnow upstream of Shiprock. The initial methodology was to stock en masse in two locations: the confluence of the Animas River with the San Juan River (RM 180.2) and just downstream of the State Highway 64 bridge in Shiprock (RM 148.0). Since then the USFWS stocked the majority of Colorado pikeminnow directly into low-velocity habitats, such as shoals, side channels, and backwaters, in two approximately 16-km (10-mile) reaches of river. The first reach extended from the confluence of the Animas River to the Hatch Trading Post in New Mexico, and the second extended from the Hogback Diversion to the Shiprock bridge. Additionally, BIO-WEST stocked 20,000 fish into acclimation areas between Bloomfield, New Mexico, and Hogback Diversion in each year. In 2005, a total of 302,270 YOY Colorado pikeminnow were stocked into the San Juan River, including the 20,000 that were stocked into acclimation areas by BIO-WEST (Table 3).

Table 3. Location and number of Colorado pikeminnow stocked in October and November 2005.

AGENCY	AREA	RIVER MILES	NO. PTYLUC[a]
October 20, 2005			
U.S. Fish and Wildlife Service	Animas Confluence to Hatch Trading Post	180.2–169.5	80,550
BIO-WEST, Inc.	Side Channel below Fruitland Diversion	175.8	6,000
BIO-WEST, Inc.	Side Channel above PNM Weir	167.5–167.4	14,000
U.S. Fish and Wildlife Service	Hogback Diversion to Shiprock	159.2–147.9	34,000
		TOTAL	**134,550**
November 3, 2005			
U.S. Fish and Wildlife Service	Animas Confluence to Hatch Trading Post	180.2–169.5	52,600
U.S. Fish and Wildlife Service	Hogback Diversion to Shiprock	159.2–147.9	115,120
		TOTAL	**167,720**

[a] PTYLUC = Colorado Pike minnow (*Ptychocheilus lucius*).

In addition to the YOY Colorado pikeminnow stocked into the San Juan River between 2002 and 2005, the SRJIP also stocked more than 16,000 age-1, age-2, and age-5 Colorado pikeminnow near the confluence of the San Juan and Animas rivers in 2004–2006 (Table 4). Most of the age-1 and age-2 fish were excess fish from the John W. Mumma Native Aquatic Species Restoration Facility (Mumma) in Colorado, but the SJRIP also arranged for 500 age-1 fish from the Dexter National Fish Hatchery and Technology Center (DNFHTC) to be released into the San Juan River in July 2005 and an additional 1,981 age-5 fish from the Bubbling Ponds Fish Hatchery near Sedona, Arizona, in August–September 2006.

Monitoring

After the YOY Colorado pikeminnow stocking effort in 2005, we made three sampling trips to document the fate of the stocked fishes. The initial sampling trip was conducted approximately 4 weeks after stocking on November 11–17, 2005. The second trip was conducted March 17–27, 2006 and the third sampling trip conducted July 24 – August 11, 2006.

During the November 2005 and March 2006 trips, we sampled each of the stations for 1 day, accessing each with a 14-foot or 16-foot raft. Within each station, we sampled as many backwaters, shoals, and other low-velocity habitats available for young Colorado pikeminnow as was practicable in a day (Trammell and Archer 2000). From Clay Hills to Lake Powell (November 2005 trip) we attempted to sample as many backwater habitats as practicable, concentrating on extremely low-velocity habitats encountered between sampling stations. In July 2006 we changed the sampling protocol to attempt to increase the number of Colorado

Table 4. Number of age-1 and age-2 Colorado pikeminnow stocked at RM 180.2 at different times between 2003 and 2005.

STOCKING DATE	HATCHERY ORIGIN	NUMBER OF AGE-1 FISH	NUMBER OF AGE-2 FISH	NUMBER OF AGE-5 FISH
November 6, 2003	Mumma [a]	1,005	0	-
June 9, 2004	Mumma	-	1,219	-
July 7, 2005	DNFHTC [b] / Mumma	500	1,491	-
November 7, 2005	Mumma	-	2,399	-
July 13, 2006	Mumma	-	3,524	-
July 20, 2006	Mumma	-	3,989	-
August 3, 2006	Bubbling Ponds [c]	-	-	1,722
September 6, 2006	Bubbling Ponds	-	-	259

[a] Mumma = John W. Mumma Native Aquatic Species Restoration Facility.
[b] DNFHTC = Dexter National Fish Hatchery and Technology Center.
[c] Bubbling Ponds = Bubbling Ponds Hatchery near Sedona, Arizona.

pikeminnow captured and marked for a population estimate. We also wanted to develop this estimate for the entire river, so we sampled systematically every third mile beginning at RM 178 down to RM 49. We intended to sample in this manner down to Clay Hills Crossing (RM 2.9), but downstream from RM 49 high flows reduced the amount of low-velocity habitat and the effectiveness of seining in many habitats. Therefore, we sampled all the habitats that were conducive to seining between RM 46 and RM 10. Below RM 10 we resumed sampling every third mile down to Clay Hills Crossing. During the November 2005 and March 2006 trips, we used 4 m x 2 m x 3 mm and 3 m x 2 m x 3 mm double-weighted seines to sample low-velocity habitats. As in previous years we used two 9 m x 2 m x 6 mm double-weighted seines for sampling in July–August because Colorado pikeminnow larger than 100 mm TL were much less susceptible to capture by the smaller seines (Golden et al. 2006). When using the larger seines, one was held at the bottom of the habitat unit, and we used the second seine to sample down to that seine in an attempt to block the escape of larger fish (block seining).

We collected the following information for each sample: river mile location, GPS location (UTM), habitat type, seine type, area sampled (length and width), average depth, maximum depth, and substrate type of the area sampled. Water temperatures were collected periodically throughout the day using a hand-held thermometer. We identified all fish collected to species and counted them. Occasionally we collected fish that were too small to identify to species in the field. We identified these specimens to the lowest practical level (usually family). We measured a minimum of 50 individuals of each species for standard length within each station, except for Colorado pikeminnow, all of which we measured. If we collected large numbers (>

100) of Colorado pikeminnow in a single seine haul (e.g., November 2004 and November 2005) after we had already recorded 100 Colorado pikeminnow lengths for that station, we only measured a subset of individuals, so that they could be quickly returned to the river. We returned native fishes to the river unharmed, but sacrificed nonnative fishes. We used a separate data sheet for each seine haul. We examined all Colorado pikeminnow for the presence of visible implant elastomer (VIE) tags (manufactured by Northwest Marine Technology, Inc.). We used a passive integrated transponder (PIT) tag reader to scan all Colorado pikeminnow over 150 mm captured during our sampling efforts. We inserted a PIT tag into any Colorado pikeminnow larger than 150 mm (TL) without a PIT tag.

As in previous years, other SJRIP cooperators also collected data on the Colorado pikeminnow stocked in 2005. The University of New Mexico's (UNM's) razorback sucker and Colorado pikeminnow larval fish surveys, the SJRIP small-bodied fish monitoring, and one sampling effort by the UDWR in conjunction with their nonnative removal sampling provided additional seining information. University of New Mexico crews sampled from Cudei Diversion (RM 142.0) to Clay Hills Crossing using a 1 m x 1 m x 1 mm larval seine (Brandenburg et al. 2004, Brandenburg et al. 2005). The UDWR sampled from Mexican Hat to Clay Hills Crossing in August 2004 using a 4 m x 2 m x 3 mm seine (Jackson 2004). Finally, the New Mexico Game and Fish Department (NMGFD) conducted the SJRIP annual small-bodied fish monitoring from the confluence of Animas River to Clay Hills Crossing using 3 m x 2 m x 3 mm seine in September and October (Propst et al. 2000). Each of these cooperators provided capture information for use in analyses presented in this report.

The USFWS New Mexico Fishery Resources Office (NMFRO) and UDWR nonnative fish species removal projects, along with SJRIP standardized large-bodied fish monitoring, provided additional information via electrofishing captures of Colorado pikeminnow each year of the study. From April to November 2006, the NMFRO used raft-mounted electrofishing to sample three sections of river: PNM Weir to Hogback Diversion (RM 166.7–159.2); Hogback Diversion to Shiprock (RM 158.7–148.9); and Shiprock to Mexican Hat (RM 147.9–53.0) (J. Davis, NMFRO, pers. comm.). The UDWR used raft-mounted electrofishing to sample from Mexican Hat to Clay Hills Crossing from March to August in all study years and sampled from RM 93.0 down to RM 3.3 in 2006 (D. Elevrud, UDWR, pers. comm.). The SJRIP cooperators used raft-mounted electrofishing to sample from the confluence of the Animas River to Clay Hills Crossing for the SJRIP large-bodied fish monitoring in September and October 2006 (D. Ryden, USFWS, pers. comm.). We used the data collected during these studies to provide a more complete picture of the fate of stocked YOY Colorado pikeminnow through their first 2–3 years in the river.

A comparison of all data collected during this study with the monitoring of the 1996 and 1997 stocking of YOY Colorado pikeminnow into the San Juan River (Trammell and Archer 2000) can be found in the comprehensive report prepared in 2006 (Golden et al. 2006). Golden et al. (2006) compared 1996 and 1997 stocking data on Colorado pikeminnow retention, growth, and survival as a baseline against which to compare our data collected from 2002–2005. In both 1996 and 1997, the UDWR stocked more than 100,000 fish, which were split into two groups and stocked near Shiprock and Mexican Hat. The UDWR completed follow-up monitoring from Shiprock to Clay Hills Crossing using methods that differed slightly from those outlined for this study, but those efforts provided a historical perspective with which to compare the current efforts.

Stocking Experiments

Acclimation Studies

As in 2003 and 2004, 20,000 of the YOY Colorado pikeminnow stocked in 2005 were acclimated in confined areas to determine if allowing stocked Colorado pikeminnow to adjust to their new environment in the river might decrease downstream displacement and increase initial retention (percentage of stocked fish that are recaptured in subsequent monitoring efforts). These fish were marked with VIE tags to distinguish them from other stocked fish of the same year class. Golden et al. (2006) noted that there have been several studies that have shown the potential benefits of such acclimation efforts (Cresswell and Williams 1983, Tipping 1998, Brown and Day 2002, Mueller et al. 2003). Two habitats (a large backwater and a low-velocity side channel) were selected in the 0-km reach between Fruitland and the Hogback diversions for acclimation of 20,000 Colorado pikeminnow. We stocked 6,000 VIE-marked Colorado pikeminnow into five net pens near RM 175.8 and 14,000 VIE-marked Colorado pikeminnow into a side channel between RM 167.5 and 167.4 (Figure 1). In previous years a larger number of habitats were used, but those efforts showed that fewer high-quality habitats were preferable to spreading the stocked fish out among five to ten sub-optimal habitats.

We stocked the 20,000 Colorado pikeminnow into the two selected habitats concurrent with the main stocking effort (October 20, 2005) and attempted to hold them in the habitats for 7 days after they were stocked. During our subsequent monitoring efforts for stocked Colorado pikeminnow outlined above, we looked for marked fish during each of our sampling trips following the acclimation periods. We noted the presence of marks on Colorado pikeminnow collected during our monitoring to determine an increased retention success for Colorado pikeminnow used in acclimation studies.

Pilot Population Estimate

In late summer and early autumn 2006, we conducted a pilot population estimate for age-1 and age-2 Colorado pikeminnow in conjunction with already existing sampling programs. The "mark" period occurred during the July–August 2006 YOY Colorado pikeminnow monitoring project trip. Colorado pikeminnow collected by block seining in all nine stations and at

Figure 1. Acclimation areas at RM 175.8 (top) and at RM 167.4 (bottom) in October 2005.

miscellaneous locations in the San Juan Canyon during that trip were marked. In addition, cooperators marked all Colorado pikeminnow collected by raft-mounted electrofishing during NMRFO nonnative removal efforts between Hogback Diversion and Shiprock from July 25–27, 2006, and UDWR nonnative removal between Mexican Hat and Clay Hills Crossing from August 3–11, 2006. Before fish were marked, cooperators scanned Colorado pikeminnow larger than 150 mm presence of a PIT tag, recorded any PIT-tag numbers, and injected a PIT tag into any fish without one. All Colorado pikeminnow smaller than 150 mm were marked with orange VIE tags during the "mark" period.

The recapture period occurred during SJRIP annual autumn monitoring, which took place from September 18–22, 2006, and October 2–9, 2006. The SJRIP cooperators scanned all Colorado pikeminnow over 150 mm TL that were collected with 2 x 4 m seines during small-bodied fish monitoring and with raft-mounted electrofishing during large-bodied fish monitoring for the presence of a PIT tag or orange VIE tag. BIO-WEST compiled the mark and recapture information from all the different cooperators. Despite increased effort in 2006 relative to the pilot population effort in 2005, recaptures were again too few to use the Program MARK to develop a population estimate (Otis et al. 1978, Rexstad and Burnham 1992).

Data Analysis

Unless otherwise noted, we used SYSTAT 10.2 to perform all the analyses described below. We used an α level of 0.05 for all the analyses described below.

Golden et al. (2006) found that catch per unit effort (CPUE) data for Colorado pikeminnow (and other native fish species) were not normally distributed and that none of several attempted transformations of the data were able to generate an approximate normal distribution. Because of this, it was not possible to use a nested ANOVA with Tukey's Honestly Significant Difference multiple comparison test to examine differences in CPUE for YOY Colorado pikeminnow (and other species) between trips, among stations within trips, and within stations among trips. Golden et al. (2006) also examined the distribution of Colorado pikeminnow abundance and CPUE from backwater habitats, but could not make those data approximate the normal distribution either. The large number of 0 values in the data was responsible for the lack of normality and the large number of 0 values also seemed to prevent meaningful analysis of the data using nonparametric tests. As a result of these efforts to find the best tool for analyzing these data, Golden et al. (2006) chose to use the number of Colorado pikeminnow per seine haul (catch rate) vs. the number per m^2 as the dependent variable in all analyses for several reasons.

Prior to the analyses outlined below, we scaled all our Colorado pikeminnow catch rate data in an attempt account for the different numbers of fish stocked in each year. We transformed the number of Colorado pikeminnow collected in each seine haul to what it theoretically would have been had 100,000 fish been stocked using the following transformation:

$$SCPM = (100{,}000/N)CPM$$

where SCPM = the scaled number of Colorado pikeminnow, N = the total number of Colorado pikeminnow stocked in that year, and CPM = the number of Colorado pikeminnow in the seine haul. In addition, we transformed the scaled catch rate data using the natural log of the scaled catch rate + 1 prior to all analyses.

The distributional problems outlined above prevented us from using parametric tests designed to examine differences between stations within trips, and between trips within stations. However, we examined differences between trips by using the catch rate at each station within each sampling trip as the sample unit. From the station means we calculated a grand mean (or mean of means) for each sampling trip. The grand mean is normally distributed, so we used the originally proposed ANOVA with Tukey's Honestly Significant Difference multiple comparison test to examine differences in the grand mean of Colorado pikeminnow catch rate between trips.

While using the grand mean allowed us to provide some level of statistical inference with our data, it does have drawbacks. Using stations as the sample unit instead of individual seine hauls severely reduces the available sample size and, subsequently, the ability to detect change. In addition, using station means as the sample unit prevents any evaluation of intra-site variability in catch and may mask some trends present in the data. There is also no way to statistically compare catch rates within years between stations and within stations between years.

Since we could not compare differences within stations among years using parametric or non-parametric statistics, we graphed the mean catch rate generated for each station during each trip, using each seine haul as the sampling unit. Golden et al. (2006) graphed the bootstrapped 95% confidence intervals around sample means (Manly 1997, Resampling Stats 2003) and found that even with 10,000 iterations the bootstrapped confidence intervals had a wide degree of overlap. A review of data collected in 2005–2006 indicated a similar distribution of the data, so we did not proceed with any further randomization analyses.

We also included information on stocked Colorado pikeminnow captured during UNM spring-summer larval sampling efforts, NMFRO and UDWR nonnative species removal efforts, and September–October standardized monitoring efforts to provide a complete picture of the fate of the stocked fish. For electrofishing projects we calculated the CPUE of Colorado pikeminnow as the number of fish per hour of electrofishing, scaled the CPUE for the number of Colorado pikeminnow stocked in that year, and transformed it using the natural log of the scaled catch rate + 1, prior to calculating the mean and standard error. Similar to previous seining data, Golden et al. (2006) found that the UNM larval fish data and the small-bodied fish monitoring data showed no relationship between the number of Colorado pikeminnow collected in a seine haul and the area sampled by that seine haul (Spearman R = 0.08 and 0.06). Therefore, number of Colorado pikeminnow per seine haul in the UNM larval fish data were also scaled to the (catch rate) data for the total number of fish stocked, and the natural log of the scaled catch rate + 1 used for calculating the mean and standard error. Since all of these projects differed in collection methods and objectives, we presented the data graphically but did not attempt statistical comparisons.

We used a chi-square goodness-of-fit test to examine whether we collected acclimated Colorado pikeminnow in a higher proportion than would be expected based on the percentage they comprised of the total number of fish stocked. We used the proportion that acclimated fish comprised of the total number of fish stocked that year as the expected proportion and compared it to the proportion that acclimated fish comprised of the total number of Colorado pikeminnow collected in each sampling trip following stocking.

We used ANOVA with Tukey's Honestly Significant Difference multiple comparison test to compare average standard and total lengths for Colorado pikeminnow at similar times after stocking among the different stocking efforts as well as among different times after stocking within the same stocking effort. We also calculated instantaneous growth rates for Colorado pikeminnow from the initial trip after stocking to March of the following year, as well as between March and July of the following year. We used the following equation to calculate instantaneous growth rates:

$$GR = 100[(\ln L_f - \ln L_i)/(t)]$$

where GR = the instantaneous growth rate, L_f = the final average length, L_i = the initial average length, and t = the number of days elapsed between sampling periods (Moyle and Cech 2004). We used the middle day of our sampling trip as the point to calculate the number of days elapsed between trips. We calculated instantaneous growth rates using the same equation for Colorado pikeminnow between stocking and the first, second , and third autumn they remained in the river. We calculated the total number of days elapsed for this comparison as the period between the last day of our initial sampling trip after stocking and the last day of the autumn SJRIP large-bodied fish monitoring.

We used a t-test to compare the grand mean of Colorado pikeminnow catch rate in side channel habitat vs. main channel habitat during each trip. We used a chi-square goodness-of-fit test to examine whether we collected stocked Colorado pikeminnow in a higher proportion of samples in side channel or main channel habitats than would be expected based on the proportion of main and side channel habitats that we sampled. Similarly, we used a chi-square goodness-of-fit test to examine whether we collected a higher proportion of Colorado pikeminnow in different habitat types than would be expected based on the proportion of our samples taken in the different habitat types.

We used a chi-square goodness-of-fit test to compare whether Colorado pikeminnow were present in a higher proportion of backwater samples than we would have expected based on the total number of backwaters sampled. We used a paired t-test with Bonferroni-adjusted probabilities to compare the combined scaled average Colorado pikeminnow catch rate from each time period after stocking. We performed similar analyses to determine Colorado pikeminnow use and abundance in habitats with and without cover. We also employed paired t-tests with Bonferroni-adjusted probabilities to compare depth of all samples vs. the depth of samples containing Colorado pikeminnow.

