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ABUNDANCE OF AGE-0 NATIVE FISH SPECIES

AND

NURSERY HABITAT QUALITY AND AVAILABILITY

IN THE SAN JUAN RIVER

NEW MEXICO, COLORADO, AND UTAH

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FINAL REPORT

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This report is dedicated to the memory of our friend and colleague Michael James Arra.

EXECUTIVE SUMMARY

These studies were done as part of the Utah Division of Wildlife Resources (UDWR) early life-stage fisheries investigations. The contents of this report suggest that the management of flows in the San Juan River offer a variety of opportunities to enhance native species recruitment, while also enhancing and maintaining quality nursery habitat, at least as it pertains to young-of-year (YOY) Colorado pikeminnow. The first chapter represents an overview of the study area, study objectives, and generalized methods.

The second chapter represents an analysis of inter-annual flow regime variation and fish species community composition in the San Juan River from 1991 through 1996. The timing (Julian date) and magnitude of the spring peaks were strongly correlated with year-class strength of some native fish species. No strong correlations were apparent for non-native species. However, we wish to add a caveat to these data. First, the data set is very small (seven years only represents seven points in this kind of analysis) and should not be considered a robust analysis as such. Second, the correlation of Julian date and native species year-class strength may be spurious in that the timing of the spring peak may affect the size of the native fish fauna (and hence the catchability of these fish) instead of the actual size of the recruiting age class. In addition, in years when flow declined earlier and main-channel temperatures were warmer, age-0 native Catostomids were much larger during late summer, possibly increasing over-winter survival.

In Chapter Three, data is presented regarding the availability of backwater habitats throughout the San Juan River system. Comparisons are made between the San Juan River and the lower Green and lower Colorado rivers which have been shown to be important nursery areas for age-0 Colorado pikeminnow and still support large numbers of age-0 pikeminnow. The analysis suggests that more nursery habitat is available at lower discharges, suggesting that reaching base summer discharge early in the season would increase availability of backwater habitats to age-0 fishes. In addition, we found very few positive correlations between high spring discharges and increased nursery habitat availability. To the contrary, in Section 1 (the low gradient area at the inflow of Lake Powell), where the vast majority of the age-0 Colorado pikeminnow were captured during the research period, many significant negative relationships existed between backwater habitat and high spring discharges. High spring peaks with long descending limbs could have significant negative impacts on availability of nursery habitat the following summer in this important section of the San Juan River. Comparisons of backwater habitat availability between sections showed that Section 1 had higher densities and more area of backwaters per mile during every year, except 1995, than any of the other study sections of the San Juan River or the sections with which comparisons were made on the Lower Green River near Mineral Bottoms or Lower Colorado River below Moab.

Finally, in chapter 4, an evaluation of stocked young-of-year Colorado pikeminnow is provided, including growth, distribution, retention, and an analysis of habitat availability and use by Colorado pikeminnow. Approximately 100,000 Colorado pikeminnow were stocked at Shiprock NM, and at Mexican Hat, UT, in November 1996 and again in August 1997, and a further 10,571 were stocked at Shiprock in July 1998. The stocked fish exhibited excellent growth rates, comparable or exceeding those seen in wild pikeminnow in the Green and Colorado rivers. The initial recapture rate was 0.3-0.5% of the stocked fish. Catch rates declined steadily thereafter. At age-1 (55-120 mm) the fish underwent a shift in habitat use away from backwaters, where they began being collected

during the USFWS electrofishing efforts. Although initial survival was low, survival from age-1 to age-2 appeared to be essentially 100%.

Multinomial analysis suggested the stocked Colorado pikeminnow were found proportionally more often in backwater habitats formed by secondary channels and scour channels than those habitats occurred. Although these types of habitats were selected for, it is important to note that all types of habitats were used to some extent. Similarly, although pikeminnow seemed to select for deeper habitats, they were sometimes collected in the shallowest habitats. Some 'quality' habitats contained no pikeminnow at all, and many smaller habitats contained no fish of any species.

Distribution patterns were related to flow and habitat availability. The fish initially dispersed generally downstream. Subsequent sharp flow spikes related to monsoonal rains tended to displace the fish downstream in the Lower San Juan below Mexican Hat, while little displacement was observed in the Upper San Juan between Shiprock and Mexican Hat. The braided character of the upper San Juan provides some low velocity habitat at higher flows, while the narrow canyon-bound Lower San Juan provides very little low velocity habitat at those same high flows. The pikeminnow were retained in the Upper San Juan for at least two years, where they remained well distributed. Although this stocking effort has been successful to date, the question remains if wild spawned Colorado pikeminnow would be as likely to be retained, or if they would drift out of the San Juan River and into Lake Powell.

CHAPTER ONE

OVERVIEW AND BACKGROUND

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INTRODUCTION

The effects of dams on large river systems have been well documented over the past two decades (Ward and Stanford 1979, 1983, Petts 1984, Gregory et al. 1991). Changes in temperature regime, sedimentation and scouring, lateral habitat formation and maintenance, overall species diversity pools and the primary and secondary productivity of river segments affected by dams have all been documented. These changes are a consequence of alterations of hydrograph periodicity and magnitude due to changes in dam releases. The “serial discontinuity concept” coined by Ward and Stanford (1983) represents a conceptual model in which the longitudinal changes associated with the transfer of materials from headwater streams to large rivers was developed to provide a predictive framework for considering such changes in river ecology and physical processes.

Much of the previous work detailing dam operations and their effects on large river ecosystems have concentrated on the timing and magnitude of spring peaks, common to most north and south temperate river ecosystems (Andrews 1986, Davies and Walker 1986). These studies typically concentrate on the positive aspects of predictable, seasonal floods such as the physical effects of scouring, lateral habitat inundation and temperature regime changes as well as biotic interactions such as spring peaks affecting the community composition of fishes and invertebrates, the formation and maintenance of riparian habitats and the importance of life-history cues such as spawning.

The role of natural floods in biological and physical processes in rivers has also received much attention. Unpredictable, large floods are usually treated as a large scale perturbation and the loss of habitat and individuals at all trophic levels are typically used as response variables. Scouring of substrates, resulting in the loss of periphyton and bacteria important to the river food web is often found and related to long-term instabilities in river ecosystems (Golladay and Hax 1995, Molles 1985, Palmer 1992, Power and Stewart 1987). In addition, decreases in densities of both fish and invertebrates are also often reported as a direct result of large flood events (Lancaster and Hildrew 1993, Molles 1985, Richardson 1992, Williams and Hynes 1976). In virtually all cases, the effects of unpredictable flood events are reported as significant and negative phenomena.

The decline of Colorado pikeminnow (*Ptychocheilus lucius*) in the San Juan River can be partly attributed to several major dam-related changes within the river system. Navajo Reservoir upstream has altered the temperature and flow regime of the river and has limited the upstream migration of Colorado pikeminnow. The downstream impoundment of Lake Powell has permanently inundated potentially important nursery habitat areas of the lower San Juan, and Glen Canyon of the Colorado River. Alteration of the natural flow regime allowed the proliferation of numerous non-native species, which increased competition for space and food resources. The remaining section of the San Juan River may still be capable of supporting a wild population of Colorado pikeminnow or it may be beyond repair and cannot provide a self sustaining population. The goals of this study were to evaluate Colorado pikeminnow reproduction in the San Juan River, to evaluate the availability of low-velocity nursery habitat for young-of-year Colorado pikeminnow in relation to discharge, and to evaluate the fish species community composition in nursery habitats in relation to discharge.

STUDY OBJECTIVES

This study objectives were developed from the results from earlier studies on the San Juan River (Meyer and Moretti 1988, Roberts and Moretti 1989, Platania 1990, Buntjer et al. 1993, Buntjer et al. 1994, Archer et al. 1995) and on other Upper Basin rivers. The study addresses the objectives outlined below. Objectives 1, 2, 3 and 4 are the original objectives for this study. Objectives 5-7 were added in 1996, when experimental stocking of Colorado pikeminnow began.

- 1) To empirically monitor the annual recruitment of age-0 Colorado pikeminnow in relation to flow patterns in the San Juan River.
- 2) To characterize nursery habitat availability in relation to flow patterns in the San Juan River.
- 3) To determine habitat availability and use for age-0 and juvenile Colorado pikeminnow.
- 4) To characterize the early-life stage ichthyofaunal community in low-velocity (nursery) habitats in relation to flow patterns in the San Juan River.
- 5) To determine the quality and quantity of low-velocity habitats in the San Juan River for use by Colorado pikeminnow through experimental stocking of age-0 fish.
- 6) To determine the effects of diversion canals on age-0 Colorado pikeminnow drift/movement (e.g., stranding, etc.).
- 7) To determine overwinter survival and growth of experimentally stocked age-0 Colorado pikeminnow.

Chapter Two addresses objectives 1 and 4. This portion of the study was designed to monitor the annual recruitment of Colorado pikeminnow, and evaluate the relationship of some habitat and flow variables to recruitment. However, very few wild young-of-year Colorado pikeminnow were collected during the study, therefore this chapter concentrates on other species in the early-life stage ichthyofaunal community in low-velocity nursery habitats.

Chapter Three concentrates on objectives 2 and 3, wherein nursery habitat availability and quality was evaluated in relation to hydrologic variables.

Chapter Four addresses objectives 5, 6, and 7. We evaluated the experimental stocking of young-of-year Colorado pikeminnow in 1996-1998, in terms of short- and long-term survival, retention, dispersal, and habitat use.

The subject of benthic invertebrates, presented in the appendix, was not included in the objectives, as it was not part of the original study. We believe the information on invertebrate densities in the San Juan River is pertinent and applicable to this study. The work was performed as part of a separate study; Effects of Food Availability and Competition on Age -0 Colorado Pikeminnow Growth and Lipid Accrual in the San Juan River - Eric K. Archer - *A thesis submitted in partial fulfillment*

of the requirements for the degree of Master of Science in Aquatic Ecology). This Thesis is presented in the Appendix.

Relationship to Long Range Plan

- 5.2.3.1.** Monitor the fate of habitat availability as a result of different flows.
- 5.2.5.** Determine and monitor habitat use of endangered and other native fishes.
 - 5.2.5.1.** Determine habitat requirements for different life stages.
 - 5.2.5.2.** Identify subreaches that provide habitats for the different life stages.
- 5.2.6.** Identify limiting habitats
- 5.2.7.** Identify, recommend, and implement flows designed to maximize and maintain suitable habitats for all life stages of endangered and other native fish species.
- 5.3.1.** Identify and characterize the historic and current fish species community fish structure.
- 5.3.2.** Determine the status and trends of the resident fish species.
- 5.3.3.** Determine the life history of endangered and other native fish species and relationships to all other resident fish species.
- 5.3.5.** Characterize fish community response to different annual flow regimes.
- 5.3.6.** Identify limiting factors for the endangered and other native fishes.
- 5.3.8.** Determine the need for and implement, if necessary, an augmentation program for endangered fish species in appropriate historic habitat.
 - 5.3.8.1.** Evaluate reproduction and recruitment potential.
 - 5.3.8.2.** Develop augmentation plans for endangered fish species.
 - 5.3.8.4.** Successfully augment endangered fish species populations in the San Juan River Basin.
- 5.4.1.** Characterize distribution and abundance of non-native fish species.
- 5.4.2.** Identify and characterize habitats used by non-native fish species and effects of native fish species habitat use.

SAN JUAN RIVER STUDY AREA DESCRIPTION

The San Juan River is a major tributary of the Colorado River and drains 99,200 km² in Colorado, Utah, Arizona, and New Mexico (Fig. 1-1). From its origins in the San Juan Mountains of southwestern Colorado at elevations exceeding 4,250 m, the river flows westward for about 570 km to the Colorado River. The major perennial tributaries to the San Juan River are the Navajo, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers, and McElmo Creek. In addition there are numerous ephemeral arroyos and washes contributing little total flow but large sediment loads.

Navajo Reservoir, completed in 1963, impounds the San Juan River, isolating the upper 124 km of river and partially regulating downstream flows. The completion of Glenn Canyon Dam and subsequent filling of Lake Powell in the early 1980's inundated the lower 87 km of the river, leaving about 359 km of river between the two bounding features.

From Navajo Dam to Lake Powell, the mean gradient of the San Juan River is 1.67 m/km. Locally, the gradient can be as high as 3.5 m/km, but taken in 30 km increments, the range is from 1.24 to 2.41 m/km. Between the confluence of the San Juan River with Lake Powell and the confluence with Chinle Creek about 20 km downstream of Bluff, UT, the river is canyon bound and restricted to a singled channel. Upstream of Chinle Creek, the river is multi-channeled to varying degrees with the highest density of secondary channels between the Hogback Diversion about 13 km east of Shiprock and Bluff, Utah. The reach of river between Navajo Dam and Farmington, NM, is relatively stable with predominantly embedded cobble substrate and few secondary channels. Below the confluence with the Animas River, the channel is less stable and more subject to floods from the unregulated Animas River. Between Farmington and Shiprock, cobble substrate still dominates, although it is less embedded. Between Shiprock and Bluff, the cobble substrate becomes mixed with sand to an increasing degree with distance downstream, resulting in decreasing channel stability.

Except in canyon-bound reaches, the river is bordered by non-native salt cedar (*Tamarix chinensis*), Russian olive (*Elaeagnus angustifolia* L.), native cottonwood (*Populus fremonti*), and willow (*Salix* sp.). Non-native woody plants are most abundant with cottonwood and willow accounting for less than 15% of the riparian vegetation. Non-native woody plants are most abundant with cottonwood and willow only common on islands free of livestock grazing.

Discharge of the San Juan River is typical of rivers in the American Southwest. The characteristic annual pattern is one of large flows during spring snowmelt, followed by low summer, autumn, and winter base flows. Base flows are frequently punctuated by convective storm-induced flow spikes during summer and early autumn. Prior to closure of Navajo Dam, about 73% of the total annual discharge (based on San Juan River near Bluff, UT, USGS gage #09379500) of the drainage occurred during spring runoff (1 March through 31 July). The median daily peak discharge during spring runoff was 10,400 cfs (range = 3,810 to 33,800 cfs). Although flows resulting from summer and autumn storms contributed a comparatively small volume to total annual discharge in the basin, the magnitude of storm-induced flows exceeded the peak snowmelt discharge about 30% of the years, occasionally exceeding 40,000 cfs (mean daily discharge). Both magnitude and frequency of these storm induced flow spikes are greater than those seen in the Green or Colorado rivers.

Closure of Navajo Dam altered the annual discharge pattern of the San Juan River. The natural flows of the Animas River ameliorated some aspects of regulated discharge by augmenting spring discharge. Regulation resulted in reduced magnitude and increased duration spring runoff in wet years

and seriously reduced magnitude and duration spring flows during dry years. Overall, flow regulation by operation of Navajo Dam has resulted in post-dam peak spring discharge averaging about 54% of pre-dam values. After dam closure, base flows were increased substantially over pre-dam base flows.

Since 1992, Navajo Dam has been operated to mimic a “natural” hydrograph with the volume of release during spring linked to the amount of precipitation during the preceding winter. Thus in years with high spring snowmelt, reservoir releases were “large”, and “small” in low runoff years. Base flows since 1992 were typically greater than during pre-dam years but less than post-dam years.

The primary study area for most studies conducted under the auspices of the San Juan River Seven Year Research Program, including that reported herein, were accomplished in the mainstem San Juan River and its immediate vicinity between Navajo Dam and Lake Powell. Between Navajo Dam and Shiprock, there is considerable human activity within the floodplain of the San Juan River. Irrigated agriculture is practiced throughout this portion of the valley and much of the immediate uplands. Much of the river valley not devoted to agriculture (crop production and grazing) consists of small communities (e.g. Blanco and Kirtland) and several larger towns (e.g. Bloomfield and Farmington). The valley of the Animas River, the San Juan's largest tributary in the study area, is similarly developed. Downstream of Shiprock to Bluff small portions of the river valley (and uplands) are farmed; dispersed livestock grazing is the primary land use. In the vicinity of Montezuma Creek and Aneth, petroleum extraction occurs within the floodplain and the adjacent uplands. Between Bluff and the confluence with Lake Powell, there are few human-caused modifications of the system.

To enhance comparisons among studies and to provide a common reference for all research, a multivariate analysis of a variety of geomorphic features of the drainage was performed to segregate the river into distinct geomorphic reaches. This effort (Bliesner and Lamarra, 1999) identified eight reaches between Navajo Dam and Lake Powell. The following provides a brief characterization of each reach.

Reach 1 (RM 0 to 16, Lake Powell confluence to near Slickhorn Canyon) has been heavily influenced by the fluctuating reservoir levels of Lake Powell and its backwater effect. Fine sediment (sand and silt) has been deposited to a depth of about 12 m in the lowest end of the reach since the reservoir first filled in 1980. This deposition of suspended sediment into the delta-like environment of the river/reservoir transition has created the lowest-gradient reach in the river. This reach is canyon bound with an active sand bottom. Although there is an abundance of low velocity habitat at certain flows, it is highly ephemeral, being influenced by both river flow and the elevation of Lake Powell.

Reach 2 (RM 17 to 67, near Slickhorn Canyon to confluence with Chinle Creek) is also canyon bound but is located above the influence of Lake Powell. The gradient in this reach is higher than in either adjacent reach and the fourth highest in the system. The channel is primarily bedrock confined and is influenced by debris fans at ephemeral tributary mouths. Riffle-type habitat dominates, and the major rapids in the San Juan River occur in this reach. Backwater abundance is low in this reach, occurring most in association with the debris fans

Reach 3 (RM 68 to 105, Chinle Creek to Aneth, Utah) is characterized by higher sinuosity and lower gradient (second lowest) than the other reaches, a broad floodplain, multiple channels, high island count, and high percentage of sand substrate. This reach has the second highest density of backwater habitats after spring peak flows, but is extremely vulnerable to change during summer and autumn storm events, after which this reach may have the second lowest density of backwaters. The active channel leaves debris piles deposited throughout following spring runoff, leading to the nickname “Debris Field”.

Reach 4 (RM 107 to 130, Aneth, Utah, to below “the Mixer”) is a transitional reach between the upper cobble-dominated reaches and the lower sand-dominated reaches. Sinuosity is moderate compared with other reaches, as is gradient. Island area is higher than in Reach 3 but lower than in Reach 5, and the valley is narrower than in either adjacent reach. Backwater habitat abundance is low overall in this reach (third lowest among reaches) and there is little clean cobble.

Reach 5 (RM 131 to 154, the Mixer to just below Hogback Diversion) is predominantly multi-channeled with the largest total wetted area (TWA) and largest secondary channel area of any of the reaches. Secondary channels tend to be longer and more stable than in Reach 3 but fewer in number overall. Riparian vegetation is more dense in this reach than in lower reaches but less dense than in upper reaches. Cobble and gravel are more common in channel banks than sand, and clean cobble areas are more abundant than in lower reaches. This is the lowermost reach containing a diversion dam (Cudei). Backwaters and spawning bars in this reach are much less subject to perturbation during summer and fall storm events than the lower reaches.

Reach 6 (RM 155 to 180, below Hogback Diversion to confluence with the Animas River) is predominately a single channel, with 50% fewer secondary channels than Reaches 3, 4, or 5. Cobble and gravel substrates dominate, and cobble bars with clean interstitial space are more abundant in this reach than in any other. There are four diversion dams that may impede fish passage in this reach. Backwater habitat abundance is low in this reach, with only Reach 2 having less. The channel has been altered by dike construction in several areas to control lateral channel movement and over-bank flow.

Reach 7 (RM 181 to 213, Animas River confluence to between Blanco and Archuleta, New Mexico) is similar to Reach 6 in terms of channel morphology. The river channel is very stable, consisting primarily of embedded cobble substrate as a result of controlled releases from Navajo Dam. In addition, much of the river bank has been stabilized and/or diked to control lateral movement of the channel and over-bank flow. Water temperature is influenced by the hypolimnetic release from Navajo Dam and is colder during the summer and warmer in the winter than the river below the Animas confluence.

Reach 8 (RM 213 to 224, between Blanco and Archuleta and Navajo Dam) is the most directly influenced by Navajo Dam, which is situated at its uppermost end (RM 224). This reach is predominantly a single channel, with only four to eight secondary channels, depending on the flow. Cobble is the dominant substrate type, and because lateral channel movement is less confined in this reach, some loose, clean cobble sources are available from channel banks. In the upper end of the reach, just below Navajo Dam, the channel has been heavily modified by excavation of material used in dam construction. In addition, the upper 10 km of this reach above Gobernador Canyon are essentially sediment free, resulting in the clearest water of any reach. Because of Navajo Dam, this area experiences much colder summer and warmer winter temperatures. These cool, clear water conditions have allowed development of an intensively managed blue-ribbon trout fishery to the exclusion of the native species in the uppermost portion of the reach.

The specific study area for the Nursery Habitat component consisted of four separate and distinct 5 mile sections within the above-described reaches. The following section designations correspond to the river miles listed: Section 1 (RM 13.0 - 8.0 in Reach 1); Section 2 (RM 25.2 - 20.2 in Reach 2) ; Section 3 (RM 89.0 - 84.0 in Reach 3); and Section 4 (RM 131.0 - 126.0 across the border between Reaches 4 and 5).

Fish Community

The fish assemblages in backwater habitats differ greatly among the sections. Section 4 has been shown to be an important area for the native fishes of the San Juan River; flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and speckled dace (*Rhinichthys osculus*), (Buntjer et al. 1994, Archer et al. 1995). Catch rates in this section are typically highest for all three common age-0 native fish species (Buntjer, et al. 1994). Since 1987, only three wild age-0 Colorado pikeminnow have been captured in the upper section of river. In August 1994, one age-0 (14 mm) Colorado pikeminnow was captured at RM 126.2 in a backwater created by the mouth of the Mancos River (Archer et al. 1995). In October 1987, two age-0 (30 mm, 38 mm) Colorado pikeminnow were captured at RM 125.6 and RM 122.3 (Platania 1990). Both specimens were collected from secondary channel backwaters.

Section 3 low-velocity habitats are dominated by red shiners (*Cyprinella lutrensis*) and fathead minnows (*Pimephales promelas*), as well as a host of other non-native species including an increasing population of black bullhead (*Ameiurus melas*). Catch rates for native species are variable and much lower than upstream. No wild age-0 Colorado pikeminnow have ever been collected from this section.

Section 2 low-velocity habitats are also dominated by non-native species, especially red shiners. Native catostomids are collected from this section in low numbers. Five fish collected from this section have been identified as age-0 Colorado pikeminnow (one in 1994 and four in 1995).

Section 1 is dominated by non-native species, although the majority of age-0 pikeminnow captured in the San Juan River have been captured in this section. The non-native fish community in this section is very diverse, and includes all of the fauna of the upper sections plus some species which have migrated up from Lake Powell. These include threadfin shad (*Dorosoma petenense*), green sunfish (*Lepomis cyanellus*) and striped bass (*Morone saxatilis*). The presence of the two centrarchid species represents a large predation threat to age-0 native fish species. Non-native red shiners are by far the most abundant species, likely resulting in competitive interactions with small native fishes. The low-gradient, sand dominated section of the San Juan River (Section 1) has been shown to retain more wild age-0 Colorado pikeminnow than the higher gradient, upstream sections (Archer et al. 1996). The only wild Age-1+ Colorado pikeminnow collected from the San Juan River in recent years were also collected from this area. Densities of other age-0 native species are very low in this section.

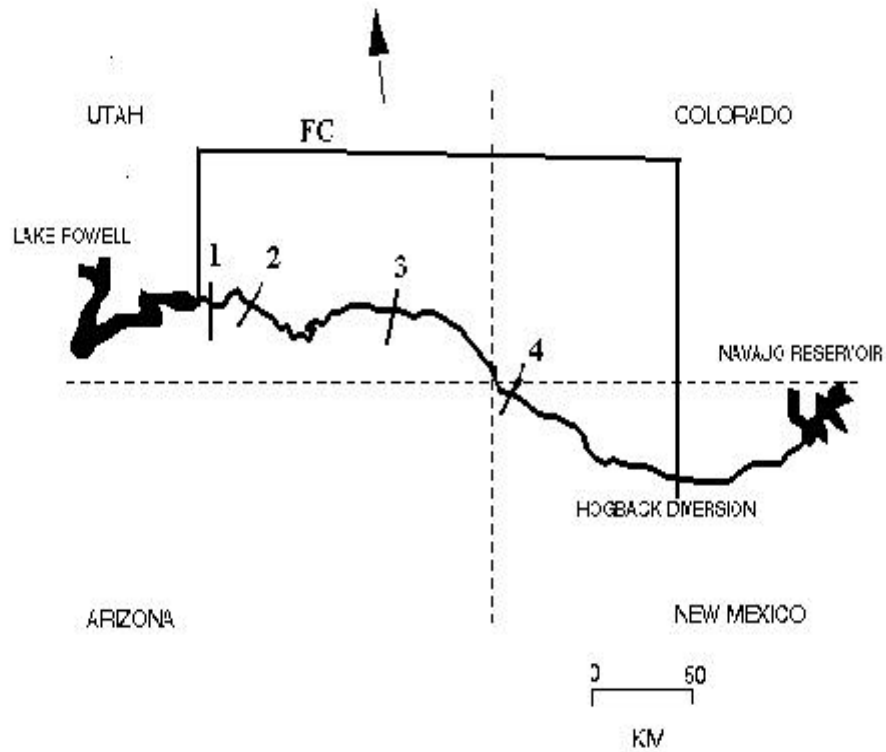


Fig. 1-1. Study area San Juan River New Mexico, Colorado, and Utah. Areas sampled during the Fish Community (FC) are shown. Section locations used during Nursery habitat sampling are also given.

METHODS - SAMPLING PROTOCOLS

During the 1991-1997 study period two different sampling protocols were used to examine low-velocity habitat availability and age-0 fish communities within the San Juan River. The methods used during each are discussed in detail below. Prior to 1994, only Fish Community protocols were used during all trips. From 1994-1995, Fish Community protocols were followed during the late September trip and Nursery Habitat protocols were used for all other sampling efforts. From 1996-1998, a combination of both protocols were used on each sampling trip. Fish Community protocols were followed for the entire study area outside of the nursery habitat sections, and Nursery Habitat protocols were followed within the nursery habitat sections.

Fish Community Sampling

During the Fish Community trips, backwater habitats were sampled in the San Juan River from Hogback diversion, RM 158 to Clayhills crossing, RM 3. During the first three years of the study (1991-1993), fish community sampling occurred during July, August and September. From 1994-1997, fish community sampling occurred during late September only.

Two backwaters habitats were sampled in each five mile section. Backwaters were targeted for sampling in this study because YOY Colorado pikeminnow have been shown to be most abundant in these habitats types in the Green and Colorado rivers (McAda and Tyus 1984, Tyus and Haines 1991, Tyus and Karp 1991). Where available, we selected backwaters to sample which were at least 30m², and 0.3m deep. All sample locations were located to the nearest 0.1 mi using aerial photos.

Post-larval and YOY fish were collected in all years using 1.6 mm mesh (4 m long x 1 m deep). In the first three years, some samples were taken with a 0.8 mm mesh, 1 m long x 0.5 m deep seine. No differentiation was made in the analyses because all effort was presented as #fish/100m² seined. Samples were preserved using 10% formalin. Only specimens that could be reliably identified in the field were counted and released. Fishes collected in the first seine haul of each mesh size in each 5 mile section were measured. The number of seine hauls at each site varied from one to three, depending on the size of the habitat. For each seine haul, seining efficiency was recorded on a scale of 0 to 3, with "0" being the most efficient and "3" being the least efficient, dependent on water and mud depth.

Physical habitat measurements were recorded for each sample site and included length, mean width, maximum water depth and substrate of the habitat. The length, width and depth of each seine haul was also recorded. Depth measurements included the maximum water depth and the depth one-half the distance from the maximum depth to the end of the seine hauls. The orientation of each seine haul relative to the long axis of the habitat (i.e., across or parallel) was also recorded. At each depth measurement, primary and secondary substrate particle sizes were estimated and recorded using the Brusven substrate index (Bovee 1982). Other measurements included habitat and main channel water temperatures (°C).

Nursery Habitat Sampling

Nursery Habitat sampling protocols were adopted from studies conducted on other Upper Basin rivers (Green and Colorado rivers)(Trammell et al. 1999; Trammell and Chart 1999). This study was a more intensive approach than the Fish Community sampling, and was initiated in 1994 to allow comparisons between the San Juan and the Upper Basin rivers. With this approach, all backwaters and many other low-velocity habitats, throughout a designated five mile section were sampled three times a year (April, August and September). Unlike the fish community sampling, there were no size restrictions for the habitats sampled. In the San Juan River, sampling in sections 1-3 was established in 1994 and Section 4 was added in 1995. All sections were sampled from 1995-1997.

Post-larval and YOY fish were collected using 1.6 mm mesh (4 m long x 1 m deep) seines. Fish samples were preserved using 10% formalin. Only specimens that could be reliably identified in the field were counted and released. Fishes collected in the first seine haul of each mesh size in each 5 mile section were measured. The number of seine hauls at each site varied from one to three, depending on the size of the habitat.

Nursery habitats were classified according to the scheme developed for the Green River (Trammell and Chart 1999) (Table 1). The classification system relates types of nursery habitats to the hydrologic processes that formed them. Specific nursery habitats sampled included true backwaters, backwaters with slight flow, and isolated pools. The majority of habitats were true backwaters, or backwaters with very slight flow.

Physical habitat measurements were collected at three transects: the mouth, 1/3, and 2/3 of the longitudinal length of the habitat. Depth measurements were taken at the point of maximum depth and 1/2 the distance either way along the transect. Both water depth and water-plus-substrate depth were measured. At each depth measurement, primary and secondary substrate particle sizes were estimated and recorded using the Brusven substrate index (Bovee 1982, Table 2). Surface temperature was recorded ($^{\circ}\text{C}$) at the midpoint of each transect. Turbidity was scored at each transect on a scale of 0 to 2. A value of 0 denotes clear visibility to the bottom, 1 indicates approximately 6" of visibility and 2 denotes virtually no visibility. The length, width, and depth of each seine haul was also recorded.

All native fish identified in the field were measured and released. Fish species collected during the study period are listed in Table 3. Non-native fishes were recorded as either sub-adult or adult or preserved in 10% formalin for later identification. Fish density (fish/100 m²) was computed for all species by section. All preserved fishes were identified and counted at either the UDWR Moab field office laboratory or Utah State University. Samples were then sent to the University of New Mexico for verification and curation in the Museum of Southwestern Biology.

Table 1. List of habitat types used for nursery habitat study. **All habitats were backwaters**, or backwaters with slight flow, with differences in size and description attributed to the formation process.

Secondary Channel (SeC) - Habitats formed by the erosion/deposition cycle of secondary channels during passage of a flood, and revealed by receding water levels. Usually relatively deep and permanent.

Secondary chute, or scour, channel (SC) - Smaller version of SC habitat formed by erosion/deposition cycle of small channel behind large alternating sandbar. Scoured out during floods and revealed during receding water.

Migrating Sand Waves (MS) - Habitats formed by the relative movement of adjacent migrating sand waves. Relatively shallow and ephemeral.

Horseshoe Vortex (HS) - Habitats formed by scour holes generated at high flows at the upstream ends of islands due to development of horseshoe vortex patterns. Moderately deep and semi-permanent.

Flood Plain (FP) - Habitats formed by the inundation of abandoned channels or flood plains. Related to seasonal high flows or rainfall events.

Flooded Tributary Mouth (FT) - Habitats formed by rising river levels flooding into tributary mouths. Related to seasonal high flows or rainfall events.

Shoreline Eddy (SE) - Habitats formed by recirculating areas due to irregularities of the bank.

Constricted Reach Eddy (CE) - Habitats formed by large eddies generated by constriction of the channel by debris fans.

Shoreline (SH) - Shallow, sloping shoreline areas.

Boulder Pocket (BP) - areas of low-velocity habitat behind shoreline boulders, typically very small.

Table 1-2. Classification of substrate sizes used for nursery habitat sampling in the San Juan River, New Mexico, Colorado, and Utah, 1994-1997. Size categories are from a modified Brusven Substrate index (Bovee 1982).

<u>Substrate type</u>	<u>Substrate size (mm)</u>
Silt	(< 1)
Sand	(1-4)
Gravel	(5-75)
Cobble	(76-300)
Boulder	(> 300)

Table 1-3. List of fish species collected in low-velocity habitats in the San Juan River, New Mexico, Colorado, and Utah.

Scientific name	Common name	Status	Abbreviation
Cyprinidae			
<i>Cyprinella lutrensis</i>	red shiner	I	CYPLUT
<i>Cyprinus carpio</i>	common carp	I	CYPCAR
<i>Gila robusta</i>	roundtail chub	N	GILROB
<i>Pimephales promelas</i>	fathead minnow	I	PIMPRO
<i>Ptychocheilus lucius</i>	Colorado pikeminnow	EN	PTYLUC
<i>Rhinichthys osculus</i>	speckled dace	N	RHIOSC
Catostomidae			
<i>Catostomus discobolus</i>	bluehead sucker	N	CATDIS
<i>Catostomus latipinnis</i>	flannelmouth sucker	N	CATLAT
<i>Catostomus spp.</i>	white sucker hybrid	I	CATSPP
Ictaluridae			
<i>Ameiurus melas</i>	black bullhead	I	AMEMEL
<i>Ictalurus punctatus</i>	channel catfish	I	ICTPUN
Cyprinodontidae			
<i>Fundulus zebrinus</i>	plains killifish	I	FUNZEB
Poeciliidae			
<i>Gambusia affinis</i>	mosquitofish	I	GAMAFF
Centrarchidae			
<i>Lepomis cyanellus</i>	green sunfish	I	LEPCYA
<i>Micropterus salmoides</i>	largemouth bass	I	MICSAL
Clupeidae			
<i>Dorosoma petenense</i>	threadfin shad	I	DORPET

N = native to Colorado River drainage

EN = endemic to Colorado River drainage

I = introduced to Colorado River drainage

CHAPTER TWO

AGE-0 NATIVE FISH

YEAR CLASS ABUNDANCES AND SIZE

IN RELATION TO

FLOW AND TEMPERATURE PATTERNS IN THE

SAN JUAN RIVER 1991-1997

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INTRODUCTION

Growth of age-0 fish is a highly variable and dynamic process. Blaxter (1988) suggested that the larval period is critical to many fish species. It is important that larval fish grow quickly to lessen predation (Nielsen 1980, Post and Evans 1989) and acquire sufficient fat reserves to survive through winter (Henderson et al. 1988). Three important factors have been shown to influence the growth and survivorship an age-0 fish cohort: prey availability (Henderson 1985, Cryer et al. 1986), competition (Fausch and White 1988), and temperature regime (Brett 1979). Water temperature can have a strong influence on the early life stages of many fish species. It influences the egg incubation period (Koenst and Smith 1976), growth of age-0 fish (Forney 1966, Craig 1982), and may ultimately influence recruitment (Busch et al. 1975).

With the construction of main stream dams on both the Upper Green and San Juan rivers, hypolimnetic releases have lowered temperatures downstream for an undetermined distance. As a result, spawning may be occurring later in the season resulting in less time for growth before the onset of winter (Kaeding and Osmundson 1988). Many studies of age-0 temperate zone fish species have indicated that overwinter survival is directly related to size (Oliver 1977, Toney and Coble 1979, Canjuak 1988, Henderson et al. 1988). Several studies have suggested the effect of body size is actually due to the correlation between fish body size and total body lipid content (Oliver 1977, Isely 1981, Miranda and Hubbard 1994). The size of any recruiting age class of fish is a result of not only the number of individuals spawned but also environmental conditions in which they find themselves. We evaluated the effect of discharge on water temperature, and the importance and influence of water temperature on growth of native catostomids.

This Chapter addresses objectives 1 and 4. This portion of the study was designed to monitor the annual recruitment of Colorado pikeminnow, and evaluate the relationship of some habitat and flow variables to recruitment (Objective 1). However, very few wild young-of-year Colorado pikeminnow were collected during the study, therefore this chapter concentrates on other species in the early-life stage ichthyofaunal community in low-velocity nursery habitats (Objective 4).

METHODS

Field Collections

Data collected during the UDWR early life-stage Fish Community and Nursery habitat study were used to determine native and non-native fish community composition during August and September 1991-1997 (see sampling protocols section).

Statistical Analyses

Year Class Strength

Analyses were performed on August and September data from 1991-1996, and 1991-1997 periods. Separate analyses were performed because the extremely low catch rates for native species during 1997. We performed linear regressions to test for associations between native/non-native

relative fish abundances and a variety of metrics describing flow events. We believe the low catch rates in 1997 were partly due to high discharge at the time of sampling during August of 1997 due to monsoonal events, therefore statistical analyses were performed on all years combined (1991-1997) and using just 1991-1996. For both analyses, the independent, or driver variables were: the Julian date of the peak flow, the spring peak magnitude (cfs), and the number of days the flows stayed above 5000, 7000, and 8000 cfs. For linear regressions, the densities of bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), speckled dace, (*Rhinichthys osculus*), total native fish, red shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*) and total non-native fish as well as the proportion of native and non-native fish, were used as the dependent, or response variables.

Length Frequency

Length-frequency data collected during 1991-1993 were used to examine Catch-per-unit-effort (CPUE) in relation to average size. During exploratory analyses, it was apparent that catch rates varied significantly between trips in the same year. Estimates of year-class strength were strongly dependent on which data were used. In order to more accurately assess true densities of age-0 native species, the relative timing of sampling in relation to the spawning period appeared to be critical given the exponential decline in catch rates over any given season due to natural mortality or changes in habitat selection.

In order to assess the size and growth of age-0 Catostomids, length-frequency data collected between 1991-1997 were used to compute catch rates and percent of fish in 10 mm (total length) size classes. Data collected between (RM 156-119.2) were used for the 1991-1993 period. Because of changes in protocol in subsequent years, data from UDWR Nursery habitat Section 4 (RM 131-126) were used for the period of 1994-1997. All summer sampling trips (June-September) were included to allow comparisons between years. Fish were categorized into 10 mm size classes and means were computed for each species during each trip.

Discharge / Temperature / Size relationship

Temperature data from the Montezuma Creek gage (above nursery habitat section 3) and discharge data from the San Juan River near Bluff, UT, gage (USGS gage #09379500) were used to relate temperature to discharge from 1993-1997 period. Because of inadequate data, 1991-1992 was not used. Total degree days were computed by summing daily temperatures for the following periods: June, July, June-July and June-August. Daily differences between flow and main-channel temperature were tested using an Analysis of Covariance (ANCOVA). Average and total discharge were compared with degree-day accumulation for each time period using linear regression. Degree day accumulation for each period was then regressed with average length of each catostomid species. Significance was set at an alpha level of 0.05. Statistical analyses were performed using SAS (1997) for personal computers, or Corel Quattro Pro 8.

RESULTS

Year-Class strength

The majority of fish collected were composed of five species, two non-native: red shiner and fathead minnow, and three native: bluehead sucker, flannelmouth sucker and speckled dace. Other species collected were of much lower abundance, including channel catfish, common carp, mosquitofish and green sunfish, among others even more rarely collected (Table 1-2). Catch rates for the two most common non-native fish, and three most common native fish, and the percent composition of the combined native and non-native species during 1991-1997 in August and September are provided in Table 2-1. Value for the hydrologic variables are presented in Table 2-2. Results of the regression analysis for 1991-1997 are presented in Table 2-3a and 2-3b.

The only significant correlations found were between the relative abundance of natives and non-natives and the Julian date of the spring peak in August (Table 2-3a), and in September, the magnitude of the spring peak and the number of days above 7000 and 8000 cfs (Table 2-3b). The relative abundance of native species was positively correlated with late, high peaks, and the relative abundance of non-natives was negatively correlated with late, high peaks. Catch rates of native species, particularly bluehead sucker, declined in the fall, resulting in a greater relative abundance of non-natives in the fall in each year.

Bluehead sucker were generally positively correlated with high peaks of long duration except for the last year of the study, 1997, which was the highest peak, and the highest number of days over 8000cfs. Catch rates of bluehead sucker were much lower than the next highest peak year. Speckled dace were significantly positively correlated with the number of days above 5000cfs, and 7000cfs, and nearly significantly correlated with the peak. Flannelmouth sucker were generally negatively correlated with all hydrologic variables, although not significantly. They were significantly correlated with days over 5000cfs in September. In contrast, the abundances of specific non-native species were not predictable (Table 2-3a, 2-3b) using any of the hydrologic variables included in the analysis. The percent of non-natives is predictable, however, with percent of non-natives being lower in years with a later peak.

Table 2-1. Catch rates (number/100m²) of native and non-native fish and percent composition for August 1991-1997. Headers are: Bluehead sucker (CATDIS), Flannelmouth sucker (CATLAT), Speckled dace (RHIOSC), Red shiner (CYPLUT), Fathead minnow (PIMPRO), Percent non-native (%NON) and Percent native (%NATIVE).

YEAR	CATDIS	CATLAT	RHIOSC	CYPLUT	PIMPRO	%NON	%NATIVE
AUGUST							
1991	62.9	51	46	298	204	76	24
1992	48	40	37	51	147	89	11
1993	154	14.5	118	882	272	80	20
1994	47	6	41.6	138	21	64.3	35.7
1995	200	0.9	86	51.7	2.9	18	82
1996	0.15	0	0.45	81.9	10	99.4	0.6
1997	6.4	8	55.1	75	34.4	73.4	26.6
SEPTEMBER							
1991	.8	.3	15.6	174	129	95	5
1992	2.9	2.9	30	104	117	86	14
1993	9.9	23.4	87.9	433	306	86	14
1994	8.7	1.9	239	1402	2389	94	6
1995	5.2	.5	25	73	65	84	16
1996	0	.03	1.5	275	337	99.998	.002
1997	.12	.3	13.7	50	7.9	80.4	19.6

Table 2-2. Hydrologic variable used in regression analysis, 1991-1997. Data from San Juan River gage near Bluff (#09379500).

Year	Peak (cfs)	Date	Number of days above:		
			>5000	>7000	>8000
1991	4150	May 20	0	0	0
1992	8510	May 27	44	12	4
1993	9650	May 28	109	36	13
1994	8290	June 4	41	10	1
1995	11600	June 18	63	31	19
1996	3560	May 16	0	0	0
1997	11900	June 3	49	37	29

Table 2-3a. Results of regression analysis showing variables that were significantly associated with one or more native or non-native fish species abundance during August 1991-1997 (p=0.05). (NS) = no significant relationships existed between any of the variables tested.

Dependent Variable	y-intercept	Slope	Independent Variable	r ²	p
Bluehead	-	-	-	NS	
Flannelmouth	-	-	-	NS	
Speckled dace	-3.4	+0.85	Days > 5000 cfs	0.71	0.01
Speckled dace	-1.5	+0.35	Days > 7000 cfs	0.63	0.02
Native Total	-	-	-	NS	
Red shiner	-	-	-	NS	
Fathead	-	-	-	NS	
Non-native total	-	-	-	NS	
% Non-native	178.24	-0.38	Julian date of peak	0.80	0.004
% Native	139.7	+0.38	Julian date of peak	0.80	0.004

Table 2-3b. Results of regression analysis showing variables that were significantly associated with one or more native or non-native fish species abundance during September 1991-1997 (p=0.05). (NS) = no significant relationships existed between any of the variables tested.

