SAN JUAN RIVER BASIN RECOVERY IMPLEMENTATION PROGRAM MONITORING PLAN AND PROTOCOLS

February 13, 2012

TABLE OF CONTENTS

INTRODUCTION

The San Juan River Basin Recovery Implementation Program (SJRIP) was initiated in October 1992 to protect and recover populations of two federally-listed endangered fish species in the San Juan River Basin (Basin) while water development proceeds in compliance with all applicable federal, state, and tribal laws. The two listed fish species are the Colorado pikeminnow (*Ptychocheilus lucius*; formerly known as Colorado squawfish) and razorback sucker (*Xyrauchen texanus*). Activities and actions within the Program serve as the "reasonable and prudent alternative" for projects in the San Juan River Basin and help to ensure that those projects will not jeopardize the continued existence of the endangered species. It is anticipated that actions taken under the Program will benefit other native fishes in the Basin and prevent them from becoming endangered.

A 7-year research program, operating from 1991-1997, provided baseline information that was used to identify and characterize factors limiting the two endangered species. This research program was incorporated into the SJRIP when it was formed in 1992. Following the completion of the research program, the SJRIP initiated a variety of management and conservation activities including endangered fish augmentation, non-native fish removal, removal of dispersal barriers, and mimicry of the natural flow regime. The SJRIP developed a standardized monitoring plan and protocol in order to measure the San Juan River's fish community and habitat response to management actions and evaluate the SJRIP's progress toward endangered species recovery (Propst et al. 2000). The monitoring program also provides a basis of new information used to update management and conservation activities in the SJRIP's adaptive management process. The monitoring plan and protocols were updated in 2006 (Propst et al. 2006) and from April to June 2009, the SJRIP held a series of workshops to evaluate and revise the SJRIP's monitoring plan and protocols and develop a comprehensive monitoring program that addresses annual and long-term data analysis and integration. This document finalizes the series of drafts and revisions to the monitoring plan and protocols.

The goal of the comprehensive monitoring plan is to provide a standardized methodology to guide the SJRIP's annual and long-term monitoring activities. The specific field and analytical methodologies of each protocol are described in the remainder of the document. The overarching goals of the monitoring are to:

1. Track the status and trends of San Juan River's fish community.
2. Track water quality, temperature, channel morphology, and habitat in the San Juan River.
3. Evaluate endangered fish species progress towards recovery.

4. Evaluate the effect of management actions, especially endangered fish stocking, non-native fish removal, and mimicry of the natural flow regime on the populations of native and non-native fishes in the San Juan River.

FISH MONITORING PROTOCOLS

LARVAL FISHES

The larval fish monitoring program is designed to locate spawning and nursery areas, gauge the timing of fish reproductive effort, and estimate the relative abundance of endangered, other native, and non-native fish larval fish. Investigations into the reproductive success of Colorado pikeminnow began on the San Juan River using larval drift surveys from 1991 to 2001. Larval seines have been used to document razorback sucker since 1998 and were used to document Colorado pikeminnow starting in 2002.

RELEVANT LONG RANGE PLAN TASK

Task 5.1.2.1 Conduct larval fish studies to determine if reproduction is occurring, locate spawning and nursery areas, and to gauge the extent of annual reproduction.

MONITORING GOAL

Quantitatively assess the annual reproductive success of Colorado pikeminnow and razorback sucker in the San Juan River.

MONITORING OBJECTIVES

1. Annually determine if Colorado pikeminnow reproduction occurred in the San Juan River and estimate the distributional extent and relative abundance of larvae.
2. Annually determine if reproduction by razorback sucker occurred in the San Juan River and estimate the distributional extent and relative abundance of larvae.
3. Determine the spawning periodicity of Colorado pikeminnow and razorback sucker between mid-April and early September and examine potential correlations with temperature and discharge.
4. Document and track trends in the use of specific mesohabitat types by larval Colorado pikeminnow and razorback sucker.
5. Document habitat availability (particularly backwaters) for larval razorback sucker during the spring runoff period.
6. Document and estimate relative larval production of the entire ichthyofaunal community in the San Juan River.

7. Provide detailed analysis of data collected to complement the overall program effort to determine progress towards recovery of Colorado pikeminnow and razorback sucker in the San Juan River.

HYPOTHESES

1. Densities of larval fishes will be influenced by specific mesohabitat types.
2. Relative abundance of larval fishes will be highest in mesohabitat types that contain cover, inundated vegetation and submerged debris which provides protection from aquatic and avian predators.
3. Elevated spring discharge increases relative reproduction of native fishes, as determined by annual relative abundance and distribution of native larval fishes.
4. Elevated spring discharge decreases reproductive success of non-native fishes, as determined by annual relative abundance and distribution of non-native larval fishes.
5. Modification of physical attributes of San Juan River by natural flow regime mimicry, mechanical creation of nursery habitats and decreased entrainment of adults into irrigation canals will result in increased relative abundance, expanded distribution, and multiple ontogenetic life stages of larval Colorado pikeminnow and razorback sucker.
6. Modification of biological attributes of San Juan River fish community (non-native removal and native fish stocking) will result in increased relative abundance, expanded distribution, and multiple ontogenetic life stages of larval Colorado pikeminnow and razorback sucker.

ASSUMPTIONS

1. Sampling methods are appropriate for species, life stages, and mesohabitats sampled.
2. Although sampling efficiency cannot be assumed to remain constant between sample locations, between sample periods, or among years, it is assumed that variability in efficiency does not affect interpretation of trends and relative abundance.
3. Relative measures of abundance (e.g., CPUE) are assumed to be directly related to actual abundance or density.
4. Sampling and analysis methods are repeatable and consistent.

RESPONSE VARIABLES

1. Species density of larvae by ontogenetic life stage of Colorado pikeminnow, razorback sucker, and other species by mesohabitat type.
2. Species density of larvae by ontogenetic life stage of Colorado pikeminnow, razorback sucker, and other species by geomorphic reach.
3. Species distribution of larvae by ontogenetic life stage of Colorado pikeminnow, razorback sucker, and other species (spatially and temporally).

4. Quantity of low velocity habitat.

METHODS

Study Area

Access to the river and collection localities will be gained through the use of 16 foot (ft) inflatable rafts that transport both personnel and collecting gear. There are not a predetermined number of collections per river mile or geomorphic reach for this study. Instead, collections are made in as many suitable larval fish habitats as possible within the river reach being sampled. Previous San Juan River investigations clearly demonstrated that larval fish most frequently occur and are most abundant in low velocity habitats such as pools and backwaters (Lashmett 1993). Sampling of the entire study area (river mile 141.5 to 2.9) is done during a single week in which the study area is divided into an “upper” section (Cudei, NM to Mexican Hat, UT) and a “lower” section (Mexican Hat, UT to Clay Hills, UT) once per month from April to August (5 sampling trips per year cover the entire study area). Sampling trips for both portions of the study area are initiated on the same day. Larval razorback sucker have been detected further upstream through time. As these detections approach the upstream limit of this sampling protocol (RM 141.5), sampling efforts should shift further upstream to Shiprock, NM (RM 147.9). In the future, the upstream starting location of larval sampling will be directed by collection of larval endangered fish so the protocol may shift even further upstream as determined by on-the-ground conditions.

Sampling

Collecting efforts for larval fish concentrate on low velocity habitats using small mesh seines (1 m x 1 m x 0.8 mm). Several seine hauls (between 3 and 12) are made at each individual collection site depending on the size of the habitat. For each collection site, the length (in meters) of each seine haul is determined in addition to the number of seine hauls per site. Mesohabitat type, length, minimum and maximum depth, substrate, turbidity (using a secchi disk), and presence of cover are recorded in a field data sheet for each collection site. The backwater habitat area will be delineated at the water/land interface using a handheld GPS unit with either a Pathfinder Pro XH or XT receiver. GPS points will be logged at the rate of 1 point per second and saved into the Ranger handheld as line generic files. Water quality measurements (dissolved oxygen, PH, conductivity, specific conductance, salinity, and temperature) are also obtained using a multi-parameter YSI water quality meter. A minimum of one digital photograph is recorded at each collection site. River mile is determined to tenth of a mile using the 2008 standardized aerial maps produced for the SJRIP and used to designate the location of collecting sites. In addition, geographic coordinates are determined at each site with a Garmin Navigation Geographic Positioning System (GPS) unit and are recorded in Universal Transverse Mercator (UTM) Zone 12 (NAD27). In instances where coordinates can not be obtained due to poor GPS satellite signal, coordinates will be determined in the laboratory using a Geographic Information System based on the recorded river mile. Mesohabitat designations follow those defined by Bliesner et al. (2008).

All retained specimens are placed in plastic bags (Whirl-Paks) containing a solution of 95% ethyl alcohol (ETOH) and a tag inscribed with unique alpha-numeric code that is also recorded on the field data sheet. Samples are returned to the laboratory where they are sorted and identified to species. Specimens are identified by personnel with expertise in San Juan River Basin larval fish identification. Underlit stereo-microscopes are used to aid in identification of larval individuals. Age-0 specimens are separated from age-1+ specimens using published literature to define growth and development rates for individual species (Snyder 1981, Snyder and Muth 2004). Both age classes are enumerated, measured (minimum and maximum size [mm]), and catalogued in the Division of Fishes of the Museum of Southwestern Biology (MSB) at the University of New Mexico (UNM). Results in annual reports will pertain to age-0 fish. Total length (TL) and standard length (SL) are measured on larval Colorado pikeminnow and razorback sucker to be consistent with information gathered by the San Juan River Basin and Upper Colorado River Basin programs.