RESULTS

Discharge

Because a “water year” runs from October 1 of the preceding year to September 30 of the following year (e.g., the 2006 water year ran from October 1, 2005, to September 30, 2006), fish stocked in a given year are subjected to the following “water year.” Therefore, fish stocked in October 2005 were subjected to conditions of the 2006 water year. The water years surrounding the 2002 stocking event (2002 and 2003) were low-flow years, as was the 2004 water year (Figure 2). Conversely, the 2005 water year had substantially higher spring runoff than in either 2003 or 2004. Discharge in 2005 was similar to the water years surrounding the 1996 and 1997 YOY stocking efforts. The 1997 and 1998 water years had substantially higher spring runoff, higher summer flows, and more summer spike flows than the 2002–2004 water years. The 2006 water year was intermediate between the low-flow years of 2002–2004 and the higher flows of 2005. Runoff in 2006 started about the same time as in the low-flow years, but peaked about mid-way between the low-flow and high-flow peaks. In the early part of the 2007 water year, there were very high flows that peaked at much higher values than any of the years discussed above.

Discharge immediately following stocking and during acclimation experiments varied between years and may have directly, or indirectly, impacted the initial retention of Colorado pikeminnow (Figure 3). Average daily discharge was similar following the 2002 and 2004 stocking. Average daily discharge was lower following the 2003 stocking and higher following the 2004 stocking. Within a week after at least one of the stocking efforts in 2002, 2003, and 2004, there was a 200–500 cfs increase in average daily discharge, after which daily discharge remained fairly steady into December. Conversely, when the SJRIP stocked Colorado pikeminnow in 2005, it was on the tail end of a relatively large (800 cfs) increase in average daily discharge, after which flows continued to decline for nearly 2 weeks and then remained steady into December 2005.

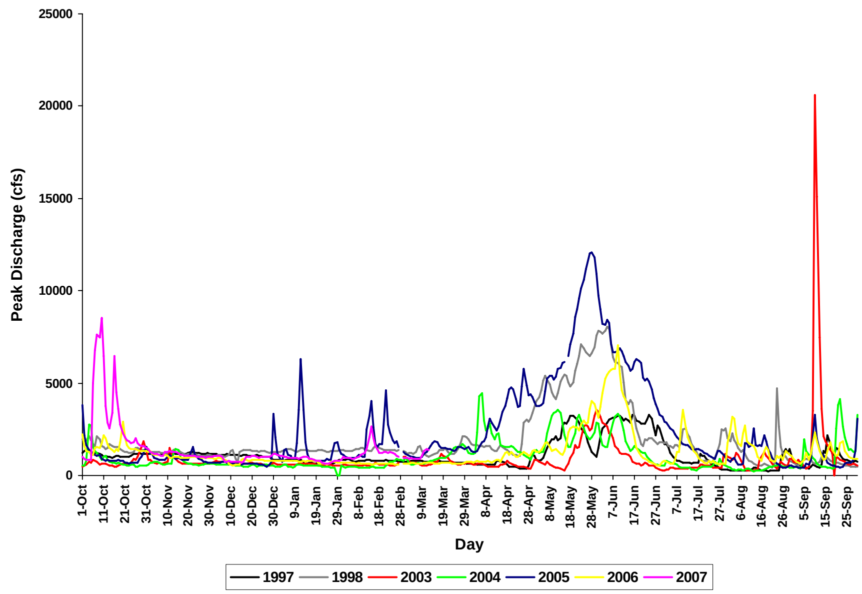

Figure 2. Average daily discharge for the San Juan River near Bluff, Utah (USGS gage 09379500), for water years 1996-1997 and 2002-2007 (a water year is October 1 - September 30).

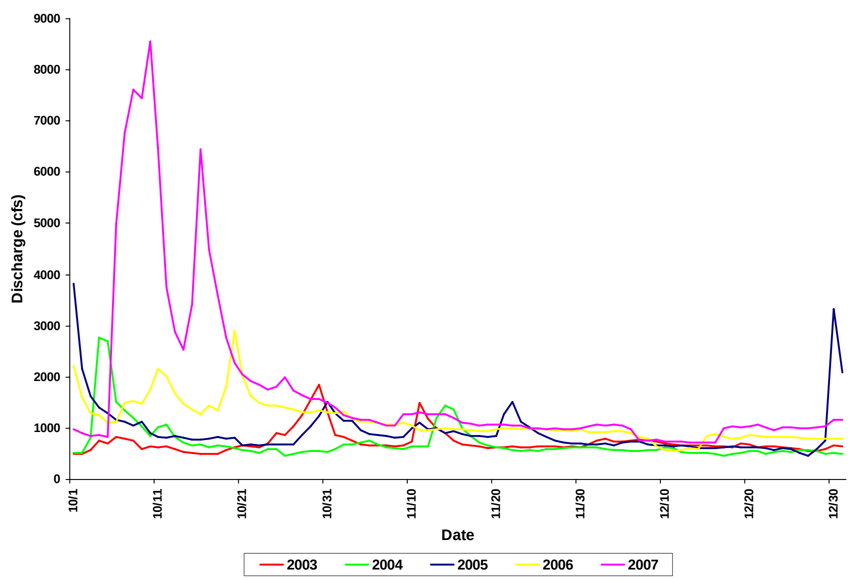

Figure 3. Average daily discharge between October 1 and December 31 for the San Juan River near Farmington, New Mexico (USGS gage 09365000), during water years 2003-2007 (a water year is October 1 - September 30).

Temperature

As with discharge, water temperatures in water year 2005 differed from previous years. In the 2006 water year, a later runoff resulted in water temperatures that were intermediate between the 2003–2004 low-flow years and the 2005 high flow year (Figure 4). Mean temperature at the Farmington and Shiprock gages in May and June of 2006 were higher than in 2005 (Figure 5), but in early June, during high runoff, temperatures were similar to those in 2005 (Figure 4). However, the rapid heating in the latter half of the month in 2006 was much higher than in 2005, when runoff was more prolonged.

There have been slight differences in average water temperatures before and after each stocking event among years during this study, but these have been generally minor. Water temperatures in the period between October 1, 2006, and December 31, 2006, were within the range of conditions experienced in previous years (Figure 6).

Colorado Pikeminnow Retention

Stocked Young-of-Year (YOY) Colorado Pikeminnow

YOY Colorado Pikeminnow Monitoring

Similar to previous years (Golden et al. 2006) we collected Colorado pikeminnow during 2005–2006 that were primarily from the most recent stocking, but there were a few fish from previous stockings (Table 5). Since different numbers of fish were stocked each year, we would expect that different numbers of fish would be recovered, so we also scaled catch to the total number of fish stocked. The number and proportion of 2005-stocked Colorado pikeminnow that were captured during monitoring in 2005—2006 was similar to previous trips in November 2005 and July 2006, but slightly lower than in previous years in the March 2006 sample. Golden et al. (2006) discussed the influence of time since stocking on catch rate during the first post-stocking monitoring trip and high initial loss of stocked fish apparent in this data.

Effort during each sampling trip fluctuated with a variety of factors (Tables 6 and 7). In July 2006 both the number of seine hauls and total area sampled were high because of the shift in sampling protocol to 1mile in every 3 miles using the block seining technique.

We used the catch rate (number per seine haul) of Colorado pikeminnow to account for differences in effort among years. We also scaled the average catch rates to account for the difference in the total number of fish stocked among years (Figure 7). The scaled catch rate in November 2005 was higher than after the 2002 or 2003 stocking. The scaled catch rate for that sample was not as high as the first sample after the 2004 stocking, but there was overlap in error bars (2 standard errors) indicating that these samples were not statistically distinct. As discussed

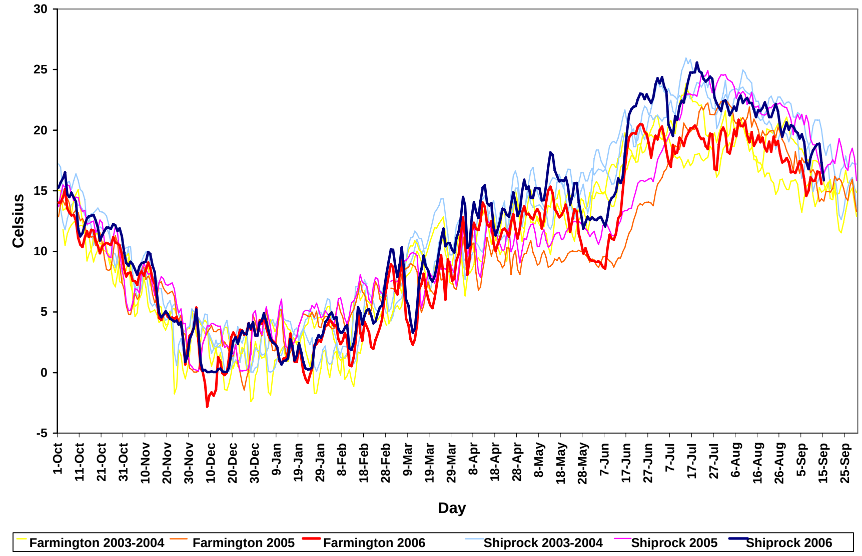

Figure 4. **Average daily water temperatures near Farmington and Shiprock, New Mexico, during water years 2003-2006 (Keller-Bliesner Engineering data).**

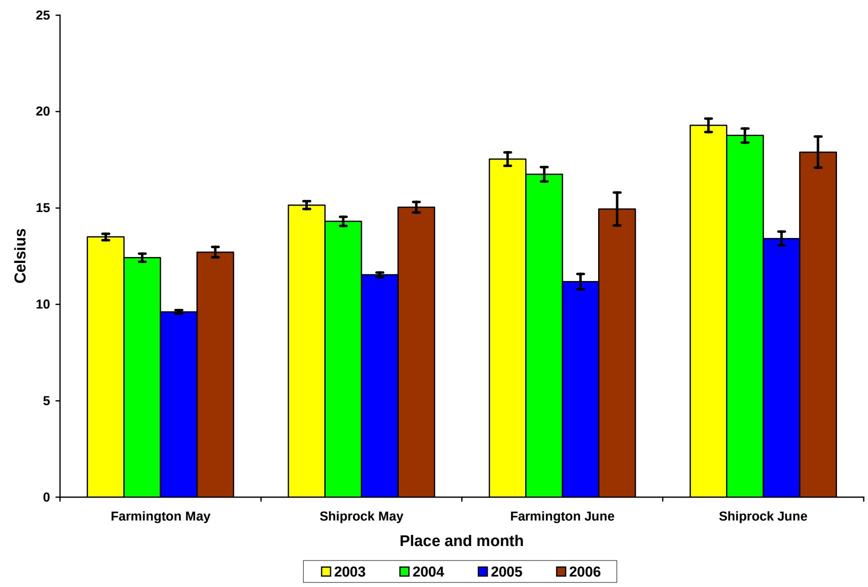

Figure 5. **Mean average daily water temperature in May and June at Farmington and Shiprock, New Mexico, in 2003-2006 (Keller-Bliesner Engineering data). Error bars represent +/- 1 standard error.**

Figure 6. **Average daily water temperatures near Farmington, New Mexico in October, November, and December of flow years 2003-2006 (Keller-Bliesner Engineering data).**

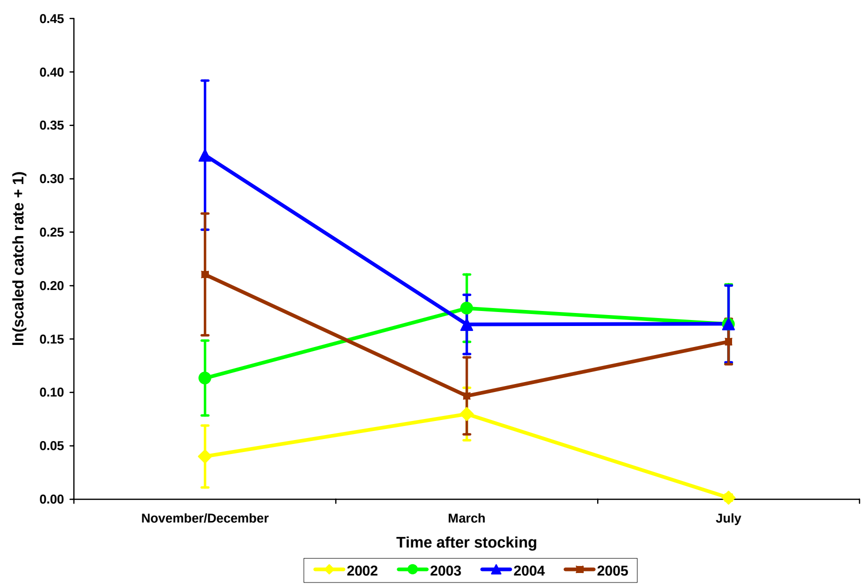

Figure 7. **Scaled Colorado pikeminnow catch rate from the three sampling trips (all stations combined) following stocking efforts in 2002-2005. Error bars represent +/- two standard errors.**

Table 5. Number and percent of Colorado pikeminnow stocked as age-0 fish in 2002-2005 and recaptured during monitoring in 2005-2006.

2005–2006 SAMPLE DATE	STOCKED IN 2002	STOCKED IN 2003	STOCKED IN 2004	STOCKED IN 2005
November/December	0	0	12 (12)	1011 (957)
			0.005%	0.3345% (0.3166%)
March	0	0	0	390 (333)
				0.1290% (0.1101%)
July/August	0	2 (0)	40 (9)	189 (63)
		0.0006%	0.0015% (0.0032%)	0.075% (0.028%)

[a] The number and proportion in parentheses represents Colorado pikeminnow collected in the six stations sampled in all years.

Table 6. Number of seine hauls pulled in each of the young-of-year (YOY) Colorado pikeminnow monitoring project collections from 2002-2006.

MONTH	2002–2003	2003–2004	2004–2005	2005–2006
November/December	364 (273)[a]	489 (295)	394 (245)	402 (298)
March	411 (328)	666 (406)	604 (386)	434 (303)
July	464 (384)	329 (160)	301 (170)	439 (224)

[a] The number in parentheses represents the number of seine hauls pulled in the six stations sampled in all years.

Table 7. Total area (m^2) sampled in each of the YOY Colorado pikeminnow monitoring project collections from 2002-2005.

MONTH	2002–2003	2003–2004	2004–2005	2005–2006
November/December	10,483 (8,316)[a]	15,097 (9,720)	17,898 (11,703)	22,637(16,167)
March	18,119 (15,172)	25,977 (15,870)	24,075 (16,375)	15,346 (11,117)
July	19,168 (16,816)	62,255 (36,193)	57,563 (34,379)	78,799 (39,832)

[a] The number in parentheses represents the area sampled in the six stations sampled in all years.

by Golden et al. (2006), there was a direct relationship between the number of stocked YOY Colorado pikeminnow captured in the first post-stocking sample (conducted 1-6 weeks after stocking in November/December) and length of time since stocking. In March 2006 the scaled catch rate decreased to a value lower than the March samples in either 2003 or 2004 and similar to the value observed in 2002. The grand mean catch rate in July 2006 was similar to that of previous samples. The only major difference among years in the July sample occurred in 2002 before the block-seining technique was used.

Golden et al. (2006) examined the 95% bootstrapped confidence intervals around the scaled average catch rate values for each station during each sampling trip in 2002–2005 and found that even resampling with 10,000 iterations, there were wide confidence intervals around the means as a result of the highly skewed and variable distribution of our data. Based on those observations, no significant differences could be found among samples within any station using randomization techniques. We found that the distribution of data collected in 2005–2006 was similar to previous years and, therefore, it was not possible to statistically analyze potential differences among sample periods within individual stations.

Other San Juan River Basin Recovery Implementation Program (SJRIP) Cooperators

As in Golden et al. (2006), we evaluated data from other SJRIP cooperators in addition to that collected by BIO-WEST. The majority of the data are from raft-mounted electrofishing efforts by UDWR and NMFRO (nonnative removal efforts), along with large-bodied fish monitoring captures. From these data, we found that Colorado pikeminnow stocked as age-0 fish in each of the stocking efforts from 2002–2005, were collected as age-1, age-2, age-3, and age-4 fish in 2005–2006 (Figure 8). As in previous years, the 2005-stocked Colorado pikeminnow recaptures increased in electrofishing samples by September 2006.

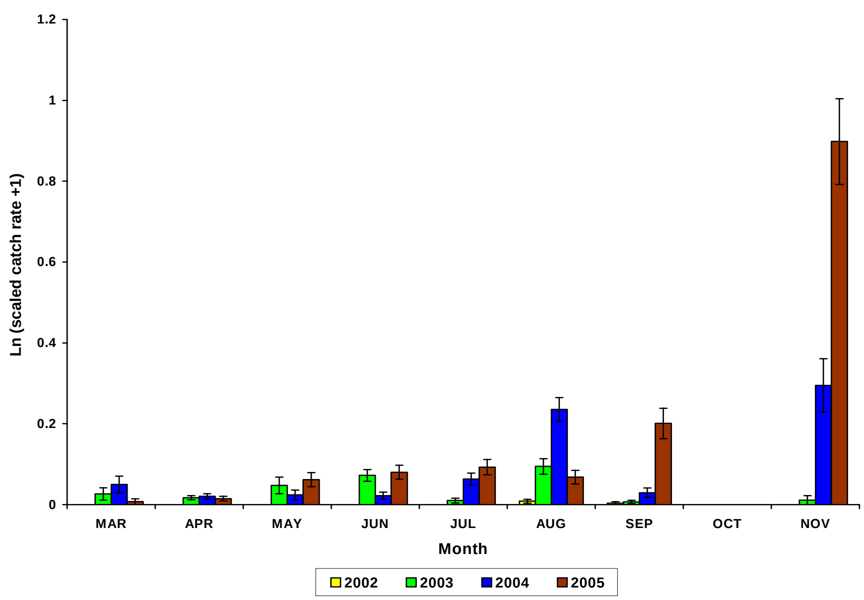

Figure 8. Scaled catch per unit effort (CPUE) for Colorado pikeminnow stocked in 2002-2006 and captured during SJRIP projects using raft-mounted electrofishing in 2006. Error bars represent +/- one standard error.

The age of older fish was determined with PIT tag data (Figure 9) or, when no PIT tag was present, a fish was presumed to have been stocked as YOY and captured for the first time. The age of the fish was determined by examining growth of each cohort and using the size range of each year class (Figures 10 and 11) to determine the age of the fish.