Dependent Variable	y-intercept	Slope	Independent Variable	r ²	p
Bluehead	-	-	-	NS	
Flannelmouth	29.14	+3.5	Days > 5000 cfs	0.55	0.035
Speckled dace	-	-	-	NS	
Native Total	-	-	-	NS	
Red shiner	-	-	-	NS	
Fathead	-	-	-	NS	
Non-native total	-	-	-	NS	
% Non-native	43921	-432.98	Peak	0.83	0.003
% Non-native	200.93	-2.05	Days > 7000 cfs	0.74	0.008
% Non-native	133.2	-1.39	Days > 8000 cfs	0.70	0.012
% Native	3622.7	+432.96	Peak	0.83	0.003
% Native	-3.82	+2.05	Days > 7000 cfs	0.74	0.008
% Native	-5.34	+1.38	Days > 8000 cfs	0.70	0.012

Length Frequency

Length-frequency data collected during 1991-1997 was used to determine relative, although not exact, spawning times, CPUE in relation to size, and size during the August trip (used in year class analyses). Percent of catch in 10 mm (TL) size classes for each sample period from June to September 1991-1993 was analyzed to examine differences in spawning time (early vs late) and size-related habitat shifts. The 1991 June trip was the only sample period in which a majority of the flannelmouth suckers captured were less than 20 mm (Fig. 2-1). By July in all years, a large proportion of the specimens collected were > 20 mm total length (TL). During 1991, the percent composition of the catch followed a pattern of increasing percentage of specimens collected in the larger classes from June-August. In 1992, the first sampling occurred during mid July. Collections included specimens from < 10 mm to > 40 mm total length. Two weeks later, a greater proportion of the total catch was in the < 20 mm size class and average size had declined. In 1993, sampling occurred during late July. Collections were dominated by the 10, 20, and 30 mm size classes. Specimens were of smaller average total length than in either 1991 or 1992 when sampling occurred as much as 11 days earlier.

When bluehead sucker samples were compared for the July collections from 1991-1993, a pattern similar to the flannelmouth sucker trend was observed. The average size of the fish captured declined during the second trip (Figure 2-2).

Differences in average size of fish collected on similar dates in different years indicated relative spawning times, with small fish indicating a later spawning period (1993), and larger fish indicating an earlier spawning period (1991 and 1992). However, because of the large amount of variation in the data in the years with the earliest sampling dates, it is not possible, using seining data, to completely distinguish between differences in spawning time or growth rates.

It appears that in some years spawning occurred over an extended period. In every year during the July sampling periods, multiple size classes were represented. In 1992, specimens ranged from < 10 mm to > 40 mm total length (TL). The smallest size classes were represented in every year, suggesting an extended spawning period.

Catch rates (CPUE) in relation to size

Sufficient data for the period from 1991-1993 existed for native catostomids (bluehead and flannelmouth suckers) to examine the relationship between age-0 fish size and catch per unit effort (Fish/100m²). The general trend observed suggests that as the size of fish captured increased, catch rates declined. Each species was analyzed and presented separately. Note that June sampling occurred in 1991 only, and that sampling dates were variable during the July 1991-1993 period (Figs. 2-1 & 2-2).

Flannelmouth sucker. Catch rates (CPUE) of flannelmouth sucker followed a pattern of apparent decline with increasing size during June through September sampling from 1991-1993. In 1991, CPUE declined significantly between mid June and July and then increased slightly in August, with another large decline by mid September (Fig. 2-1). Catch rates were considerably higher in July 1992 than in 1991 or 1993. CPUE increased further during late July 1992, as average size declined. By mid August, catch rates dropped drastically and continued to decline through mid September, as size increased further. In 1993, CPUE was generally lower than in 1991 or 1992, and the pattern observed was different from the two previous years. Catch rates started out low in July and declined in August followed by an increase to the highest catch rate of the year during the mid September sample period, when fish were the largest. The slopes of the CPUE regression lines in relation to size were different in each year of sampling. With only three years of data it is not possible to create a model that accurately predicted CPUE by size class.

When CPUE was compared among years, average size is most similar in the early July trip in 1991 compared to the late July trip in 1992 and the mid July trip 1993 (23 mm). The data indicate that 1992 exhibited greater year class strength than either 1993 or 1991. When only data from the August trips were compared, CPUE were higher in 1991 than in 1992 or 1993 despite a greater average size. If September data are used for comparison, the pattern is reversed with the 1993 CPUE the highest, followed by 1992 and 1991.

The estimate of year-class strength for flannelmouth suckers is complicated by two unexplained variables: differential mortality and size selective habitat use. This comparison suggests that our sampling is size biased due to concentrating sampling efforts on backwater habitats. In addition, we tend to catch fewer flannelmouth suckers as they increase in size. It is unclear if this reduction in CPUE

is due strictly to shifts in habitat selection or if avoidance is also affecting our catch. It is our opinion that the best estimates of true year class strength are achieved by using the earliest possible dates, which avoids much of the bias associated with size. However, the earliest standardized trips occurred in August 1995-1997. Therefore, year class strength estimates for the whole research period must be based on these data.

Bluehead sucker. Catch rates during the June-September 1991-1993 sampling trips varied significantly. The general trend observed was similar to that of flannelmouth suckers; catch rates declined and size increased through time (Fig. 2-2). In 1991, catch rates increased during June and July, peaked in August, and declined in mid September. In 1992, catch rates peaked during late July (at over 200/100 m²) when average size was lowest (18 mm TL). Two weeks later, catch rates had declined significantly and average size increased to 26 mm TL. By September, very few age-0 blueheads were collected. The July, 1993, CPUE was similar to that observed in 1992 during mid-July. In August, catches rates declined slightly, but remained high compared to 1991 and 1992. By September, catch rates dropped drastically but again remained higher than September 1991 or 1992.

The CPUE for bluehead sucker, and the related year-class strength estimates varied significantly depending on which sampling date was used in the computation. When CPUE for bluehead suckers was compared among years that average size was most similar (early July 1991; late July trip in 1992; and, early August 1993). The results indicate that the greater reproductive success occurred in 1992. When August for the 1991-1993 period were compared, 1993 was the strongest year class followed by 1991 and 1992. This is to be expected given that average size follows the exact opposite pattern with 1992 having the greatest mean size. September follows the same pattern with the 1993 CPUE being highest with the smallest mean size. CPUE statistics for both species of native Catostomids based solely on comparisons between years for a standard date likely result in large biases in year class estimates. Year classes are underestimated when fish are larger at the time of sampling and therefore perhaps not as vulnerable to the sampling gear or in different habitats.

For 1991-1997, data on year class strength and size are available for August and September. August collections were used in the length frequency analysis that follow. August data collected during the 1991-1997 period showed large variation in year class total lengths (Fig. 1-2). Sampling dates were similar between years except for 1995 and 1997 when sampling occurred one and two weeks later, respectively. The average size of the fish collected varied greatly from the smallest in 1992 (21.8 mm TL) to a maximum of 42.3 mm in 1996. In most years, the majority of the specimens collected were between 20-40 mm TL.

On average, the largest flannelmouth suckers during August sampling were caught in 1996, followed by 1994 and 1991. In 1996, 50% of all the fish captured were > 40 mm TL and no fish collected were < 20 mm TL. In 1994, all specimens collected were again > 20 mm, with the majority of fish being between 20-30 mm TL. In 1991, there was a wide range of sizes with 50 percent of the fish between 20-30 mm, and about 25 percent were > 40 mm and < 20 mm TL (Fig. 1-3).

The smallest fish were caught in 1992 when specimens averaged 22 mm TL. In 1995, the average TL was 24 mm, and in 1997, 25 mm. In 1992, 40% of the specimens collected during late July sampling were less than 20 mm TL. However, as mentioned above, two distinct size classes were present in 1992. The 1995 and 1997 year class collections were dominated by specimens less than 30 mm TL. In 1993 collections were evenly distributed between greater and less than 30 mm TL.

When August 1991-1997 bluehead sucker year class data were compared between 1991-1997, the patterns observed were similar to those noted for flannelmouth suckers. Average size during 1996 was greater than any other year, at 33 mm TL (Fig. 1-4). This was 10 mm larger than the next closest year, which was 1991 when average size was 23 mm TL. Very few bluehead suckers were collected during August of 1996. However, 70% were greater than 30 mm in TL. In 1991, 18% of the age-0 bluehead suckers collected were 30 mm or greater. In other years, a very small proportion of bluehead suckers were in the 30 mm or larger size classes. In 1995, average size was the lowest at 15 mm TL with 96% of the year class smaller than 20 mm TL during August. In 1993, average size was 17 mm TL with 80% of the specimens less than 20 mm TL.

Discharge/ Temperature/ Size

To examine the differences observed in average size of the two native catostomid species during August 1991-1997, regression analyses were performed using the average length of flannelmouth and bluehead suckers as the response variable and degree day accumulation from the Montezuma Creek gage (for the following periods: total for June 1-July 31, total for June and total for July)(Table 2-4). In addition, average discharge (San Juan River near Bluff, UT) for the period of June 1-July 31 was regressed against average size of both catostomid species (Table 2-4).

For flannelmouth suckers, all four regressions resulted in significant relationships (Table 2-5). The largest amount of variation in mean flannelmouth sucker total length was explained by total degree days during the month of June ($r^2 = 0.989$). Total degree days for the entire June-July period was also highly correlated to flannelmouth sucker total length ($r^2 = 0.951$). Average discharge was negatively correlated to average length and explained 92% of the variation in average TL.

Bluehead sucker mean total length also showed strong correlations with degree day accumulation. However, only total degree day accumulation in June and average discharge were significant at an alpha level of 0.05. Total degree days June-July and total degree days in July were marginally significant ($P = 0.066$ and 0.096 , respectively).

In summary, degree day accumulation has a significant effect on the size of both catostomid species during early August. The strongest relationships in average size of both catostomid species were positively related to total degree days in June and negatively related to average discharge.

Table 2-4. Data used for regression analysis including total degree days for June 1-July 31, total degree days for June, total degree days for July, average discharge, and average total length for bluehead and flannelmouth suckers during 1993-1997.

Year	Total DD June/July	Total DD June	Total DD July	Average Discharge	Avg. TL CATDIS	Avg. TL CATLAT
1993	1175	474	701	4409	17.0	29.7
1994	1189	500	689	3967	20.3	35.1
1995	1048	441	607	6404	15.4	24.1
1996	1325	560	765	1815	33.0	42.3
1997	1087	443	644	5123	20.8	25.0

Table 2-5. Results of regression analysis showing variables that were significantly associated with average total length of flannelmouth and bluehead suckers during August 1993-1997 sampling ($p=0.05$). TL in mm, degree days in C, discharge in cfs.

Dependent	Independent Variable	Slope	r^2
<u>Flannelmouth Sucker</u>			
Mean TL	Total Degree Days	0.069	0.951
Mean TL	Degree Days June	0.153	0.989
Mean TL	Degree Days July	0.117	0.866
Mean TL	Average discharge	-0.004	0.922
<u>Bluehead Sucker</u>			
Mean TL	Total Degree Days	0.055	0.728
Mean TL	Degree Days June	0.123	0.728
Mean TL	Degree Days July	0.093	0.657
Mean TL	Average discharge	-0.004	0.812
<u>Discharge</u>			
Total Degree Days	Average discharge	-0.183	0.974
Total Degree Days	Total discharge	-0.003	0.974

Discharge/Temperature relationship

The relationship between discharge and main channel water temperature was examined in an attempt to explain differences observed in size of age-0 native catostomid as a function of degree day accumulation for the period of 1993-1997 (Fig. 2-5).

An Analysis of Covariance (ANCOVA) was used to explore differences in the temperature-discharge relationship by year. Significant differences were observed between every pair of years examined. This result was expected, given the highly variable nature of the discharge history of the San Juan River.

Total degree-day accumulation was then compared with average and total discharge at the San Juan River near Bluff, UT for the period of June 1 through July 31 (Fig. 2-6). The results of these regressions are presented in Table 2-4. Both regressions resulted in an r^2 of 0.974 with negative slopes. The high proportion of the variation in total degree-day accumulation was explained by both response variables, average and total discharge during the period. In conclusion, discharge strongly affected main channel water temperature; higher flows resulted in lower water temperatures for that period. This is a surprisingly strong fit given only five years of data were used and differences such as air temperature and weather patterns were present, but not included in the models.

DISCUSSION

Our sampling regime was primarily designed and implemented to monitor the annual recruitment of age-0 Colorado pikeminnow in relation to flow patterns in the San Juan River. However, too few wild young-of-year Colorado pikeminnow were collected during this study to make any evaluation possible. Therefore we concentrated on the relationship of flow patterns to the five most common fish species: three native species and two non-native.

The relative proportion of native to non-native species suggests a positive response of natives to higher flows. However, high flows also appear to result in smaller fish in the fall, which could lead to lower overwinter survival and recruitment. Many studies of age-0 temperate zone fish species have indicated that overwinter survival is directly related to size (Oliver 1977, Toneys and Coble 1979, Canjuak 1988, Henderson et al. 1988).

The relationships between flow and year class strength of individual species were weakened because the relationships between CPUE and year class strength are confounded by several variables. Differences in spawning times and duration, variable mortality rates, size related habitat shifts, and capture efficiency could drastically affect our year class strength estimates of age-0 fishes.

Sampling occurred too late to accurately predict timing of spawn for either native catostomid. However, it appears that in some years spawning occurred over an extended period because the < 20 mm size class was represented in varying proportions. In years where flows declined quickly, temperatures warmed earlier and a larger proportion of the individuals collected were in the > 30 mm size classes. Muth et al. (1998), in an analysis of razorback sucker spawning periods, documented spawning from mid-April to late June and typically spanned 4-6 weeks. They also found that spawning occurred over a wide range of discharge (78-

623 m³/sec) and water temperatures (8-19.5 C). They concluded that native razorback suckers are adapted to the variable and fluctuating environment (Muth et al. 1998).

If there are significant differences in spawning times, the analysis presented above likely underestimates year class strength during years when spawning occurred earlier. Estimates are further confounded by variable mortality rates. The use of the data from August sampling (10-15 weeks post spawn) for year class estimates of catostomids is inadvisable, while September estimates were worse. The densities of non-native predators (primarily red shiner) in backwaters, and intra- and interspecific competition may be further disguising the relationship between the spring hydrograph and spawning success of catostomids. The best solution for more accurate year class strength estimates, is earlier, and likely repeated, sampling, shortly after swim up, before large biases are incurred. Muth et al. (1998) reported that razorback sucker larvae were collected 20-30 days after first estimated spawning and were typically most abundant before mid-June.

The data also indicate that size at sampling time influences CPUE of both catostomid species. These differences are due to either capture efficiency, or more likely, changes in habitat utilization related to size. It appears that many age-0 catostomids vacate backwater habitats in mid summer. This has been documented by other Upper Basin researchers on both the Green and Colorado rivers (Trammell and Chart 1999). Because of the timing and abruptness of this decline, it is unlikely that all of the decline in CPUE is due strictly to mortality. This can further bias estimates of year class strength by under estimating the abundance of cohorts that are larger and utilizing habitats other than backwaters.

Flows designed to ensure the continued propagation of wild native fishes must consider recruitment to age-0+ age classes very strongly. Growth and survival of age-0 fish are highly variable and dynamic processes. Blaxter (1988) suggested that the larval period is critical to many fish species. It is important for larval fish to grow quickly both to lessen predation (Nielsen 1980, Post and Evans 1989) and acquire sufficient fat reserves to survive through winter (Henderson et al. 1988).

Water temperature can have a strong influence on the early life stages of many fish species. It influences the egg incubation period (Koenst & Smith 1976), growth of age-0 fish (Forney 1966, Craig 1982) and may ultimately influence recruitment (Busch et al. 1975).

With the construction of main stem dams on both the upper Green and San Juan rivers, hypolimnetic releases have lowered temperatures downstream for an undetermined distance. As a result, spawning may be occurring later in the season, resulting in less time for growth before the onset of winter (Kaeding and Osmundson 1988). Muth et al. (1998) concluded that small differences in growth rates of razorback suckers can be biologically significant if size dependent processes are important determinants of larval survival.

Fish are dependent on stored lipid reserves during winter periods to meet their basal metabolic requirements (Henderson et al. 1988, Post and Evans 1989). Studies of age 0 fish support these ideas (Shelton et al. 1979, Post and Evans 1989, Tyus and Haines 1991) with the documentation of the elimination of the smaller mode of a bimodal length distribution during winter. Oliver (1977) concluded that a critical amount of energy reserves (lipids) was required to survive the winter period and that larger fish survived significantly better in his study of smallmouth bass. Thompson (1989) also found that larger age 0 Colorado pikeminnow entered the winter with higher lipid reserves and survived significantly better.

Size of age 0 catostomids (particularly flannelmouth suckers) was highly correlated to degree day accumulation. The strongest correlations in size were with degree day accumulation in June and total degree days (June-July). Degree day accumulation is tightly correlated with the hydrograph. In years where flows declined slowly, water temperature remained cooler and both native suckers species were smaller. Similar results were seen in the Green and Colorado rivers for Colorado pikeminnow (Trammell and Chart 1999; Trammell et al. 1999). They found that high spring peaks and extended high flows resulted in later spawning, smaller fish in the fall, and lower overwinter survival of age 0 Colorado pikeminnow..

During this study, flows were implemented to more closely mimic the natural variations in magnitude and duration of the spring hydrograph, with higher spring peaks and lower summer and winter base flows than had occurred since the closure of Navajo Dam. Hydrographs with a high peak followed by a long descending limb, such as the one observed in 1995 and to a lesser degree in 1997, resulted in lowered degree day accumulation, and shorter growing season for age 0 fish.

Bestgen et al. (1997) modeled survival of Colorado pikeminnow under “cool” and “warm” conditions and found that survival was one third lower with a cool thermal regime. He attributed the difference to increased vulnerability to predation because of slower growth, concluding that management actions to increase growth rates may enhance recruitment of Colorado pikeminnow. While this model was designed for Colorado pikeminnow that spawn much later than catostomids, the implications are the same, if smaller individuals are vulnerable to predation for a longer period.

A pattern of decline in adult and juvenile flannelmouth sucker CPUE has been well documented in standardized electro-fishing data (Ryden 2000). Since 1991, flannelmouth sucker catch declined by more than 50% during the river-wide fall monitoring trips. While the causative agent of the flannelmouth sucker decline is unclear at this time, it is interesting to note that the condition factor for flannelmouth sucker has increased since 1991 (Buntjer 1998), potentially due to less intraspecific competition, while spawning success and recruitment has generally declined. Numbers of adult and juvenile bluehead sucker have also showed signs of decline river-wide since the advent of research flows in 1991.

The low level of flannelmouth and bluehead sucker recruitment in the San Juan River is alarming. The association of this decline with the mimicry of a more natural hydrograph is also alarming, and may raise questions about the paradigm of a natural hydrograph in an unnatural system such as the San Juan River. The highest spring peak (1997) appeared to be detrimental to the native catostomids. In the Green and Colorado rivers, year class strength of Colorado pikeminnow was highest in years with moderate spring peaks (Trammell and Chart 1999; Trammell et al. 1999). Because insufficient numbers of age 0 Colorado pikeminnow have been captured in the San Juan River during the research period to suggest flow recommendations, other native species population dynamics must be considered heavily. However, the continued existence of native species populations in densities equivalent to that at the start of the research period is already in question.

CONCLUSIONS

Objective 1: To empirically monitor the annual recruitment of age 0 Colorado pikeminnow in relation to flow patterns in the San Juan River.

- ! Annual recruitment of age 0 Colorado pikeminnow in the San Juan river was extremely low. Only 21 were collected during the seven-year research period.
- ! Insufficient numbers of age 0 Colorado pikeminnow were captured to evaluate the relationship to flow patterns in the San Juan River.
- ! High peak flows result in proportionately more natives and stronger year classes of native fishes, but also result in poor growth, thereby possibly reducing overwinter survival.

Objective 4: To characterize the early-life stage ichthyofaunal community in low-velocity (nursery) habitats in relation to flow patterns in the San Juan River.

- ! The proportion of native to non-native species is variable in August, but the proportion of non-natives was always higher than natives in September.
- ! The proportion of native species was positively correlated with high, late peaks of long duration.
- ! Year class estimates of native catostomids were generally positively associated with high peak flows, except for the highest flow year (1997).
- ! Year class estimates of native catostomids were underestimated by seine sampling in the fall.
 - " size related mortality and habitat shifts result in low CPUE.
 - " year class strength of native catostomids can best be evaluated by repeated seine sampling in July and August in order to collect fish soon after spawning.
- ! The average total length of native catostomids in August was positively correlated with high degree day accumulation from June-July.
- ! Degree day accumulation was negatively correlated with the average discharge for June-July.

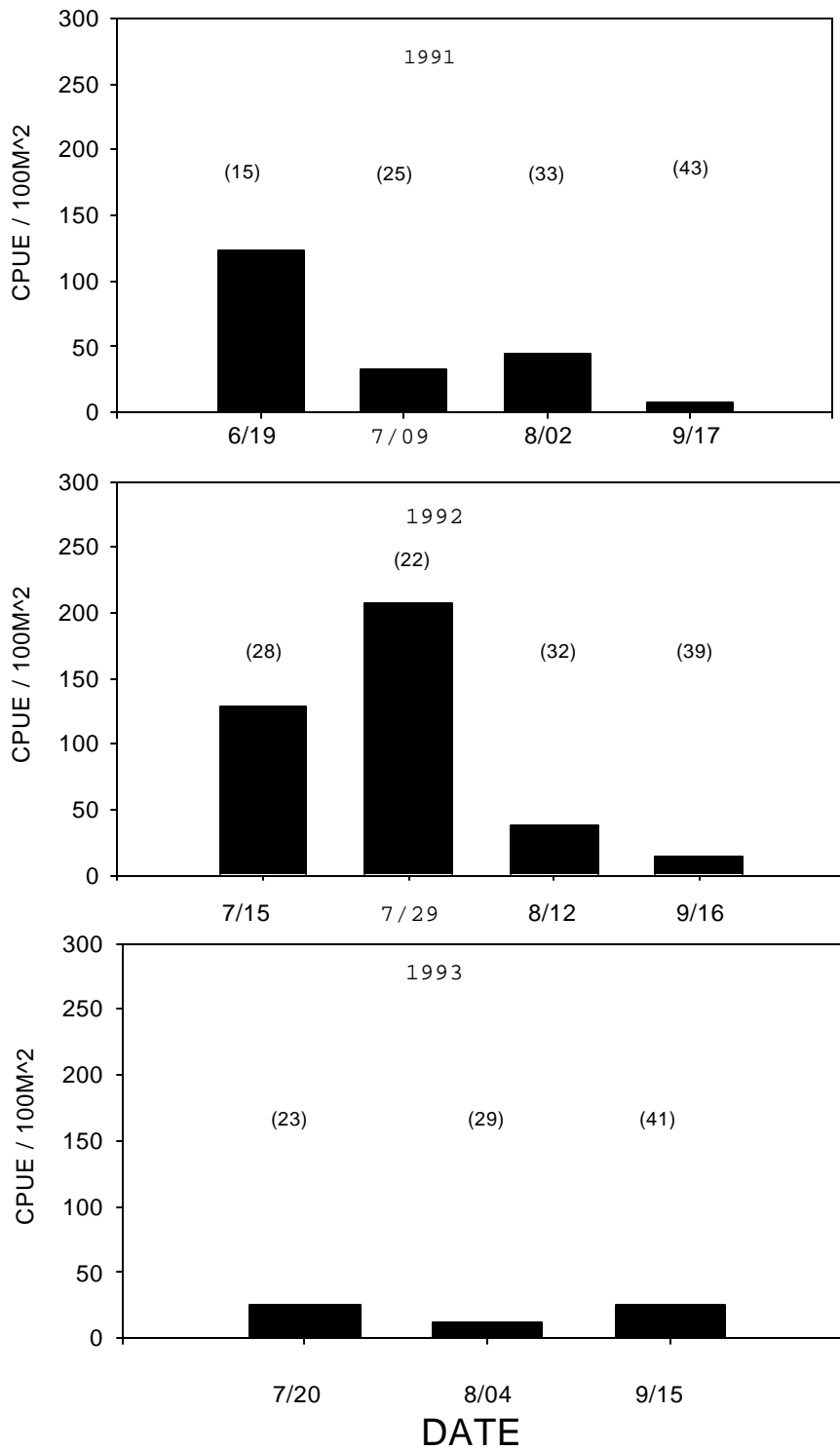


Fig. 2-1. Catch rates (number/100 m²) by sampling date for Flannelmouth sucker from 1991-1993. Average TL are presented in parentheses.

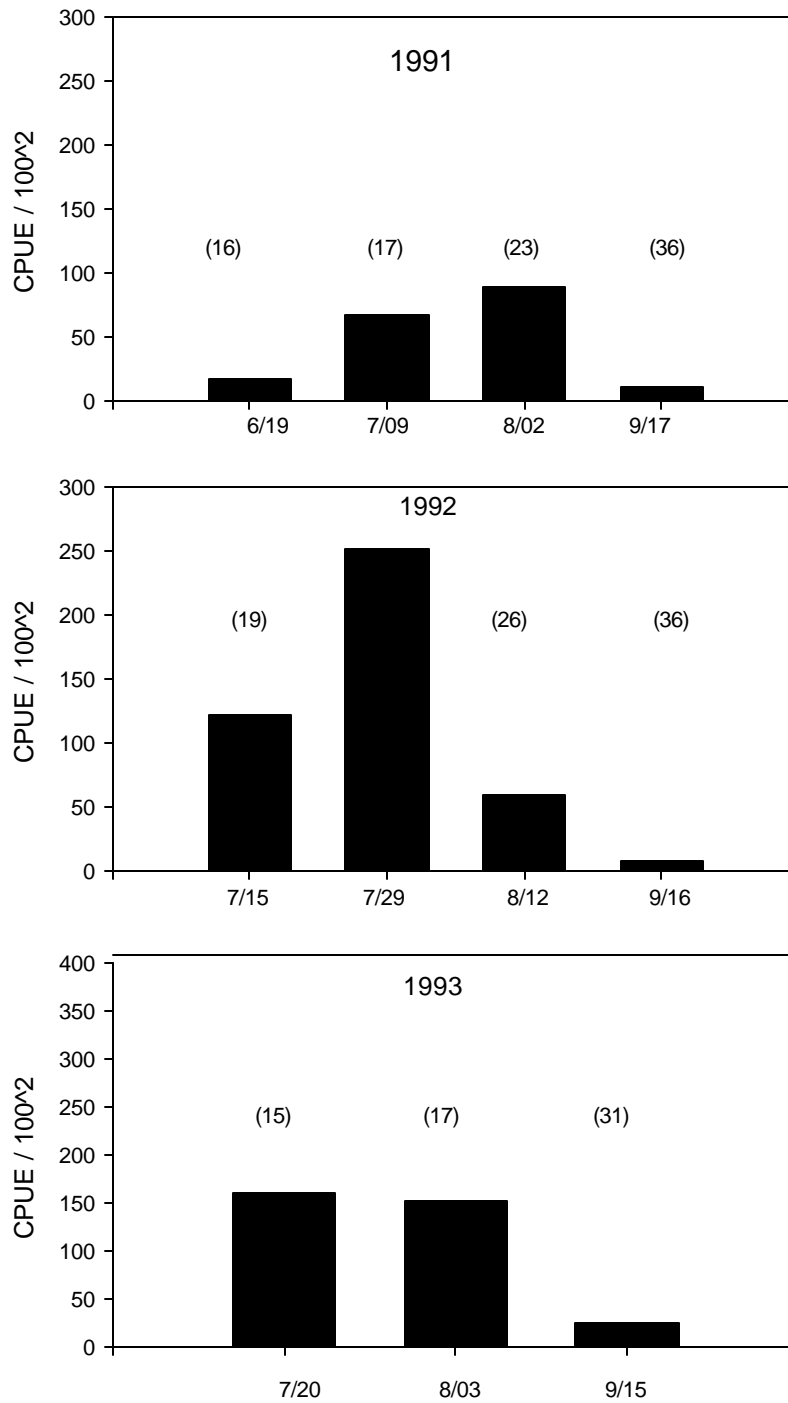


Fig. 2-2. Catch rates (number/100m²) by sampling date for bluehead suckers 1991-1993. Average TL are presented in parentheses.

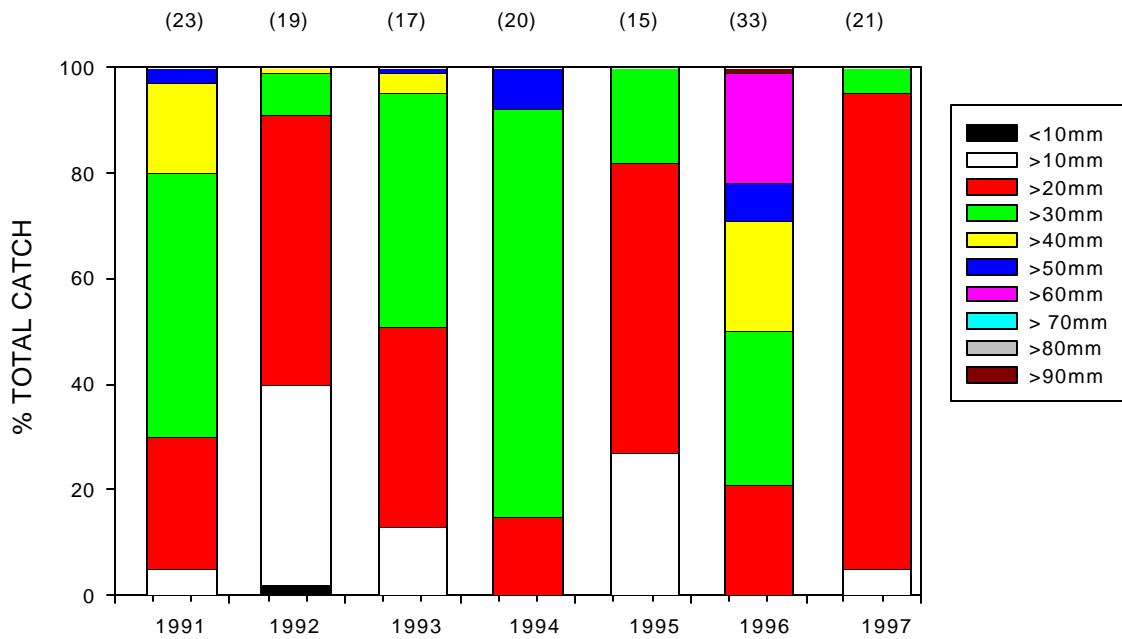


Fig. 2-3. Length frequency and average size (in parentheses) for flannelmouth sucker during August 1991-1997.

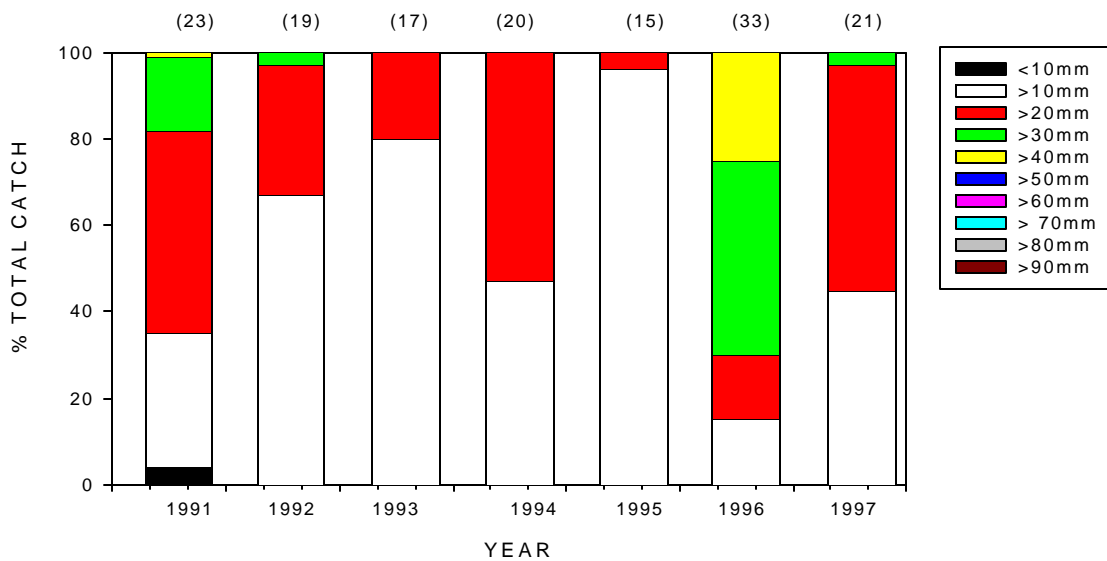


Fig. 2-4. Length frequency and average size (in parentheses) for bluehead suckers during August 1991-1997.

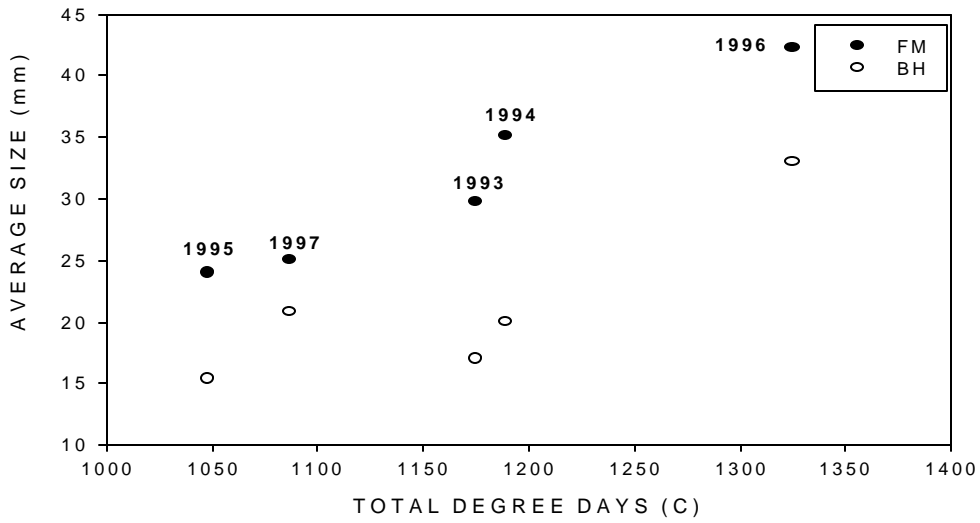


Fig. 2-5. Total Degree Day accumulation during June and July at the Montezuma Creek gage and average size of Flannelmouth and Bluehead sucker collected during August 1993-1997 sampling.

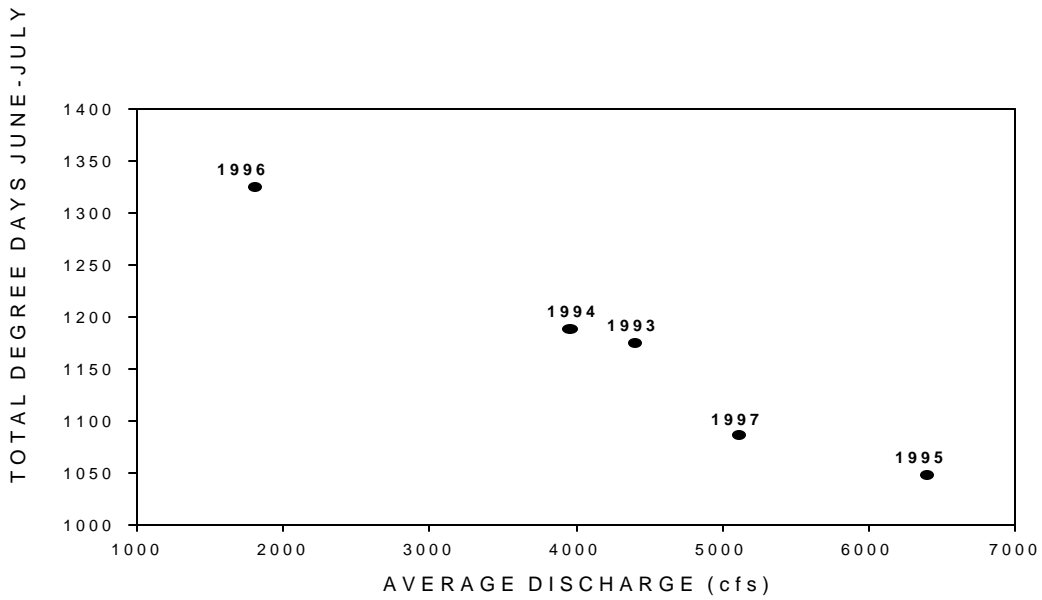


Fig. 2-6. Average discharge (San Juan River near Bluff, UT, USGS gage # 09379500) and Total Degree Day accumulation (C) (Montezuma Creek gage) during June and July.

CHAPTER THREE

NURSERY HABITAT

**SURVEY OF THE SAN JUAN RIVER,
NEW MEXICO AND UTAH, 1994-1997**

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INTRODUCTION

Backwater habitats have been recognized as important nursery habitats for young-of-year Colorado pikeminnow (Tyus and Haines 1991), and are considered to be important to successful recruitment (Tyus and Karp 1991). Backwaters are areas of no-or low-velocity flow, usually formed by irregularities in sediment features within the river channel such as sand bars and side channels. These habitats are formed by the cycle of sediment deposition during peak flows and subsequent scouring processes during and after peak flows. In a study of backwater availability and flow regulation, in the Green River, Pucherelli and Clark (1989) found that backwater availability increased through the summer as flows decreased. A gradually decreasing hydrograph was required to maximize availability, but they speculated that high spring flows may be necessary to establish the proper sediment conditions. Habitat availability at base flow is a product of channel morphology, hydrology, and antecedent conditions. In the nursery habitat areas of the Green and Colorado rivers, geomorphology studies found that backwater habitat availability was quite variable, but in general increased as flow declined within years, and was greater in years with low or moderate peak flows (Trammell et al 1999, Trammell and Chart 1999). Within-channel morphology in a dynamic system such as the San Juan River may vary greatly from year to year. Thus, annual variability in habitat availability is expected.

The construction of upstream dams in the San Juan River have altered the flow regime of the river, likely influencing nursery habitat formation and availability. The downstream impoundment of Lake Powell has permanently inundated potentially important nursery habitat areas of the lower 60 miles of the San Juan River. The purpose of this portion of the study was to identify nursery habitat in the remaining portion of the San Juan River under research flows, and addresses Objective two: to characterize nursery habitat availability in relation to flow patterns in the San Juan River, and Objective three: to determine habitat availability and use for age 0 and juvenile Colorado pikeminnow.

METHODS

Study area

The more intensively sampled nursery habitat sections, referred to in Chapter 1, were used for this portion of the study. Beginning with the most upstream section, and progressing downstream, they were designated as Section 4 (RM 131.0-126.0), Section 3 (RM 89.0-84.0), Section 2 (RM 25.2-20.2) and Section 1 (RM 13.0-8.0). Each nursery habitat section is contained within a larger Geomorphic Reach, as defined earlier in Chapter 1. Nursery Habitat Sections 1-3 are contained within Geomorphic Reaches 1-3, respectively, while Nursery Habitat Section 4 straddles the border of Geomorphic Reaches 4 and 5. Each section differs in basic geomorphology which affects habitat formation and availability, as described in Chapter 1.

Nursery habitats were sampled according to the methods described in the Sampling Protocols section. The nursery habitats sampled in this study were all backwaters with no or very little flow. The backwaters were formed by a variety of processes, listed in Table 1-1: such as abandoned secondary channels, scour channels behind large sandbars, eddies below channel constrictions, or flooded tributary mouths. They are the same habitats as those used for analyses in Chapter 4.

Statistical analysis

Nursery habitat / discharge relationship

Regression analyses were performed using data collected from 1994-1997 during UDWR Nursery habitat studies. This analysis was used to find associations between discharge at the time of sampling and number and area of available nursery habitats in the four nursery habitat study sections of the San Juan River. The first analysis combined data collected during April, August and September among sections and years. Because of differences among the four sections, data from each section was analyzed separately; first, by combining data collected during August and September for each section and then by month in which sampling occurred (August or September). In all three analyses, the dependent variables were: 1) Total number of nursery habitats; 2) Total number of deep nursery habitats (> 0.5 m); 3) Total area of nursery habitat; and, 4) Total area of deep nursery habitats (> 0.5 m).

Hydrologic parameters and habitat availability

To examine the influence of the spring hydrograph on nursery habitat availability, we performed a regression analysis using the following three independent variables 1) Peak discharge; 2) Number of days flows exceeded 5000 cfs; and, 3) Number of days flows exceeded 8000 cfs (Chapter 2; Table 2-2). The dependent or response variables in these models were: 1) Total number of backwater type habitats; 2) Total number of deep habitats (> 0.5 m); 3) Total habitat area; and, 4) Total area of deep habitats (> 0.5 m). For all statistical tests of significance, an alpha level of 0.10 was used due to low sample sizes and power, except when otherwise noted as $P < 0.05$.

Comparisons among sections

The amount of low-velocity nursery habitat throughout the San Juan River is variable by month and year. To examine differences among the nursery habitat sections of the San Juan River, total number of backwater habitats, total number of deep habitats and total area (m^2) of nursery habitats were compared for the 1994-1997 period. In addition to comparisons among the four San Juan River sections, the standard ten-mile long nursery habitat sections of the lower Green and lower Colorado rivers were compared to the San Juan River for total number and total area of nursery habitat available per mile. The first analysis pooled August and September data. The second analysis examined difference by month (August and September) and section. Comparisons were made by computing the number and area of backwater habitats per mile and then using a two-way ANOVA (SAS).

RESULTS

Nursery Habitat / Discharge Relationship

The values for the total number of backwater habitats, total number of deep habitats and total area (m^2) of all, and of deep nursery habitats, by year, month and section are given in Tables 3-2 through 3-11. All results of the several linear regression analyses are shown in the appendices (a-d), while the significant results are presented individually, in Tables 3-1, 3-5, 3-9 and 3-13. When data

were combined among years and sections and the relationship between discharge at the time of sampling and habitat availability was examined, no significant relationships were found (appendices a-d). However, there was a trend towards increases in total nursery habitat numbers, and number of habitats with maximum depth greater than 0.50 m, at lower flows. To further explore the relationships among years, each section was examined separately, first by combining all trips within each year and then by each month separately in which sampling occurred (April, August and September).

In Section 4, there were no significant relationships between discharge and any of the four independent variables tested when April, August and September data were combined. In Section 3, there was a significant positive relationship between flows and total area of nursery habitats and total area of habitats greater than 0.5 m in depth (Table 3-1). In Section 2, no significant relationships existed between discharge at the time of sampling and the four habitat availability variables tested. In Section 1, when all trips were combined for all years, there was a significant negative correlation between increased discharge and total number of nursery habitats and total number of nursery habitats greater than 0.5 m in depth.

Table 3-1. Results of regression analysis showing variables that were significantly ($p \leq 0.10$) associated with discharge at the time of sampling by section, with all trips combined 1994-1997.

