SAN JUAN RIVER BASIN RECOVERY IMPLEMENTATION PROGRAM

Final - San Juan River Standardized Monitoring Program Five Year Integration Report

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EXECUTIVE SUMMARY

The long-term monitoring program (Propst et al. 2000) requires data integration and synthesis at specified intervals. The purpose of this integration report is to 1) evaluate progress toward recovery of endangered fishes; 2) evaluate monitoring protocols; 3) evaluate the flow recommendations based on the monitoring data and 4) make recommendations, if needed, to monitoring protocols and flow recommendations.

The San Juan River Basin Recovery Implementation Program (SJRIP) has, as one of its two primary goals, the conservation of populations of Colorado pikeminnow and razorback sucker in the San Juan River basin. To aid in the evaluation of achievement of this Program goal, the following Monitoring Plan goals were developed (Propst et al. 2000).

1. Track the status and trends of endangered and other fish populations in the San Juan River.

2. Track changes in abiotic parameters, including water quality, channel morphology, and habitat, important to the fish community.

3. Utilize data collected under Goals 1 and 2 to help assess progress toward recovery of endangered fish species.

The first data integration and synthesis of the monitoring program was separated into three parts. First, evaluate the abiotic factors in the San Juan River that are important to the fish community; second, evaluate the status and trends of endangered fish and other fish populations in the San Juan River; and third, use the data collected under the first items to help assess progress towards recovery of endangered fish species. Evaluation of progress towards recovery is a U.S. Fish and Wildlife responsibility. The population data presented herein is intended to assist them in that effort.

There is a substantial effort required after data collection for data entry, analysis and presentation for each monitoring protocol. The deadline for data analysis and draft reports is March 31 of the year following data collection. The exception to this is habitat mapping which lags by an additional year after data collection. The Biology Committee decided to include the data for 1999-2003 for biological monitoring (i.e. larval, small bodied and large bodied fish) and data for 1999–2002 for physical habitat data. The analysis in this report reflects those respective time periods. Annual reports are available on the SJRIP web site.

Habitat Response to Flows

Abiotic parameters that influence the quantity and quality of aquatic habitat have been monitored from 1992 to present. Data used in this report is from the period 1998-2002. The changes in physical conditions were assumed to affect the fish community. The goal of the abiotic monitoring program was to track changes in abiotic parameters, including water quality, channel morphology and habitat important to the fish community.

Water quality remains good even during the drought of the past few years. Selenium concentrations remain low in the mainstem, with most readings below detection limits. The operation of Navajo Dam has had an impact on water temperatures in the designated critical habitat for the Colorado pikeminnow and razorback sucker. The results of detailed temperature modeling being completed by the Bureau of Reclamation are not yet available. The general impact of the Navajo Dam releases is to slightly warm the water in winter months and cool it in the summer months, particularly during peak release (Bliesner and Lamarra 2002, Bliesner 2004). There is a relatively substantial temperature suppression during July – September. No other water quality concerns were identified during 1999-2003.

There has been no significant change in any habitat category except backwater and low velocity categories which have declined. Channel complexity can be inferred from island count which did not change significantly between 1992 and 2002, except in Reach 4. The data indicate that there has been no loss of bank full channel width or complexity as a result of implementation of the flow recommendations. Although the channel is narrower now than pre-dam, it appears that the trend toward narrowing has flattened or stopped since 1988.

There is no significant loss of base flow channel width with time, although there is a slight narrowing and deepening of the channel at the 10 cross sections measured in Reaches 3-6. This slight narrowing of cross-sections at control locations may have contributed to the reduction in base flow island count in Reach 4, the only reach with a significant reduction in base flow island count. Habitat complexity was also assessed by the change in habitat richness (number of mapped habitats per reach) with time. There is no statistically significant trend with flow or time and the analysis indicates that there has been no change during 1998-2003.

The impacts to habitat for endangered fish from the reduction in backwater and low velocity habitat is unknown at this time. The biological monitoring has documented reproduction and an increase of razorback sucker larvae during the monitoring period. Further investigations have started and changes to the monitoring program instituted that will combine examination of habitat use, habitat complexity and habitat availability for endangered and native fish in the San Juan River at concurrent locations.

Status and trends of endangered fish and other fish populations

One of the objectives of the standardized monitoring program is to track the status and trends of endangered and other fish populations in the San Juan River. There are three specific fish monitoring protocols designed to track the status and trends. These are: 1) large-bodied (sub-adult and adult) monitoring, 2) Larval fish monitoring, and 3) Small-bodied fish monitoring.

The large-bodied fish monitoring program has documented an increase in Colorado pikeminnow and razorback sucker in the river over the monitoring period, likely the result of the continued stocking and successful survival and growth of those fish. These two species also have been collected more frequently during the non-native removal efforts in the more recent years than in the past. Several Colorado pikeminnow in the sub-adult age class were captured. Colorado pikeminnow and razorback sucker used the fish ladder at the PNM weir and were passed upstream with access to the upper San Juan near Farmington, New Mexico.

Flannelmouth sucker and bluehead sucker continued to be the most abundant species collected during large-bodied fish sampling. A large cohort of age 0 suckers was documented in 2000 and those fish recruited to older age classes with time.

The two most numerous non-native species, channel catfish and common carp, were still present with little change in abundance during 1998-2003. Channel catfish populations do have a different size structure and lack the very large individuals (> 450mm) that were present prior to the non-native removal efforts. The dominant non-native species collected during small-bodied and larval collections are red shiner and fathead minnow.

The objective of the larval fish monitoring is to document reproduction by the endangered Colorado pikeminnow and razorback sucker. Colorado pikeminnow larvae were collected in 2001. Razorback sucker larvae have been collected each year since 1998. The larval collections also have documented juvenile razorback that were spawned in the river. This was the first documentation of razorback sucker recruitment from young of the year to juvenile life stages.

The small-bodied fish monitoring protocol was designed to detect the young of the year and juvenile Colorado pikeminnow and razorback sucker as well as other fishes. This sampling effort collected small Colorado pikeminnow in 1998 and 1999 but none during 2000-2003. No razorback sucker were collected during small-bodied fish sampling during 1998-2003. Of the other native species, flannelmouth sucker, bluehead sucker and speckled dace were captured every year during 1998-2003. Both sucker species showed an increase in abundance. Speckled dace abundance varied but there is no apparent population trend. The two species most frequently collected during small-bodied fish monitoring were red shiner and fathead minnow. These two species also were the most abundant species captured by larval sampling in low velocity habitats.

Significant differences in Catch Per Unit Effort (CPUE) were found between at least two years for all common species and age classes. Among the two listed species, adult Colorado pikeminnow and juvenile razorback sucker did not show any significant differences among years. Significant increasing trends in CPUE were found for juvenile bluehead sucker, juvenile common carp, and adult razorback sucker. Significant decreasing trends in CPUE were found for adult bluehead sucker, adult and juvenile channel catfish, adult common carp, and juvenile Colorado pikeminnow.

A statistical analysis was completed to evaluate large-bodied and small-bodied sampling effectiveness at detecting changes in population trends. Analyses indicated that current large-bodied sampling efforts were able to detect annual changes in CPUE of 20% or greater for all but juvenile channel catfish (26.7%) among the four common species. There were not enough Colorado pikeminnow or razorback sucker captured to complete a power analysis. Statistical analyses indicated that the current small-bodied sampling efforts were able to detect changes of 30% or less for one native (speckled dace) and four non-native species for sample size of 400. For changes of 20%, detection would be possible for only two species (speckled dace and red shiner) for 400 samples. Currently, small-bodied fish sampling collected less than 150 samples annually in 1998-2002 and 394 samples in 2003.

Evaluation of Progress toward Recovery

The third part of the integration report was to use the data collected under Monitoring Goals 1 and 2 to help assess progress towards recovery of endangered fish species. Progress toward recovery of the two listed species will ultimately be evaluated by collections of those species. At this time, the numbers of the two species are too low for most analyses. Larval, juvenile and adult razorback sucker were collected in all years. Stocked Colorado pikeminnow were collected most frequently in the last two years. There is some evidence that young-of-the-year Colorado pikeminnow stocked several years ago grew to sub-adult size. Adult Colorado pikeminnow were collected in very low numbers. It is expected that as the stocked fish grow and recruit to subsequent life stages, adult Colorado pikeminnow captures will increase. Until that time, the progress toward recovery was inferred from other portions of the monitoring program, including the relationships between fish density and habitat characteristics. There were two initial hypothesis stated for evaluation of the fish and habitat relationships. The first hypothesis, that fish densities were correlated to habitat characteristics, can be evaluated with the existing monitoring datasets. The second hypothesis, that spatial and temporal changes in habitat were correlated to fish densities, requires a longer record of monitoring data and can not be statistically tested at this time.

Evaluation of Initial Hypotheses

> Hypothesis 1: Fish densities are correlated to habitat characteristics.
>
> Hypothesis 2: Spatial and temporal changes in habitat are correlated to changes in fish densities.

Assessment towards Recovery

> Hypothesis: The flow recommendations and other management actions are appropriate for recovery of endangered fish.
>
> Hypothesis: The status of the endangered fish is moving toward recovery.

Hypothesis: The recovery goals for the San Juan River have been met.

It is apparent from the three statistical approaches used in this analysis that there are significant habitat factors (taken singularly, in combination, or transformed by Principle Components) that predict the spatial distribution of native and non-native species by life stage in the San Juan River. Significant relationships were found for each year from 1998 through 2002. Common habitat-based parameters were found between each year.

The evaluation of progress toward recovery of endangered fish is the responsibility of the U.S. Fish and Wildlife Service. The data presented herein and from other areas of the program are used by the Fish and Wildlife Service to determine progress toward recovery.

CONCLUSIONS

The current monitoring protocols have several objectives and sub-objectives for each protocol. The physical habitat protocols, as set during the initial monitoring period, met the objectives and tracked changes in selected water quality parameters. The protocols determined changes in channel morphology and substrate composition. The protocol determined changes in cobble bar characteristics and determined trends in quantity and quality of low velocity habitats. All of the stated objectives were met with the current protocols; however, since these protocols were not conducted concurrently with fish sampling, there was difficulty in linking direct response of change in habitat with change in fish populations or fish habitat use. Recommendations have been made to allow that direct comparison of habitat use and habitat availability.

The biological monitoring protocols include larval fish sampling, small-bodied fish sampling and large-bodied fish sampling. The larval fish sampling is designed to determine relative annual reproductive success of Colorado pikeminnow and razorback sucker. The larval protocols, as designed, are able to detect reproductive success for Colorado pikeminnow and razorback sucker. These protocols will continue as they currently exist to continue the monitoring of those populations.

The small-bodied fish and large-bodied fish sampling can detect relative changes in populations although the level of detection differs by protocol. Small-bodied fish sampling can detect changes of 40% or greater with the current sample numbers and the large-bodied fish sampling can detect changes in trends of 20% or greater for the large-bodied abundant species. Both of these protocols will continue. The suggested change to the small-bodied protocols is listed in the recommendations to allow a detection of relative abundance at a lower percent change in population.

Habitat, Channel Morphology, and Water Quality

- Backwater habitat type has shown a significant reduction with time during 1998-2002
- There was no change in other habitat types.

- The current habitat monitoring protocol does not collect habitat concurrent with fish collections.
- There is no means to directly compare fish use of specific habitat types.
- There was no change in channel width during the monitoring period.
- There appeared to be no change in channel complexity.
- There were no significant changes in water quality shown during the monitoring period.
- Navajo dam water release temperature causes a 2-3°C decrease in water temperature in the San Juan River at Farmington during summer months and a slight increase in winter months.
- There is a delay in reaching 20ºC by approximately 2 weeks due to Navajo Dam release temperatures at this location.
- Impacts further downstream could not be determined without use of a temperature model.
- During the 1998-2003 monitoring period, the recommended conditions for flows of 8,000 cfs and 10,000 cfs did not occur primarily due to drought conditions in the basin. The flow recommendations specify criteria for flow magnitude, duration and recurrence. The recommended number of years between occurrences of these high-flow conditions was not exceeded during 1998-2003. While the flow recommendations were met during this period, it was not possible to test the habitat response to these high flow conditions.
- The desired 2,500 cfs and 5,000 cfs flows did occur, however, the expected habitat response to these flows was not seen.
- Further investigation in the habitat-flow response is needed.

Endangered Fishes and Fish Community

- The larval sampling regime did not collect Colorado pikeminnow during the 1998 – 2003 monitoring period.
- Few Colorado pikeminnow were collected by the small bodied monitoring in 1998 – 2000 and none were collected in 2001-2003.
- Colorado pikeminnow were collected in the large bodied fish monitoring.
- Wild spawned razorback sucker larvae were collected in all years 1998- 2003.
- No young of the year razorback sucker were collected during small bodied fish monitoring.
- Juvenile and adult razorback sucker were collected during adult fish monitoring.
- The large bodied fish monitoring protocol can detect changes in relative abundance as low as 20% for flannelmouth sucker, bluehead sucker, channel catfish and common carp.
- The small bodied fish monitoring protocol can detect changes in relative abundance as low as 20% for red shiner and speckled dace.
- Minimum change detectable for native suckers is approximately 40%.
- The current fish monitoring protocols, with the exception of small bodied fish starting in 2003, do not collect fish by specific habitat type.

- The lack of habitat specific collections precluded a direct analysis of fish response to habitat changes.

RECOMMENDATIONS

Based on the results of the 1998-2003 data, the following recommendations were made:

Habitat

- Continue annual habitat monitoring river-wide during fall low flows.
- Add two complex reaches to conduct detailed fine scale habitat mapping concurrent with Colorado pikeminnow and razorback sucker monitoring.

Channel Morphology

- Survey channel cross sections every five years after spring runoff instead of semi-annually before and after runoff.
- Collect topographic survey data and develop 2-D Models of the reaches selected for detailed habitat mapping

Water Quality

- Discontinue water quality sampling beginning in 2005 with the exception of turbidity and water temperature.
- It should be the responsibility of each applicant undergoing Section 7 consultation to provide USFWS with any water quality data required as a condition of their consultation.

Fish Monitoring

- Larval monitoring should continue using the current protocol.
- Large bodied fish monitoring should continue using the current protocol.
- Population estimates should become part of the monitoring as Colorado pikeminnow and razorback sucker become more abundant.
- Small bodied fish monitoring should continue with the following adjustments:
    - Continue the basic protocol and collect 400- 450 samples per year by habitat type
    - Continue the block and shock technique started in 2004
    - Initiate a block and seine technique for a 3 year test with annual review at each winter meeting during the test period.

Flow Recommendations

- Investigate the ability to obtain high peak flows (i.e. greater than 8,000 and 10,000 cfs) during runoff more frequently than currently recommended.
- As part of the above investigation, change the shape of the ascending and

descending limb of the hydrograph and do not try to meet the 2,500 cfs and 5,000 cfs flow recommendations.

- Use the Riverware model as the method to make the above determination.

Integration Report

- Data collection for habitat and fish should be better coordinated during the monitoring to improve the ability to integrate multiple data sets from separate studies.

- The next integration report should be completed in 2009 for monitoring data 2004-2008.

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INTRODUCTION

The long-term monitoring program for the San Juan River Basin Recovery Implementation Program (SJRIP) (Propst et al. 2000) calls for a data integration and synthesis report covering the monitoring data from 1998-2001 in conjunction with data used to prepare the research period final report and the flow recommendation report. This report covers the monitoring completed under the SJRIP from 1998 through 2003. All principle investigators responsible for monitoring were included in this data integration process.

The monitoring program was designed to track changes in fish abundance over time. This includes all life stages and species and, in particular, the two endangered species. These abundance data are made available to the U.S. Fish and Wildlife Service to assist them in evaluating progress toward recovery.

This is the first integration of the standardized monitoring program for the SJRIP. The synthesis and integration of monitoring was to be completed by the individual investigators for each monitoring protocol in 2002 but, due to delays within the SJRIP, was completed in 2005. The monitoring data include adult, juvenile and small-bodied fish community, larval drift, habitat, geomorphology and water quality. The individual investigators responsible for each component completed reports on the five years of monitoring and, where applicable, made comparisons with the earlier research conducted during the seven-year research program.

The SJRIP has, as one of its two primary goals, the conservation of populations of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) in the San Juan River basin. To aid in the evaluation of achievement of these Program goals, the following Monitoring Plan goals were developed by Propst et al. (2000).

1. *Track the status and trends of endangered and other fish populations in the San Juan River.*

2. *Track changes in abiotic parameters, including water quality, channel morphology, and habitat, important to the fish community.*

3. *Utilize data collected under Goals 1 and 2 to help assess progress towards recovery of endangered fish species.*

Meeting these program goals will be accomplished by achieving the following objectives. These objectives form the foundation for the monitoring actions identified. Objectives are listed as they relate to each of the three SJRIP Monitoring Plan goals.

1. *Track the status and trends of endangered and other fish populations in the San Juan River;*
    a. *determine relative annual reproductive success of Colorado pikeminnow and razorback sucker and*

b. determine population trends, including size-structure, of adult and juvenile fishes of the San Juan River.

2. *Track changes in abiotic parameters, including water quality, channel morphology, and habitat, important to the fish community;*
    - *a. track changes in selected water quality parameters,*
    - *b. determine changes in channel morphology and substrate composition,*
    - *c. determine changes in cobble bar characteristics, including suspected and potential spawning bars,*
    - *d. determine trends in quantity and quality of low-velocity habitats, and*
    - *e. determine trends in habitat diversity and abundance.*

3. *Utilize data collected under Goals 1 and 2 to help determine progress towards recovery of the endangered fish species.*
    - *a. produce annual summaries of monitoring results and*
    - *b. provide detailed analyses of data collected to help determine progress towards endangered species recovery in 3 years and thence every 5 years.*

INTEGRATION OBJECTIVES AND HYPOTHESES

The overall integration objectives and hypotheses formulated for this assessment for the first five years of the monitoring program were separated into three parts. First, evaluate the abiotic factors in the San Juan River that are important to the fish community; second, evaluate the status and trends of endangered fishes and other fish populations in the San Juan River; and third, use the data collected under the first items to assess progress towards recovery of endangered fish species. At the July 16-17, 2003 Biology Committee meeting, goals and hypotheses were identified to test progress of the Program. The following sections provide a synthesis and integration of those evaluations for the monitoring programs.

Habitat Response Objectives And Hypotheses

Monitoring Protocol Goal 2 (Propst et al. 2000) states: “Track changes in abiotic parameters, including water quality, channel morphology and habitat, important to the fish community.” Under that goal, four hypotheses were stated: (1) no significant change in habitat parameters, (2) no significant change in water quality, (3) no significant change in channel complexity, (4) No significant alteration of habitat from the flow recommendations.

Fish Community Objectives and Hypotheses

The objective of the standardized monitoring program is to track the status and trends of endangered and other fish population in the San Juan River. There were two hypotheses for native fish populations to evaluate the flow recommendations and recovery actions; 1) No significant change in native fish populations, and 2) No significant change in endangered fish populations.

The non-native fishes are collected in conjunction with the native fish monitoring. There is one hypothesis to evaluate the response of non-native fish to the flow recommendations and recovery actions; No significant change in non-native fish populations

Recovery Progress Objectives

Population goals for both Colorado pikeminnow and razorback sucker were established for the San Juan River (USFWS 2000). Progress toward recovery of the listed fishes in the San Juan River is determined from biological response of those species to flow recommendations with the ultimate response resulting in populations reaching the specified population level. The objective of this task was to determine if populations: 1) are increasing riverwide, and 2) have met the specified population level.

Evaluation of Monitoring Protocol Objectives

Each monitoring protocol has specific objectives (Propst et al. 2000). The evaluation of monitoring protocols was to determine if the current protocols meet the specific protocol objectives and provide data to determine the status and trends for abiotic factors, the endangered fish and other fish in the San Juan River.

Flow Recommendation Evaluation Objectives

The objective for evaluating flow recommendations was to determine if the current flow recommendations are resulting in the responses expected in habitat as well as fish populations. We expected that the elements of the flow recommendations would either alter or maintain habitat as predicted with the initial flow recommendations. A goal of the flow recommendations was to increase endangered fish and other native fish populations.

METHODS

INTEGRATION REPORT

Two subgroups, biological and physical habitat, were established for completion of the integration report. Each subgroup was composed of Biology Committee members, principal investigators and peer review members were encouraged to attend. The membership was based on primary responsibilities during monitoring activities.

Biological Subgroup: Fish and Wildlife Service, New Mexico Game and Fish, University of New Mexico, Utah Dept. of Wildlife Resources, Drs. Ross and Ryel, Miller Ecological Consultants, Inc.

Physical Subgroup: Keller-Bliesner Engineering, Ecosystems Research, Bureau of Reclamation, Fish and Wildlife Service, Miller Ecological Consultants, Inc., Drs. Pitlik, Ryel, and Wesche.

Each investigator prepared a summary report of individual findings covering the 1998-2001 period and, where applicable, compared those findings to the 1991-1997 research final reports. The data presented in annual monitoring reports for 2002 and 2003 also were included in this integration report. In addition, each investigator contributed a summary that evaluated the progress towards recovery, flow recommendations, and monitoring plan.

The integration report process of the standardized monitoring program included the following three phases: 1) a draft report for the Biology Committee and Peer Review panel; 2) a draft final report to be submitted to the Biology Committee, Peer Review Panel and Coordination Committee; and, 3) a final report on the integration and synthesis of the first five years of the standardized monitoring program.

The following approach was used for analysis and integration of the monitoring data, evaluation of the flow recommendations, and evaluation of Standardized Monitoring Plan.

1. <u>Data analysis.</u> Each investigator evaluated data collected in each study for the Standardized Monitoring Plan. The individual investigators were responsible for integration with previously collected data, where applicable. The extended dataset was used to assess relationships to flow and assist the evaluation of progress toward recovery. Conclusions reached for the Flow Recommendations were evaluated with the monitoring results and changes explained. Specific methods for each monitoring protocol were presented in each monitoring report.

2. <u>Integration of findings of all studies</u>. Group data exchange and analysis meetings were held among individual researchers, including participation with appropriate peer reviewers, to explore relationships between study findings.

3. Evaluate and update flow recommendations based on new findings. Based on the response of geomorphology, habitat and fish community to flows since implementation of the flow recommendations, the original basis of the flow recommendations were evaluated.

4. Evaluate and update Standardized Monitoring Plan. The Standardized Monitoring Plan was reviewed and updated, as needed, based on the integrated findings.

HABITAT RESPONSE ANALYSIS METHODS

The annual reports for channel morphology, habitat mapping, and water quality provide a detailed description of the field methodologies (Bliesner and Lamarra 2002). A full description of the analysis methods and results for habitat response analysis is provided in Bliesner (2004).

Habitat Methods

Twenty-seven individual habitat parameters, grouped in seven categories, have been mapped for over ten years (Table 1). An eighth category, consisting of low velocity and backwater types, without pool habitat was developed after analyzing the data.

The reach from RM 82 to 158 was mapped annually from December 1992 through 2002 (Figure 1). The river from Clay Hills (RM0) crossing to Farmington (RM180), NM was mapped annually from October 1993 to present. USGS gage flow data for the dates of mapping were used to develop the flow at each river mile mapped and the average flow computed for each reach. These flow data were used in the regression analysis.

Regression analyses were completed for all habitat types except vegetation associated types, which are more typically associated with high flow conditions, to generate flow/habitat relationships. The predicted habitat area for the given flow conditions on each date were subtracted from the measured habitat area and the residual plotted against date to determine change with time.

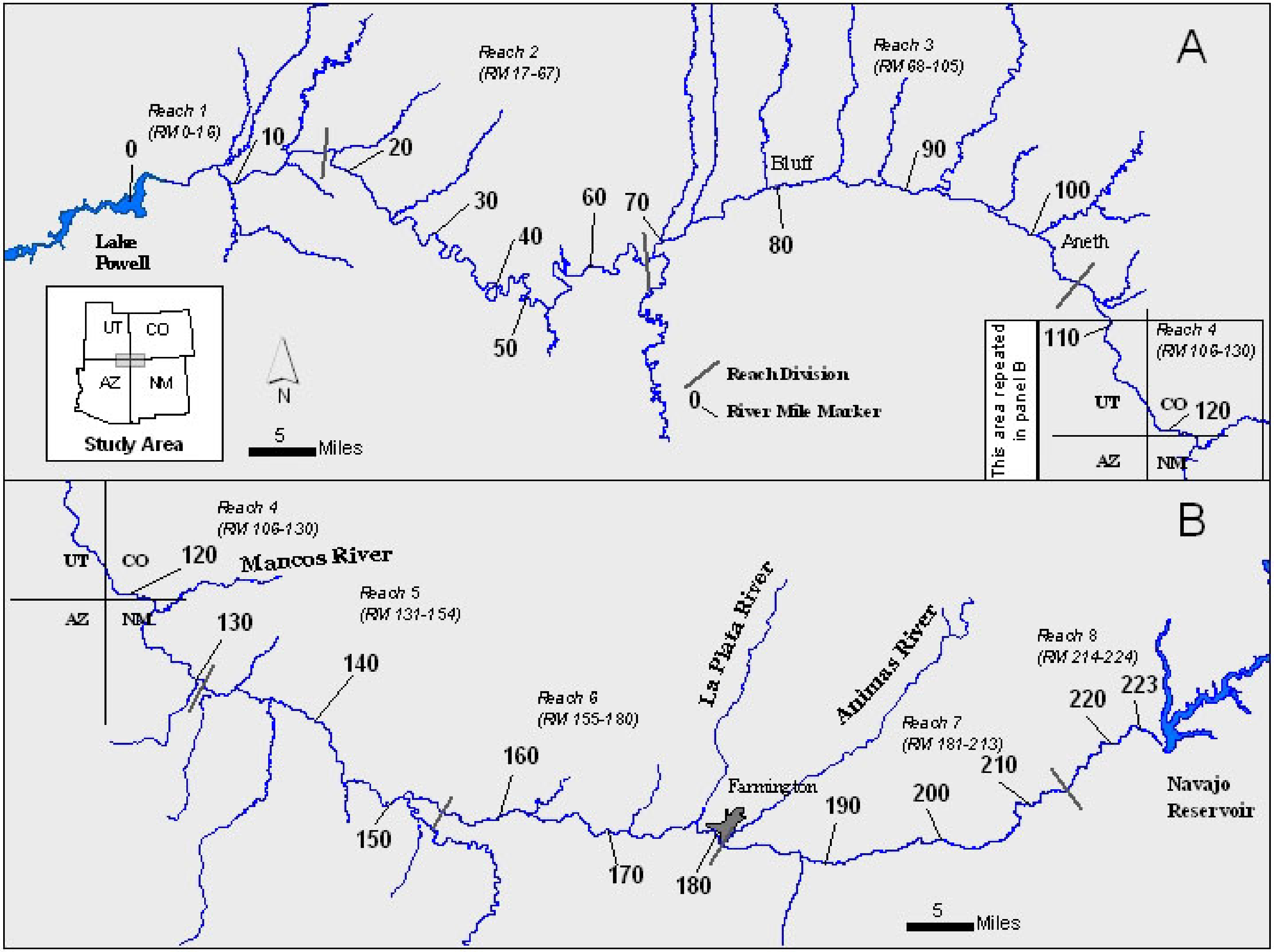


Figure 1. San Juan River montiroing study area.