The term young-of-year (YOY) can include both larval and juvenile fishes. It refers to any fish, regardless of developmental stage, between hatching or parturition and the date (1 January) that they reach age 1 (i.e., YOY = age-0 fish). Larval fish is a specific developmental (morphogenetic) period between the time of hatching and when larval fish transform to juvenile stage. The larval fish terminology used in this report is defined by Snyder (1981). There are three distinct sequential larval developmental stages: protolarva, mesolarva, and metalarva. Fishes in any of these developmental stages are referred to as larvae or larval fishes. Juvenile fishes are those that have progressed beyond the metalarva stage and no longer retain traits characteristic of larval fishes. Juveniles were classified as individuals that 1) had completely absorbed their fin folds, 2) had developed the full adult complement of rays and spines, and 3) had developed segmentation in at least a few of the rays.

Statistical Analysis

Differences in mean catch per unit effort (CPUE) are determined by species among years, trips, and reaches using a one-way analysis of variance (ANOVA). Samples collected in isolated pools are not included in yearly or between year trend analyses. A Poisson distribution provides the best fit to the raw data. A variety of transformations (e.g., logarithmic, reciprocal, square root) are applied on the mean CPUE data for between year comparisons. A natural log transformation yields the best variance-stabilizing qualities and produced a relatively normal distribution. Pair-wise comparisons between years, trips and reaches are made for each species and significance (i.e., $p<0.05$) is determined using the Tukey-Kramer HSD test. Finally, a nonparametric Analysis of Variance (Kruskal– Wallis test) is run for the various data sets to compare results to the parametric analyses.

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

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

Habitat occupancy graphs are generated using log transformed mean CPUE in order to measure density of age-0 species within sampled habitats. The larval surveys adopted the standardized habitat designations beginning in 2005. Data collected prior to 2005 were sorted by primary habitat type sampled and in some cases, primary and secondary habitat types were combined (i.e. pool + edge pool = pool) to reflect the current habitat designations being used by the SJRIP.

This study is initiated each year prior to spring runoff and completed near the end of the summer season (late September). Daily mean discharge during the study period was acquired from U.S. Geological Survey Gauges (#09371010) near Four Corners, Colorado and (#09379500) near Bluff, Utah. Bluff discharge and temperature was used for all data analysis in this report except for back-calculated spawning dates of Colorado pikeminnow in which Four Corners discharge and temperature was used. Temperature data (mean, max, min) is supplied by Keller-Bliesner Engineering and taken at the state highway 160 bridge crossing in Colorado (river mile 119.2) and Mexican Hat, Utah (river mile 52.0).

STRENGTHS

1. Systematic.
2. Community based sampling.
3. Detect long-term species trends.
4. Sampling methods effective over wide range of flow conditions.
5. Sampling of study area by two crews simultaneously (versus one crew over a longer time period) reduces chance that dramatic change in abiotic conditions (rapid increase in flow or turbidity) will skew data.
6. Data and results can be easily integrated with small-bodied monitoring.

WEAKNESSES

1. Currently, the entire known occupied range (above rivermile 141.5 and below rivermile 2.9) of Colorado pikeminnow and razorback sucker is not sampled.
2. Small percentage of all available low velocity shoreline habitat is sampled.
3. Currently, late summer sampling (i.e. September) is not providing meaningful data regarding endangered species.
4. Sampling gear is limited to habitats less than 1 meter deep.
5. Area of available habitat is not quantified so “dilution” effect on catch rates is not quantified.

SMALL-BODIED FISHES

Autumn monitoring of small-bodied and age-0 fishes of the San Juan River is designed to characterize survival and recruitment of wild-spawned Colorado pikeminnow and razorback sucker, survival of stocked age-0 Colorado pikeminnow, provide information on habitat use by wild and stocked individuals, monitor status and habitat use by potential Colorado pikeminnow prey and competitors of both Colorado pikeminnow and razorback sucker, and provide data to assess the effects of flow on density of small-bodied and age-0 fishes.

RELEVANT LONG RANGE PLAN TASK

Task 5.1.2.2 Conduct juvenile fish studies to determine if young fish are surviving and recruiting and the areas and habitat used for rearing.

MONITORING GOAL

Quantitatively document effects of management actions (e.g., natural flow regime mimicry) on survival of post-larval early life stages of native and nonnative fishes and their recruitment into subsequent life stages and use this information to recommend appropriate modifications to recovery strategies for Colorado pikeminnow and razorback sucker in the San Juan River.

MONITORING OBJECTIVES

1. Annually, during autumn, document occurrence and density of native and nonnative small-bodied fishes in San Juan River.
2. Document primary channel shoreline and near-shoreline, secondary channel, and backwater mesohabitat use by age-0 Colorado pikeminnow, razorback sucker, and roundtail chub, as well as other native and nonnative fishes.
3. Obtain data that will aid in the evaluation of the responses (e.g., reproduction, recruitment, and growth) of native and nonnative fishes to different flow regimes and other management actions (e.g., impediment modification).
4. Track trends in species populations (e.g., abundance, relative condition, and size structure).
5. Characterize patterns of mesohabitat use by native and nonnative small-bodied fishes (including age-0 Colorado pikeminnow, razorback sucker, flannelmouth sucker, bluehead sucker, common carp, and channel catfish).

ASSUMPTIONS

1. Modification of physical attributes of San Juan River (e.g., natural flow regime mimicry and removal of dispersal impediments) will elicit measurable response (e.g., density, distribution, and size-structure) by fishes.
2. Modification of biological attributes of San Juan River fish assemblage (e.g., nonnative removal and native fish augmentation) will elicit measurable response (e.g., density, distribution, and size-structure) by fishes.
3. Sampling methods are appropriate to species, specimen size, and habitats sampled.
4. Sampling efficiency remains constant.

HYPOTHESES

1. Autumn density of age-0 native fishes is influenced by spring discharge and duration.
2. Autumn density of age-0 nonnative fishes is influenced by spring discharge quantity and duration.
3. Survival of age-0 native fishes is affected by quantity of summer base flow.
4. Quantity of summer base flow affects reproductive success/survival of age-0 nonnative fishes, as determined by autumn densities of age-0 specimens.

5. Native fishes respond positively to natural flow regime mimicry and nonnative fishes respond negatively.
6. Densities of native fishes are greater in areas of high habitat complexity/diversity than in areas of low habitat complexity/diversity.
7. Age 0 to age 3 Colorado pikeminnow are found where density of age-0 and small-bodied fish is greatest.
8. Small-bodied native fishes respond positively to mechanical removal of nonnative predators.

RESPONSE VARIABLES

1. Species occurrence/frequency of occurrence (longitudinal distribution).
2. Species density/reach.
3. Species occurrence/mesohabitat type.
4. Population size structure.
5. Diversity indices (e.g., Shannon-Weiner and Morisita).

METHODS

Study Area

In 1998, autumn monitoring of small-bodied fishes in wadeable habitats of the San Juan River primary and secondary channels and backwaters (including embayments) occurred from Shiprock, New Mexico (RM 147.9, Reach 5) downstream to Chinle Creek, Utah (RM 68.6, Reach 3). In 1999, autumn monitoring was extended upstream to the San Juan-Animas rivers confluence (RM 180, Reach 6) and downstream to Clay Hills Crossing (RM 3, Reach 1). The primary channel was sampled at each sampled secondary channel or at 3-mile intervals (designated miles) if no secondary channel was present in a 3-mile reach. In 1999, a secondary channel was sampled only if it occurred within the 1-mile reach to be sampled in every third mile. This protocol excluded a large proportion of secondary channels (30 to 50%, depending upon the starting point of the 3-mile sampling interval). To adequately sample these habitats, beginning in 2000, all secondary channels longer than 200 m and having surface water during monitoring were sampled. All backwaters (greater than 50 m^2), regardless of occurrence within designated miles, were sampled. Current annual sampling will occur from the San Juan-Animas confluence to San Island (RM 76.4), the San Juan River between Sand Island and Clay Hills Crossing will be sampled every fifth year. Sampling procedures in this reach will be the same as that between San Juan-Animas confluence and Sand Island.

Sampling

Small-bodied fishes monitoring is designed to sample efficiently and effectively those habitats having the greatest likelihood of supporting age-0 individuals of large-bodied species and all age classes of small-bodied species. Small-bodied fishes are collected from primary channel habitats at 3-mile intervals. Small-bodied monitoring occurs in conjunction with adult monitoring. Sample intervals are coordinated to occur in miles that are skipped by the adult monitoring crews. During autumn of each year, primary channel shoreline and near-shoreline, secondary channel, and backwater habitats of the San Juan River will be sampled at 3-mile intervals. All collections were made by pulling a seine through a mesohabitat or kicking into a seine. During several years exploratory sampling methods were added, but there was no significant difference detected between the collections made with these additional methods and traditional methods. Consequently, all data were grouped for analysis within those years.

Primary channel sample sites are about 200-m long (measured along shoreline). Length of secondary channel sample sites vary depending upon extent of surface water, but are normally 100 to 200 m. River mile, GPS readings (UTM NAD83), and water quality information (pH, dissolved oxygen, conductivity, and temperature) are recorded for each site. Within each site (primary and secondary channels), all mesohabitats (see Bliesner and Lamarra 2000 for definitions) present are sampled in rough proportion to their surface area within a site. Beginning in 2003, data (including fishes collected) from each sampled mesohabitat within a site are recorded separately.

At each sample location (except backwaters), all mesohabitats present (8 to 10) will be sampled with 3.0 x 1.2 m (3 mm mesh) seine. For backwaters, a minimum of two samples will be obtained; one seine haul will be made across backwater mouth and a second will be made parallel to its long axis. With 8 to 10 samples per site, a total of 220 to 280 primary channel, 160 to 200 secondary channel (assuming 20 side channels are present), and 20 backwater (assuming 10 backwaters are present) samples will be obtained each year. Each catch will be inspected to determine presence of protected species and other native fishes. Total length (TL) of each native fish is measured, recorded, and the fish released. Nonnative fishes were fixed in 10% formalin and returned to the laboratory.