SECTION	TRIP	DEPENDENT VAR.	SLOPE	P	r ²
3	1,2,3	Total habitat area	1.148	0.007	0.54
3	1,2,3	Total area deep habitat	0.532	0.050	0.33
1	1,2,3	Number habitat	-0.001	0.102	0.24
1	1,2,3	Number deep habitat	-0.002	0.073	0.29

Each section was also examined separately for each month (April, August and September) for relationships between discharge at the time of sampling and available habitat. The results are presented by month and section below.

April Samples

Data were available for Sections 1-3 for the period of 1994-1997. Section 4 was added in August of 1995, so data are only available for 1996 and 1997 for the spring sample period. Flows were highly variable during the spring sampling period in 1994 and 1996 with sampling only occurring during flows less than 1000 cfs. During 1995 and 1997, sampling occurred at discharges greater than 2500 cfs. There were no significant relationships in any of the sections between discharge at the time of sampling and any of the habitat variables tested during the April sampling period (Tables 3-2 - 3-4).

Section 4. Flows were five times higher during 1997 than during 1996 sampling (Fig. 3-1). The low number of years of data available in Section 4 during spring limits statistical analyses of these

data. In 1996, 19 nursery habitats were available in Section 4 compared to only 10 during the 1997 sampling. Because of the higher discharge during 1997 sampling, many of the nursery habitats formed by main-channel features were unavailable. Many of the larger habitats formed by secondary channels, however, were retained. Total backwater area was similar between years (Fig. 3-2). Because of the relationship between backwater depth and river stage, many of the nursery habitats sampled in 1997 were deeper than during 1996.

Section 3. No significant relationships existed between discharges at the time of sampling and the number or area of nursery habitats available in Section 3. The number of nursery habitats available in each depth class varied by year. The largest number of nursery habitats were observed in the lowest flow year (1994; Fig. 3-3). However the second lowest flow year (1996) had the lowest number of backwaters. Very few habitats > 0.5 m in depth were available in Section 3 during April sampling in any year. Total area of available nursery habitat was greatest at the highest discharges at which sampling occurred, and lowest during 1994, the year with the greatest number of nursery habitats (Fig. 3-4).

Section 2. No significant relationships existed between discharge at the time of sampling and the nursery habitat variables tested during spring. However, total nursery habitat numbers were different among years. During 1994 (low discharge), only six nursery habitats were available as compared to 29 during 1996, which was another low discharge year. During 1996, the total number of nursery habitats was the highest and the total number of habitats in the two deepest depth classes was also the greatest (Fig. 3-5).

There were no significant relationships between discharge during the sample period and total number of nursery habitat or total area of nursery habitat greater than 0.5 m in depth. Total area of available nursery habitat was greatest in 1997 (the highest discharge) followed by 1996 (which was the lowest discharge year). Area of deep (> 0.5 m) nursery habitat was maximized at the highest discharges at which sampling occurred during spring sampling in Section 2 (Fig. 3-6).

Section 1. There were no significant relationships between discharge and total number or number of deep nursery habitats during April sampling in Section 1. In Section 1, the total number of nursery habitats available consistently declined between 1994 and 1997. In 1994 and 1996, sampling occurred at similar discharges, however, the number of nursery habitats was very different (Fig. 3-7). In 1994, there were 56 backwater habitats available compared to 33 during April of 1996, which was preceded by the high water year in 1995. The lowest number of available nursery habitats occurred in 1997 (the year in which flows were highest), when only 19 nursery habitats were available throughout the five mile section.

The number of deep (> 0.5 m) nursery habitats was similar between years, with the exception of 1997, when only one nursery habitat had a maximum depth greater than 0.5 m. The primary reason for the similarities among years was that most of the deeper nursery habitats available were tributary mouth backwaters that are formed by large canyons such as Ojeto Wash and Steer Gulch during the spring. During every year except 1997, the sediment plugs which can isolate these nursery habitats following high flows had been blown out by flash floods during the monsoonal rains.

Discharge at the time of sampling was not significantly correlated to total area of nursery habitats or total area of deep nursery habitats. The greatest area of nursery habitat was in 1994 (low flow) when 7418 m² of nursery habitat was available followed by 1997 with 6263 m². The lowest total area of nursery habitat was observed in the spring of 1996 (another low flow period) when 4878 m² of

nursery habitat was available. Area of deep (> 0.5 m) nursery habitats followed a similar pattern to total number of habitats with the greatest amount of deep nursery observed in the high discharge years of 1994 and 1995 (Fig. 3-8).

Table 3-2. Total number of low-velocity habitats and discharge (Q in cfs) at the time of sampling in the Nursery Habitat study sections, San Juan River, April 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 Q number	NA	577 21	577 6	585 56
1995 Q number	NA	2,750 20	2,750 11	2,670 43
1996 Q number	628 19	656 15	573 29	517 33
1997 Q number	3,450 9	3,450 16	3,450 20	3,370 19

Table 3-3. Total area (m²) of low-velocity habitats in Nursery Habitat study sections in the San Juan River, April 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994	NA	1,350	2,794	7,418
1995	NA	3,917	911	5,629
1996	3,800	4,580	2,675	4,878
1997	16,170	6,198	5,227	6,263

Table 3-4. Total number and area (m²) of deep (> 0.5 m) low-velocity habitats in Nursery Habitat study sections San Juan River, April 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 number area	NA	2 87	2 1,726	8 1,688
1995 number area	NA	0 0	3 273	10 3,498
1996 number area	1 138	2 1,699	8 964	7 900
1997 number area	1 1,166	2 2,399	5 3,936	1 9

August Sampling

Flows were variable during the August sampling period. During 1994 and 1996, sampling occurred during low discharge. In 1995, sampling occurred during medium discharge, and, in 1997, during high summer discharge associated with a rain event. Data were available for Sections 1-3 for the period of 1994-1997. Section 4 data was available from 1995-1997 (Tables 3-6 - 3-8).

Section 4. None of the nursery habitat variables tested were significantly correlated to discharge at the time of sampling in August. Medium flows in 1995, resulted in the greatest number of habitats in all four depth classes (Tables 3-6 - 3-8). A large portion of these were shallow main-channel scour channel backwaters behind cobble bars. The majority of the nursery habitats were retained at the lowest flows at which sampling occurred in 1996 but the deepest nursery habitats were lost because of the extremely low stage of the river. At the highest flow (1997), only 14 nursery habitats were available in the five mile section.

No significant relationships were found between discharge at sampling and total area of all habitats or area of deep nursery habitats (Table 3-5). Total nursery habitat area and area of deep nursery habitats was greatest during 1995 sampling which occurred at medium discharges. The low discharge during sampling in 1996 resulted in less than 500 m² of nursery habitat that were greater than 0.5 meters in depth. Only slightly more was available during high flows of 1997. In summary, 1995 resulted in the highest abundance of all four nursery habitat categories. Discharges between 1200 cfs and 2000 cfs likely maximize nursery habitat in Section 4. At low discharges, many main channel bars become exposed, creating habitat. However, many of the larger secondary channel backwaters are lost.

Table 3-5. Results of regression analysis by section showing habitat variables that were significantly ($p < 0.10$) associated with discharge at the time of sampling, by section, during August 1994-1997 sampling.

SECTION	TRIP	DEPENDENT VAR.	SLOPE	P.	r^2
3	2	Number habitats.	-0.001	0.060	0.88
2	2	Total habitat area	-0.412	0.050	0.88

Section 3. There was a significant negative relationship between total number of nursery habitats and increasing discharge at the time of sampling in Section 3 during the August sample period (Table 3-5). The greatest number of nursery habitats were available during the lowest discharge at which sampling occurred in 1996 (Table 3-6). During 1994 and 1995, total numbers were very similar. In 1997, when discharge was greater than 3000 cfs, the number of habitats was greatly reduced.

There were no significant relationships between discharge and total area or total area of deep (> 0.5 m) nursery habitats in Section 3 during August sampling. The greatest amount of habitat area occurred during 1997 when the total number of nursery habitats was the lowest. In 1996, when the greatest number of habitats were available there was 3948 m² of habitat available compared to just under 3000 m² in 1994 and 1995. The greatest amount of deep nursery habitat (> 0.5 m) was available at the highest and lowest discharges. Very little deep nursery habitat was available in Section 3 during 1994 and 1995. During 1996, five habitats accounted for just over 1500 m² of deep nursery habitat compared to 2 habitats in 1997 which resulted in very similar total area of deep nursery habitat.

In summary, the greatest number of nursery habitats were available at the lowest flow at which sampling occurred in Section 3. Nursery habitat area was maximized during the highest discharges, but total nursery habitat numbers were low.

Section 2. The total number of nursery habitats and discharge at sampling were not significantly correlated in Section 2 during August. The highest number of nursery habitats were available during the lowest discharge (1996). The lowest number of habitats were available during the highest discharge (1997). The greatest number of deep nursery habitats were available during 1995 (Table 3-5). There was a significant negative relationship between increasing discharge and total area of available nursery habitat in Section 2 during August (Table 3-5). The lowest discharges (1996) resulted in greatest total nursery habitat area (2327 m²). During 1994 and 1995, total area of nursery habitat was very similar (. 2100 m²). In 1997, which was the highest discharge at which sampling occurred, nursery habitat total area was reduced by nearly half to 1236 m². Total area of habitats greater than 0.5 m in depth was greatest in 1995 and 1994 followed by 1997 and 1996, respectively. While 1996 had the second highest number of nursery habitats in the deep class, most were small resulting in very little total area.

At very low discharges, large numbers of main channel bars become exposed, creating large numbers of backwater habitats throughout the canyon sections (RM 58-0). The availability of habitat from Mexican Hat (RM 56.0) to Johns Canyon (RM 25.2) was many times greater during 1996 than during any other year of the study. In Section 2, low discharges result in the greatest number of

habitats. However, the number and area of deep habitat were maximized at somewhat higher discharges.

Section 1. There were no significant relationships between discharge at sampling and total number of habitats or total number of deep nursery habitats during August in Section 1. Nursery habitat numbers were greatest in 1996 (the lowest discharge). A total of 52 nursery habitats were available in the five mile section in 1996 and 21 of those were greater than 0.5 m in depth. In 1994 and 1997, two years with very different discharges, total numbers and number of nursery habitats greater than 0.5 m in depth were similar. In 1995, there were far fewer nursery habitats than in any other year of sampling.

Total area of habitat was very similar in 1994, 1996 and 1997 ranging between 13,258 m² and 13,933 m² of total backwater habitat. In 1995, the year with the lowest number of nursery habitats, the total area of backwater habitats was lowest (4964 m²). Total area of deep nursery habitats was highest during years with the lowest discharges of 1996 and 1994 with 10,660 m² and 8,769 m², respectively. Area of deep nursery habitats was the also lowest during 1995 with 2,267 m² followed by 1997 with 3,884 m².

In summary, the number of nursery habitats in Section 1 during August was maximized at the highest and lowest discharges. Total area of available habitat was greatest at the highest discharge. However, total area and the number of deep nursery habitat were greater at the lowest discharges in Section 1 during August. For all four categories which habitat was ranked, 1995 was lowest (Table 3-6 - 3-8).

Table 3-6. Total number of low-velocity habitats and discharge at the time of sampling (Q in cfs) in Nursery Habitat study sections San Juan River, August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 Q number	NA	646 21	546 18	439 36
1995 Q number	1,390 46	1,240 22	1,240 23	1,470 14
1996 Q number	210 29	262 27	262 28	317 52
1997 Q number	3,050 14	3,110 12	2,780 8	2,320 37

Table 3-7. Total area (m²) of low-velocity habitats in Nursery Habitat study sections in the San Juan River, August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994	NA	2,960	2,136	13,258
1995	6,248	2,947	2,156	4,964
1996	3,443	3,948	2,337	13,933
1997	2,421	5,664	1,236	15,163

Table 3-8. Total number and area (m²) of deep (> 0.5 m) low-velocity habitats in Nursery Habitat study sections San Juan River, August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 number area	NA	2 133	7 1,372	18 8,769
1995 number area	6 2,370	1 238	12 1,775	6 2,267
1996 number area	1 444	5 1,242	9 448	21 10,660
1997 number area	4 757	2 1,341	4 657	15 3,884

September Sampling

September sampling occurred during three medium low flow periods and a high period during 1997 when flows were greater than 3,000 cfs. Prior to sampling in all four years, monsoonal rain events had loaded the system with sediment, reducing nursery habitat availability in all sections. River-wide, no significant relationships existed between discharge at the time of sampling and the availability of nursery habitat. Data was available for Sections 1-3 for the period of 1994-1997. Section 4 data was available from 1995-1997 period (Tables 3-10 - 3-12).

Section 4. The total number of available nursery habitats in Section 4 during September was down by half or more from August levels in all years. The greatest reduction was during 1995 when

total nursery habitats declined from 46 in August to 11 in September. During September sampling in Section 4, a significant negative relationship existed between discharge at sampling and total number of deep nursery habitats available in Section 4 (Table 3-9). The greatest number of nursery habitats was found during 1996, followed by 1995 (Table 3-10). The lowest number of nursery habitats was observed during the highest flow of 1997, when only seven nursery habitats were available throughout the section. Availability of deep nursery habitats was low in all years in Section 4. Two nursery habitats greater than 0.5 m in depth were sampled in 1995 and 1996 and zero in 1997 (Fig. 3-1).

Total number and area of nursery habitats greater than 0.5 m in depth in Section 4 was negatively correlated to discharge ($F=0.01$, $r^2= 0.999$). This relationship was largely driven by the presence of two large habitats during 1995 and 1996. Total area was highest in 1996 and similar in 1995 and 1997. Total area of deep nursery habitats was very similar in 1995 and 1996 with 1607 m² and 1588 m² of nursery habitat greater than 0.5 m in depth (Fig. 3-2).

Table 3-9. Results of regression analysis showing habitat variables that were significantly associated with discharge at the time of sampling by section during September 1994-1997 sampling.

Section	Trip	Dependent variable	Slope	P	r ²
4	September	Number deep habitats	-0.001	0.02	0.99
4	September	Area deep habitats.	-0.741	0.01	0.99
3	September	Area habitat.	1.892	0.08	0.83
3	September	Area deep habitat	1.233	0.07	0.86
1	September	Number deep habitat.	-0.001	0.04	0.92

Section 3. There was not a significant relationship between discharge at sampling and total number or total number of deep nursery habitats available during September. Total number of available habitats was similar in 1995 and 1997. Very few backwater habitats greater than 0.5 m in depth were available during September in any year (Fig. 3-4). The high discharges during 1997 resulted in the greatest number of habitats in Section 3 (Table 3-10).

Discharge was significantly correlated with total area of habitat and the total area of habitat greater than 0.5 m in depth in September (Table 3-9). Total area of available habitat was highest during 1997, which had the highest discharge of any year. This was due to several very large flow-through sites which only existed at higher flows. Total area of habitat available was second highest in 1996, which was the lowest discharge. In summary during September sampling in Section 3 numbers and area of nursery habitats was maximized at the highest flows.

Section 2. During September, there were no significant relationships between discharge and number or area of nursery habitat available. Eighteen nursery habitats were available during 1995 and 1996. Four deep nursery habitats were available in 1995 and five were available in 1996. In 1997 (the highest discharge year), there were two-thirds as many nursery habitats as in the previous two

years. However, there were more deep nursery habitats in 1997 than in any other year. During 1994, there were fewer total habitats and fewer deep habitats than during any other year (Fig. 3-10).

Section 1. During September sampling, there was no significant relationship between discharge at the time of sampling and total number of nursery habitats. There was a significant negative relationship between the total number of deep nursery habitats and discharge at the time of sampling ($F=0.04$, $r^2= 0.92$). The highest number of habitats were available during 1996 ($n=30$), followed by 1994 ($n=28$). Twenty nursery habitats were found in 1995 and 16 in 1997 (the highest flow year). The total number of deep nursery habitats followed a similar pattern with 12 in 1996, 10 in 1995, 10 in 1994, and 5 in 1997 (Fig. 3-11). In Section 1, during September, total number and area of backwater type nursery habitats declined as discharge increased.

Table 3-10. Total number of low-velocity habitats and discharge at the time of sampling (Q in cfs) in Nursery Habitat study sections San Juan River, September 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 Q number	NA	1,080 1	1,040 5	937 28
1995 Q number	947 11	947 11	1,010 18	1,190 20
1996 Q number	1,020 14	914 11	914 18	870 30
1997 Q number	3,110 7	3,440 12	3,920 12	5,260 16

Table 3-11. Total area (m²) of low-velocity habitats in Nursery Habitat study sections San Juan River, September 1994-1997.

YEAR	REACH 4	REACH 3	REACH 2	REACH 1
1994	NA	310	1,071	9,308
1995	2,483	1,746	1,855	4,408
1996	3,716	2,841	3,035	9,840
1997	2,323	6,412	1,664	5,141

Table 3-12. Total number and area (m²) of deep (> 0.5 m) low-velocity habitats in Nursery Habitat study sections San Juan River, September 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994 number area	NA	0 0	3 784	10 5,047
1995 number area	2 2,370	1 1,333	4 399	10 3,600
1996 number area	2 444	0 0	5 664	12 7,799
1997 number area	0 757	2 3,540	6 1,402	5 2,042

Hydrologic parameters and habitat availability

To examine the influence of the spring hydrograph on nursery habitat availability, we performed regression analyses using the following three independent variables: 1) Peak discharge; 2) number of days flows exceeded 5000 cfs; and, 3) number of days flows exceeded 8000 cfs. In these models, the dependent or response variables were: 1) Total number of backwater type habitats; 2) total number of deep habitats (> 0.5 m); 3) total nursery habitat area; and, 4) total area of deep nursery habitats (> 0.5 m). An alpha level of $P < 0.10$ was used to determine significant relationships.

When all sections were combined across all years, 1994-1997, there were no significant relationships ($P < 0.10$)(appendices a-d). Because of the geomorphic differences among sections, each section was then examined separately, first with data from August (Trip 2) and September trips (Trip 3) combined and then for each trip (August and September) separately.

Section 4. When trips were combined in Section 4, no significant relationships existed between the flow variables and any of the nursery habitat variables tested. During August sampling, a significant positive relationship existed between days greater than 5000 cfs and total area of nursery habitats greater than 0.5 m in depth (Table 3-13). During September, a slightly negative relationship existed between the peak discharge and total area of nursery habitat.

Section 3. When data were pooled across trips, there was a positive relationship between days above 8000 cfs and total area of habitat and total area of nursery habitat greater than 0.5 m in depth (Table 3-13). During August, there was a negative relationship between total number of deep habitats and peak discharge and the number of days flows exceeded 5000 cfs. During September, a significant positive relationship existed between days that flows exceeded 8000 cfs during the previous spring and total number of nursery habitats and total area of deep nursery habitats.

Table 3-13. Results from linear regression models showing variables that were significantly associated with one or more of the nursery habitat variables. Models can be derived from the y-intercept and slopes from the table.

SECTION	TRIP	y-VARIABLE	x-VARIABLE	P	SLOPE	r ²
4	2	NUMBER DEEP HABITATS.	DAYS > 5000	0.10	0.07	0.97
4	3	AREA HABITAT	PEAK	0.05	-0.16	0.99
3	2,3	AREA HABITAT	DAYS > 8000	0.09	94.5	0.39
3	2,3	AREA DEEP HABITAT	DAYS > 8000	0.06	62.0	0.47
3	2	NUMBER DEEP HABITATS	PEAK	0.07	-0.001	0.85
3	2	NUMBER DEEP HABITATS	DAYS >5000	0.01	-0.06	0.98
3	3	NUMBER DEEP HABITATS	DAYS > 8000	0.01	0.07	0.98
3	3	AREA DEEP HABITAT	DAYS > 8000	0.03	113.03	0.92
2	1,2	AREA HABITAT	PEAK	0.09	-0.11	0.40
1	2,3	NUMBER HABITATS	PEAK	0.07	-0.002	0.44
1	2,3	NUMBER DEEP HABITATS	PEAK	0.03	-0.001	0.38
1	2,3	AREA DEEP HABITAT	PEAK	0.04	-0.78	0.77
1	2,3	NUMBER HABITATS	DAYS >5000	0.05	-0.35	0.49
1	2,3	NUMBER DEEP HABITATS	DAYS >5000	0.05	-0.15	0.32
1	2,3	AREA DEEP HABITAT	DAYS >5000	0.01	-103.00	0.65
1	2,3	NUMBER DEEP HABITATS	DAYS > 8000	0.07	-0.02	0.29
1	2,3	AREA DEEP HABITAT	DAYS > 8000	0.01	-201.31	0.68
1	2	AREA DEEP HABITAT	PEAK	0.07	-0.95	0.86
1	2	NUMBER HABITATS	DAYS >5000	0.09	-0.05	0.83
1	3	NUMBER HABITATS	PEAK	0.09	-0.001	0.81
1	3	AREA HABITAT	PEAK	0.10	-0.064	0.80
1	3	AREA DEEP HABITAT	PEAK	0.03	-0.61	0.94
1	3	NUMBER HABITATS	DAYS > 8000	0.01	-0.46	0.98
1	3	AREA HABITAT	DAYS > 8000	0.08	-181.48	0.84
1	3	AREA DEEP HABITAT	DAYS > 8000	0.10	-155.64	0.81

Section 2. When data were pooled there was a significant negative relationship between peak discharge and the total area of nursery habitats available in section 2. No significant relationships existed between any of the variables measured during August or September sampling.

Section 1. When data were pooled for August and September sampling, there were some significant negative relationships between the nursery habitat variables and the discharge variables. The total number of available nursery habitats was negatively correlated with peak discharge and days above 5000 cfs (Table 3-13). Total number of deep (> 0.05 m) nursery habitats was negatively correlated to all three flow variables. Total area of nursery habitat was not significantly correlated with any of the flow variables tested. Total area of deep nursery habitats was significantly related to all three flow variables tested. Days above 5000 cfs and total area of deep habitats were negatively related. There was also a significant negative relationship between days above 8000 cfs and total deep nursery habitats and total area of deep nursery habitats. The relationship between the number of days flows stayed above 8000 cfs and the creation of deep nursery habitats in Section 1 is negative.

During August, peak discharge was negatively correlated with the total area of deep nursery habitats. Days above 5000 cfs was also negatively correlated with total number of nursery habitats. During September, significant negative relationships existed between peak discharge and total habitat numbers, total area, and total area of habitats > 0.5 m in depth (Table 3-13). Days with flows above 8000 cfs and number of habitats were also significantly correlated. Total area of habitats and total area of habitat > 0.5 m in depth were also significantly correlated to days above 8000 cfs with both relationships showing negative slopes of -181 and -155, respectively.

Comparisons among sections

The amount of low-velocity nursery habitat throughout the San Juan River is variable by month and year. In order to examine differences between the five mile sections of the San Juan River, total number, the total number of deep nursery habitats, and total area (m²) of nursery habitats were compared from 1994-1997. In addition to comparisons among the four San Juan River sections, the standard ten mile long nursery habitat sections of the lower Green and lower Colorado rivers were compared to the San Juan for total number of nursery habitats and total area of nursery habitat available per mile. The first analysis lumped August and September data together. The second analysis examined difference by month (August and September) by section. Comparisons were made by computing number and area of backwater type habitats per mile and then using a two-way ANOVA (SAS).

August and September combined

Total number of backwater habitats per mile were significantly greater in Sections 4 and 1 than in Sections 3 and 2 of the San Juan River. Nursery habitat numbers in Sections 4 and 1 were also greater than either of the comparison reaches on the lower Green and lower Colorado rivers during the same time period.

Total area of available backwater nursery habitats was significantly greater in Section 1 of the San Juan River than any of the other comparison sections of the San Juan or the comparison reaches of the Green or Colorado rivers ($F = 8.25$, $P = 0.0001$). In summary, when August and September data are combined, Section 1 of the San Juan River (at the inflow of Lake Powell) had significantly more

nursery habitats, and more nursery habitat area per mile than either Sections 3 or 2, or either section of the lower Green or lower Colorado rivers with which comparisons were made (Tables 3-14 - 3-19).

August Sampling

Total numbers of low-velocity nursery habitats were variable between years during August sampling (Table 3-14). Total number of nursery habitats per mile was significantly greater in Section 1 than either of the reaches on the Green or Colorado rivers ($F = 3.88, P = 0.026$). While the total number of nursery habitats in Section 1 was greater than the other locations in every year except 1995, differences among sections of the San Juan River were not significant ($P > 0.05$). Following the high discharge of 1995, total numbers of nursery habitats in Section 1 were less than half of any other year. Total area of backwater habitats followed a very similar pattern (Table 3-15) with area of habitats per mile being significantly greater in Section 1 than any of the other nursery habitat sections of the San Juan, Green or Colorado rivers ($F = 6.24, P = 0.0018$). Total area of nursery habitat was far greater in Section 1 than any other nursery habitat sections of the San Juan River in every year except 1995 when Section 4 contained four large nursery habitats which resulted in more total area. Total number of deep habitats was greater in Section 1 than the other sections of comparison on the San Juan River, except for 1995 (Table 3-16).

Table 3-14. Total number of low-velocity habitats **per mile** in Nursery Habitat study sections San Juan (5 miles), Green, and Colorado rivers (10 miles) August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1	GREEN	COLORADO
1994	NA	4.2	3.6	7.2	2.2	2.7
1995	9.2	4.4	4.6	2.8	2.1	2.4
1996	5.8	5.4	5.6	10.4	2.0	2.4
1997	2.8	2.4	1.6	7.4	NA	NA

Table 3-15. Total area (m²) of low-velocity habitats **per mile** in Nursery Habitat study sections in the San Juan (5 miles), Green, and Colorado rivers (10 miles) August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1	GREEN	COLORADO
1994	NA	592.0	427.2	2651.6	2106.9	1088.5
1995	1249.6	589.4	431.2	992.8	351.0	559.1
1996	688.6	789.6	167.4	2786.6	790.9	629.8
1997	484.2	1132.8	247.2	3032.6	NA	NA

Table 3-16. Total number of deep (> 0.5 m) low-velocity habitats **per mile** in Nursery Habitat study sections San Juan River (5 miles) August 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994	NA	0.4	1.4	3.6
1995	1.2	0.2	2.4	1.2
1996	0.2	1.0	1.8	4.2
1997	0.8	0.4	0.8	3.0

In summary, Section 1 of the San Juan River during August sampling consistently had higher densities of backwater habitats than any of the other study sections of the San Juan River. Densities were also greater than those observed on either the lower Green or lower Colorado rivers. Total area of habitat per mile available to age 0 fish was also consistently greater in Section 1 of the San Juan River than any of the other sections of comparison.

September Sampling

In September, total nursery habitat numbers were down from August sampling in the San Juan River sections (Table 3-17). However, differences were only significant in Section 1 ($F = 8.38$, $P = 0.027$). In Section 4, total numbers declined by half or more in every year, but differences were not significant because of large amounts of variance. Total area of available backwater habitats also declined between August and September in nearly every year and every section but differences were not significant ($P > 0.05$) (Table 3-18). During September the total number of deep nursery habitats declined in nearly every section in every year but differences were not significant ($P > 0.05$). In Section 1, the number of deep habitats declined in every year except 1995, when deep nursery habitat numbers increased from 6 in August, to 10 in September (Table 3-19). This increase can be attributed to tributary mouth habitats becoming available during September that were unavailable during August.

Table 3-17. Total number of low-velocity habitats **per mile** in Nursery Habitat study sections San Juan (5 miles), Green, and Colorado rivers (10 miles) September 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1	GREEN	COLORADO
1994	NA	0.2	1.0	5.6	1.4	2.2
1995	2.2	2.2	3.6	4.0	2.7	1.5
1996	2.8	2.2	3.6	6.0	2.2	2.1
1997	1.4	2.4	2.4	3.2	NA	NA

Table 3-18. Total area (m²) of low-velocity habitats **per mile** in Nursery Habitat study sections San Juan (5 miles), Green, and Colorado rivers (10 miles) September 1994-1997.

YEAR	REACH 4	REACH 3	REACH 2	REACH 1	GREEN	COLORADO
1994	NA	62.0	214.2	1861.6	1572.4	1428.3
1995	496.6	349.2	371.0	881.6	359.9	307.4
1996	743.2	568.2	607.0	1968.0	596.8	1047.6
1997	464.6	1282.4	332.8	1028.2	NA	NA

Table 3-19. Total number of deep (> 0.5 m) low-velocity habitats **per mile** in Nursery Habitat study sections San Juan River (5 miles) September 1994-1997.

YEAR	SECTION 4	SECTION 3	SECTION 2	SECTION 1
1994	NA	0	0.6	2.0
1995	0.4	0.2	0.8	2.0
1996	20.4	0	1.0	2.4
1997	0	20.4	1.2	1.0

Total number of nursery habitats available during September were highest in Section 1 in every year. Total area was also highest in Section 1 in every year with the exception of 1997 when Section 3 contained more total nursery habitat area but only two nursery habitats.

DISCUSSION

Availability of backwater nursery habitats in the San Juan River system is a highly variable and dynamic process. Many factors affect the amount and depth of the available backwater habitats, such as discharge, magnitude and duration of the spring peak, frequency and magnitude of summer monsoonal flow spikes. These factors have different effects in each section and during different times of the year. The lowermost section of the San Juan is additionally affected by the elevation of Lake Powell. The four years of data that are presently available (1994-1997) limit statistical analyses of habitat availability in relation to the previous spring hydrograph. While some relationships between the hydrograph and habitat availability are apparent in the data sets, more insight into these relationships could be gained if the number of years of data were increased. Discharge at the time of sampling appears to affect habitat availability more than the spring hydrograph. It appears that each section

reacts differently to hydrologic variables because of geomorphic differences between sections of the San Juan River. Therefore, habitat cannot be maximized in each section or the entire river with one flow management strategy.

Sediment movement during rain events is an important factor affecting low-velocity habitat availability in the San Juan River. The negative impacts on number and depth, of available nursery habitats by summer storm events has been shown. In all years of August sampling, except 1997, data was collected before storm events and is a reflection of the amount of nursery habitat created by the previous spring hydrologic cycle. In every year monsoonal rain events occurred prior to the September sampling period and resulted in major reductions in the number and depth of available backwater-type habitats. The effect varied by section but consistently resulted in fewer backwater type habitats.

Section 4

Section 4 of the of the San Juan River is in an unrestricted meander section dominated by cobble substrates. In this section, backwater type nursery habitats are primarily formed at the lower end of abandoned secondary channels or created behind cobble bars in the main channel. Many of the geomorphic features which create nursery habitat in this section are persistent from year to year. Their depths vary and are dependent on the stage of the river and accumulation of sediment load.

The greatest number of nursery habitats in Section 4 occurs at flows between 1000 cfs and 1500 cfs. This is enough water to inundate the lower ends of the secondary channels but low enough that main channel features which create nursery habitats can persist. Section 4 never contains high numbers of deep nursery habitats, but during very low discharges, no deep habitats are typically available. At flows greater than 3000 cfs many of the secondary channels that create habitats are flowing and unavailable as low-velocity habitat. Many of the main channel features are also inundated at these flows. While the abandoned secondary channel habitats can account for large amounts of habitat area in this section of the river, numbers of this habitat type are typically low.

The limited number of years of sampling in Section 4 (n=3) make it difficult to draw major conclusions regarding the effects of the previous spring hydrograph on nursery habitat availability. However, the analysis did show that the availability of deep nursery habitats in Section 4, was positively correlated to the number of days flows stayed above 5000 cfs. The area of available nursery habitat in Section 4, however, was negatively correlated to the spring peak discharge.

Section 3

Section 3 of the study area is an unrestricted meander section dominated by large mixed sand and cobble bars. The channel is frequently braided and is the most dynamic of any of the four study sections. Many of the backwater type habitats in this section are created by the scour action of high flows across the many large, relatively permanent bars. The high flows of 1997 reworked the channel and consequently changed the location of many of the nursery habitats that had been present during previous years.

Section 3 consistently had the highest number of nursery habitats at the lowest discharges. Many of these were small, shallow, scour channel backwaters on the downstream side of large sediment features. At flows below 500 cfs, many secondary channels become isolated at the upper ends, creating large, often deep nursery habitats. Total area of nursery habitats was greatest at the

highest flows but also high at the lowest flows at which sampling occurred. Likewise, more deep habitats were available at the highest and lowest discharges.

The apparent effect of the spring flows on this section of the San Juan River is dependent on which data is examined and therefore is inconclusive. Using August data, it appears that higher peak discharges and days above 5000 cfs results in fewer deep nursery habitats. When September data is used the area and number of habitats available in this section was positively correlated to the number of days that flow was greater than 8000 cfs.

Section 2

Section 2 is a canyon bound, high gradient area dominated by cobble and boulder substrates. Many of the rapids in this stretch of river are created by debris fans protruding into the main channel resulting in the pool-drop nature of this section. Many of the nursery habitats in this section are deep scours created by eddy return channels below constrictions in the channel. Habitats are typically formed in the deposition areas below constrictions and the locations of many are consistent from year to year. The greatest number of nursery habitats are typically found at discharges between 250 cfs and 1500 cfs. The number and area of deep nursery habitats was also highest at medium discharges. At higher flows, many of the depositional zones become inundated and nursery habitat availability drops.

The spring hydrograph seems to have had little affect on backwater availability in Section 2. The only significant correlation was a negative one between peak discharge and area of available nursery habitat when August and September data were combined. It appears that discharge at the time of sampling has a greater affect on the amount of nursery habitat available than the previous spring hydrograph.

Section 1

Section 1 is located below the high water level of Lake Powell. Sediment deposits have changed the character of the river in this section to a low gradient restricted meander with a fine sediment dominated bed. The majority of the sediment features in this stretch of river are reworked from year to year. Most nursery habitats in this section are created by scour action across the many large mobile sand bars which dominate this section or by tributary mouth backwater created by the ephemeral washes that drain into the San Juan River. The availability of tributary mouth habitats is dependant on whether the wash has flowed since flows in the San Juan River were high enough to plug the mouth of the wash with sediment.

The greatest number of backwater habitats in this section of the river were found during the lowest discharges. The greatest number of deep nursery habitats were also present at the lowest discharges. Total area of available nursery habitat was more variable, but typically highest at the lowest discharges. The area of available nursery habitat was highly sensitive to the availability of the tributary mouth habitats. At flows above 3000 cfs, the majority of the sediment features that create nursery habitat in the main channel in this section are covered with water and nursery habitat availability is diminished.

In Section 1, there were sixteen significant correlations between the spring hydrologic variables tested and nursery habitat availability. All of these were negative relationships. This suggests that high spring discharges, with long descending limbs, have a negative effect on both number and area of available nursery habitat during the following summer in Section 1. Following the high runoff year of

1995, nursery habitat availability was decreased in Section 1. The same pattern has been observed in the lower Green and Colorado River nursery habitat studies where “high” spring discharges resulted in the lowest number and area of backwater-type habitats (Trammell and Chart 1999; Trammell et al. 1999). Section 1 is also influenced by the elevation of Lake Powell. Small changes in the elevation of Lake Powell have large effects on the length of this low gradient area at the in-flow and can affect the overall availability of suitable nursery habitat. This effect was seen in 1995, when Lake Powell elevation was high, which contributed to the low availability of habitat in Section 1.

The data indicate that discharge at the time of sampling has a large effect on nursery habitat availability in every section. In nearly every section, the greatest number and area of backwater type habitat was available at the lowest discharges experienced, despite differences in the previous spring hydrograph. Many of the habitats in the upper three sections are available year to year despite differences in spring hydrographs. Most of the significant correlations found between the spring hydrograph and the availability of nursery habitat were negative.

The number and area of available backwater nursery habitat is probably important to age 0 fishes. While area of available nursery habitat is important, several large habitats which result in large amounts of nursery habitat area may be less preferable to young fish, than many smaller nursery habitats resulting in the same amount of area. It is unlikely that age 0 fish move upstream great distances, and therefore, as habitats are lost, fish likely move downstream until another suitable habitat is encountered. Therefore, it may be important that the number of nursery habitats available to fishes is maximized as well as the total area of those nursery habitats.

The comparisons of backwater-type habitat available between the San Juan River nursery habitat sections and the nursery habitat reaches of the lower Green and lower Colorado rivers, where age 0 Colorado pikeminnow are relatively abundant, showed that total number and total area of available backwater type nursery habitats per mile was comparable in all sections, and was significantly higher in Section 1 of the San Juan River during August. During August sampling, Section 1 of the San Juan River had greater densities of backwater type habitats than any of the other sections, in every year except 1995. During September, Section 1 of the San Juan again had significantly more nursery habitats per mile than San Juan Sections 3-4 or either of the reaches of comparisons on the Green or Colorado rivers. Total area during September was also consistently highest in Section 1 but differences were not statistically significant.

The biological importance of backwater habitats in each section must also be considered. Section 1 of the San Juan River is similar in several ways to the nursery habitat areas of the lower Green and Colorado rivers, which are important to age 0 Colorado pikeminnow. Section 1 is the only section of the San Juan River where the bed is sand dominated and canyon bound. It is also the only section where gradient drops to levels similar to the lower Green and Colorado rivers. Since 1987, only three age 0 Colorado pikeminnow specimens (including one larvae at 14 mm TL) have been captured above this section. Two of these specimens were collected in New Mexico in 1987 (Platania 1990). While the number of age 0 pikeminnow captured during the research period was low, there is a pattern of more captures in years when Lake Powell elevation was lower, with concomitant increase in the amount of available habitat. Formation and maintenance of backwater habitat in Section 1, at the inflow area of Lake Powell may be particularly important to the recruitment of Colorado pikeminnow.

CONCLUSIONS

Objective 2) To characterize nursery habitat availability in relation to flow patterns in the San Juan River.

- ! Habitat availability was not highly correlated to spring hydrograph variables of peak magnitude, and days above 5000 and 8000 cfs.
 - " In general, the highest spring peaks resulted in the least available habitat in the summer and fall in all nursery habitat sections.
 - " At least one habitat variable was negatively correlated with high spring peaks in all sections. Section 1 had 16 significantly negative correlations with the spring hydrograph variables.
 - " Habitat availability following moderate to low peaks was variable in all reaches.
- ! Habitat availability was quite variable, but was related to discharge during the time of sampling.
 - " In general, the lowest flows encountered during sampling were associated with greater amounts of available habitat in all sections.
 - " In the upper two sections (3 and 4) habitat increased again at the highest discharges sampled, due to the large number of side channels in these highly braided sections.
 - " In the lower two sections (1 and 2) habitat was greatest at the lowest flows and lowest at the highest flows.
 - " Reduction in the amount of available habitat was seen between August and September following monsoonal flow spikes in late summer. Reduction was proportionately greater in the lower two sections.
- ! Habitat availability cannot be maximized in each section or the entire study area with one flow management strategy.

Objective 3) To determine habitat availability and use for age 0 and juvenile Colorado pikeminnow.

- ! Too few wild age 0 Colorado pikeminnow were collected during the study to evaluate habitat use.
- ! Total habitat availability in numbers and area compared favorably to nursery habitat reaches used by Colorado pikeminnow on the Green and Colorado rivers.
- ! Formation and maintenance of backwater habitat in Section 1, at the inflow area of Lake Powell may be particularly important to the recruitment of Colorado pikeminnow because:
 - " Section 1 had significantly more habitat than the other nursery habitat sections
 - " Most of the wild Colorado pikeminnow collected since 1991 by this or other studies were collected in or below Section 1.

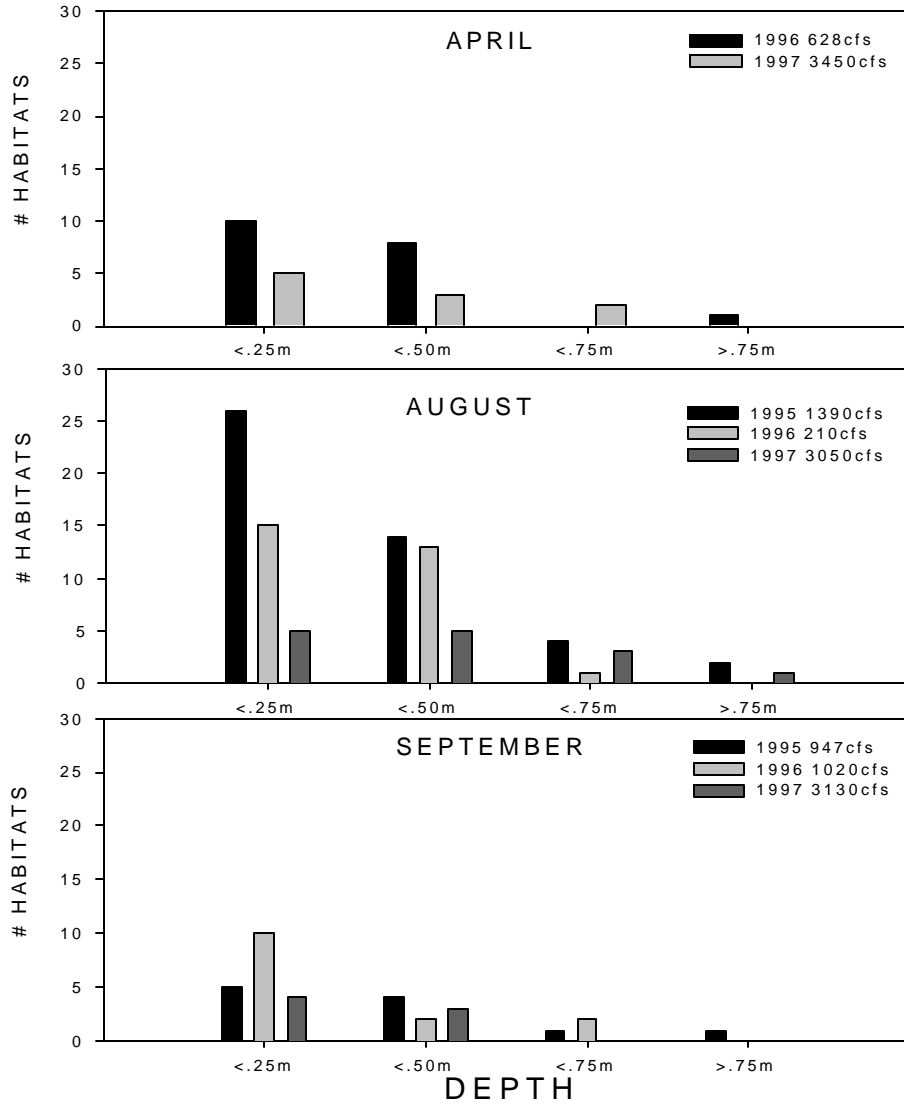


Fig. 3-1. Total number of nursery habitats by depth class for Section 4, during April, August and September Nursery habitat sampling 1995-1997. Data from each year are shown separately.