Table 1. Seven general habitat categories used in habitat analysis in the San Juan River.

RUN TYPES	RIFFLE TYPES	BACK-WATER TYPES	LOW VELOCITY TYPES	SHOAL TYPES	SLACK-WATER TYPES	VEGETATION ASSOCIATED HABITAT TYPES
shoal/run	Riffle	backwater	pool	sand shoal	slackwater	overhanging vegetation
run	shore riffle	backwater pool	debris pool	cobble shoal	pocket water	inundated vegetation
scour run	riffle chute	embayment	rootwad pool			
shore run	shoal/riffle		eddy			
undercut run	chute		edge pool			
run/riffle	rapid		riffle eddy			

Water Quality Methods

Water quality samples were collected quarterly at 12 sites in the San Juan River (Bliesner, 2004) and key tributaries in February, May, August, and November. The 1994-2003 data set has been analyzed for trends in concentration of parameters with time and for violations of the New Mexico chronic water quality standards for warm water fisheries.

Water temperature monitors collected daily maximum, minimum, and mean water temperatures on the San Juan River at Navajo Dam, Archuleta, Farmington, Shiprock, Four Corners, Montezuma Creek, and Mexican Hat and on Animas River at Farmington. Data from the Animas at Farmington and San Juan at Farmington stations were used to determine the impact of Navajo dam operation on water temperature.

Channel Complexity Methods

Large scale channel change determined from an assessment of the bank full channel area and island count from the 1930s to 1998 was based on interpretation of aerial photography in the early 1930s, early 1950s, early 1960s, 1986-88 and 1998. Short-term change in base flow channel configuration was assessed utilizing cross-section measurement data and the habitat mapping data.

STATUS AND TREND OF ENDANGERED AND OTHER FISHES METHODS

Endangered fishes and other fishes were evaluated from data summarized in individual monitoring reports. There are three specific fish monitoring protocols designed to track the status and trends of fishes in the San Juan River. These are: 1) Sub-adult and adult monitoring, 2) Larval fish monitoring, and 3) Small-bodied fish monitoring. Details of each sampling protocol are presented in Propst et al. (2000). The two primary capture techniques are seining (for larval and small-bodied fishes) and electrofishing (for large-bodied fishes). Data from each fish monitoring program were summarized to present the combined data as percent relative abundance for key species and catch-per-unit-effort (CPUE).

Relative abundance metrics for each sampling protocol differ by collection technique. Data from seining is reported as number of fish per area sampled. Data from electrofishing are presented as number of fish per unit time of electrofishing. The data from the three fish monitoring programs individually show status and trends for each life stage. Integration across the monitoring programs requires a common metric. Analyses were conducted for the most common species which included bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnus*), channel catfish (*Ictalurus punctatus*), and common carp (*Cyprinus carpio*), and for the two endangered species targeted in recovery efforts, Colorado pikeminnow and razorback sucker.

EVALUATION OF MONITORING PROTOCOLS

Statistical Review of Fish Monitoring Protocols

Large-bodied fish

Population changes and trends of large-bodied fishes captured by electrofishing were assessed over the fall monitoring period 1999-2003. The analyses included assessing changes and trends in catch rates of adults and juvenile fish and changes in length frequency of adults. Analyses were conducted for four common species (bluehead sucker, flannelmouth sucker, channel catfish and common carp) and for the two endangered species targeted in recovery efforts, Colorado pikeminnow and razorback sucker.

Statistical tests were conducted to assess change in catch rates (CPUE, fish/hr electrofishing) among years (1999-2002) and to assess trends (increasing, decreasing or no change) for adult and juvenile fishes. It was hypothesized that significant trends or differences in population sizes would reflect actual changes in fish abundance.

Analysis of variance (ANOVA) and analysis of covariance (ANCOVA) were used to assess changes among years and trends, respectively, for adult and juvenile fishes. Each electrofishing sample run (year) was considered to be an independent sample. ANOVA tests performed for each species and age group (adult, juvenile) were blocked by reach and year. ANCOVA tests were blocked by reach using time (year) as a covariate. CPUE for both analyses were natural logarithm transformed (ln[x+1]) to reduce differences in variance among cells of the ANOVA (variance was usually related to the mean CPUE). The Tukey-Kramer multiple-comparison test was used to test among years for differences in CPUE when the overall ANOVA was significant for the factor, ‘year’. Increasing or decreasing trends were considered significant if the regression coefficient for slope for ‘year’ in the ANCOVA was significantly different than 0.0. All tests were conducted at $p < 0.05$. A power analysis was also conducted to determine what annual change in CPUE was necessary for detecting significant changes in populations.

Mean lengths of adults were compared using ANOVA, blocked by reach and year for each species. The Tukey-Kramer multiple-comparison test was used to test among years for differences mean length when the overall ANOVA was significant for the factor, ‘year’. The Kolmogorov-Smirnov test for distributions was used to test for differences in the shape of the distributions. Distributions of length with similar means can have quite different shapes, but a simple test of means would not detect this difference. All tests were conducted at $p < 0.05$.

Small-bodied fish

Data collected for small-bodied fishes from seine hauls were assessed to determine changes among years in catch rates. These same data were used to determine power of this protocol to detect change in populations.

Among year comparisons were conducted for the period 1998-2003 using analysis of variance (ANOVA), blocking across year and reach ($p \leq 0.5$). Tukey-Kramer multiple comparisons were used to determine significant differences between pairs of years ($p \leq 0.5$). Densities were ln(x+1) transformed prior to analysis to reduce the heterogeneity of variance among cells in the ANOVA. Further blocking by habitat or primary and secondary channel was not conducted due to collections not being separated by mesohabitat from 1998 through 2002. It was assumed for this analysis that samples were collected in habitats in proportion to availability.

Because reaches 1 and 6 were not sampled in 1998, two separate ANOVA analyses were conducted; one covering the period 1998-2003 for reaches 2-5 and one for the period 1999-2003 for reaches 1-6. An analysis was conducted to assess the variation among samples using the old and new method of quantification for ln (density+1). Lumped samples may increase variation among samples due to lumping across disparate habitats, while samples reported from each individual habitat may help to reduce variation. The coefficient of variation among individual samples (st. dev. / mean * 100) and for estimated means (st. err. / mean *100) were calculated using all samples for each year 1999-2003 when reaches 1-6 were sampled.

EVALUATION OF FLOW RECOMMENDATIONS

Fish-Habitat Relationships

As part of the data integration process, an attempt was made to statistically relate the geomorphic habitat mapping data with the adult monitoring data from 1998 to 2002 (Lamarra 2004, Appendix III). Data from 1998 through 2002 were best suited for complete analysis because both data sets were spatially complete (River Mile 180 to River Mile 2) and collected at comparable times. The analysis on the five years of data followed three lines of investigation.

The first analysis involved the determination of the possible linear interrelationships between all parameters. These interrelationships were determined with a Pearson's Correlation Matrix for all sixty seven (67) parameters. Significance was set at $p \leq 0.05$.

The second line of investigation utilized step-wise multiple linear regressions in an attempt to define the habitat variables or combination of variables which were significantly related to the spatial distribution of fish densities (catch per unit effort or CPUE). This analysis was done at several levels of resolution starting at a riverwide analysis followed by individual river reaches.

The final analysis also utilized step-wise multiple linear regressions with the same five fish groups as dependent variables. However, instead of areas of individual habitat categories (e.g. riffle, run, backwater) as the independent variables, the habitat data were used to develop variable loading axis via Principle Components Analysis (PCA). The concurrent PCA case scores calculated from the habitat data within the individual axis "models" were then used in the regression analysis as the independent variables in the multiple regression analysis.

The main objective of the pair-wise analysis between fish CPUE and the surface area of habitats was to determine if fish abundance could be predicted by singular habitat abundances within the San Juan River. The Pearson's Correlation Matrix was used to infer relationships between fish CPUE (as a dependent variable) and the Specific or General Habitat parameters (used as independent variables).

Habitat-Flow Response Methods

The response of habitat to the flow recommendations was assessed by examining the relationship between backwater and low velocity habitat and flow parameters during the research and monitoring periods (1993 through 2002). Sediment depth in backwaters was also compared to flow parameters and habitat conditions to determine the effect of flow on sediment depth and the influence of sediment depth on backwater habitat area. Cobble bar condition was assessed by measured depth and area of open interstitial space in designated bars in the system.

RESULTS AND DISCUSSION

HABITAT RESPONSE ANALYSIS 1992-2002

Habitat

Hydrology, habitat and channel morphology data collected during the research period, 1992-1997, were used to develop flow recommendations that were assumed to improve or maintain habitat quality and channel complexity. Prior to implementation of the flow recommendation there were large runoff events in 1985 and 1987. In fact, these events were larger than those in either 1993 or 1995, the two highest flow years in the study period. Further, both of these flow events occurred before implementation of the flow recommendations in 1999. Both 1993 and 1995 were test years with somewhat modified release patterns relative to the final recommendation. The same is true for 1997, the last year that the high flow criteria were met.

Data collected in the monitoring program were intended to test the hypothesis of no change in habitat. Since flows during the research period have met the flow recommendations, this report utilizes all data collected between 1992 and 2002, including the 1999 to 2002 monitoring data, in testing the hypotheses. The 1999-2002 data set is too small to allow significance testing. Where available, 2003 data have also been included.

The response of backwater and low velocity habitat to flow for this short period of record was difficult to discern. Only backwater habitat and backwater plus other low velocity (without pools) showed a significant reduction with time (Table 2). Island count also showed a significant reduction in Reach 4, but not in any other reach or for the mapped reach as a whole. No other habitat category showed a significant trend with time for the period analyzed. Based on just the 1991 to 2002 data, it appears that the hypothesis of no change is rejected for backwaters and backwaters combined with other low velocity habitat.

Table 2. Regression results for the residuals[1] of each habitat-flow relationship with time for ten habitat categories.

Reach	1	2	3	4	5	6	1-6	3-6	RM 87-158	Notes
Backwater type	73% Decrease $R^2 = .81$ p<.01	57% Decrease $R^2 = .64$ p<.03	No significant change	No significant change	76% Decrease $R^2 = .82$ p<.01 1991-2002 02=62 area	24% Decrease $R^2 = .85$ p<.01	51% Decrease $R^2 = .64$ p=.04		87% decrease $R^2 = .73$, p<0.01	Reaches 3, 4, 5 and RM 87-158 from 1991 to 2002. Remainder 1993-2002. 1991 data from USBR video survey vs on-ground mapping for later data. Most relationships show initial decrease with flat response later. Reach 5 1961 backwater mapping at 325 cfs about the same area as 2002 at 390 cfs.
Other Low Velocity Type	No significant change	No significant change	No significant change	No significant change	No significant change	Decrease R^2=.61, p=0.04	No significant change		No significant change	Reaches 4 & 5 1992-2002, balance 1993-2002
Backwater + Low Velocity - Pool type	Decrease, then stable R^2=.87 p<0.01	No significant change	No significant change	Decrease then stable R^2=.55 p=0.04	Decrease then stable R^2=.72 p<0.01	Decrease then stable R^2=.81 p<0.01	Decrease then stable R^2=.66 p=0.02		Decrease then stable R^2=.68 p=0.01	Reaches 4 & 5 1992-2002, balance 1993-2002
Slackwater type	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change			Reaches 4& 5 1992-2002, balance 1993-2002
Shoal type	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change			Reaches 4 & 5 1992-2002, balance 1993-2002
Riffle Type	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change			Reaches 4 & 5 1992-2002, balance 1993-2002
Run Type	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change	No significant change			Reaches 4 & 5 1992-2002, balance 1993-2002
Total Wetted Area	Increase, decrease, no net change $R^2 = .61$ p = .04	No significant change	No significant change	No significant change	No significant change	No significant change		No significant change	No significant change	Reaches 4, 5, RM 87-158 1992-2002, balance 1993-2002
Island Count	n/a	n/a	No significant change	35% decrease $R^2 = .73$ p < .01	No significant change	No significant change		No significant change	No significant change	Reaches 4, 5, RM 87-158 1992-2002, balance 1993-2002
Sand Fraction	n/a	low 94-96 end = beginning $R^2 = .73$ p<.01	low 94-95 end = beginning $R^2 = .78$ p<.01	low 94-95 end = beginning $R^2 = .80$ p<.01	low 93-94 end = beginning $R^2 = .52$ p = .05	low 93-95 end > beginning $R^2 = .59$ p = .06		low 93-95 end = beginning $R^2 = .79$ p<.01	low 93-95 end = beginning $R^2 = .77$ p<.01	Reaches 4, 5, RM 87-158 1992-2002, balance 1993-2002

[1]Residual equals predicted habitat subtracted from measured habitat.

Note: Sand fraction numbers are years (e.g. 94-96 = 1994-1996).

Water Quality

Trends of the constituents with time were examined by linear correlation. There were no statistically significant trends for this data set. During the drought years in the latter part of the record there was a slight elevation in TDS and the associated constituents due to reduced flows and increased percentage of return flow during the late summer. However, the water quality remains good even during these drought times.

Selenium concentrations remain low in the mainstem, with most readings below detection. Looking at the trend with time from 1994 to 2003, there appear to be fewer detectable readings, and those readings tend to be smaller. There is an increasing trend of detectable readings down river as more tributary flow enters the system, but this has not increased with time. With the exception of the measurement of 9 ppb total recoverable selenium at Mexican Hat, the maximum concentration measured in the San Juan River during the 1994 to 2003 period is 2 ppb, with most of the detectable readings at 1 ppb, the detection limit. The water quality standard exceedences do not appear to be a result of implementation of the flow recommendations and there is no trend with time.

The operation of Navajo Dam has had an impact on water temperatures in the designated critical habitat for the Colorado pikeminnow and razorback sucker. Since the results of detailed temperature modeling being completed by the Bureau of Reclamation are not yet available, the existing data were analyzed to assess the probable change in water temperature as a result of the coldwater releases from Navajo Dam. The non-regulated (without the reservoir in place) temperature in the San Juan River at Farmington was assumed to be the same as the Animas River at Farmington (Bliesner 2004). The coincident period of record is from 1/1/93 to 1/16/96 and 7/9/99 to 11/4/01. The general impact of the Navajo Dam releases is to slightly warm the water in winter months and cool it in the summer months, particularly during peak release. There is a relatively substantial temperature suppression during July-September (Figure 1). The coincident data set includes the portion of the 1999 water year that experienced high summer releases during this period. To examine the effect of this high release, that period of record was removed from the data set and is more representative of the flow recommendations (Figure 2). While the temperatures are still suppressed during this period, the suppression is about ½ of the suppression with the high summer release included.

The impact of the changed flow regime with the flow recommendations and the impact of temperatures further down stream could not reliably be analyzed using this approach. Temperature modeling now being completed as a research element of the SJRIP is designed to answer these questions, although the impact of this temperature suppression on endangered fish species has not been determined. A literature review on temperature requirements for Colorado pikeminnow and razorback suckers is presently underway. This review will be used to determine possible impacts.

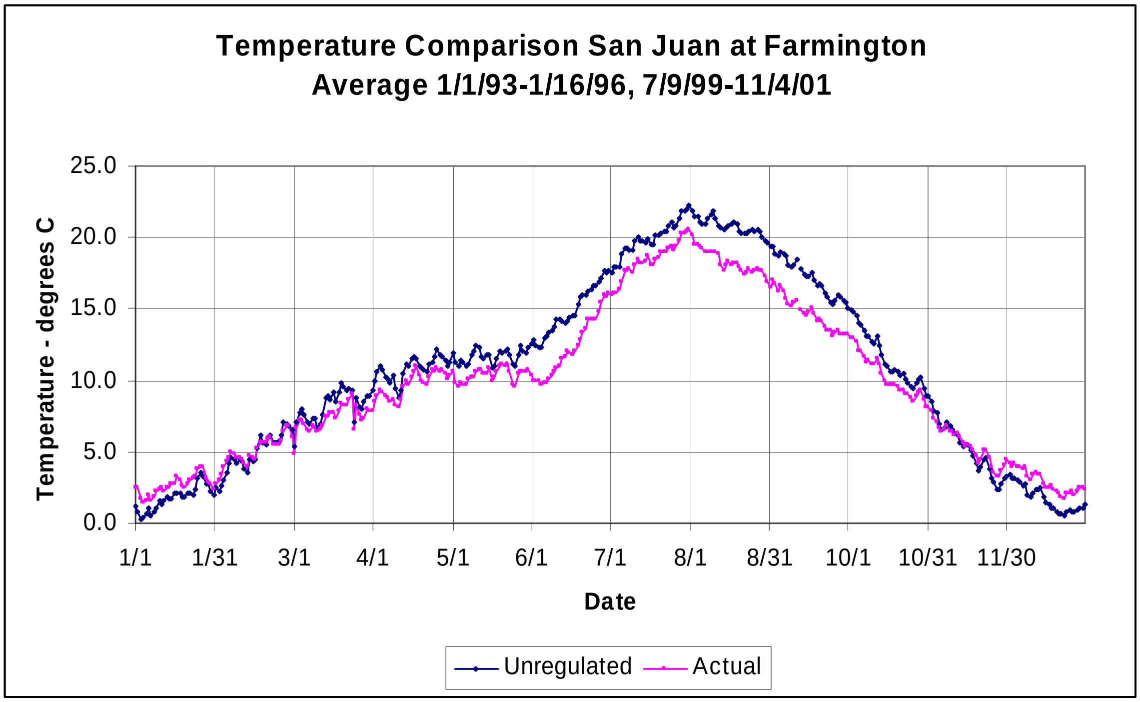


Figure 2. Comparison of the average simulated unregulated (no reservoir) water temperatures in the San Juan River at Farmington and the actual average temperatures for the period 1/1-93-1/16/96 and 7/9/99 – 11/4/01.

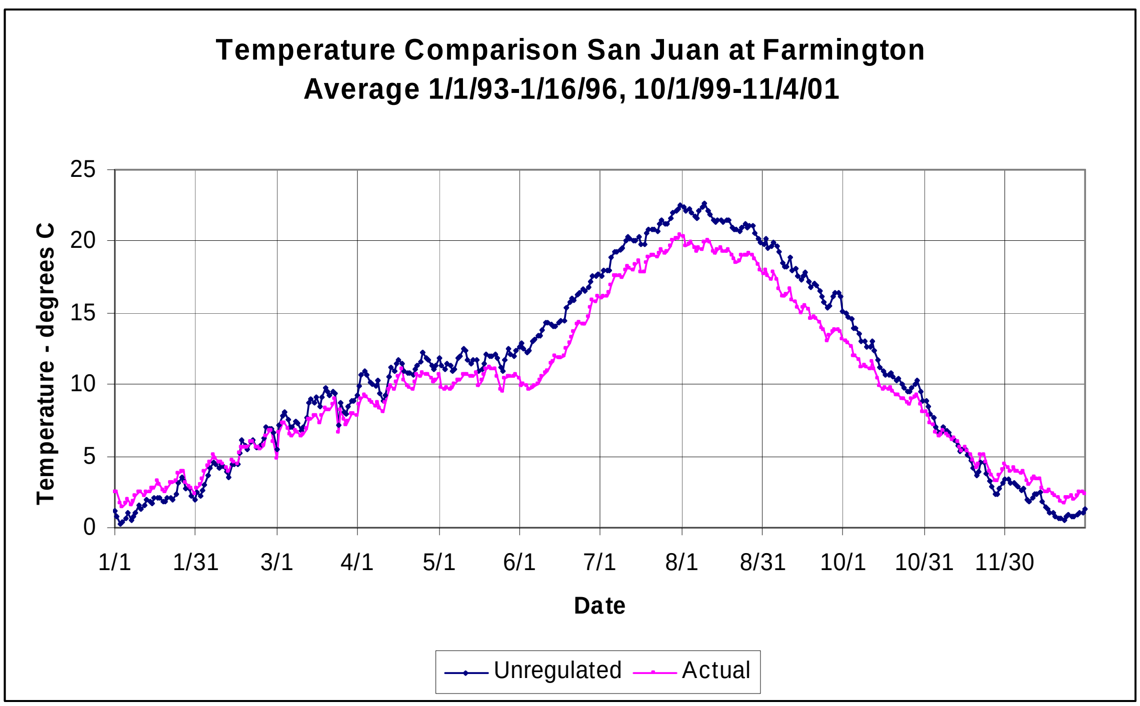


Figure 3. Comparison of the average simulated unregulated (no reservoir) water temperatures in the San Juan River at Farmington and the actual average temperatures for the period 1/1-93-1/16/96 and 10/1/99 – 11/4/01, removing the effects of the high summer release in 1999.

Channel complexity

Channel area decreased in Reach 3 at nearly the same rate between 1934 and 1988 (Figure 4). The greatest loss of channel area was in Reach 3. Reaches 4 through 6 actually increased slightly in channel area between 1950 and 1960 during a long drought period and then resumed their previous rate of decline between 1960 and 1988. Between 1988 and 1998, the channel area appears to have stabilized in all reaches except Reach 6, where it continued narrowing at about the same rate as the previous period.

Between 1934 and 1950, island area increased in all but Reach 6, due in part to increased vegetation of sand bars (Figure 5). The riparian area in Reach 6 was already vegetated due to irrigation return flow and elevated water table, increasing channel stability.

The trends for island count are similar to the island area trends, except there was a continuous reduction in island count from 1934 to 1960 (Figure 6). Again, vegetation played a major role here, as sand bars became vegetated. Between 1960 and 1988, island count increased along with island area, influenced by both vegetation and high flows. Between 1988 and 1998, island count continued to increase for all but Reach 6, where there was a slight decrease.

Change in channel complexity can be inferred by a change in island count. Island count did not show any statistically significant change between 1992 and 2002, except in Reach 4, where there was a statistically significant reduction in island count (Table 2). The other reaches, and Reaches 3 through 6 combined, show no significant trend in island count with time.

Ten years of channel monitoring to determine the influence of flow changes on channel change is a very short period of record and the four years of data since full implementation of the flow recommendations is inadequate to draw any conclusions. However, the data indicate that there has been no loss of bank full channel width or complexity as a result of implementation of the flow recommendations (Bliesner 2004). Although the channel is narrower now than pre-dam, it appears that the trend has flattened or stopped since 1988. Bank full channel complexity, as measured by island count and area, has increased some since 1988, continuing the trend of increasing complexity with time that has occurred since 1960.

There is no significant loss of base flow channel width with time, although there is a slight narrowing and deepening of the channel at the 10 cross sections measured in Reaches 3-6. This slight narrowing of cross-sections at control locations may have contributed to the reduction in base flow island count in Reach 4, the only reach with a significant reduction in base flow island count. Channel complexity as measured by the number of habitats mapped shows no trend with time.