After fish collection, area, depth, and cover of sampled mesohabitats will be determined. Retained specimens were identified and enumerated in the laboratory. Total length was measured for all retained specimens. Personnel of the University of New Mexico Museum of Southwestern Biology (UNM-MSB), Division of Fishes, verified identification of retained specimens and retained specimens were accessioned to the

UNM-MSB, Division of Fishes. For each seine haul, habitat type, area seined, depth in 5 locations within seined area, dominant substrate, and any cover associated with the habitat is recorded.

Attributes of spring and summer discharge were obtained from USGS Water Resources Data, New Mexico (1998 et seq.). Shiprock gauge (#09368000) data were used for all calculations. Spring was 1 March through 30 June and summer was 1 July through 30 September. Species density data were segregated by Geomorphic Reach (Bliesner and Lamarra 2000). Geographic coordinates (UTM Zone 12, NAD 83) for each site will be recorded. Basic water quality parameters (water temperature, dissolved oxygen, conductivity, specific conductance, and salinity) will be measured at each.

Statistical Analysis

Mean sample catch per unit effort (CPUE) from is calculated as the average of individual seine haul CPUEs. In annual reports, density refers to CPUE. Mean sample CPUEs are used in regression analysis of summer discharge relation to autumn abundance of commonly collected secondary and primary channel species.

Mesohabitats are grouped into general categories (shoal, run, riffle, pool, eddy, backwater). Several habitats that did not fall into these general categories (e.g., debris piles and plunge pools) are excluded from habitat graphs because of low number of samples. For each mesohabitat class, the mean sample density of each species is plotted for each year. ANOVA is used to determine if there were differences in the densities of each species among the various habitats. Post hoc analyses are used to determine preferences where ANOVA showed use was not homogenous. Due to the natural variability seen with age-0 fish populations, probability values of <0.10 are considered significant (Brown and Guy 2007).

Annual reports will primarily be a summation of data obtained each year, a synthesis of data across years to document/assess species population responses to environmental variables (mainly discharge), a summary of mesohabitat associations of fishes, and basic characterizations of species demographics (population size/age structure, recruitment, and survival). Regression analysis and MANOVA will be used to characterize biological responses to discharge attributes (e.g., mean spring discharge, mean base summer discharge, and number days summer discharge less than 500 cfs) and ANOVA will be used to compare size structure of populations across reaches within a year and across years in a reach.

STRENGTHS

1. Systematic.
2. Repeatable/consistent.
3. Community-based sampling.
4. Covers most occupied SJ habitat (except downstream from Clay Hills Crossing & upstream of Animas-San Juan rivers confluence).
5. Sampling method effective for age 0 of all species, except perhaps RBS, and all age classes of small-bodied species.
6. Methods effective over range of flows normally encountered during autumn monitoring.
7. Accomplished concurrently with large-bodied monitoring.
8. Detect long-term population trends.
9. Estimate survival of age-0.

WEAKNESSES

1. Sample small fraction of total available habitat.
2. Sample number low for detecting density changes of 10-20% with high confidence.
3. Sampling method appropriate for all species.
4. Effectiveness of sampling method for age 1+ of several species uncertain.
5. Methods perhaps not effective for age 0 RBS.

LARGE-BODIED FISHES

Sub-Adult and Adult Large-Bodied Fish Community Monitoring Protocols

The goal of the adult monitoring program is to quantitatively document trends in fish community population parameters (including relative and absolute population size and size structure) occurring over time among populations of both native and nonnative large-bodied fishes in the San Juan River. Data collected form adult monitoring is also used to determine whether changes in fish community parameters correspond to environmental variables or management actions that are being implemented by the SJRIP such as mimicry of the natural flow regime, mechanical removal of non-native fishes, removal on in-stream dispersal impediments, or augmentation of endangered fish populations. Information collected by adult monitoring is used to recommend appropriate modifications to recovery actions and strategies for the endangered Colorado pikeminnow and razorback sucker in the San Juan River.

RELEVANT LONG RANGE PLAN TASK

Task 5.1.2.3. Conduct adult fish studies to estimate densities of fish (CPUE) and estimates of population size (mark-recapture estimate).

MONITORING GOALS

Quantitatively document trends in fish community population parameters occurring over time among populations of both native and nonnative large-bodied fishes in the San Juan River. Determine whether these changes in fish community parameters correspond to either environmental variables or management actions that are being implemented by the SJRIP. Use this information to recommend appropriate modifications to recovery actions and strategies for the endangered Colorado pikeminnow and razorback sucker in the San Juan River.

SPECIFIC LARGE-BODIED FISHES MONITORING OBJECTIVES

1. Annually, during autumn, document fish community structure, species abundance (presented as catch/time, CPUE) and distribution, and size structure among populations of both native and nonnative large-bodied fishes in San Juan River. Specific emphasis shall be placed upon monitoring the population parameters among the rare San Juan River fish species -- Colorado pikeminnow, razorback sucker, and roundtail chub (both wild and stocked fish).
2. Annually obtain data that will aid in the evaluation of the responses (e.g., year-to-year survival, reproduction, recruitment, growth, and condition factor) of both native and nonnative large-bodied fishes to management actions.
3. Annually continue to perform activities that support other studies and recovery actions being implemented by the SJRIP. For example:
    a. Remove nonnative fish species which prey upon and may compete with native fish species in the San Juan River.
    b. Collect GPS waypoints in habitats where endangered Colorado pikeminnow and razorback sucker are collected.
    c. Collect tissue samples from various fish species for stable isotope, genetics, and contaminants studies.

HYPOTHESES

1. Mimicry of a natural hydrograph increases reproductive success among native fishes, resulting in increased abundance of wild sub-adult and adult fishes over time.
2. Mimicry of a natural hydrograph decreases reproductive success among nonnative fishes, resulting in decreased abundance of wild sub-adult and adult fishes over time.
3. Mechanical removal of nonnative fishes leads to an increase in abundance and/or distribution among native fishes.
4. Mechanical removal of nonnative fishes leads to a decrease in their abundance and/or distribution.

5. Modification or removal of instream dispersal impediments results in an increase in distribution (i.e., wider range) among endangered fishes (stocked or wild).
6. Modification or removal of instream dispersal impediments results in an increase in distribution (i.e., wider range) among common fishes.
7. Augmentation of endangered fishes results in the establishment of a multiple year-class population that is self-sustaining.
8. Augmentation of endangered fishes results in significant changes among common native and nonnative fishes (i.e., abundance or distribution) over time.

ASSUMPTIONS

1. Modification of physical attributes of San Juan River (e.g., mimicry of a natural flow regime and modification or removal of instream dispersal impediments) will elicit measurable response (e.g., density, distribution, and size-structure) among fish species.
2. Modification of biological attributes of San Juan River fish assemblage (e.g., removal of nonnative fishes and native fish augmentation) will elicit measurable response (e.g., density, distribution, and size-structure) among fish species.
3. Sampling methods employed are appropriate to the species, specimen size, and habitats being sampled.
4. Sampling efficiency remains relatively constant.

RESPONSE VARIABLES

1. Species distribution (presented as geomorphic reaches and/or RM ranges occupied).
2. Species abundance (presented as catch/time, CPUE) by geomorphic reach.
3. Population size structure.
4. Overall fish community structure (e.g., native:nonnative fish species ratio).

Nonnative Fish Monitoring and Control Protocols

The non-native fish removal programs mechanically remove nonnative fish to reduce their distribution and abundance and the associated negative interactions (i.e. predation and competition) they may have on the native and endangered fishes in the San Juan River. The non-native removal program also evaluates the distribution and abundance of non-native fish in response to removal efforts. During the course of non-native removal efforts, monitoring of endangered Colorado pikeminnow and razorback sucker also occurs. The large numbers of endangered fish captured during non-native fish removal is used to determine survival and recruitment of stocked fish to assess stocking success and generates mark-recapture data to estimate population parameters for these species.

RELEVANT LONG RANGE PLAN TASKS

Task 3.1.1.4 Mechanically remove nonnative fish to achieve objectives.

Task 1.3.1.1 Determine survival and recruitment of stocked RBS and CPM to assess stocking success and to determine when to implement mark-recapture population estimates.

Task 4.1.2.5 Use mark-recapture population estimators, when feasible and in conjunction with catch rate estimators, to evaluate stocking success for CPM and RBS.

MONITORING AND CONTROL GOALS

To reduce the distribution and abundance of nonnative fishes and the associated negative interactions (i.e. predation and competition) they may have on the native and endangered fishes in the San Juan River.

To capture endangered Colorado pikeminnow and razorback sucker in order to determine survival, document recruitment, and estimate population abundance of these species.

MONITORING AND CONTROL OBJECTIVES

1. Conduct multiple passes throughout the year to remove targeted large-bodied nonnative fishes from 163 river miles of the San Juan River.
2. Evaluate distribution, abundance and standing crop of nonnative fishes to determine effects of mechanical removal on nonnative fishes.
3. Generate population estimates for channel catfish from Shiprock Bridge to Clay Hills.
4. Monitor distribution, abundance and population size of Colorado pikeminnow and razorback sucker collected during nonnative fish monitoring and control trips.
5. Relate distribution and abundance patterns of native fishes to the mechanical removal of nonnative fishes.

HYPOTHESES

1. Mechanical removal of nonnative fishes leads to a decrease in their abundance, distribution and/or standing crop.
2. Mechanical removal of nonnative fishes leads to an increase in abundance and/or distribution among native fishes.

