San Juan River Fishes Response to Thermal Modification

A White Paper Investigation

San Juan River
Utah/New Mexico

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Prepared for:

San Juan River Recovery Implementation Program
Biology Committee

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION AND OVERVIEW

The San Juan River Basin is an arid to sub-arid 60,000 square kilometer subbasin of the Colorado River, originating high in the San Juan Mountains of Colorado and emptying into Lake Powell, a Bureau of Reclamation Reservoir (USGS 2005). In 1962, the San Juan River was impounded by Navajo Dam above Archuleta, New Mexico, as part of the Colorado Storage Project. Since that time, releases from Navajo Dam have been a primary control feature for in-stream flows and variations in aquatic habitat in San Juan River (from the base of the dam to Lake Powell). Prior to the construction of large scale dams and reservoirs, the Colorado basin supported a unique assemblage of endemic fishes most of which have now been listed as federally endangered species (Carlson and Muth 1989; USFWS 1995).

The reduction in the populations of the Colorado River fishes has been attributed to a number of factors. Primarily the building of mainstream dams, the associated dewatering or altered hydrographs, resultant changes in channel geomorphology and water quality, as well as the introduction of exotics, have been suggested (Miller, 1961; Minckley and Deacon, 1968; Seehaler, 1978; Johnson and Renne, 1982). The thermal alteration below the dams has been suggested as a cause for reduced reproduction and downstream displacement due to lower water temperatures from hypolimnetic discharges (Vanicek, 1967; Vanicek et al., 1970; Holden, 1973; Seethaler, et al., 1976).

Within the San Juan River basin, Navajo Reservoir not only altered the natural hydrograph, but also impacted water quality. Because of the presence of a hypolimnetic (bottom of reservoir) water release, the riverine temperatures immediately below the reservoir are now cooler in the summer (4-8˚C now vs. 20-25˚C before the dam) and warmer in the winter (4˚C now vs. 0˚C before the dam). It was therefore of interest to the San Juan River Recovery Implementation Program (SJRIP) to investigate the ramifications of these thermal alterations to the San Juan River's downstream native and non-native fish species as well as the spatial extent of these modifications.

Two preliminary investigations were undertaken to help address this question. One investigation was to conduct a "white paper" literature review. The purpose of this review was to summarize the known thermal requirements of the native and dominant non-native species in the San Juan River below Navajo Dam. Understanding the thermal requirements of the fish species in the river would allow inferences to be made about observed spatial community changes due to river temperature alterations below Navajo Dam. In addition, the literature review could act as a partial basis for evaluating the feasibility of warming Navajo Reservoir water releases in the future.

Native species considered included the Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*). Non-native species present in the San Juan River and covered in this review included channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), largemouth bass (*Micropterus salmoides*), striped bass

(*Morone saxatilis*), and rainbow trout (*Oncorhynchus mykiss*). In order to better define the thermal requirements for these species, literature reviews were separated by life stages where possible. It is fully acknowledged that thermal changes within this river system will also effect the detrital decomposition, periphyton and macroinvertebrate communities. It is however beyond the scope of this review to describe impacts to these system-wide components.

The literature review was conducted in conjunction with a second investigation. This study centered on thermal modeling on Navajo Reservoir and the San Juan River below the dam. This work was completed by the Bureau of Reclamation and is available in a separate report.

2.0 OBJECTIVES

The literature review conducted in this "White Paper Investigation" centered on one major objective. This objective, once completed and in conjunction with the thermal modeling, would allow inferences to be made concerning the probable responses of the fishery to thermal modifications at Navajo Reservoir. To help in this analysis, two additional reviews were undertaken and are covered under objectives 2 and 3, below. The specific project objectives are:

Objective 1. Review and summarize the thermal requirements of the major native and non-native species found in the San Juan River from Navajo Dam to its confluence with Lake Powell;

Objective 2. Review and summarize "case studies" of riverine responses to reservoir thermal modifications below a large western reservoir; and,

Objective 3. Briefly summarize the current spatial distribution of San Juan River fishes and conduct preliminary analysis of causative factors.

Each of these objectives will be covered in a separate section of this report.

3.0 SPECIES ACCOUNTS

The following are summaries of the thermal requirements of the major fish species found in the San Juan River. The literature reviewed included peer-reviewed journal articles, gray literature (agency or recovery program reports), abstracts of presentations, and thesis or dissertations. Temperature-related studies included a wide range in investigative approaches, such as laboratory studies or direct field observations. Because of the wide array of studies, the available thermal tolerance information has been summarized in a graphical-tabular format. Table 1 is the summary of the available information on the temperature requirements of the ten major fish species in the San Juan River (5 native and 5 non-native). In addition, a short narrative summary for each species is provided.

3.1 Overview of Terminology and Approach

In the review process, a wide range of nomenclatures were encountered. These have been normalized across all reports in this literature review in order to minimize confusion over definitions of thermal tolerances. A graphical summary of the nomenclature used in this report is presented in Figure 1. In this figure, the example used is rainbow trout, the dominant species found in the San Juan River immediately below Navajo Reservoir.

Table 1. The description of the thermal niches of various species found in the San Juan River based upon literature values. The maximum observed summer temperatures which correspond to the maximum longitudinal fish densities in the San Juan River is also provided where available. The table represents a summary from Section 3.0 and Section 6.0 of this report.