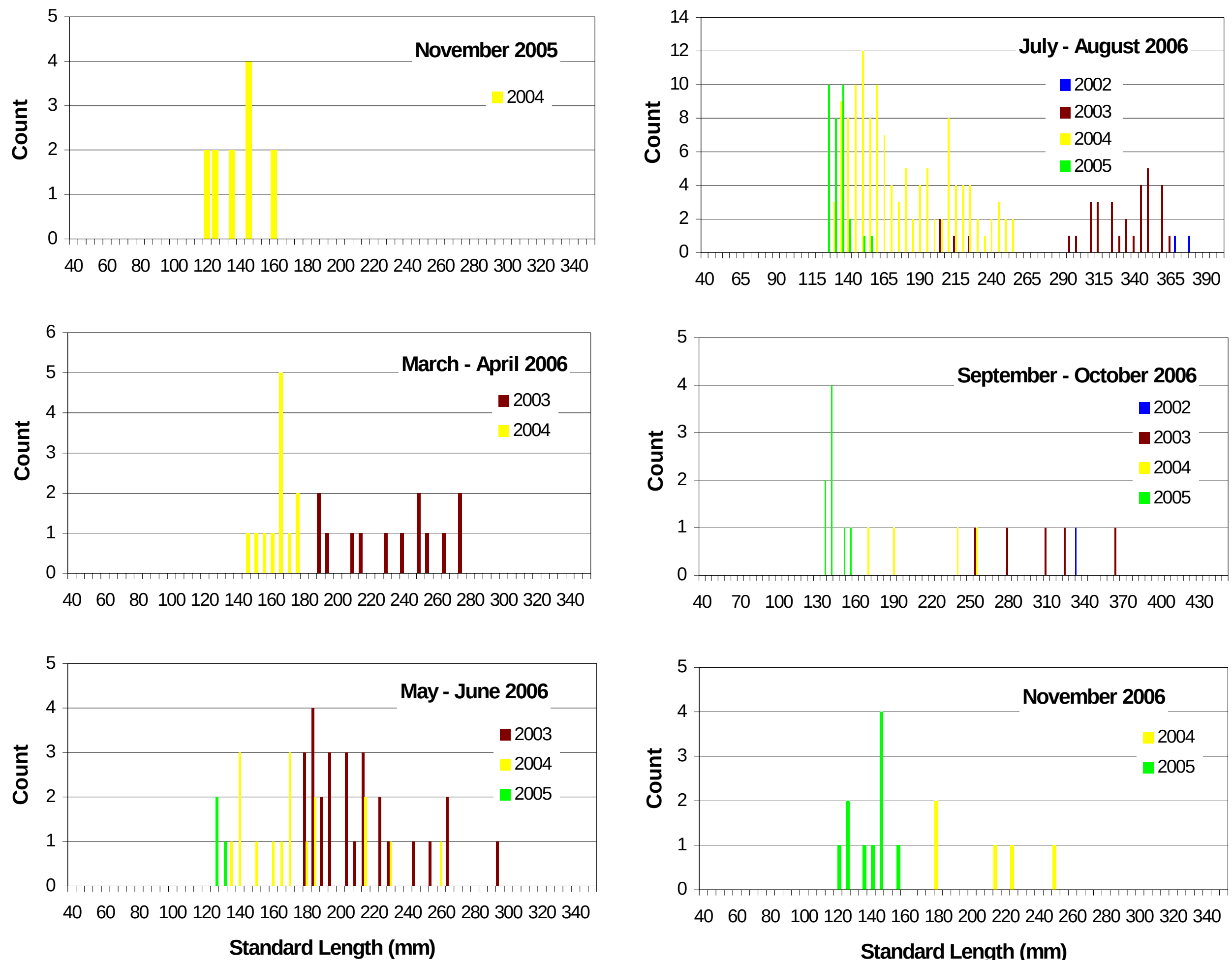

Figure 9. Length frequency histograms of Colorado pikeminnow captured by all cooperators in 2006 (n=311) that were PIT tagged prior to August 2006.

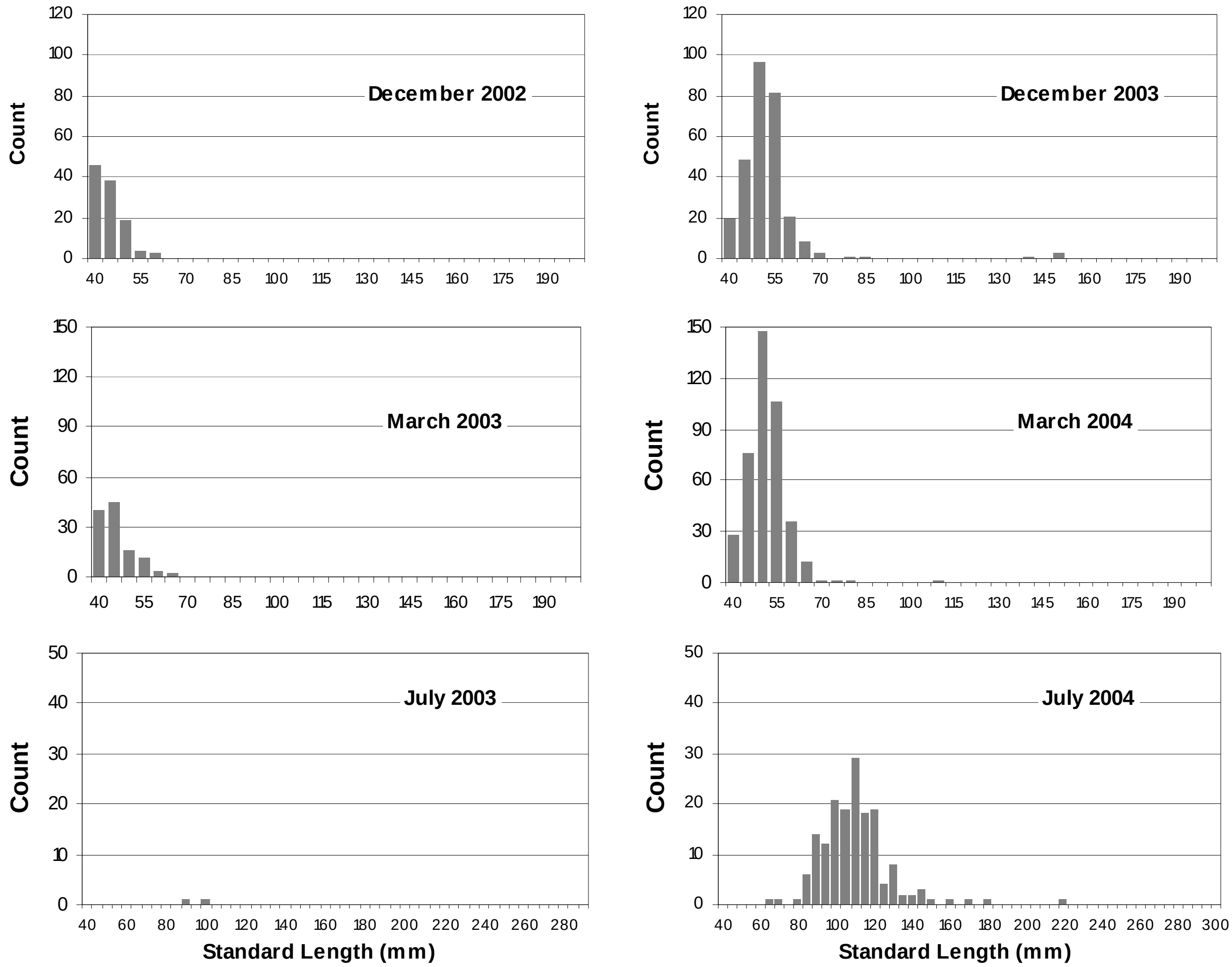

Figure 10. **Length frequency histograms of all non-PIT tagged Colorado pikeminnow captured during the YOY Colorado pikeminnow monitoring study following the 2002 and 2003 stocking efforts.**

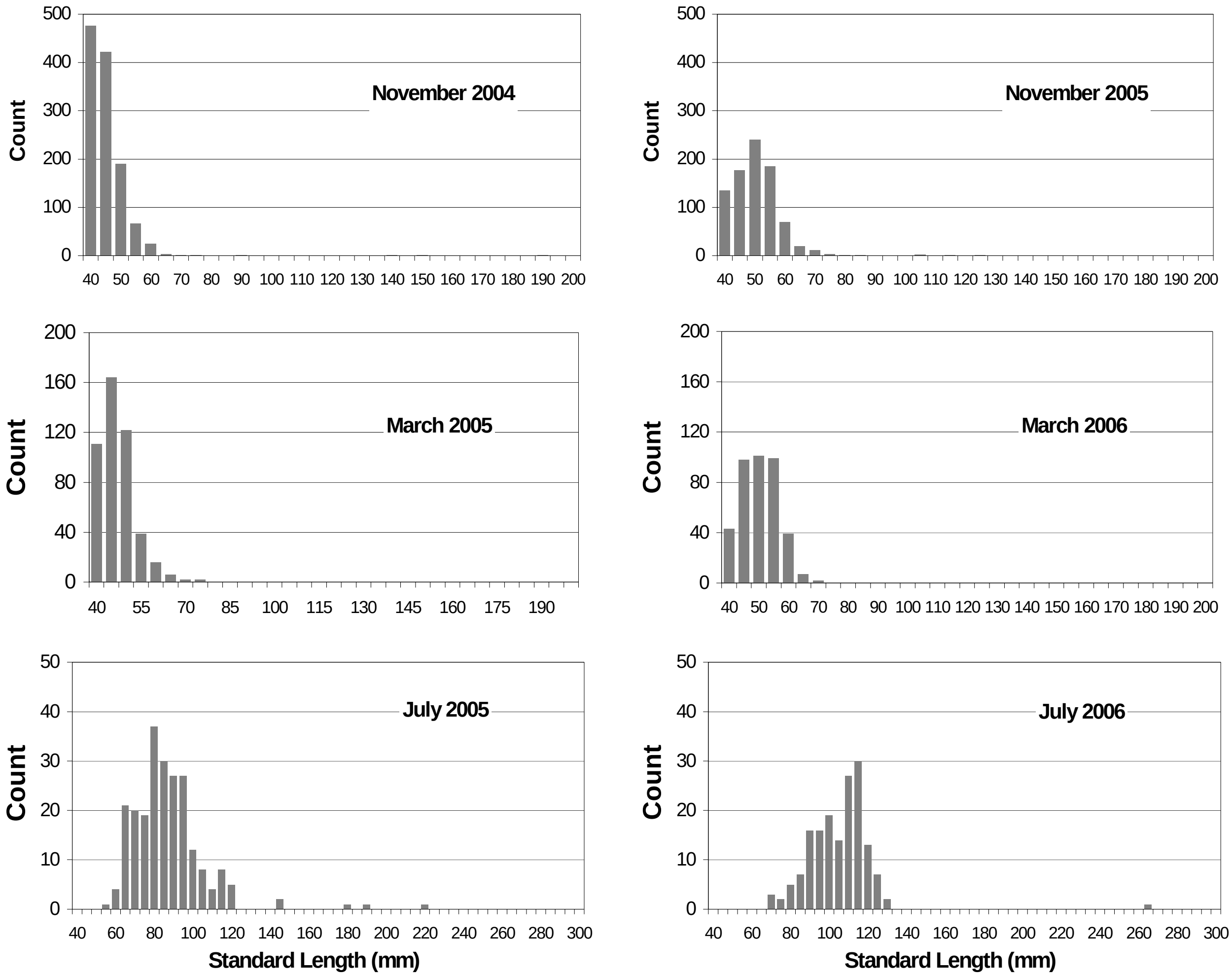

Figure 11. Length frequency histograms of all non-PIT tagged Colorado pikeminnow captured during the YOY Colorado pikeminnow monitoring study following the 2004 and 2005 stocking efforts.

Colorado Pikeminnow Stocked as Age-1 or Older

In 2006, 337 of the recaptured Colorado pikeminnow by all cooperators had been stocked as age-1 or older fish (including multiple captures of the same fish). The majority of these fish (247) were age-5 fish that had been stocked in August and September 2006 from the Bubbling Ponds Hatchery and recaptured shortly thereafter. There were also 78 age-2 fish that had been stocked in July of 2006 and 10 age-1 fish that had been stocked in October 2006 and caught later that month or in November. Only one Colorado pikeminnow that had been stocked as an age-1 fish in a previous year was recaptured in 2006. This fish was stocked in July 2005 and recaptured in

June 2006 and again in October 2006. In contrast, there were eight Colorado pikeminnow that were unmarked at capture and presumably stocked as YOY fish caught in 2006 that were estimated to be age-4 and another 119 recaptures of fish estimated to be age-3. Golden et al. (2006) indicated that fish stocked at age-1 or greater (primarily those from the Mumma hatchery) were often observed to be in poor condition and have misshapen heads and observed that most recaptures of Colorado pikeminnow that were stocked as age-1 or older fish were shortly after stocking. The lack of Colorado pikeminnow in 2006 samples that had been stocked as age-1 or greater in previous years and the relatively high occurrence of older fish that had previously been unmarked (and presumed to have been stocked as YOY) suggest that there has been greater long-term success in stocking the YOY life stage.

To account for differences in the number of fish stocked on our catch rates, we calculated the percentage of each age class of Colorado pikeminnow collected based on total numbers stocked. There have been almost 970,000 age-0 fish stocked since 2002, 1,500 age-1, 12,600 age-2 fish, 2,000 age-5 fish, and 200 age-10+ fish (these latter fish were stocked prior to 2002). Consistent with previous results, early (< 180 days) recaptures of larger fish were very high, but recaptures were much lower after this early window of time (Table 8). We found that the percentage of recapture of fish stocked at age-1 and age-2 were similar in the first month after stocking, but age-1 fish were caught in proportionally higher amounts in the second through sixth months. Between 6 months and 2 years after stocking, however, proportion of recapture for both groups was similar. Age-5 fish were first stocked in 2006 and recapture rates were very high during the first 3 months. Between the third and fourth month, however, the recapture rate was similar to fish stocked as age-1 and age-2 fish. Continued monitoring of this year class will help determine whether growing fish to that age before release may provide a greater benefit for the cost of releasing fewer fish. Previous stocking of age-10 fish appeared in 1997 appeared to be very successful with a recapture rate of over 16% after 3 years in the river (the longest period to recapture was 1,574 days). Colorado pikeminnow stocked as YOY fish have not been recaptured at rates as high as those stocked at age-1+ during first few months after stocking but their recapture rates were similar to these older fish once they reach the size to begin PIT tagging (> 150 mm TL; in the 180–365 day category in Table 8). The ability to stock much larger numbers of YOY fish has resulted in a much higher number of these fish in the river after 180 days even though the proportion of stocked fish remaining is very low. In addition, 23 recaptures have occurred more than 3 years after stocking as YOY, while no age-1 fish were recaptured between 1 and 2 years after stocking despite the fact that 1,005 fish stocked as age-1 have been in the river for that long.

Table 8. The amount of time since stocking and number of YOY and age-1+ Colorado pikeminnow that were stocked in the San Juan River and recaptured between 2002-2006. Percentages represent the proportion of fish captured relative to the proportion of fish stocked; fish stocked in 2006 were presumed to have been available for capture in the categories ranging from 0-180 days. All recaptures are included; some fish were captured multiple times in short period.

AGE AT STOCKING	DAYS SINCE STOCKING								
	0–30	31–60	61–90	91–120	121–180	181–365	366–730	731–1095	1096+
YOY	-[a]	-	-	-	-	628 0.065%	660 0.099%	172 0.045%	23 0.011%
AGE-1[b]	9 0.598%	10 0.664%	11 0.731%	2 0.133%	6 0.399%	1 0.066%	1 0.100%	-	-[g]
AGE-2[c]	98 0.776%	22 0.174%	40 0.317%	25 0.198%	1 0.008%	5 0.098%	2 0.164%	-[h]	-
AGE-5[d]	161 8.1%	52 2.6%	30 1.5%	4 0.202%	-[i]	-	-	-	-
AGE-10[e]	-	-	1 2.0%	-	14 28.6%	29 59.2%	20 40.8%	12 24.5%	8 16.3%
AGE-16[f]	10 6.8%	-	-	-	-	2 1.4%	-	-	-

[a] Many YOY Colorado pikeminnow have been caught in the first 180 days during the 2002–2006 monitoring efforts; this table focuses on fish that were large enough to PIT tag (> 150 mm TL).
[b] Includes 1,005 fish stocked on November 6, 2003 and 500 fish stocked on July 5, 2005.
[c] Includes 1,219 fish stocked on June 9, 2004, 1,491 on July 5, 2005, 2,399 stocked on November 7, 2005, 3,524 stocked on July 13, 2006, and 3,989 stocked on July 20, 2006.
[d] Includes 1,722 fish stocked on August 3, 2006 and 249 fish stocked on September 6, 2006.
[e] Includes 49 fish stocked on September 23, 1997.
[f] Includes 148 fish stocked on April 11, 2001.
[g] No age-1 fish have been in the river longer than 3 years.
[h] No age-2 fish have been in the river longer than 2 years.
[i] No age-5 fish were in the river longer than 5 months in 2006.

Stocking Protocol Changes and Experiments

Acclimation Studies

Prior to the 2005 stocking, 2 years of acclimation experiments were conducted in 2003 and 2004. A total of 20,000 YOY Colorado pikeminnow were acclimated each year, which represented a different proportion of the total number of stocked fish (11.4%, 7.1%, and 6.6% in 2003–2005, respectively). In 2003 the acclimation studies were unsuccessful because the majority of Colorado pikeminnow used in the experiments died and the batch marker failed (see Golden et al. 2006 for more detail). In 2004 a transition to VIE tags was much more labor intensive, but also more reliable than the calcein dye used in 2003. Although not tested directly in this study, the VIE tags appeared to be very reliable during the first two post-stocking monitoring trips. However, because of a period of dramatic growth between March and July tags are presumably covered by new tissue. Close (2000) found that detectability of both green and yellow VIE marks in the postocular adipose tissue of fingerling rainbow trout (*Oncorhynchus mykiss*) decreased as the fish grew and neither color was detectable after 186 days. Based on this information and our observations in the field (elastomer visibly separating), we believe that observation of the VIE tags was less reliable in the July monitoring trip.

With an improved marking method in 2004, the greatest difficulty was actually finding suitable habitats for the individual acclimation sites in the two selected acclimation reaches (Below Fruitland Diversion and APS Weir to Hogback). In an attempt to spread out the risk of putting too many fish in only a few areas, many sites were selected that had less-than-optimal conditions including some marginal side channels and other low-velocity shoreline habitats. Within the first 48 hours, we observed that many nets had been breached (Figure 9) or that marked fish were outside of the acclimation areas including all five areas in the Below Fruitland Diversion station and two of the three areas in the APS to Hogback station. Only one acclimation area remained unbreached for the full 7 days. This area consisted of a large side channel in the APS to Hogback station at RM 160.9, which had 7,000 of the VIE-marked YOY Colorado pikeminnow in it.