ASSUMPTIONS

1. Modification of physical attributes of San Juan River (e.g., mimicry of a natural flow regime and modification or removal of fish barriers) will elicit measurable response (e.g., density, distribution, and size-structure) among fish species.
2. Modification of biological attributes of San Juan River fish assemblage (e.g., removal of nonnative fishes and native fish augmentation) will elicit measurable response (e.g., density, distribution, and size-structure) among fish species.
3. Sampling methods employed are appropriate to the species, specimen size, and habitats being sampled.
4. Sampling efficiency remains relatively constant across seasons and flow regimes.

RESPONSE VARIABLES

1. Species distribution.
2. Species abundance.
3. Population size.
4. Population structure.
5. Exploitation rates.
6. Biomass.

METHODS

Study area

The large-bodied fish community monitoring is designed to effectively sample all shoreline habitats within a given river mile, collecting a representative sample of all large-bodied fish species that are present. Large-bodied fish community monitoring will be conducted each fall from the confluence of the Animas and San Juan rivers (RM 180.6) to Sand Island (RM 76.4). In addition, the section of the San Juan River from Sand Island (RM 76.4) to Clay Hills Crossing (RM 3.0) will be sampled every fifth year. The sampling technique (i.e., raft-borne electrofishing) will remain consistent throughout all sampled river reaches. Sampling will begin in the second to third week of September and will be concluded by the second to third week of October. Two out of every three river miles will be sampled (RMs to be sampled will be randomly selected each year). River miles will follow the designations printed on the 2003 Standardized Map Set of San Juan River Digital Aerial Photography.

The number of non-native removal trips conducted annually will be determined based on previous years data on nonnative fish distribution and abundance and

Program priorities. Two electrofishing rafts will sample each shoreline collecting all nonnative fishes and any rare fishes observed. Timing of trips will be based on past collection efforts when the highest number of nonnative fish would likely be collected and removed. During the first sampling pass each year, channel catfish > 200 mm TL will be anchor tagged and released for the purpose of calculating a population estimate and estimating exploitation rates. From PNM Weir to Hogback Diversion and Hogback Diversion to Shiprock Bridge three electrofishing passes will be conducted per trip. From Shiprock Bridge to Mexican Hat non-native removal efforts will utilize four electrofishing rafts. One hour after the first rafts have started sampling, two additional will begin sampling collecting only nonnative fishes. Utilizing this methodology allows for the completion of two removal passes per trip. From Mexican hat to Clay Hills non-native removal efforts will conduct one pass per trip.

Sampling

Sampling will be performed using either 14-foot or 16-foot rafts equipped with Smith-Root Model 5.0 GPP Electrofisher units. Electrofishing raft anodes will consist of a single 8-inch diameter stainless steel sphere, suspended on a 60-inch long boom extending perpendicularly from the very front of the electrofishing raft. The height of the anode will be adjusted so that the sphere remains half-way submerged during electrofishing. Two cathodes will be located in the rear of the electrofishing raft, one on either side. Each cathode will be a “witches broom” configuration consisting of 15 stainless steel cables (or droppers), each 65 inches long and 1/8-inch in diameter, radiating from a single cathode fitting on either side of the electrofishing raft. These multiple-dropper cathodes will remain fully submerged during electrofishing. Cathodes should be mounted such that the distance between the center of the anode ball (when hanging straight down from the boom) and the terminal end of the cathode droppers (when held straight back along the side of the electrofishing raft) will be 317 inches on a 16-foot raft and 293 inches on a 14-foot raft.

Two oar-powered rafts, with one netter and one rower each, will simultaneously electrofish downstream, with one electrofishing raft along each shoreline. During sampling, rowers will strive to maintain a constant rate of speed, equal to or slightly faster than the speed of the river current immediately surrounding the electrofishing raft. Whenever possible, electrofishing should occur with the raft oriented perpendicularly to the shoreline, so that the anode is ≤ 24 inches from the shoreline. In very low velocity areas or in the case of strong upstream winds, rowers can propel the electrofishing raft downstream parallel to the shoreline, as long as the raft remains within a single oar-length of the shoreline. However, once adequate river current becomes available, the rower will once again orient the raft perpendicular to the shoreline.

During electrofishing, the Smith-Root 5.0 GPP Electrofisher units should be set on the following settings: Range = High; Mode = DC; Pulses Per Second = 60 DC. The Percent Of Power setting will be manually adjusted and monitored by the rower to maintain the Output Current setting at 4 amps. In adult monitoring netters will net all stunned fish that can possibly be collected, regardless of species or body size. During non-native fish sampling trips only non-native and endangered fish will be collected. Trailing or “chase” rafts will not be used to collect fish during adult monitoring. Electrofishing rafts in adult monitoring will not “stall out” in order to collect fish that are floating upstream beyond the netters immediate reach, but this technique will be employed in non-native fish removal. No outboard motors will be used.

For adult monitoring all fish collected will be enumerated by species and life stage at the end of every sampled mile. Every fourth sampled mile (known as a “designated mile” or DM), all fish collected will be weighed (in grams) and measured (both total length and standard length in millimeters). All native fish collected will be returned alive to the river. All nonnative fish collected will be removed from the river and disposed of out of the public’s view. Nonnative predatory fishes (e.g., walleye, striped bass, largemouth bass, smallmouth bass, channel catfish) may have stomach samples taken, before being removed from the river. Tag numbers, total length, standard length, and weight will be recorded for all recaptured, FLOY-tagged fish (both native and nonnative), as well as for any rare fish collected, regardless of whether or not they are collected in DM. Colorado pikeminnow, razorback sucker, and roundtail chub ≥ 150 mm TL will be implanted with 134.2 kHz PIT (Passive Integrated Transponder) tags. Notes will be kept on any parasites and/or abnormalities observed on collected fishes.

During non-native removal trips, at designated stops a representative sample of 25 of each nonnative species will be measured for total and standard lengths (± 5 mm) and weight (± 10 grams). Remaining fish will be enumerated by species and life stage (i.e. young of year, juvenile, adult). All native fish collected will be returned alive to the river. All nonnative fish collected will be removed from the river and disposed of out of the public’s view. To determine potential predatory impacts, nonnative predatory fishes (e.g., walleye, striped bass, largemouth bass, smallmouth bass, channel catfish) may have stomach samples taken or be scanned for a PIT tag, before being removed from the river. Tag numbers, total length, standard length, and weight will be recorded for all recaptured, anchor-tagged fish (both native and nonnative), as well as for any rare fish collected. Colorado pikeminnow, razorback sucker, and roundtail chub ≥ than 150 mm TL will be implanted with 134.2 kHz PIT (Passive Integrated Transponder) tags as outlined in the SJRIP’s PIT tagging protocol (Davis 2010). Notes will be kept on any parasites and/or abnormalities observed on collected fishes.

Statistical analysis

Adult monitoring annual interim progress reports will primarily be: 1) a summation of data obtained each year; 2) a synthesis of data across years to document and assess species population responses to either management actions or environmental variables. Data analysis will likely include (but may not be limited to) regression analysis, ANOVA (using Tukey's HSD post-hoc test) and scaled CPUE comparisons to help characterize biological responses of fishes across and within years and river reaches.

Non-native fish removal annual interim progress reports will include: 1) a summation of data obtained each year; 2) a synthesis of data across years to document and assess species population responses to either management actions or environmental variables. Data analysis will include, but may not be limited to, regression analysis, ANOVA, and CPUE comparisons to help characterize biological responses of fishes across and between years and river reaches. Lincoln-Peterson population estimates will be calculated for channel catfish in two river sections (Shiprock to Mexican Hat, and Mexican Hat to Clay Hills). Population estimates for endangered Colorado pikeminnow and razorback sucker will be calculated using Program MARK.

STRENGTHS - SUB-ADULT AND ADULT LARGE-BODIED FISH COMMUNITY MONITORING

1. Systematic.
2. Repeatable/consistent.
3. Community-based sampling.
4. Covers most occupied SJ habitat (except below Clay Hills Crossing & upstream of Animas River confluence).
5. Sampling method effective for large-bodied fish of all species $\geq$ 150 mm TL.
6. Methods effective over range of flows normally encountered during autumn monitoring.
7. Accomplished simultaneously with small-bodied fish community monitoring.
8. Efficient in tracking and detecting changes in long-term population trends (able to effectively detect population density changes at the 8.6%-21.0% level).
9. Efficient in tracking persistence of stocked endangered fishes.

STRENGTHS - NONNATIVE FISH MONITORING AND CONTROL

1. Riverwide.
2. Multiple passes conducted each year.
3. Repeatable but flexible if management strategies change.

4. Sampling method effective for large-bodied nonnative fish $\geq$ 150 mm TL.
5. Methods effective over range of flows.
6. Rare fish data collected concurrent with nonnative fish monitoring and control.
7. Efficient in tracking and detecting changes in long-term population trends of both nonnative and rare fishes.
8. Efficient in tracking persistence of stocked endangered fishes.

WEAKNESSES - SUB-ADULT AND ADULT LARGE-BODIED FISH COMMUNITY MONITORING

1. Samples a relatively small percentage of the total available habitat.
2. Probably not effective at sampling fish < 150 mm TL in proportion to their actual numbers.
3. Single pass sampling regime results in relatively low capture probability for rare fish species.

WEAKNESSES - NONNATIVE FISH MONITORING AND CONTROL

1. Samples a relatively small percentage of the total available habitat.
2. Probably not effective at sampling fish < 150 mm TL in proportion to their actual numbers.
3. Not effective at sampling channel catfish at high turbidity levels.