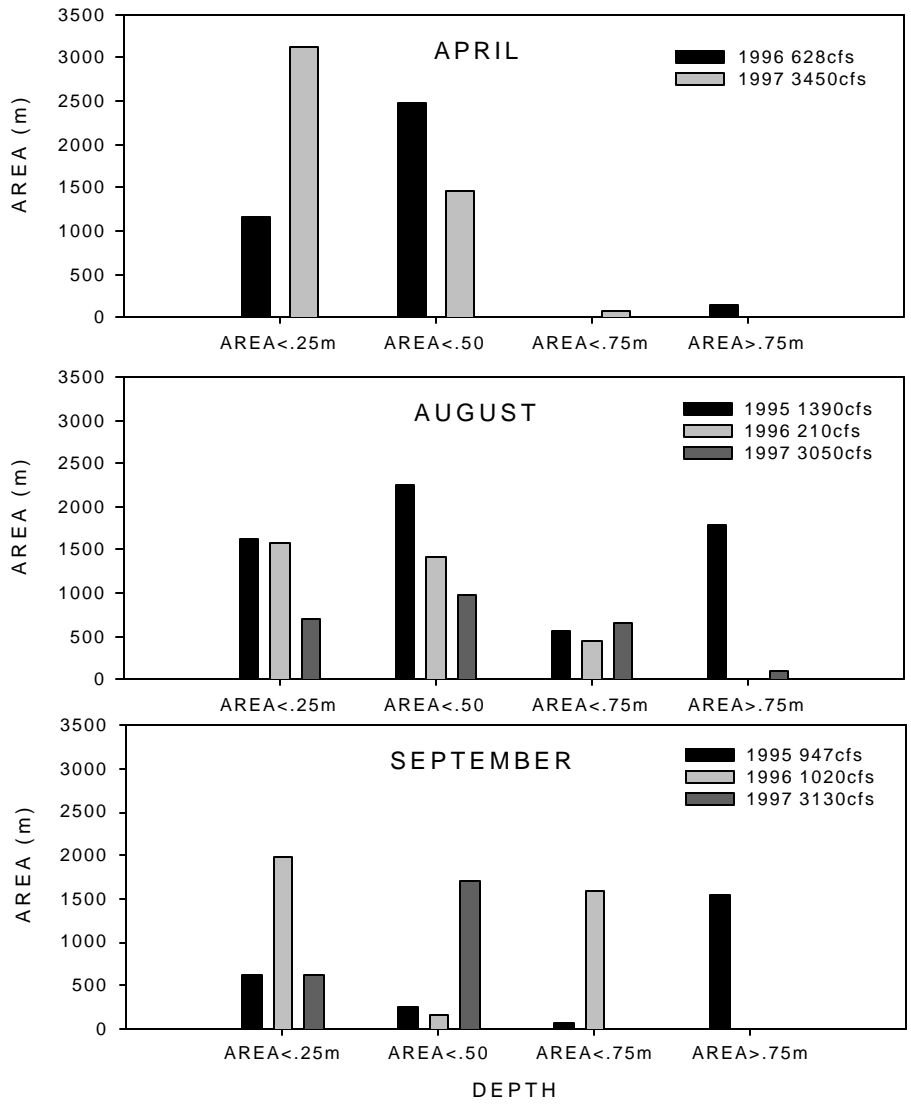


Fig. 3-2. Total area of nursery habitats by depth class for Section 4, during April, August and September Nursery habitat sampling 1995-1997. Data from each year are shown separately.

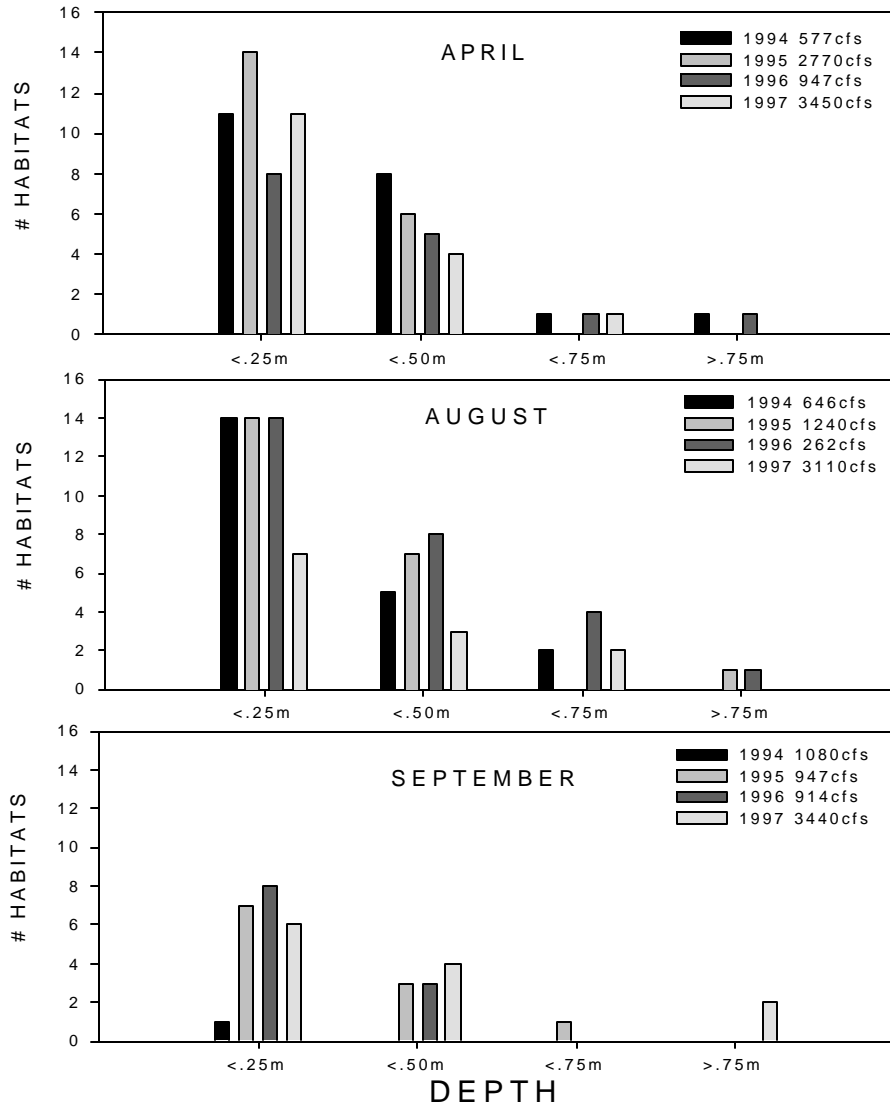


Fig. 3-3. Total number of nursery habitats by depth class for Section 3, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

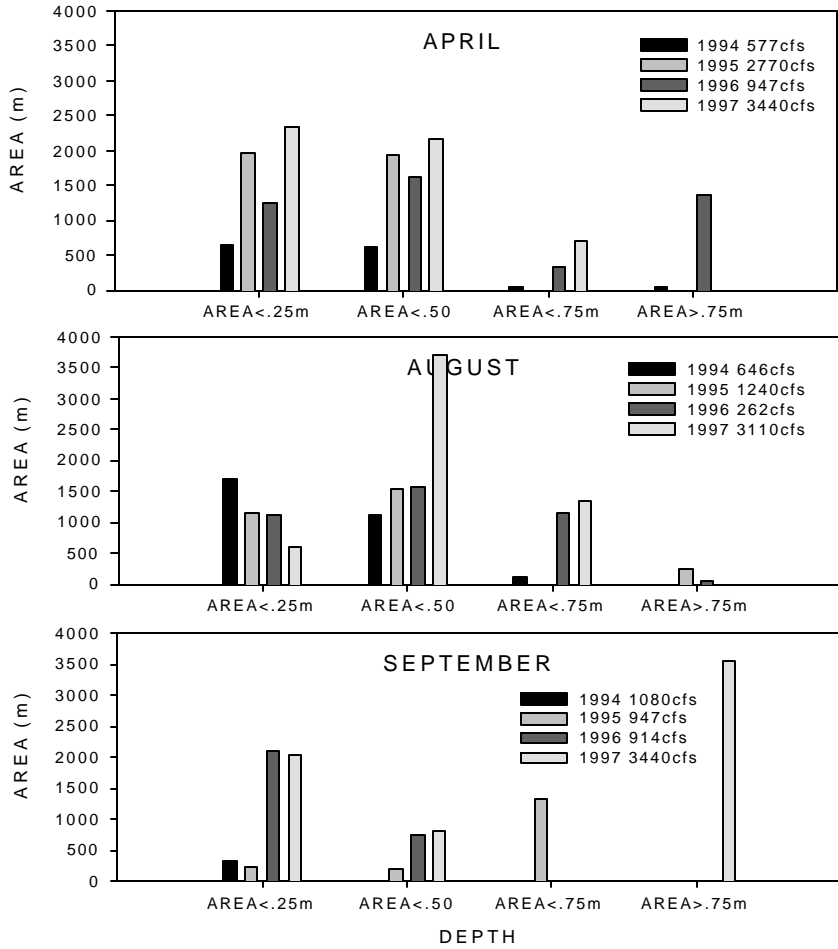


Fig. 3-4. Total area of nursery habitats by depth class for Section 3, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

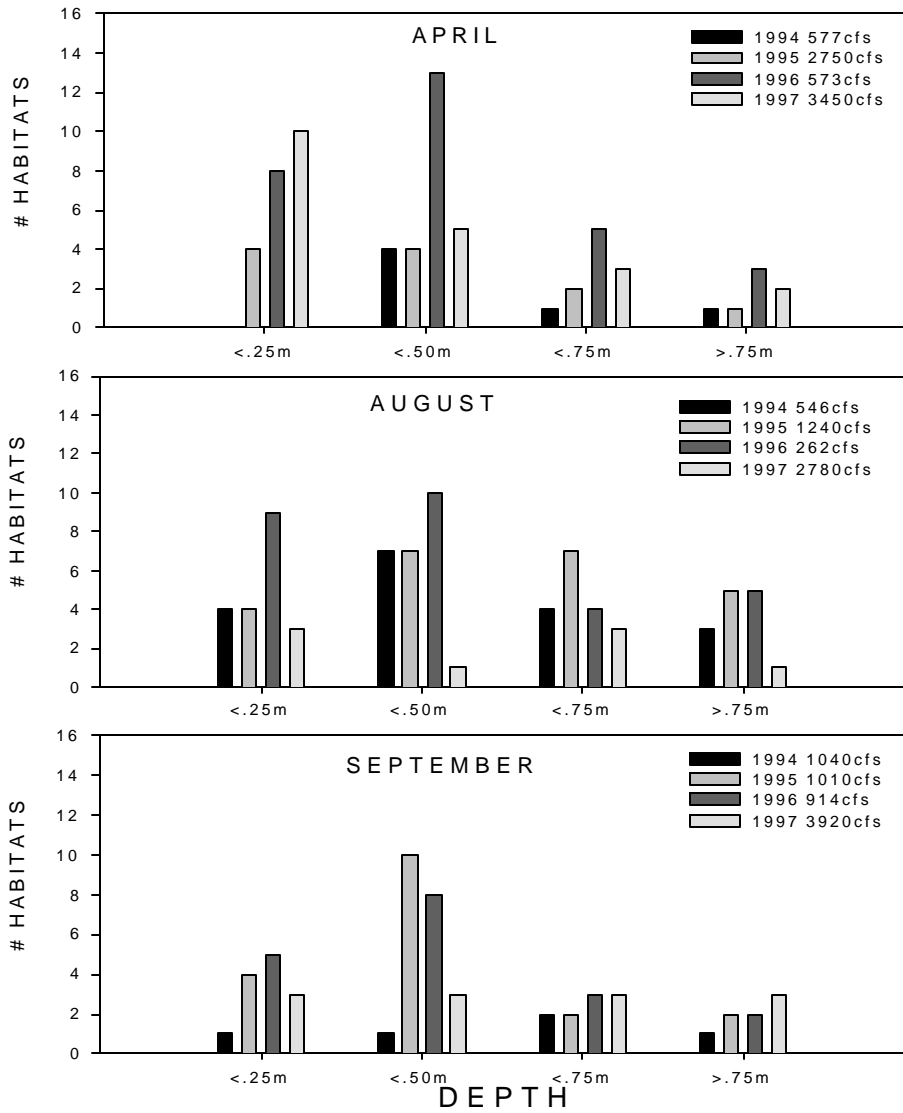


Fig. 3-5. Total number of nursery habitats by depth class for Section 2, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

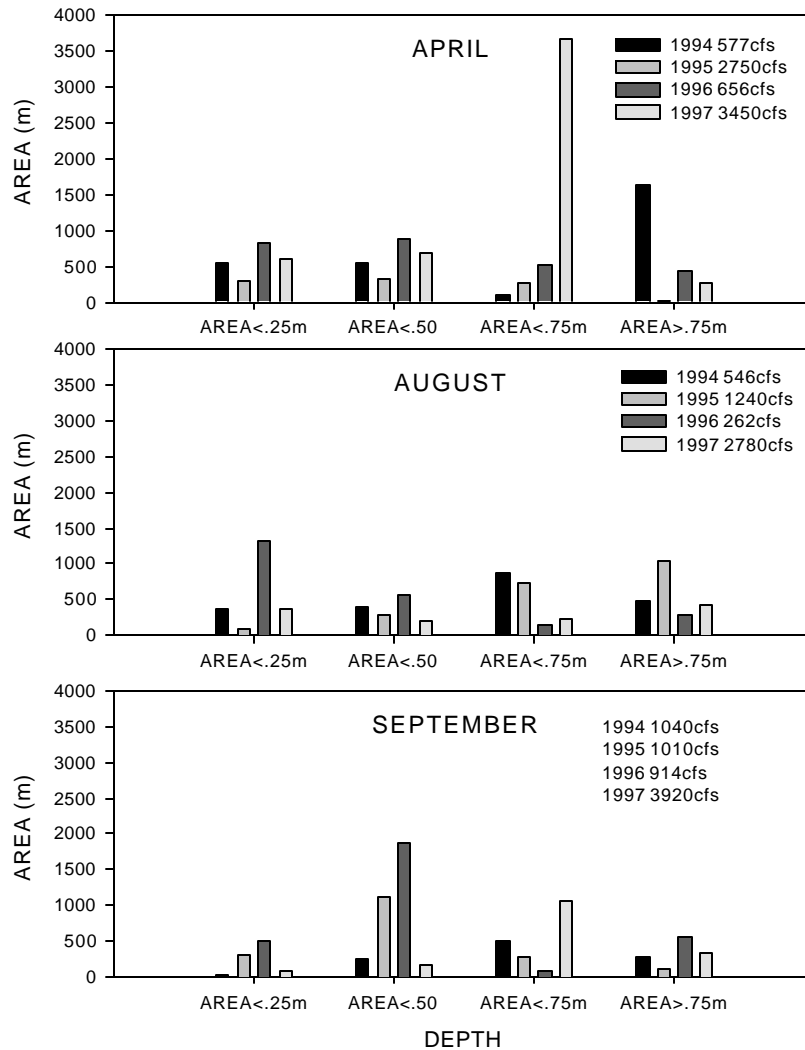


Fig. 3-6. Total area of nursery habitats by depth class for Section 2, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

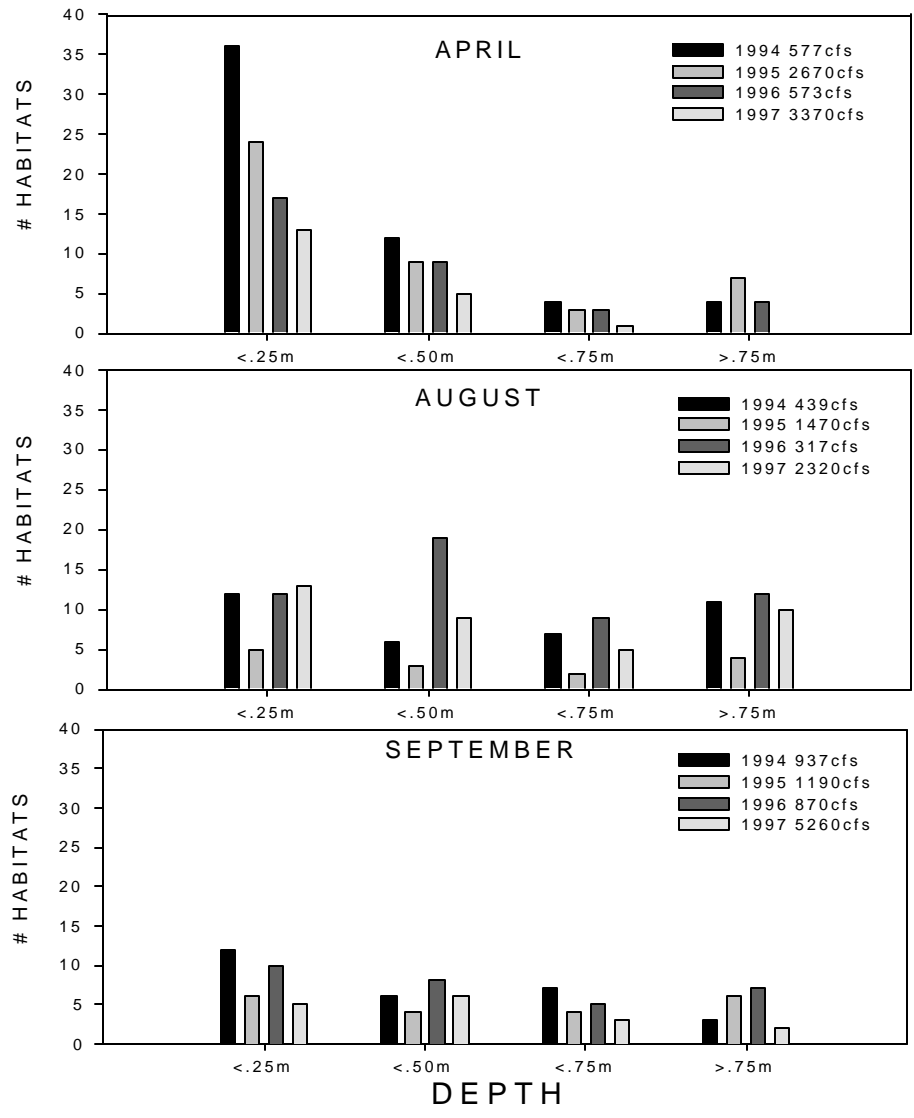


Fig. 3-7. Total number of nursery habitats by depth class for Section 1, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

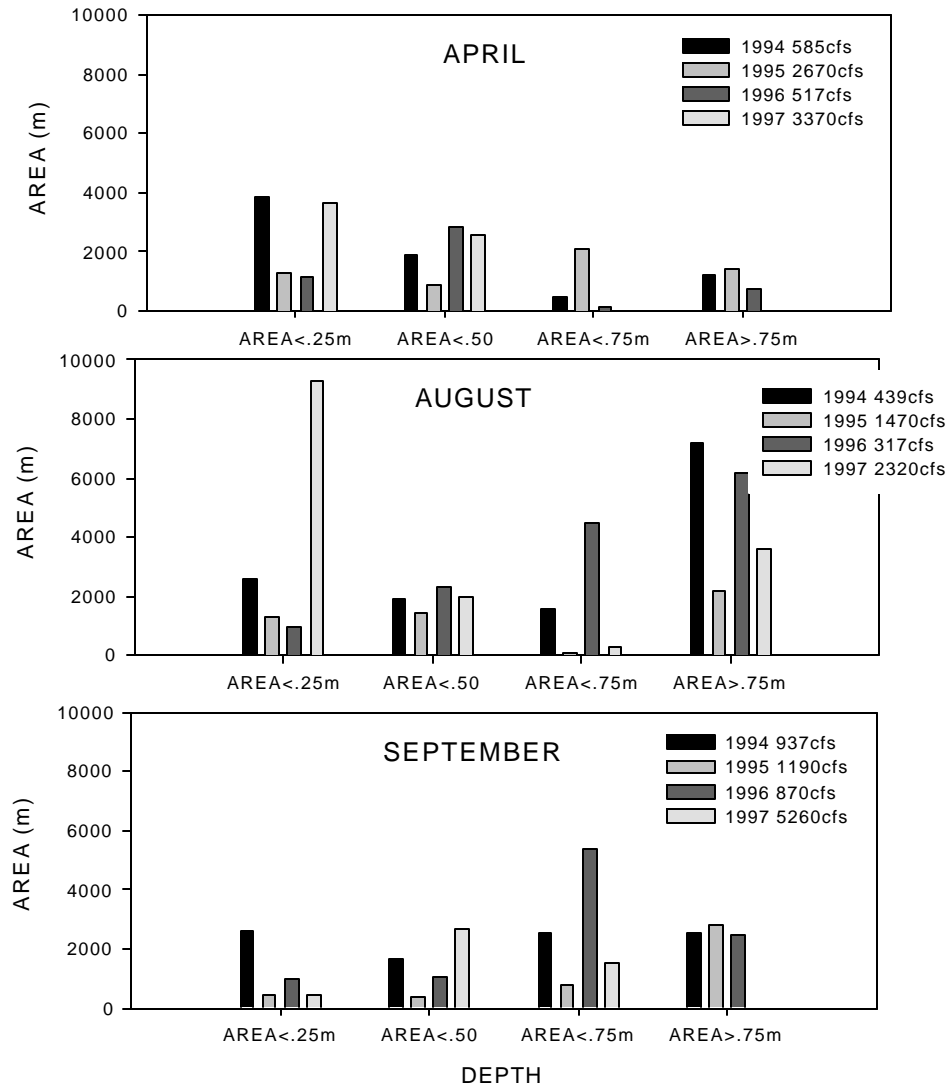


Fig. 3-8. Total area of nursery habitats by depth class for Section 1, during April, August and September Nursery habitat sampling 1994-1997. Data from each year are shown separately.

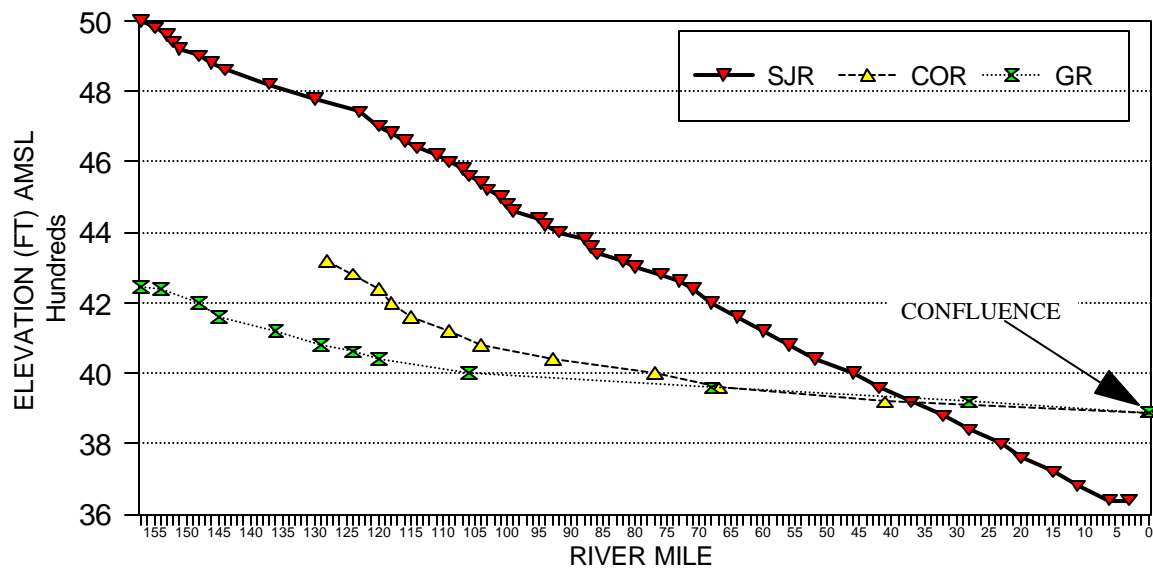


Fig. 3-9. Comparison of gradient San Juan, Colorado and Green rivers.

Appendix A

Results from linear regression models from Section 4 for trips 1-3 and trips pooled. DISCHARGE= flow at sampling. Peak=peak discharge during previous spring. DAY5= number of days flows stayed above 5000 cfs during spring. DAY8=number of days flows stayed above 8000 during spring.

trip	y-variable	x-variable	P	slope	r ²
1	TOT. HABS	DISCHARGE	*	*	*
1	TOT. HABS >.5m	DISCHARGE	*	*	*
1	TOT. AREA	DISCHARGE	*	*	*
1	TOT. AREA >.5m	DISCHARGE	*	*	*
2	TOT. HABS	DISCHARGE	0.62	*	*
2	TOT. HABS >.5m	DISCHARGE	0.65	*	*
2	TOT. AREA	DISCHARGE	0.77	*	*
2	TOT. AREA >.5m	DISCHARGE	0.96	*	*
2	TOT. HABS	PEAK	0.99	*	*
2	TOT. HABS >.5m	PEAK	0.28	*	*
2	TOT. AREA	PEAK	0.85	*	*
2	TOT. AREA >.5m	PEAK	0.59	*	*
2	TOT. HABS	DAY5	0.81	*	*
2	TOT. HABS >.5m	DAY5	0.1	0.07	0.97
2	TOT. AREA	DAY5	0.67	*	*
2	TOT. AREA >.5m	DAY5	0.41	*	*
2	TOT. HABS	DAY8	0.82	*	*
2	TOT. HABS >.5m	DAY8	0.48	*	*
2	TOT. AREA	DAY8	0.94	*	*
2	TOT. AREA >.5m	DAY8	0.79	*	*
3	TOT. HABS	DISCHARGE	0.29	*	*
3	TOT. HABS >.5m	DISCHARGE	0.02	-0.001	0.99
3	TOT. AREA	DISCHARGE	0.61	*	*
3	TOT. AREA >.5m	DISCHARGE	0.01	-0.74	0.999
3	TOT. HABS	PEAK	0.36	*	*
3	TOT. HABS >.5m	PEAK	0.64	*	*
3	TOT. AREA	PEAK	0.05	-0.16	0.99
3	TOT. AREA >.5m	PEAK	0.65	*	*
3	TOT. HABS	DAY5	0.54	*	*
3	TOT. HABS >.5m	DAY5	0.82	*	*
3	TOT. AREA	DAY5	0.22	*	*
3	TOT. AREA >.5m	DAY5	0.83	*	*
3	TOT. HABS	DAY8	0.16	*	*
3	TOT. HABS >.5m	DAY8	0.44	*	*
3	TOT. AREA	DAY8	0.15	*	*
3	TOT. AREA >.5m	DAY8	0.45	*	*
POOLED	TOT. HABS	DISCHARGE	0.23	*	*
POOLED	TOT. HABS >.5m	DISCHARGE	0.94	*	*
POOLED	TOT. AREA	DISCHARGE	0.27	*	*
POOLED	TOT. AREA >.5m	DISCHARGE	0.74	*	*
POOLED	TOT. HABS	PEAK	0.86	*	*
POOLED	TOT. HABS >.5m	PEAK	0.42	*	*
POOLED	TOT. AREA	PEAK	0.86	*	*
POOLED	TOT. AREA >.5m	PEAK	0.89	*	*
POOLED	TOT. HABS	DAY5	0.9	*	*
POOLED	TOT. HABS >.5m	DAY5	0.36	*	*
POOLED	TOT. AREA	DAY5	0.88	*	*
POOLED	TOT. AREA >.5m	DAY5	0.57	*	*
POOLED	TOT. HABS	DAY8	0.62	*	*
POOLED	TOT. HABS >.5m	DAY8	0.55	*	*
POOLED	TOT. AREA	DAY8	0.6	*	*
POOLED	TOT. AREA >.5m	DAY8	0.72	*	*

Appendix B

Results from linear regression models from Section 3 for trips 1-3 and trips pooled. DISCHARGE= flow at sampling. Peak=peak discharge during previous spring. DAY5= number of days flows stayed above 5000 cfs during spring. DAY8=number of days flows stayed above 8000 during spring.

trip	y-variable	x-variable	P	slope	R ²
1	TOT. HABS	DISCHARGE	0.87	*	*
1	TOT. HABS >.5m	DISCHARGE	0.59	*	*
1	TOT. AREA	DISCHARGE	0.3	*	*
1	TOT. AREA >.5m	DISCHARGE	0.68	*	*
2	TOT. HABS	DISCHARGE	0.06	-0.001	0.88
2	TOT. HABS >.5m	DISCHARGE	0.54	*	*
2	TOT. AREA	DISCHARGE	0.2	*	*
2	TOT. AREA >.5m	DISCHARGE	0.57	*	*
2	TOT. HABS	PEAK	0.22	*	*
2	TOT. HABS >.5m	PEAK	0.07	-0.001	0.85
2	TOT. AREA	PEAK	0.79	*	*
2	TOT. AREA >.5m	PEAK	0.75	*	*
2	TOT. HABS	DAY5	0.43	*	*
2	TOT. HABS >.5m	DAY5	0.01	-0.06	0.98
2	TOT. AREA	DAY5	0.87	*	*
2	TOT. AREA >.5m	DAY5	0.45	*	*
2	TOT. HABS	DAY8	0.18	*	*
2	TOT. HABS >.5m	DAY8	0.4	*	*
2	TOT. AREA	DAY8	0.39	*	*
2	TOT. AREA >.5m	DAY8	0.73	*	*
3	TOT. HABS	DISCHARGE	0.58	*	*
3	TOT. HABS >.5m	DISCHARGE	0.12	*	*
3	TOT. AREA	DISCHARGE	0.08	1.89	0.83
3	TOT. AREA >.5m	DISCHARGE	0.07	1.23	0.86
3	TOT. HABS	PEAK	0.85	*	*
3	TOT. HABS >.5m	PEAK	0.69	*	*
3	TOT. AREA	PEAK	0.2	*	*
3	TOT. AREA >.5m	PEAK	0.25	*	*
3	TOT. HABS	DAY5	0.94	*	*
3	TOT. HABS >.5m	DAY5	0.43	*	*
3	TOT. AREA	DAY5	0.98	*	*
3	TOT. AREA >.5m	DAY5	0.5	*	*
3	TOT. HABS	DAY8	0.41	*	*
3	TOT. HABS >.5m	DAY8	0.01	0.07	0.98
3	TOT. AREA	DAY8	0.26	*	*
3	TOT. AREA >.5m	DAY8	0.03	113.03	0.92
POOLED	TOT. HABS	DISCHARGE	0.53	*	*
POOLED	TOT. HABS >.5m	DISCHARGE	0.64	*	*
POOLED	TOT. AREA	DISCHARGE	0.0065	1.148	0.54
POOLED	TOT. AREA >.5m	DISCHARGE	0.05	0.532	0.33
POOLED	TOT. HABS	PEAK	0.58	*	*
POOLED	TOT. HABS >.5m	PEAK	0.56	*	*
POOLED	TOT. AREA	PEAK	0.55	*	*
POOLED	TOT. AREA >.5m	PEAK	0.3	*	*
POOLED	TOT. HABS	DAY5	0.6	*	*
POOLED	TOT. HABS >.5m	DAY5	0.62	*	*
POOLED	TOT. AREA	DAY5	0.91	*	*
POOLED	TOT. AREA >.5m	DAY5	0.66	*	*
POOLED	TOT. HABS	DAY8	0.78	*	*
POOLED	TOT. HABS >.5m	DAY8	0.82	*	*
POOLED	TOT. AREA	DAY8	0.09	94.5	0.39
POOLED	TOT. AREA >.5m	DAY8	0.06	62	0.47

Appendix C

Results from linear regression models from Section 2 for trips 1-3 and trips pooled. DISCHARGE= flow at sampling. Peak=peak discharge during previous spring. DAY5= number of days flows stayed above 5000 cfs during spring. DAY8=number of days flows stayed above 8000 during spring.

trip	y-variable	x-variable	P.	slope	R ²
1	TOT. HABS	DISCHARGE	0.95	*	*
1	TOT. HABS >.5m	DISCHARGE	0.84	*	*
1	TOT. AREA	DISCHARGE	0.7	*	*
1	TOT. AREA >.5m	DISCHARGE	0.54	*	*
2	TOT. HABS	DISCHARGE	0.15	*	*
2	TOT. HABS >.5m	DISCHARGE	0.47	*	*
2	TOT. AREA	DISCHARGE	0.05	-0.41	0.887
2	TOT. AREA >.5m	DISCHARGE	0.94	*	*
2	TOT. HABS	PEAK	0.299	*	*
2	TOT. HABS >.5m	PEAK	0.84	*	*
2	TOT. AREA	PEAK	0.35	*	*
2	TOT. AREA >.5m	PEAK	0.47	*	*
2	TOT. HABS	DAY5	0.49	*	*
2	TOT. HABS >.5m	DAY5	0.91	*	*
2	TOT. AREA	DAY5	0.62	*	*
2	TOT. AREA >.5m	DAY5	0.22	*	*
2	TOT. HABS	DAY8	0.29	*	*
2	TOT. HABS >.5m	DAY8	0.71	*	*
2	TOT. AREA	DAY8	0.17	*	*
2	TOT. AREA >.5m	DAY8	0.92	*	*
3	TOT. HABS	DISCHARGE	0.82	*	*
3	TOT. HABS >.5m	DISCHARGE	0.24	*	*
3	TOT. AREA	DISCHARGE	0.77	*	*
3	TOT. AREA >.5m	DISCHARGE	0.066	*	*
3	TOT. HABS	PEAK	0.84	*	*
3	TOT. HABS >.5m	PEAK	0.9	*	*
3	TOT. AREA	PEAK	0.33	*	*
3	TOT. AREA >.5m	PEAK	0.7	*	*
3	TOT. HABS	DAY5	0.8	*	*
3	TOT. HABS >.5m	DAY5	0.76	*	*
3	TOT. AREA	DAY5	0.26	*	*
3	TOT. AREA >.5m	DAY5	0.98	*	*
3	TOT. HABS	DAY8	0.82	*	*
3	TOT. HABS >.5m	DAY8	0.41	*	*
3	TOT. AREA	DAY8	0.74	*	*
3	TOT. AREA >.5m	DAY8	0.48	*	*
POOLED	TOT. HABS	DISCHARGE	0.3	*	*
POOLED	TOT. HABS >.5m	DISCHARGE	0.51	*	*
POOLED	TOT. AREA	DISCHARGE	0.871	*	*
POOLED	TOT. AREA >.5m	DISCHARGE	0.22	*	*
POOLED	TOT. HABS	PEAK	0.29	*	*
POOLED	TOT. HABS >.5m	PEAK	0.79	*	*
POOLED	TOT. AREA	PEAK	0.09	-0.11	0.4
POOLED	TOT. AREA >.5m	PEAK	0.31	*	*
POOLED	TOT. HABS	DAY5	0.41	*	*
POOLED	TOT. HABS >.5m	DAY5	0.79	*	*
POOLED	TOT. AREA	DAY5	0.12	*	*
POOLED	TOT. AREA >.5m	DAY5	0.27	*	*
POOLED	TOT. HABS	DAY8	0.46	*	*
POOLED	TOT. HABS >.5m	DAY8	0.48	*	*
POOLED	TOT. AREA	DAY8	0.26	*	*
POOLED	TOT. AREA >.5m	DAY8	0.56	*	*

Appendix D

Results from linear regression models from Section 1 for trips 1-3 and trips pooled. DISCHARGE= flow at sampling. Peak=peak discharge during previous spring. DAY5= number of days flows stayed above 5000 cfs during spring. DAY8=number of days flows stayed above 8000 during spring.

trip	y-variable	x-variable	P.	slope	R ²
1	TOT. HABS	DISCHARGE	0.04	*	*
1	TOT. HABS >.5m	DISCHARGE	0.52	*	*
1	TOT. AREA	DISCHARGE	0.95	*	*
1	TOT. AREA >.5m	DISCHARGE	0.99	*	*
2	TOT. HABS	DISCHARGE	0.56	*	*
2	TOT. HABS >.5m	DISCHARGE	0.45	*	*
2	TOT. AREA	DISCHARGE	0.91	*	*
2	TOT. AREA >.5m	DISCHARGE	0.15	*	*
2	TOT. HABS	PEAK	0.21	*	*
2	TOT. HABS >.5m	PEAK	0.22	*	*
2	TOT. AREA	PEAK	0.61	*	*
2	TOT. AREA >.5m	PEAK	0.07	-0.95	0.86
2	TOT. HABS	DAY5	0.09	-0.05	0.83
2	TOT. HABS >.5m	DAY5	0.14	*	*
2	TOT. AREA	DAY5	0.41	*	*
2	TOT. AREA >.5m	DAY5	0.12	*	*
2	TOT. HABS	DAY8	0.5	*	*
2	TOT. HABS >.5m	DAY8	0.39	*	*
2	TOT. AREA	DAY8	0.83	*	*
2	TOT. AREA >.5m	DAY8	0.11	*	*
3	TOT. HABS	DISCHARGE	0.2	*	*
3	TOT. HABS >.5m	DISCHARGE	0.04	-0.001	0.92
3	TOT. AREA	DISCHARGE	0.46	*	*
3	TOT. AREA >.5m	DISCHARGE	0.25	*	*
3	TOT. HABS	PEAK	0.09	-0.001	0.81
3	TOT. HABS >.5m	PEAK	0.25	*	*
3	TOT. AREA	PEAK	0.1	-0.064	0.8
3	TOT. AREA >.5m	PEAK	0.03	-0.61	0.94
3	TOT. HABS	DAY5	0.26	*	*
3	TOT. HABS >.5m	DAY5	0.49	*	*
3	TOT. AREA	DAY5	0.18	*	*
3	TOT. AREA >.5m	DAY5	0.14	*	*
3	TOT. HABS	DAY8	0.01	-0.46	0.98
3	TOT. HABS >.5m	DAY8	0.14	*	*
3	TOT. AREA	DAY8	0.08	-181.48	0.84
3	TOT. AREA >.5m	DAY8	0.1	-155.64	0.81
POOLED	TOT. HABS	DISCHARGE	0.1	-0.001	0.24
POOLED	TOT. HABS >.5m	DISCHARGE	0.07	-0.002	0.29
POOLED	TOT. AREA	DISCHARGE	0.29	*	*
POOLED	TOT. AREA >.5m	DISCHARGE	0.11	*	*
POOLED	TOT. HABS	PEAK	0.07	-0.002	0.44
POOLED	TOT. HABS >.5m	PEAK	0.03	-0.001	0.38
POOLED	TOT. AREA	PEAK	0.25	*	*
POOLED	TOT. AREA >.5m	PEAK	0.004	-0.78	0.77
POOLED	TOT. HABS	DAY5	0.05	-0.35	0.49
POOLED	TOT. HABS >.5m	DAY5	0.05	-0.15	0.32
POOLED	TOT. AREA	DAY5	0.17	*	*
POOLED	TOT. AREA >.5m	DAY5	0.01	-103	0.65
POOLED	TOT. HABS	DAY8	0.18	*	*
POOLED	TOT. HABS >.5m	DAY8	0.07	-0.02	0.29
POOLED	TOT. AREA	DAY8	0.39	*	*
POOLED	TOT. AREA >.5m	DAY8	0.01	-201.31	0.68

CHAPTER FOUR

EVALUATION OF REINTRODUCTION OF

YOUNG OF YEAR COLORADO PIKEMINNOW

IN THE SAN JUAN RIVER 1996-1998

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INTRODUCTION

Since 1991, Colorado pikeminnow reproduction has been documented in five of the seven years of the research project under a variety of flow regimes. However, recruitment into the adult population is very limited. Since 1991, only 41 age 0 and larval Colorado pikeminnow have been captured during backwater and drift sampling (Holden and Masslich 1997). Of these collected, the vast majority (21 age 0 and 13 larvae) were collected in the low gradient nursery habitat at the inflow area of Lake Powell. Sediment deposits have created an area of suitable nursery habitat where little may have existed historically, based on the high gradient in this area. Over-winter survival of Colorado pikeminnow in the San Juan River has only been documented twice; once with the capture of two age-1 Colorado pikeminnow from a single backwater in April 1994 (Archer et al. 1995). During the summer of 1996, two juvenile Colorado pikeminnow were captured by electrofishing at the inflow of Lake Powell (Ryden 2000).

The low levels of recruitment experienced by Colorado pikeminnow in the San Juan River have initiated further study into the mechanisms limiting age 0 success. Three hypotheses have emerged: 1) recruitment is limited by insufficient numbers of spawning adults and other factors limiting spawning, 2) the spatial and temporal dynamics of backwater (nursery) habitats prevent the retention of Colorado pikeminnow within the system and 3) interspecific competition between Colorado pikeminnow and non-native species for space and limited food resources limits survival of age 0 pikeminnow.

This chapter is concerned with the second of these hypotheses. Because natural reproduction is so low, habitat limitations and use by Colorado pikeminnow could not be properly addressed. Therefore the decision was made to stock young-of-year Colorado pikeminnow in the San Juan River in order to evaluate A) survival, growth, and retention, and B) habitat availability and use, corresponding to the overall study Objectives: 5) To determine the quality and quantity of low-velocity habitats in the San Juan River for use by Colorado pikeminnow through experimental stocking of age 0 fish, 6) To determine the effects of diversion canals on age 0 Colorado pikeminnow drift/movement (e.g., stranding, etc.), and 7) To determine overwinter survival and growth of experimentally stocked age 0 Colorado pikeminnow. The original study plan called for Colorado pikeminnow to be stocked in 1996 and 1997, and was later expanded to include stocking in 1998 as well.

METHODS

Study Area

The backwater fish community was sampled from RM 158.0 to 3.0. In addition, the more intensively sampled nursery habitat sections, referred to in Chapter 1, were also used for this portion of the study. Beginning with the most upstream section, and progressing downstream, they were designated as Section 4 (RM 131.0-126.0), Section 3 (RM 89.0-84.0), Section 2 (RM 25.2-20.2) and Section 1 (RM 13.0-8.0). Each nursery habitat section is contained within a larger Geomorphic Reach, as defined earlier. Sections 1-3 correspond to Reaches 1-3, while Section 4 straddles the geomorphic Reaches 4 and 5. Each section differs in basic geomorphology which affects habitat

formation and availability, as described in Chapter 1. However, sections 1 and 2 are relatively similar, as are sections 3 and 4. For most of the analysis, the study area was divided into the upper San Juan, from RM 158 to 53 which includes nursery habitat sections 3 and 4, and the Lower San Juan which includes nursery habitat sections 1 and 2.

The Upper San Juan flows through a broad flood plain with frequent braided channels (Bliesner and Lamarra 1999). Backwaters in the upper San Juan are typically created at the lower ends of secondary channels (Archer et al. 1995) and substrates are primarily dominated by cobble and cobble/silt. The persistence of low-velocity habitat in this section of river is greater than in the lower canyon bound reaches. While classic backwater habitats often have some slight flow at higher water levels, these low-velocity habitats often persist through spikes in flow that could mitigate the displacement of age 0 Colorado pikeminnow by providing increased refuge from higher flows. The high number of small side channels provide some low-velocity habitat at most flows. Downstream the flood plain becomes increasingly restricted by canyon walls. The lower San Juan River, below Mexican Hat, Utah (RM 53), is generally confined to a single channel within steep sided canyons (Buntjer et al. 1993). Below Grand Gulch, Utah, (RM 13.4) sediment deposits associated with Lake Powell have greatly reduced the gradient to resemble that found in the lower Green and Colorado rivers (Archer et al. 1996). The gradient through out the upper San Juan River (9 ft/mile) is much higher than comparable nursery habitat sections of the Green and Colorado rivers (1-3 ft/mile)(Fig. 4-1).