In monitoring efforts subsequent to the 2004 YOY Colorado pikeminnow stocking and acclimation efforts, acclimated fish were recaptured at a higher-than-expected rate. Though this observation was not supported by data for all reaches combined, higher recapture rates occurred within the reaches where the fish were initially acclimated. Acclimated fish comprised 7.1% (20,000 of 280,000) of the total number of YOY Colorado pikeminnow stocked in October 2004 and in November, 9.5% of the recaptured YOY Colorado pikeminnow were marked as having been acclimated, which was significantly higher than expected using a chi-square analysis ($p < 0.001$). The percent of acclimated fish declined to 6.3% of all recaptured YOY Colorado pikeminnow in March 2005 (Figure 10) (not significantly different than expected). When the data were summarized by percent of acclimated fish recaptured in the reaches in which they had been acclimated, there was more evidence to support the success of these efforts. Of the two reaches in which fish were acclimated, only one barrier remained intact for the full 7 days; the others were all breached within 48 hours. In the BFD reach, all acclimation barriers were breached and acclimated fish were recaptured in approximately the same proportion as their representation in the total number of stocked fish (5.9%) in November 2004 (5.6%) and March 2005 (4.3%).

The one acclimation barrier that remained intact for the full 7 days (with 7,000 fish) was in the APS reach. Approximately 10.5% of the fish stocked in or above the APS reach were acclimated (20,000 of 190,000), yet 42% of the fish captured in the November 2004 monitoring effort and 45% captured in the March 2005 monitoring effort had been acclimated. Both of these values represent a significant difference from the expected proportion of acclimated fish using a chi-square analysis ($p < 0.001$ for each) and suggest there is a benefit to acclimation when habitats remain intact for a full 7 days.

Acclimation efforts in 2005 focused on preventing breaches and finding sites in which nets would remain intact for the full 7-day acclimation period. As a result, only two suitable sites were found, one in the BFD reach at RM 175.8 and a second between the BFD and APS reaches near RM 167.4. We did not detect any breaches or marked Colorado pikeminnow outside the net pens at RM 175.8 throughout the entire 7-day acclimation period. We found breaches in the block nets at the side channel near RM 167.4 the day after fish were released and low numbers of fish outside the nets. We further secured the nets, and seining confirmed that large numbers of Colorado pikeminnow were still in the side channel. Therefore, we feel that the majority of the 20,000 Colorado pikeminnow were acclimated for the full 7 days.

In the first two monitoring efforts subsequent to the 2005 YOY Colorado pikeminnow stocking and acclimation efforts (November 2005 and March 2006), we found higher than expected retention of acclimated fish based on the proportion of acclimated fish to the total number of stocked fish, in all reaches combined and in the reaches where they had been acclimated(Figure 11). The proportion of recaptured fish in July 2006 that had visible marking as having been tagged was not higher than expected. In 2004 Colorado pikeminnow that had been marked as acclimated fish were found in the lower sections of the river (the canyon areas) shortly after acclimation (in the November sample); these fish were presumably those that had escaped breached habitats within the first 48 hours of the acclimation period. Following acclimation in 2005, no Colorado pikeminnow marked as acclimated fish were found downstream of the Bluff reach (downstream end at RM 77.5) during any of the monitoring efforts. Acclimated Colorado pikeminnow comprised 6.6% (20,000 of 302,000) of the total number of stocked fish and represented14% of the captured YOY Colorado pikeminnow in all reaches combined in November 2005, and 16.9% in March 2006. Each of these observations represents a significantly higher percent of recapture than expected (X^2; $p < 0.001$). The proportion of acclimated Colorado pikeminnow captured in all reaches declined to 6.3% by July. In the reach where most of the Colorado pikeminnow were acclimated in 2005,BFD, fish marked as acclimated represented 27.9% of all Colorado pikeminnow captured in November 2005, 40.0% in March , and 17.5% in July. Each of these percentages was higher than expected based on the proportion of acclimated fish that were stocked in that reach (4.3%) (X^2; $p < 0.001$).

In addition to the BFD reach, acclimation efforts in 2004 also occurred in the APS reach. In 2005 acclimation occurred in the BFD reach and the portion of river between this reach and the APS reach; therefore, an evaluation of proportional recapture of acclimated fish in subsequent monitoring (which only occurred within the study reaches) was not possible for the second acclimation area. Instead, we evaluated the occurrence of acclimated fish in monitoring samples from above the Hogback Diversion (which includes both the BFD and APS sites) relative to the acclimation efforts that occurred in this section of river. All 20,000 acclimated fish were released in this section of river, along with 133,150 non-acclimated fish (13.1% acclimated). In the post-stocking monitoring efforts in November 2005, March 2006, and July 2006, 21.4%, 36.6%, and 17.5% (respectively) of the captured Colorado pikeminnow were marked as having been acclimated. The November and March results were significantly higher than expected (X^2; $p < 0.001$). Since both acclimation sites in 2005 were upstream of the APS reach, it is not surprising that the proportion of acclimated fish captured in that reach shortly after stocking/acclimation in November (7.0%) was nearly identical to that of the total proportion of acclimated fish. By March, however, there was some evidence that acclimated fish from upstream areas had moved down into the APS reach, with 40% of marked fish occurring among the YOY Colorado pikeminnow that were captured in that reach.

No significant deviation from expected conditions (i.e., acclimated fish were not recaptured in a higher proportion than expected based on the stocking ratio) was observed in July monitoring efforts in either 2004 or 2005. We believe that this results from a reduced ability to identify VIE tags in fish that have grown substantially between the March and July monitoring efforts. However, this experiment was not designed to address that question. We have noticed that the elastomer tags began to pull apart as the fish experience a period of rapid growth between March and July (mean standard length in 2006 increased from 48.4 mm to 113.0 mm). It seems plausible that the rapid growth also results in tissue covering the tags and reducing the reliability of field observations.

In addition to the apparent value of acclimation efforts toward increasing retention and reducing downstream movement, we also observed upstream movement of acclimated Colorado pikeminnow for the first time. We collected 109 VIE-marked Colorado pikeminnow between 0.16 and 1.29 km (0.1 and 0.8 mile) upstream from the acclimation area in the Below Fruitland Diversion reach in November 2005. Both locations where fish were collected were on the opposite side of the river, indicating that the fish are capable of moving against the current. This ability was otherwise not apparent from previous monitoring data of these recently stocked Colorado pikeminnow. We feel that the primary reason for the movement was that the habitat in which we had acclimated the 6,000 Colorado pikeminnow had become shallow and clear. We only collected three Colorado pikeminnow from that area, one of which was marked.

Pilot Population Estimate

In summer and early autumn 2006 we repeated the population estimate efforts, with slight modification, that were first conducted in 2005. The focus was on generating a population estimate of age-1 and age-2 Colorado pikeminnow in the San Juan River downstream of the

Animas River using mark and recapture methodologies. To improve upon efforts in 2005, in which there were too few recaptures to generate an estimate, a greater combined effort was expended during the “mark” period (a larger proportion of the river was sampled) to increase the number of possible “recaptures” during the autumn large-bodied monitoring efforts.

Cooperators from the SJRIP marked 352 Colorado pikeminnow during late July and early August 2005 (Table 9). Unlike in 2005, when the majority (73%) of these fish were smaller than 150 mm, there was an even mix of fish above and below that threshold value used to determine which fish are PIT-tagged. We felt that it would be important to increase the number of large fish during the mark period relative to 2005 in order to increase the likelihood of recapture during the autumn monitoring with electrofishing gear. We collected 90% of the Colorado pikeminnow smaller than 150 mm by block seining, and 53% of Colorado pikeminnow larger than 150 mm with the block seining technique.

Table 9. Number of Colorado pikeminnow marked using visible implant elastomer (VIE) or passive integrated transponder (PIT) tags by cooperators in July/August 2006.

PROJECT [a]	GEAR TYPE	VIE TAGGED (< 150 mm total length)	PIT TAGGED (> 150 mm total length)	TOTAL
YOY Colorado Pikeminnow	Block Seine	159	93	252
NMFRO Nonnative Removal	Electrofishing	15	15	30
UDWR Nonnative Removal	Electrofishing	3	67	70
	Total	**177**	**175**	**352**

[a] YOY = young-of-year, NMFRO = New Mexico Fisheries Resource Office, UDWR = Utah Division of Wildlife Resources.

Although the total number of Colorado pikeminnow captured by cooperators during the 2006 annual autumn monitoring was higher than in 2005, there were still too few recaptures (4; 1.1%) of fish that were marked during the “mark” period in late July and early August (Table 10) to develop a population estimate with a meaningful confidence range. Raft-mounted electrofishing accounted for 97% of all Colorado pikeminnow collections during fall monitoring, 96% (n=319) of which were larger than 150 mm. The models in Program MARK have difficulty generating a population estimate with such a low number of recaptures, which lowers the precision of the population estimate and can cause a positive bias estimate (Ricker 1975). Capture probabilities, or the percentage of recaptures, should be greater than 10% to generate a precise estimate (Otis et al. 1978). If a Lincoln Index model were used with these data, despite the limitations of a poor recapture rate and the fact that the population is not “closed,” a total estimate of 29,304 Colorado pikeminnow would be calculated; 13,956 of these would be greater than 150 mm.

Table 10. Total number of Colorado pikeminnow collected and number of recaptures collected from the July/August mark period during the September/October 2006 autumn monitoring. Number in parentheses indicates the number of recaptures.

PROJECT	GEAR TYPE	SMALLER THAN 150 mm	LARGER THAN 150 mm	TOTAL
Large-bodied fish monitoring	Electrofishing	10 (0)	313 (4)	323 (4)
Small-bodied fish monitoring	Seine	4 (0)	6 (0)	10 (0)
	Total	**14 (0)**	**319 (4)**	**333 (4)**

Colorado Pikeminnow Growth

Young-of-Year (YOY) Colorado Pikeminnow Monitoring

Colorado pikeminnow growth averaged 0.37 mm in the first 5 months following stocking in 2005. The average size of age-0 Colorado pikeminnow that we collected during the initial monitoring trip in 2005 was similar to the average size in 2003 and about 5–7 mm larger than in 2002 and 2004 (ANOVA, $p < 0.0001$, Figures 12 and 13). Unlike those fish stocked in 2004, in which there was a 2.5 mm increase between November and March, there was a negligible increase in standard length between the initial monitoring trip and the March monitoring trip after stocking. Instantaneous growth rates between the initial and March monitoring trips revealed that 2004 was higher than the other years, but growth remained very low in this period each year (Table 11).

Between March and July, YOY Colorado pikeminnow grew by an average of 64.6 mm during 2006, which was similar to growth observed in previous years. This increase in growth was also apparent in the instantaneous growth rates between March and July of each year. Colorado pikeminnow stocked in 2005 had a faster rate of growth than between March and July than Colorado pikeminnow stocked in 2004, but still slower than those stocked in 2002 and 2003. As noted in Golden et al. (2006), the low temperatures in late April to early July of 2005 (resulting from the high spring runoff) occurred during the time period in which there was high Colorado pikeminnow growth in 2003 and 2004 (Golden et al. 2004, Golden and Holden 2005). Though mean temperatures in 2006 were closer to 2003–2004 than those in 2005 (Figure 5), there was a period in early June with low temperatures that may have affected Colorado pikeminnow growth. The average standard length of Colorado pikeminnow stocked in 2005 and recaptured in July 2006 was similar to July recaptures of fish stocked in 2002 and 2003. The July 2005

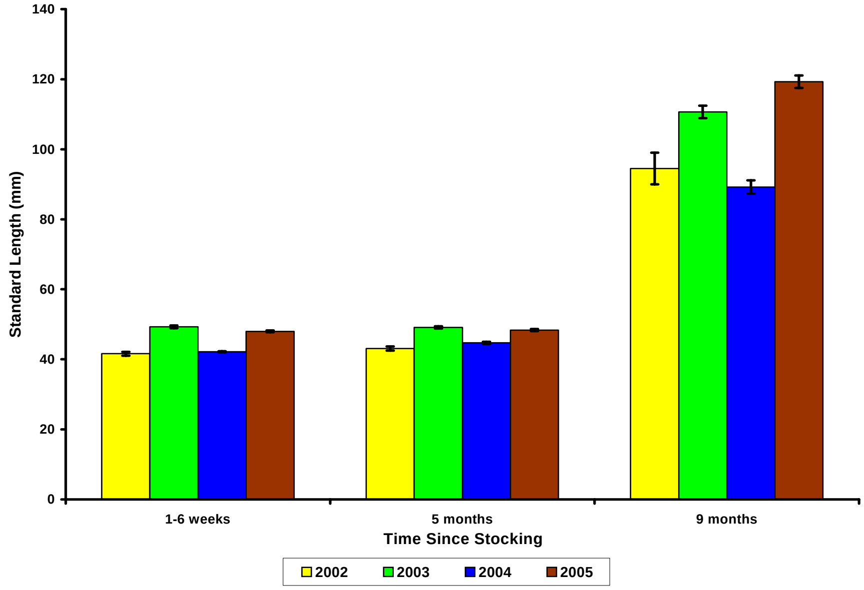

Figure 12. **Average standard length of Colorado pikeminnow stocked at age-0 in 2002, 2003, 2004, 2005, and collected during the first year of monitoring. Error bars equal +/- one standard error.**

Table 11. **Instantaneous growth rates between sampling trips after the 2002, 2003, 2004, and 2005 stocking efforts. Growth rates were calculated from average standard lengths of fish stocked as age-0 fish in those years.**

TIME PERIOD	2002 STOCKING	2003 STOCKING	2004 STOCKING	2005 STOCKING
December–March	-0.001	-0.005	0.043	0.006
March–July	0.618	0.614	0.487	0.566

sampling of 2004-stocked fish yielded fish with a noticeable difference in size compared to other years. The average length of the 2004-stocked fish in July was significantly smaller (24 mm) than Colorado pikeminnow stocked in 2003, and 10 mm smaller than the two Colorado pikeminnow we collected in July after the 2002 stocking effort (t-test, $p < 0.001$). This difference in growth may affect capture rates with gear types that have variability in effectiveness that is associated with size.

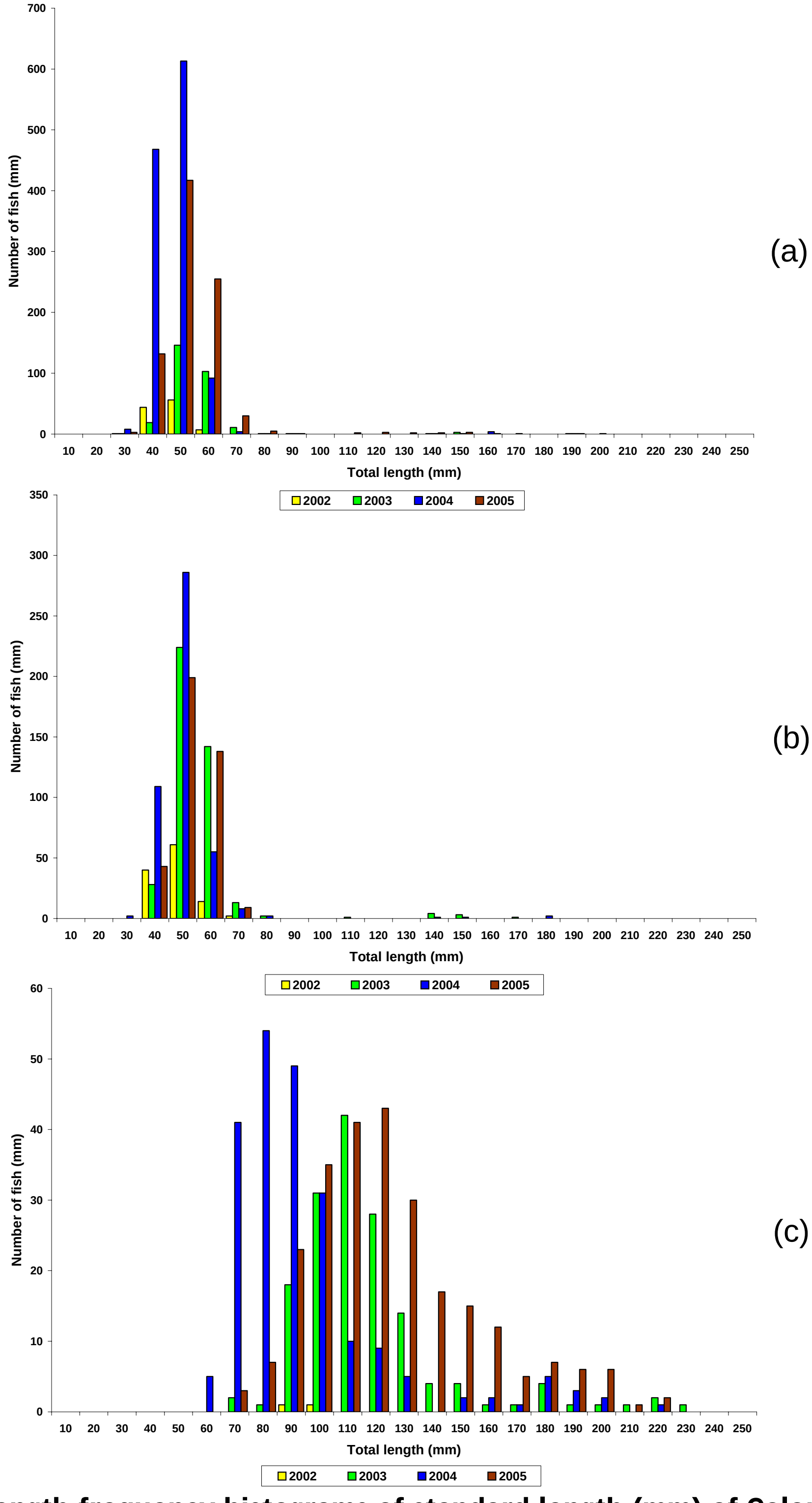

Figure 13. Length frequency histograms of standard length (mm) of Colorado pikeminnow caught in November/ December (a), March (b), and July (c) following stocking efforts in all study years.

Other San Juan River Basin Recovery Implementation Program (SJRIP) Projects

As with catch rate information, cooperators conducting a variety of other SJRIP-funded projects collected data on the size of Colorado pikeminnow in the San Juan River. The ability to estimate growth among size classes is influenced by the size-related bias in the gear types used for the YOY Colorado pikeminnow project along with other SJRIP research and monitoring programs. As Golden et al. (2006) described, seining is biased toward collecting smaller (< 100 mm TL) Colorado pikeminnow, block seining and raft-mounted electrofishing are more effective at catching Colorado pikeminnow larger than 100 mm TL with the latter being the most effective for collecting Colorado pikeminnow once they exceeded 150–200 mm TL.

Large-bodied monitoring conducted with electrofishing gear in the autumn provides an opportunity to evaluate growth of Colorado pikeminnow stocked as age-0 fish beyond the July monitoring effort of this study. As with data from the July 2005 YOY Colorado pikeminnow monitoring trips, autumn 2005 electrofishing captures indicated that Colorado pikeminnow stocked in 2004 were significantly smaller in autumn 1 year after stocking than Colorado pikeminnow stocked in 2002 or 2003 (ANOVA, $p < 0.001$). Large-bodied monitoring efforts in autumn 2006 recovered Colorado pikeminnow that were similar in size to 2004 fish during their first autumn after stocking (Figure 14). An estimate of instantaneous growth rates indicate that Colorado pikeminnow stocked in 2005 grew more slowly over their first year than any previous year class (Table 12). These instantaneous growth rate estimates also indicate the growth is substantially lower in the second year after stocking and growth rates remain about the same during the third and fourth year after stocking.