HABITAT MONITORING PROTOCOLS

To the extent possible, habitat monitoring is closely coordinated and integrated with fish community monitoring to allow assessment of changing habitat availability and fish use in response to management actions and population recovery. Standardized habitat monitoring for the San Juan River was included in the 2000 monitoring plan and was reviewed and revised for the 2011 version. The plan is designed to monitor and evaluate habitat changes through time. The data and information from habitat monitoring will be integrated with different monitoring activities to assess the effectiveness of management actions, such as flow management, fish population estimates, and nonnative fish population abundances. A focused habitat monitoring workshop is planned for 2011 to evaluate, refine, and improve habitat monitoring and mapping work on the San Juan River to insure the Program implements methodologies that are conducive to answering outstanding questions and provide the data necessary to evaluate and revise the SJRIP's flow recommendations.

RELEVANT LONG RANGE PLAN TASKS

Task 5.2.1.1 Modify the existing Standardized Habitat Monitoring Plan to incorporate findings from the 2005-2009 detailed reach study.

Task 5.2.2.2 Map habitat at different flows as described in the revised Standardized Habitat Monitoring Plan

Task 5.2.2.3 Monitor long-term habitat response of the river channel to flow recommendations.

MONITORING GOAL

Quantitatively document effects of naturally occurring conditions, management actions, and other anthropogenic activities on aquatic habitat availability in the San Juan River. Use this information to recommend appropriate modifications to recovery strategies for Colorado pikeminnow and razorback sucker in the San Juan River.

MONITORING OBJECTIVES

1. Annually, following spring runoff, document abundance and distribution of key habitats and geomorphic features (backwaters, embayments, islands and total wetted area) that indicate the response of the river channel and habitat to antecedent runoff conditions and specific management actions.
2. Maintain continuous water temperature recorders at key locations from Navajo Dam to Mexican Hat, Utah to examine the influence of artificial manipulation of water releases from Navajo Dam on water temperature.
3. Monitor key water quality parameters in the San Juan River from the Navajo Dam to Mexican Hat, Utah at least quarterly.
4. Periodically (e.g. every 5 years) map river-wide habitat abundance and distribution in the San Juan River from the Animas River confluence (RM 180) to Clay Hills Crossing (RM 2) to track long-term trends in habitat.
5. Periodically (e.g. every 5 years) document available spawning habitat for Colorado pikeminnow following spring runoff.
6. Periodically (e.g. every 5 years) document available spawning habitat for razorback sucker on the ascending limb of spring runoff.
7. Document available nursery habitat for razorback sucker during the spring runoff period (See larval fish monitoring protocol for a description of this work).
8. Develop relationships between habitat availability and antecedent flow conditions. Use key habitats for this analysis.
9. Track long-term trends of habitat availability and temperature.

ASSUMPTIONS

1. Modification of physical attributes of the San Juan River (See management actions above) will elicit measurable responses in habitat availability.
2. Spawning and nursery habitat requirements of Colorado pikeminnow are known.
3. Spawning and nursery habitat requirements of razorback sucker are known.

4. Mapping of key habitat and geomorphic features by interpretation of aerial photography is comparable to field mapping of these parameters after calibration.

HYPOTHESES

1. Channel complexity and backwater habitat availability are maintained by implementation of the flow recommendations (no decreasing trend in either).
2. Channel complexity and backwater habitat availability are positively correlated to duration, magnitude and frequency of high-flow spring runoff.
3. Channel complexity and backwater habitat availability are positively correlated to physical habitat modification.
4. Availability of spawning habitat for endangered fish recovery is positively correlated with management actions.
5. Water temperature in the critical habitat is adversely affected by management actions.

RESPONSE VARIABLES

1. Distribution and abundance (area and density) of backwaters, embayments, and total wetted area in response to antecedent runoff conditions and other management actions.
2. Distribution and abundance of other habitat categories (long-term trend analysis).
3. Distribution and abundance of suitable gravels in association with other required spawning habitat characteristics for endangered fishes.
4. Channel complexity (e.g. island count and total wetted area per river mile).
5. Daily minimum, maximum and average water temperature.

METHODS

Annual Habitat Mapping

Digital videography of the San Juan River from the Animas River confluence (RM 180) downstream to below Clay Hills Crossing (RM 0) will be acquired at a flow of from 500 to 1,000 cfs in late July or early August each year. Digital single frames will be captured from this videography to provide full coverage of the river with about 20% overlap. The digital images will be rectified to 2005 (or the latest available) digital orthographic quads (DOQ's) prior to photo-interpretation and will be archived to DVD.

Photo-interpretation will be completed to identify backwaters, embayments, islands, and total wetted area annually for RM 0 to RM 180. In the first year, 2007 photography and mapping will be used to calibrate photo-interpretation. A selection of approximately 10% of the frames will be used to calibrate the procedure and an additional 10% to verify the results prior to full analysis of the first year of aerial videography. This is a one-time task that will be required only in the first year of video interpretation. Once the digital frames have been registered, ArcGIS will be used to digitize the boundaries of the wetted channel, backwaters, embayments and islands. The data will be processed and summarized by river-mile to match existing datasets.

Field Habitat Mapping (River-Wide Survey)

Periodically (every 5 years or other period as recommended by the Biology Committee) base photography maps will be prepared at a scale of approximately 1 inch = 150 feet for river-wide mapping from the videography described above. The frames will be printed on 8.5 x 11 inch pages with the river-mile marks and provided in sheet protectors for field mapping.

For the year that field mapping will be completed, the 17 aquatic habitat types and 7 associated terrestrial types (Table 1) will be delineated on the base photographs (1 inch = 150 ft scale) by visual inspection. Each polygon delineated will be marked with its corresponding code (Table 1). The date of mapping will be recorded on the beginning map sheet for each day's mapping along with the name of the mapper. All mappers will be experienced in mapping aquatic habitat in the San Juan River. In as much as the mapping process is interpretive, annual reviews will be conducted among the mapping crews prior to mapping to assure the best possible reproducibility in interpretation among mappers. Following field mapping, the field sheets will be reviewed and missing codes or non-closed polygons corrected prior to processing.

Once the field mapping sheets are reviewed and edited, they will be scanned at a resolution of 300 dpi and then rectified to the latest available 2005 DOQ's to remove distortion. After rectification, the habitat polygons will be digitized and coded in ArcGIS to produce a shape file and database with habitat perimeter and area by type and river mile. The data will then be extracted and summarized by count and area per river mile for analysis. Average flow at mapping for each detailed reach will also be extracted from USGS gage data, using the gage or gages most representative of the reach.

Table 1. Revised categories of habitat types on the San Juan River with mapping codes (Mapping codes shown in parentheses).

Backwater Types	Other Low Velocity Types	Run Types	Riffle Types	Shoal Types	Slackwater Types	Vegetation types
(1) Backwater	(3) Pool	(10) Run	(15) Riffle	(9a) Sand shoal	(20) Slackwater	(34) Inundated Vegetation
(2) Embayment	(6) Eddy		(19) Chute	(9b)Cobble shoal	(35) pocket water	
			(32) Rapid			
			(37)Waterfall			
			(41)Plunge			
Other Wet Types			**Dry Types**			
(21) Isolated Pool	(33) Irrigation Return	(29) Tributary	(28) Sand Bar	(31) Island	(26) Rootwad Pile	(38) Bridge Pier
(39)Diverted water			(40)Diversion structure	(25) Cobble Bar	(36)Boulder	

Habitat Mapping Data Analysis

Data analysis will be the same whether photo-interpreted or field mapped, except that the number of habitat types analyzed will be different. Trend analysis will be performed on all habitat types mapped to assess trend with time and flow at mapping. Trends with time will be analyzed with raw data (habitat count and area by river-mile with time) and with data normalized for flow at mapping. Every 5^{th} year all data will be integrated to examine the relationship between habitat abundance and antecedent spring flow conditions for individual and multiple years.

Colorado Pikeminnow Spawning Habitat Monitoring

Periodically (every 5 years or other period as recommended by the Biology Committee) a synoptic survey of available Colorado pikeminnow spawning habitat will be completed. Spawning conditions needed and used by Colorado pikeminnow in the San Juan River will be identified by a separate research effort and/or from historical data from earlier survey work in the San Juan River. Based on the identified conditions, a search image will be established that includes cobble conditions (mean cobble size, depth of open interstitial space), bar position relative to stream flow, general bar shape and habitat associations.

Near the bottom of the spring runoff hydrograph (typically early to mid-July) a synoptic survey will be completed from RM 180 to RM 116 (or other range if spawning locations are identified outside this range). Candidate sites will be identified on the most recent videography based on habitat and channel morphology compared to the search image. These sites will be field visited. Aquatic habitat will be mapped and cobble bar characteristics measured (Wolman pebble count $n \geq 100$ and open interstitial space measurement $n \geq 100$) for all sites found to visually fit the search image.

Habitat maps will be rectified and digitized and the cobble data will be analyzed to provide the cobble size distribution and an exceedence plot of area versus depth of open interstitial space prepared for each site. These will be compared to minimum standards and sites categorized as suitable, marginal, or unsuitable. Subsequent sampling trips will include assessment of previously sampled bars found to be suitable to assess fate of the bars with time. The abundance of suitable sites and trend (increasing or decreasing) from the previous assessment will be compared to intervening flow conditions and management actions to assess effect.

Razorback Sucker Spawning Habitat Monitoring

Periodically (every 5 years or other period as recommended by the Biology Committee) a synoptic survey of available razorback sucker spawning habitat will be completed. Spawning conditions needed and used by razorback sucker in the San Juan River will be identified by a separate research effort and/or from historical data from earlier survey work in the San Juan River. Based on the identified conditions, a search image will be established that includes gravel conditions (mean cobble size, depth of open interstitial space), bar position relative to stream flow, general bar shape, and habitat associations.

Near the beginning of the spring runoff hydrograph (typically late April or early May) a synoptic survey will be completed from RM 180 to RM 67 (or other range if spawning locations are identified outside this range or more narrowly within this range). Candidate sites will be identified on the most recent videography based on habitat and channel morphology compared to the search image. These sites will be field visited. Aquatic habitat will be mapped and cobble bar characteristics measured (Wolman pebble count $n \geq 100$ and open interstitial space measurement $n \geq 100$) for all sites found to visually fit the search image.