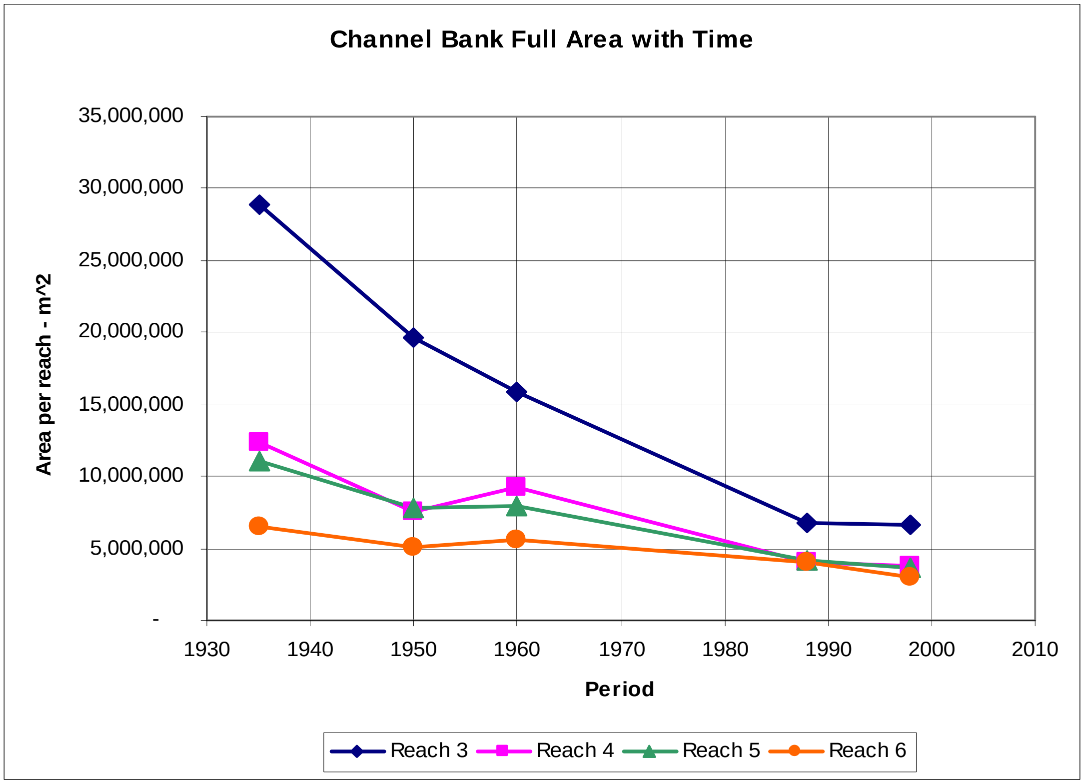


Figure 4. Channel bank full area with time for Reaches 3 through 6.

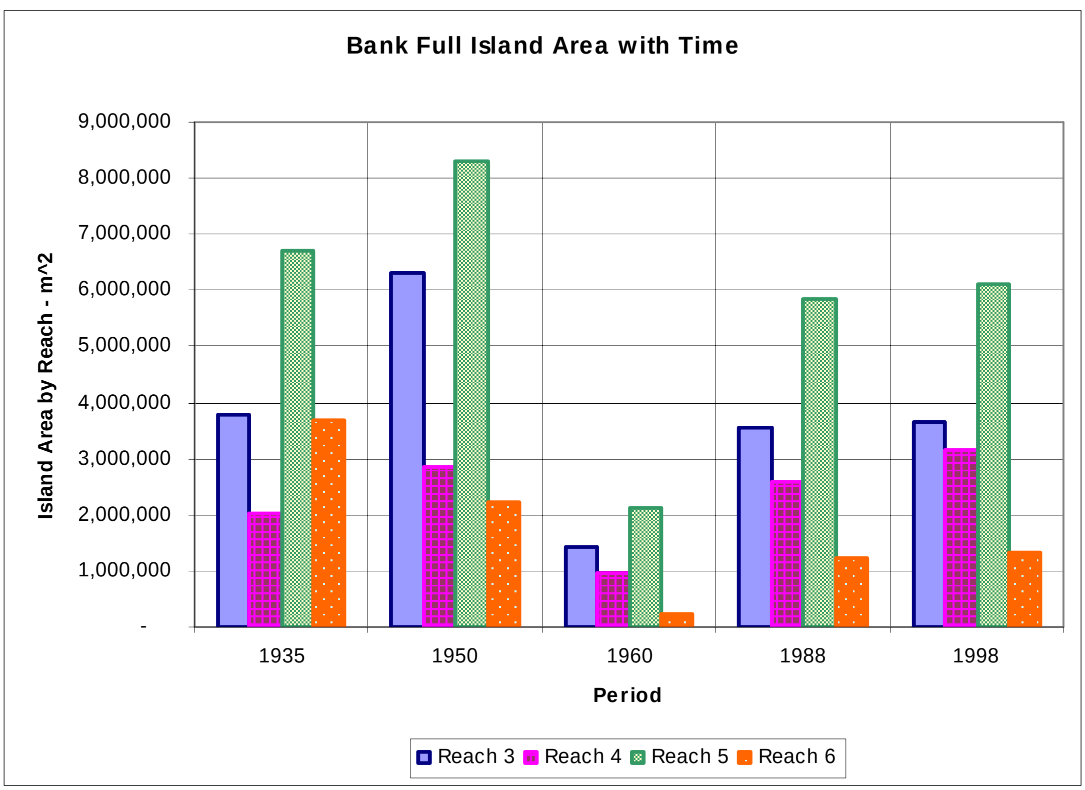


Figure 5. Bank full island area with time for Reaches 3-6.

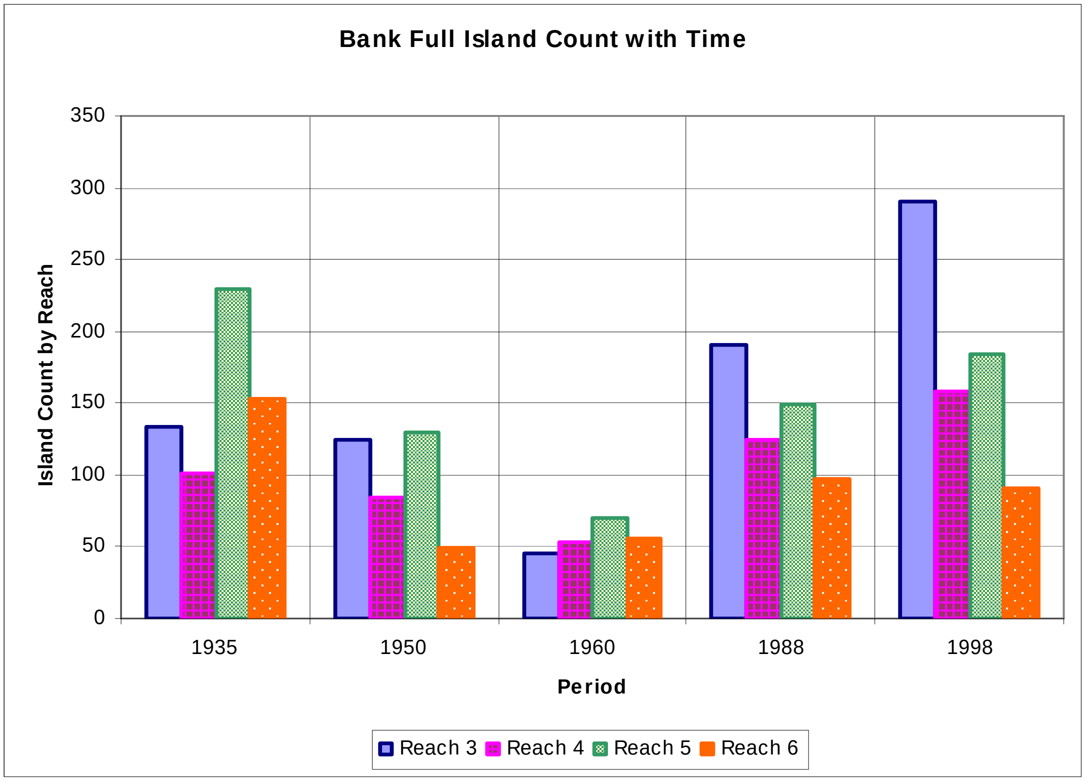


Figure 6. Bank full island count with time for Reaches 3 through 6.

Change in channel and habitat complexity can also be assessed by the change in habitat richness (number of mapped habitats per reach) with time (Figure 7). There was no statistically significant trend with flow or time and the analysis indicate that there has been no change during 1992-2002.

While there appeared to be no loss of channel complexity, the period of record is very short and there are indicators that bear watching in the future. Until a wet period is experienced again, acceptance of the hypothesis of no habitat change is tentative.

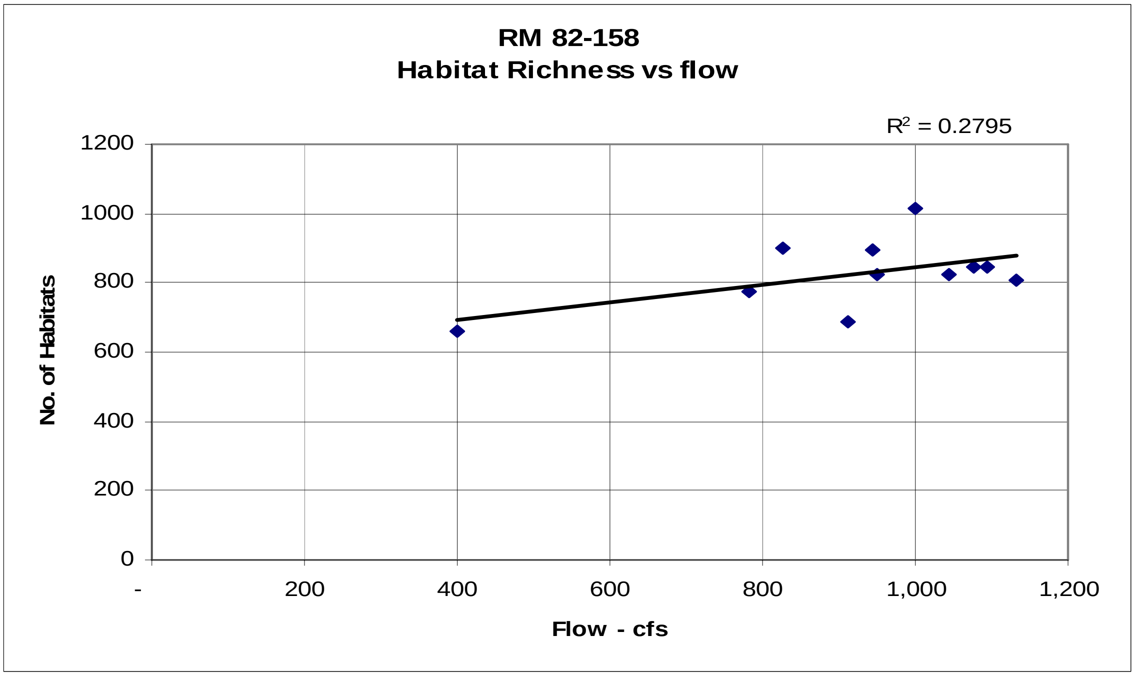


Figure 7. Habitat richness (no. of habitats) versus flow for RM 82-158, 1992 to 2002.

ENDANGERED FISHES AND FISH COMMUNITY RESULTS

Native Fishes

The objective of the standardized monitoring program was to track the status and trends of endangered and other fish populations in the San Juan River. There were three specific fish monitoring protocols designed to track the status and trends. These were: 1) Sub-adult and adult monitoring, 2) Larval fish monitoring, and 3) Small-bodied fish monitoring. There were two hypotheses for native fish populations to evaluate the flow recommendations and recovery actions.

Hypothesis 1: No significant reduction in native fish populations.

Hypothesis 2: Significant increase in endangered fish populations.

Colorado pikeminnow

Wild Colorado pikeminnow continue to be extremely rare in adult monitoring collections (Ryden 2003). Colorado pikeminnow populations have been augmented since 1996. Between 1996 and 2003, over 1 million Colorado pikeminnow were stocked in the San Juan River (Ryden 2004). These stockings include approximately 100,000 Colorado pikeminnow per year in 1996 and 1997, stocked as young-of-the-year; 10,000 young-of-the-year were stocked in 1998, approximately 500,000 larvae, no size specified, were stocked in the upper river in 1999. In summer 2000, 100,000 larvae were stocked. Colorado pikeminnow adults were stocked in April 2001 (148 adults). In 2002, over 200,000 pikeminnow were stocked at two locations in the upper river. In 2003, approximately 200,000 Colorado pikeminnow young-of-the-year were stocked in the upper river locations, similar to those locations stocked in 2002. Age-0 Colorado pikeminnow stocked in 1996 and 1997 were fairly common in collections until fall 1998, after which time their numbers appear to have decreased dramatically (Ryden 2003) (Table 3). Survival among age-0 Colorado pikeminnow stocked at larger sizes (45-55 mm TL) in the fall was much better than among age-0 Colorado pikeminnow stocked as larvae in the summer. The reason for the dramatic drop-off in Colorado pikeminnow collections after fall 1998 is unknown (Ryden 2003).

Adult Colorado pikeminnow were stocked in 1997 and again in 2001. Recaptures from both stockings were low and there was documented mortality of the adults stocked at both times. Both of these stockings were Colorado pikeminnow that had been held in hatcheries as either broodstock or for experimental water quality studies. Their condition when they were stocked was not good and some exhibited fungus from being in the hatchery or experimental situations (Ryden 2003). Although Colorado pikeminnow were rare in collections in the adult monitoring, they were collected during the non-native removal studies conducted during the summer in 1999 through 2003 (Jackson 2003). The majority of the fish captured were sub-adults and the highest numbers were collected in the downstream-most reaches of the San Juan.

Larval fish were collected by sampling drift in 1999-2001 (Farrington et al. 2004). Larval Colorado pikeminnow were not collected in 1998, 1999, and 2000 samples but one individual was collected in 2001. Seining collections for larval Colorado pikeminnow began in 2002. Larval Colorado pikeminnow were not collected during the 2002 study period despite the large number of fish collected (n=90,518).

Seventy-five Colorado pikeminnow were collected in 2003 by U.S. Fish and Wildlife Service (Ryden 2004). Colorado pikeminnow ranged in size from 35 to 75 mm SL. It was suspected, due to the size of the specimens and time of collection, that all of the Colorado pikeminnow that were collected in 2003 were fish stocked on 24 October 2002.

Larval Colorado pikeminnow were not collected during the 2003 study period despite the large number of specimens taken (n=70,352). A single sub-adult (201 mm SL) was collected on 15 July at river mile 54.4. The specimen was collected in a shoreline pool on river right, just upstream of Mexican Hat, Utah. It was presumed that this individual was a stocked fish and not a wild specimen.

Colorado pikeminnow were rarely collected during sampling for small-bodied fish in both primary and secondary channels. Four Colorado pikeminnow were collected from primary channel habitats in 1998. A total of five Colorado pikeminnow were collected from secondary channels between 1998 and 2003 (1998 n = 1, 1999 n = 1, 2000 n = 3). In addition to the previously mentioned collections, two Colorado pikeminnow were collected from backwater habitats, one in 1999 and the second in 2000 (Propst et al. 2004).

Table 3. Percent relative abundance by collector for the most commonly collected species 1998-2003 by monitoring protocol (UNM = University of New Mexico larval collection, NMGF = New Mexico Game and Fish small-bodied fish collection, FWS = US Fish and Wildlife Service sub-adult and adult large-bodied fish collection).

	1998			1999			2000		
Species	UNM	NMGF	FWS	UNM	NMGF	FWS	UNM	NMGF	FWS
flannelmouth sucker		0.7	(1)50.9	(2)30.7	0.6	(1)45.3	(1)47.4	0.2	(1)47.7
bluehead sucker		0.2	(2)18.5	(3)1	0.4	(3)16.3	(3)17.6	0.1	(3)15.8
speckled dace		(2)34.5	2.5	0.3	(2)26.0	1.2	2.1	0.7	3
roundtail chub		0.1			0.1				
Colorado pikeminnow		0.2	0.6		0.1			0.0	
razorback sucker							1.2		
channel catfish		(3)10.7	(3)14.4		0.6	(2)26.9		0.1	(2)22.4
common carp		0.1	11.9		0.1	9.8		0.7	9
red shiner		(1)43.3	0.3	(1)67	(1)68.3	0.1	(2)26.3	(1)85.7	0.3
fathead minnow		6.3		0.9	(3)3.5		5	(2)7.0	
plains killifish		0.2						0.0	
western mosquito fish		3.8			0.5		0.2	(3)5.4	

	2001			2002			2003		
Species	UNM	NMGF	FWS	UNM	NMGF	FWS	UNM	NMGF	FWS
flannelmouth sucker	(2)8	0.8	(1)45.2	(3)5.2	1.3	(1)48.2	(3)4.6	5.5	(1)48.4
bluehead sucker	0.3	0.2	(3)13	2.6	0.6	(2)25.3	1.2	1.0	(2)22.1
speckled dace	0.1	(2)8.7	2.1	2.3	(3)4.1	1.7	1.4	13.8	4.2
roundtail chub									
Colorado pikeminnow		0	0	0	0	0	0.1	0	0.4
razorback sucker	0.1	0	0	0.6	0	0.2	0.4	0	0.2
channel catfish		0.5	(2)28.7	0.1	1.4	(3)15.2	0.3	(3)8.0	(3)16.0
common carp	0.3	0.0	8.9	0.4	0.3	8.1	0.0	0.0	6.8
red shiner	(1)87.2	(1)80.7	1.6	(1)67.4	(1)72.9	0.5	(1)71.7	(1)62.3	1.1
fathead minnow	(3)3.5	(3)5.9		(2)21.0	(2)15.6		(2)18.5	7.5	
plains killifish		0.4		0.1	0.4		0.2	0.6	
western mosquito fish	0.5	2.8		0.4	3.4		1.3	1.3	

Razorback sucker

Stocking larger size-class razorback sucker (> 300 mm TL) appeared to increase post-stocking survival (Ryden 2003). Relative to numbers stocked, recapture events with razorback sucker were much more common than for stocked Colorado pikeminnow. Suspected spawning aggregations of adult razorback sucker were found at RM 100.2 in

May 1997, April 1999, and April 2001 (Ryden 2003). Crews from UNM documented spawning, through the collection of larval razorback sucker, for six straight years (1998-2003). No razorback sucker was collected in the small-bodied fish monitoring.
A total of 186 larval and juvenile razorback sucker were collected during the 1999 through 2001 larval razorback sucker survey. The 2000 razorback sucker survey collected 129 larval razorback sucker (Brandenburg et al. 2004). Razorback sucker accounted for 0.1% of the total catch. Forty-three samples contained razorback sucker, two samples contained between 10 and 20 individuals, and a single sample taken in 2000 at river mile 8.1 contained 86 individuals. This area is the most downstream location at which larval razorback sucker were collected over the three year period. That single collection accounted for 46.2 % of larval razorback sucker collected between 1999 and 2001. 2001 was the first year that juvenile specimens were collected (n=2). Both specimens were collected at the end of the 2001 razorback sucker survey, 14 June 2001, at river mile 8.1. Light traps collected four larval razorback sucker, two in 1999 and two in 2001 (Brandenburg et al. 2004).

The greatest increase in razorback sucker abundance was between 2001 and 2002. There was a sixteen-fold increase in the number of razorback sucker collected in 2002 (n=813) versus 2001 with YOY individuals being collected throughout the study area. This was the third year (of five) in which larval razorback sucker were collected in light-traps in the San Juan River. In 2002, razorback sucker exhibited a more uniform longitudinal distribution in the San Juan River compared to previous years.

The 2002 larval razorback sucker collections yielded more and larger juvenile razorback sucker than have been previously taken. Prior to 2002, there had been only two juvenile razorback sucker collected under this study. Much like the overall distribution of larval razorback sucker, juvenile razorback sucker were taken in each of the reaches sampled.

Larval razorback sucker was not as abundant in 2003 relative to the previous year, yet more razorback sucker were collected in 2003 than 1998 to 2001 combined (Brandenburg et al. 2003). A total of 472 larval and juvenile razorback sucker were taken during the 2003 larval razorback sucker survey. Larval razorback sucker were collected from reaches 3, 2, and 1 during the 2003 survey. The most upstream collection of razorback sucker larvae was at river mile 97.0, which happened to be the first collection to produce larval razorback in 2003.

Other Native Fishes

Roundtail chub (*Gila robusta*) was very rarely collected during all monitoring trips (Table 3). It does not appear to have a resident population present in the San Juan River at this time. A total of three roundtail chub were collected during the adult monitoring trips, 1999 through 2003. In addition, nine more roundtail chub were collected in other rare fish studies by U.S. Fish and Wildlife Service (Ryden 2003, Ryden 2004). Juvenile roundtail chub were present in 1998 and 1999 larval samples but were not collected between 2000 and 2003. Five roundtail chub were collected during small-bodied fish monitoring between 1998 and 2003 (Propst et al. 2004). Two roundtail chub were collected from primary channels (1998 n = 1, 1999 n = 1). Three roundtail chub were collected between 1998 and 2002 (1998 n = 2, 1999 n = 1) from secondary channels.

Flannelmouth sucker numerically dominated adult monitoring collections. All life stages occur throughout the study area (RM 180.0-2.9). The flannelmouth sucker population appeared to be relatively stable based on relative abundance (Table 3). A decline in flannelmouth sucker CPUE in Reaches 5-3 observed in mid- to late-1990s has stopped and numbers have increased substantially in those reaches since that time (Ryden 2003). Flow manipulations from Navajo Dam since 1992 do not appear to be causing dramatic long-term shifts in numbers of flannelmouth sucker present in study area. A very large number of age-0 flannelmouth sucker were collected in 2000, mostly upstream of the PNM Weir. Numbers in Reach 1 (and 2), adjacent to Lake Powell have shown statistically significant declines since 1995 (Ryden 2003, Ryden 2004).

In 1999, flannelmouth sucker had the second highest abundance of fish in larval collections (Table 3). Flannelmouth sucker had the highest abundance in 2000 and was the dominant catostomid taxon in 2001-2003 (Brandenburg et al. 2004). Flannelmouth sucker was the first sucker taxon to spawn in 2003. This spawning pattern has been documented since larval seining began in 1997 (Brandenburg et al. 2004).

Flannelmouth suckers were rare in 1998 and 1999 collections for small-bodied fishes. There were fewer than 10 specimens collected riverwide in each year. Flannelmouth sucker were more common from 2000 to 2002 with the collections ranging from 20 to 141 individuals riverwide (Propst et al. 2004). Secondary channel collections for small-bodied fish showed that flannelmouth sucker, as in the primary channel, were uncommon in 1998 and 1999, but more common in 2000 through 2002. Fewer than 20 specimens riverwide were collected in 1998 and 1999, but more than 20 specimens riverwide were collected in 2000 through 2002.

Bluehead sucker population is centered on upstream reaches of the study area, specifically Reach 6. Bluehead sucker have never been collected in Reach 1 adjacent to Lake Powell during adult monitoring. Bluehead sucker juvenile and adult population appeared to be relatively stable. Flow manipulations from Navajo Dam since 1992 do not appear to be causing dramatic long-term shifts in numbers of bluehead sucker present in study area. Like flannelmouth sucker, a very large number of age-0 bluehead sucker were collected in 2000, mostly upstream of the PNM Weir (Ryden 2003, Ryden 2004).

Bluehead sucker represented less than 1.0% of the larval fish collected in 1999-2001 (Table 3). Bluehead sucker represented 2.6% and 1.2% of the larval fish collected in 2002 and 2003, respectively (Brandenburg et al. 2004).

Bluehead sucker were rare in 1998 and 1999 small-bodied fish collections in primary channel habitats. Fewer than 10 specimens per year were collected riverwide. Bluehead sucker were more common in the small-bodied fish collections 2000 through 2003 with up to 61 individuals collected riverwide (Propst et al. 2004). Bluehead sucker were moderately common in secondary channels in 2002 and 2003. Bluehead sucker from both habitats represented 1% or less of the total fish collected (Table 3).

Native Fish Summary

Flannelmouth and bluehead sucker continue to dominate the native fish community in the San Juan River during the monitoring period 1998-2003. Colorado pikeminnow and razorback sucker were present and collected in higher numbers at the end of the monitoring period in 2003 than found in the beginning of the period in 1998 and 1999, likely the result of the continued augmentation program and the successful survival and growth of those stocked fish.

Comparison of catch per unit effort (CPUE) among the three sampling protocols for larval, small-bodied and large-bodied (juvenile and adult fish) have no distinct trends in the 1998-2003 period. CPUE was normalized for each sampling protocol to compare collections. The highest CPUE was used as a 1.0 value and all others were assessed against that value as a proportion of that capture rate for individual collections. There is a slight similarity between the flannelmouth CPUE in adult and larval collections for 1998-2003. When adult numbers are high, the larval collections were also high (Figure 8). There appears to be a slight decrease over time for adult, juvenile and larval flannelmouth sucker. This same similarity is not seen with the comparison of bluehead CPUE (Figure 9).

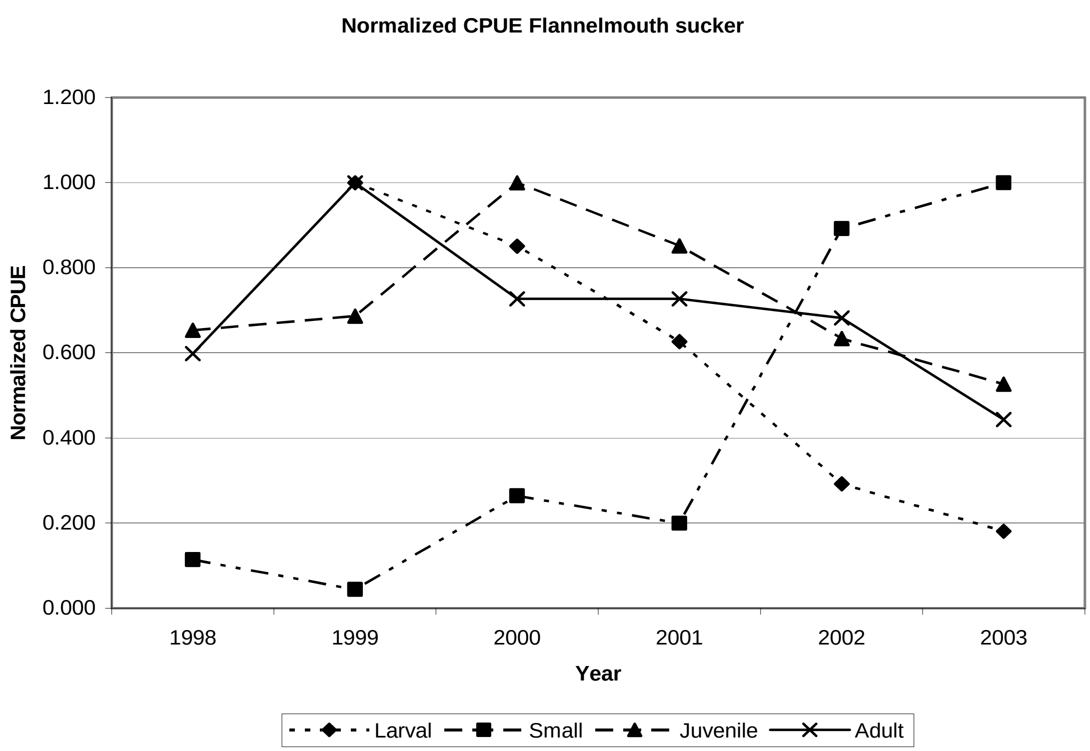


Figure 8. Comparison of flannelmouth sucker CPUE among larval, small-bodied and large-bodied (adult and juvenile) monitoring protocols.