Table 12. Instantaneous growth rates for Colorado pikeminnow stocked as age-0 fish from 2002-2005 and recaptured in autumn electrofishing surveys.

TIME	2002	2003	2004	2005
Stocking to first autumn	0.38	0.34	0.34	0.30
First autumn to second autumn	0.11	0.07	0.08	
Second autumn to third autumn	0.04	0.10		
Third autumn to fourth autumn	0.07			

Colorado Pikeminnow Habitat Use

The 2005–2006 samples were collected in a larger proportion of side channel habitat than in previous years during November and March (48% and 52%, respectively) but a smaller proportion of side channels were sampled in July 2006 (17%) compared to previous samples (see Golden et al. 2006 for data comparison) (Figure 15).

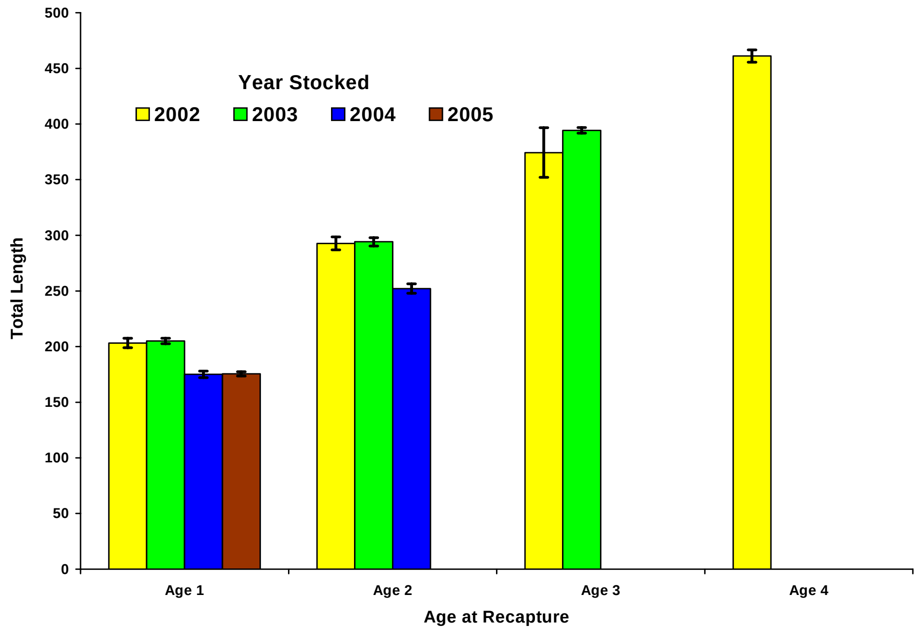

Figure 14. **Average standard lengths of Colorado pikeminnow stocked as age-0 fish in 2002, 2003, 2004, 2005, and collected during electrofishing surveys conducted in September and October 2003-2006.**

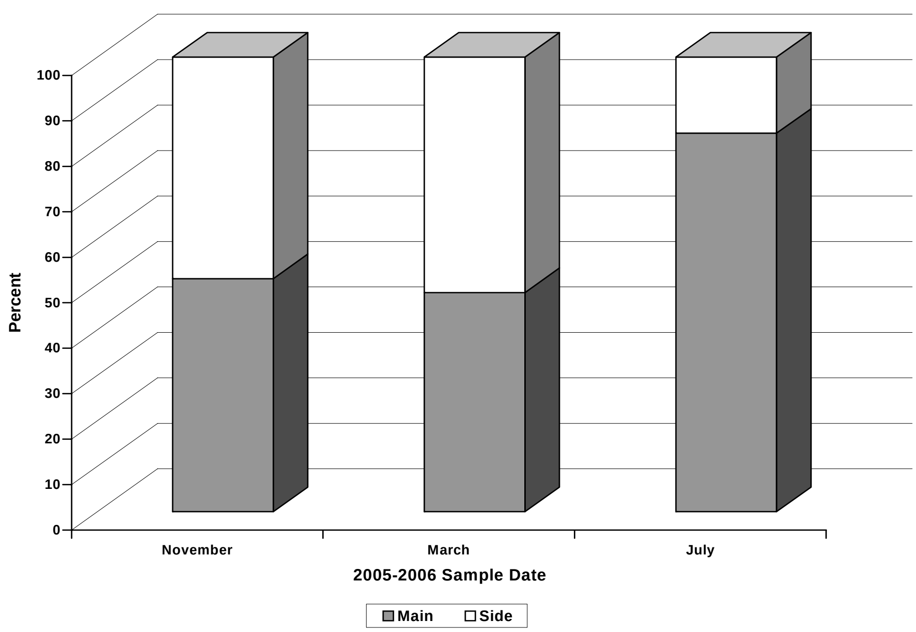

Figure 15. **Percent of samples collected in main channel and side channels combined by sample date.**

We compared the proportion of Colorado pikeminnow found in side channel and main channel habitats in 2005–2006 with the proportion of samples taken in those channel types. We found that in March 2006, a higher proportion of Colorado pikeminnow occurred in side channel habitats than would be expected based on the percentage of samples collected in side channel habitats (Table 13, X^2, $p < 0.01$). There were no significant differences between observed and expected frequency of Colorado pikeminnow in side channels vs. the main channel in November 2005, July 2006, or when all data were combined among the three trips following the 2005 stocking. Prior to 2006 combined samples from 2002–2005 in November/December and those in July each indicated a higher proportion of occurrence of Colorado pikeminnow in side channels than would be expected, but not during March monitoring trips. While the 2006 data is in contrast to the previous data, all information suggests that side channels are important to the species and the critical time may vary among years.

Table 13. Observed vs. expected number of samples containing Colorado pikeminnow in main channel habitats vs. side channel habitats.

SAMPLING TRIP	EXPECTED NUMBER OF SAMPLES WITH PTYLUC (main/side)	OBSERVED NUMBER OF SAMPLES WITH PTYLUC	CHI-SQUARE P-VALUE
All 2005–2006 trips	180/114	190/104	0.24
November 2005	46/43	37/52	0.07
March 2005	23/25	14/34	< 0.01
July 2005	131/26	139/18	0.08

[a] PTYLUC = Colorado Pike minnow (Ptychocheilus lucius).

Catch rates also support the idea that side channels are important to Colorado pikeminnow. An evaluation of the grand mean of scaled catch rates (using station as the sampling unit) in side channels and the main channel revealed significant differences in each trip where the scaled catch rate was significantly higher in side channels in both November 2005 ($p < 0.001$) and March 2006 ($p = 0.021$). Surprisingly, the scaled catch rate in side channels were significantly lower than in the main channel in July 2006 ($p = 0.025$).

Colorado pikeminnow showed trends in habitat use outside their use of main channel vs. side channel habitats. For analysis purposes we condensed the wide variety of individual habitat types identified in the field into 10 major types (Appendix A). We compared the percent of samples with Colorado pikeminnow present in each habitat type (Figure 16) with the percent of samples collected in that habitat type (Figure 17). In the November 2005 sample, Colorado pikeminnow were caught in a higher number of low-velocity habitats than would be expected based on the percent of samples collected in these habitats, including backwaters and pools, but the distribution of Colorado pikeminnow captures among all habitat types was not significantly different than expected (chi-square analysis; $p = 0.180$). In March 2006 Colorado pikeminnow were captured in debris piles in much higher proportion than expected based on proportion of samples collected from such habitats. They were also more common in pools and backwaters

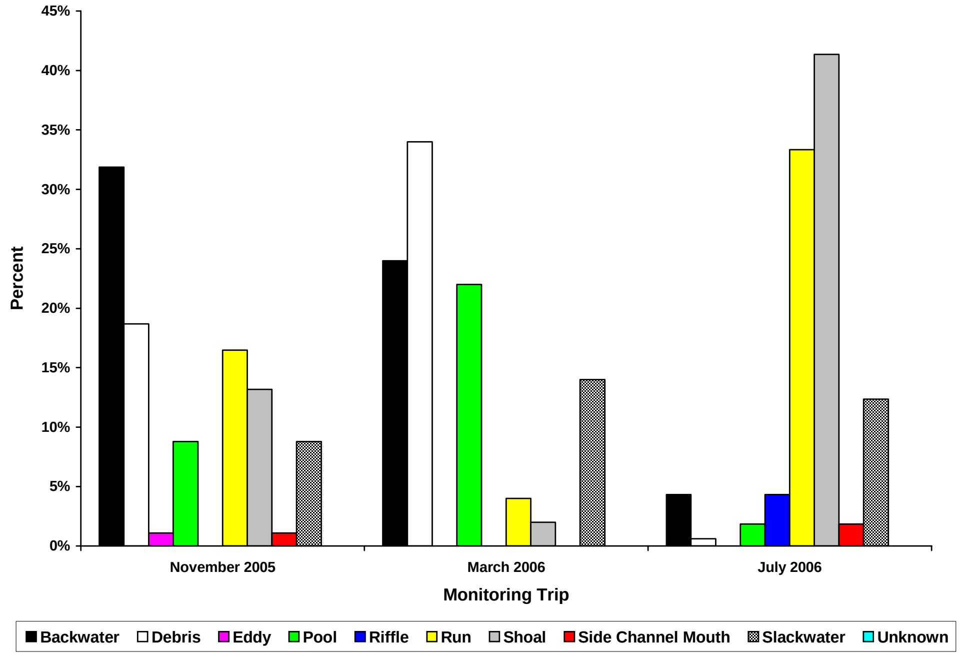

Figure 16. Proportion of samples with Colorado pikeminnow within each habitat type during each monitoring trip in 2005-2006.

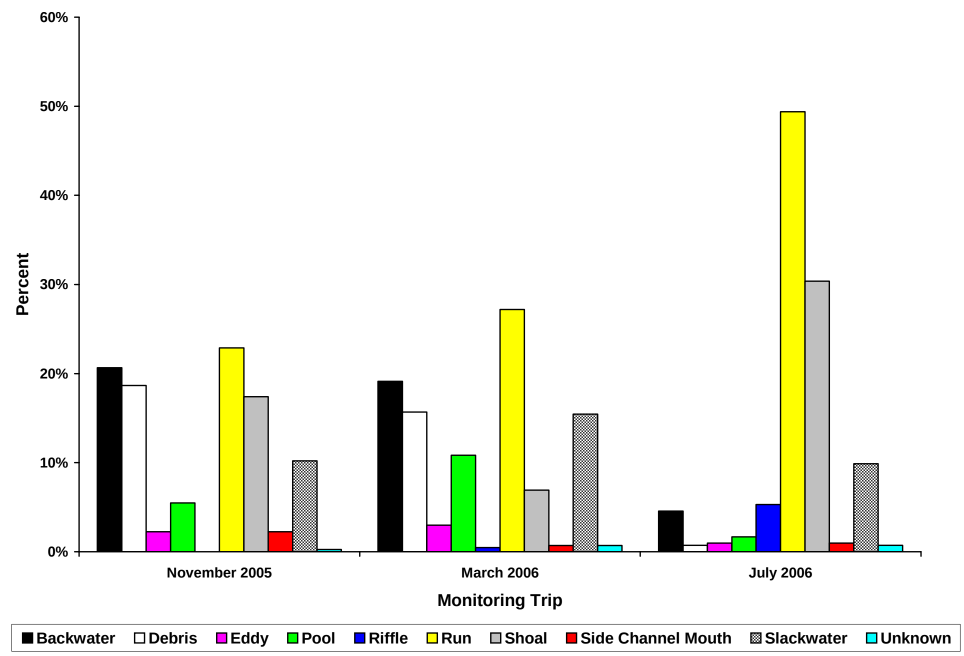

Figure 17. Proportion of samples of each habitat type (all sampling periods combined) during each monitoring trip in 2005-2006.

than expected and much less common than expected in runs. The distribution among habitats was significantly different than expected (X^2; $p < 0.001$). In July 2006 the distribution among habitats was again significantly different than expected (X^2; $p = 0.012$) with Colorado pikeminnow, much more common than expected in shoal habitats, and less than expected in runs. The use of backwaters and debris piles by Colorado pikeminnow in the first two monitoring trips and shoal habitats during July was also observed in previous years (Golden et al. 2006).

In addition to Colorado pikeminnow being found in a higher than expected proportion of backwater habitats in 2006 (as in previous years), the grand mean of scaled Colorado pikeminnow catch rate from all trips after the 2005 YOY stocking was significantly higher in backwater habitats than in non-backwater habitats (Figure 18; t-test, $p < 0.001$). Colorado pikeminnow catch rate in backwater habitats was significantly higher than in non-backwater habitats during November 2005 ($p = 0.026$) and March 2006 ($p < 0.001$) but not in July 2006 ($p = 0.977$). These latter results are similar to those observed during the 2002–2005 monitoring period (Golden et al. 2006). Therefore, as we saw in the chi-square analysis of habitat use, scaled catch rate data indicated a higher abundance of Colorado pikeminnow in backwater habitats for the first 6 months after stocking. However, as Colorado pikeminnow reached larger sizes 9–10 months after stocking, we no longer found them to be as abundant in backwater habitats.

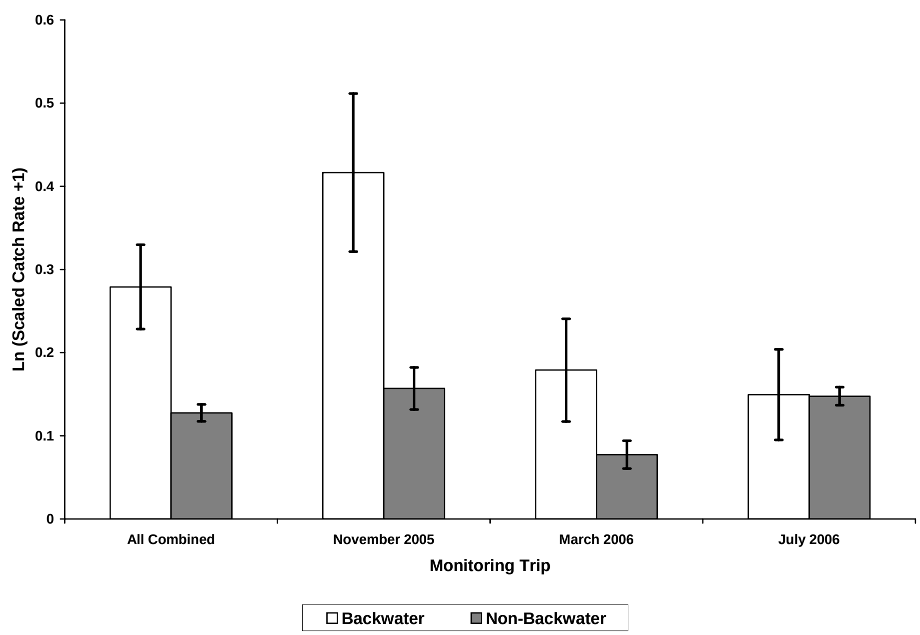

Figure 18. The scaled average Colorado pikeminnow catch rate in backwater and non-backwater habitats from 2005-2006 during each monitoring period after stocking. Error bars represent +/- one standard error.

During the initial sampling trips in 2002, 2003, and 2004, we found Colorado pikeminnow in areas with some type of cover (e.g., woody debris, overhanging or inundated vegetation, tires, boulders) in higher proportions than would be expected in a random distribution among habitat types (Golden et al. 2006). There was no significant difference in the proportion of samples with and without cover in November 2005 (Figure 19)(X^2; $p = 0.124$). In 2006 we observed a significant difference in the March sample (X^2; $p < 0.001$) for the first time. The only July monitoring trip in which we found Colorado pikeminnow in habitats that had cover in significantly higher proportions than expected was in 2004 ($p < 0.001$).

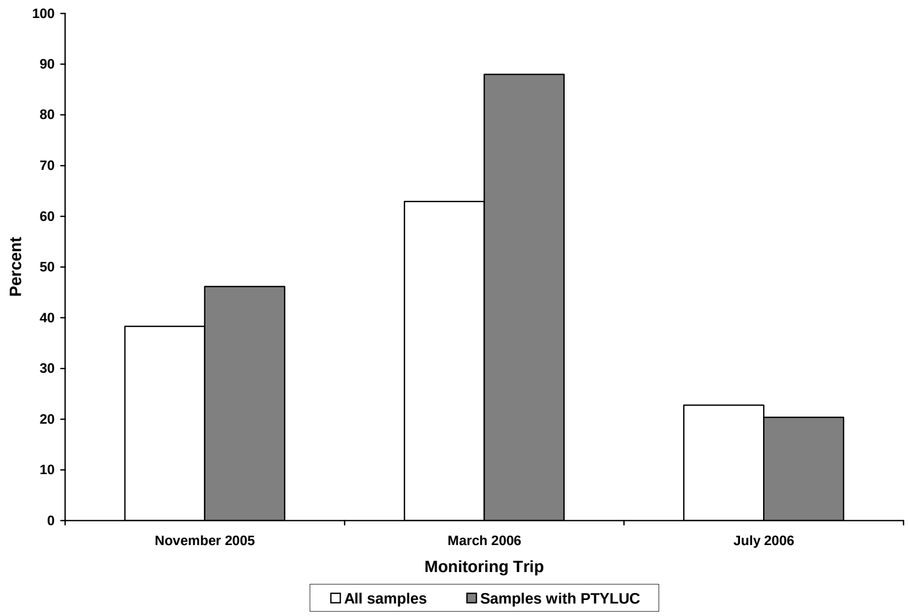

Figure 19. Proportion of all samples with cover and proportion of samples with cover in which Colorado pikeminnow were collected during each 2005-2006 monitoring trip.

In addition to evaluating proportion of sites with and without cover that had Colorado pikeminnow present, we also evaluated the scaled catch rate in sites with and without cover (Figure 20). Prior to the 2005–2006 efforts, the scaled average catch rate of Colorado pikeminnow was significantly higher (t-test, $p = 0.007$) in samples where cover was present only during the November/December samples. This occurred again in November 2005 (t-test, $p = 0.002$), but also occurred in March 2006 (t-test, $p < 0.001$). As in previous years, there was no difference in catch rate between sites with and without cover in July 2006. The significant difference in catch rate in March 2006 was not surprising because of the significantly higher

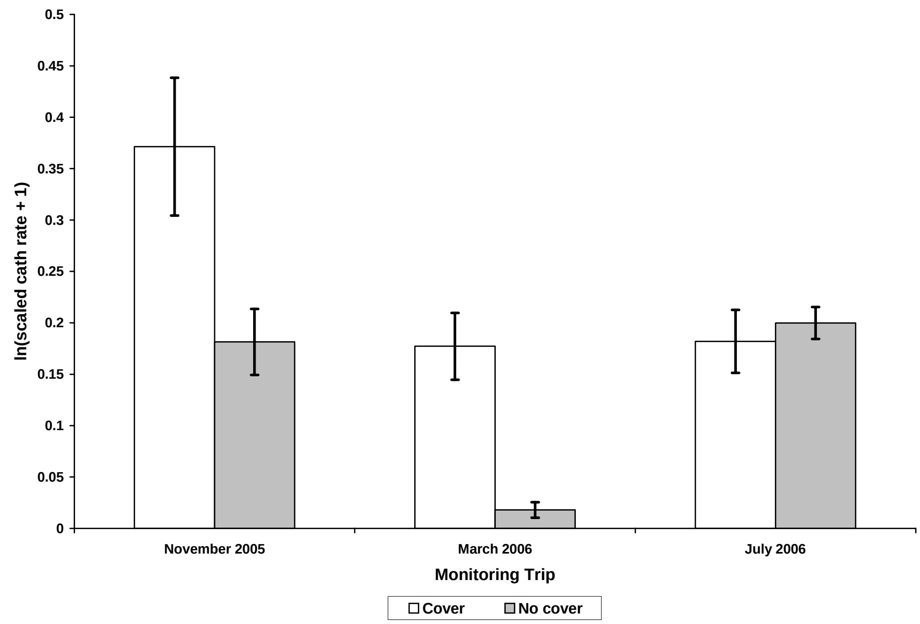

Figure 20. **Scaled average catch rate for Colorado pikeminnow in samples with and without cover in 2005-2006 samples. Error bars represent +/- one standard error.**

frequency of occurrence in sites with cover (discussed in preceding paragraph). The significant difference in November 2005 between sites with and without cover suggests that although there was not a significantly higher frequency of occurrence of Colorado pikeminnow in sites with cover in November 2005, those sites with cover that did have the fish, had high numbers of them.