Habitat maps will be rectified and digitized and the cobble data will be analyzed to provide the size distribution and an exceedence plot of area versus depth of open interstitial space prepared for each site. These will be compared to minimum standards and sites categorized as suitable, marginal, or unsuitable. Subsequent sampling trips will include assessment of previously sampled bars found to be suitable to assess fate of the bars with time. The abundance of suitable sites and trend (increasing or decreasing) from the previous assessment will be compared to intervening flow conditions and management actions to assess effect.

Water Temperature Monitoring

Onset Corporation HOBO Water Temp Pro loggers (or equivalent) with built-in thermocouple temperature sensors are installed in the locations described in Table 2. In 2011, new installations will be required at the mouth of the Mancos River and McElmo Creek. The recorders will be inspected and read twice each year, once in the spring and once in the fall. Battery condition will be monitored and loggers changed out when the battery life falls below that required to continue until the next reading point. Following each download, data will be quality checked with bad data removed. Vandalism, natural causes or equipment malfunction can cause loss of data that are beyond control of the sampler. Every attempt will be made to assure quality data within the scope described, but some missing data will be inevitable. Data integrity similar to that in the existing database will be provided.

The records will be maintained in a Microsoft Access database. The main data table will store the 15-minute data and will be constructed as shown in Table 3. Data tables summarizing daily maximum, minimum and average temperatures will be generated for each of the eight sites by query of the main data table and stored in the database in the format shown in Table 4. Table 5 shows the information stored to describe each session, including geo-spatial data to allow importation into a Geographic Information System.

After the autumn logger download, data for the water year will be compiled and the daily average temperatures plotted along with the daily hydrograph of the San Juan River at Four Corners, New Mexico. A summary report will be prepared that will include presentation of the daily average temperature data with a discussion of data collection procedures, data quality and repair requirements during the season. Anomalous data, if any, will also be discussed.

Table 2. Water temperature monitoring locations.

Location	RM
Near Navajo Dam	225.0
Archuleta - San Juan at USGS Gage Location	218.6
Farmington - San Juan at USGS Gage Location	180.1
Shiprock - San Juan at USGS Gage Location	148.0
Four Corners - San Juan at USGS Gage Location	119.4
Montezuma Creek - San Juan at Montezuma Creek Bridge	93.6
Mexican Hat - San Juan near Bluff Gage Location	52.1
Farmington - Animas at USGS Gage Location	n/a
Mancos River at confluence with San Juan	n/a
McElmo Creek at confluence with San Juan	n/a

Table 3. Temperature database main table format

Temp			
ID	**RecDate**	**RecTime**	**DegC**
4C	7/9/1999	4:04:27 PM	23.48
4C	7/9/1999	4:49:27 PM	23.74

Table 4. Daily temperature summary table format

AnimasFarminton				
ID	**RecDate**	**Tmax**	**Tmin**	**Tavg**
AF	7/8/1999	22.11	18.36	19.2
AF	7/11/1999	20.13	15.81	17.9

Table 5. Temperature station description database table

StationID					
ID	**Location**	**Notes**	**Lat**	**Lon**	**Datum**
4C	Four Corners	Located at the Four Corners USGS gage	37.00195	-109.0311	NAD83
AF	Animas at Farmington	Located an the Animas at Farmington USGS gage	36.72154	-108.2017	NAD83
AR	Archuleta	Located at the Archuleta USGS gage	36.80278	-107.699	NAD83
FM	Farmington	Located at the Farmington USGS gage	36.72221	-108.2251	NAD83
MC	Montezuma Creek	Located left bank at sheet piling upstream side of the Mont. Ck bridge	37.2579	-109.3096	NAD83
MH	Mexican Hat	Located right bank near the USGS mini-monitor enclosure upstream of Mex Hat bridge	37.15059	-109.8669	NAD83
ND	Navajo Dam	Base of Navajo Dam on river left immediately downstream of outlet	36.80484	-107.6148	NAD83
SR	Shiprock	Located at the Shiprock USGS gage	36.781	-108.6899	NAD83
MA	Mancos R. at S.J. confluence	Site to be field located near the confluence with the San Juan	TBD	TBD	NAD83
ME	McElmo Cr. At S.J. confluence	Site to be located near the confluence with the San Juan	TBD	TBD	NAD83

Statistical Analysis

Habitat data analysis is the same whether photo-interpreted or field mapped, except that the number of habitat types habitats analyzed will be different. Trend analysis will be performed on all habitat types mapped to assess trend with time and flow at mapping. Trends with time will be analyzed with raw data (habitat count and area by river-mile with time) and with data normalized for flow at mapping. Every 5th year all data will be integrated to examine the relationship between habitat abundance and antecedent spring flow conditions for individual and multiple years.

Annual reports will be a summation of the data collected from the previous year. Data analysis is the same whether photo-interpreted or field mapped. Photo-interpreted data will include backwaters, embayments, islands and total wetted area. Trend analysis will be performed on all habitat types mapped to assess trend with time and flow at mapping. Trends with time will be analyzed with raw data (habitat count and area by river-mile with time) and with data normalized for flow at mapping. Every 5th year all data will be integrated to examine the relationship between habitat abundance and antecedent spring flow conditions for individual and multiple years.

ANNUAL TASKS

1. Distribution and abundance (area and density) of backwaters, embayments and total wetted area in response to antecedent runoff conditions and other management actions.
2. Channel complexity (e.g. island count and total wetted area per river mile).
3. Daily minimum, maximum, and average water temperature.

EVERY 5TH YEAR ANALYSIS

1. Distribution and abundance of other habitat categories (long-term trend analysis).
2. Distribution and abundance of suitable gravels in association with other required spawning habitat characteristics for endangered fishes.
3. Track long term trends of habitat availability and temperature.

ANNUAL HABITAT MAPPING

1. Videography of channel at flow between 500 and 1,000 cfs.
2. Rectified digital images from the videography.
3. Polygon area, perimeter and geo-referenced location of backwaters, embayments, islands, and channel margins.
4. Flow at mapping (flight date) for each USGS gage.
5. Date of mapping.
6. Antecedent runoff hydrograph.
7. Data summarized by river mile, geomorphic reach and full range.

PERIODIC RIVER-WIDE HABITAT MAPPING

1. Rectified habitat map.
2. Polygon area, perimeter and geo-referenced location of 17 habitat types.

3. Date of mapping for each daily segment.
4. Flow at mapping for each geomorphic reach.
5. Antecedent runoff hydrograph for all years between mappings.
6. Data summarized by river mile, geomorphic reach, and full range.

COLORADO PIKEMINNOW SPAWNING HABITAT MONITORING

1. Habitat map of identified spawning site (geo-referenced data as described above).
2. Cobble size (Wolman pebble count) and depth of open interstitial space for each site.
3. Site location and categorization (suitable, marginal, unsuitable).
4. Date of mapping.
5. Flow at mapping for each site.
6. Antecedent runoff hydrograph.
7. Flow statistics since last mapping.

RAZORBACK SUCKER SPAWNING HABITAT MONITORING

1. Habitat map of identified spawning site (geo-referenced data as described above).
2. Cobble size (Wolman pebble count) and depth of open interstitial space for each site.
3. Site location and categorization (suitable, marginal, unsuitable).
4. Date of mapping.
5. Flow at mapping for each site.
6. Runoff hydrograph.
7. Flow statistics since last mapping.

RAZORBACK SUCKER NURSERY HABITAT MONITORING

1. Videography at three flows during spring runoff.
2. Rectified digital images from videography.
3. Polygon area, perimeter, and geo-referenced location of backwaters and embayments.
4. Flow at mapping (flight date) for each USGS gage.
5. Date of mapping.
6. Runoff hydrograph.
7. Data summarized by river mile, geomorphic reach, and full range.

WATER TEMPERATURE MONITORING

1. Daily 15-minute, maximum, minimum, and average water temperature at 10 locations
2. Daily mean flow at each USGS gage

STRENGTHS

1. Systematic.
2. Repeatable/consistent.
3. Covers most occupied SJR habitat (except below Clay Hills Crossing & upstream of Animas confluence).
4. Data integrates with historical data set.
5. Allows detection of long-term trends for all habitat parameters.
6. Allows correlation to antecedent runoff hydrology for backwaters and channel complexity.
7. Provides monitoring mechanism to assess effectiveness of physical habitat modification activities.

WEAKNESSES

1. Does not allow correlation of habitat type availability for types other than backwaters and islands with antecedent hydrology.
2. Annual mapping only relates to habitat availability for non-runoff periods.
3. Runoff period mapping limited to backwaters and embayments and only conducted every 5 years, limiting the opportunity to correlate availability to annual hydrologic conditions.
4. Spawning bar characterization may not be correlated to specific antecedent hydrology.
5. Photo-interpretation of backwater habitats, particularly at high flow, less accurate than on-the-ground mapping.

DATA SYNTHESIS AND INTEGRATION PROTOCOLS

To adequately evaluate management actions, the data from all monitoring, management, and research activities is collectively synthesized as a comprehensive data set. The monitoring data is analyzed for each individual protocol during annual data analysis by the principal investigator for each protocol. This annual data analysis uses statistics appropriate for each protocol to test relevant hypotheses and examine data temporally and spatially. The integrated data from individual protocols is used to address questions that synthesize data across protocols. Some synthesis questions can be addressed with the monitoring data that is collected each year while other questions require datasets over multiple years or specific research efforts. Prioritization of questions critical to Colorado pikeminnow and razorback sucker recovery in the San

Juan River is a critical element in carrying out annual and long-term data integration exercises. These questions will be developed each year following the review of draft annual reports.