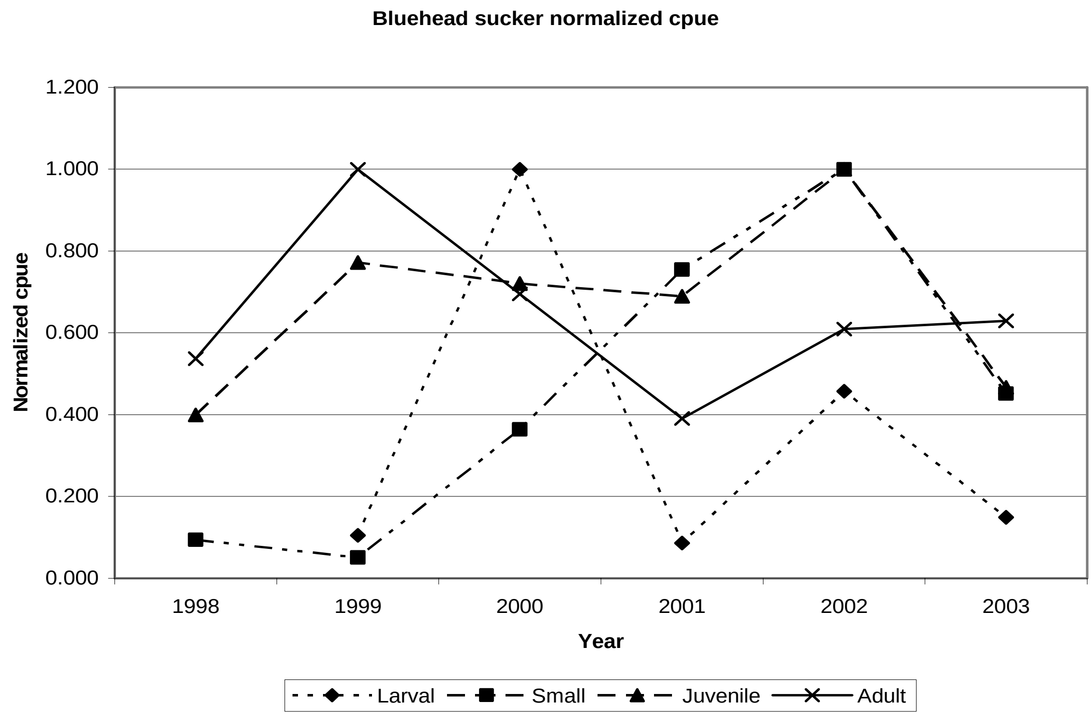


Figure 9. Comparison of bluehead sucker CPUE among larval, small-bodied and large-bodied (adult and juvenile) monitoring protocols.

Non-Native Fishes

Non-native fishes were collected in conjunction with the native fish monitoring. The three monitoring protocols for specific life history stages collected data on non-native fishes. There was one hypothesis to evaluate the response of non-native fish to the flow recommendations and recovery actions.

Hypothesis: Significant decrease in non-native fish populations

Channel catfish adults and juveniles occurred in large numbers in the study area from downstream of the PNM Weir to Lake Powell (RM 166.6-0.0) and continued to be the most commonly-collected large-bodied non-native fish species in the San Juan River (Ryden 2003) (Table 3). The channel catfish population appeared to be relatively stable during 1998-2003. Flow manipulations from Navajo Dam since 1992 did not appear to have dramatic, long-term, negative impacts on population size. Mechanical removal efforts appeared to have had the following effects: 1) reduced numbers of large channel catfish (> 525 mm TL) riverwide in adult monitoring collections since 1996; 2) length-frequency distributions skewed towards smaller fish riverwide since 1996; 3) an increase in CPUE for smaller size-class channel catfish; and 4) recolonization of lower Reach 6 by upstream movement from Reach 5 (Ryden 2003). Although large numbers of age-0 channel catfish were not collected during 2000 adult monitoring collections, very large numbers of age-1 channel catfish were collected during 2001 adult monitoring collections.

Adult common carp were ubiquitous and occurred throughout the entire study area from the Animas River confluence to Lake Powell (RM 180.0-0.0), and continue to be the second most commonly-collected large-bodied non-native fish species in the San Juan River (Ryden 2003). CPUE for common carp upstream of the PNM Weir was usually only about half of that for common carp downstream of the PNM Weir. Common carp tended to be longer (mean TL) and heavier (mean WT) upstream of the PNM Weir than those downstream of the PNM Weir. Common carp CPUE in lower Reach 6 (RM 166.6-158.6) has declined over the last several years, indicating that mechanical removal efforts may be having an effect on this species in this section of the river (Ryden 2003). A very large number of age-0 common carp were collected in 2000, mostly upstream of the PNM Weir (Ryden 2003).

Largemouth bass (*Micropterus salmoides*) were usually very rare in adult monitoring collections. Relatively large number of largemouth bass collected on the fall 2000 adult monitoring trip may have been due to low stable flows and clear-water conditions present in the river throughout summer 2000 (Ryden 2003). Most largemouth bass collected in the San Juan River were juveniles. Most were collected in upstream reaches of the study area in close proximity to irrigation returns which suggests that off-channel sources may be continually providing access to the river through irrigation canals (Ryden 2003). In summer 2000, during an extended period of low flows and clear water, an extremely large number of striped bass (*Morone saxatilis*) invaded the San Juan River, being collected as far upstream as the PNM Weir (RM 166.6) (Ryden 2003). Most striped bass collected on this trip had fish remains in their stomachs, most of which were native fish (Ryden 2003). Striped bass appeared to be unable to tolerate high volume or turbid river flows and were usually much less common in electrofishing collections after these types of flow events. An additional non-native predatory species, walleye (*Sander vitreus*) have been very rare in adult monitoring collections over the last several years. Like Colorado pikeminnow, walleye are obligate piscivores (at $\geq$ age-1), thus bringing them into potential competition for food resources with Colorado pikeminnow. Like striped bass, walleye appear to be unable to tolerate high volume or turbid river flows. Walleye are usually absent from electrofishing collections after these types of flow events (Ryden 2003).

Red shiner (*Cyprinella lutrensis*) was infrequently captured in the large-bodied fish monitoring and usually represent 2% or less of the relative abundance of all species. This is likely due to the type of equipment used and areas sampled during the adult large-bodied fish monitoring efforts. Red shiner was the most abundant species in the larval collections in 1999 and represented the highest CPUE in 1999 (Brandenburg et al. 2004a). Red shiner was also the most abundant fish collected in 2000-2003 larval sampling (Farrington et al. 2003). Red shiner was the most common species collected in the small-bodied fish monitoring in all years in both primary and secondary channels. The relative abundance for the small-bodied fish collections are nearly the same as those for the larval collections.

Fathead minnow (*Pimephales promelas)* was uncommonly collected in the adult large-bodied fish monitoring. As with the analysis and abundance for red shiner, this may be due to the type of gear used for collection and the habitats sampled. Fathead minnow accounted the third highest CPUE in larval collections (Brandenburg et al. 2004a). The 2002 larval catch of fathead minnow nearly equalled that of red shiner. Fathead minnow made up 12.4% of all specimens collected (Farrington et al. 2003). Fathead minnow were usually either the second or third most abundant species collected in the small-bodied monitoring collections (Table 3). Fathead minnow generally represented from 6 to 15% of the relative abundance of species caught. The pattern of fathead minnow occurrence in the small-bodied fish monitoring was similar to that of the larval fish monitor.

Non-Native Fish Summary

The most common non-native large-bodied species were channel catfish and common carp. The size structure of channel catfish appeared to be altered by the non-native removal efforts. The dominant non-native species collected during small-bodied and larval collections were red shiner and fathead minnow.

The CPUE for the two most common species in the sub-adult and adult monitoring were compared to CPUE rates for larval and small-bodied fish monitoring data. As discussed for native species, the difference in units of CPUE make comparisons difficult. Further, as shown with native species, there is no evident trend in the CPUE data for the five years of monitoring (Figures 10 and 11). There are both increases and decreases in abundance based on CPUE over the five years of monitoring.

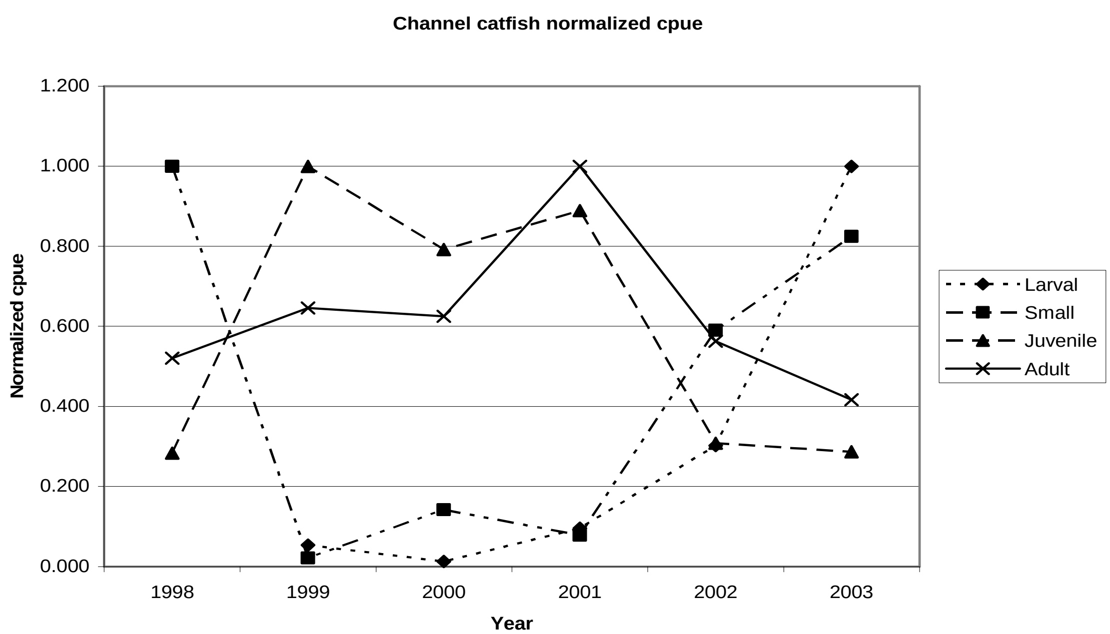


Figure 10. Comparison of normalized cpue values 1998 – 2003, channel catfish.

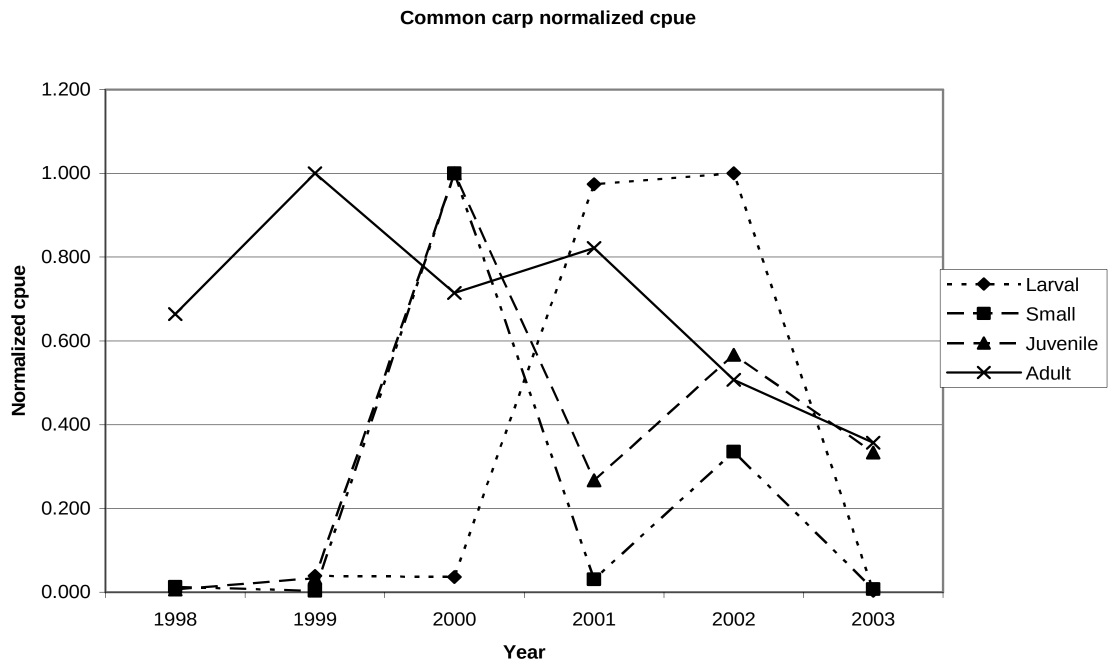


Figure 11. Comparison of normalized cpue values 1998 – 2003, common carp.

EVALUATION OF LARGE-BODIED AND SMALL-BODIED SAMPLING PROTOCOLS

Large-Bodied Fish

Population changes and trends were assessed over the monitoring period 1999-2003 for large-bodied fishes in the San Juan River captured in fall monitoring efforts by electrofishing. The analyses included assessing changes and trends in catch rates of adults and juvenile fish and changes in length frequency of adults. Analyses were conducted for four common species (bluehead sucker, flannelmouth sucker, channel catfish and common carp) and for the two endangered species targeted in recovery efforts, Colorado pikeminnow and razorback sucker.

Significant differences in CPUE were found between at least two years for all common species and age classes (Table 4). Among the two listed species, adult Colorado pikeminnow and juvenile razorback sucker did not show any significant differences among years. Significant increasing trends in CPUE were found for juvenile bluehead sucker, juvenile common carp, and adult razorback sucker (Table 4). Significant decreasing trends in CPUE were found for adult flannelmouth sucker, adult and juvenile channel catfish, adult common carp, and juvenile Colorado pikeminnow.

Power analyses indicated that current sampling efforts were able to detect annual changes in CPUE of 20% or greater for all but juvenile common carp (26.7 %) among the four common species (Table 5). Insufficient numbers of Colorado pikeminnow and razorback suckers were captured to do a meaningful power analysis.

Table 4. Results of ANOVA and ANCOVA tests for CPUE (fish/hr) among years. Different letters indicate significant (p < 0.05) differences among years for a species and age group using Tukey-Kramer multiple-comparison test. Trend is the slope of the covariate, 'year', used in ANCOVA tests. The p-level indicates significant trend when p < 0.05.

	YEAR						
SPECIES	**1999**	**2000**	**2001**	**2002**	**2003**	**Trend**	**p-level**
Bluehead sucker, adult	a	a	b	a	a	-0.43	0.0816
Bluehead sucker, juvenile	a	a	b	b	a	15.9	0.0000
Flannelmouth sucker, adult	a	b	b	a,b	c	-11.7	0.0000
Flannelmouth sucker, juvenile	a	b,c	c	a	a,b	0.24	0.8919
Channel catfish, adult	a	a,b	b	a	c	-13.8	0.0000
Channel catfish, juvenile	a	a	a	b	b	-31.8	0.0000
Common carp, adult	a	a,b	a	b	c	-20.6	0.0000
Common carp, juvenile	a	b	c	b	a,c	3.6	0.0172
Colorado pikeminnow, adult	a	a	a	a	a	0.49	0.5918
Colorado pikeminnow, juvenile	a	a	a	a	b	2.28	0.0000
Razorback sucker, adult	a	a	a,c	b	b,c	2.2	0.0001
Razorback sucker, juvenile	a	a	a	a	a	-0.01	0.9535

Table 5. Percent annual change in CPUE among years that is detectable using ANOVA and Tukey-Kramer multiple-comparison test under current sampling program.

SPECIES	**Detectable Annual Change (%)**
Bluehead sucker, adult	17.4
Bluehead sucker, juvenile	16.3
Flannelmouth sucker, adult	14.8
Flannelmouth sucker, juvenile	15.5
Channel catfish, adult	19.7
Channel catfish, juvenile	17.0
Common carp, adult	17.2
Common carp, juvenile	26.7

Length-frequency analyses

The distribution of total lengths of adult large-bodied fishes in the San Juan River was compared among years to assess differences in size structure. These differences may indicate recruitment pulses or lack of recruitment. Analyses were conducted only for the four common species as insufficient numbers of individuals of Colorado pikeminnow and razorback sucker were captured for this analysis.

Significant differences in mean total length and distribution of adult fish (by reach) were found for all species among at least two years (Table 6). Significant differences among years were in general more frequent for distributions than mean length, indicating that distributions may be more sensitive to change than mean length. Current sampling and numbers of fish measured indicates that differences in mean total length of 10-30 mm can be detected.

Table 6. Results of ANOVA tests for differences in mean total length (upper) and Kolmogorov-Smirnov test for differences in length frequency distributions (lower) for the four common large-bodied fishes. Different letters indicate significant ($p < 0.05$) differences among years for a species. Mean lengths (mm) are shown in the upper portion of the table.

Test of mean length (mm)

	YEAR				
SPECIES	**1999**	**2000**	**2001**	**2002**	**2003**
Bluehead sucker, adult	353 a	367 b,c	362 b	349 a,c	347 a
Flannelmouth sucker, adult	450 a	464 b,c	462 b	463 b,c	469 c
Channel catfish, adult	390 a,b	370 b	391 a	401 a	469 c
Common carp, adult	472 a	467 a	470 a	483 b	490 b

Test of distribution

	YEAR				
	1999	**2000**	**2001**	**2002**	**2003**
Bluehead sucker, adult	a	b	c	d	e
Flannelmouth sucker, adult	a	b	b	c	c
Channel catfish, adult	a	a	b	c	d
Common carp, adult	a	a	a	b	b

Small-Bodied Fish

Data collected for small-bodied fishes from seine hauls were assessed to determined changes among year in catch rates, power of this metric to detect change, and a review of sample units. These analyses were conducted for the nine most numerous species and for Colorado pikeminnow [Ptyluc]. The nine species were bluehead sucker [Catdis], flannelmouth sucker [Catlat], common carp [Cypcar], red shiner [Cyplut], plains killifish (*Fundulus zebrinus*) [Funzeb], mosquitofish (*Gambusia affinis*) [Gambus], channel catfish [Ictpun], fathead minnow [Pimpro], and speckled dace (*Rhinichthys osculus*) [Rhiosc]. This analysis refers to catches in units of density (# m^{-2}), but can also be considered to simply be a catch-per-unit-effort, where effort is area sampled.

In general, patterns for the two analyses were similar (see Appendix I, Figures 1-10) for all fishes. A few exceptions occurred; most notably bluehead sucker in 2001 where very high numbers were found only in reach 1, and the mean density calculated for reaches 2-5 were much lower as compared to reaches 1-6. Significant differences among at least two years were found for nearly all fishes in both analyses. Fishes with higher densities (e.g., fathead minnow, red shiner) were generally more likely to show significant differences for the same percent change.

The ability of this sampling regime to detect differences among years was assessed. The percent change in density that would result in a significant difference was calculated for each species using the mean square error and the assumption that 95% confidence intervals calculated for pair of years would not overlap.

The ability to discern differences among year differed among species (Appendix I, Figures 11-20). As expected, increased sample sizes reduced the size of the difference among density estimates necessary to have statistical significance. Detecting changes of 30% or less was possible for one native (speckled dace) and four non-native (channel catfish, mosquitofish, fathead minnow, red shiner) species for sample sizes of 400. For changes of 20%, detection would be possible for two (speckled dace and red shiner) species for 400 samples (Figure 12).

Sampling during the period 1998-2002 was conducted by lumping individual seine hauls into group samples with only the total area and total numbers reported. In 2003, each individual seine haul was recorded as an individual sample, resulting in about twice as many samples. In both cases, it was assumed by the researchers that sampling was done roughly within habitats according to their spatial extent.

The coefficient of variation among individual samples was typically greater for the samples collected by individual habitats, but the coefficient of variation for the means was less (Table 7) for all but one species (common carp). This suggests that separating samples by habitat may result in more precise estimates than result when samples are lumped by habitat within a sampling area. This was a result of both larger numbers of samples, but also due to increased variation resulting from lumped samples.

Table 7. Coefficient of variation (CV) calculated for ln(density+1) for individual samples (st. dev. / mean * 100) and for estimated means (st. err. / mean * 100). No Ptyluc were captured in 2003 so estimated CV could not be calculated.

	Variation among individual samples		Variation among means	
species	1999-2002	2003	1999-2002	2003
bluehead	462.8	486.6	41.7	24.2
flannelmouth	265.5	418.1	25.4	20.8
common carp	552.4	1407.0	53.9	69.9
red shiner	117.3	168.5	11.3	8.4
plains killifish	512.1	715.8	44.4	35.6
western mosquitofish	358.7	567.9	35.4	28.2
channel catfish	339.5	218.2	31.6	10.8
fathead minnow	220.6	402.5	20.7	20.0
Colorado pikeminnow	712.1	------	75.8	------
speckled dace	160.0	210.9	14.9	10.5

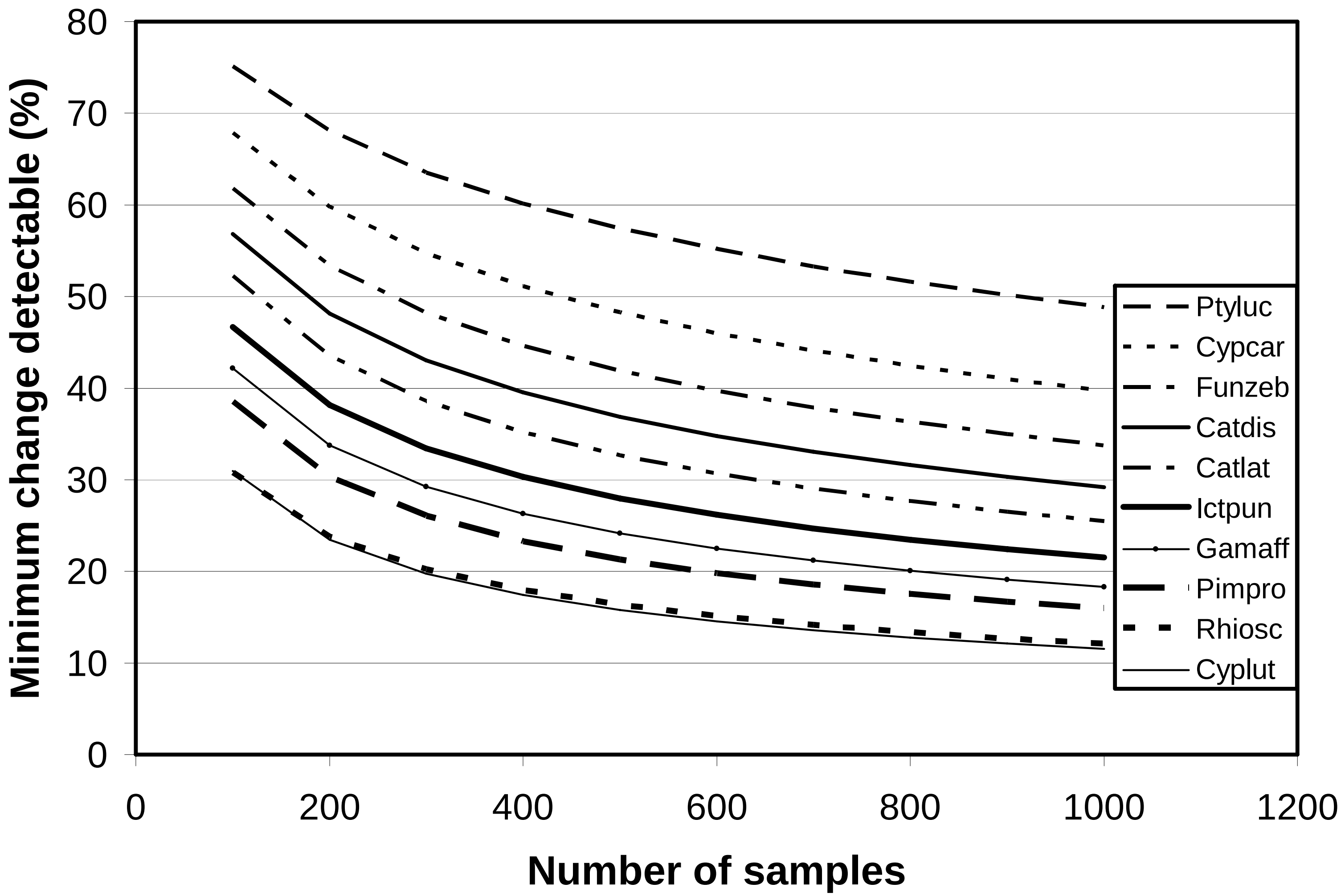


Figure 12. Sample size and percent change that is detectable between years for ln(x+1) density for small bodied protocol.