Golden et al. (2006) found that the average and maximum depths of all samples collected during the entire study where Colorado pikeminnow were found were not significantly different than those without Colorado pikeminnow. This was consistent with results observed in 2005–2006 (Figures 21 and 22), although there was a significantly greater average and maximum depth in samples containing Colorado pikeminnow in November 2005 ($p \leq 0.05$).

We also examined the average and maximum depths of samples in backwater habitats (Figures 23 and 24). Golden et al. (2006) found that using data from all samples, backwaters where Colorado pikeminnow were collected had significantly greater average and maximum depths than backwaters where Colorado pikeminnow were not collected (t-test, $p < 0.004$). They also noted that the difference in depth was only significant in March samples ($p < 0.03$). In 2005–2006, there were no significant differences, although the backwater sites that had Colorado pikeminnow in the March sample actually had a shallower average and maximum depth. Consistent with data from previous years, the backwaters with Colorado pikeminnow in July

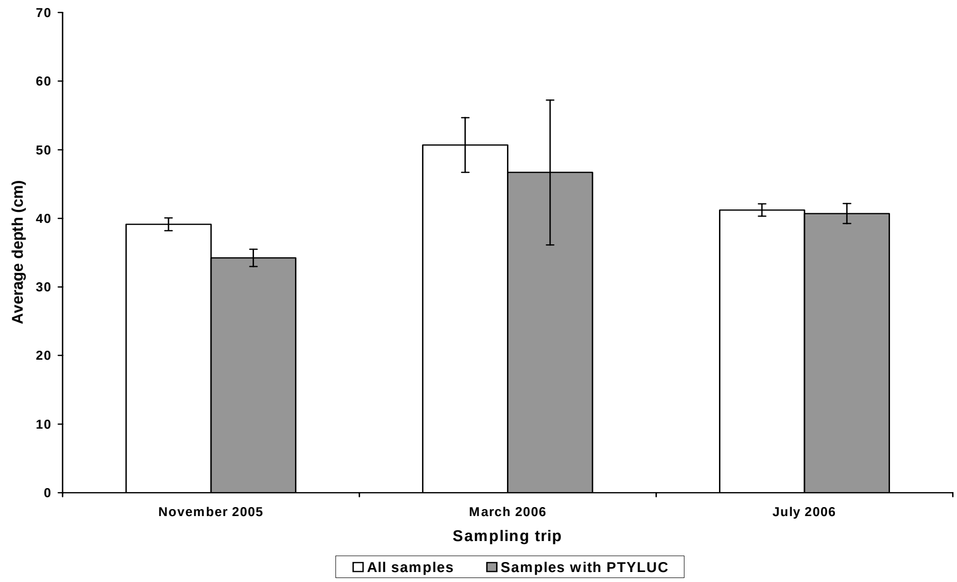

Figure 21. **Mean average depth of all samples and samples where Colorado pikeminnow were collected during 2005-2006 monitoring trips. Error bars represent +/- one standard error.**

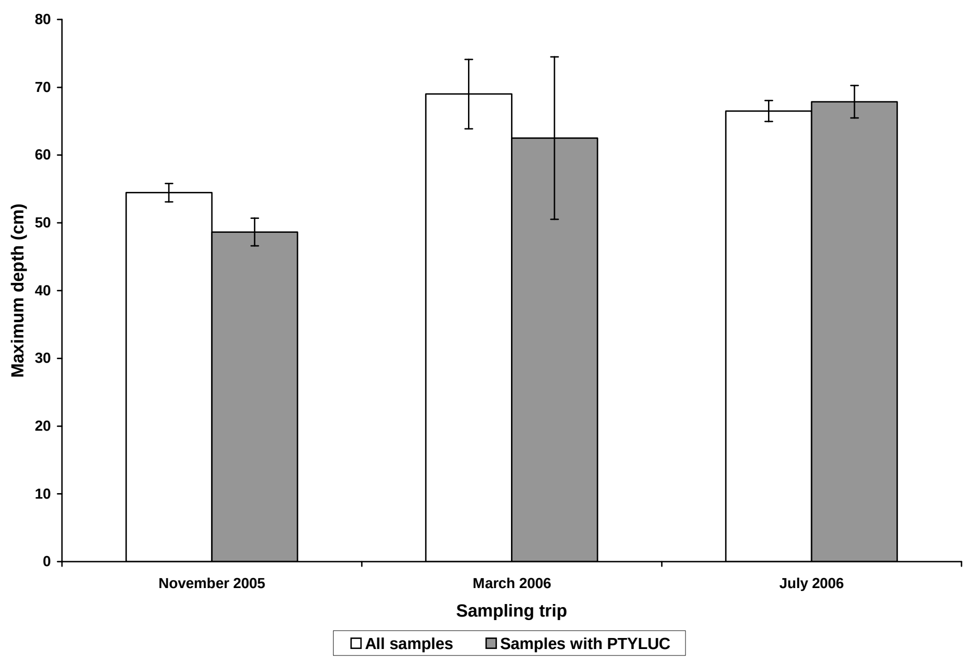

Figure 22. **Mean maximum depth of all samples and samples where Colorado pikeminnow were collected in 2005-2006 monitoring trips. Error bars represent +/- one standard error.**

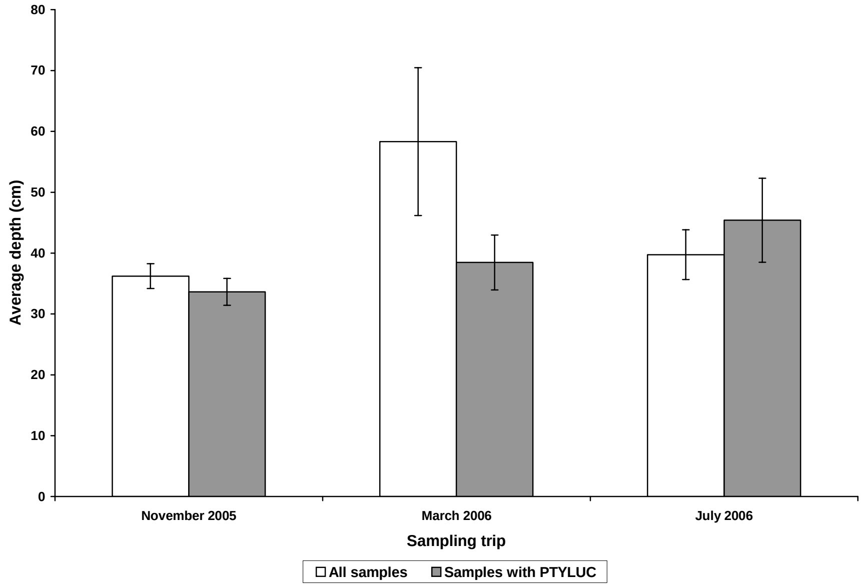

Figure 23. **Mean average depth of all samples from backwater habitats vs. samples from backwater habitats where Colorado pikeminnow were collected during 2005-2006 monitoring trips. Error bars represent +/- one standard error.**

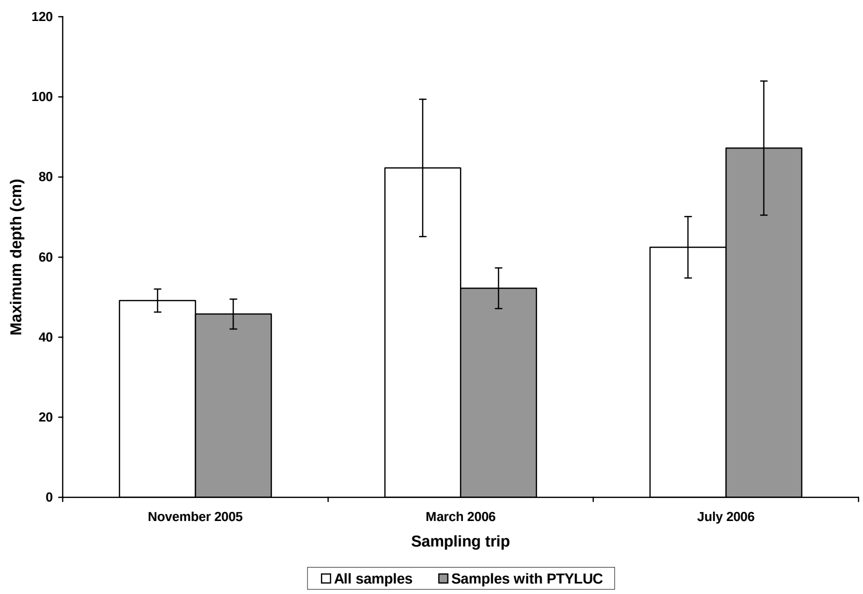

Figure 24. **Mean maximum depth of all samples from backwater habitats vs. samples from backwater habitats where Colorado pikeminnow were collected during 2005-2006 monitoring trips. Error bars represent +/- one standard error.**

2006 sample had a greater maximum depth on average (not significant) and similar average depth. Because of the sporadic occurrence of significant differences in average and maximum depth between sites with and without Colorado pikeminnow, this does not appear to be a critical factor influencing habitat selection. However, the tendency of backwaters with Colorado pikeminnow to be deeper in July than backwaters overall indicate that this may be an important combination of factors that could have important population level impacts during that time of year.

To summarize the results of the Colorado pikeminnow habitat use data, we found the species in a higher proportion of samples from side channel habitats than was expected in 2006, as in previous years. Catch rates were also higher in side channels than the main channel in November 2005 and March 2006. Surprisingly, catch rates were higher in the main channel than side channels in July 2006, which was not observed in previous years (see Golden et al. 2006). However, this may be influenced by a transition of the larger fish to shoal habitats and the relative availability of this habitat type in side channels vs. the main channel, or it may be related to higher temperatures in side channels relative to the main channel in July.

Low-velocity habitats, including backwaters, pools, and habitats with debris piles, contained Colorado pikeminnow in higher frequency than higher-velocity habitats, such as runs, during November 2005 and March 2006.

Cover was observed to be important during November and December in previous years, but it was most important in March following the 2005 stocking effort. This was the first year that there was a significant difference in the observed vs. expected frequency of Colorado pikeminnow in sites with cover during March. We found that average and maximum water depth did not differ substantially among all sites and those with Colorado pikeminnow. There were also no significant differences in depth of backwaters that had Colorado pikeminnow vs. backwaters overall, despite past observations of deeper conditions in March. Backwaters with Colorado pikeminnow also tended to have deeper maximum depths than all backwaters combined in July 2006, similar to previous observations, but it was not a statistically significant difference.

Other Fish Data

During YOY Colorado pikeminnow monitoring events, we collected four native species other than Colorado pikeminnow: bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace (Appendix B). Prior to 2006, we had collected 12 total razorback sucker throughout the study, 6 of which had presumably come from SJRIP stocking efforts (ranging from 316–455 mm TL). In July 2006, an additional 21 razorback sucker (each previously PIT tagged) were captured; these fish ranged in size from 249–468 mm TL.

In 2005–2006 native fish catch rates were higher above Hogback Diversion than downstream (Figure 25). Golden et al. (2006) noted that there was substantial variation within reaches between years, but we could not compare those statistically (see Methods section) (Golden et al. 2006). Between sample periods, the only distinct observation was higher catch rates in the APS reach in July than in the other two periods.

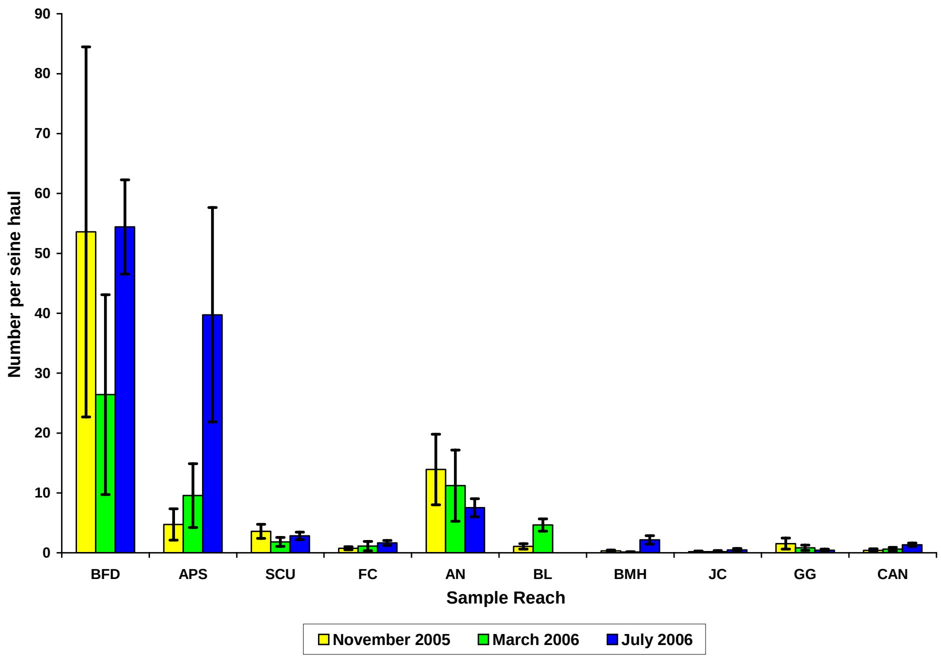

Figure 25. Combined native fish catch rate (number of fish per seine haul with seine haul as the sample unit) at each station in 2005-2006 monitoring trips. Error bars represent +/- one standard error.

As in previous years, we found the highest catch rates for nonnative fishes between PNM Weir and Sand Island in 2005–2006 (Figure 26). The stations below Mexican Hat had consistently lower catch rates of both native fishes and nonnative fishes. As discussed in Golden et al. (2006) red shiner was the dominant nonnative fish species, and trends in the overall nonnative catch rate mirrored trends in red shiner abundance. Red shiner was most abundant from the APS Weir station downstream to the Bluff station, as was fathead minnow (*Pimephales promelas*), the second most abundant nonnative fish species. As in previous years, we collected relatively high numbers of YOY largemouth bass (*Micropterus salmoides*) and YOY channel catfish in our July 2006 samples. Largemouth bass were most numerous in stations upstream from Aneth, Utah, whereas channel catfish were most numerous in the stations below Mexican Hat.

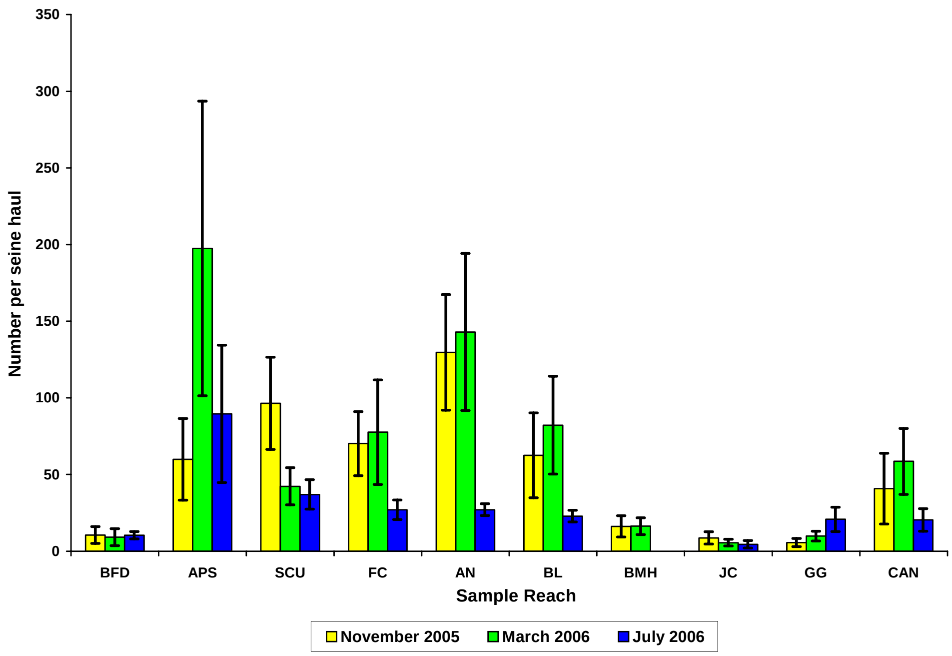

Figure 26. Combined nonnative fish catch rate (number of fish per seine haul with seine haul as the sample unit) at each station during 2005–2006 monitoring trips. Error bars represent +/- one standard error.

Nonnative fishes were more numerous than native fishes on every sampling trip, but not in every station. Native fishes outnumbered nonnative fishes in the Upper San Juan station during all collections at that station. Native fishes also outnumbered nonnative fishes in several of the collections made in the Lower Animas and Below Fruitland Diversion stations. At all downstream stations nonnative fishes always outnumbered native fishes, primarily because of the increased number of red shiner and fathead minnow.

DISCUSSION

Retention

Despite the difficulties with making inferential comparisons of our data, examining the combined data from our project and other SJRIP research and monitoring projects does highlight a few key findings regarding the retention of stocked Colorado pikeminnow. Golden et al. (2006) showed that catch rates declined quickly during the initial weeks after stocking and that the majority of stocked YOY Colorado pikeminnow were lost within 1 month. The low percentage of return for the number of stocked fish 4–5 months after stocking indicates that the bulk of stocked fish are lost to our sampling efforts. This may indicate mortality, or possibly the low catch rates may be a result of fish dispersal throughout the 180 river miles downstream of the Animas River (or a combination of both). The lower catch rate in March 2006 relative to the same sample period following the 2003 and 2004 stocking efforts may have been a consequence of very low water temperatures (as low as 2.3 degrees Celsius) for several days in the week preceding that sample effort and fairly low water temperatures during sampling (5.3–9.7 degrees Celsius at Farmington). These conditions also resulted in much less effort (fewer total seine hauls) than in March during the previous 2 years. By July 2006 catch rates were similar to those in July 2004 and 2005, which further suggest that retention through March 2006 was probably similar to previous years and the reduced catch rates were more a factor of sampling conditions. As in previous years data from 2005–2006 indicate that the bulk of stocked fish were lost in the first few weeks following stocking, but after this initial loss there was little loss/mortality between 5 and 9 months after stocking.