Data synthesis and integration

The annual data synthesis uses data from individual protocols and combined data sets to answer specific questions regarding the San Juan River ecosystem and the recovery of the endangered fish. Some of these analyses could be conducted annually while others could occur less frequently or cover long-term data sets. The initial list of topics for inquiry for the integration process was developed during the 2009 Monitoring Protocol Workshops. These topics are listed by relevant protocol.

We recommend that each of the monitoring projects incorporate a discrete "Data Synthesis and Integration" section in their annual repots. Items identified as level "01" in this document can immediately be incorporated into the "Data Synthesis and Integration" sections of future reports. The authors of those reports can elaborate on the results of the specific "Data Synthesis and Integration" topic and can update that information on an annual basis.

Data synthesis and integration categories:

01 = Already doing this integration
02 = Should do this integration ASAP
03 = Should wait to do this integration
04 = Probably can't do this integration with available data

Larval fish *(number in parenthesis indicates integration level)*
1. Determine the mesohabitats used by larval fish of different stages **(01)**.
2. Determine the larval fish habitat quality, quantity, and persistence **(04)**.
3. Determine larval fish habitat use in other rivers in the basin **(03)**.
4. Determine the number of larval fish lost to Lake Powell **(04)**.
5. Determine the number of larval fish expected to retain in the river **(04)**.
6. Determine the number of larval fish needed annually for successful recruitment **(04)**.
7. Determine the maximum allowable predation level that ensures recruitment of larval fish and improves progress toward recovery **(04)**.
8. Determine how to create or maintain critical habitats that are needed to retain larval fish in the system **(01)**.

Small bodied fish *(number in parenthesis indicates integration level)*
1) Determine presence or absence of Colorado pikeminnow and razorback sucker **(01)**.
2) Determine survival and recruitment of juvenile Colorado pikeminnow and razorback sucker **(01)**.

3) Determine if Colorado pikeminnow and razorback sucker populations are limited by the number of fish in the 150-250 TL mm size class **(03)**.
4) Determine the habitat use of juvenile Colorado pikeminnow and razorback sucker **(01)**.
5) Determine critical limiting factors– non-native predation and competition, water quality, flow, habitat, productivity or food, electrofishing, passage, loss over waterfall **(04)**.
6) Determine the statistical strength of the current sample size and locations **(02)**.
7) For each species, determine if the abundance of juvenile fish is correlated with the abundance of larval fish **(02)**.

Large bodied fish *(number in parenthesis indicates integration level)*

1) Determine the trend in rare fish population by size class **(01)**.
2) Determine the number of spawning rare fish **(04)**.
3) Determine the recruitment of stocked Colorado pikeminnow and razorback sucker to the adult population **(04)**.
4) Determine the recruitment needed to establish self-sustaining populations of Colorado pikeminnow and razorback sucker **(04)**.
5) Determine if the current monitoring can measure recruitment (**04**).
6) Determine critical limiting factors: nonnatives predation and competition, water quality, flow, habitat, productivity or food, electrofishing, passage, loss over waterfall **(04)**.
7) Determine the spawning locations for Colorado pikeminnow and razorback sucker **(04)**.

Geomorphology and habitat *(number in parenthesis indicates integration level)*

1) Quantify habitat availability by habitat type for all life stages of the rare fish **(04)**.
2) Determine the quantity and quality of nursery habitat **(01)**.
3) Determine the spatial and temporal distribution of habitat **(01)**.
4) Determine the spatial and temporal distribution of spawning habitat **(01)**.
5) Determine the year to year quantity of habitat **(01)**.
6) Determine the factors that affect habitat complexity **(04)**.
7) Determine the spatial distribution of spawning and nursery habitats **(04)**.
8) Determine habitat trends across years **(01).**

Long term cross protocol synthesis and integration *(number in parenthesis indicates integration level)*

1) Determine whether the population numbers for Colorado pikeminnow and razorback sucker in the Recovery Goals need to be adjusted **(01)**.
2) Set criteria to begin mark-recapture population estimates **(01)**.
3) Identify other abundance estimators and determine how to incorporate them into our sampling **(02)**.
4) Determine the number of adult fish as a result of stocking **(01)**.
5) Determine if the survival rate of stocked fish is sufficient to reach self-sustaining population goals **(02)**.
6) Determine if survival rates can be increased **(04)**.
7) Evaluate the stocking program and protocols to ensure that we are stocking the

“right” number of fish **(02)**.

8) Determine if the flow recommendations should be revised **(01)**.
9) Determine if the biologic response to flows can be detected with the current monitoring protocols **(01)**.
10) Determine if the changes in razorback sucker population by life stage over time can be detected by the current protocols **(01)**.
11) Determine how changes to spatial or temporal locations for data collection affect the statistical robustness of the data **(02)**.
12) Determine how the river miles monitored affect the accuracy and precision of the monitoring data **(02)**.

Table 6. Summary of data integration and analysis by protocol or activity

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
01		1: Determine the mesohabitats used by larvae of different stages.	Larval, habitat, flow, water temperature	High flow habitat availability	Data are available for analysis
04		2: Determine the larval habitat quality, quantity and persistence.	Habitat area, Habitat area by flow Habitat quality and quantity assessment attempted (2010) but not successful (2010 report)	Habitat-fish density relationship, high flow habitat availability	Some data from larval capture but only indirectly
03		3: Compare the habitats used by larval fish in other rivers in the basin to the habitat use in the San Juan River	SJR larval data by habitat type; Upper Colorado Basin larval fish habitat use data; Lower basin		Literature review. Need to review the larval fish studies from the Upper and lower Colorado River basin
04		4: Determine the number of larval fish lost to Lake Powell.	Bead study, Larval CPM stocking This is a research question Can include more non-drift comparisons	Estimate of percent of stocked fish lost	Could indirectly estimate from the bead and larval studies conducted in the late 1990s. Measurement would require a specific research effort.

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
04		5: Determine the number of larval fish expected to retain in the river.	Bead study, Larval CPM stocking This is a research question Can include more non-drift comparisons	Estimate of percent of stocked fish that are retained	Data analysis using existing data. Could indirectly estimate from the bead and larval studies conducted in the late 1990s. Measurement would require a specific research effort.
04		6: Determine the number of larval fish needed annually for successful recruitment (i.e., larval fish mortality).	Use results of #5 above, survival rates,	Number of spawning fish, Survival rate estimates from egg to larvae A modeling study	Data analysis. This should be conducted in conjunction with other life stages. A population model could be used for initial estimates and for sensitivity analysis.
04		7: Determine the maximum allowable predation level that ensures recruitment and improves progress toward recovery.	Use population model	Estimate of predation by species	Research needed to determine the rate of predation
01		8: Determine how to create or	Larval CPM and razorback study, habitat mapping	Determine survival or	Need further research or

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
		maintain critical habitats that are needed to retain larvae in the system.	The RERI Project will begin to address this question.	recruitment based on amount of habitat available	specific study
Inte-gration Level	**Small bodied fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
01		1: Determine the presence or absence of juvenile Colorado pikeminnow and razorback sucker.	Small bodied data, non-native removal data		Just do it.
01		2: Determine survival and recruitment of juvenile Colorado pikeminnow and razorback sucker	Larval capture data, small bodied capture data, large bodied capture data This should be included in small-bodied report	Data to track cohorts from one life stage to another, population estimates by life stage	Trend for native suckers the same relative density as other protocols.
03		3: Determine if Colorado pikeminnow and razorback sucker populations are limited by the number of fish in the 150-250 mm size class. Provide sizes of CPM and RZS at the time of the small-bodied sampling effort.	Need to look at fish sampled in habitats during small-bodied sampling efforts (and non-native removal).	New study?	Research question
01		4: Determine the habitat use of	Small bodied data, complex reach study	No fish (razorback	

Inte-gration Level	Larval fish	Data Analysis Integration Activity	Data Available	Missing Data	Comments
		juvenile Colorado pikeminnow and razorback sucker.		sucker) so can not yet do	
04		5: Determine the critical limiting factors – non-natives predation and competition, water quality, flow, habitat, productivity or food, electrofishing, passage, loss over waterfall.			Integration effort
02		6: Determine the statistical strength of the current sample size and locations.	Small bodied data set Ron Ryel did a power analysis to assess statistical strength (need to find citation).		
02		7: Determine if the abundance of juvenile fish is correlated with the abundance of larval fish.	Small bodied data set, larval data set Yvette and Howard did this this can be done - not necessary annually but can do better at integrating aspects of larval and small-bodied reports		Common species track, expect rare species to track when abundant
Inte-gration Level	**Large bodied**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
01		1: Determine the trend in rare fish population by size class.	Adult monitoring data, non-native removal data		Data analysis of existing data set
04		2: Determine the number of spawning razorback sucker and Colorado pikeminnow.		New telemetry study? Increased Jun-Jul capture effort.	May need more fish in system before we know the answer.

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
04		3: Determine the recruitment of stocked Colorado pikeminnow and razorback sucker to the adult population			Some data on RZS but not nearly as much on CPM, may need more fish
04		4: Determine the recruitment needed to establish self-sustaining populations of Colorado pikeminnow and razorback sucker.	Adult monitoring data, non-native removal data, stocking data Can not accomplish this in the short-term		Calculate with assumptions on life history and use population model. Too many unknowns
04		5: Determine if the current monitoring can measure recruitment to the adult population.			Yes
04		6: Determine the critical limiting factors – non-natives predation and competition, water quality, flow, habitat, productivity or food, electrofishing, passage, loss over waterfall			Integration issue
04		7: Determine the spawning locations for Colorado pikeminnow and razorback sucker.	Larval data, non-native removal, collection of ripe fish This is being attempted (and refined annually) using larval fish data and otoliths.	Telemetry data during spawning	Non-native monitoring does this to some extent Need radio telemetry

Inte-gration Level	Larval fish	Data Analysis Integration Activity	Data Available	Missing Data	Comments
			Direct (radio telemetry) versus indirect (otoliths) determinations		study to determine. Research rather than monitoring.