These analyses indicate that under current sampling, only large differences can be detected among densities of small-bodied fishes. The ability to detect differences was generally less for species of lower density. Increases in sample size can improve precision, but very large samples would be needed to detect changes of less than 20% for most species.

These analyses should be considered to be a best case scenario in detecting differences in density among years. The power analysis assumed that the samples represented random samples within reaches and years. It also assumed that available habitat does not change among years; density for the same number of fish would be lower with more available habitat. Non-random sampling or great differences in available habitat would introduce biases into the estimates and could make the statistical tests invalid.

Analyses indicated that more precise estimates could be obtained by keeping individual seine hauls separated, although only one year of data (2003) was available to evaluate using individual seine hauls as samples. Samples separated by habitat also permit additional assessments of density, especially if merged with estimates of available habitat. Such analyses could decrease bias in the estimated densities by reducing the effects of habitat change. However, such an estimation scheme would have to ensure that habitats were similarly identified, and that the areas seined were representative of the areas quantified by habitat.

EVALUATION OF FLOW RECOMMENDATIONS

Habitat Response to Flows

One assumption for the flow recommendations was that flows greater than 8,000 cfs (approximate average bank full flow) were necessary for channel maintenance. It was also assumed that periodic flows above 10,000 cfs were important for generating new cobble sources and maintaining a highly dynamic channel in the long-term. It was further hypothesized that flows around 5,000 cfs or above were important to flush sediment from secondaries and maintain backwater habitats between larger events. The 2,500 cfs criteria was based on anticipated need to have flows of this magnitude to maintain open interstitial space in cobble bars for spawning purposes.

Fine sediments collect in the San Juan River during summer storm events that generate flow in erodable, ephemeral tributaries. Flows of sufficient magnitude to flush these fine sediments through the system are needed to maintain channel capacity and habitat quality. The most effective flows would be those of sufficient magnitude to mobilize the sediment and of sufficient duration to transport the fine sediment through the system. For the San Juan River, sediment transport is related to flow. As expected, the most significant parameter in predicting backwater habitat area following runoff was flow during runoff. Only 1995 and 1997 met the 10,000 cfs criteria, but 1993, 1995 and 1997 met the 8,000 cfs criteria. All but 1994 and 2002 met the 5,000 cfs criteria. Flows in 1993 were as effective as flows in 1995, and although 1998 through 2001 met the 5,000 criteria, the condition was insufficient to maintain backwater habitat (Figure 13).

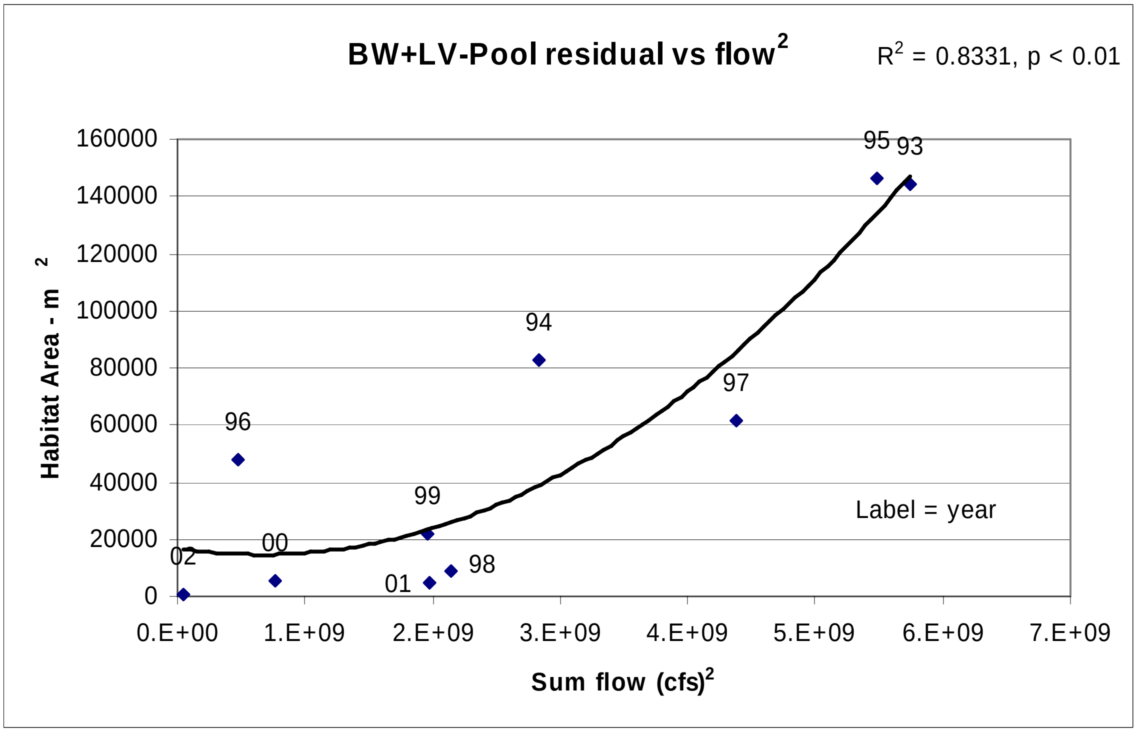


Figure 13. Backwater and low velocity habitat, adjusted for flow at mapping, versus sum of flow^2 for the March through July runoff period.

Correlation of backwater and low velocity habitat area with days above 8,000 cfs and 10,000 cfs were not very meaningful because of the number of zeros or very low numbers of occurrences in the data sets. Correlation with days above 5,000 and 2,500 cfs were not very instructive, because at high numbers of occurrences they were highly correlated to larger flow events. To better assess the effectiveness of the 5,000 cfs criteria, backwater and low velocity habitat area was plotted against days when flows were in the range of 4,000 to 6,000 cfs when the total flow for the year did not exceed 8,000 cfs. It was apparent that flows in the 5,000 cfs range were not effective, unless the peak flows also were much higher (Figure 14).

While 1997 met all the flow requirements, habitat response was not as expected. That year was influenced by sediment laden storm flows on the descending limb, and an extended descending limb as part of the flow tests. The increased sediment load was not the expected response. In addition, the increased sediment remaining in the river had reduced habitat quality.

Large flows were also somewhat important to maintaining base flow channel complexity as exhibited by the relationship between flow and island count (Figure 15). While the correlation was not high, it was significant, showing an increase in post-runoff island count with increased flow during runoff.

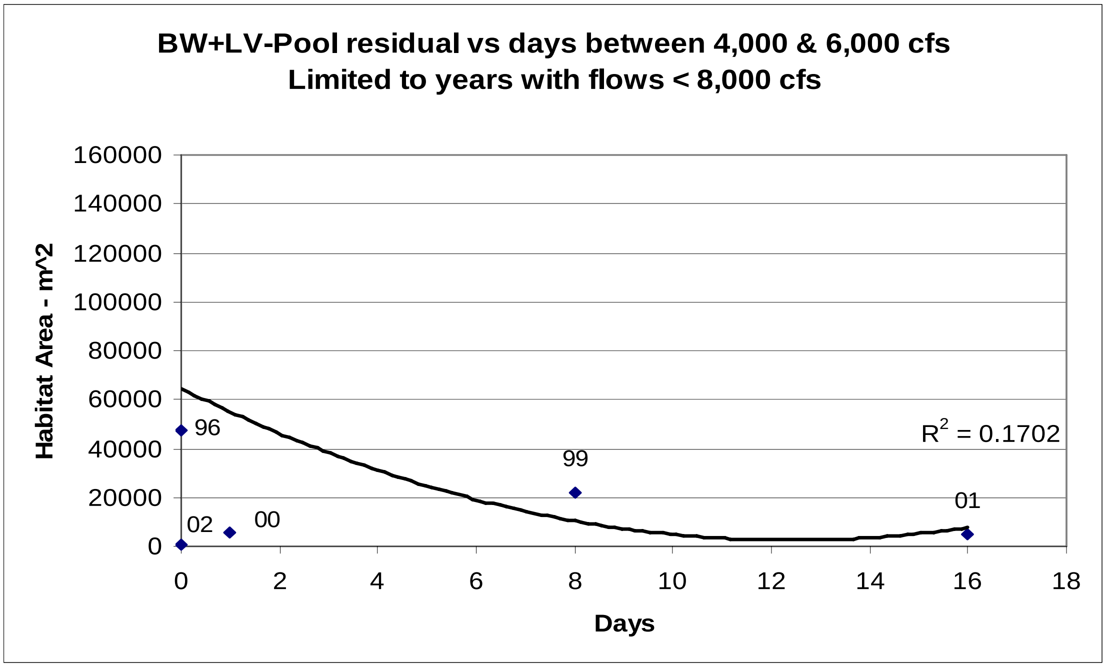


Figure 14. Relationship between backwater and low velocity habitat area, adjusted for flow at mapping, and days between 4,000 and 6,000 cfs, limited to years when flows were less than 8,000 cfs.

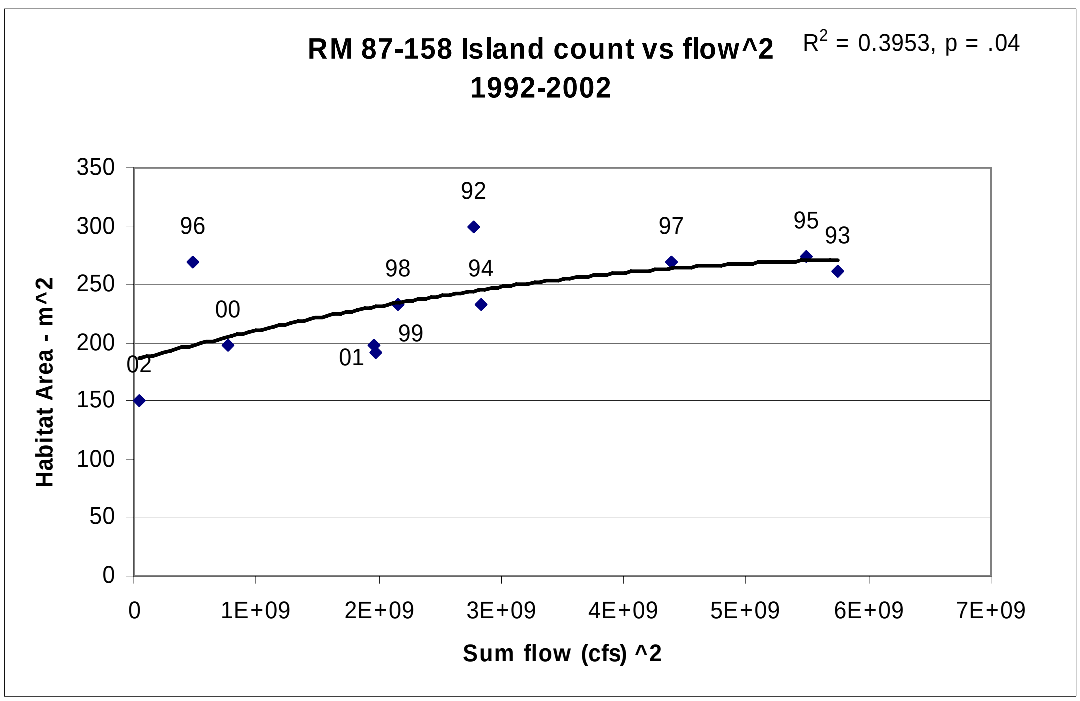


Figure 15. Island count versus sum of flow^2 during runoff for 1992-2002, RM 87-158.

Large flows (approximately bank full and higher) were most effective in moving sediment through the system and long duration of high flows during runoff correlate well with backwater and low velocity habitat area post-runoff (Figure 13). The data analyzed indicate that flows above 8,000 cfs were effective in maintaining backwater habitat (1993, 1995, 1997 in Figure 12) , while flows in the range of 5,000 cfs are not (Figure 13). Flows above 10,000 cfs were not critical to backwater area maintenance in the short term (Figure 13). The data set is too short to determine, in the long term importance of flows above 10,000 cfs for overall channel maintenance. Larger flows also assisted in maintaining channel complexity (island count), but the relationship was not as strong (Figure 15).

Effectiveness of the 2,500 cfs criteria was evaluated by examining the depth of open interstitial space (depth to embeddedness) in the four cobble bars that have been identified as potential spawning bars and have been monitored as described in the long term monitoring plan.

Open interstitial space in cobble bars did not appear to be correlated to the 2,500 cfs criteria, at least for the monitored bars (Figure 16). There were 13 days of flows at or above 2,500 cfs in 2003 and the bars had less open interstitial space than in 2002 with no days above 2,500 cfs. Further, there was no correlation between days above 2,500 cfs and the amount of clean cobble or mean depth of open interstitial space (Figure 17). However, in all years there was some clean cobble on the bars.

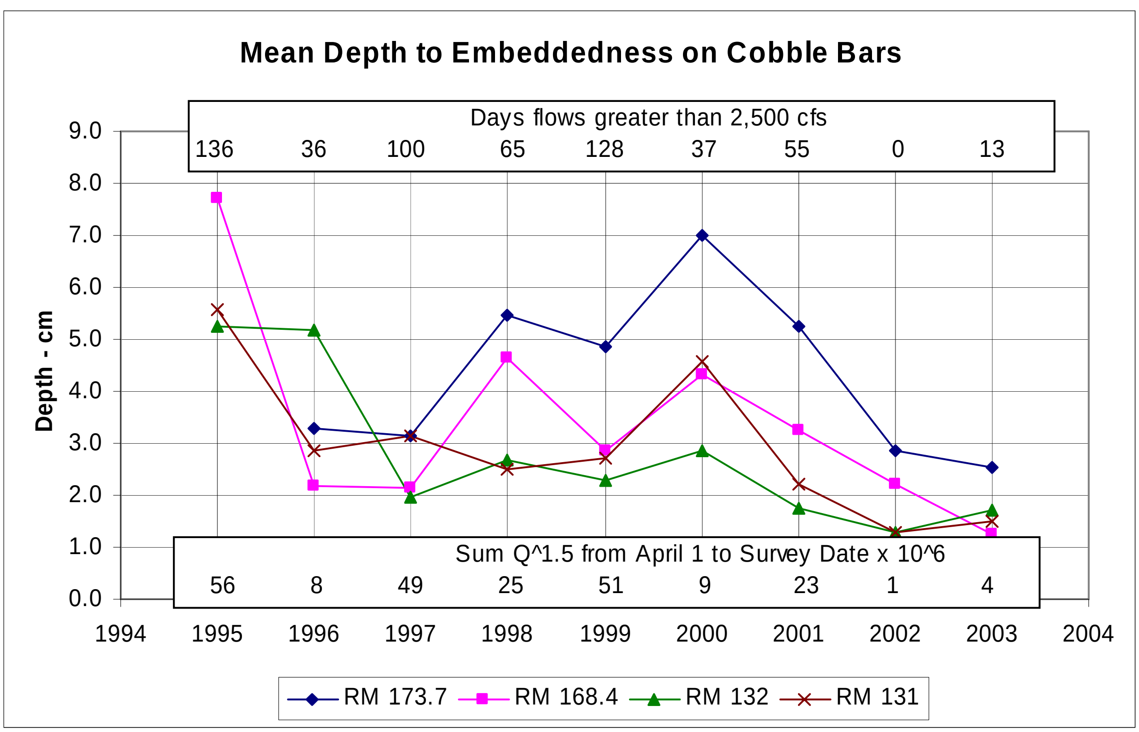


Figure 16. Mean depth to embeddedness on four cobble bars from 1995 through 2003.

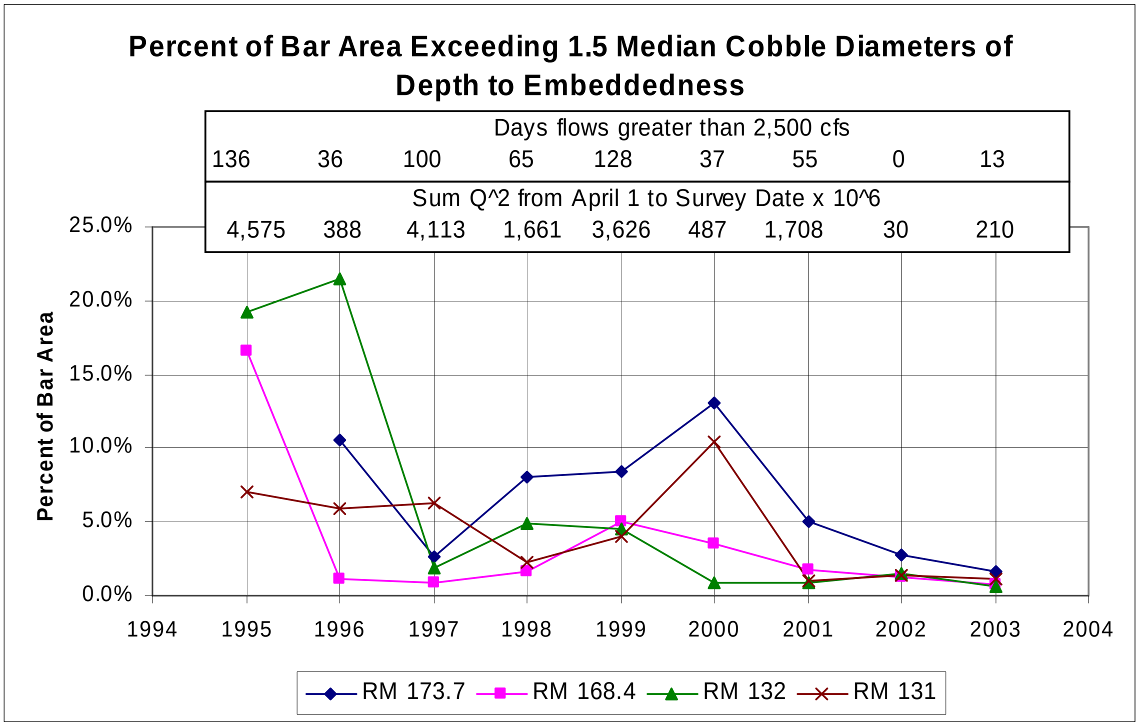


Figure 17. Percent of bar area with depth to embeddedness exceeding 1.5 times the median cobble diameter from 1995 to 2003.

Creation of backwater habitat can be influenced by the nature of the releases from Navajo dam, but is as much or more dependent upon the recurrence of wet years. Backwater area for Reach 5 was measured from 1962 aerial photography and found to be about the same as the 2002 value. Also shown on the figure is the average annual discharge for the 10 preceding years. Both measurements occurred after a period of drought with about the same 5-year period without meeting the high flow criteria. The 1991-1995 period occurred after an extended wet period and the backwater area was the highest measured (Figure 18). It appears that the river likely experienced relatively long-term cycles of backwater and low velocity habitat abundance, associated with the hydrologic wet and dry cycles. While manipulation of the hydrograph through dam releases can maximize the utilization of the available water and increase frequency of meeting at least the 8,000 cfs criteria, some periodic swings in availability of backwater and low velocity habitat are likely to occur in response to the wet-dry patterns of hydrology typical in the San Juan Basin.

The recommendation for flows at 5,000 cfs and 2,500 cfs do not appear to be causing the expected response. It will be necessary to experience a cycle of wet years to determine if the high flow portion of the recommendations performs as expected.

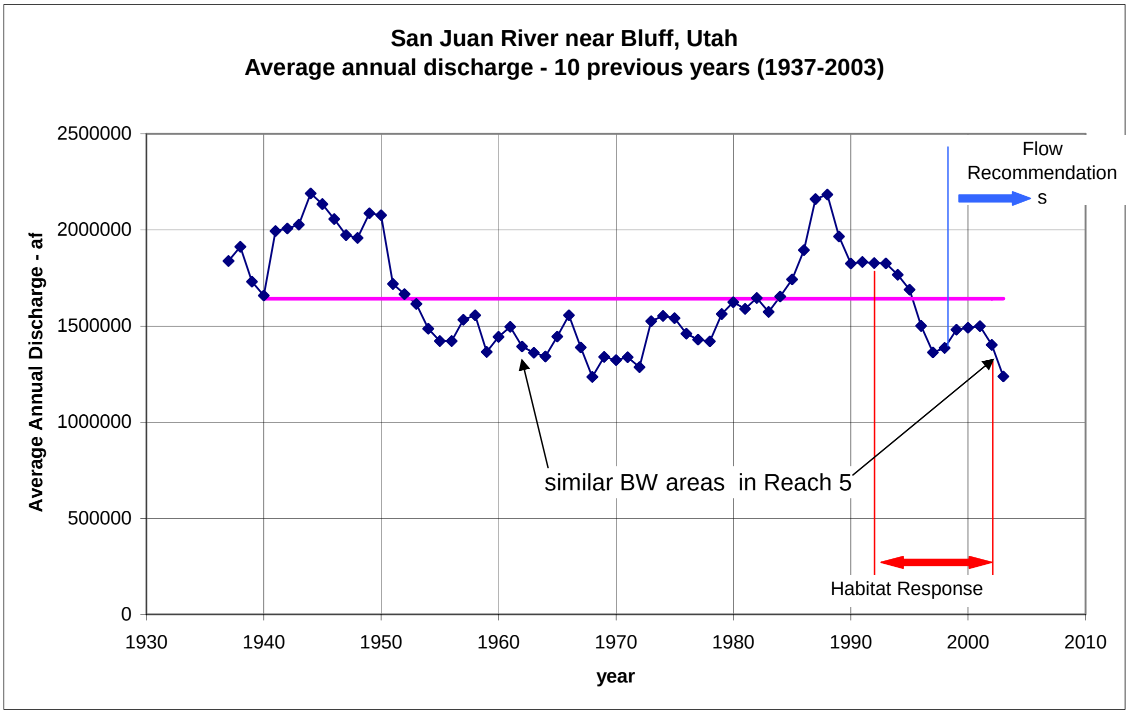


Figure 18. San Juan River near Bluff, Utah, Average annual discharge – 10 previous years (1937-2003) with indication of periods of low backwater habitat abundance.

Habitat-Fish Relationship Statistical Summary

As part of the data integration process, an attempt was made to statistically inter-relate the geomorphic habitat mapping data with the adult monitoring data from 1998 to 2002 (Lamarra 2004). Data from 1998 through 2002 were best suited for complete analysis because both data sets were spatially complete (River Mile 180 to River Mile 2) and collected at comparable times. The analysis on the five years of data followed three lines of investigation.

The main objective of the pair-wise analysis between fish CPUE and the surface area of habitats was to determine if fish abundance could be predicted by singular habitat abundances within the San Juan River. The Pearson's Correlation Matrix was used to infer relationships between fish CPUE (as a dependent variable) and the specific or general habitat parameters (used as independent variables). The results of this analysis indicated that the habitat variables, island count and pocket water were significantly correlated to more than 70% of the "fish species life stages" dependent variables while cobble shoals, slackwaters, and cobble bars were significantly correlated to over 50% of these variables. This would suggest that across all fish species and life stage analyzed, the five above mentioned habitat types are singularly important in the prediction of the spatial distribution of the fish species by life stage.

In the second analytical approach, the spatial distribution of specific habitats types within the San Juan River was compared to the spatial distribution of the four dominant fish species (juveniles, adults, and totals) CPUE using a step-wise multiple regression. The advantage of using a multiple variable approach is that the distribution of fish maybe related to combinations of several habitat types rather than a single variable. This approach allows the investigation of several habitat types as independent variables in predicting the spatial distribution of fish in the San Juan River. The step-wise multiple regression analysis focused on the habitats that significantly predicted river-wide fish distributions by life stage.

The bluehead sucker dependent variables had r^2 values ranging from 0.21 to 0.72 with the independent specific habitat variables. For the riverwide distribution of this fish, juvenile bluehead CPUE was correlated with river mile, island count, and shoals and to a lesser extent riffle habitats. In a similar manner, adult bluehead CPUE was correlated with river mile, island count and sand or cobble shoals. In addition, adult bluehead densities were also related to pool habitat densities. It was apparent that on a riverwide scale, juvenile and adult blueheads demonstrate a significant statistical relationship with the river mile (a possible longitudinal gradient of unknown cause), island count (possible relationship to complexity or edge effects), shoal and riffle habitats (possible relationship to increased primary and secondary production).

The flannelmouth sucker, although having a similar range of r^2 values (0.33 to 0.70), had a different combinations of independent habitat variables predicting riverwide CPUE when compared to the bluehead sucker. Although river mile was the dominant regression variable, riffles and island area were important for juvenile flannelmouths while pool habitat and total wetted area were important regression variables for adults.

The channel catfish and common carp riverwide step-wise multiple regression analysis was relatively unsuccessful. Although significant at the $p= 0.05$, the habitat variables explained on average only 30 % of the variation in catfish CPUE, and 35% of the common carp CPUE. Even with low r^2 values, an inspection of those variables which were in the regression equations provides some insight into habitat importance. For example, catfish and carp CPUE were found to be related to low velocity habitats such as slackwater, flooded vegetation and irrigation returns. A cobble substrate component (shoals or riffle) was also found to be important in the multiple regression equations.

The third and final statistical approach was also regression based. However, the difference in this analysis was that the spatial distribution of specific habitats types was expressed as a component score of the Principle Component Analysis(PCA) and compared to the spatial distribution of the four dominant fish species (juveniles, adults, and totals) CPUE using step-wise multiple regression. Principle Components Analysis (PCA) is a commonly used methodology in the analysis of large interrelated data sets and is designed to capture the variance in the data set in terms of principle components. In essence, the analysis attempts to reduce the dimensionality of the data (i.e., reduce the number of variables such as specific habitat types) while keeping intact the importance and the variance of defining variables. In summary, the objective of the PCA analysis was to (1) reduce the number of variables, and (2) determine if the new restructured PCA factors (based upon the specific habitat data) were related to the spatial distribution of the

CPUE from the "fish species by life stage" dependent variables. In the PCA approach used in this investigation, an attempt was made to reduce the number of habitat variables by having the PCA express multiple variables as a single "factor". The new "factor" was a linear combination of the previous specific habitat variables.