We have assumed that the initial loss of stocked fish in each year has been attributable to a combination of downstream drift and mortality, although it is possible that our ability to detect fish decreased with the amount of time elapsed since they were stocked. Data from the acclimation experiments showed that drift can be dramatic: some fish that were acclimated in 2004 in the range of RM 159–179 were found as far downstream as RM 7.2 (three marked fish were recovered in this site) by the November monitoring effort that began just 1 week after acclimation. Presumably, these fish were from the sites that had breached enclosures (each occurring within 48 hours after acclimation). In the San Juan River, Dudley and Platania (2000) found that protolarval Colorado pikeminnow stocked below the Hogback Diversion (RM 159) could drift to Clay Hills Crossing (RM 2.9) in as little as 3 days. Masslich and Holden (1996) summarized a number of studies showing that stocked Colorado pikeminnow drifted long distances downstream and noted that YOY Colorado pikeminnow (50–100 mm) were stocked in the Colorado River several times in the early 1980s and that the fish generally dispersed from the stocking area within 30 days and were found up to 17 miles downstream within 6 days. In many stocking programs and research examining post-release survival of stocked fish in North America and throughout the world, the majority of stocked fishes, regardless of size, are lost within the first few days after release (Cresswell 1981, Wiley et al. 1993, Maynard et al. 1995, Cowx 1998, Brown and Laland 2001, Brown and Day 2002). The authors of these studies likewise attributed loss of fish to drift and mortality, and not a change in the detectability of the species. Our acclimation efforts suggest that this propensity for drift and mortality of YOY Colorado pikeminnow immediately after stocking can be ameliorated. We recaptured a high proportion of acclimated fish within or adjacent to the areas where acclimation occurred.

Despite this propensity for large-scale drift and mortality immediately after stocking, Trammell and Archer (2000) showed that stocking YOY Colorado pikeminnow in the San Juan River had some success at producing age-1 and age-2 Colorado pikeminnow in 1996 and 1997. Some of these fish are still being caught during current monitoring efforts, including one fish that was captured nearly 9 years after stocking (it was stocked on November 4, 1996, and recaptured on July 28, 2005). Several fish that were stocked as YOY have also been recaptured at age-4 through age-7 during recent monitoring efforts. The combined results of SJRIP-funded research from 2002–2005 showed that more-recent stocking efforts are also somewhat successful at producing age-1, age-2, and even age-3 Colorado pikeminnow. Therefore, while we are losing a large amount of stocked fish initially, some of the fish are recruiting into large size classes.

Our catch rate data and catch rate data from other SJRIP cooperators also suggest that the success of the 2005 stocking effort, in terms of retention, was similar to the two previous stocking efforts. Golden et al. (2006) discussed the lower success of the 2002 effort, but that appears to have been corrected by changes in stocking protocols including reducing handling stress and accounting for differences in water quality and habitat availability in the receiving waters.. In 2002 Colorado pikeminnow were stocked in a traditional hatchery manner, where all the fish were transported in a large tank and dumped directly into the main channel of the river. Brown and Day (2001) cite other conservation biology literature as calling this “hard release.” This results in disoriented fish that are often dispersed downstream before being able to seek out suitable habitat. We also observed high mortality in the 2003 acclimation efforts that suggested that stress from handling and transport may have been reducing initial survival of this fish. Modification of stocking protocols to reduce stress (since 2003 all Colorado pikeminnow leaving the DNFHTC have been allowed a 7-day rest between handling periods prior to transport) and put fish directly into suitable habitat rather than introducing fish in mass quantities directly into the main current probably had a large influence on increased success in subsequent stocking events.

Another factor that likely impacted retention success of Colorado pikeminnow from the 2002 stocking effort was habitat availability throughout the river. As noted in Golden et al. (2006), Colorado pikeminnow have a preference for low-velocity habitats, particularly backwaters. In 2005–2006, we found Colorado pikeminnow in a significantly higher proportion of backwater habitats than expected, based on a random distribution, and Colorado pikeminnow catch rates were significantly higher in backwater habitats. These results have been consistent over the 2002–2006 monitoring program. Our data support the idea that backwaters are among the important low-velocity habitat types that are used by Colorado pikeminnow during certain times of the year and, as such, changes in the amount of backwater habitat from year to year could impact the retention and survival of stocked YOY Colorado pikeminnow. Habitat studies on the San Juan River have shown a decrease in both the number and area of backwaters from 1996 through 2003; in 2002 and 2003 the area of backwater habitat available in the San Juan River was at its lowest point since habitat studies began in 1992 (Bliesner and Lamarra 2004, Bliesner and Lamarra 2005). This reduction in nursery habitat is likely influencing the success of various stocking efforts. The lack of backwater habitat in autumn 2002 could have been a major factor in the poor initial retention and survival to age-1 of the YOY Colorado pikeminnow stocked that year. Creation of backwaters in portions of the San Juan River has been a topic discussed by the SJRIP and based on the importance of such habitats to Colorado pikeminnow and lack of naturally occurring backwaters, such a project may be very beneficial to the species.

The number of backwaters appeared to have remained steady between 2004 and 2005 (Bliesner 2006), but the scale of the habitat mapping may not be sufficient to identify habitat availability for the Colorado pikeminnow. These habitat mapping efforts have provided a valuable broad-scale perspective of habitat changes for Colorado pikeminnow each year, however, the scale of this mapping has not been consistent with the scale of habitat identified during fish sampling. The brush pile experiments conducted in previous years illustrate the impact that small changes in discharge can have on the amount of backwater and other low-velocity habitat available when fish are stocked. The habitat mapping has provided useful information to determine the fluctuation of backwater habitats overall, but the presence or absence of Colorado pikeminnow in any sample (whether a backwater or not) is often influenced more by very localized conditions, such as the presence of cover and habitat that is immediately adjacent to the backwater habitat. Our data has shown that Colorado pikeminnow are closely associated with habitats that contain debris piles, primarily in November, but we found them in a significantly higher number of habitats with cover in March 2006. It is often difficult to characterize these critical habitat features for the fish at the scale that the river is mapped, but a closer correlation between habitats sampled for Colorado pikeminnow (particularly those that result in captures) is needed to more accurately describe habitat changes in the river as they relate to population dynamics of Colorado pikeminnow.

Although changes to stocking protocols appear to have increased retention success of YOY Colorado pikeminnow since the 2002 and 2003 stockings, another factor that we believe has great potential in further increasing this retention is acclimating the fish to the stocking site prior to release. Our data (November 2005 and March 2006) show that downstream dispersal is substantially reduced and survival of YOY Colorado pikeminnow is significantly increased if the fish are acclimated for 7 days compared with un-acclimated fish stocked at the same time. Following the 2005 stocking we actually saw acclimated YOY fish move upstream for the first time during monitoring efforts in this study. It appears that allowing fish to acclimate to the conditions of a site gives them an opportunity to adjust to the current, water temperature and other water quality parameters, and actively select habitats rather than drifting downstream immediately, presumably because they are disoriented with the change in water conditions and unable to react to the sudden introduction to swift currents. Being able to actively select habitats may also permit use of preferred habitat types and potentially result in higher survival. With a higher recapture rate of fish acclimated in 2005 in the areas where these fish were stocked (above Hogback Diversion), it appears that these fish are not lost as quickly after stocking as the un-acclimated fish. Although the proportion of acclimated fish overall (6.6%) was too low to see a substantial increase in initial retention of the entire 2005 year class, a higher percentage of acclimated fish overall in future years would provide a better opportunity to evaluate the influence on initial retention. Based on the 2005 results, it appears that such an effort may have significant impact toward reducing the problem of high initial loss/mortality of stocked fish.

Larger and older Colorado pikeminnow are also being stocked in the San Juan River. The results of SJRIP-funded research from 2002–2006 show that initial return rates for Colorado pikeminnow stocked at sizes greater than 200 mm TL appear to be considerably higher than those for Colorado pikeminnow stocked at sizes between 40–50 mm standard length. However, stocking fish at larger sizes is not always a better strategy (Wiley et al. 1993, Willett 1996, Naslund 1998, Margenaus 1999). There are much higher costs associated with raising fish to larger sizes and fewer fish can be stocked. In addition, we found that the larger Colorado pikeminnow appeared to drift as far downstream as the YOY Colorado pikeminnow following stocking. There are also concerns about the health of fish raised for longer periods in a hatchery. Golden et al. (2006) noted that fish released from Mumma in November 2003 showed evidence of deformities, most likely from being reared in the hatchery for 12 additional months.

The time scale with which success is judged also plays a role in what size class appears to be the best. Mckeown et al. (1999) showed significant changes in relative survival of stocked muskellunge between short-term estimates (30 days) and survival to adulthood (age 5). We are still just looking at the first few years of stocking age-1 and age-2 fish, but YOY have been stocked since 1996 and individuals from that year class were recaptured as recently as July 2005. There appear to be equal proportion of Colorado pikeminnow (relative to the amount stocked) of fish stocked as YOY, age-1, and age-2 recaptured between one and two years after stocking, but the absolute number of YOY fish remaining is much higher because a much larger number can be stocked. Monitoring over the next couple of years will provide an opportunity to see the relative contribution of each stocking size to the adult population.

In addition to evaluating the relative contribution of fish stocked at different size classes to the adult population, it is also important to factor in the cost of rearing fewer fish to larger sizes before release (Mitzner 1992, Wiley et al. 1993, Larscheid 1995, Margenau 1999, Wahl 1999). While survival is increased for muskellunge stocked at larger sizes, Margenau (1999) showed that stocking of eggs, fry, fingerlings, or yearlings can each be the most cost-effective method for contributing to the adult population, depending on the environmental conditions of the receiving waters. The cost to raise YOY Colorado pikeminnow (~ 50 mm TL) is around $0.24/fish, whereas the cost to raise Colorado pikeminnow to larger sizes (> 150 mm TL) increases to at least $5.00/fish (Ulibarri 2006). Using these figures, it would cost $72,000 to raise 300,000 YOY Colorado pikeminnow. For that same amount, approximately 14,400 larger Colorado pikeminnow could be reared. Using data on return rates generated from the number of YOY Colorado pikeminnow that have been recaptured between two and three years after stocking (0.045%) and the number of age-1 fish that have been recaptured between one and two years after stocking (0.10%) we would expect to see 135 fish stocked as YOY recaptured as age-2 to age-3 fish, but only 14.4 fish stocked as age-1 fish recaptured as age-2 to age-3 fish. Numbers reported for return of YOY Colorado pikeminnow by Golden et al. (2006) were not as high because that report focused on return of fish stocked as YOY in 2002 and returning as age-3 fish. It is apparent that the 2002 year class was much less successful than the following stockings, so the cumulative return rate of all YOY fish as age-2 to age-3 fish is much higher (see Table 8). With such small percentages as return rates, a small shift in one direction can make a large difference in the relative value of stocking YOY fish vs. age-1 or older fish, but the most comprehensive evaluation to date suggests that the YOY stocked fish provide the greater contribution to the population of age-2 to age-3 Colorado pikeminnow. It remains to be seen, however, which size class will be more successful at producing adult fish. Golden et al. (2006) suggested that the program should continue to stock larger fish at some level, and while the most recent analyses suggest recaptures of YOY stocked fish may be better, the range of uncertainty around these return estimates dictate that all methods should be continued until there is a clear distinction between in the long-term success of each.

Pilot Population Estimate

As in 2005 there were not enough recaptures to generate a population estimate in 2006. Golden et al. (2006) noted that the number of Colorado pikeminnow collected by all SJRIP-funded efforts appears relatively low, but there was a noticeable increase in recaptures among all cooperators in 2006. We still believe that an accurate, precise population estimate is critical to determine whether our sampling efficiency is low or whether survival rates for Colorado pikeminnow are lower than those estimated in the Augmentation Plan (Ryden 2003). This would also provide a comparable metric with which to judge the success of the different stocking efforts. Unfortunately, our first attempt at an estimate failed because our recapture rate was extremely low.

Golden et al. (2006) suggested that the most likely explanation for the low recapture rate of Colorado pikeminnow was gear bias. In the "mark" period during 2005, a high proportion of marked Colorado pikeminnow were captured with block seines (average length of 106 mm), and these fish are less susceptible to being recaptured with electrofishing gear in the recapture period. . Even with the 6–8 week window of time between mark and recapture, the average fish would have needed an additional 44 mm of growth to reach the size of fish that are most effectively caught with electrofishing gear. To offset this problem in 2006, more large fish (>150 mm) were captured and PIT tagged in the mark period (n=175 in 2006; n=119 in 2005) but this difference was not enough to result in substantially higher recaptures. Another problem that was identified in 2005 was that different sections of the river were sampled during the mark and recapture portions of the population estimate sampling. Therefore, in 2006, the standard methodology for the YOY monitoring was modified to account for this difference. Again, this modification did not have a substantial impact on the results. Despite the change in methodology to attempt to increase overlap of sampling efforts in the mark and recapture periods, the large spatial scale in which we tried to conduct the population estimate (over 150 river miles) meant that different field crews were unlikely to sample the same areas in each effort. With these limitations on the existing sampling protocols, it was not possible to generate a population estimate using the program MARK. A simple Lincoln Index estimate indicated nearly 30,000 juvenile pikeminnow in the river In order to generate a more rigorous population estimate, a study needs to be designed to focus exclusively on this goal.

As noted in Golden et al. (2006) the UDWR has had some success with preliminary Colorado pikeminnow population estimates in the section of river between Mexican Hat and Clay Hills Crossing using data from multiple electrofishing passes during nonnative removal efforts (Jackson 2006). We feel that it is still possible to generate a viable population estimate using mark-recapture with refined techniques that include a focused approach that targets smaller sections of the river. Rather than a single population estimate for the entire river, it may be necessary to generate population estimates in smaller sections and either extrapolate this information or develop a protocol for rotating among various sections each year to develop a more comprehensive estimate for the entire river.

Growth

Differences in Colorado pikeminnow growth in the San Juan River between study years may have been related to variability in discharge. Over the four years of stocking and subsequent monitoring, the largest difference in growth was observed in 2005 when Colorado pikeminnow stocked as YOY in the fall were significantly smaller in July than those recaptured in July sampling in 2004 or 2006. There was no significant difference in size between those captured in July 2005 and July 2003, but only two fish were captured in the latter sample. In addition, the 2004-stocked fish were significantly smaller in the fall monitoring (by 31–36 mm) than Colorado pikeminnow stocked in autumn 2002 and autumn 2003. Although not directly evaluated in this study, the occurrence of high runoff in the late spring and early summer 2005, and corresponding reduced growth of the fish, suggests that there may be a correlation between the two.
In 2006 we also noted smaller mean length of Colorado pikeminnow recaptured during fall monitoring, despite our observations of mean lengths of this cohort in July that were similar to 2003 fish. We believe that this latter observation is at least partially influenced by the designation of year class in Colorado pikeminnow that were stocked as YOY and captured for the first time during fall monitoring. Many of these fish are within a range of overlap on the growth curve for each year class and may have been incorrectly categorized. We believe that it is important to preserve as many useful data as possible from these fish, but a review of the year-class designations of fish caught in the fall is needed. Labeling all first-time captures during fall monitoring as “unknown age” is the most conservative way to deal with this problem, but this method reduces the pool of fish that can be used in the future to evaluate cohort dynamics.

CONCLUSIONS AND RECOMMENDATIONS

1. Directing efforts to increase retention above Hogback Diversion appear to have been successful.

After the 2002 stocking effort, we collected very few Colorado pikeminnow above the Hogback Diversion; no Colorado pikeminnow were collected above Hogback Diversion during large-bodied fish monitoring in autumn 2003. After the stocking events in 2003, 2004, and 2005, there were 14, 11, and 24 Colorado pikeminnow collected during large-bodied fish monitoring efforts upstream of Hogback Diversion. The acclimation efforts may have contributed to this success. Although none of these fish had a VIE mark indicating that it had been acclimated, it is unlikely that those tags would still be visible after nearly a year with the growth that the stocked fish exhibit during the summer months. This increase in retention appears to be due primarily to the incorporation of soft release strategies in the stocking effort starting in 2003.

2. Acclimation of YOY Colorado pikeminnow increases retention in the river and in the area they are stocked.

It is clear from the November and March samples following acclimation in 2004 in the APS reach and in 2005 that acclimated fish were staying in the area above Hogback Diversion in much higher proportions than expected. These areas all had good acclimation sites that held fish for the full 7 days without major breaching. The acclimation efforts in 2004, when all sites except the one in the APS reach were breached within 48 hours, suggest that acclimation is less effective when conducted for 2 days or less. No data are available to determine the relative effectiveness of acclimation periods ranging from 2–7 days. The combined effect of stocking Colorado pikeminnow using soft release strategies and acclimating as many as possible may substantially increase the initial retention and survival of Colorado pikeminnow to age-1.

3. Stocking YOY fish is at least as effective in long-term retention as stocking age-1 or older fish.

Data collected in 2002–2006 suggest that a much higher number of YOY Colorado pikeminnow can be expected to be recaptured between 2 and 3 years after stocking (135) compared with age-1 fish recaptures 1 to 2 years after stocking (14.4) with the same cost of raising each year class in the hatchery. Golden et al. (2006) described a different outcome, with more fish stocked at larger sizes being captured as age-3 fish than YOY stocked Colorado pikeminnow. However, their analysis focused on the recapture rates of YOY fish stocked in 2002. Much of the evidence gathered in the 4 years of monitoring suggests that the 2002 year class had much lower retention than subsequent stockings of YOY fish. With a cumulative analysis that described the recapture rate of all YOY fish between 2 and 3 years after release and similar analysis of fish stocked at age-1 (Table 8) the data show that recapture rates are similar among year classes after 1 to 3 years in the river, but absolute number of returns favor stocking YOY fish because so many more can be stocked for the same cost. We acknowledge that these estimates of return rates have substantial error and small changes in the very low percentage rates in either direction could have a dramatic affect on predicted return rates (absolute numbers). We suggest that continuing to stock multiple age classes will provide more opportunity to evaluate long-term contribution of each to the adult population with future monitoring efforts before deciding to focus on one particular stocking protocol.

4. Habitat mapping efforts are not conducted at the same scale as fish sampling; more coordination is needed between these two components to be able to relate changes in habitat to fish population dynamics.

There appears to be a dramatic change in habitat that is available to Colorado pikeminnow in the San Juan River (Bliesner and Lamarra 2004, Bliesner and Lamarra 2005, Bliesner 2006); however, it has been difficult to link these broad-scale changes to a scale that more directly impacts the fish. Bliesner and Lamarra (2006) noted that habitat designations by fisheries crews sampling the river did not match up well with habitat mapping designations of the same locations. Part of the problem is that fish associate with habitat features that can be very small, such as an individual debris pile, and these features may change too quickly to be accurately mapped. Another difficulty has been that the habitat mapping efforts have not been extensively evaluated with the available fisheries data. A more effective approach would be to incorporate both habitat mapping and fisheries into the same study to improve the ability to link the data sets and ensure that fish sampling and habitat mapping are occurring simultaneously and at the same scale. Without this close association, it will continue to be difficult to relate critical habitat variation to population dynamics of Colorado pikeminnow.