The lower San Juan is the only area where classic nursery habitat for Colorado pikeminnow currently exists in the San Juan River system. The majority of the backwaters are associated with the numerous sandbars within this section of river. The substrate of backwater habitats in this reach is predominantly sand and sand/silt. During early summer this short section of river can have very high densities of low-velocity habitats. Low-velocity habitat density in this section is greater in many years than in the Lower Green River where age 0 Colorado pikeminnow are relatively abundant (Chapter 3). The length of this section is directly dependent on the level of Lake Powell. At full pool (3700 ft. Above Mean Sea Level), Lake Powell historically filled to Grand Gulch (RM 13). During the summer of 1996, Lake Powell was at 3695 ft (AMSL), near RM 6 (Archer pers. observation.). Backwater persistence is directly related to flow. Small increases in discharge in this canyon-bound section can top many of the sand bars and eliminate many habitats, some permanently through deposition, while others return as flood waters recede.

The Upper and Lower San Juan differ considerably in species richness and total fish within nursery habitats. Catch rates in the upper San Juan are typically the highest for all three common age 0 native fish species (Buntjer et al. 1994). While non-native red shiner (*Cyprinella lutrensis*) and fathead minnow (*Pimephales promelas*) are present, their numbers are typically lower than in the lower San Juan. Since 1987, only three wild age 0 Colorado pikeminnow have been captured in this section of river. In August 1994, an age 0 (14 mm) Colorado pikeminnow was captured at RM 126.2 in a backwater created by the mouth of the Mancos River (Archer et al. 1995). In October 1987, two age 0 (30 mm, 38 mm) Colorado pikeminnow were captured at RM 125.6 and RM 122.3 (Platania 1990). Both specimens were collected from secondary channel backwaters. This area (Reach 5) also contains the only suspected spawning bar for Colorado pikeminnow in the San Juan River, approximately 131 RM above Lake Powell (Ryden 1996).

The lower San Juan is dominated by non-native species. However, the majority of age 0 pikeminnow captured in the San Juan have been captured in this area. The non-native fish community in this reach of river is very diverse and includes all of the fauna of the upper reaches, plus some species which have migrated up from Lake Powell. These include Threadfin shad (*Dorosoma petenense*), Green sunfish (*Lepomis cyanellus*) and Striped bass (*Morone saxatilis*) (Archer et al. 1996). Non-native red shiners are by far the most abundant species. Actual densities of red shiners within the Lower San Juan vary considerably by habitat, but overall fish density is typically much higher than the Upper San Juan (Archer et al. 1995).

The low-gradient, sand dominated section of the San Juan River has been shown to contain more wild age 0 pikeminnow than the higher gradient upstream reaches. The distance from the spawning site and the reduction in gradient likely explain most of this pattern. The high density of low-velocity habitats may also increase retention of age 0 Colorado pikeminnow, despite the temporary loss of habitat during flood events. Since 1991, 21 of the 22 age 0 Colorado pikeminnow captured during UDWR and Bureau of Reclamation (BOR) early life stage studies have been collected at the inflow of Lake Powell. The only age 1 Colorado pikeminnow collected from the San Juan River were also collected from this area. Densities of other age 0 native species are very low in this section.

Stocking

Approximately 100,000 Colorado pikeminnow were divided into two groups and stocked at Shiprock, NM (RM 148) and at Mexican Hat, UT (RM 52) in 1996 and 1997. In 1998, fewer fish were available, with 10,571 pikeminnow stocked at Shiprock. Each year, prior to stocking, the fish were treated for the prevention of Asian tapeworm (*Protocephalus* spp.). Each year, the fish were also batch marked with a tetracycline hydrochloride bath, leaving a fluorescent mark on the otoliths. In 1996, the fish were also spray-marked in two color batches to distinguish fish stocked at the upper and lower sites. All fish were provided by the Dexter National Fish Hatchery (New Mexico).

Sampling

In the San Juan River, nursery habitats and fish were sampled at two levels of intensity. From RM 158 to 3, two habitats per each 5 miles were sampled. In addition, every potential nursery habitat was sampled in each of the four nursery habitat sections. Sampling procedures were similar to those used for nursery habitat studies conducted on the Green and Colorado rivers (Trammell and Chart 1999, Trammell et al. 1999), and are described in the Sampling Protocols section. Fish were collected by seining with 1 to 4 seine hauls per habitat, depending on the size of the habitat. Length, width and depth of each area seined was recorded. Fish density was computed as #fish/100m². Additionally, some electrofishing was conducted in 1996 during the first two trips, using a backpack Coffelt shock unit.

The percent change in catch rate for the study area from one trip to the next is presented as a 'survival rate' for ease of discussion, although this is not a true survival rate as the population of fish was not estimated for each trip. It is intended to represent the relative catch rate from trip to trip. Colorado pikeminnow were measured to the nearest 1 mm to evaluate growth.

Dispersal and displacement patterns after stocking were evaluated graphically, and related to the monsoonal floods. Backwater habitats were classified to a type based on formation process. These types are listed in Table 1 of the Sampling Protocols section. Colorado pikeminnow habitat selection for the upper and lower reaches and all trips was evaluated using a multinomial test for presence/absence in each habitat type. Little overlap by fish stocked at Shiprock or Mexican Hat was observed between the upper and lower reaches, therefore for most of the analyses, the study area was divided into the Upper San Juan, from RM 158 to 53 which includes nursery habitat sections 4 and 3, and the Lower San Juan which includes nursery habitat sections 1 and 2.

RESULTS

Stocking summary

In 1996, the plan called for stocking the Colorado pikeminnow in early summer at 25 mm. However due to some delays involving disease and parasite testing, the fish were not stocked until November 4, at an average of 55 mm, which is much larger than wild spawned pikeminnow would be at that time. Wild age 0 pikeminnow are about 35-40 mm in the fall in the Green and Colorado rivers (McAda et al. 1998). The first sampling trip was conducted two weeks later, and produced a total of 520 pikeminnow, from a combination of seining and electrofishing. In the Upper San Juan, the majority (110 of 114) were collected by electrofishing in low-velocity side channels, while in the Lower San Juan, the majority were collected by seining backwater habitats (405 of 406). These 520 fish represent 0.5 % of the number stocked. A subsequent "survival rate" was calculated for each trip based on the percent caught of the initial catch; i.e. $389/520 = 74.8\%$ for the second trip.

Trip 2 was conducted three weeks later, on December 9-13. In both reaches, the majority of pikeminnow were collected by seining. In the Upper San Juan, only 2 of 124 were electrofished, and in the Lower San Juan, 11 of 265 were electrofished. Thereafter, seining was the only means used to collect age 0 pikeminnow. The 1996 year class was collected on 7 of the first 8 sampling trips, last collected in October 1997. However, age 1 Colorado pikeminnow continued to be collected by the U.S. Fish and Wildlife service using boat-mounted electrofishing gear (Dale Ryden, pers. comm.). Riverwide collections of the 1996 year class are detailed in Tables 4-1 and 4-2 by trip.

On the second and third 1996 sampling trips fish were examined for the presence of the fluorescent spray mark. It was observed that the marks could be detected as well with or without a UV-light. Fish stocked at the upper site received a red mark, while fish stocked at Mexican Hat received a blue mark. On trip 2 in the Upper San Juan, 21 out of 124 (16.9%) had a red mark. In the Lower San Juan 35 (13.2%) out of 265 had a blue mark and 8 (3.0%) had a red mark. On trip 3, only fish in the Lower San Juan were found to have a mark: 21 of 114 had a blue mark (18.4%), and one had a red mark (0.9%). The occurrence of few red-marked fish in the Lower San Juan indicates a low incidence of downstream displacement from the upper stocking site. Due to the low success of this batch mark, no further attempts were made to detect marked fish.

In 1997, two groups of Colorado pikeminnow were again stocked; 62,578 at Shiprock, and 54,300 at Mexican Hat, for a total of 116,878. The fish were 48 mm in length on average, with fish stocked at Shiprock about 5 mm smaller than those at Mexican Hat. As in 1996, the sizes were larger

than what wild-spawned pikeminnow would be at that time. Collections of the 1997 year class of Colorado pikeminnow are detailed in Tables 2 and 3. In addition, some stocked fish were collected by other researchers, including some above the upper stock site. On Sept. 30, 1997 their seining produced 30 stocked pikeminnow in the 8 miles above the stocking site (Dave Propst, NMGF, pers. comm.). Downstream of the stock site, they also collected 173 pikeminnow from several habitats ranging from riffles to backwaters during the first week of October, 1997, including 130 pikeminnow from one backwater.

Immediately following stocking, drift nets were set in a diversion canal approximately 9 miles below the stock site to evaluate the loss of pikeminnow out the canal. The Cudei diversion blocks a large portion of the river, diverting the flow into a short canal. Most of the flow returns immediately to the river, but about 5 cfs is further diverted into an irrigation canal. This canal was sampled continuously for 65 hours, in which 38 Colorado pikeminnow were collected, at approximately 1.5 fish/hour for the first 48 hours. Additional sampling one week later produced no pikeminnow in 38 hours of sampling although other fish were collected, so sampling was discontinued.

In 1998, fewer fish were available to be stocked. A total of 10,571 Colorado pikeminnow were stocked at Shiprock, NM, and none at Mexican Hat. The fish were stocked at an average length of 24 mm, on July 2nd. This size and timing was much more similar to wild-spawned pikeminnow, although still a little larger than would naturally occur. Drift nets set in the Cudei diversion canal three days after stocking produced no fish in 48 hours of sampling.

Growth

The 1996 year class was stocked at the end of the growing season, when river temperatures had fallen below 13 °C and therefore did not exhibit any growth through the spring of 1997, until the following summer. Between the second spring trip (5/1/97) and the first summer trip (8/12/97), after river temperatures had risen again, the pikeminnow had grown an average of 73 mm (Table 4-1). The pikeminnow continued to exhibit excellent growth, as shown in Fig. 4-2 and Tables 1 and 2, as did the 1997 year class. The average total length of the stocked Colorado pikeminnow at age 2 (179 and 167 mm, respectively to 1996 and 1997) was comparable with wild age-2 pikeminnow collected in the Colorado River at 180 mm (Osmundson et al. 1996). Lengths of age 1 and 2 were quite variable (Fig. 4-3), but distinct differences were obvious between the year classes.

The 1997 year class was stocked at 45 mm, and grew 10 mm by the end of that growing season (Table 4-3). Again, growth ceased until the first summer trip, which was conducted earlier than in 1996. When similar trips dates were compared (8/12/97 and 8/18/98) the two year classes were almost identical in size. Again, USFWS electrofishing collections tracked the continued growth of this year class (Fig. 4-2 and 3, Table 4-2).

The 1998 year class was stocked much earlier in the growing season, and smaller, at 24 mm. These fish exhibited accelerated growth over that of the previous two year classes, reaching an average length of 75 mm by the fall trip, and 86 mm by the final 1998 trip, 30 mm larger than the 1996 or 1997 year classes (Fig. 4-2, Table 4-3). This large size may explain the poor catch rates experienced in the last two trips. The pikeminnow may have reached the size at which they vacate backwater habitats, regardless of the season.

Survival

As expected, catch and catch rates declined with each trip, for each year class. However, in each year Colorado pikeminnow were collected on each trip until they outgrew the collection gear, and shifted into different habitats. Similar efforts, in area seined, were expended on each trip. Catch rates (#/100m²) followed a pattern similar to total catch (Fig. 4-4). The change in catch rate from December to late March/early April, over the critical overwinter period, was nearly identical for 1996 and 1997, with spring catch rates at 62.5% and 62.7 % of the previous winter rate, respectively. In 1998, the spring catch rate was only 28% of the previous winter, but that represents only one fish collected.

The overwinter survival of the 1996 and 1997 year classes was very similar to the average overwinter survival seen in the Green and Colorado rivers. Trammell and Chart (1999) and Trammell et al. (1999) showed overwinter survival rates ranging from 0 to 100% in the Colorado River, and 7 to 70% in the Green River, with averages of 32 and 42%. Haines et al. (1998), using a mark-recapture technique to generate population estimates in the Green River, derived overwinter survival rates of 56 and 62% for 1992-1994. McAda and Ryel (1999) derived overwinter survival rates from fall to spring from 1988 to 1996 in the Colorado River. Their estimates ranged from 7 to 100%, with a mean of 50%, and most between 25 and 70%.

In this study, another sudden drop in catch rates occurred during the second growing season; when the fish reach a certain size ($55 < x < 120$), they undergo a shift in habitat use from low-velocity backwater areas to shoreline and secondary channels. At that point seining was no longer effective in collecting these fish, but they began to be collected during the USFWS electrofishing efforts (Table 4-2). The electrofishing catch was almost identical from age 1 to age 2, with some anomalously low catches in between trips (Fig. 4-3). In October 1997, 35 age 1 pikeminnow were collected in the Upper San Juan. In May of 1998, 38 pikeminnow were collected, now age 2. In the fall of 1998, 40 age 2 pikeminnow were collected. Survival of pikeminnow from age 1 to age 2 appeared to be essentially 100%.

Table 4-1. 1996 year class Colorado pikeminnow collected by seining^a and backpack electrofishing^b in the San Juan River, 1996-1997.

Trip date	Total PTYLUC	Number in Upper San Juan	Number in Lower San Juan	Avg length TL (mm)	Range	Recapture (%) of 520	total CPE ^c #/100m ²	area seined (m ²)
AGE 0								
11/4/96	100,000	50,000	50,000	55	25-85			
11/15/96	409 ^a 111 ^b	4 110	405 1	55	36-80	(0.5)*	4.3	9465
12/8/96	376 ^a 13 ^b	122 2	254 11	54	26-77	75.0	2.4	15939
3/6/97	198 ^a	84	114	54	40-83	38.0	1.5	13221
4/27/97	188 ^a	120	68	55	40-76	36.0	1.2	15666
AGE 1								
8/12/97	8 ^a	8	0	128	110-163	1.5	0.09	8742
9/1/97	0	0	0					9379
9/22/97	8 ^a	8	0	140	124-217	1.5	0.12	6858
10/15/97	8 ^a	8	0	150	143-173	1.5	0.07	11978

* initial recapture rate (out of 100,000 stocked)

^a fish collected by seining

^b fish collected by back-pack electrofishing

^c seining effort only

Table 4-2. Additional age 1 and age 2 Colorado pikeminnow collected by boat-mounted electrofishing in the San Juan River, 1996-1998 (USFWS, Ryden 2000).

Trip date	year class	Total PTYLUC	Avg length TL (mm)	Range	Recapture (%) of 520
8/97	1996 age 1	3	143	124-161	0.6
10/97	1996 age 1	35	179	136-235	6.7
4/98	1996 age 1	4	160.5	148-171	0.8
5/98	1996 age 1	38	171.7	130-250	7.3
8/98	1996 age 2	7	292	262-315	1.3
10/98	1996 age 2	40	285	242-267	7.7
8/98	1997 age 1	1	151	151	0.3 (of 307)
10/98	1997 age 1	55	167	100-210	18.0 (of 307)

Table 4-3. 1997 year class Colorado pikeminnow collected by seining in the San Juan River, 1997-1998.

Trip date	Total PTYLUC	Number in Upper San Juan	Number in Lower San Juan	Avg length TL (mm)	Range	Recapture (%) of 307	CPE #/100m ²	area seined (m ²)
AGE 0								
8/15/97	116,878	62,578	54,300	45	35-55			
9/1/97	307	104	203	48	43-64	(0.3)*	3.3	9379
9/22/97	212	140	72	52	35-66	69.3	3.1	6858
10/15/97	223	180	43	55	36-71	72.9	1.86	11978
12/4/97	74	23	51	56	49-71	24.2	0.86	8606
3/31/98	78	47	31	56	44-78	25.5	0.54	14304
AGE 1								
7/22/98	11	4	7	111	95-132	3.6	0.14	7694
8/18/98	4	4	0	127	105-134	1.3	0.06	6566
9/16/98	1	1	0	179	179	0.3	0.02	3976

* initial recapture rate (out of 116,878 stocked)

Table 4-4. 1998 year class Colorado pikeminnow collected by seining in the San Juan River, 1998-1999. Stocked only at Shiprock, NM.

Trip date	Total PTYLUC	Avg length TL (mm)	Range	Recapture (%) of 54	CPE #/100m ²	area seined (m ²)
7/2/98	10,571	24	18-28			
7/22/98	54	40	32-44	(0.5)*	0.70	7694
8/18/98	44	55	42-67	81.5	0.72	6566
9/16/98	11	75	54-90	20.4	0.28	3976
11/2/98	4	86	82-91	7.4	0.07	5572
4/1/99	1	76	76	1.9	0.02	4500

* initial recapture rate (out of 10,571 stocked)

Dispersal and retention

In general, the stocked pikeminnow were retained in the system for at least two years, and remained well distributed throughout the river, particularly in the Upper San Juan. After stocking, the fish dispersed generally downstream, and occasionally slightly upstream. On September 30, 1997, stocked pikeminnow were collected up to 7.5 miles above the Shiprock stock site (Dave Propst,

NMGF, pers. comm.). Within reaches, dispersal and displacement patterns seemed to be associated with flow patterns. The natural propensity of the San Juan River to undergo several spike flood events in late summer and fall affects the stability and availability of the habitat as shown in Chapter 3. During flood events, there is more habitat available in the Upper San Juan than the Lower San Juan. As a result, following flood events, the pikeminnow were displaced downstream more in the Lower San Juan than in the Upper San Juan. Although initial catch rates were higher in the Lower San Juan, they declined more quickly, and by the 4th or 5th trip catch and catch rates in both reaches were essentially equal and low (Fig. 4-5). Although there was more overall displacement within the Lower San Juan, the last 13 miles of lake-influenced low gradient habitat retained fish for a longer period of time than upstream areas, frequently as long as fish remained in the Upper San Juan. The annual hydrograph for 1996-1997 is shown in Fig. 4-6, and the hydrograph for 1997-1998 is shown in Fig. 4-7. Stocking dates and trip dates are shown in relation to flood events. Figs. 8, 9 and 10 show the collections and distribution patterns of stocked fish by mile, per trip.

In 1996, between trips 1 and 2, and between 2 and 3, there were no floods, and little displacement was seen in either reach, although numbers collected were reduced over the winter (trips 2 and 3). Between trips 3 and 4, and between 4 and 5 there were flood events. After the first event, fish in the Lower San Juan were displaced downstream, and numbers were further reduced than in the Upper San Juan. After the second event, no fish were collected in the Lower San Juan, although fish were still being caught in the Upper San Juan (Fig. 4-8). Numbers were further reduced between trips 5 and 6 (Fig. 4-5). This time period included a period of growth and a shift in habitat use away from backwaters.

In 1997, between trips 1 and 2, there was a small flood event which resulted in reduced numbers and downstream displacement in the Lower San Juan, while the pikeminnow were retained high in the Upper San Juan (Fig. 5), and catch actually increased (Fig. 9). Between trips 2 and 3, there was a large flow spike, which again reduced the numbers and displaced fish in the Lower San Juan, while in the Upper San Juan distribution remained much the same. Between trips 3 and 4 there were no flood events, but numbers were reduced in both sections, less in the Lower San Juan than the Upper San Juan. Some downstream displacement still occurred in both reaches. Between trips 4 and 5, which was the overwinter period, numbers were reduced in the Lower San Juan, but not in the Upper San Juan. Distribution remained the same in both reaches. Numbers were further reduced between trips 5 and 6 (Fig. 4-5). As in 1996, this time period included a period of growth and a shift in habitat use away from backwaters.

In 1998, the catch and dispersal patterns could not be compared between reaches because fish were only stocked at the upper site. Although the same amount of effort was expended in both reaches, none of the 1998 stocked fish were ever collected in the Lower San Juan (Fig. 4-10). There were spike flows between each of the first 4 trips. Between trips 1 and 2, and 2 and 3, the flow spikes were relatively short and low. Numbers were reduced more between trips 2 and 3, which had the larger flow spike. Between trips 3 and 4, an 11,000 cfs flow spike was experienced which was higher than the spring peak discharge, although shorter in duration. After this event, catch was greatly reduced, and some downstream displacement was observed. On the final trip in March 1999 (not shown) one pikeminnow was collected at RM 128.6. Due to the accelerated growth of this year class, by the 4th trip (November) the pikeminnow may have reached the size at which they vacate backwater habitats, regardless of the season, or flow events.

Once the Colorado pikeminnow reached age 1 and age 2, they were collected primarily by boat-mounted electrofishing along shorelines in the main channel (Ryden 2000). The majority of their efforts were in the Upper San Juan. Age 1 and 2 pikeminnow were consistently collected throughout the Upper San Juan from October 1997 to October 1998 (Fig. 4-11), with the exception of an anomalously low catch in April 1998. A few pikeminnow were also collected in the Lower San Juan in August 1997 and August 1998.

Habitat availability

Total nursery habitat availability in area was evaluated from the four nursery habitat reaches, wherein all habitats were measured and sampled. Total area of habitat was compared between reaches and with comparable reaches on the Green and Colorado rivers for August and September 1994-1996 in Chapter 3. Area for the Green and Colorado rivers was not measured in 1997 or 1998.

Total habitat area compared favorably with the Green and Colorado river nursery habitat sections. Total habitat area available on the San Juan River was greater than or equal to that found in those rivers (Fig. 4-12), particularly in the lower two reaches (1 and 2). The San Juan river experienced a greater loss of habitat between the August and September sampling than the other rivers, due to the monsoonal flow spikes which occur in those months. Habitat loss was greater in the lowest nursery habitat section (one) than the upper sections in 1994-1997, but not in 1998. This is because habitat loss occurred before the August trip in 1998. Total habitat numbers and areas are given for each nursery habitat section, for the August and September trips for 1996-1998 in Table 4-5. The flow-habitat relationships are discussed in more detail in Chapter 2. In general, habitat availability in area does not appear to be more limiting on the San Juan River than it is on the Green and Colorado rivers, which have stronger recruitment of Colorado pikeminnow.

Table 4-6 lists the numbers of each habitat type and the number of each habitat type in which pikeminnow were collected, for the upper and Lower San Juan, by trip for 1997-1998. Most habitats encountered were classified as either scour channel (SC) or secondary channel (SEC) habitats. These habitat types were very similar, the differences based mainly on size and stability, with the secondary channels being larger and more permanent. Some of the classifications of these habitats in the field may have overlapped, but both offer similar quality in terms of depth, and both were preferentially occupied by the Colorado pikeminnow.

Habitat use

Using the backwater habitat classifications, a multinomial analysis was performed to evaluate habitat use by the Colorado pikeminnow. For this analysis, the river was divided into the Upper and Lower San Juan, and habitat use pooled for all trips. Habitat use was also pooled for all trips and both reaches (Table 4-7). Although all habitats were usually sampled in only the nursery habitat sections, in the first 5 miles below each stocking site, all nursery habitats were also sampled. Many of the pikeminnow were collected in this first five miles, particularly in the upper section, and few pikeminnow were collected in the nursery habitat reaches for some trips (Table 4-5). For these reasons, we used all the habitats and pikeminnow collections, not just the nursery habitat sections.

In both the upper and Lower San Juan, and when reaches were combined, the Colorado pikeminnow appeared to select for scour channel and secondary channel type habitats (Fig. 4-13). These habitats tend to be large, deep and relatively permanent. The only habitat selected against was migratory sandwave types, which tend to be small, shallow, midchannel bar habitats. However, all habitat types were used to some extent.

The multinomial test (Table 4-7) revealed a significant p-value for the Lower San Juan ($p=0.03$), and for both reaches combined ($p=0.002$). This value indicates that at least one habitat is being used at a significantly greater or lesser proportion than it occurs. Looking at the differences between observed and expected use, we see that pikeminnow were consistently found in scour channel (SC) habitats more often than expected, and they were found in migratory sandwave (MS) habitat less often than expected.

The average maximum depth of habitats occupied by Colorado pikeminnow was higher than in habitats in which pikeminnow were not collected (Table 4-6). The differences were small and not significant because the pikeminnow were sometimes found in very shallow habitats. Also, the deepest habitats were difficult to sample, and some pikeminnow may have been missed. Graphing maximum depth of habitat against frequency of occurrence of pikeminnow did not reveal a consistent pattern of selection towards deeper habitats (not shown). Nevertheless, depth does seem to be a factor in habitat use by Colorado pikeminnow.

It is important to note that although the pikeminnow do tend to select for the secondary channel and scour channel habitats, they use all the habitat types to some extent. Although they tend to select for large, deep habitats they are also found in the shallowest and smallest of habitats as well. We speculate that the pikeminnow are using these habitats temporarily, in transition to more quality habitats.

Table 4-5. Total habitat numbers and total habitat area for the four nursery habitat sections on the San Juan River, August and September, 1996-1998.

August				September		
Section	Number of habitats	Number with PTYLUC	Total Area (m ²)	Number of habitats	Number with PTYLUC	Total Area (m ²)
1996						
4	29	NA*	3443	14	NA	3716
3	27	NA	3948	11	NA	2841
2	28	NA	2337	18	NA	3035
1	52	NA	13933	30	NA	9840
1997						
4	14	0	2421	7	4	2323
3	12	1	5664	12	1	6412
2	8	0	1236	12	2	1664
1	37	0	15163	16	7	5141
1998						
4	9	6	2664	8	1	5224
3	9	0	2002	3	1	2248
2	7	0	421	11	0	1102
1	19	0	6808	12	0	2200

*in 1996 fish were not stocked until November

Table 4-6. Numbers of each habitat type and the number of each habitat type in which Colorado pikeminnow (PTYLUC) were collected, in the Upper and Lower San Juan, 1997-1998.

1997

Date	Habitat types	BP	HS	FT	MS	SC	SE	SEC	SH	Avg. Dmax ^a With PTYLUC	Avg. Dmax Without PTYLUC
Sep 2 Upper	PTYLUC	0	0	0	0	6	2	9	1	0.40	0.36
	Total	2	0	0	4	23	9	46	6		
Lower	PTYLUC	4	0	6	3	20	11	3	0	0.51	0.32
	Total	8	1	10	11	31	16	5	1		
Sep 22 Upper	PTYLUC	0	0	1	1	9	3	8	1	0.34	0.38
	Total	0	0	3	6	22	7	23	7		
Lower	PTYLUC	0	0	0	0	11	0	0	2	0.69	0.51
	Total	3	0	6	3	19	15	0	11		
Oct Upper	PTYLUC	0	0	0	0	10	2	13	0	0.46	0.40
	Total	0	0	1	1	27	5	37	1		
Lower	PTYLUC	0	0	3	4	11	3	0	0	0.42	0.30
	Total	3	0	7	22	38	14	0	0		
Dec. Upper	PTYLUC	0	0	0	0	3	2	5	0	0.46	0.43
	Total	1	3	0	8	24	5	27	3		
Lower	PTYLUC	0	0	0	2	6	1	0	0	0.45	0.41
	Total	1	0	3	10	35	10	4	7		
Apr. 98 Upper	PTYLUC	0	0	3	0	15	0	0	0	0.47	0.39
	Total	0	0	9	11	56	3	0	1		
Lower	PTYLUC	0	0	4	1	3	3	0	0	0.39	0.21
	Total	5	0	13	35	14	28	0	0		

^a Dmax is the maximum depth (m) of a habitat, AVG Dmax is the average of Dmax for all habitats.

BP=Boulder pocket, HS=Horseshoe vortex, FT=flooded tributary, MS=migratory sandwave, SC=scour channel, SE=shoreline eddy, SEC=secondary channel, SH=shoreline

Table 4-6. (Continued) Numbers of each habitat type and the number of each habitat type in which pikeminnow were collected, in the Upper and Lower San Juan, 1997-1998.

1998

Date	Habitat types	BP	HS	FT	MS	SC	SE	SEC	SH	Avg. Dmax [‡] With PTYLUC	Avg. Dmax Without PTYLUC
July Upper	with PTYLUC	0	0	0	0	14	1	0	0	0.52	0.57
	Total	0	0	1	0	44	2	0	0		
Lower	with PTYLUC	0	0	1	0	1	3	0	0	0.92	0.63
	Total	5	0	3	6	18	15	0	0		
Aug. Upper*	with PTYLUC	0	0	0	2	12	0	0	0	0.36	0.27
	Total	0	0	1	4	41	3	0	0		
Sep. Upper*	with PTYLUC	0	0	0	0	5	1	0	0	0.61	0.55
	Total	0	1	3	0	31	5	0	0		

BP=Boulder pocket, HS=Horseshoe vortex, FT=flooded tributary, MS=migratory sandwave, SC=scour channel, SE=shoreline eddy, SEC=secondary channel, SH=shoreline

* No PTYLUC were collected in the Lower San Juan, so no analysis was possible on the 1998 year class.

Table 4-7. Multinomial test of habitat use by Colorado pikeminnow in the Upper and Lower San Juan, and both reaches combined, pooled for all trips for 1997-1998.

Upper San Juan

Habitat type	Number	Percent (%)	Observed with PTYLUC	Expected	chi-square
BP	3	0.6	0	0.8	0.78
HS	4	0.8	0	1.0	1.04
FT	18	3.6	4	4.7	0.10
MS	34	6.8	3	8.8	3.84
SC	248	49.9	74	64.4	1.44
SE	39	7.9	11	10.1	0.08
SEC	133	26.8	35	34.5	0.01
SH	18	3.6	2	4.7	1.53
TOTAL	497	100	129	129	8.82, P=0.2666

Lower San Juan

Habitat type	Number	Percent (%)	Observed with PTYLUC	Expected	chi-square
BP	25	5.7	4	6.1	0.71
HS	1	0.2	0	0.2	0.24
FT	42	9.6	14	10.2	1.41
MS	87	20.0	10	21.2	5.88
SC	155	35.6	52	37.7	5.44
SE	98	22.5	21	23.8	0.34
SEC	9	2.1	3	2.2	0.30
SH	19	4.3	2	4.6	1.49
TOTAL	436	100	106	106	15.81, P=0.027

Table 4-7. (Continued) Multinomial test of habitat use by Colorado pikeminnow in the Upper and Lower San Juan River, and both reaches combined, pooled for all trips for 1997-1998.

Upper and Lower COMBINED

Habitat type	Number	Percent (%)	Observed with PTYLUC	Expected	chi-square
BP	28	3.0	4	7.0	1.29
HS	5	0.5	0	1.2	1.25
FT	60	6.4	18	15.0	0.59
MS	121	12.9	13	30.3	9.86
SC	403	42.9	126	100.9	6.27
SE	137	14.6	32	34.3	0.15
SEC	148	15.8	38	37.0	0.02
SH	37	3.9	4	9.3	2.99
TOTAL	939	100	235	235	22.42, P=0.002

BP=Boulder pocket, HS=Horseshoe vortex, FT=flooded tributary, MS=migratory sandwave, SC=scour channel, SE=shoreline eddy, SEC=secondary channel, SH=shoreline

DISCUSSION

Young of year Colorado pikeminnow use a variety of habitats, but primarily are found in backwaters, as well as low-velocity secondary channels resembling backwaters. Among backwater habitats, pikeminnow are found proportionately more often in large, deep scour channel or secondary channel habitats. Total backwater habitat availability does not appear to be limited in area, compared to the habitat availability in the nursery habitat reaches of the Colorado and Green rivers, which have relatively strong populations of Colorado pikeminnow. Trammell et al. (1999) and Trammell and Chart (1999) concluded that habitat quantity was not the main limiting factor of Colorado pikeminnow recruitment in the Colorado and Green rivers. Based on their conclusion, and our finding that habitat availability is equal or greater in the San Juan River, we can conclude that habitat quantity in area is probably not the most limiting factor in the San Juan River. However, there may be some differences in habitat quality based on persistence through time, related to the frequent late summer spates.

However, habitat-flow relationships were not strong. Managing habitat quantity with flows would be problematic due to the uncontrollable spate events in late summer/fall during the monsoon season. Both peak discharge and summer/fall base flows differ in their effect on habitat availability in the several reaches. Increased base flows in the upper two reaches result in no change or an increase in habitat availability, while the same increase in flow results in decreased habitat in the Lower San Juan. Habitat quality is also affected by flood events, as habitats can be scoured out, or new sediments deposited. Although the Lower San Juan, particularly the lowest nursery habitat section (Grand Gulch), provide the most available backwater habitat, the smaller sediments and low sandbars which form the majority of the habitats in this section make these habitats less persistent than those in the Upper San Juan because they are easily overtopped by small rises in discharge. This resulted in more downstream displacement of the stocked

pikeminnow in the Lower San Juan than in the Upper San Juan. Within the Lower San Juan, the last 13 miles (Grand Gulch area) retained pikeminnow longer than the upstream canyon section, which in effect becomes a “raceway” at higher flows.

The stocked Colorado pikeminnow remained well distributed in the Upper San Juan, until age 2, and may continue to be collected. Most of the electrofishing conducted by the USFWS was done in the Upper San Juan, so most of the age 1 and 2 fish collected by the service were in this reach. That the fish remained well distributed and catch rates of the 1996 year class remained fairly stable was very encouraging towards the success of this and future stocking efforts. The relative success of this stocking effort is gratifying considering the variability of conditions in the San Juan River, and the relatively unsuccessful attempts elsewhere in the Upper Basin of the Colorado River (Trammell et al. 1993). We consider this stocking effort to be successful. A percentage, albeit small, of the stocked fish survived in the San Juan not only through the summer and first winter, but as long as three years (to date), thus demonstrating that nursery habitat and food resources in the San Juan River are adequate to promote growth and survival of age 0 and juvenile Colorado pikeminnow.

However, the question remains if wild spawned Colorado pikeminnow would be as successful in being retained in the remaining portion of the San Juan River. All of the pikeminnow were stocked at sizes larger than those collected in the drift, and were presumably ready to enter and remain in backwater habitats. Larval Colorado pikeminnow are found in the drift up to 11-12 mm, and usually collected in backwaters thereafter (Trammell and Chart 1999, Anderson 1999). Colorado pikeminnow spawn on the descending limb of the hydrograph in June and July as water temperatures rise (Haynes et al. 1984, Osmundson et al. 1995). Following hatch, larvae emerge from the substrate, become entrained in the current below spawning areas and are transported to low-gradient nursery habitat areas which may be located substantial distances downstream. Drift by larval Colorado pikeminnow has been documented in the Yampa, Green and Colorado rivers (Nesler et al. 1988, Valdez et al. 1985, Bestgen et al. 1998). On the Green and Colorado rivers wild spawned Colorado pikeminnow often drift long distances downstream from spawning areas to nursery habitat areas. For example, the lowermost spawning area in the Green River (Gray Canyon) is located near RM 170, while the highest concentrations of age 0 Colorado squawfish below the spawning area are found from RM 120-0; a distance of 50-170 miles below the spawning site (Muth et al. 2000), however, some age 0 pikeminnow are collected above the concentration areas.

The only suspected spawning site on the San Juan River is at RM 131. Drifting long distances in the San Juan River from this location would deliver them into the lower river, or into Lake Powell. In fact, 19 of 21 wild age 0 pikeminnow collected in the San Juan River since 1991 have been collected in the Lower San Juan. If larvae are produced at this location by the stocked fish, when mature, or by wild fish, they would presumably drift to the Lower San Juan, where we have shown they are unlikely to be retained, except in the lowermost 13 miles of river. The importance of maintaining habitat in this area must not be overlooked. However, these 13 miles of nursery habitat may not be adequate to support enough recruitment to sustain a reproducing population of Colorado pikeminnow. Typically, nursery habitat areas for Colorado pikeminnow in other rivers are much longer. The four standardized nursery habitat reaches in the upper Colorado River Basin’s Interagency Standardized Monitoring Program, which are based on historic concentrations of age 0 Colorado pikeminnow, include the lower 100-120 miles of the Green and Colorado rivers, another 119 miles in the middle Green River near Ouray, UT, and 30 miles on the Colorado River near Grand Junction, CO (USFWS 1987).

CONCLUSIONS

Objectives 5) To determine the quality and quantity of low-velocity [nursery] habitats in the San Juan River for use by Colorado pikeminnow through experimental stocking of age 0 fish.

- ! Quality of nursery habitat is indirectly suggested to be adequate through the excellent growth and survival of stocked fish.
- ! Colorado pikeminnow used scour channel or secondary channel backwater habitats, which tend to be larger, deeper and more permanent than other types of backwater habitats, proportionately more often than they occurred. These are considered to be 'quality' habitats.
- ! All types of backwater habitats were used to some extent.
- ! Nursery habitat availability does not appear to be limiting Colorado pikeminnow recruitment on the San Juan River.
 - " Nursery habitat availability compared favorably with that in nursery habitat areas of the Green and Colorado rivers where recruitment of Colorado pikeminnow occurs, particularly in section 1, at the Lake Powell inflow.
 - " Some 'quality' habitats contained no Colorado pikeminnow.
 - " Many smaller habitats contained no fish of any species.
- ! However, the location of the nursery areas in relation to suspected spawning areas may mean that only the lower part of the San Juan is available to wild spawned fish.

Objective 6) To determine the effects of diversion canals on age 0 Colorado pikeminnow drift/movement (e.g., stranding, etc.).

- ! Fish loss into the Cudei diversion was minimal.
 - " In 1997, sampling began 9 hours after stocking. A total of 38 fish were captured in the diversion in 48 hours of continuous sampling, and none in the remaining 20 hours of sampling, representing 0.06% of fish stocked at the upper site.
 - " In 1998, 0 fish were captured in the diversion in 48 sampling hours beginning three days after stocking.

Objective 7) To determine overwinter survival and growth of experimentally stocked age 0 Colorado pikeminnow.

- ! We consider this stocking effort to be successful, based on survival, growth and long-term retention of stocked Colorado pikeminnow.
- ! Overwinter survival of age 0 Colorado pikeminnow, at an average of 62.6%, compared favorably with wild pikeminnow on the Green and Colorado rivers (25-75%).

- ! Survival from age 1 to age 2 was excellent, with no reduction in catch rates based on electrofishing data (Ryden 2000).
- ! Growth of stocked Colorado pikeminnow was excellent.
 - " The 1996 and 1997 year class at age 1 and age 2 were within the size range of wild pikeminnow in those age classes in the Green and Colorado rivers.
 - " The 1998 year class stocked at a small size earlier in the summer grew faster than the other two year classes, and were larger than their wild counterparts in the Green and Colorado rivers.
- ! In general the stocked pikeminnow were retained in the system for at least two years and remained well distributed throughout the river.
 - " After stocking, fish dispersed generally downstream.
 - " Dispersal and displacement varied by river reach and was associated with flow patterns.
 - More downstream displacement was seen in the Lower San Juan, particularly after flow spikes.
 - Fish were retained in the upper portion of the Upper reach, and in the lower 13 miles of the Lower reach.
 - " Age 1 and 2 fish remained well distributed throughout the study area.
- ! Although the success of the stocking of age 0 fish is evident, the question remains if wild spawned Colorado pikeminnow larvae would also survive and be retained in the San Juan River.

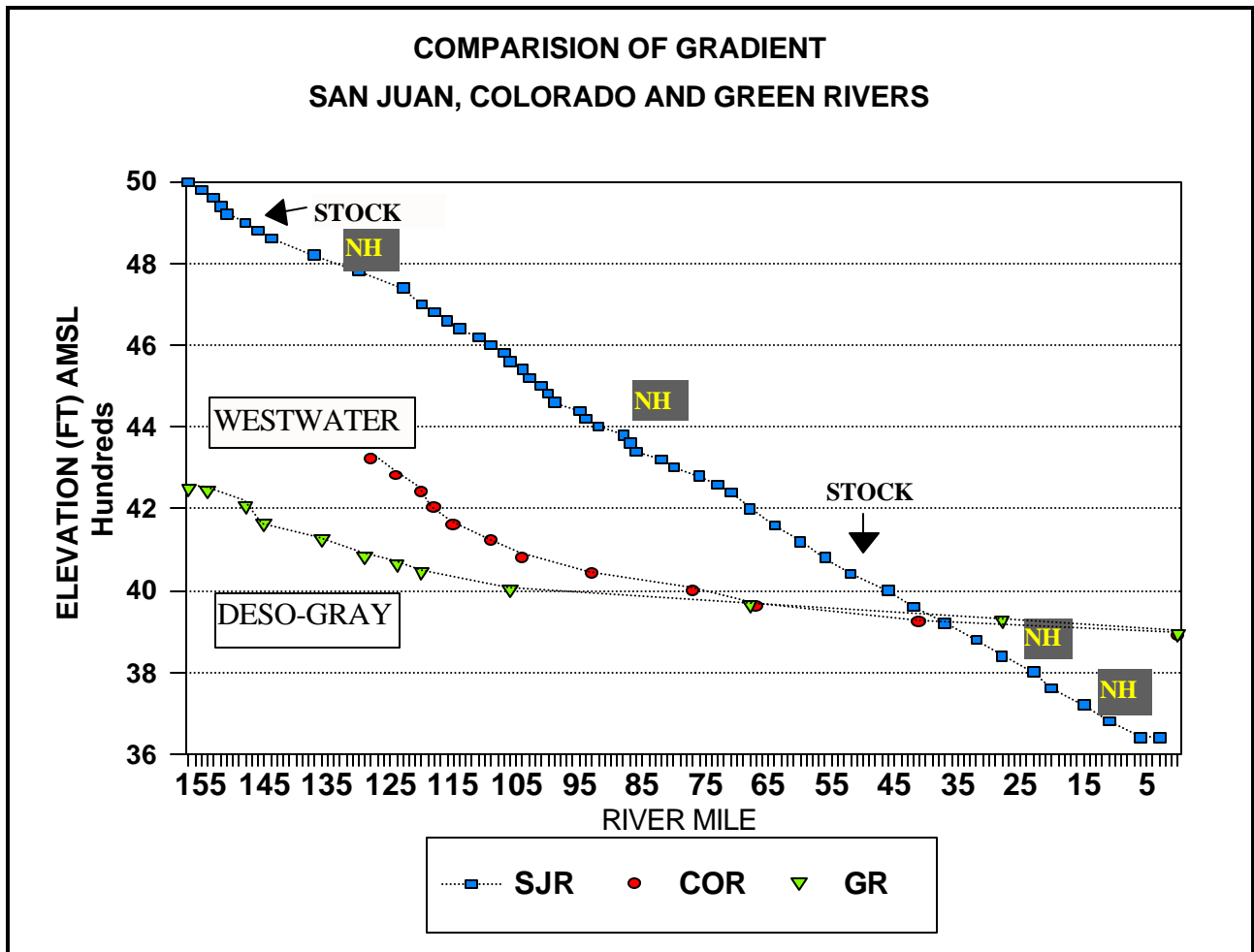


Fig. 4-1. Comparison of gradient in the San Juan, Green and Colorado rivers, with stock sites and nursery habitat reaches indicated.