Inte-gration Level	Geomorphology and Habitat	Data Analysis, Integration Activity	Data Available	Missing Data	Comments
04		1: Quantify habitat availability by habitat type used by all life stages of the rare fish.	From existing data, complex reach, larval, small bodied, adult, previous radio telemetry studies		
01		2: Determine the quantity and quality of nursery habitat.	Habitat and larval data sets		Larval study collects habitat quality data. Older habitat studies also have quality data.
01		3: Determine the spatial and temporal distribution of habitat.	Habitat data sets up to 2007	Need riverwide mapping to update	
01		4: Determine the spatial and temporal distribution of spawning habitat.	Data from spawning, Riverwide habitat and spawning habitat monitoring program up to 2005.		Data analysis of existing data. New monitoring protocol would update this data set.
01		5: Determine the year to year quantity of habitat.	Riverwide habitat mapping	Riverwide data for subset of habitat types	Data analysis of existing data. This is in the annual reports

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
					through 2007. 2008 report has trend with time. See question 10.
04		6: Determine the factors that affect habitat complexity.	Data analysis of existing habitat data	Literature review	
04		7: Determine the spatial distribution of spawning and nursery habitats.	Habitat data sets, previous radio telemetry studies	New radio telemetry to update locations	Available habitats can be done without radio telemetry. Actual use and checking search image requires telemetry
01		8: Determine habitat trends across years.	Habitat data sets		Data analysis currently in annual reports
Inte-gration Level	**Long term cross protocol synthesis and inte-gration**	**Data Analysis, Integration Activity**	**Data Available**	**Missing Data**	**Comments**
01		1: Determine whether population numbers for Colorado pikeminnow and razorback sucker in the Recovery Goals need to be adjusted.	Population model		See research question #7

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
01		2: Set criteria to begin mark-recapture population estimates.			See research question #7
02		3: Identify other abundance estimators and determine how to incorporate them into our sampling.		Literature review	CPUE or population estimators – currently using CPUE should go to population estimates
01		4: Determine the number of adult fish as a result of stocking.	Adult monitoring data, non-native removal data	Population estimates	Could make initial estimate as office exercise, then go to field data
02		5: Determine if the survival rate of stocked fish is sufficient to reach self sustaining population goals.	Non-native removal, adult monitoring		Initial estimate for razorbacks, not enough numbers for CPM.
04		6: Determine if survival rates can be increased.			Stocking experiments RZS, need recruitment for CPM
02		7: Evaluate the stocking program and protocols to ensure that we are stocking the “right” number of fish.			See 5 & 6
01		8: Determine how flow recommendations	2006 Integration report, preliminary G3 hydrology model runs, biological data sets	Final Gen3 hydrology model, data	

Inte-gration Level	**Larval fish**	**Data Analysis Integration Activity**	**Data Available**	**Missing Data**	**Comments**
		should be revised.		synthesis of monitoring data	
01		9: Determine if the biologic response to flows can be detected with the current monitoring protocols.			No
01		10: Determine if the changes in razorback sucker population by life stage over time can be detected by the current protocols.	Larval monitoring, small bodied monitoring, adult monitoring, non-native removal		
02		11: Determine if the San Juan River can support all the life history stages for the rare fish.			Yes but don't know if it is enough for self sufficiency
02		12: Determine how changes to spatial or temporal locations for data collection affect the statistical robustness of the data.	Larval data, small bodied data, adult data, habitat data		PI should check data

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SUMMARY OF DATA ANALYSIS, DATA SETS, AND ANALYSIS METHODS USED FOR FISH MONITORING PROTOCOLS

Life stage	Data analysis	Data sets used	Analysis method
	Species relative abundance (CPUE) by mesohabitat type	Larval capture	Mean, maximum, and standard error by year, trip, and habitat type
	Spatial and temporal species distribution	Larval capture, location data, geomorphic reach	Mean, maximum, minimum by year, trip, and habitat type for each geomorphic reach and by sampling period. Differences in mean CPUE are determined by species between years using a parametric or non-parametric one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made for each species and significance (i.e., $p<0.05$) is determined using the Tukey-Kramer HSD.
Larval	Species persistence of multiple ontogenetic life stages	Larval capture, location data, multiple years	Comparisons between years of spatial and temporal presence and CPUE of fish species by larval stage.
	Total length for all non-endangered fishes	Larval capture	Mean, maximum, and standard error by year, trip, and habitat type
	Length of all endangered fishes (SL and TL)	Larval capture	Length data reported for all fish captured
	Calculated spawning date for Colorado pikeminnow	Larval capture	Calculated hatching dates for larval Colorado pikeminnow using the formula: -76.7105+17.4949(L)-1.0555(L)2+0.0221(L)3 for larvae under 22 mm, where L=length (mm TL). For larvae 22-47 mm TL the formula A=-26.6421+2.7798L will be used. Spawning dates are then calculated by adding five days to the post-hatch ages to account for incubation time at 20 - 22oC (Nesler et al. 1988).

Life stage	Data analysis	Data sets used	Analysis method
	Calculated spawning date for razorback sucker	Larval capture	Hatch dates of razorback sucker larvae are calculated by subtracting the average length of larvae at hatching (8.0 mm TL) from the total length at capture divided by 0.3 mm (Bestgen et al. 2002), which is the average daily growth rate of wild larvae observed by Muth et al. (1998).
Small-bodied	Logitudinal occurrence	Small-bodied	Density (number per area sampled and + 2 SE)/species/geomorphic reach, and mean number (+ 2 SE) per habitat type. Between-year and reach differences evaluated one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made for each species and significance (i.e., $p<0.05$) is determined using the Tukey-Kramer HSD test and a nonparametric Analysis of Variance (Kruskal–Wallis test) for the various data sets to compare results to the parametric analyses. MANOVA used to relate occurrence with discharge attributes between years.
	Density of residents	Small-bodied	Density (number per area sampled) of each species by year and by habitat type for each geomorphic reach. Differences in mean CPUE are determined by species between years using a one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made for each species and significance (i.e., $p<0.05$) is determined using the Tukey-Kramer HSD test and a nonparametric Analysis of Variance (Kruskal–Wallis test) for the various data sets to compare results to the parametric analyses. MANOVA used to relate occurrence with discharge attributes between years.

Life stage	Data analysis	Data sets used	Analysis method
	Total length for all specimens	Small-bodied	Length-frequency histograms constructed for each species and ANOVA used to compare among year differences in size-structure of each species population.
	Mesohabitat associations for each species	Small-bodied and habitat	Occurrence of each species by mesohabitat plotted and use evaluated by ANOVA within each geomorphic reach. Differences in mean CPUE per mesohabitat are determined by species between years using a one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made for each species and significance (i.e., $p<0.05$) is determined using the Tukey-Kramer HSD test and a nonparametric Analysis of Variance (Kruskal–Wallis test) for the various data sets to compare results to the parametric analyses. MANOVA used to relate occurrence with discharge attributes between years.
	Physical attributes of mesohabitats	Habitat	Mean, maximum and minimum and standard error of measured habitat attributes (depth and substrate). Differences in mean habitat attributes are determined between years using a one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made using the Tukey-Kramer HSD test and a nonparametric Analysis of Variance (Kruskal–Wallis test) for the various data sets to compare results to the parametric analyses.
	Rare fish recapture data	Small-bodied	Individual measurements for each fish captured. Longitudinal distribution of rare fishes plotted.
	Colorado pikeminnow prey availability	Small-bodied	CPUE of suitable-sized native and nonnative prey per size class of CPM per reach.

Life stage	Data analysis	Data sets used	Analysis method
	Survival of age-0 fish	Small-bodied	Comparison of larval fish capture data, small-bodied capture data, and adult capture data.
Large-bodied	Riverwide occurrence (reaches and RMs occupied) and relative abundance for all collected fish species (CPUE)	Large-bodied	Total number collected and CPUE by species, and geomorphic reach, within and among years along with a measure of variability (2 SE = roughly a 95% confidence interval) riverwide and by geomorphic reach. Differences in mean CPUE are determined by species between years using a one-way Analysis of Variance (ANOVA). Pair-wise comparisons between years are made for each species and significance (i.e., p = 0.10 or less) is determined using the Tukey-Kramer HSD test.
	Representative length for all specimens	Large-bodied	Mean, maximum, and minimum TL by year along with a measure of variability (2 SE = roughly a 95% confidence interval) riverwide and by geomorphic reach.
	Rare fish capture data	Large-bodied and non-native	Individual measurements, tag data (e.g., PIT tag or anchor tag), and location for each fish captured; growth and movement
	Native to non-native fish ratios	Large-bodied	Ratios of native to non-native fish for adult large-bodied fish

Life stage	Data analysis	Data sets used	Analysis method
	Riverwide occurrence (reaches and RMs occupied) and relative abundance for all collected fish species (CPUE)	Non-native	Total number collected and CPUE by species, and geomorphic reach, within and among years along with a measure of variability (2 SE = roughly a 95% confidence interval) riverwide and by geomorphic reach. Differences in mean CPUE are determined by species between years using a one-way Analysis of Variance (ANOVA) (ranked data if data are heteroscedastic and transformations are unsuccessful in attaining equal variance). Pair-wise comparisons between years are made for each species and significance (i.e., p = 0.10 or less) is determined using Nemenyi post-hoc tests.
	Population estimates and exploitation rates	Non-native and large-bodied	Lincoln-Peterson population estimate and proportion of tagged fish recaptured