5. Pursue habitat enhancement and restoration opportunities.

Related to the previous recommendation, the number and size of backwaters in the San Juan River appears to have declined over the last 10 years and is a limiting factor in the success of Colorado pikeminnow stocking efforts and for any future hope of establishing a self-sustaining population of Colorado pikeminnow. We recommend investigating small-scale habitat enhancements designed to enhance post-stocking retention of Colorado pikeminnow in Geomorphic Reach 6 (see Stamp et al. 2005 for examples), as well as initiating investigations of larger-scale habitat restoration, such as nonnative vegetation removal, throughout critical habitat.

6. Generating a population estimate of Colorado pikeminnow in the San Juan River will require focusing on smaller sections of river and extrapolating results or increasing the number of mark and recapture locations.

For a second year we have documented that developing a population estimate is difficult or impossible using data collected from existing SJRIP-funded projects to piecemeal enough data to generate a population estimate. However, we believe that it is important to continue to attempt to meet this goal by building on some of the past successes in smaller portions of the river (Jackson 2006). The importance of developing a population estimate cannot be overstated and will provide the SJRIP with an accurate assessment of the success of each stocking effort or the success the Augmentation Plan has made towards achieving Recovery Goals. While there may be alternative methods to developing a statistically comparable metric to accomplish these goals, we recommend continuing to attempt a mark and recapture population estimate for juvenile Colorado pikeminnow (>150 mm total length) with more focused efforts directed to this goal. We feel that the most promising method would be to focus on generating a series of population estimates for portions of the river that can be delineated as distinct river segments (such as geomorphic reaches) and effectively sampled both during a mark and a recapture period. Though it may not be possible to conduct an entire river-wide effort covering all relevant sections in 1 year, it may be possible to extend such efforts across years and then begin repeating efforts in each reach in subsequent years to evaluate change and gather the information necessary to generate an overall population estimate for the entire river. While this would require extensive effort and occur over multiple years, the ability to document success of the stocking and recovery efforts is critical to decisions on appropriate endpoints (e.g., reduction or cessation of stocking) and long-term management of the Colorado pikeminnow to maintain the recovered population.

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A comprehensive list of people who have participated in sampling efforts in 2002–2005 was presented in Golden et al. (2006). For 2005–2006 efforts we add Darek Elverud (UDWR) and Ron Rogers (BIO-WEST) to that list and again thank each individual for their contributions. In addition, Michael Golden (now with UDWR) was responsible for all data collection efforts over the previous four years of monitoring and conducted a comprehensive analysis of all data that was presented in last year's report. This report builds on all of those analyses and serves to describe the most recent data collected by Mr. Golden.

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LITERATURE CITED

Bliesner, R. 2006. Keller-Bliesner Engineering. Personal communication with Mike Golden of BIO-WEST, Inc. regarding results of 2005 habitat studies. 3/14/06.

Bliesner, R. and V. Lamarra. 2004. Hydrology/Geomorphology/Habitat studies: 2003 Annual report. Prepared by Keller-Bliesner Engineering and Ecosystems Research Institute for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 76 p.

Bliesner, R. And V. Lamarra. 2005. Hydrology/Geomorphology/Habitat studies: 2004 Annual report. Prepared by Keller-Bliesner Engineering and Ecosystems Research Institute for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 70 p.

Bliesner, R. And V. Lamarra. 2006. Hydrology/Geomorphology/Habitat studies: 2005 Annual report. Prepared by Keller-Bliesner Engineering and Ecosystems Research Institute for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Brandenburg, W.H., M.A. Farrington, and S.J. Gottleib. 2004. Razorback sucker larval fish survey in the San Juan River during 2003. Prepared by University of New Mexico, Museum of Southwestern Biology, Fishes Division for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 60 p.

Brandenburg, W.H., M.A. Farrington, and S.J. Gottleib. 2005. Razorback sucker larval fish survey in the San Juan River during 2003. Prepared by University of New Mexico, Museum of Southwestern Biology, Fishes Division for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 99 p.

Brown, C. And R.L. Day. 2002. The future of stock enhancements: Lessons for hatchery practice from conservation biology. Fish and Fisheries 3: 79-94.

Brown, C. and K. Laland. 2001. Social learning and life skills training for hatchery-reared fish: Review paper. Journal of Fish Biology 59: 471-493.

Close, T.L. 2000. Detection and retention of postocular visible implant elastomer in fingerling rainbow trout. North American Journal of Fisheries Management 20:542-545.

Cowx, I.A. 1998. Stocking strategies: issues and options for future enhancement programmes. Pages 3-13 in I.A. Cowx (editor) Stocking and introduction of fish. Fishing News Books, London, England.

Cresswell R.C. 1981. Post-stocking movements and recapture of hatchery-reared trout released into flowing waters - a review. Journal of Fish Biology 18:429-442.

Cresswell, R.C. and R. Williams. 1983. Post-stocking movements and recapture of hatchery trout released into flowing waters - effect of prior acclimation to flow. Journal of Fish Biology 23:265-276.

Davis, J.E. 2004. Non-native species monitoring and control in the upper San Juan River, New Mexico. Draft Annual Report. Prepared by USFWS, Albuquerque, for the San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM.

Davis, J. 2006. U.S. Fish and Wildlife Service, New Mexico Fishery Resources Office. Personal communication with Mike Robertson of BIO-WEST, Inc. regarding results of 2006 non-native fish removal studies. 11/28/06.

Dudley, R.K. and S.P. Platania. 2000. Downstream transport rates of passively drifting particles and larval Colorado pikeminnow in the San Juan River 1999. San Juan River Basin Recovery Implementation Program. USFWS, Albuquerque, NM. 33 p.

Elverud, D. 2007. Utah Division of Wildlife Resources. Personal communication with Mike Robertson of BIO-WEST, Inc. regarding results of 2006 non-native removal studies. 12/15/06.

Farrington, M. 2006. University of New Mexico. Personal communication with Mike Robertson of BIO-WEST, Inc. regarding results of 2006 larval fish sampling. 11/27/06.

Golden, M.E., P.B. Holden, and B. Albrecht. 2006. Retention, growth and habitat use of Colorado pikeminnow stocked as age-0 fish in the San Juan River from 2002-2005: final summary report. Prepared by BIO-WEST, Inc. for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM. 141 p.

Golden, M.E. and P.B. Holden. 2005. Retention, growth and habitat use of stocked Colorado pikeminnow in the San Juan River 2003-2004: Annual report. Prepared by BIO-WEST, Inc. for the San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. PR 874-2: 87 p.

Holden, P.B. and M. E. Golden. 2005. Development of stocking protocols for Colorado Pikeminnow in the San Juan River or why did all of our fish die? Prepared by BIO-WEST, Inc. for the San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. PR-950-1.

Jackson, J.K. 2004. Nonnative control in the lower San Juan River 2003, annual progress report. Prepared by Utah Division of Wildlife Resources, Moab, Utah for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM.

Jackson, J.K. 2006. Nonnative control in the lower San Juan River 2005, DRAFT interim progress report. Prepared by Utah Division of Wildlife Resources, Moab, Utah for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM. 37 p.

Kaeding, L.R. and D.B. Osmundson. 1988. Interaction of slow growth and increased early-life mortality: an hypothesis on the decline of Colorado squawfish in the upstream regions of its historic range. Environmental Biology of Fishes 22: 87-298.

Larscheid, J.G. 1995. Development of an optimal stocking regime for walleyes in east Okoboji Lake, IA. Pages 472-483 in H.L. Schramm Jr. and R.G. Piper (editors) Uses and effects of cultures fishes in aquatic systems. American Fisheries Society Symposium 15. American Fisheries Society, Bethesda, MD.

Manly, B.F. 1997. Randomization, bootstrap, and Monte Carlo methods in biology. Chapman and Hall, New York, NY. 399 p.

Margenau, T.L. 1999. Muskellunge stocking strategies in Wisconsin: the first century and beyond. North American Journal of Fisheries Management 19: 223-229.

Masslich, W. and P.B. Holden. 1996. Expanding the distribution of Colorado squawfish in the San Juan River: A discussion paper. BIO-WEST, Inc., Logan, UT. PR 576-1. 35 p.

Maynard, D.J., T.A. Flagg and C.V.W. Mahnken. 1995. A review of seminatural culture strategies for enhancing the postrelease survival of anadromous salmonids. Pages 307-314 in H.L. Schramm Jr. and R.G. Piper (editors) Uses and effects of cultures fishes in aquatic systems. American Fisheries Society Symposium 15. American Fisheries Society, Bethesda, MD.

McKeown, P.E., J.L. Forney, and S.R. Mooradian. 1999. Effects of stocking size and rearing method on muskellunge survival in Chautauqua Lake, New York. North American Journal of Fisheries Management 19: 249-257.

Miller, W.J., V. Lamarra. 2000. Preliminary draft: a method for estimating population goals for Colorado pikeminnow in the San Juan River. Report presented to the biology committee San Juan recovery implementation program. May 26, 2000.

Mitzner, L. 1992. Evaluation of walleye fingerling and fry stocking in Rathbun Lake, Iowa. North American Journal of Fisheries Management 12: 321-328.

Moyle, P.B. and J.J. Cech, Jr. 2004. Fishes: an introduction to ichthyology. Fifth Edition. Prentice-Hall, NJ.

Mueller, G. A., P.C. Marsh, D. Foster, M. Ulibarri, and T. Burke. 2003. Factors influencing poststocking dispersal of razorback sucker. North American Journal of Fisheries Management 23: 270-275.

Naslund, I. 1998. Survival and dispersal of hatchery-reared brown trout, *Salmo trutta*, released in small streams. Pages 59-76 in I.A. Cowx (editor) Stocking and introduction of fish. Fishing News Books, London, England.

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62.

Paroz, Y. 2007. New Mexico Department of Fish and Game. Personal communication with Mike Robertson of BIO-WEST, Inc. regarding results of 2006 small-bodied fish monitoring. 1/3/2007.

Propst, D.L., S.P. Platania, D.W. Ryden, and R.L. Bliesner. 2000. San Juan River Monitoring plan and protocols. San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM.

Propst, D.L. and A.L. Hobbes. 1999. Seasonal abundance, distribution, and age-structure of fishes in San Juan River secondary channels. San Juan River Basin Recovery Implementation Program. U.S. Fish and Wildlife Service, Albuquerque, NM. 183 p.

Resampling Stats. 2003. Resampling Stats for Excel 3.2. Arlington, VA.

Rexstad, E., and K. Burnham. 1992. User's Guide for Interactive Program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, CO. 29 p.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin 191, Fisheries Research Board of Canada.

Ryden, D. 2003. An augmentation plan for Colorado pikeminnow in the San Juan River. Final Report. Prepared by the U.S. Fish and Wildlife Service, Colorado River Fishery Project for the San Juan Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM.

Ryden, D.W. 2004. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 2003. Interim Progress Report. U.S. Fish and Wildlife Service, Grand Junction, CO.

Stamp, M., J. Grams, M. Golden, D. Olsen, and T. Allred. 2005. Feasibility evaluation of restoration options to improve habitat for young Colorado pikeminnow in the San Juan River. Draft report. Prepared by BIO-WEST, Inc for the for the San Juan River Basin Recovery Implementation Program, U.S. Bureau of Reclamation, Salt Lake City, UT. PR 947-1 under contract agreement 04-FG-40-2158.

Tipping, J.M. 1998. Return rates of transported steelhead smolts with and without a rest period before release. The Progressive Fish Culturalist 60: 284-287.

Trammell, M. and E. Archer. 2000. Evaluation of reintroduction of young of the year Colorado pikeminnow in the San Juan River 1996-1998. Pages 4-1 to 4-33, in Archer, E., T. A. Crowl, and M. Trammell (editors). Age-0 native species abundances and nursery habitat quality and availability in the San Juan River, New Mexico, Colorado, and Utah. Utah Division of Wildlife Resources, Salt Lake City, UT.

Trammell, M. and T. Chart. 1999. Aspinall studies : evaluation of nursery habitat availability and Colorado Pikeminnow young of year habitat use, in the Colorado River, Utah 1992-1996. Utah Division of Wildlife Resources, Moab Native Fishes Field Office, Project 44-A. 49 p.

Ulibarri, M. 2006. Center Director, Dexter National Fish Hatchery and Technology Center. Personal communication with Mike Golden of BIO-WEST, Inc. regarding rearing costs of Colorado pikeminnow. 4/21/06.

[USFWS] U.S. Fish and Wildlife Service. 2002. Colorado pikeminnow (*Ptychocheilus lucius*) recovery goals. Amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Region 6, Denver, CO.

Wahl, D.H. 1999. An ecological context for evaluating the factors influencing muskellunge success. North American Journal of Fisheries Management 19: 238-248.

Wiley, R.W., R.A. Whaley, J.B. Satake, and M. Fowden. 1993. An evaluation of the potential for training trout in hatcheries to increase poststocking survival in streams. North American Journal of Fisheries Management 13: 171-177.

Willett, D.J. 1996. Use of scale patterns to evaluate the stocking success of silver perch (*Bidyanus bidyanus* [Mitchell]), released at two different sizes. Marine and Freshwater Research 47: 757-61.

APPENDIX A: MAJOR HABITAT TYPES

Table 1. **Individual habitat designations, their corresponding habitat type, and whether we considered them preferred habitat for analysis purposes.**

NAMED HABITAT	HABITAT TYPE	PREFERRED HABITAT
Backwater	Backwater	Yes
Backwater/debris pile	Debris	Yes
Backwater/eddy	Backwater	Yes
Backwater/pool	Backwater	Yes
Backwater/run	Backwater	Yes
Backwater/shoal	Backwater	Yes
Backwatermouth	Backwater	Yes
Debris pile	Debris	Yes
Debris pile/pool	Debris	Yes
Eddy	Eddy	No
Eddy/embayment	Backwater	Yes
Eddy/pool	Eddy	No
Eddy/run	Eddy	No
Eddy/shoal	Eddy	No
Eddy/slackwater	Eddy	No
Embayment	Backwater	Yes
Embayment/debris pile	Debris	Yes
Irrigation return	Backwater	Yes
Irrigation return/backwater	Backwater	Yes
Irrigation return/debris pile	Debris	Yes
Isolated pool	Backwater	Yes
Pocket water	Slackwater	Yes
Pool	Pool	No
Riffle	Riffle	No
Riffle/eddy	Riffle	No
Riffle/pool	Pool	No
Riffle/run	Riffle	No
Run	Run	No
Run/embayment	Backwater	Yes
Run/pool	Run	No
Run/debris pile	Debris	Yes
Run/side channel mouth	Run	No
Side channel mouth	Side channel mouth	No
Shoal	Shoal	No
Shoal run	Shoal	No
Shore eddy	Eddy	No
Shore pool	Pool	No
Shore run	Run	No
Slackwater	Slackwater	Yes
Slackwater run	Slackwater	Yes
Submerged backwater	Backwater	Yes
Unknown	Unknown	No

APPENDIX B: OTHER FISH SPECIES COLLECTED

Table 1. Number of each species other than Colorado pikeminnow collected in each station during the November 2005 monitoring trip.

STATION	CAT DIS	CAT LAT	RHI OSC	XYR TEX	YOY SUC	AME MEL	CAT COM	CAT HYB	CYP CAR	CYP LUT	FUN ZEB	GAM AFF	ICT PUN	LEP CYA	LEP MAC	MIC SAL	PIM PRO
AN	79	31	280			20			6	2659	16	40	7	1			1790
APS	9	34	6						2	2873		19		1		17	204
BFD	563	1023	655				1		1	203	2	25		4		2	288
BL	3	23	34			9			2	2900	1	46	20	1		1	333
BMH	2	2	4						1	305			2				96
BWF						1				881							
CAN						1			1	262			56				88
FC	3	8	11			2			2	2803	3	8	7			2	471
GG	1	2	2							145		12			1	1	34
JC			2							208		1					9
SCU	3	33	13						3	5380	5	44	1	2	1	1	449

CATDIS = bluehead sucker
CATLAT = flannelmouth sucker
RHIOSC = speckled dace
XYRTEX = razorback sucker
YOYSUC = unidentified YOY sucker
AMEMEL = black bullhead
CATCOM = white sucker
CATHYB = sucker hybrid
CYPCAR = common carp
CYPLUT = red shiner
FUNZEB = plains killifish
GAMAFF = western mosquitofish
ICTPUN = channel catfish
LEPCYA = green sunfish
LEPMAC = bluegill sunfish
MICSAL = largemouth bass
PIMPRO = fathead minnow

Table 2. Number of each species other than Colorado pikeminnow collected in each station during the March 2006 monitoring trip.

Station	CAT DIS	CAT LAT	RHI OSC	XYR TEX	YOY SUC	AME MEL	CAT COM	CAT HYB	CYP CAR	CYP LUT	FUN ZEB	GAM AFF	ICT PUN	LEP CYA	LEP MAC	MIC SAL	PIM PRO
AN	26	30	379			23				2457	27	78	4	4	2		4125
APS	97	50	52						2	2669	1	18		13		10	4198
BFD	424	57	235							15	8	8		1			224
BL			20						2	4062		3				1	206
BMH		1								569			1				1
CAN		1				2			1	1328				2			31
FC	5		29			2				3158	7		4	1			1020
GG		1	1			1				351			6				37
JC									1	154			1				
SCU	7	6	92			1				1890	1	1		7		1	469

CATDIS = bluehead sucker
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CATHYB = sucker hybrid
CYPCAR = common carp
CYPLUT = red shiner
FUNZEB = plains killifish
GAMAFF = western mosquitofish
ICTPUN = channel catfish
LEPCYA = green sunfish
LEPMAC = bluegill sunfish
MICSAL = largemouth bass
PIMPRO = fathead minnow

Table 3. Number of each species other than Colorado pikeminnow collected in each station during the July 2006 monitoring trip.

Station	CAT DIS	CAT LAT	RHI OSC	XYR TEX	YOY SUC	AME MEL	CAT COM	CAT HYB	CYP CAR	CYP LUT	FUN ZEB	GAM AFF	ICT PUN	LEP CYA	LEP MAC	MIC SAL	PIM PRO
GR1	2	10	3			6			2	40		5	564	1			66
GR2	10	46	40			107			3	323	1		778	2			320
GR3	6	131	368		2	2			8	1130			842				132
GR4	2	38	149	1	1	2			1	918	1	31	522	1		6	287
GR5	23	115	101	10	18	31		9	7	1441	5	39	160			56	1534
GR6	774	1899	619	10	149	22			41	606		28	16	5		480	1045
JC			0							2			33				1

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CATLAT = flannelmouth sucker
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XYRTEX = razorback sucker
YOYSUC = unidentified YOY sucker
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