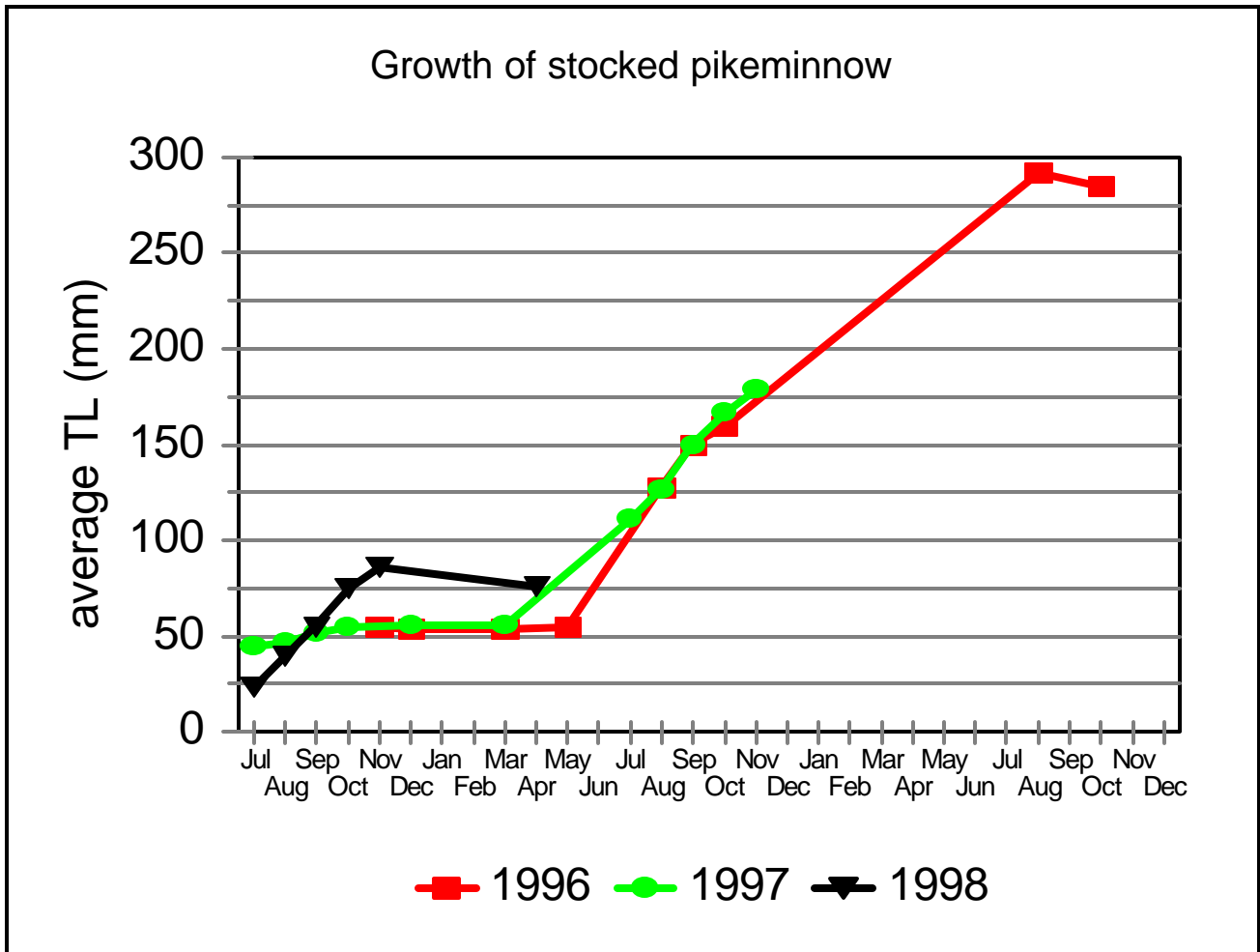


Fig. 4-2. Growth of Colorado pikeminnow stocked in the San Juan River, 1996-1998.

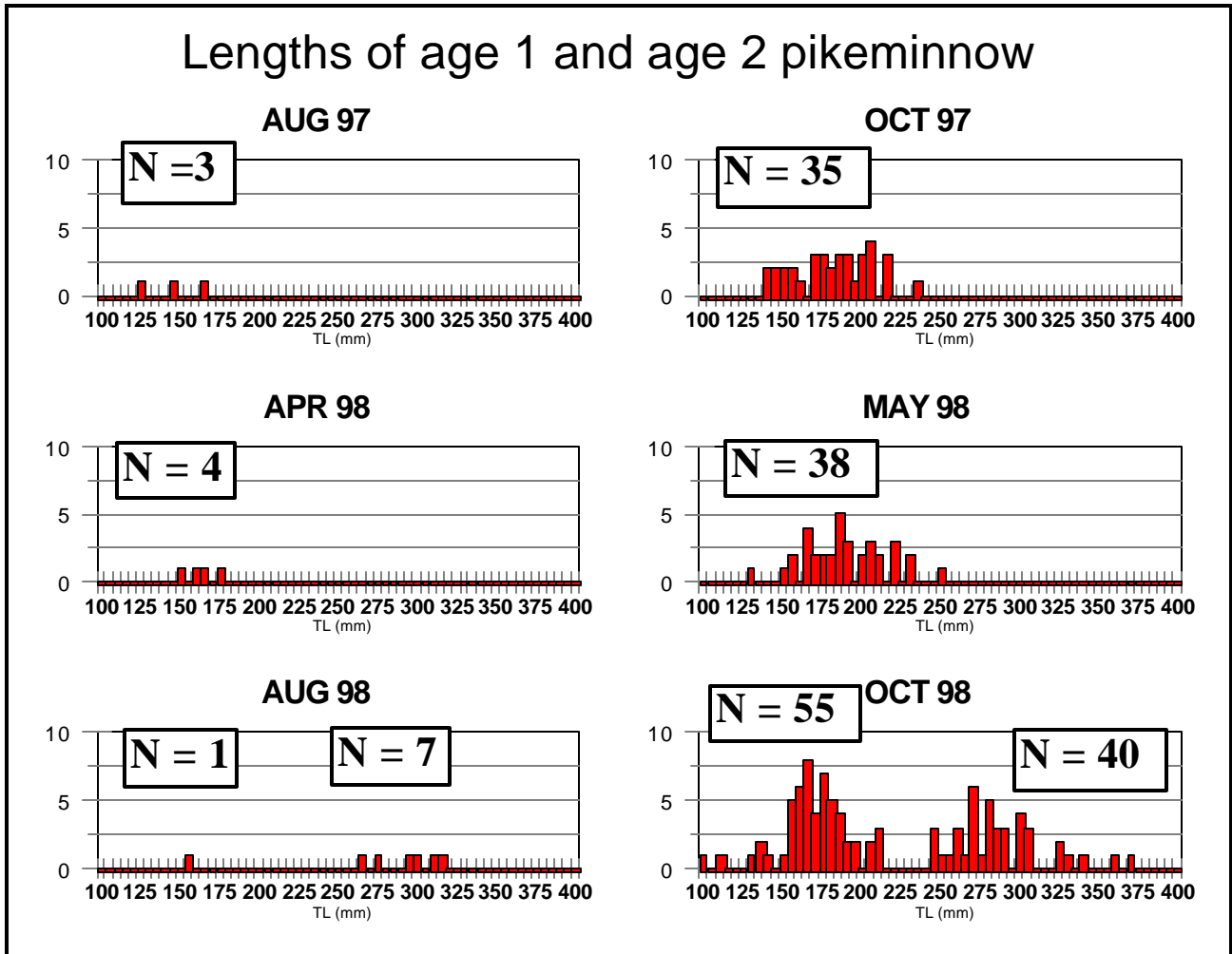


Fig. 4-3. Continued growth of age 1 Colorado pikeminnow stocked in the San Juan River as age 0.

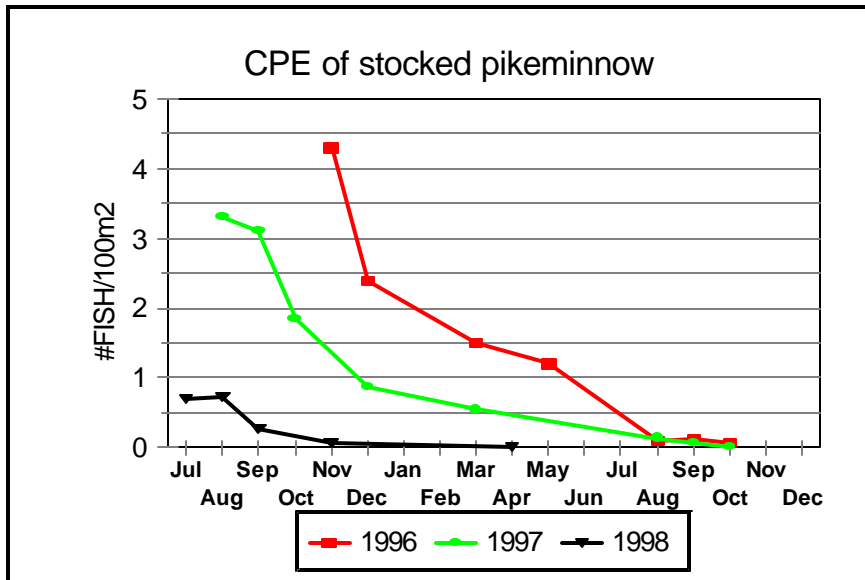
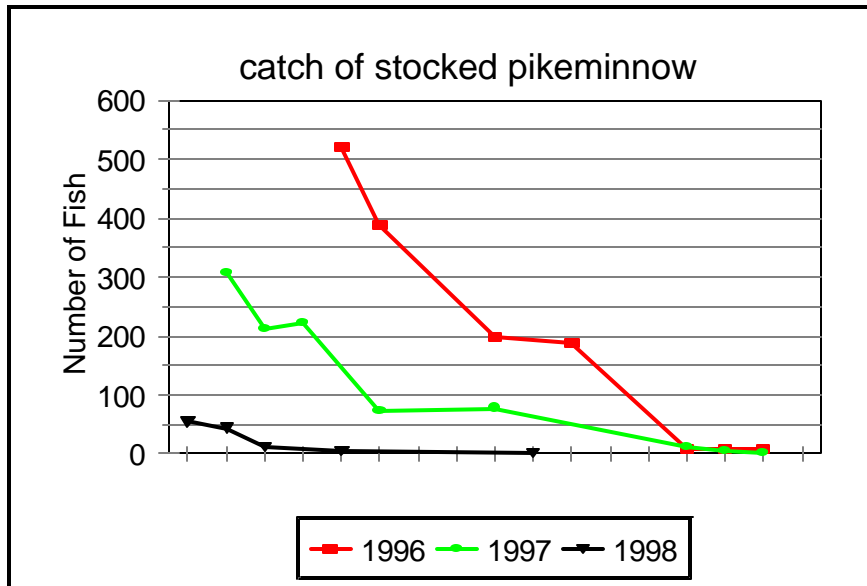


Fig. 4-4. Catch and catch rate (#fish/100m²) of age 0 and age 1 Colorado pikeminnow, stocked in the San Juan River, 1996-1998.

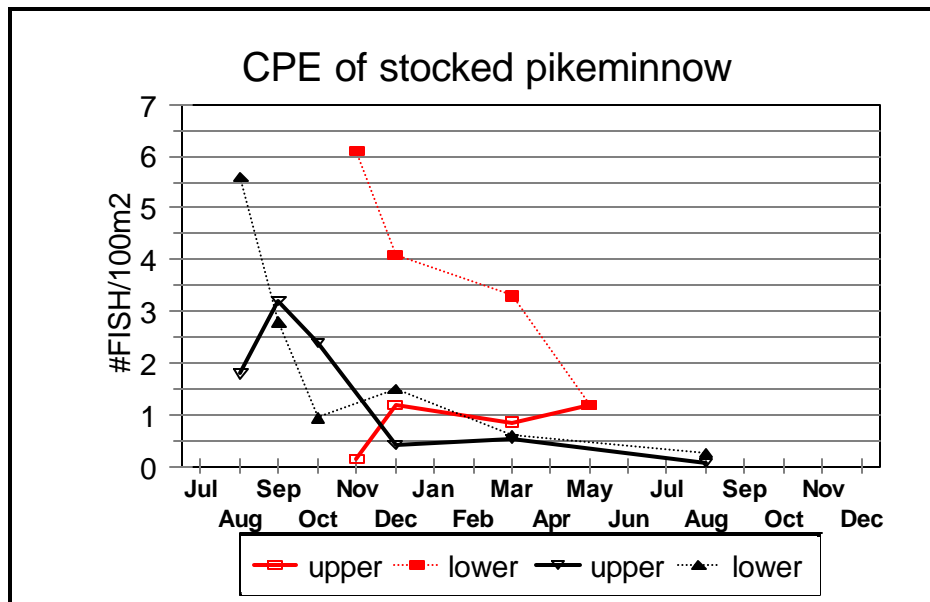
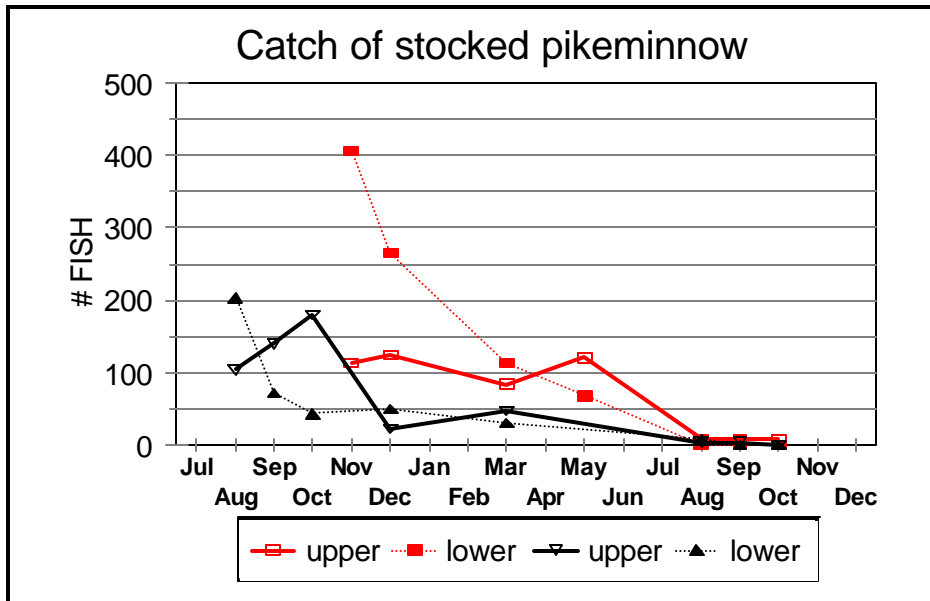


Fig. 4-5. Catch and catch rate (#fish/100m²) of age 0 and age 1 Colorado pikeminnow, stocked in the San Juan River, 1996-1998.. Comparison of the Upper and Lower San Juan.(above and below RM 76.0).

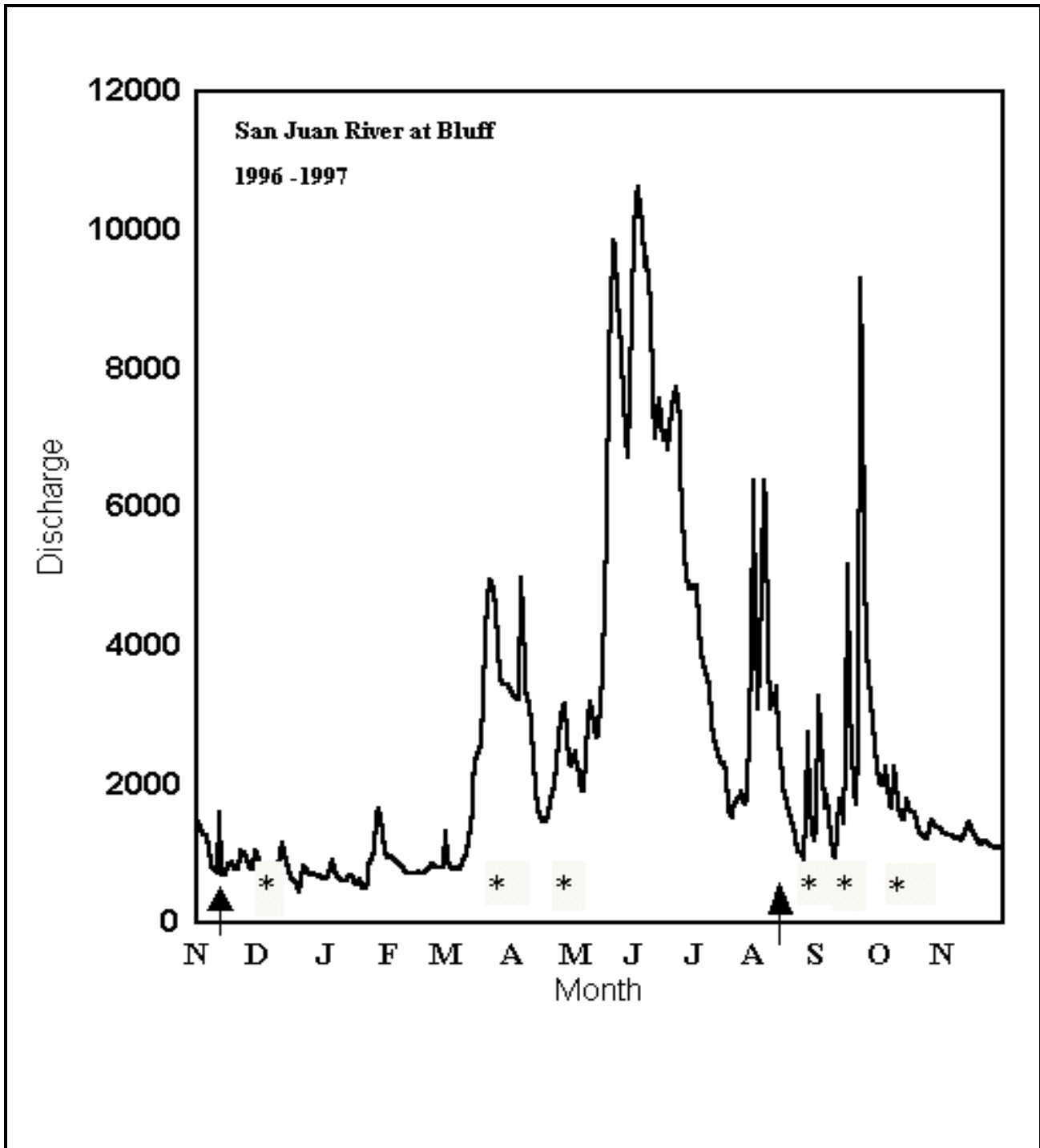


Fig. 4-6. Discharge in the San Juan River, 1996-1997. Stocking and trip dates are indicated by arrow, and stars.

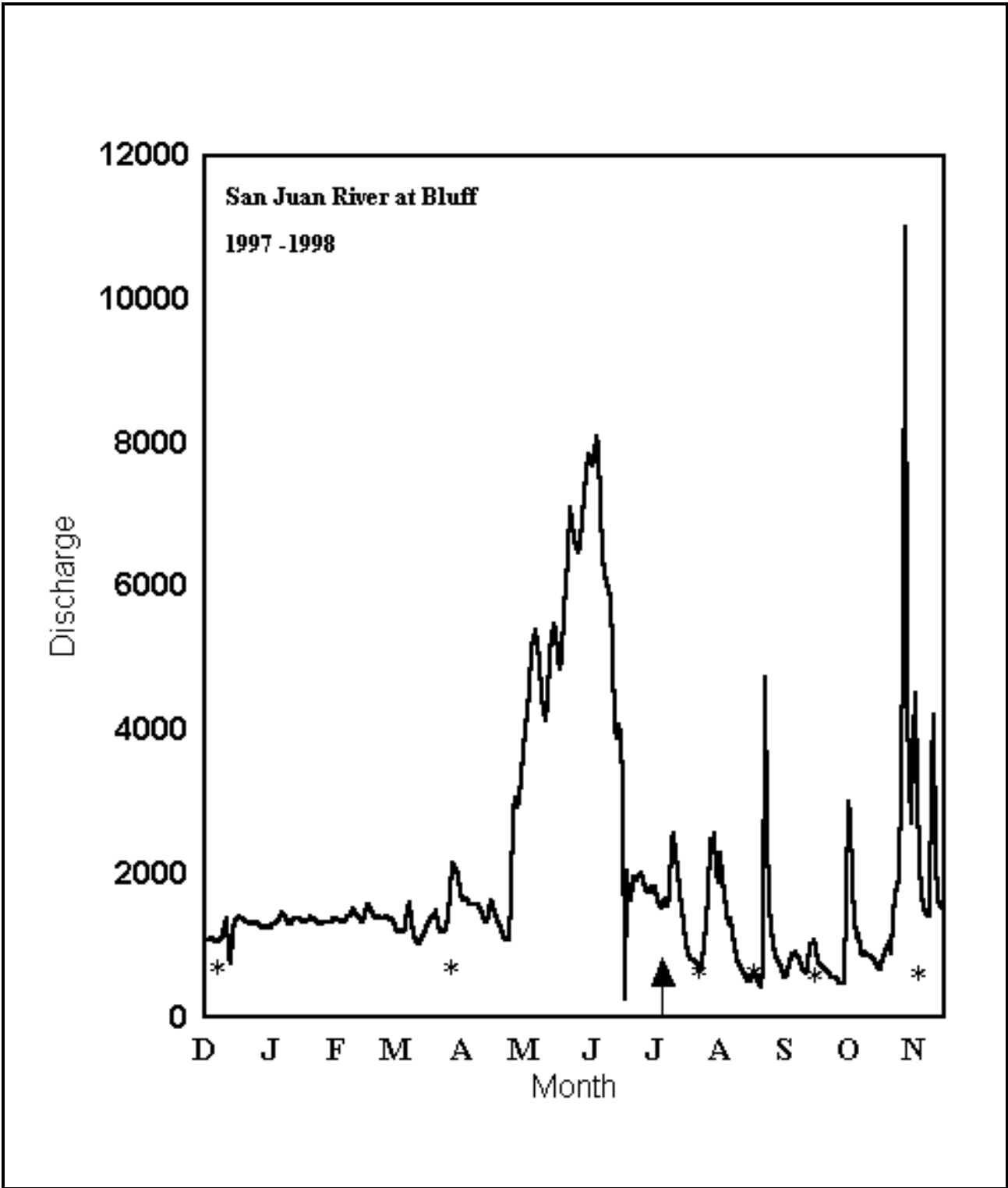


Fig. 4-7. Discharge in the San Juan River, 1997-1998. Stocking and trip dates are indicated by arrows, and stars, respectively.

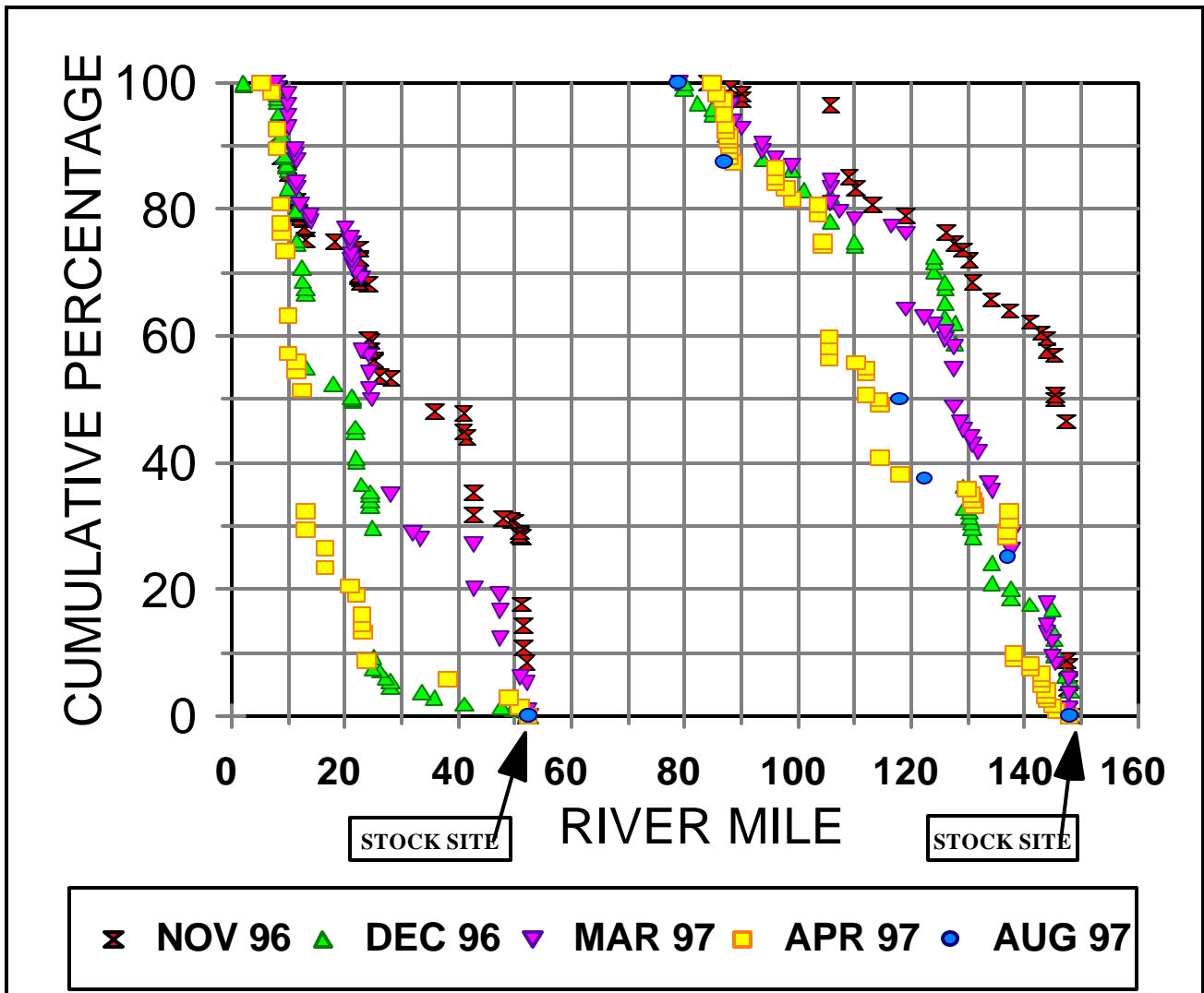


Fig. 4-8. Distribution and dispersal of 1996 year class of Colorado pikeminnow in the San Juan River.

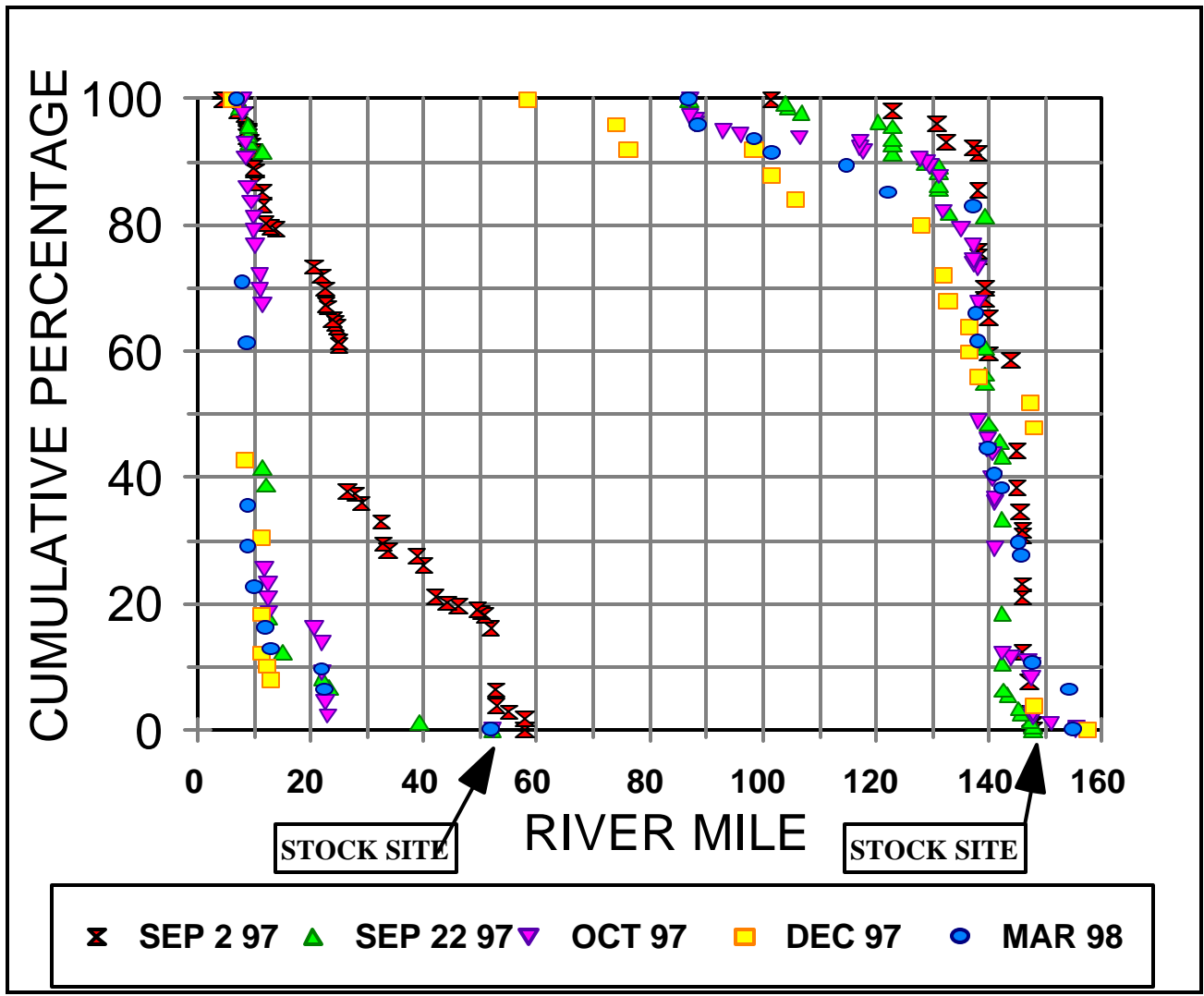


Fig. 4-9. Distribution and dispersal of 1997 year class of Colorado pikeminnow in the San Juan River.

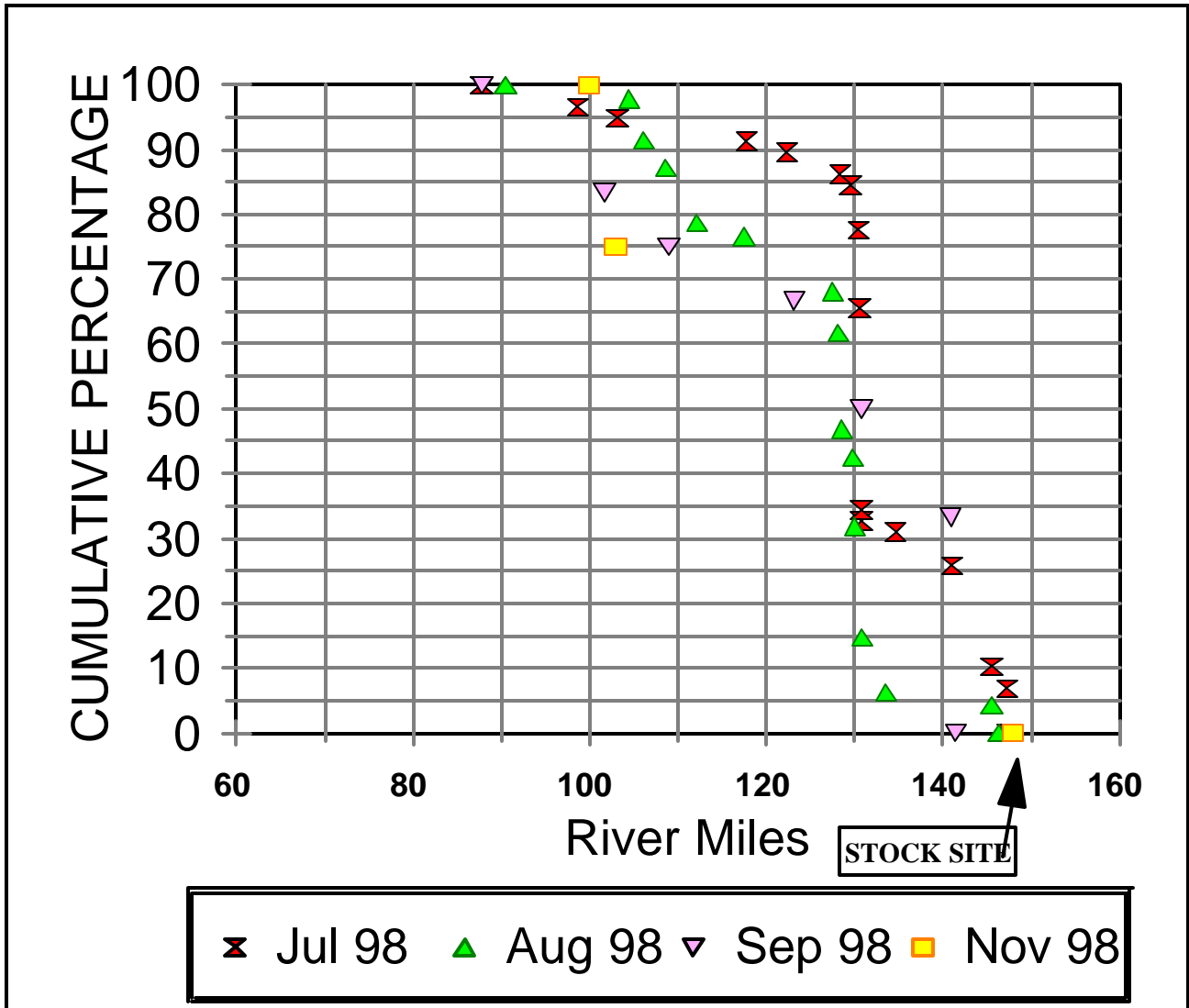


Fig. 4-10. Distribution and dispersal of 1998 year class of Colorado pikeminnow in the San Juan River.

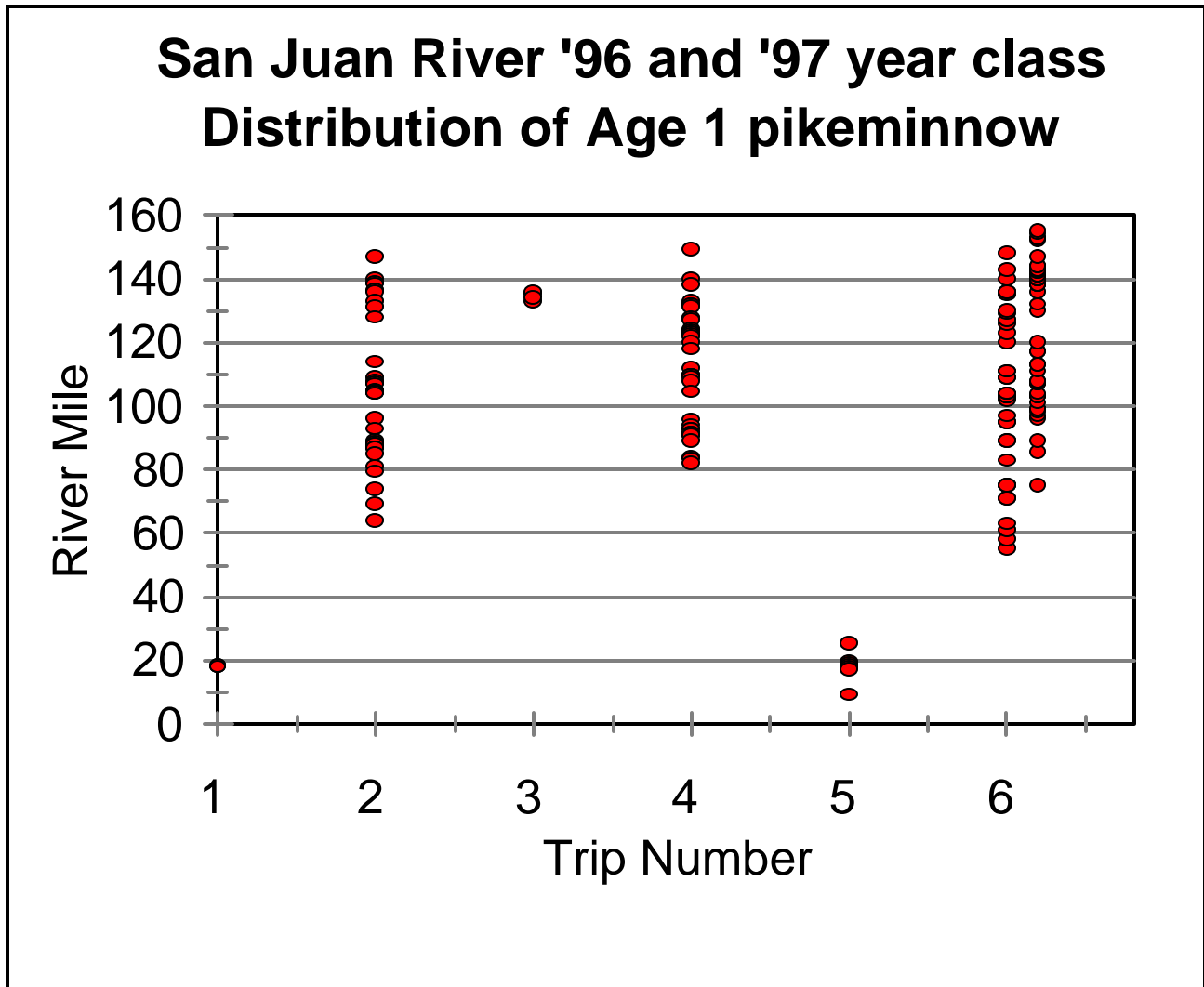


Fig. 4-11. Distribution of age 1 Colorado pikeminnow, stocked in the San Juan River in 1996 and 1997. Fish collected by USFWS.

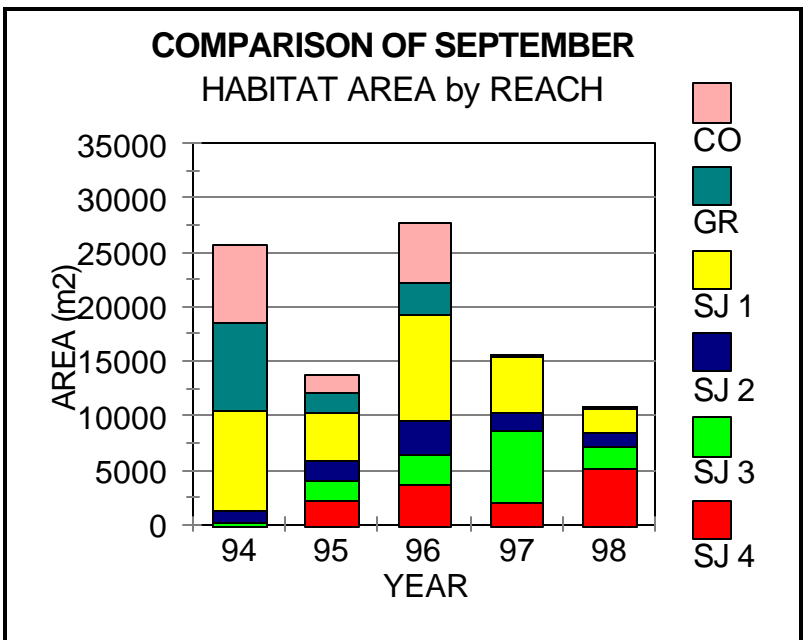
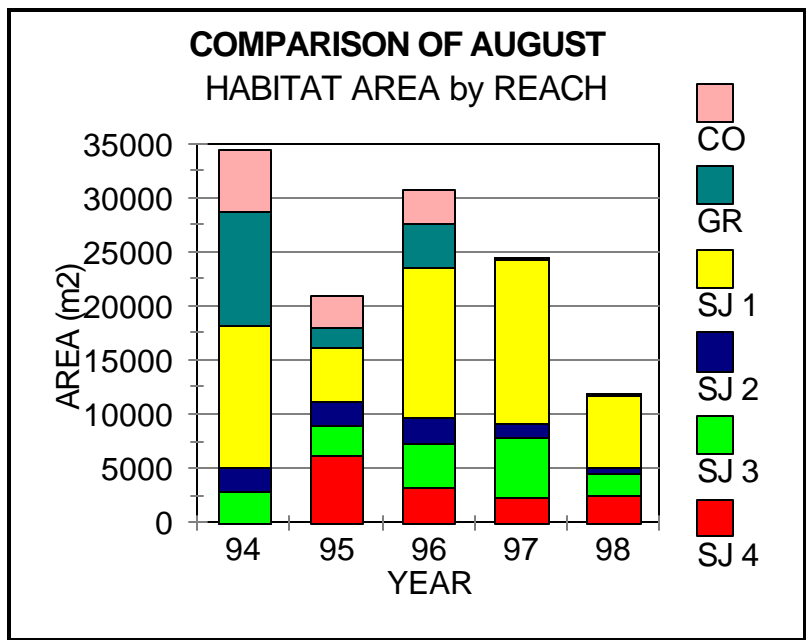


Fig. 4-12. Comparison of total habitat area in the nursery habitat reaches of the San Juan, Green, and Colorado rivers, 1994-1998.

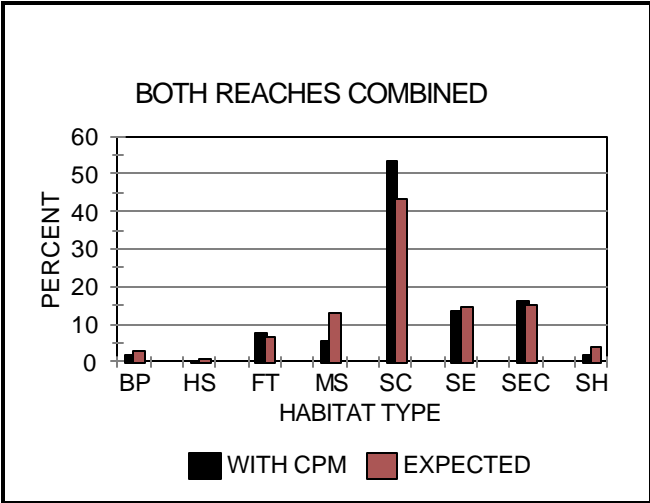
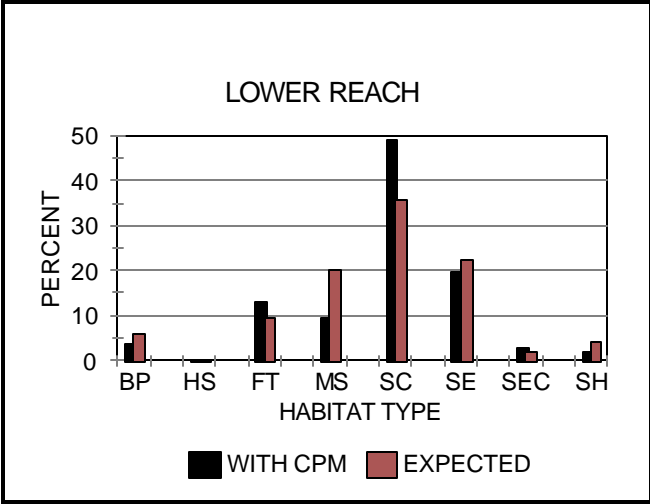
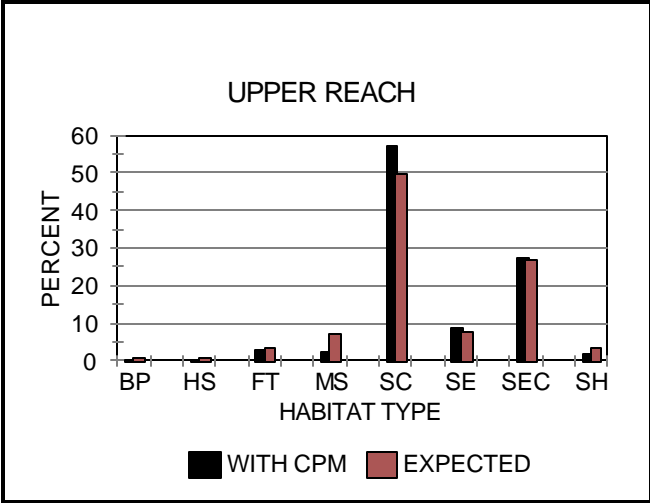


Fig. 4-13. Habitat selection by stocked Colorado pikeminnow in the San Juan River, 1997-1998.