When comparing the different years used in the analysis (1998-2002) the habitats selected with the highest variable loading values which produced the unique PCA axis had a great degree of similarity. For example, for all years, the first PCA axis was dominated by run habitats with secondary emphasis on riffles. The second axis was dominated by either pocket water or slackwaters, both of which are low velocity habitat types associated with the river edge. The third axis was dominated by the selection of shoal type habitats. This habitat type was usually associated with the heads or bottoms of islands. The fourth axis was dominated by cobble type habitats while the fifth axis was associated with habitats that were cobble based or low velocity habitats surrounded by cobble habitats (i.e. eddies or rootwad piles).

It appears that the first step in the PCA analysis which was the simplification of the 38 habitat types into several PCA axis was successful and comparable between years. The results of the step-wise multiple regression analysis using the case scores from the PCA loading variables and the PCA factors axis (denoted as A1, A2, etc.) and which also included River Mile as an independent variable had results similar to the regressions in the specific habitat analysis noted above. The native suckers (bluehead and flannelmouth) had goodness-of-fit values (r^2) over 0.50 in over 75% of the equations (between 1998 and 2002). The highest r^2 values were found in 2000 with values between 0.50 and 0.69 for both species. In contrast, the two non-native fishes (common carp and channel catfish) had no goodness-of-fit (r^2) values in excess of 0.48. As with the specific habitat analysis, river mile (RM) was the dominant variable across species and years. The step-wise selection of the PCA axis was not uniform between species, life stage, or years. The two native species (bluehead and flannelmouth suckers) had regression coefficients associated with the A1 PCA axis (the first PCA axis was dominated by run habitats with secondary emphasis on riffles). A2 through A5 were used to a lesser extent in the multiple regression equations for these native species. The two non-native species (common carp and channel catfish) used in this analysis did have somewhat different results in the regression analysis. River mile was the most common regression coefficient variable followed by PCA axis A2 and A3 for the non-native species. These axis were dominated by low velocity edge habitats and low velocity habitats associated with islands.

Given that the results of the PCA axis analysis (habitats selected by the PCA were similar to the independent variables selected in the habitat specific step-wise multiple regressions) and that the PCA axis based multiple regressions were as significant in predicting fish life stage CPUE, the PCA approach was considered more advantageous because of the assurance that the PCA factors (axis) were truly independent and not inter-correlated. That assurance cannot be given for the specific habitat variables approach in the step-wise multiple regressions. The Pearson's correlation matrix indicated a high degree of inter-correlation between specific habitat types.

It is apparent from the three statistical approaches used in this analysis that there are significant habitat factors (taken singularly, in combination, or transformed by Principle Components) that predict the spatial distribution of native and non-native species by life stage in the San Juan River. Significant relationships were found for each year from 1998 through 2002. Common habitat based parameters were found between each year.

CONCLUSIONS

The current monitoring protocols have several main objectives and sub-objectives for each protocol. The physical habitat protocols, as set during the initial monitoring period, were able to track selected water quality parameters. The protocols determined changes in channel morphology and substrate composition. The protocol determined changes in cobble bar characteristics and determined trends in quantity and quality of low velocity habitats. All of their stated objectives were met with the current protocols; however, since these protocols were not conducted concurrently with fish sampling, there was difficulty in linking direct response of change in habitat with change in fish populations or fish habitat use. Recommendations have been made to allow that direct comparison of habitat use and habitat availability.

The biological monitoring protocols include larval fish sampling, small-bodied fish sampling and large-bodied fish sampling. The larval fish sampling is designed to determine relative annual reproductive success of Colorado pikeminnow and razorback sucker. The larval protocols, as designed, are able to detect reproductive success for Colorado pikeminnow and razorback sucker. These protocols will continue as they currently exist to continue the monitoring of those populations.

The small-bodied fish and large-bodied fish sampling can detect relative changes in populations although the level of detection differs by protocol. Small-bodied fish sampling can detect changes of 40% or greater with the current sample numbers and the large-bodied fish sampling can detect changes in trends of 20% or greater for the large-bodied abundant species. Both of these protocols will continue. The suggested change to the small-bodied protocols is listed in the recommendations to allow a detection of relative abundance at a lower percent change in population.

Habitat, Channel Morphology, And Water Quality

- Backwater habitat type has shown a significant reduction with time during 1998-2002
- There was no change in other habitat types.
- The current habitat monitoring protocol does not collect habitat concurrent with fish collections and therefore there is no means to directly compare fish use of specific habitat types.
-
- There was no change in channel width during the monitoring period.
- There appeared to be no change in channel complexity.
- There were no significant changes in water quality shown during the monitoring period.
- Navajo dam water release temperature causes a 2-3°C decrease in water temperature in the San Juan River at Farmington during summer months and a slight increase in winter months.
- There is a delay in reaching 20ºC by approximately 2 weeks due to Navajo Dam release temperatures at this location.

- Impacts further downstream could not be determined without use of a temperature model.
- During the 1998-2003 monitoring period, the desired flow criteria for 8,000 cfs and 10,000 cfs were not met primarily due to drought conditions in the basin, however, the recommended number of years between occurrences was not exceeded during 1998-2003.
- The desired 2,500 cfs and 5,000 cfs criteria were met, however, the expected habitat response to these flows was not seen.
- Further investigations in the habitat-flow response is needed.

Endangered Fishes And Fish Community

- The larval sampling regime did not collect Colorado pikeminnow during the 1998 – 2003 monitoring period.
- Few Colorado pikeminnow were collected by the small bodied monitoring in 1998 – 2000 and none were collected in 2001-2003.
- Colorado pikeminnow were collected in the large bodied fish monitoring.
- Wild spawned razorback sucker larvae were collected in all years 1998- 2003.
- No young of the year razorback sucker were collected during small bodied fish monitoring.
- Juvenile and adult razorback sucker were collected during adult fish monitoring.
- The large bodied fish monitoring protocol can detect changes in relative abundance as low as 20% for flannelmouth sucker, bluehead sucker, channel catfish and common carp.
- The small bodied fish monitoring protocol can detect changes in relative abundance as low as 20% for red shiner and speckled dace.
- Minimum change detectable for native suckers is approximately 40%.
- The current (since 2003) small-bodied fish sampling allows analysis of fish density by habitat.
- The current fish monitoring protocols, with the exception of small bodied fish starting in 2003, do not collect fish by specific habitat type.
- The lack of habitat specific collections precludes a direct analysis of fish response to habitat changes.

Flow Recommendations

- The flow recommendations were met during the 1998-2003 time period. However, no flows exceeded the criteria of days greater than 8,000 cfs and 10,000 cfs due to drought conditions in the basin.
- It appears from the data that the flows for 2,500 cfs and 5,000 cfs do not maintain habitat as expected in the absence of 8,000 and 10,000 cfs flows.
- Modifications to the current recommended flow regime should be investigated to determine whether reshaping the hydrograph will provide better habitat maintenance over time.

RECOMMENDATIONS

Based on the results of the 1998-2003 data, the following recommendations were made:

Habitat

- Continue annual habitat monitoring river-wide during fall low flows.
- Add two complex reaches to conduct detailed fine scale habitat mapping concurrent with Colorado pikeminnow and razorback sucker monitoring.
- Evaluate the need for annual habitat monitoring after flows exceed 10,000 cfs during runoff.

Channel Morphology

- Survey channel cross sections every five years after spring runoff instead of semi-annually before and after runoff.
- Collect topographic survey data and develop 2-D Models of the reaches selected for detailed habitat mapping

Water Quality

- Discontinue water quality sampling beginning in 2005 with the exception of turbidity and water temperature.
- The USFWS may require each applicant undergoing Section 7 consultation to provide water quality data necessary for their consultation. The SJRIP should use that data as it is available.

Fish Monitoring

- Larval monitoring should continue using the current protocol.
- Large bodied fish monitoring should continue using the current protocol.
- Population estimates should become part of the monitoring as Colorado pikeminnow and razorback sucker become more abundant.
- Small bodied fish monitoring should continue with the following adjustments:
    - Continue the basic protocol and collect 400- 450 samples per year by habitat type
    - Continue the block and shock technique started in 2004
    - Initiate a block and seine technique for a 3 year test with annual review at each winter meeting during the test period.

Flow Recommendations

- Investigate the ability to obtain high peak flows (i.e. greater than 8,000 and 10,000 cfs) during runoff more frequently than currently recommended.
- As part of the above investigation, change the shape of the ascending and

descending limb of the hydrograph and do not try to meet the 2,500 cfs and 5,000 cfs flow recommendations.

- Use the Riverware model as the method to make the above determination.

Integration Report

- Data collection for habitat and fish should be better coordinated during the monitoring to improve the ability to integrate multiple data sets from separate studies.
- The database should be updated annually to prepare for data anslysis and data synthesis.
- The next integration report for monitoring protocols should be completed in 2009 for monitoring data 2004-2008.

LITERATURE CITED

Bliesner, R. 2004. San Juan River Basin Recovery Implementation Program Habitat Response Analysis 1992-2002. Keller-Bliesner Engineering, Logan, Utah.

Bliesner, R., and V. Lamarra. 2002. Hydrology, geomorphology, and habitat studies; final report. San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Brandenburg, W. H., M. A. Farrington, and S. J. Gottlieb. 2004. Razorback sucker larval fish survey in the San Juan River during 1999-2002 three-year summary. University of New Mexico, Albuquerque, New Mexico.

Brandenburg, W. H., M. A. Farrington, and S. J. Gottlieb. 2003. Razorback sucker larval fish survey in the San Juan River during 2002. University of New Mexico, Albuquerque, New Mexico.

Brandenburg, W. H., M. A. Farrington, and S. J. Gottlieb. 2004. Razorback sucker larval fish survey in the San Juan River during 2003. University of New Mexico, Albuquerque, New Mexico.

Farrington, M. A., W. H. Brandenburg, and S. J. Gottlieb. 2003. Colorado pikeminnow larval fish survey in the San Juan River during 2002. University of New Mexico, Albuquerque, New Mexico.

Farrington, M. A., W. H. Brandenburg, and S. J. Gottlieb. 2004. Colorado pikeminnow larval fish survey in the San Juan River during 2003. University of New Mexico, Albuquerque, New Mexico.

Golden, M. E., and P. B. Holden. 2003. Summary of monitoring activities and other studies conducted by the San Juan River Basin Recovery Implementation Program, 1999-2002. Bio-West, Inc., Logan, Utah.

Lamarra, V. 2004. Statistical analysis of habitat availability and fish abundance in the San Juan River. Ecosystems Research Institute, Logan, Utah.

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

Propst, D. L., A. H. Kingsburg, and R. D. Larson. 2004. Small-bodied fish monitoring San Juan River, 1998-2002. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Ryden, D. W. 2003. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 1999-2001 integration report. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Ryden, D. W. 2003. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 2002, interim progress report. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Ryden, D. W. 2004. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 2003, interim progress report. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

U.S. Fish and Wildlife Service. 2002a. Colorado pikeminnow (*Ptchocheilus lucius*) Recovery Goals: amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Pairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2002b. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

Appendix I -- Statistical Evaluation Of Large-Bodied And Small-Bodied Fish Sampling Protocols

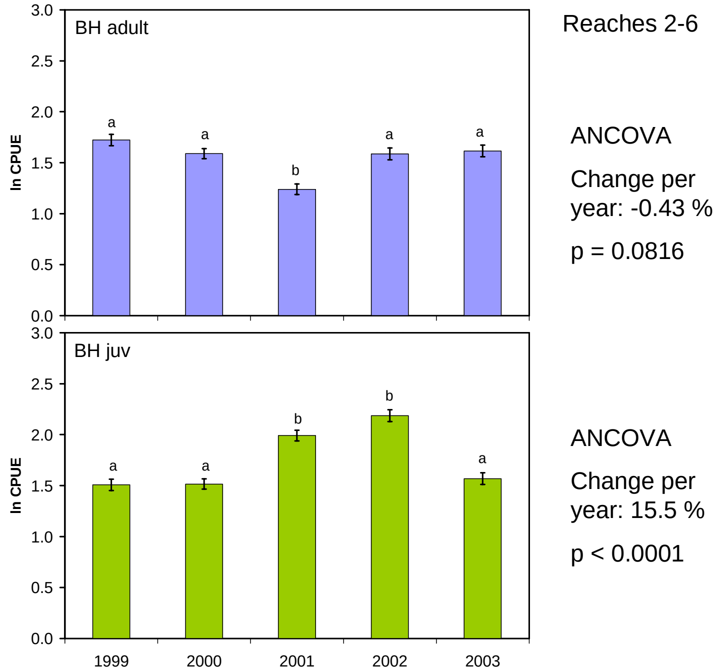


Figure1. Change per year ln CPUE for adult and juvenile bluehead sucker (bars with same letters are not significantly different).

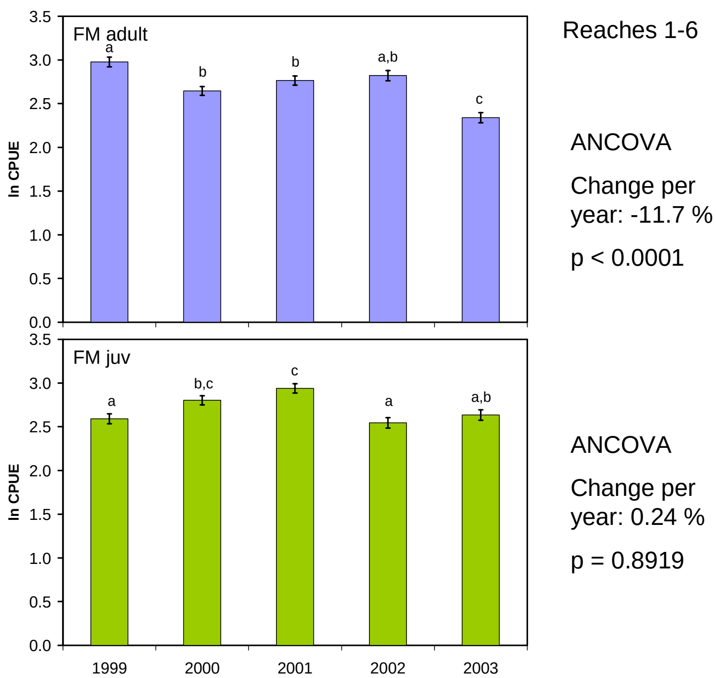


Figure2. Change per year ln CPUE for adult and juvenile flannelmouth sucker (bars with same letters are not significantly different).

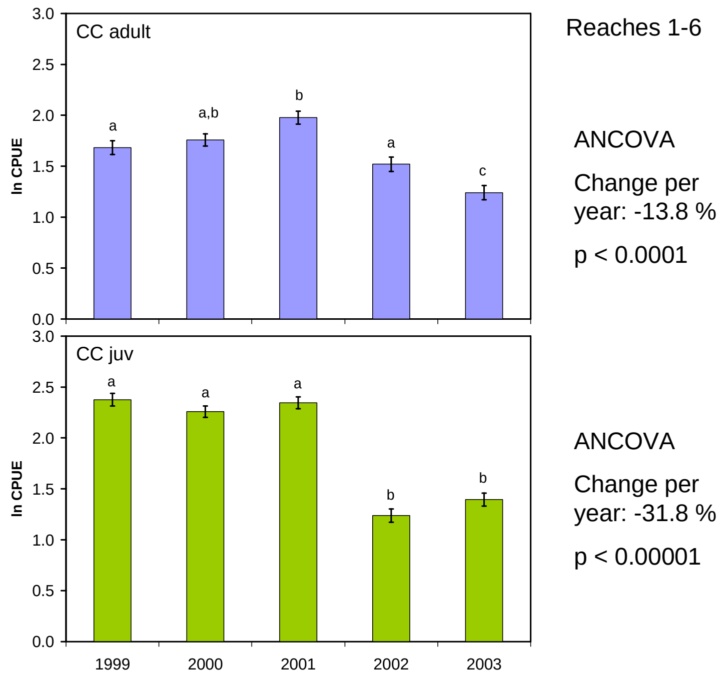


Figure 3. Change per year ln CPUE for adult and juvenile channel catfish (bars with same letters are not significantly different).

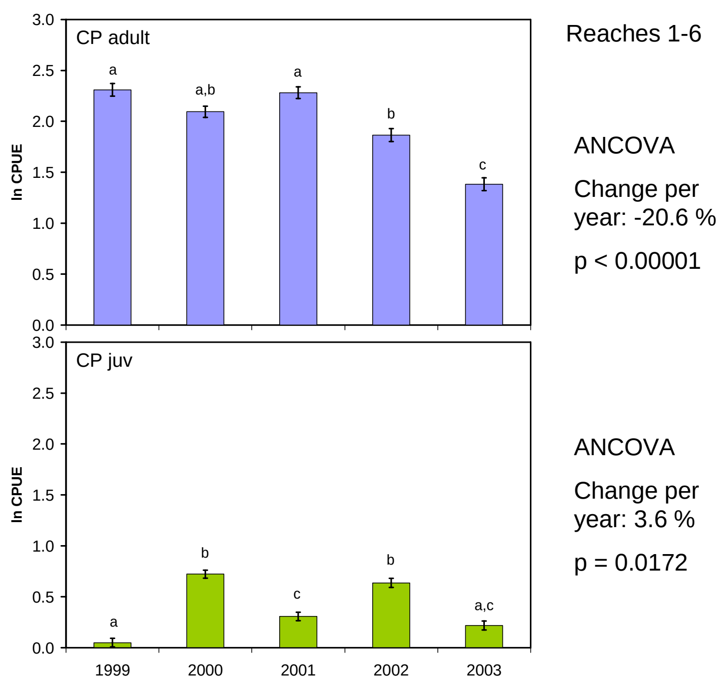


Figure 4. Change per year ln CPUE for adult and juvenile common carp (bars with same letters are not significantly different)..

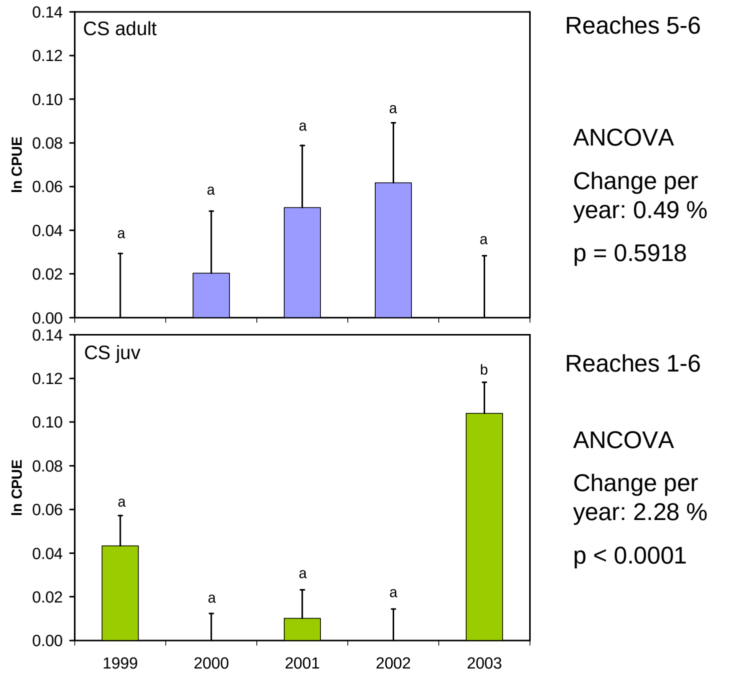


Figure 5. Change per year ln CPUE for adult and juvenile Colorado pikeminnow (bars with same letters are not significantly different)..

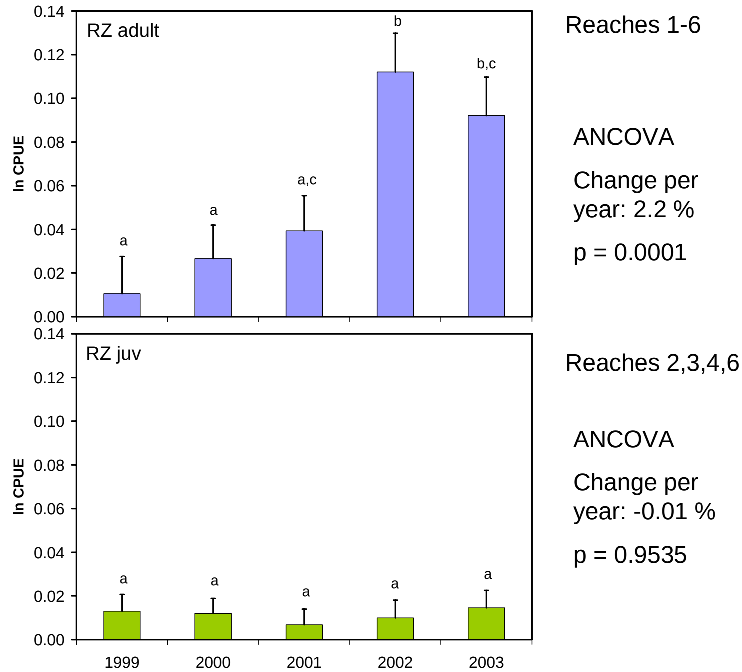


Figure 6. Change per year ln CPUE for adult and juvenile razorback sucker (bars with same letters are not significantly different)..

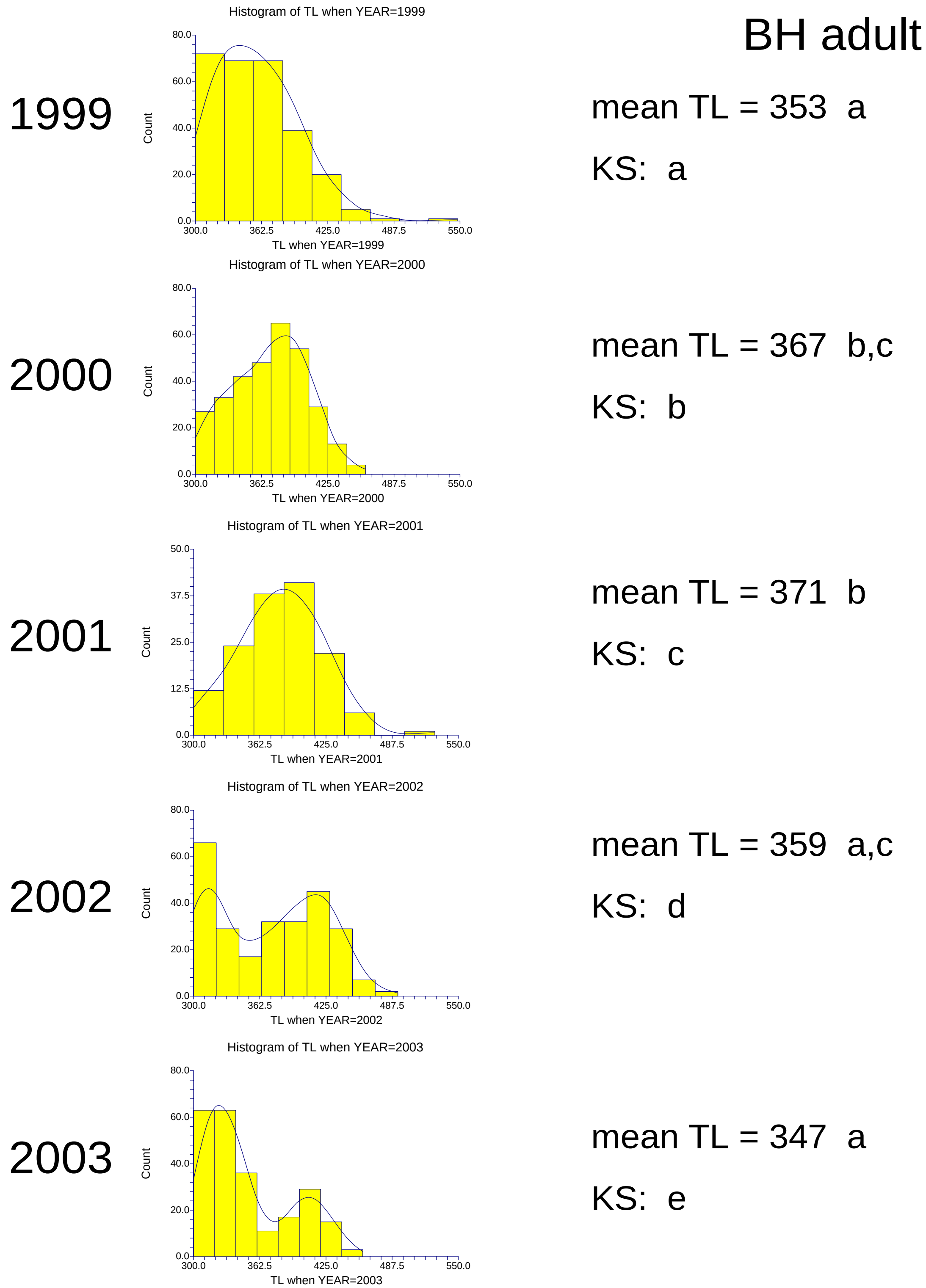


Figure 7. Length frequency histogram for adult bluehead sucker (bars with same letters are not significantly different)..