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APPENDIX

**EFFECTS OF FOOD AVAILABILITY AND COMPETITION
ON AGE-0 COLORADO PIKEMINNOW GROWTH
AND LIPID ACCRUAL IN THE SAN JUAN RIVER**

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

AQUATIC ECOLOGY

ABSTRACT

Effects of Food Availability and Competition
on Age-0 Colorado Pikeminnow Growth
and Lipid Accrual in the San Juan River

by

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With the extirpation of Colorado pikeminnow (*Ptychocheilus lucius*) from the reaches downstream of Glen Canyon Dam, pikeminnows are restricted to the Upper Colorado River Basin above Lake Powell. With the loss of the lower portion of the Colorado system Pikeminnow are now confined to the northern portion of their historic range, including the San Juan, Colorado, and Green Rivers. Fishes at the northern portions of their range of environmental tolerance, often experience high over-winter mortality during early life stages. Lack of recruitment to adult stock has been speculated as a major component in the decline of Pikeminnow within the basin.

Food availability, competition, and temperature regime have all been suggested as possible mechanisms limiting survival of early life stages. However, there is very little quantitative evidence available to test these ideas. The objective of this study was to evaluate which mechanisms may be contributing to the decline of Pikeminnow in the San Juan River Basin.

A series of studies were conducted to examine food availability and the potential for food limitation in the San Juan River. Results of this study indicated that are differences in the availability of food resources between the study reaches of the San Juan River and the Green River reach near Orray.

In order to evaluate food limitation in the San Juan River we assessed growth, condition factor and lipid accrual of stocked age-0 Colorado Pikeminnow in the two study reaches with differing invertebrate densities. Our results from the riverine food limitation study are inconclusive because of several confounding factors. First, stocking occurred late in the growing season which severely limited the time available for differences between the reaches to develop. Second differences between lots at the time of stocking in all of the variables measured further disguised differences between the study reaches.

The controlled experiments which were conducted also failed to accurately evaluate potential food limitation because invertebrate densities in the experiments were unrealistically high and not correlated with any of the variables measured.

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INTRODUCTION

The evolution of life history characteristics of organisms is heavily dependent the environmental conditions they experience. It was suggested by Wilson and MacArthur (1967) with their model of r- and K-selection that species subjected to a variable environment often experience high mortality due to density independent factors. In such organisms a life history which favors a strategy of early reproduction, and high fecundity should be selected for.

For many long lived organisms survivorship characteristics are perhaps the most important aspect determining overall population dynamics. Many have suggested that the larval period is critical to many fish species (Blaxter 1988). It is important that larval fish grow quickly both to lessen predation (Nielsen 1980, Post and Evans 1989) and acquire sufficient fat reserves to survive through winter (Henderson et al. 1988). Three important factors have been shown to influence the growth and survivorship of age-0 fish: prey availability (Henderson 1985, Cryer et al. 1986), competition (Fausch and White 1988) and temperature regime (Brett 1979).

Prey Availability

The availability of prey items to fish is an important factor in growth. Ivlev (1961) showed that in many fish species growth increased with increasing prey abundance. As prey density increases, growth increases until an asymptote is reached, where food is no longer limiting. Post and McQueen (1994) concluded that prey availability explained a large amount of the variability in growth among age-0 cohorts. A strong relationship between benthic invertebrate densities and age-0 growth was also found for walleye (*Stizostedion vitreum*, Fox 1989). However, in a study of five species inhabiting a eutrophic lake, Mooij et al. (1994) concluded that in most years age-0 fish were not limited by food. Another study of a New Zealand stream with coexisting populations of native galaxiids and introduced Rainbow trout (*Salmo trutta*) Glova et al. (1992) found no negative effects on either condition or abundance, despite extensive overlap in resource use. Food limitation is species and system dependent and general ecological theories must be tested system by system.

The availability of prey items in aquatic systems is dependent on two factors: 1) the overall production of the system 2) the number of individuals competing both intra- and interspecificly for the available resources.

Competition

The importance of interspecific competition has been a topic of much debate in the field of ecology (Connell 1983, Schoener 1982, 1983). It is believed by many that competition is the primary factor structuring natural communities (Strong 1980). However, direct experimental evidence of competition is rare (Pianka 1981). Competition between species occurs as either interference or exploitation competition. Interference competition occurs when one individual denies access to, or uses aggressive interactions, to prevent competitors from utilizing a resource. Exploitative competition occurs when competitors scramble to obtain as much of the available resource as possible, resulting in resource levels being depleted. In a study of yellow perch (*Perca flavescens*) and pumpkinseed

(*Lepomis giffosus*) Hanson and Leggett (1985) concluded that intraspecific competition for food heavily influenced cohort growth rates.

Post and McQueen (1994) concluded that density dependent processes effect prey availability in aquatic systems because of exploitative competition of fish. If competition for limited resources is indeed occurring between fish species, it will result in lowered growth rates and potentially lowered over-winter survival.

Many studies have shown that total fish biomass is strongly correlated to overall nutrient levels and largely independent of species numbers (Hall et al. 1970, Boyd 1981, Hanson and Leggett 1982). This could have major implications in the Colorado River Basin, which is now dominated by non-native species, many of which occupy the same habitats as age-0 Colorado pikeminnows.

However, to clearly demonstrate competition, a reduction in fitness must be observed, either indirectly as decreased growth or directly as fecundity or survival (Sale 1979, Connell 1983, MacNally 1983). Despite much speculation on the impacts of non-natives in the Colorado River Basin, few if any studies have documented such reductions in fitness. The outcome of intraspecific competition between species can be influenced by environmental temperature.

Temperature

Water temperature can have a strong influence on the early life stages of many fish species. It influences the egg incubation period (Koenst & Smith 1976) and growth of age-0 fish (Forney 1966, Craig 1982) and may ultimately influence recruitment (Busch et al. 1975). Fish are ectothermic animals that regulate their temperature within several degrees of their environment. This results in digestive and metabolic rates being determined by environmental temperature. Enzymatic reaction rates which determine the amount of food which can be digested by fish increases with increasing temperature (Brett 1979). At temperatures above and below the species specific optimal, reaction rate is dramatically decreased, resulting in slower digestion and growth rates (Thornton and Lessem 1978). Metabolic costs in fish are also determined by environmental temperature. In order for fish to maintain proper heat balance with increasing temperature, metabolic rates must be increased, requiring more food be consumed for maintenance (Porter and Gates 1969).

The temperature at which fish species are capable of the fastest growth is species dependent. The optimal temperature for growth of a fish species was defined by Jobling (1981) as "the temperature at which growth rate is highest when fish are reared under conditions of maximum, or excessive feeding." Mooij et al. (1994) showed that in warmer years age-0 Pikeperch (*Stizostedion lucioperca*) had a higher growth rate than smelt (*Osmerus eperlanus*). Therefore, the temperature experienced by age-0 fish can have major impacts on the outcome of competition between species.

Fish are dependent on stored lipid reserves during winter periods to meet their basal metabolic requirements (Henderson et al. 1988; Post and Evans 1989). Miranda and Hubbard (1994) documented a reduction in total body lipids in age-0 fish over the winter period. Smaller fish within a cohort tend to have higher maintenance costs per unit of body mass than larger ones (Paloheimo and Dickie 1966). This has been hypothesized as one of the reasons for higher over-winter mortality of smaller individuals (Miranda and Hubbard 1994). Many studies of age-0 fish would support these ideas, because they have documented the elimination of the smaller mode of a bimodal length distribution during winter (Shelton et al. 1979; Post and Evans 1989; Tyus and Haines 1991).

Oliver et al. (1979) concluded in their study of smallmouth bass (*Micropterus dolomieu*) that a critical amount of energy reserves (lipids) was required to survive the winter period, and that larger fish survived significantly better. Thompson (1989) also found that larger age-0 Colorado pikeminnows entered the winter with higher lipid reserves and survived significantly better. If over-winter survival is a limiting factor in stock recruitment, growth and lipid reserves are good measures of differences in potential survival rates.

COLORADO RIVER BASIN BACKGROUND AND HISTORY

The Colorado River Basin is separated into upper and lower basins near Lee's Ferry, Arizona. The upper basin is further subdivided into its three major river systems. The Green, upper main stem Colorado, and San Juan rivers. These are the three major tributaries which now fill Lake Powell.

Geology

The geology of the Colorado River Basin ranges from 625 million year old rock to recent alluvial deposits. Areas in mountainous reaches are primarily composed of resistant, nutrient-poor, metamorphic and igneous rocks (Iorns et al. 1965). In the lower reaches the Colorado river flows primarily through sedimentary sandstone, silstone, and shale.

Climate

The climate of the Upper Colorado Basin ranges from semi-arid receiving as little as 15 cm of annual precipitation a year to high mountain areas which receive as much as 150 cm annually (Iorns et al. 1965). Runoff per unit area is the lowest of any major drainage in the North America (U.S. Department of the Interior 1987). The Upper Basin receives an estimated 95 million acre feet (MAF) of annual precipitation. It was estimated by Skogerboe (1982) that 80 MAF of this is lost annually to evapotranspiration.

History

The Colorado river basin contains four endemic species found no where else. These include Colorado Pikeminnow (*Ptychocheilus lucius*) formally called Colorado squawfish, Humpback chub (*Gila cypha*), bonytail chub (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*). All four species are protected under the Endangered Species Act.

The decline of native fishes of the Colorado River Basin has been attributed to many changes within the riverine environment, including water development and the associated changes in both flow and stream morphology, the introduction of non-native species, fish harvesting, pesticides and water pollution (Miller 1961, Minckley and Deacon 1968, Seethaler 1978, Behnke and Bensen 1983, Miller et al. 1980, Holden 1991, Quartarone 1993).

With the construction of main stream dams on both the upper Green and San Juan rivers, dam operations have altered the natural hydrograph to varying degrees. The main effected of the dams has

been the reduction of the magnitude and the duration of the spring high flow period. In addition, summer base flows are typically higher to accommodate irrigation needs. Another impact of present dam operation is the reduction in water temperatures due to hypolimnetic releases.

With the extirpation of Colorado pikeminnows from the Lower Basin, populations are now confined to the northern portion of their historic range. Oliver et al. (1979) concluded that fishes near the northern limit of their range often experience high over-winter mortality. Many studies of age-0 temperate zone fish species have indicated that over-winter survival is directly related to size (Henderson et al. 1988, Oliver et al. 1979, Canjak 1988, Toneys and Coble 1979). Several studies have suggested the effect of body size is actually due to the correlation between fish body size and total body lipid content (Isely 1981, Oliver et al. 1979, Miranda and Hubbard 1994).

The introduction of numerous non-native species into the Colorado River system, which historically contained very few species of fish, may have increased competition for food and space. Fausch and White (1988) suggested that exotic species introduced into systems in which they did not evolve could result in a greater niche overlap between sympatric species.

San Juan River

The San Juan River is a major tributary of the Colorado River in the Upper Colorado River Basin. From headwater to the confluence with the Colorado River, the San Juan River drainage basin encompasses 99,200 km² flowing approximately a distance of 355 miles in Colorado, New Mexico and Utah (Carlson and Carlson 1982). The San Juan Basin spans a large array of climatic zones from high elevation alpine forests, to low elevation arid plateaus.

San Juan River originates from the San Juan mountains in southwestern Colorado and flows southwest into New Mexico where natural flow is controlled by Navajo Dam (Platania 1990). Downstream from the hypolimnetic release of Navajo Dam, the San Juan River flows approximately 228 RM River Miles (RM) from Navajo Reservoir to Lake Powell.

The geology of the San Juan River Basin varies in age from Precambrian to Holocene (Blisner 1998). Over its course the San Juan flows through many zones of lithology, including crystalline, igneous and metamorphic rock in the upper reaches and primarily sedimentary sandstone, siltstone, and shale in the lower river reaches.

The San Juan is typical of many river systems in the arid regions of the southwest with predictable spring peaks followed by periods of lower summer and fall discharges.

Colorado Pikeminnow Background

The Colorado pikeminnow (*Ptychocheilus lucius*) was federally recognized as endangered in 1967. It became one of the first species to be covered under the Endangered Species Act of 1973 (Federal Register 39(3): 1175; e.g., Tyus, 1991). This large, endemic cyprinid was once widespread throughout the Colorado River Basin (Miller 1961, Minckley 1973, Holden and Wick 1982). It is now extirpated from the reaches downstream of Glen Canyon Dam (Minckley 1973) and confined to the Upper Basin, above Lake Powell, including the San Juan, Colorado and Green rivers, as well as several smaller tributaries (Minckley 1973).

Of the three major river systems with populations of Colorado pikeminnow the San Juan population is the lowest with the highest probability of extirpation. The decline of Colorado pikeminnows in the San Juan River can be attributed to several major changes within the river system. Navajo Reservoir upstream has altered the temperature and flow regime of the river and has limited the upstream migration of Colorado pikeminnows. The downstream impoundment of Lake Powell has permanently inundated potentially important nursery habitat areas of Glen Canyon. The introduction of numerous non-native species has increased competition for space and food resources. The question is whether the remaining section of the San Juan River is capable of supporting a wild population of Colorado pikeminnow or whether it is beyond repair and cannot provide a self sustaining population.

Since 1991, Colorado pikeminnow reproduction has been documented in five of the seven years of the research project despite a variety of flow regimes. However, recruitment into the adult population is likely very limited. Since 1991, only 30 age-0 Colorado pikeminnows have been captured during backwater and drift sampling (San Juan River Flow Recommendation 1999). Of these collected, the vast majority were collected below the high water mark of Lake Powell, in an area of low gradient nursery habitat at the inflow (Archer et al. 1999). Sediment deposits have created an area of suitable nursery habitat where likely none existed historically (Chart, 1995 personal comm.). Over-winter survival of Colorado pikeminnows in the San Juan River has only been documented twice with the capture of two age-1 Colorado pikeminnows from a single backwater in April 1994 (Archer et al. 1995). During the summer of 1996, two juvenile Colorado pikeminnows were captured by electro-fishing at the inflow of Lake Powell (Schaugaard 1997).

The low levels of recruitment experienced by Colorado pikeminnows in the San Juan River have initiated further study into the mechanisms limiting age-0 success. Three hypotheses have emerged: 1) recruitment is limited by insufficient numbers of spawning adults, 2) the spatial and temporal dynamics of backwater (nursery) habitats prevent the retention of Colorado pikeminnows within the system and 3) interspecific competition between Colorado pikeminnows and non-native species for space and limited food resources limits survival of age-0 pikeminnows.

Many studies conducted on Upper Basin Rivers indicate a reduction in density and a shift in size class length to generally larger individuals over the winter period (Tyus and Haines 1991). These shifts are possibly the result of size selective mortality of the smaller individuals. Converse and Lentsch (1996) used scale analysis of age-0 and adult pikeminnows to examine the relationship between formation of a first year annulus and survival to the older age classes. They estimated that Colorado pikeminnows that reached 45 mm Total Length (TL) by the end of the first growing season were 16 times more likely to survive through the winter period.

Weight specific basal metabolism has been shown to increase as fish size decreases (Shuter et al. 1980, Shuter and Post 1990). Higher metabolic rates of smaller individuals results in the quicker depletion of stored energy reserves than in larger individuals.

Thompson (1989) conducted experiments with three different size classes of hatchery reared, age-0 Colorado pikeminnows. Fish were held at winter temperatures for 210 days. His results showed larger fish entered winter with higher lipid reserves and survived significantly better. Bestgen et al. (1997) also concluded that growth rates of age-0 Colorado pikeminnows had major effects on cohort survival. Individuals with faster growth rates outgrew predation pressure sooner.

Interspecific competition between Colorado pikeminnow and introduced red shiners has been implicated as a factor in the growth and survival of age-0 Colorado pikeminnow (McAda and Tyus

1984, Holden 1977). Minckley (1991) suggested that the introductions of non-natives have had a greater impact on native species than the dams.

Information on the influence of food availability and competition on growth and ultimately survival of age-0 Colorado pikeminnows is very limited. The purpose of this study is to examine what mechanisms have the greatest influence on growth of age-0 Colorado pikeminnows.

Benthic invertebrates, especially Chironomids, have been shown to be an important food for Colorado pikeminnows, as well as speckled dace (*Rhinichthys osculus*), red shiner (*Cyprinella lutrensis*) and channel catfish (*Ictalurus punctatus*) (Muth and Snyder 1995).

Flash floods associated with the monsoon season of August and September likely reduce the standing crop of benthic invertebrates. This reduction in benthic invertebrate densities following flash floods has been documented in many other desert river systems (Fisher et al. 1982, Molles 1985). The effects of such reductions in food availability on fish growth and lipid accumulation, and ultimately over-winter survival of native fish is not well understood.

The first objective of this study was to investigate availability of food resources (benthic invertebrates) to age-0 Colorado pikeminnows in backwater habitats in two distinct reaches of the San Juan River and compare these reaches with the Orray reach of the Green River where age-0 Colorado pikeminnows are more abundant. The second objective was to examine if food availability may be limiting growth, condition factor, and lipid accrual, which may in turn limit overwinter survival of age-0 Colorado pikeminnows.

With the extirpation of Colorado pikeminnows from the Lower Basin, populations are now confined to the northern portion of their historic range. Oliver et al. (1979) concluded that fishes near the northern limit of their range often experience high over-winter mortality. Many studies of age-0 temperate zone fish species have indicated that over-winter survival is directly related to size (Henderson et al. 1988, Oliver et al. 1979, Canjak 1988, Toney et al. 1979). Several studies have suggested the effect of body size is actually due to the correlation between fish body size and total body lipid content (Isely 1981, Oliver et al. 1979, Miranda and Hubbard 1994).

STUDY SITE

The San Juan River is a major tributary of the Colorado River in the Upper Colorado River Basin. The San Juan River drainage basin encompasses 99,200 km² (Carlson and Carlson 1982). The San Juan River originates from the San Juan mountains in southwestern Colorado and flows southwest into New Mexico where natural flow is controlled by Navajo Dam (Platania 1990).

Downstream from the hypolimnetic release of Navajo Dam, the San Juan River flows approximately 228 RM River Miles (RM) from Navajo Reservoir to Lake Powell. This distance varies by approximately ten miles, depending on the level of Lake Powell.

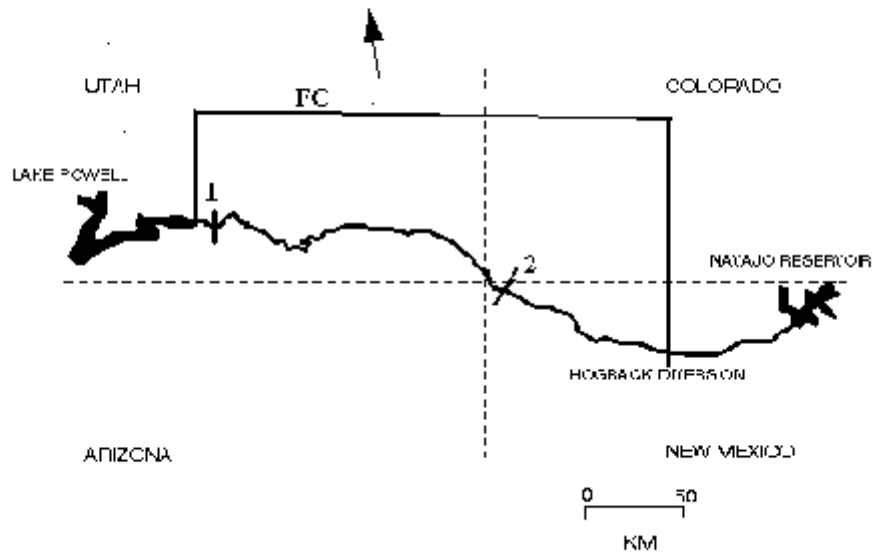


Fig. 1. Study reaches used in invertebrate and food limitation study San Juan River New Mexico, Colorado, and Utah.

The upper experimental reach (2) (Figure 1) was approximately seven miles above Four Corners. In this reach the San Juan River flows through a broad flood plain with frequent braided channels (Blisner 1998). Downstream the flood plain becomes increasingly restricted by canyon walls. Below Mexican Hat, Utah, the San Juan is generally confined to a single channel within steep sided canyons (Buntjer et al. 1993). Below Grand Gulch, Utah, RM 13.4 sediment deposits associated with Lake Powell have greatly reduced the gradient (Archer et al. 1996). The second experimental reach (Reach 1) is located in this area, RM 13-8. Low-velocity nursery habitats available to Colorado pikeminnows within the two study reaches of the San Juan River differ in both geomorphic formation and physical characteristics. Backwaters in the upper reach are typically created at the lower ends of secondary channels (Archer et al. 1994) and substrates are primarily dominated by cobble and cobble/silt. The persistence of low-velocity habitat in this section of river is greater than in the lower canyon bound reaches. While classic backwater habitats are often converted to flow-throughs, low-velocity pool habitats often persist through spikes in flow that could lessen the displacement of age-0 Colorado pikeminnows by providing increased refuge from higher flows.

The lower reach is the only area where classic nursery habitat for Colorado pikeminnows remains in the San Juan River system. The majority of these backwaters are associated with the numerous sandbars within this section of river. The substrate of backwater habitats in this reach is predominantly sand and sand/silt. During early summer this short section of river can have very high densities of low-velocity habitats. During August of 1995, the five mile Utah Division of Wildlife Resources (UDWR) nursery habitat reach contained 52 low-velocity habitats (Archer et al. 1996) Low-velocity habitat density in this section is greater in many years than in the Lower Green River

where age-0 Colorado pikeminnows are relatively abundant. The length of this section is directly dependent on the level of Lake Powell. At full pool (3700 ft. Above Mean Sea Level), Lake Powell historically filled to Grand Gulch (RM 13). During the summer of 1996, Lake Powell was at 3795 ft (AMSL), near RM 6 (Archer et al. 1997).

Backwater persistence is directly related to flow. Small increases in discharge in this canyon-bound section can top many of the sand bars and eliminate many habitats permanently through deposition, while others return as flood waters recede.

The two study reaches differ considerably in species richness and total fish biomass within nursery habitats. The upper reach catch rates are typically the highest for all three common age-0 native fish species (Buntjer et al. 1994). While non-native red shiner and fathead minnows (*Pimephales promelas*) are present, biomass in sampled habitats is typically lower than the lower study reach. Since 1987, only three wild age-0 Colorado pikeminnows have been captured in this section of river. In August 1994, an age-0 (14 mm) Colorado pikeminnow was captured at RM 126.2 in a backwater created by the mouth of the Mancos River (Archer et al. 1995). In October 1987, two age-0 (30 mm, 38 mm) Colorado pikeminnows were captured at RM 125.6 and RM 122.3 (Platania 1990). Both specimens were collected from secondary channel backwaters. This reach also contains the only known spawning bar for Colorado pikeminnows in the San Juan River, approximately 131 RM above Lake Powell (Ryden and Pfeifer 1996).

The lower reach is dominated by non-native species. However, the majority of age-0 pikeminnows captured in the San Juan have been captured in this reach. The non-native fish community in this reach of river is very diverse and includes all of the fauna of the upper reach, plus some species which have migrated up from Lake Powell. These include Threadfin shad (*Dorosoma petenense*), Green sunfish (*Lepomis cyanellus*) and Striped bass (*Morone saxatilis*) (Archer et al. 1996). Threadfin shad were captured in large numbers during UDWR sampling in 1995 and 1996. Non-native red shiners are by far the most abundant species. Actual densities of red shiners within the reach vary considerably by habitat, but overall fish biomass is typically much higher than the upper reach (Archer et al. 1995).

The low-gradient, sand dominated section of the San Juan River has been shown to retain more age-0 pikeminnows than the higher gradient upstream reaches. The distance from the spawning site and the reduction in gradient likely explain most of this pattern. The high density of low-velocity habitats also likely increases retention of age 0 Colorado pikeminnows. Since 1991, 19 of the 21 age 0 Colorado pikeminnows captured during UDWR and Bureau of Reclamation (BOR) early life stage studies have been collected at the inflow of Lake Powell. The only age 1+ Colorado pikeminnows collected from the San Juan River were also collected from this area. Densities of other age 0 native species are very low in this section.

METHODS

Invertebrate Survey

During the summers of 1995 and 1996, benthic invertebrates communities in reaches 1 and 2 of the San Juan River, and the Orray reach of the Green River were collected and enumerated. Samples were collected during August and September. San Juan River samples were collected during UDWR nursery habitat fish studies. In 1995, sampling occurred August 7-16 and September 22-30. Trips began at RM 136 and terminated at Clayhill Crossing (RM 3). As a result, samples from Reach 2 were collected as many as eight days prior to the downstream Reach 1. Green River samples were collected August 19-21 and October 3-4 in 1995.

In 1996, San Juan sampling occurred slightly earlier, July 30- August 12, and September 19-25. Green River samples were collected on August 14 and September 29-30.

Eight backwaters were sampled during each period in both rivers. Four deep (>.5m) and four shallow (<.5m) backwaters were randomly selected. In the San Juan River two deep and two shallow backwaters were sampled in each reach. In the Green River all samples came from backwaters on Orray National Wildlife Refuge.

Methods changed slightly between 1995 and 1996 but were consistent between rivers. In each habitat benthic and pelagic samples were collected across a transect at 1/6 and 2/3 the distance from the mouth to the end of the backwater. In 1995, benthic samples consisted of four-104 mm benthic cores.

In 1996, samples were collected at the same location within the habitats but the number of cores in a sample were increased to twenty-54 mm cores because of the patchy nature of benthic invertebrates.

Sample Processing.--All benthic samples were sieved in the field using 250 Fm mesh. Samples were preserved in 90% ethyl alcohol and returned to the laboratory for processing. The entire sample was counted and identified to the family level by the Bureau of Land Management (BLM) Aquatic Invertebrate Laboratory at Utah State University.

San Juan Pikeminnow Collections

Field collections took advantage of a large stocking effort in which 50,000 age-0 Colorado pikeminnows were released into each reach of the San Juan River. These fish were raised at Dexter National Fish Hatchery in Roswell, New Mexico. Stocking occurred on August 19, 1997, at Shipwreck bridge New Mexico (RM 148) and Mexican Hat Utah (RM 53). For comparisons twenty-five free roaming Colorado pikeminnows were collected from each reach during four different sample periods: At time of stocking, after one month, two months, and four months. Specimens were measured to nearest mm, immediately frozen in liquid nitrogen, and transported to the lab for further analysis (Table 1).

Field Experiment

A controlled experiment was conducted in the same reaches used in the above mentioned invertebrate study. This experiment assessed growth, condition factor, and lipid accumulation between the two reaches. Fish treatments were pikeminnows with and without Red shiners. All replicates contained a total of 20 fish (Table 1).

This experiment was run in 2 m x 2 m mesh cages with 1/8 inch mesh. This mesh size was large enough to not impede movement of invertebrates and zooplankton while retaining the experimental fish.

Invertebrate densities were sampled in each treatment at the start, after three weeks and after six weeks at the conclusion of the experiment. Samples consisted of 10 two inch benthic cores. Benthic invertebrates were also sampled in six other backwaters within each reach to allow comparisons between the cage experiment and ambient river conditions. Methods and analyses were identical to the above river collections.

TABLE 1. Experimental design for field experiments.

Treatment		
	Reach 1	Reach 2
With Competitors (10 Red shiners)	10 Pikeminnows (4 Reps)	10 Pikeminnows (4 Reps)
Without Competitors	20 Pikeminnows (4 Reps)	20 Pikeminnows (4 Reps)

Laboratory Tank Experiment

Tank experiments were conducted at the USU Millville Pond Facility near Logan, Utah. This experiment assessed growth, condition, and lipid accumulation at different food levels (invertebrates), with and without red shiners. The food levels attempted to mimic the densities of benthic invertebrates observed in the two study reaches of the San Juan River.

Experiments were run for six weeks in 2.4 m round flow-through tanks. The treatments are listed in Table 2. Each treatment consisted of three replicates, each containing a total of twenty fish. Fish were selected, weighed and measured to the nearest mm and randomly assigned to a treatment. Initial size ranged between 40-49 mm total length.

Invertebrate communities were sampled in each experimental tank at the start: after 3 weeks, and after six weeks. Benthic samples consisted of 10 two inch core samples. Samples were sieved with 250Fm sieve and enumerated to family. Invertebrate densities (Number/m²) were computed for each treatment for each sampling date. The mean of the three sample periods was then computed to get an average invertebrate density (umber/m²) over the experiment.

Food Limitation

Three methods were used to evaluate food limitation of age-0 Colorado pikeminnows in the San Juan River. 1) Free roaming stocked Colorado pikeminnows were collected from the two study reaches with differing benthic invertebrate densities. 2) Cage experiments were attempted in both reaches, with and without red shiners. 3) Tank experiments were performed at Utah State University (USU), at varying invertebrate densities with and without red shiners. In all three components of the study food limitation was evaluated using instantaneous growth (GTH), condition factor (K) and percent total body lipids (FAT). The methods used in the three separate components of the study were identical.

Growth.--Fish were measured to the nearest mm. Instantaneous growth per day was calculated for each sample period by equation 1:

$$GTH = \log_e L_{\text{time } T} - \log_e L_{\text{time } T-1} / \text{number of days.}; (1)$$

where L is total length (mm)(Ricker 1975). In the field component of this study growth was calculated for each sample period. In controlled experiments growth per day over the whole experimental period was computed.

Condition factor.--Fish were dried at 60°C for 24 hours and weighted to the nearest .001 g. K was calculated by the by equation 2:

$$K = (W \times 10^5) / L^3.; (2)$$

W is weight (g) and L is total length (mm), (Weatherley & Gill 1987).

Lipid Levels.--For lipid analysis, fish were dried at 60°C for 24 hours and weighted to the nearest .001 g. Fat was then extracted using a modification of the procedure described by Bligh and Dyer (1959). The percent of total body lipids was computed by dividing total fat grams by dry weight of the fish (in grams) of all individuals in the replicate, equation 3. For analysis of the field collections relative rate of change from initial fat content was computed by equation 3:

$$(\text{Fat}_{\text{time } N} - \text{Fat}_{\text{initial}} / \text{Fat}_{\text{initial}}).; (3)$$

STATISTICAL ANALYSES

Invertebrate Survey

A one-way Analysis of Variance (ANOVA, SAS for personal computers, 1985) was used to determine significant differences ($P < 0.05$) of the following within reach variables: 1) Position within a habitat. 2) Deep and shallow habitats. 3) Within reaches between years.

Analysis between reaches and rivers was done by combining all habitats within a reach across years. A two-way ANOVA was used to examine relationships between reaches, months and years.

San Juan Pikeminnow Collections

Growth--Instantaneous growth for each period, between reaches was compared using Analysis of Co-variance (ANCOVA , SAS). Time period was used as the co-variate to compare between reaches.

Condition Factor--The relative rate of change in condition factor was used to examine differences between reaches. An Analysis of Co-variance (ANCOVA) using time as the co-variate was used to examine differences between reaches.

Lipids--The relative rate of change in percent total body lipids was used to examine differences between reaches. An Analysis of Co-variance (ANCOVA) with time as the co-variate was used to examine differences between reaches.

Laboratory and Field Experiment

Growth--Growth between treatments was analyzed using Analysis of Co-variance (ANCOVA) The mean number of invertebrates (MINV) measured in each treatment was used as the co-variate to compare between treatments (with and without Red shiners). Regression analysis was performed to examine the relationship between food availability (MINV) and growth across fish treatments.

Condition Factor--In laboratory and field experiments, absolute increase $K_2 - K_1$ was used for analysis. Analysis of co-variance was performed using the mean number of invertebrates as the co-variate to compare between fish treatments. Regression analysis was performed to examine the relationship between mean invertebrate density and condition factor across fish treatments.

Lipids--In laboratory and field experiments, absolute lipid increase, $Fat_2 - Fat_1$, was used for analysis. Analysis of co-variance using the mean number of invertebrates as the co-variate to compare between fish treatments. Regression analysis, using lipid levels as the dependent variable and mean invertebrate density as the independent variable, was performed to examine the relationship between food availability and lipid accrual across fish treatments.

RESULTS

Invertebrate Survey

No significant differences in total benthic invertebrates were found between either the mouth and the end of the backwater during either sample period, nor between either year ($P > 0.05$). When deep and shallow habitats were compared, no significant differences were observed at the reach nor river levels during August ($F = 0.05$, $P = 0.82$) or September ($F = 0.25$, $P = .62$).

In Reach 1, invertebrate densities were not significantly different between years during August or September (FIG. 2). In Reach 2, there were no significant differences between August samples between 1995 and 1996 ($F = 1.71$, $P = 0.23$) However, in Reach 2 densities were significantly greater in 1996 than in 1995 during September ($F = 23.49$, $P < 0.00$, FIG. 3).

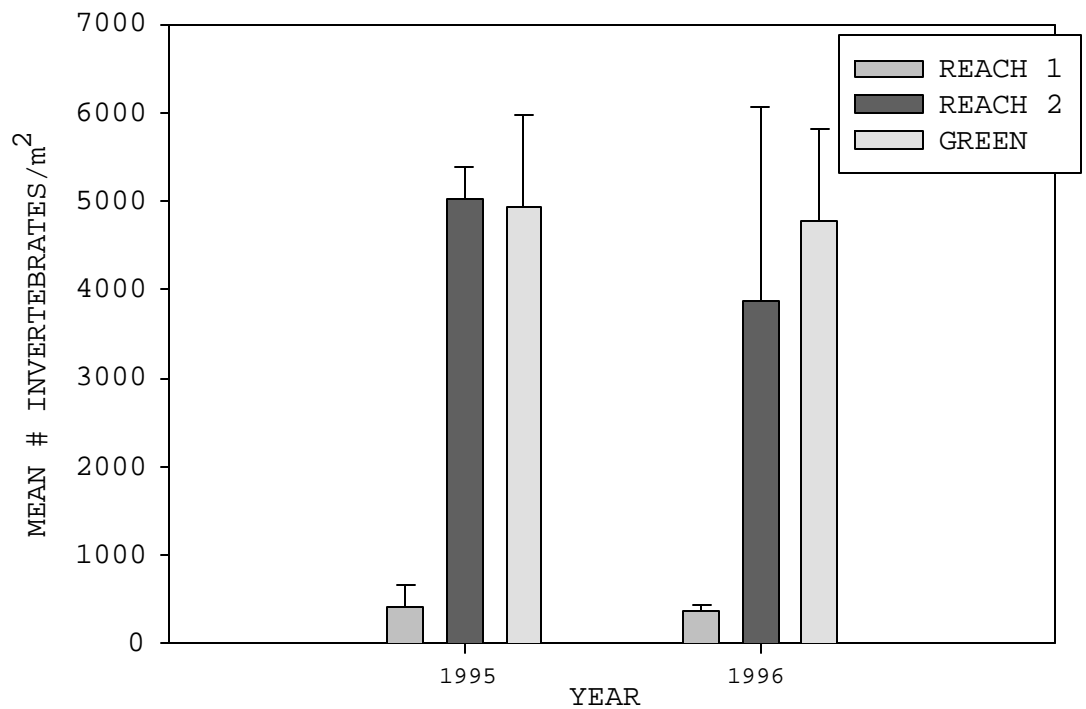


Fig. 2. Mean invertebrate density (#/m²) during August San Juan and Green Rivers 1995 and 1996.

Comparisons between reaches of the San Juan and the Green River resulted in significant interactions between months ($F = 18.69$, $P = 0.0001$) and reaches ($F = 62.12$, $P = 0.0001$).

During August sampling in Reach 2 of the San Juan and the Orray reach did not differ significantly between August of either year ($P > 0.05$). However, Reach 1 of the San Juan River was significantly lower than the Green River reach and Reach 2 of the San Juan in total invertebrate density during both years, and when years were combined.

During September sampling there was a significant interaction between reaches. The Green River had significantly higher density of benthic invertebrates than either reach of the San Juan River during both years and when years were combined ($P > 0.05$ FIG. 5)

San Juan River Collections

Growth.--No significant differences existed between reaches in instantaneous growth ($P > 0.05$). At the time of stocking, Reach 1 fish were on average 4.7 mm larger (Table 3). However, there

was a trend of higher growth in Reach 2 over the study period (FIG. 4). During the first three sample periods, mean size increased more in Reach 2 than in Reach 1.

Growth within reaches was significantly different over time ($F = 32.41$, $P = 0.01$). Age-0 Colorado pikeminnows total length increased during the first three sample periods (August 19 - October 15). Mean total length of Reach 2 fish increased by 2 mm more than Reach 1 fish during sample periods 1-3. By mid October, growth rates diminished and from mid-October to December mean size declined in both reaches.

Condition.--Relative change in condition factor was not significantly different between study reaches ($P > 0.05$). At stocking condition factor was higher in Reach 1 than the lot stocked in Reach 2 (Table 4). During September and December sampling Reach 2 fish had higher condition factors. However, during October condition was slightly lower in Reach 2.

Relative condition was not significantly different within reaches over the study period ($F = 2.91$, $P = 0.17$). Condition in both reaches declined the first month following stocking. In Reach 1 condition increased slightly between sample period two and three but declined between three and four. In Reach 2 condition increased during every period following the initial decline following stocking (FIG. 5).

Lipids.--Relative lipid content was not significantly different between reaches over the study period ($P > 0.05$). At stocking lipid levels were higher in Reach 1 (Table 5). By sample period two, differences among reaches were small. During periods three and four, percent total body lipids was greater in Reach 2 than in Reach 1.

Relative lipid content varied significantly within reaches over the study period ($F = 16.67$, $P = 0.03$). At the time of stocking lipid levels of the hatchery reared pikeminnows ranged between 36.8 and 32.3 percent of total dry weight. By mid-September both lots dropped to around 17 percent lipids. In sample periods two and three lipid levels continued to decline in both reaches, but Reach 2 levels remained higher than Reach 1 (FIG. 7). Between the October and December sampling dates lipid levels increased in both reaches and Reach 2 remained higher.

River Experiment

The river experiment was destroyed by a large flash flood that occurred during early August 1997. Flows at the Bluff USGS gage rose from 1480 cfs on July 29 to 6270 cfs on August 6 1997. No data were collected from this experiment.

Tank Experiment

Growth.-- Growth between fish treatments was not significantly different ($P > 0.05$). However, there was a trend towards higher growth rates for the pikeminnows with Red shiner treatment (0.0031 ± 0.0003) [mean \pm SE] than for the pikeminnows only treatment ($0.0023 \pm .0003$). Invertebrate density and growth were not significantly correlated ($P = 0.23$, $r^2 = 0.14$, FIG. 7).

Condition.--Absolute change in condition factor was not significantly different between fish treatments ($P > 0.05$). However, there was a trend towards higher growth rates for the pikeminnows with Red shiner treatment (0.171 ± 0.0098) [mean \pm SE] than for the pikeminnows only treatment ($0.166 \pm .0062$, FIG 6). Condition factor and mean invertebrate densities were not significantly correlated ($P = 0.63$, $r^2 = 0.02$).

Lipids.--Percent total body lipids was not significantly different between fish treatments ($P > 0.05$). The treatment means were very similar for pikeminnows and Red shiner treatment (27.44 ± 1.45) [mean \pm SE] and pikeminnows only treatment (27.55 ± 1.095). The relationship between lipids and mean invertebrate density were weak and not significant ($P = 0.24$, $r^2 = 0.13$)

DISCUSSION

The results of this study indicate that food availability may be limiting in some reaches during some periods and differences occur between the study reaches of the San Juan River. Our study concluded that physical factors such as position within a habitat were not important in explaining significant differences in invertebrate densities. This agrees with the work done by Schaugaard (1997) on the Green River in 1993. At the majority of the sites, the end of the backwater had consistently higher invertebrate densities, but differences were not significant. This was particularly true during September sampling in the San Juan, when many habitats had been scoured by monsoon flood events.

The relationships between habitat depth and invertebrate densities were also weak. However, the majority of the highest density sites were < 0.5 m deep. This also agrees with the work done by Schaugaard (1997).

The lack of significant differences between years within reaches during August or September sampling periods indicates that the sample methods employed were adequate to accurately measure patchy benthic invertebrate densities. The only significant relationship within a reach, was between September 1995 and 1996 in the Reach 2. The September 1996 sample period was on the descending limb of a monsoon season flash flood that scoured many of the habitats one or two days prior to sampling. The effect of the flood event was lessened in the lower reach because ten days had passed before sampling occurred, compared to two in the upper reach.

Our reported densities of benthic invertebrates in the Green River are less than in a study conducted by Wolz and Shiozawa (1995) in the same reach of the Green River. However, much of the difference can be explained by differences in sampling methodology. In their study, one backwater was sampled during July and August resulting in replication of samples within a backwater. Samples consisted of one 47 mm core per sample. In our study, backwaters within reaches were the replicated sample unit. Wolz also used smaller mesh sieves, which collected a higher proportion of the smaller taxa such as Nematoda.

The significantly lower densities of benthic invertebrates in Reach 1 of the San Juan River compared to the Green River during August and September of both years could have implications on growth and survival of wild age-0 Colorado pikeminnows. The lower gradient section of Reach 1 has been shown to be an important area of nursery habitat for Colorado pikeminnows in the San Juan River (Trammell 1997). If densities of benthic prey are limiting consumption by age-0 Pikeminnows, growth, condition and lipid accrual could be negatively affected (Ivlev 1961, Walters and McQueen 1994, Fox 1989). This could have major implications on survival (Henderson 1985, Cryer et al. 1986) and ultimately recruitment of wild pikeminnows given the importance of this reach of the San Juan River (Archer et al. 1996).

Reach 2 of the San Juan River consistently had higher densities of benthic invertebrates than Reach 1. This reach was also not different during August from the Orray reach of the Green River that

has been shown to be an important area of Colorado pikeminnows nursery habitat. However, since 1991, only one wild age-0 Pikeminnows has been collected from Reach 2 despite extensive sampling (Archer et al. 1999).

During September, invertebrate densities in the San Juan River were lower in both years than in the Green River. The lower invertebrate densities observed during September sampling were the result of flood events that occurred during early September in 1995 and mid-September during 1996. At flows above 2000 cfs many backwater habitats present at base summer flows in both reaches of the San Juan River can be inundated and scoured (Archer et al. 1996). Both reaches showed declines in abundances of invertebrates following flood events.