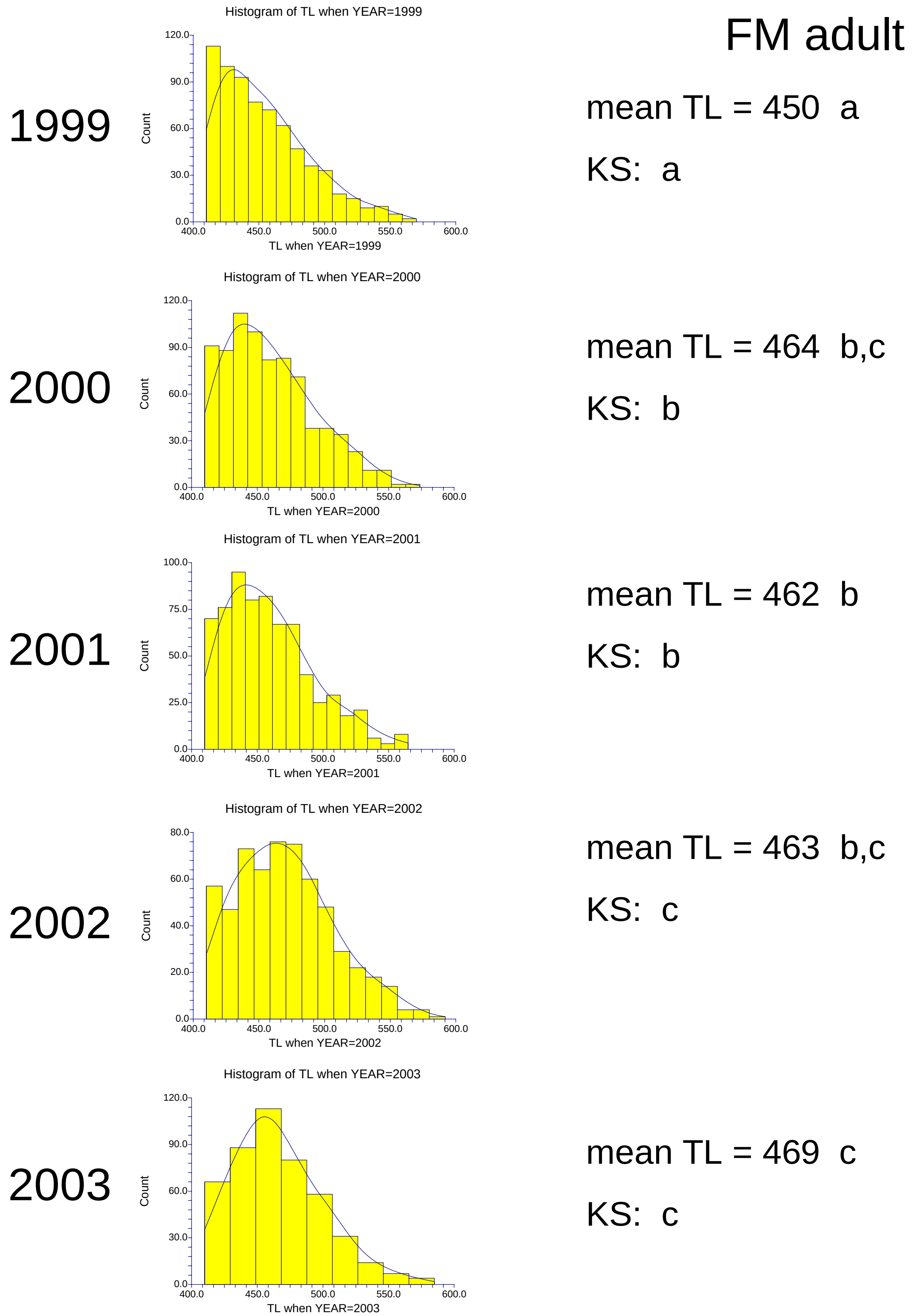


Figure 8. Length frequency histogram for adult flannelmouth sucker (bars with same letters are not significantly different)..

CC adult

1999

mean TL = 390 a,b

KS: a

2000

mean TL = 370 b

KS: a

2001

mean TL = 391 a

KS: b

2002

mean TL = 401 a

KS: c

2003

mean TL = 469 c

KS: d

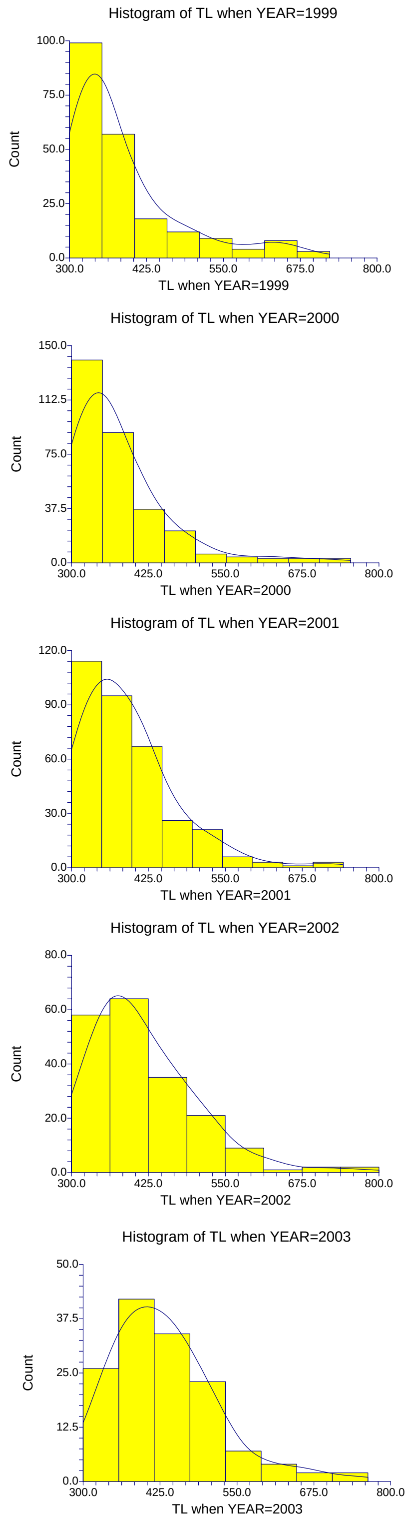
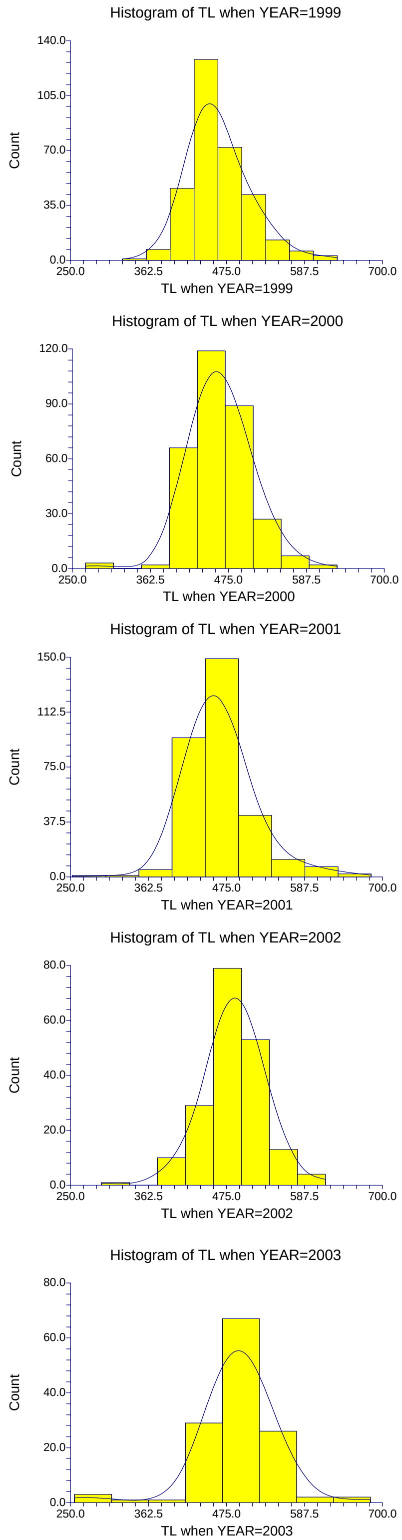


Figure 9. Length frequency histogram for adult channel catfish (bars with same letters are not significantly different)..



CP adult

1999

mean TL = 472 a

KS: a

2000

mean TL = 467 a

KS: a

2001

mean TL = 470 a

KS: a

2002

mean TL = 483 b

KS: b

2003

mean TL = 490 b

KS: b

Figure 10. Length frequency histogram for adult common carp (bars with same letters are not significantly different)..

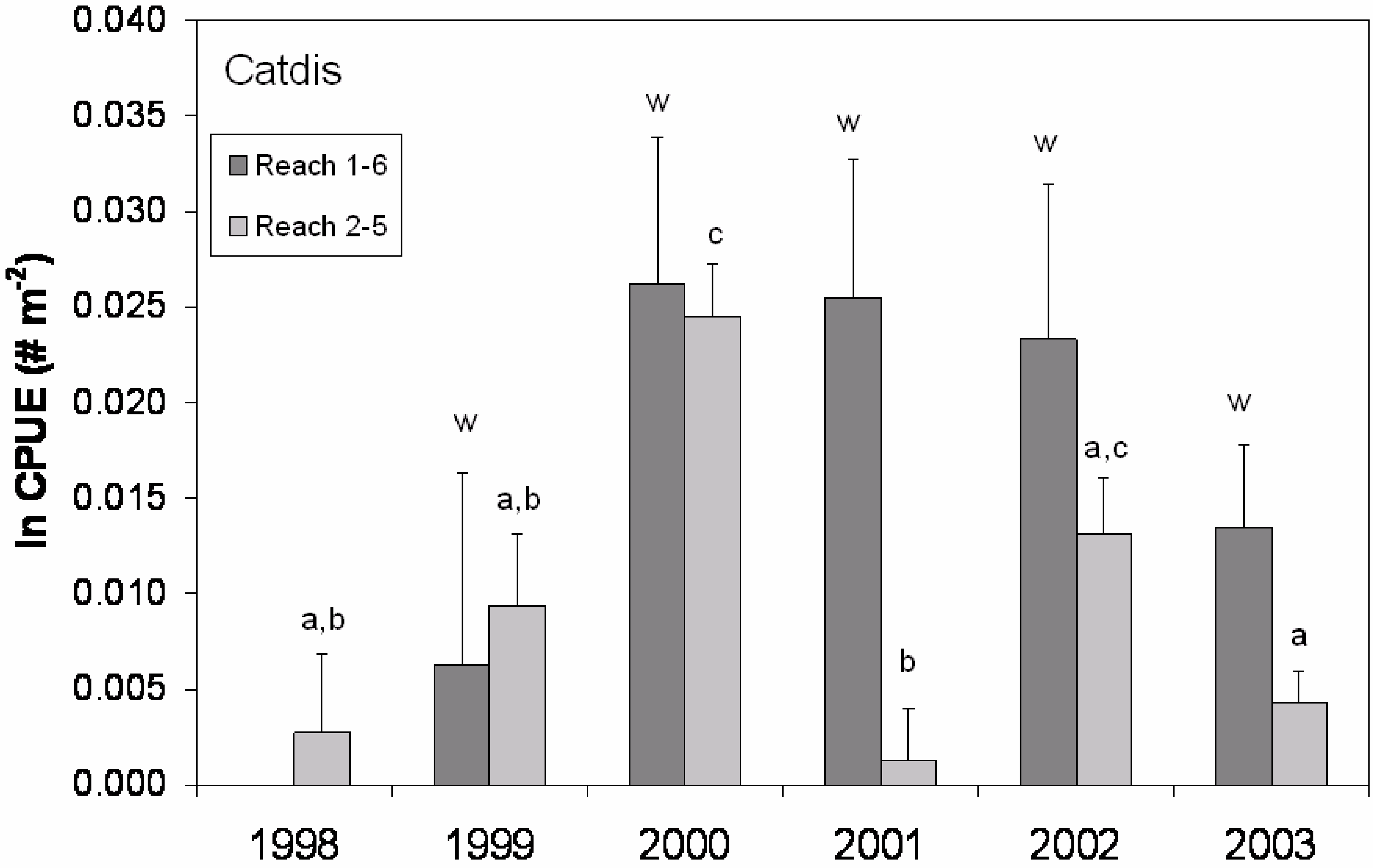


Figure 11. ln(x+1) density (# m^{-2}) for bluehead sucker [Catdis] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

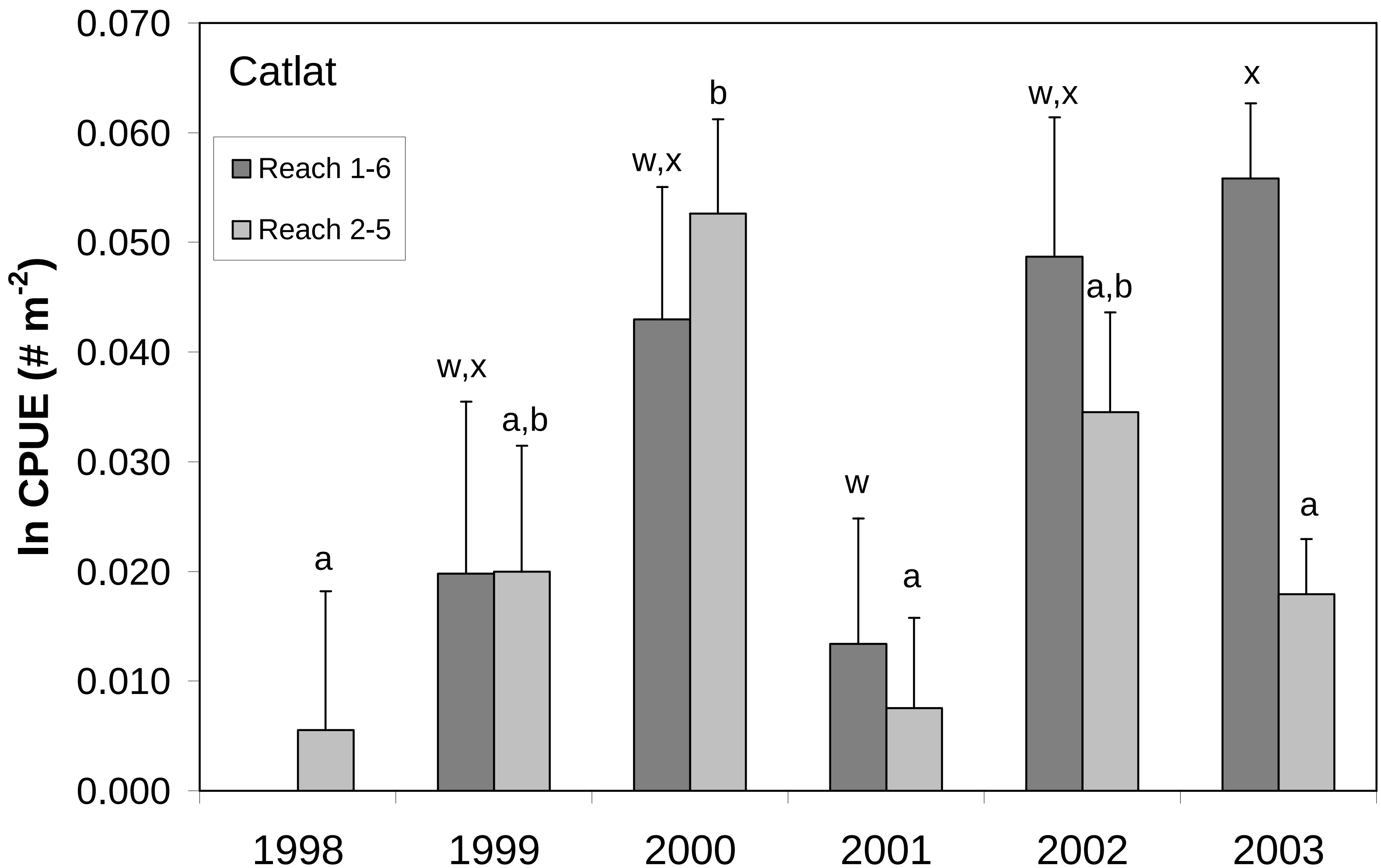


Figure 12. ln(x+1) density (# m^{-2}) for flannelmouth sucker [Catlat] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

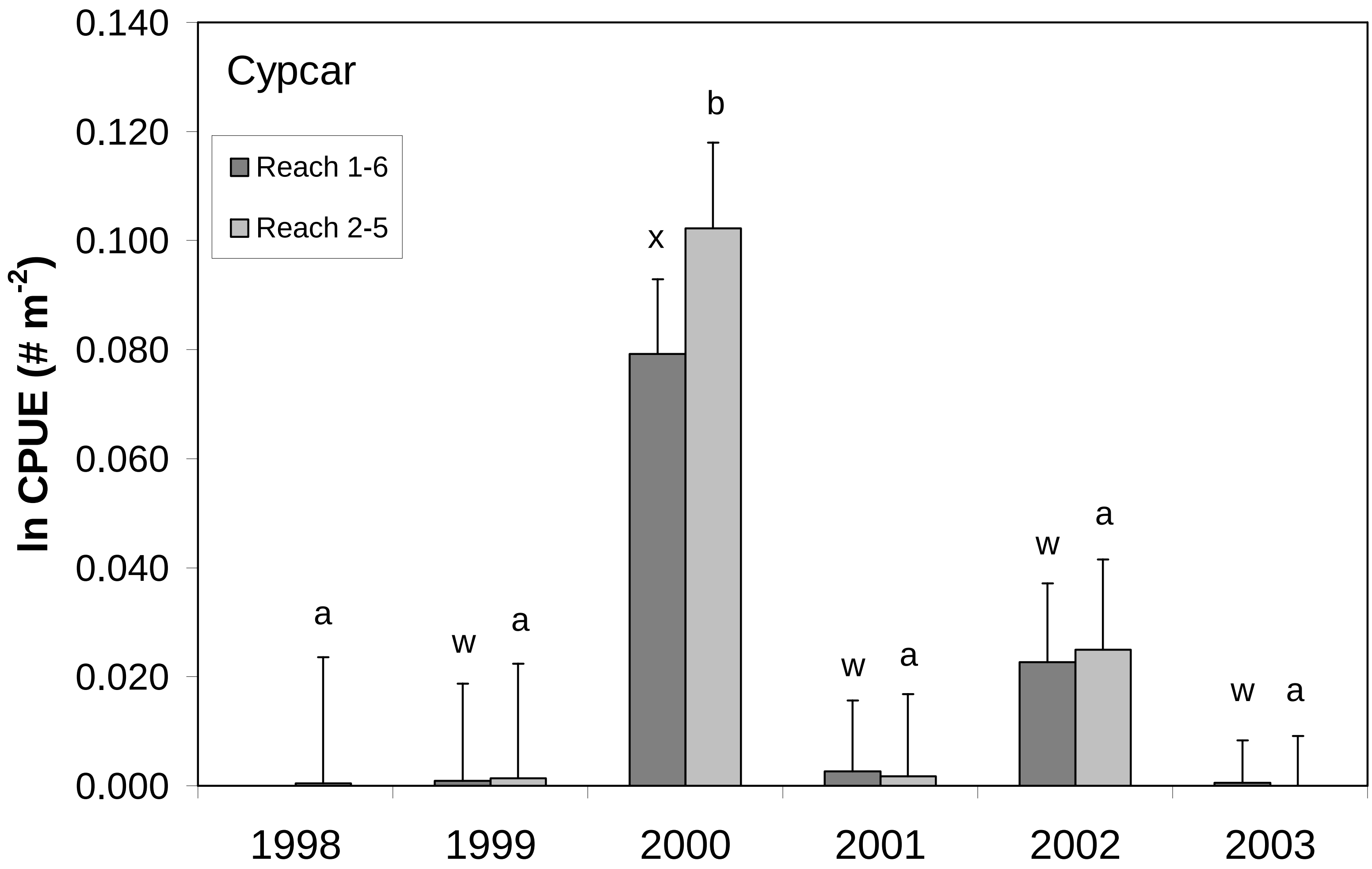


Figure 13. ln(x+1) density (# m^{-2}) for common carp [Cypcar] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

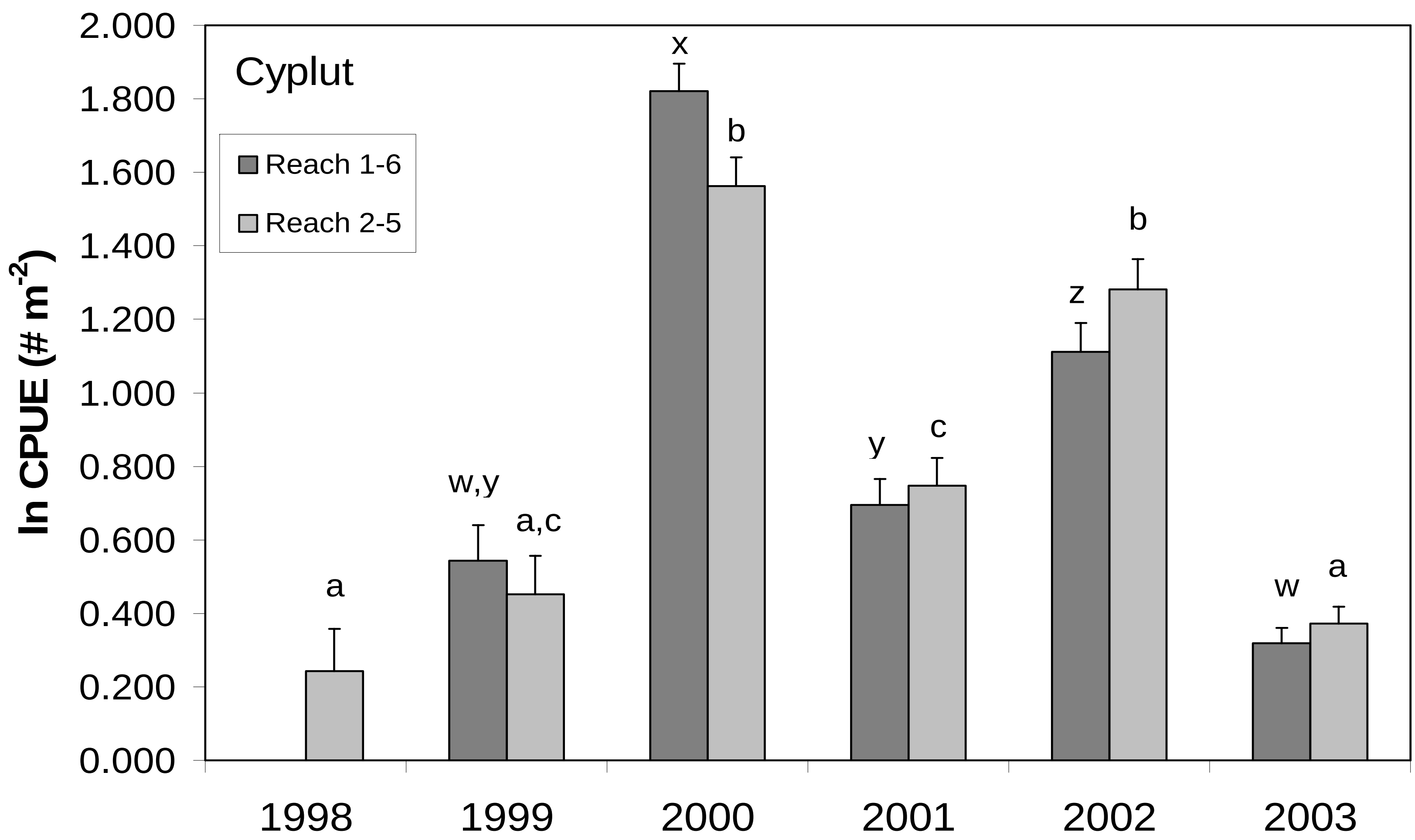


Figure 14. ln(x+1) density (# m^{-2}) for red shiner [Cyp lut] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