Similar reductions in benthic invertebrate densities following flash floods has been documented in many other desert river systems (Fisher et al. 1982, Molles 1985). Fisher et al. (1982) found a 98% reduction in invertebrate biomass following a large flood event. However, he concluded that benthic invertebrate numbers recovered within three weeks, and biota diversity recovered in two months.

Gurtz and Wallace (1984) found that larger more stable substrate showed less of an effect than did smaller sand or silt substrates. This suggest that the impact of flood events may be less severe in Reach 2 which is primarily dominated by cobble while Reach 1 is exclusively sand/silt substrate.

In another study of a desert stream, Boulton et al. (1992) concluded that timing was more important than the magnitude of flood events. He hypothesized that the stability of benthic algae was the determining factor in resilience of benthic invertebrates during flood events. He found that mid-summer mats of algae were more stable than mid-fall mats which had degenerated. Hence, late summer and fall flood events such as those often observed in the San Juan River could have had more detrimental effects on benthic invertebrate biomass.

Our study shows that Reach 2 of the San Juan River and the Orray Reach had higher densities of benthic invertebrates than Reach 1 of the San Juan at the inflow of Lake Powell during the summers of 1995 and 1996. However, the flashiness of the hydrograph of the San Juan River could lower invertebrate levels significantly in both reaches to levels which may be insufficient to provide optimal prey densities for age-0 Colorado Pikeminnows.

In the field study of growth, condition and lipid accrual we saw no significant differences between the two study reaches of the San Juan River. While instantaneous growth was higher in Reach 2 during both September and October, differences were small and not statistically significant. However, Muth and Snyder (1995) concluded that small differences in growth rates of razorback suckers (*Xyrauchan texanus*) can be biologically significant if size dependent processes are important determinants of larval survival. Many studies of age-0 temperate zone fishes would support these ideas, because they concluded that overwinter survival was directly related to size (Henderson et al. 1988, Oliver et al. 1979, Canjak 1988, Toney et al. 1979).

Condition factor also showed a pattern which suggests that Reach 2 provided better conditions, however again differences were not statistically significant. During December of 1997 at the conclusion of the study, condition factor was higher in Reach 2 than in Reach 1.

Percent body lipids were also higher in Reach 2 at the conclusion of the study, however differences were again not statistically significant. At the initiation of the study lipid levels of the stocked Colorado pikeminnows were very high ranging from 36.8 % in Reach 1 to 32.0 % in Reach 2. However, it appear that because of the hatchery origin to these fish lipid levels were unrealistic high compared to wild individuals. Thompson (1989) found that lipid levels of hatchery-reared fish were

almost twice as great as those of wild individuals. Following stocking lipid levels dropped drastically from initial levels in both reaches through sample period three. During sample period four, lipid levels increased slightly in both reaches to levels similar to those observed during mid-September (14.7-17.5%). Thompson also concluded that age-0 pikeminnows must maintain lipid levels greater than 3-6% of their total dry weight to survive the winter period (Thompson 1989).

Our results from the riverine food limitation study are inconclusive because of several confounding factors. First, because of lack of Department of Agriculture Disease Certification, stocking occurred six weeks later than desired. This resulted in a short growing season which severely limited the time available for differences between the two reaches to develop. By October 11, 1997 (only 43 days post stocking) main-channel temperatures dropped below 13^o C (USGS 1998), the threshold for growth of Colorado pikeminnows (Black and Bulkley 1985). In addition, one week prior to stocking and two weeks following stocking large flood events occurred (Trammell 1997). These events likely affected food availability in both reaches. We observed declines in both condition and percent body lipids in both reaches from the time of stocking to the first sample period. Considering the highly variable nature of the hydrograph during late summer and fall of 1997, this was a relatively short period for significant differences to develop between reaches.

Second, our results are further confounded by the differences between lots at the time of stocking. Stocked groups differed in the size, condition and lipid content. The downstream group, which was stocked at Mexican Hat, was on average 4.7 mm larger than the Shipwreck lot. This difference may have further disguised differences between reaches in the variables measured.

Finally, this component of the study lacked statistical power because of the design. By comparing reaches over time it was necessary to use the means of all fish collected within a reach for statistical analysis to avoid pseudo replication. While the means provide insight into the relationships, only three numbers from each reach were available for inclusion in statistical analysis.

In an attempt to increase our statistical power, we attempted to conduct field enclosure experiments within each reach. This would have provided us with replicates within reaches under natural field conditions and thus considerably more statistical power. Unfortunately, this experiment was destroyed by a flash flood before any data could be collected.

The laboratory tank experiments that attempted to mimic the densities of invertebrates within the study reaches did not result in realistic invertebrate densities. By the end of the experiment invertebrate densities rose dramatically in all treatments and many were two or three fold higher than desired levels. It is unlikely that consumption of the experimental fish were limited at the observed densities. We saw no significant correlations between invertebrate densities within treatments and any of the measures used to assess food limitation.

In conclusion, because of highly variable nature of the hydrograph, temporal variations in food availability undoubtedly limit growth, and ultimately survival of age-0 Colorado pikeminnows in the San Juan River. While Reach 2 of the San Juan provides similar prey densities during early summer as the Orray reach of the Green River, use of this reach by age-0 wild Colorado pikeminnows is very limited. It is still unclear if backwater habitat persistence, quality or the gradient of this reach limits retention of naturally spawned individuals. Whatever the mechanism limiting retention of fish in the upper reaches of the San Juan, the importance of the low gradient area in Reach 1 can not be denied. This reach had consistently lower prey densities than the other study reaches.

However, at this time the effects of the lower food availability in Reach 1 are unknown. It appears that Reach 2 may have provided better conditions for growth. To fully address this question larval fish will have to be stocked early in the growing season and followed through their development.

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Table 2. Means, standard deviations, and change between sample periods, for growth by reach from Colorado pikeminnows collected during field studies, San Juan River, 1997.

Source	Date	Reach 1 Mean (SD)	Reach 2 Mean (SD)	Reach 1 Change	Reach 2 Change
Length	08/19	47.42 (5.06)	42.54 (3.99)	-	-
	09/01	49.97 (3.19)	45.72 (3.94)	+2.55	+3.18
	09/22	53.83 (4.41)	49.59 (4.84)	+3.86	+3.87
	10/15	56.11 (4.62)	53.17 (4.56)	+2.28	+3.57
	12/05	55.65 (4.06)	50.35 (4.31)	-0.46	-2.81

Table 3. Means, standard deviations, and change between sample periods, for condition by reach from Colorado pikeminnows collected during field studies, San Juan River, 1997.

Source	Date	Reach 1 Mean (SD)	Reach 2 Mean (SD)	R 1	R 2
Cond	08/19	0.164 (0.20)	0.137 (0.025)	-	-
	09/01	0.111 (0.02)	0.117 (0.015)	-0.15	-0.02
	10/15	0.123 (0.02)	0.119 (0.010)	+0.12	0.00
	12/05	0.119 (0.01)	0.125 (0.020)	-0.00	+0.01

Table 4. Means, standard deviations, and change between sample periods, for lipids by reach, from Colorado pikeminnows collected during field studies, San Juan River, 1997.

Source	Date	Reach 1 Mean (SD)	Reach 2 Mean (SD)	R 1 Change	R 2 Change
Lipids	08/19	36.81 (1.52)	32.22 (1.21)	-	-
	09/22	17.92 (1.43)	17.26 (1.75)	-18.89	-14.96
	10/15	9.84 (0.06)	13.34 (0.45)	-8.08	-3.92
	12/05	14.73 (1.47)	17.42 (2.33)	+4.89	+4.08

Table 5. Means and standard errors for growth, condition, and percent lipids from the laboratory tank experiment.

Source	Treatment	Mean	(SE)
Growth	Pikeminnows Only	0.0029	(0.0003)
	Pikeminnow and Red Shiners	0.0031	(0.0005)
	Combined	0.0030	(0.0004)
Condition	Pikeminnows Only	0.1662	(0.0063)
	Pikeminnow and Red Shiners	0.1707	(0.0098)
	Combined	0.1682	(0.0082)
Lipids	Pikeminnows Only	27.55	(1.0952)
	Pikeminnow and Red Shiners	27.44	(1.4535)
	Combined	27.49	(1.2292)

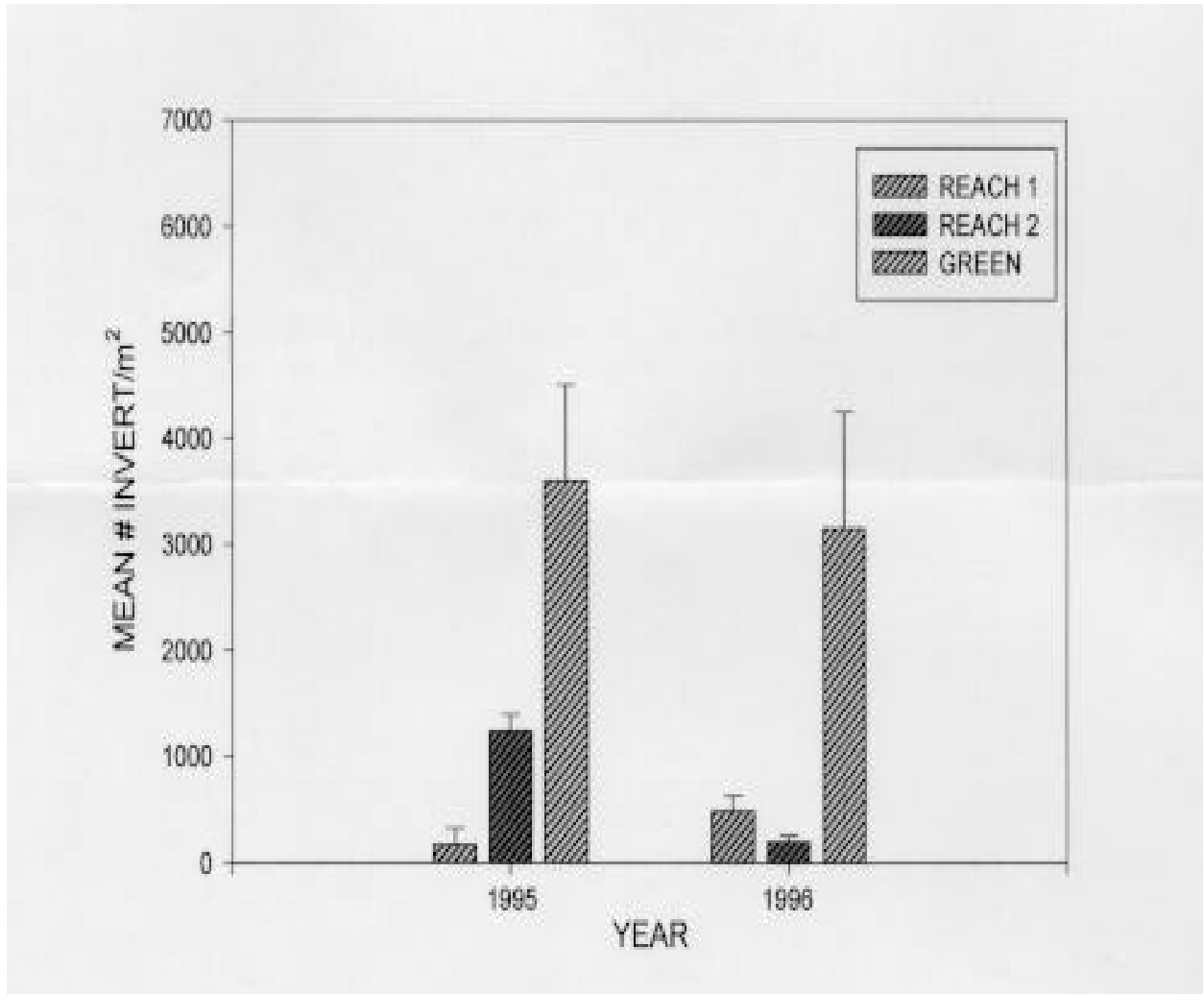


Fig. 3. Mean invertebrate density (3/m²) during September San Juan and Green rivers 1995 and 1996.

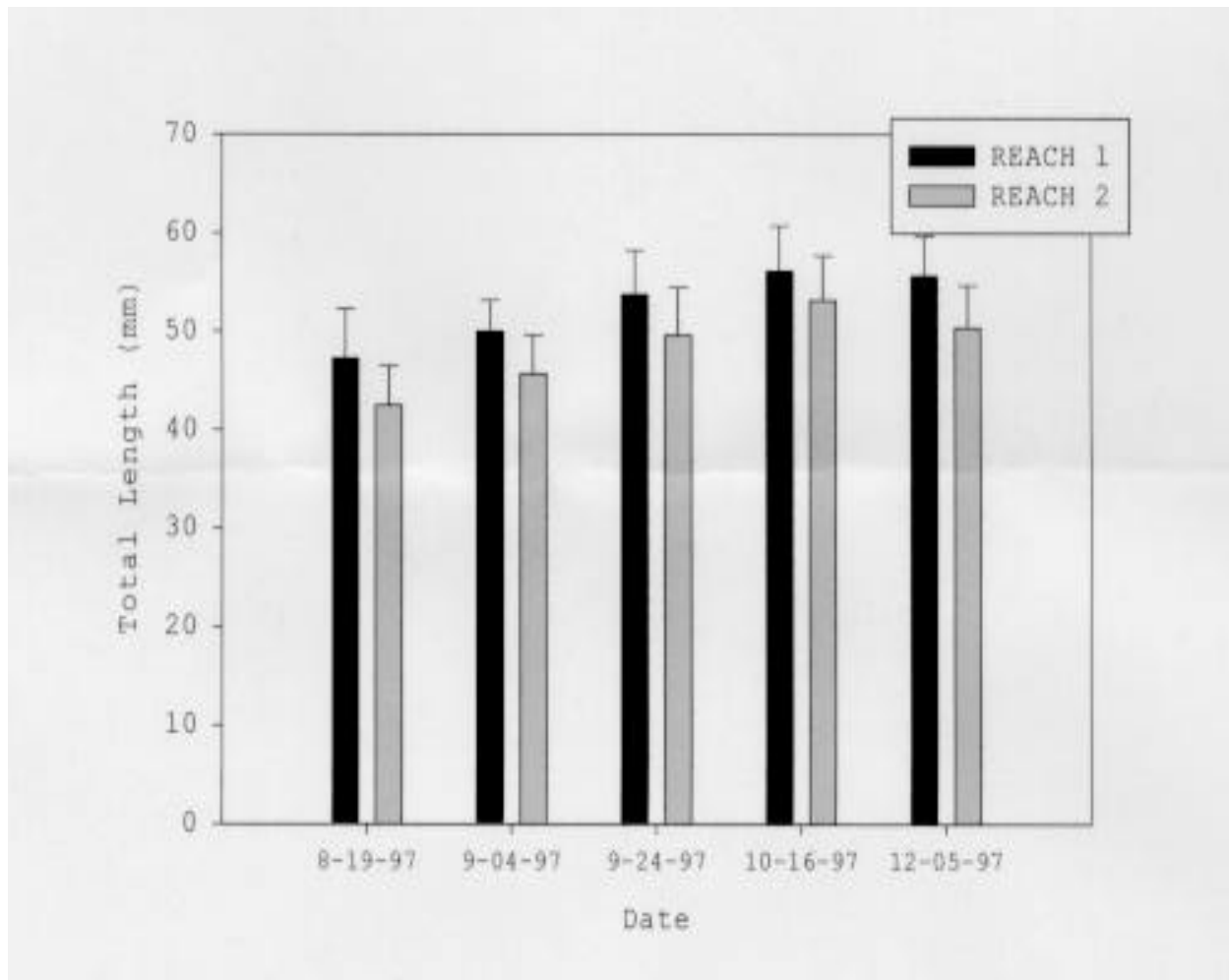


Fig. 4. Total length for Colorado pikeminnow by a sampling date. Means and standard deviations are shown.

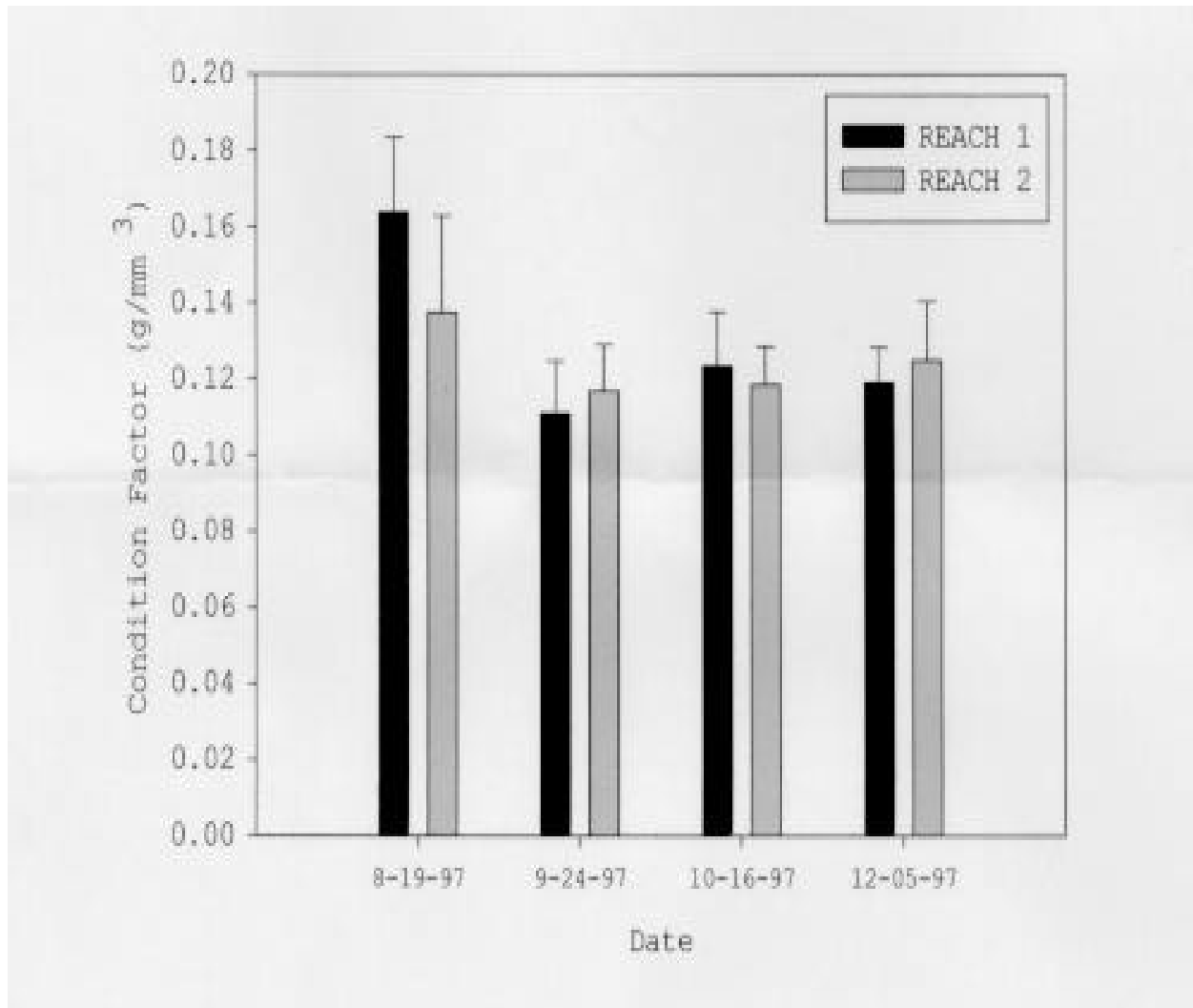


Fig. 5. Condition factor for Colorado pikeminnow by sampling date. Means and standard deviations are shown.

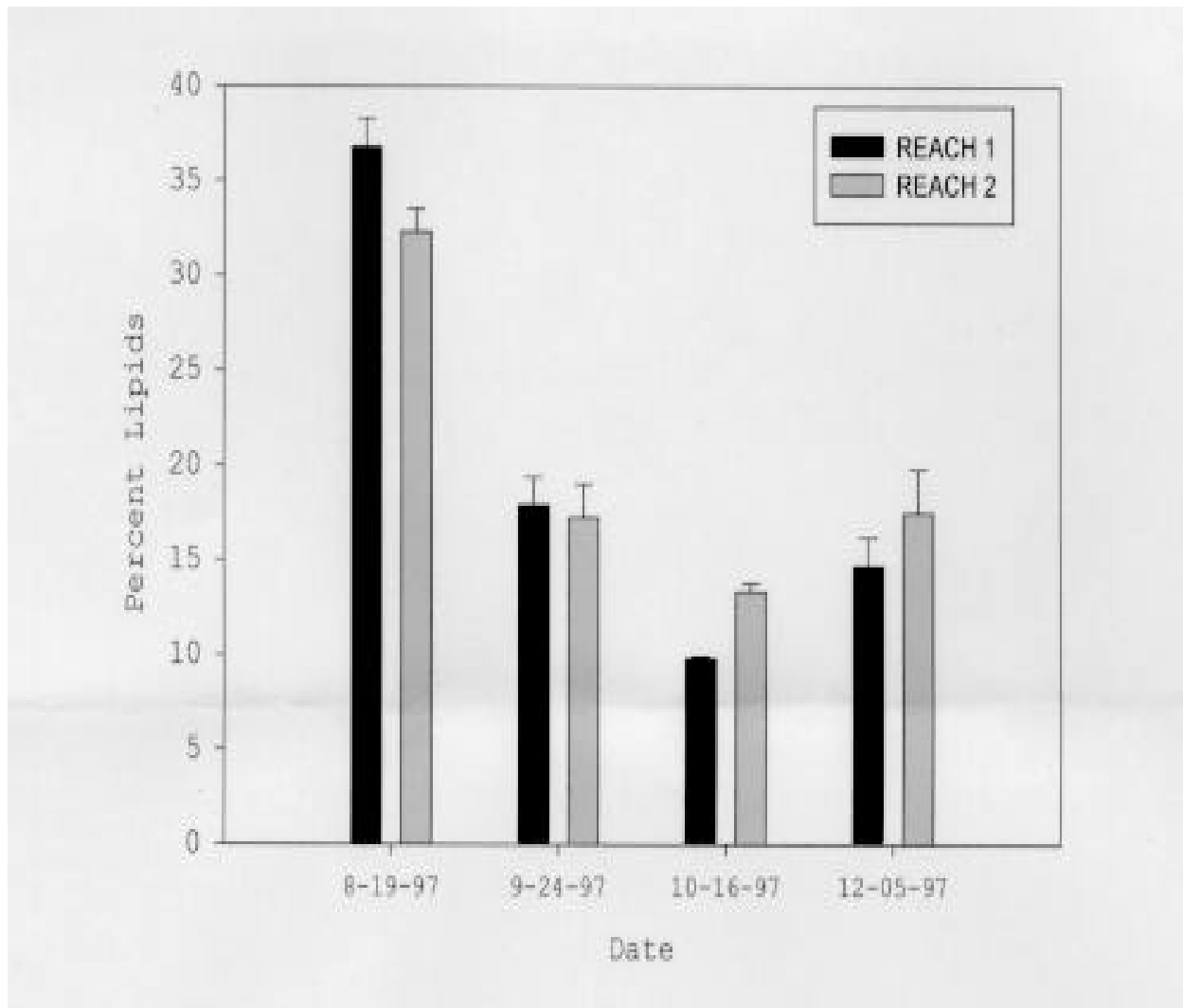


Fig. 6. Percent lipids (g/g dry weight) for Colorado pikeminnow by reach and sampling date. Means and standard deviations are shown.

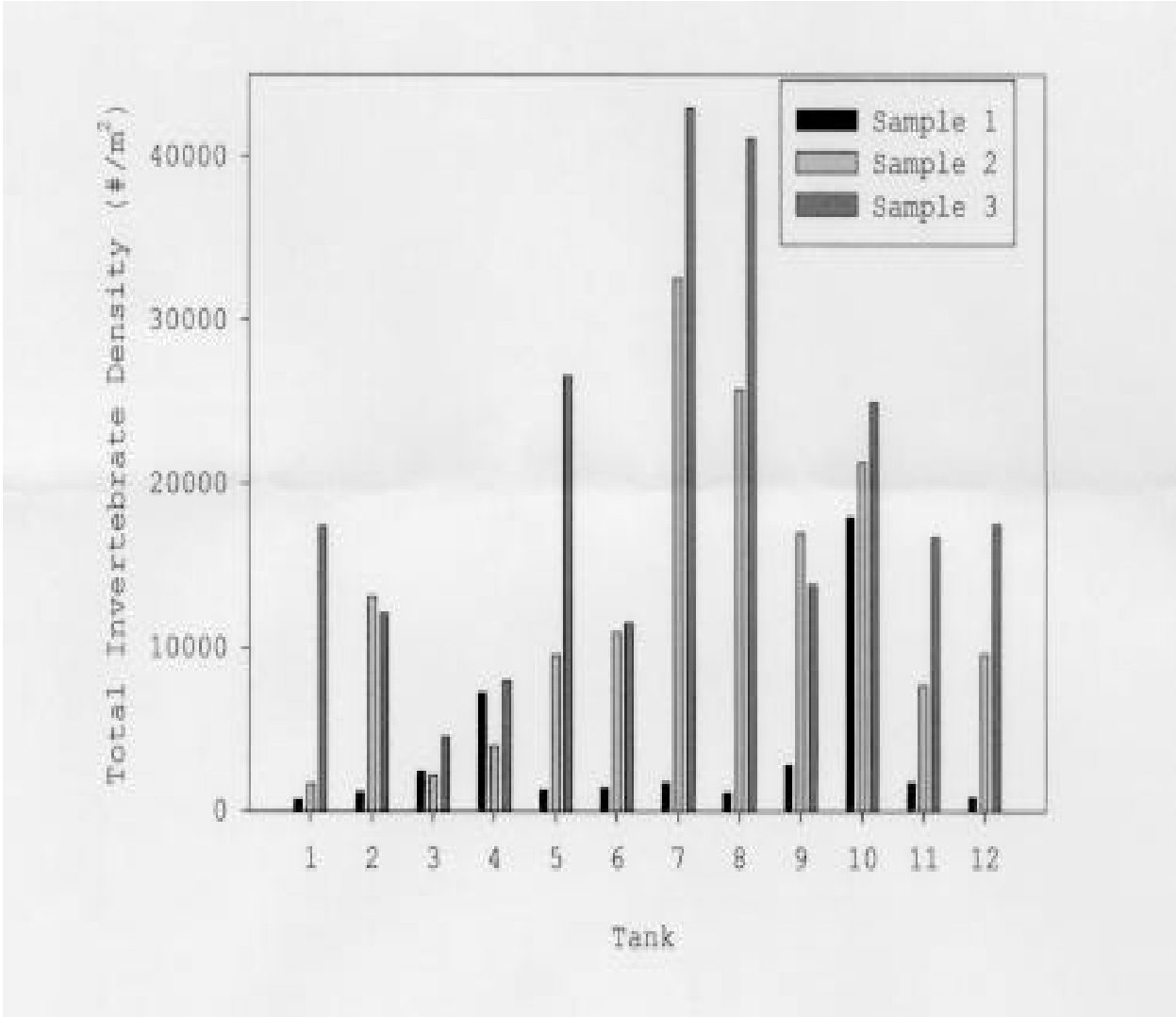


Fig. 7. Total invertebrate densities for tank experiment by sample period.

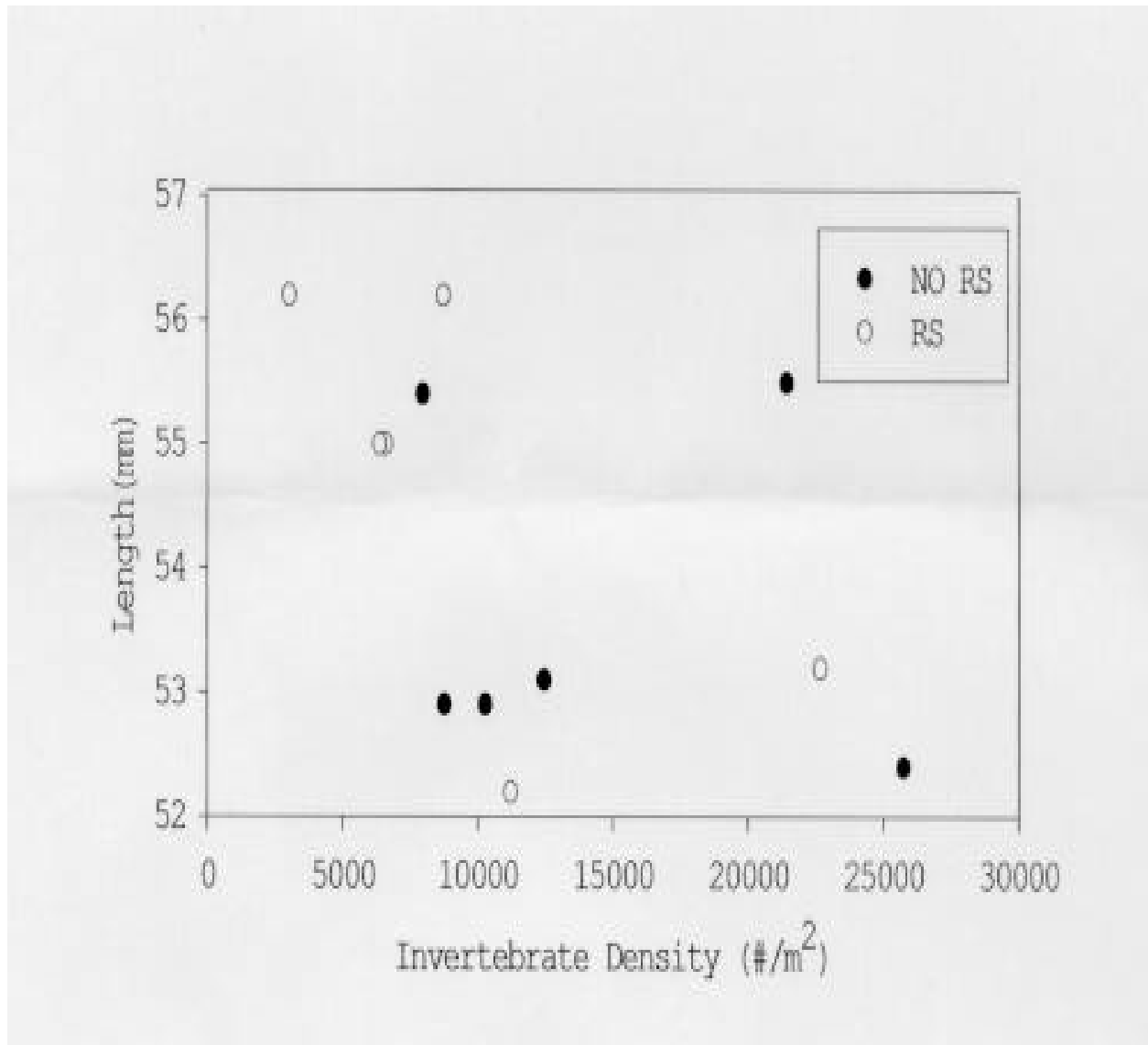


Fig. 8. Mean length Colorado pikeminnow and invertebrate density, from tank experiment. With red shiner (RS) and without red shiner (NO).

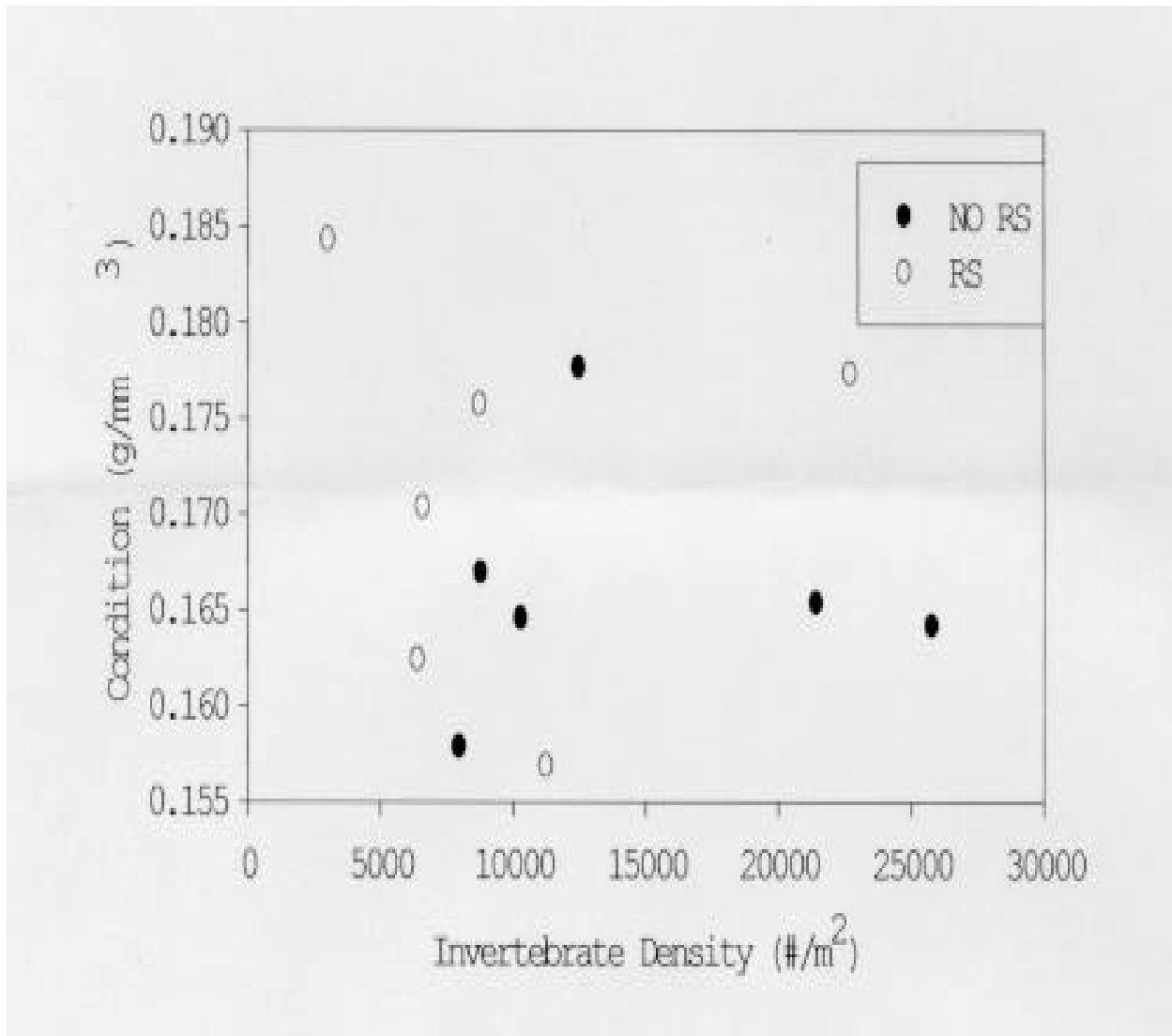


Fig. 9. Condition factor Colorado pikeminnow and invertebrate density, from tank experiment. With red shiner (RS) and without red shiner (NO).

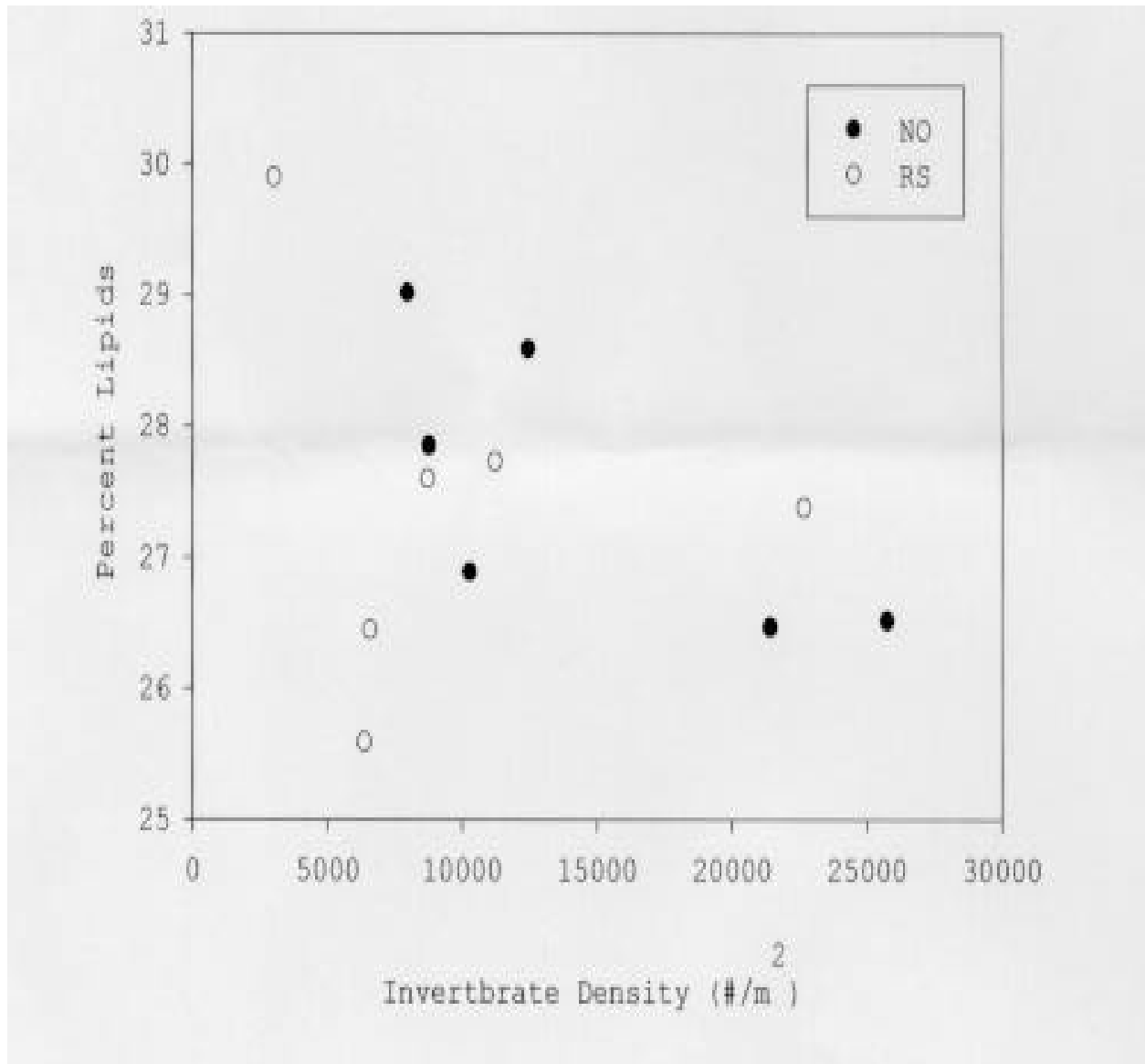


Fig. 10. Percent lipids (g/g dry weight) Colorado pikeminnow and invertebrate density, from tank experiment. With red shiner (RS) and without red shiner (NO).

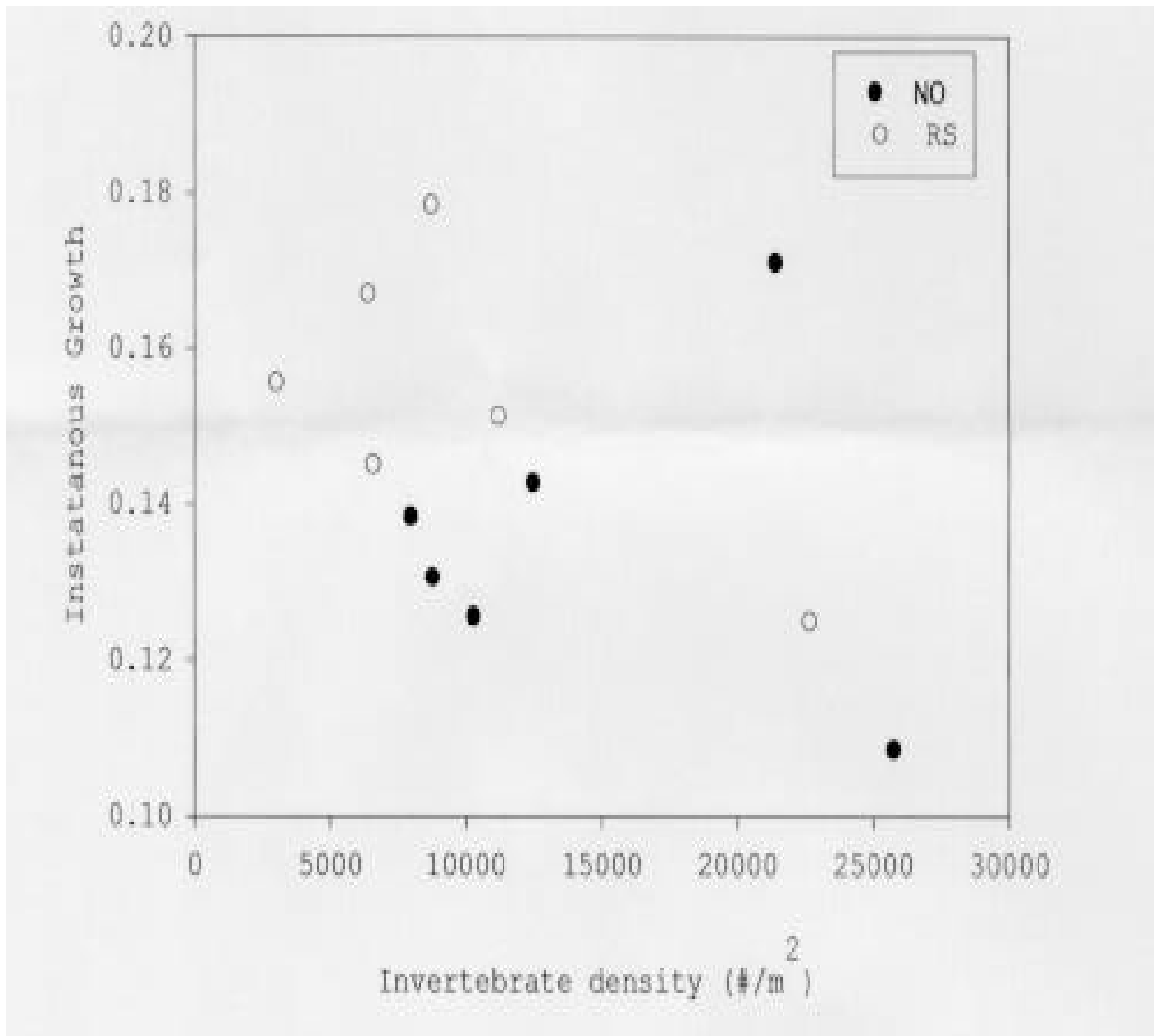


Fig. 11. Instantaneous growth Colorado pikeminnow and invertebrate density, from tank experiment. With red shiner (RS) and without red shiner (NO).