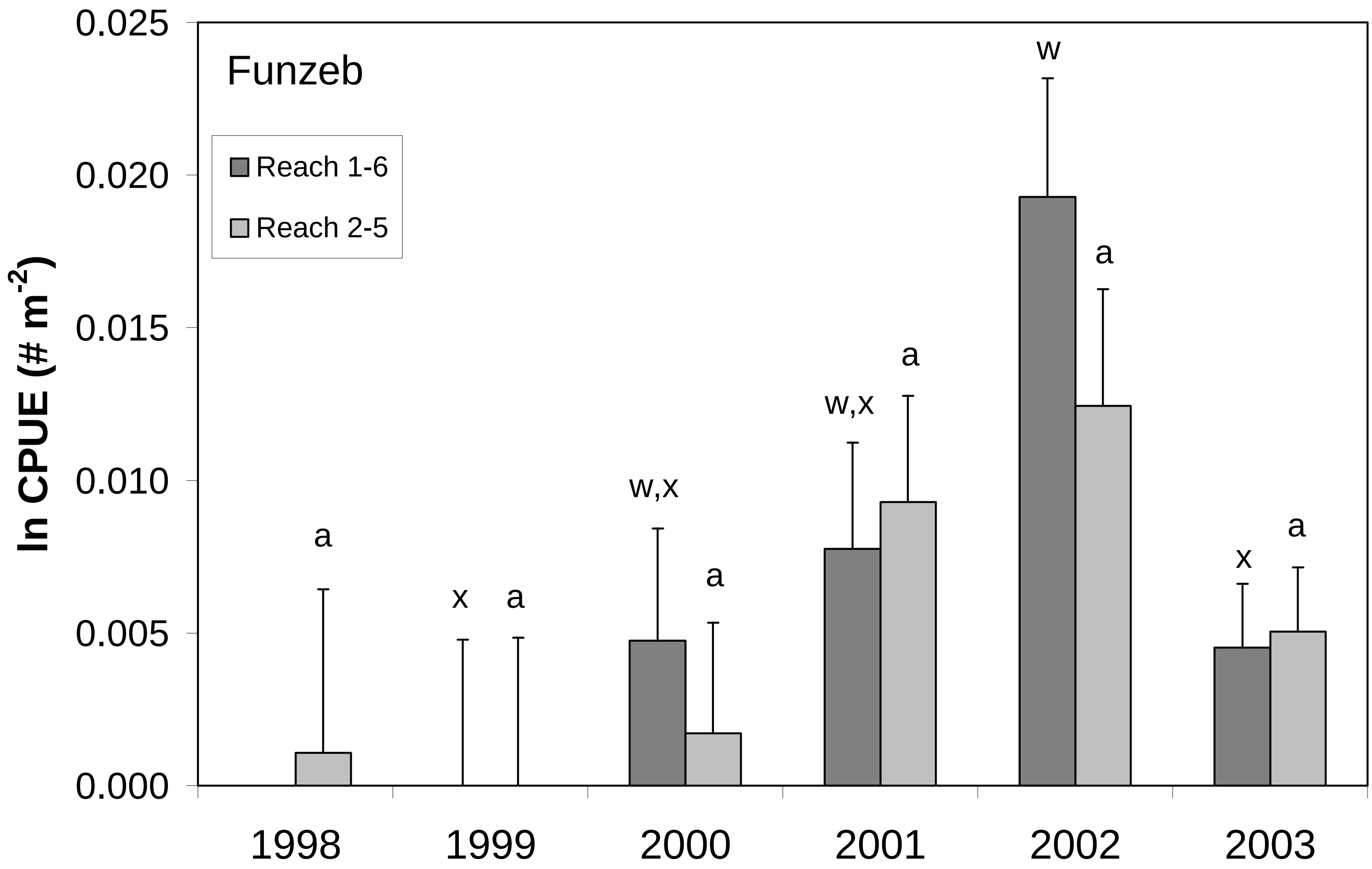


Figure 15. ln(x+1) density (# m^{-2}) for plains killifish [Funzeb] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

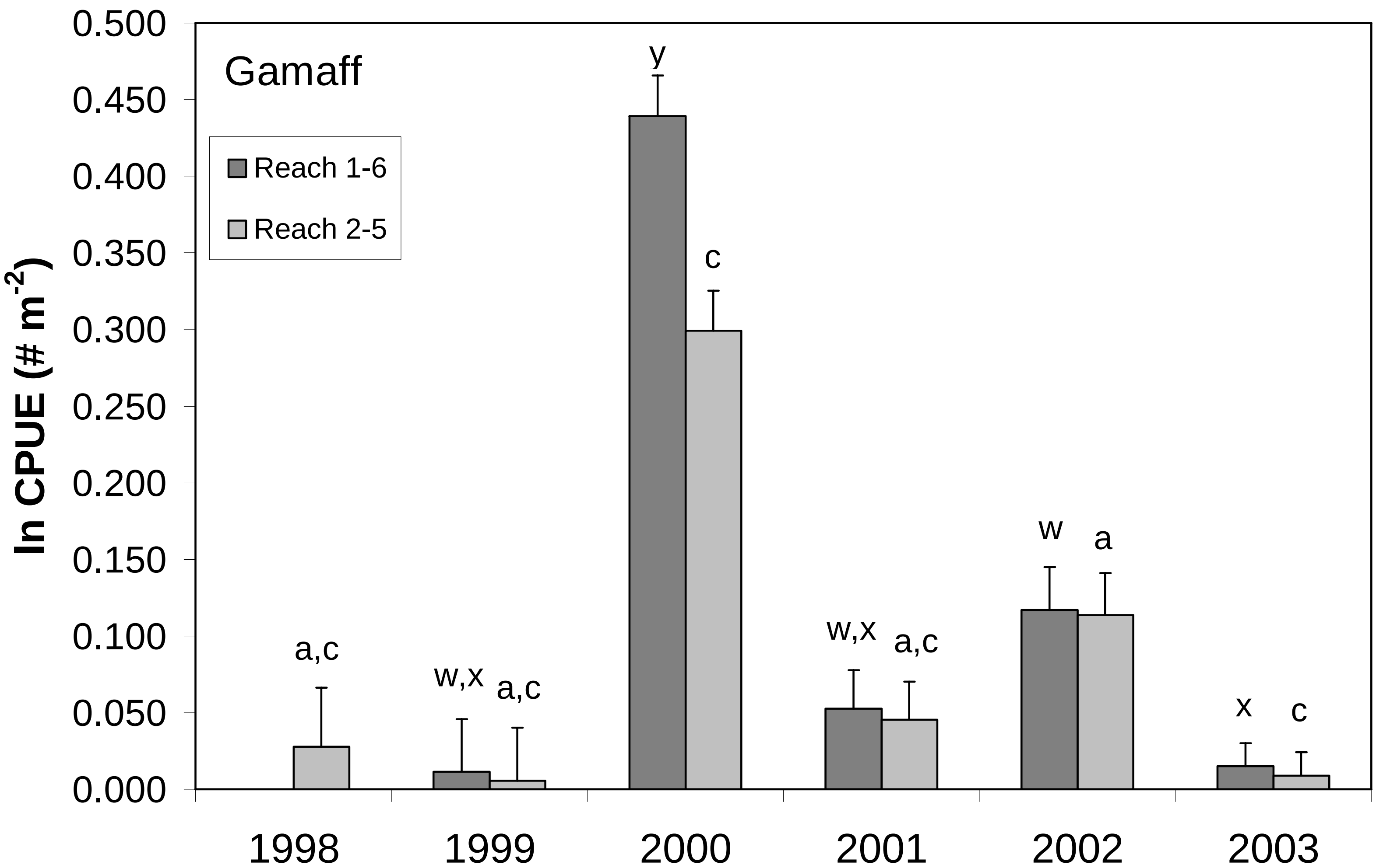


Figure 16. ln(x+1) density (# m^{-2}) for mosquitofish [Gambus] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

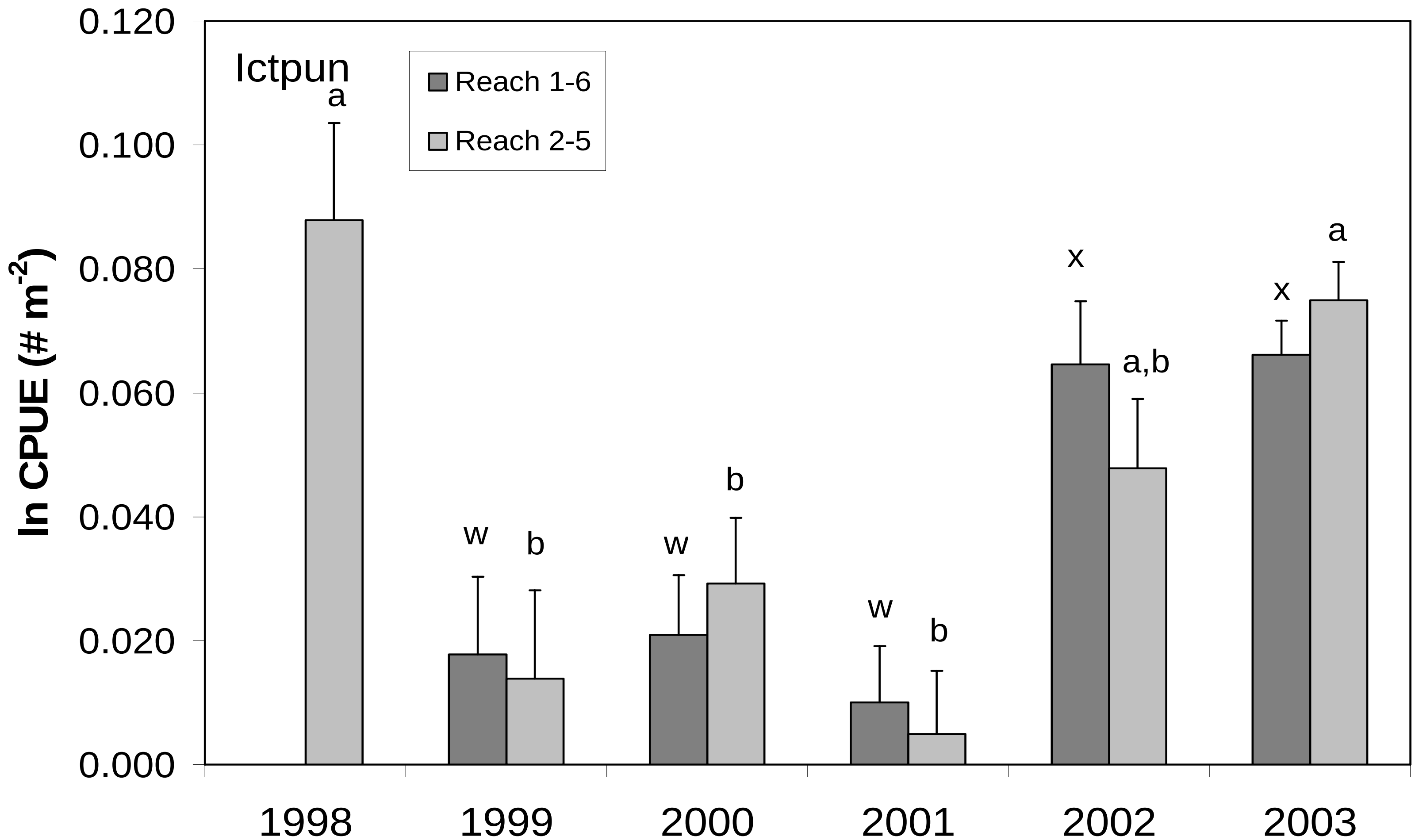


Figure 17. ln(x+1) density (# m^{-2}) for channel catfish (Ictpun] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

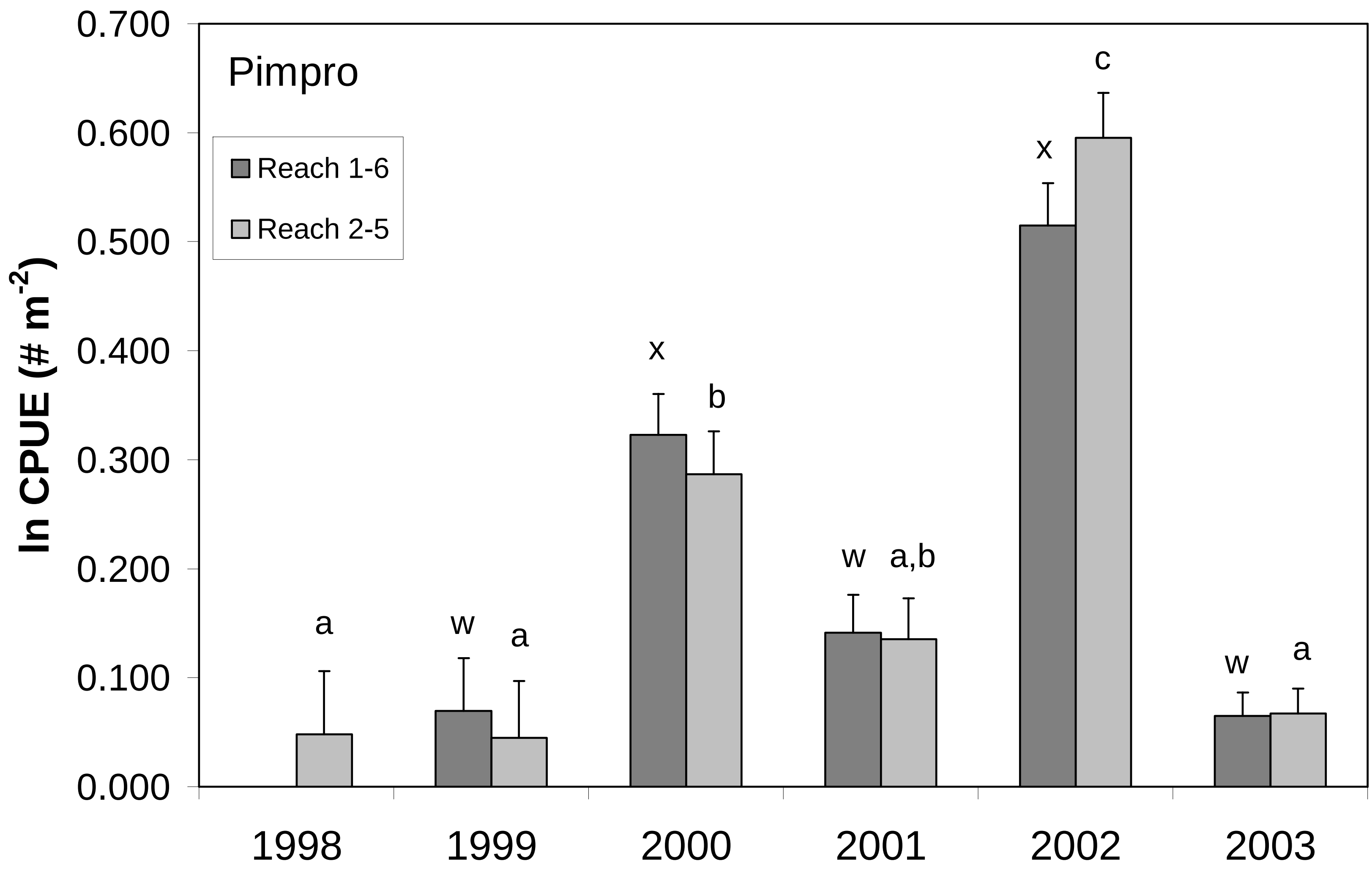


Figure 18. ln(x+1) density (# m^{-2}) for fathead minnow [Pimpro] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

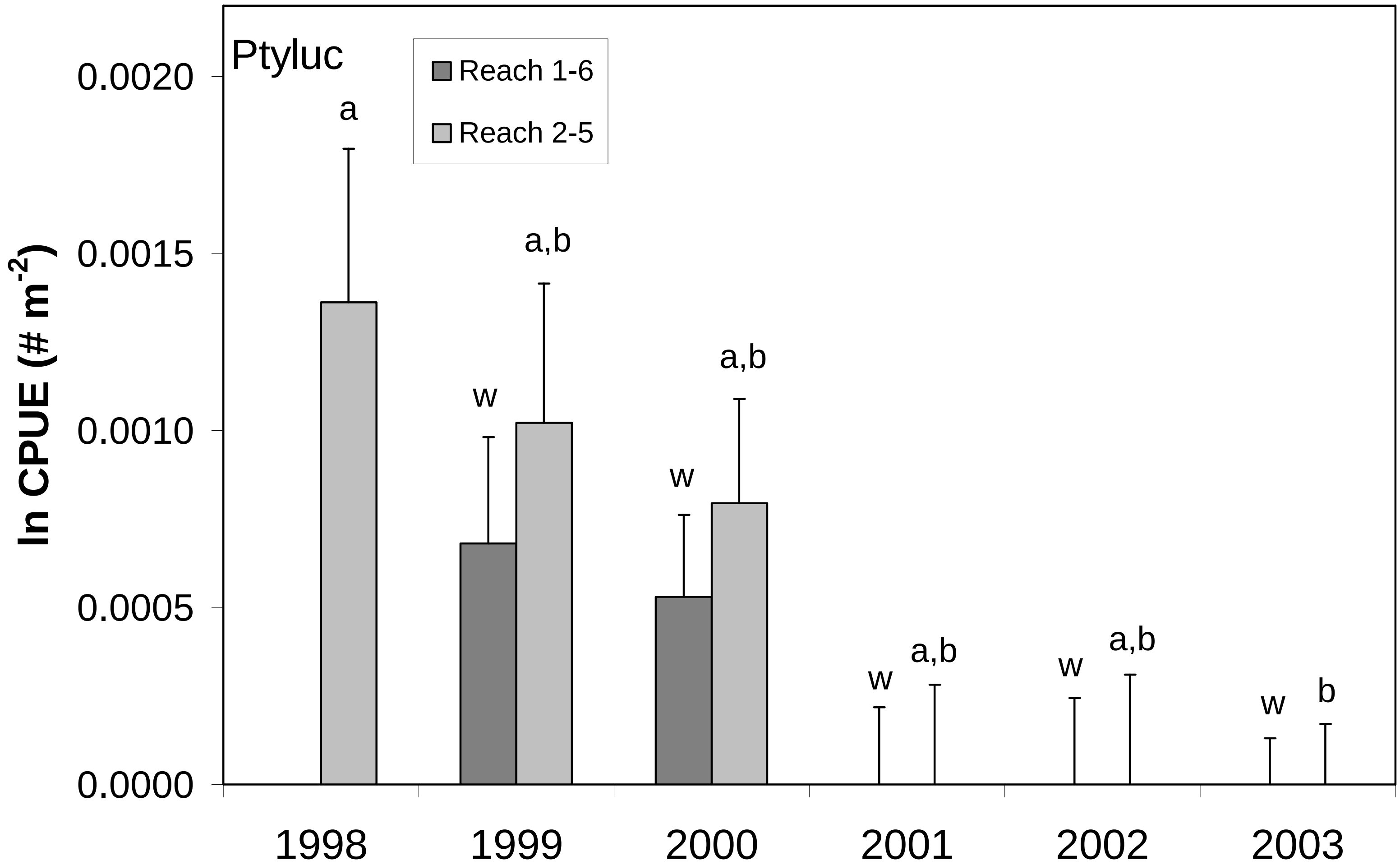


Figure 19. ln(x+1) density (# m^{-2}) for Colorado pikeminnow [Ptyluc] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

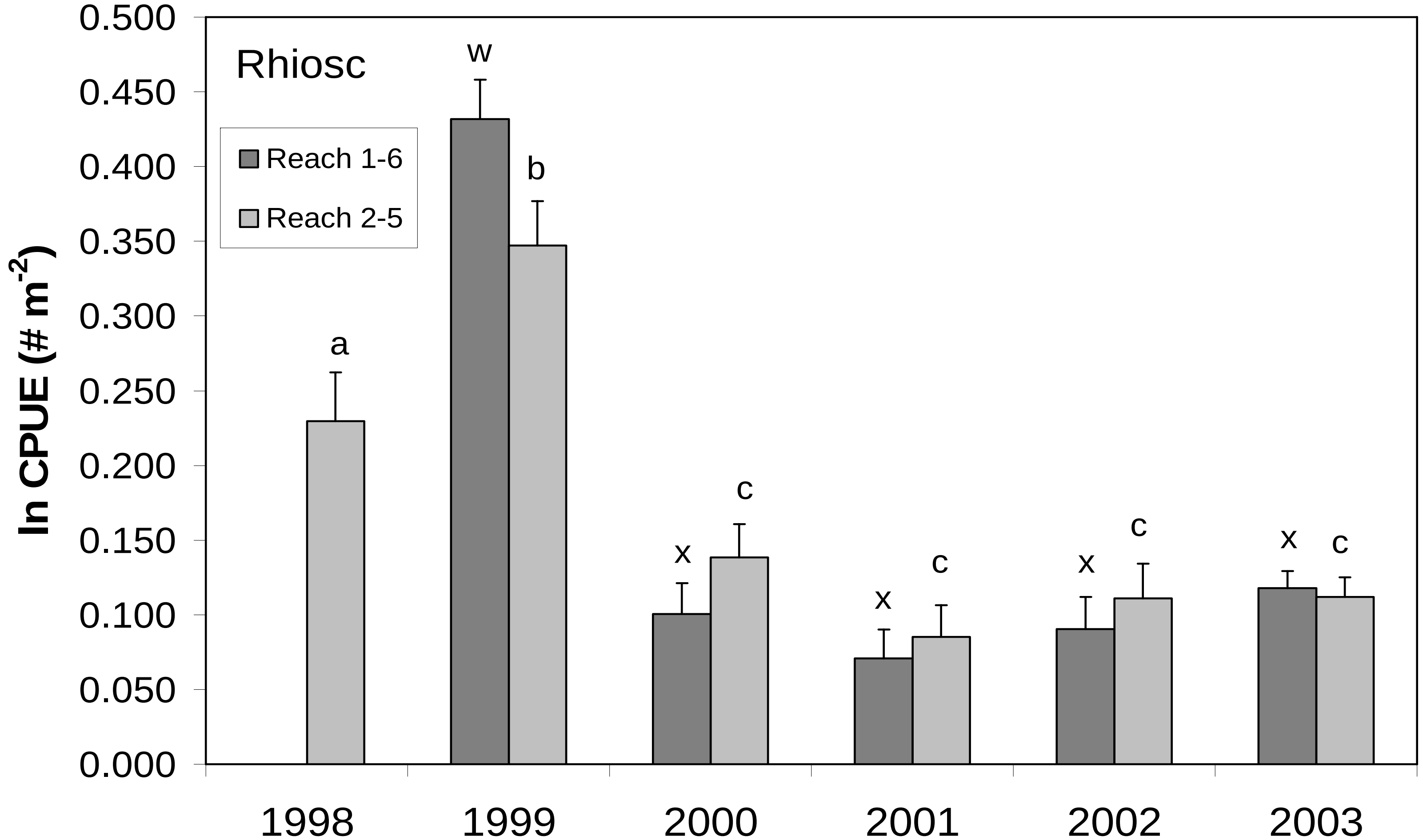


Figure 20. ln(x+1) density (# m^{-2}) for speckled dace [Rhiosc] for samples collected in 1998-2003 for reaches 2-6 and 1999-2003 for reaches 1-6. Error bars are 1.0 se. The same letters within an analysis indicate no significant difference between pairs of years.

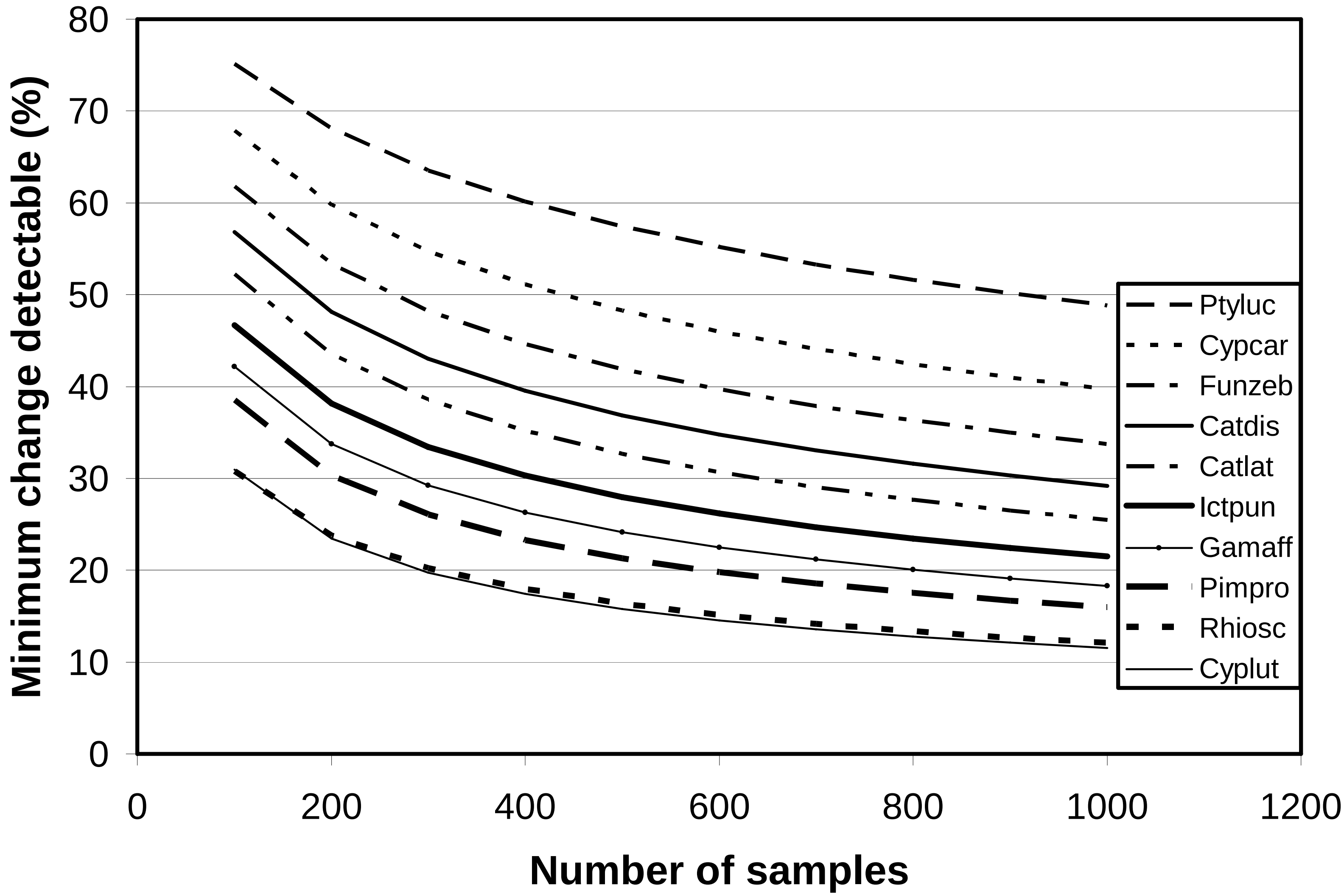


Figure 21. Sample size and percent change that is detectable between years for ln(x+1) density.