	TEMPERATURE (˚C)																												Authors
	8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	
Channel Catfish																													Allen & Strawn 1968, Aquatic Life Habitat Assessment (internet literature), Buentello et al. 2000, Brown 1942, Byerly et al. 2005, Clemens & Sneed 1957, Warm Water Fishes Optimal Temperatures (internet literature), San Juan River 28.6˚C
Egg								🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X	🟨	🟨	🟨	🟨	🟨	🟨	
Larval														🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X							
Juvenile														X	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨	X	
Adult														X	🟨	🟨	🟨	🟨	🟨	🟨	O	A	O	🟨	🟨	🟨	🟨	X	
Largemouth Bass																													Adams et al. 1982, Aquatic Life Habitat Assessment (internet literature), Coutant 1975, Rice et al. 1983, Scheller et al. 1999, Stuber et al. 1982
Egg								🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X						
Larval													🟨	O	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X						
Juvenile			🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	O	O	O	O	O	🟨	🟨	🟨	🟨	🟨	
Adult			🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	O	O	O	O	O	🟨	🟨	🟨	🟨	🟨	
Colorado Pikeminnow																													Bestgen 1996, Bestgen & Bundy 1998, Bestgen & Williams 1994, Bestgen et al. 1998, Bulkley & Berry 1983, Bliesner & Lamarra 2000, Carter et al. 1985, Clarkson & Childs 2000, Marsh 1985, Hammon 1981, Tyus & Hanies 1991, Black 1982, San Juan River 25-26˚C
Egg									X	🟨	🟨	🟨	O	O	O	O	O						X						
Larval													🟨	🟨	🟨	🟨	A	O	🟨	🟨	🟨		X						
Juvenile													🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	X								
Adult													🟨	🟨	🟨	🟨	🟨	O	A	🟨	🟨	🟨	🟨						
Flannelmouth Sucker																													Bestgen & Crist 2000, Clarkson & Childs 2000, Deacon et al.1987, Holden & Crist 1981, Robins & Childs 2001, Valdez 1990, Word et al. 2002, Deacon et al. 1987 - 25.9˚C, San Juan River 25.0˚C
Egg				X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨								
Larval				X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨								
Juvenile				X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨								
Adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	A	🟨	🟨	🟨	🟨	🟨						
Common Carp																													Aquatic Life Habitat Assessment (internet literature), Backiel & Stegman 1968, Davies et al. 1986, San Juan River 22-23˚C
Egg									🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	X										
Larval									🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X										
Juvenile									🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X			
Adult									🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	A	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	X			
Roundtail Chub																													Bestgen 1985, Chart et al. 1999, Propst, David L. (internet literature), Southeastern Utah's Fish Species (internet literature), Deacon et al. 1987 - 23.8˚C
Egg										X	🟨	🟨	🟨	🟨	🟨	O	O	O	O										
Larval													🟨	🟨	🟨														
Juvenile				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨							
Adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	🟨	🟨	🟨	🟨							
Razorback Sucker																													Bulkley & Berry 1983, Clarkson & Childs 2000, Gorman & Vanhoosen 2001, Marsh 1985, Minckley 1991, Papoulias & Minckley 1992, Valdez 1999, Bozek 1984, Valentine 1981, San Juan River 22-23˚C
Egg	X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	🟨	🟨	🟨	X											
Larval		X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	🟨	🟨	🟨	X											
Juvenile		X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	🟨	🟨	🟨	X											
Adult													🟨	O	A														
Striped Bass																													Aquatic Life Habitat Assessment (internet literature), Bettoli 2005, Moss 1985, Southeastern Utah's Fish Species (internet literature)
Egg			🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	O	🟨	🟨															
Larval			🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	O	🟨	🟨															
Juvenile									O	O	O	O	O	O	O	O	O	O	🟨	🟨	🟨	🟨	🟨	X					
Adult									O	O	O	O	O	O	O	O	O	O	🟨	🟨	🟨	🟨	🟨	X					
Bluehead Sucker																													Bestgen & Crist 2000, Gorman & Vanhoosen 2001, Holden & Crist 1981, Robins & Childs 2001, Valdez 1990, San Juan River <20˚C
Egg										🟨	🟨	🟨	O	O	🟨	🟨	🟨	🟨	X										
Larval	X	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	O	🟨	🟨	🟨	🟨	X										
Juvenile	X																												
Adult	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	O	A	🟨	🟨	🟨	🟨	🟨											
Rainbow Trout																													Hokanson & Koenst 1986, Huh et al. 1976, Siegworth & Summerfelt 1990, Smith & Koenst 1975, Summerfelt 1996, Warm Water Fishes Optimal Temperatures (internet literature)
Egg	🟨	🟨	🟨	🟨	🟨	O	O	🟨	🟨	O	🟨	🟨	🟨					X											
Larval	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	O	🟨	🟨	🟨					X											
Juvenile	🟨	🟨	🟨	🟨	🟨	🟨	O	🟨	🟨	O	🟨	🟨	🟨					X											
Adult	🟨	🟨	🟨	🟨	🟨	🟨	O	O	🟨	O	🟨	🟨	🟨					X											

🟨 Tolerance limits

A Maximum observed summer temperatures which correspond to the maximum longitudinal fish densities

X Known minimum or maximum

O Optimum temperature compiled from various studies

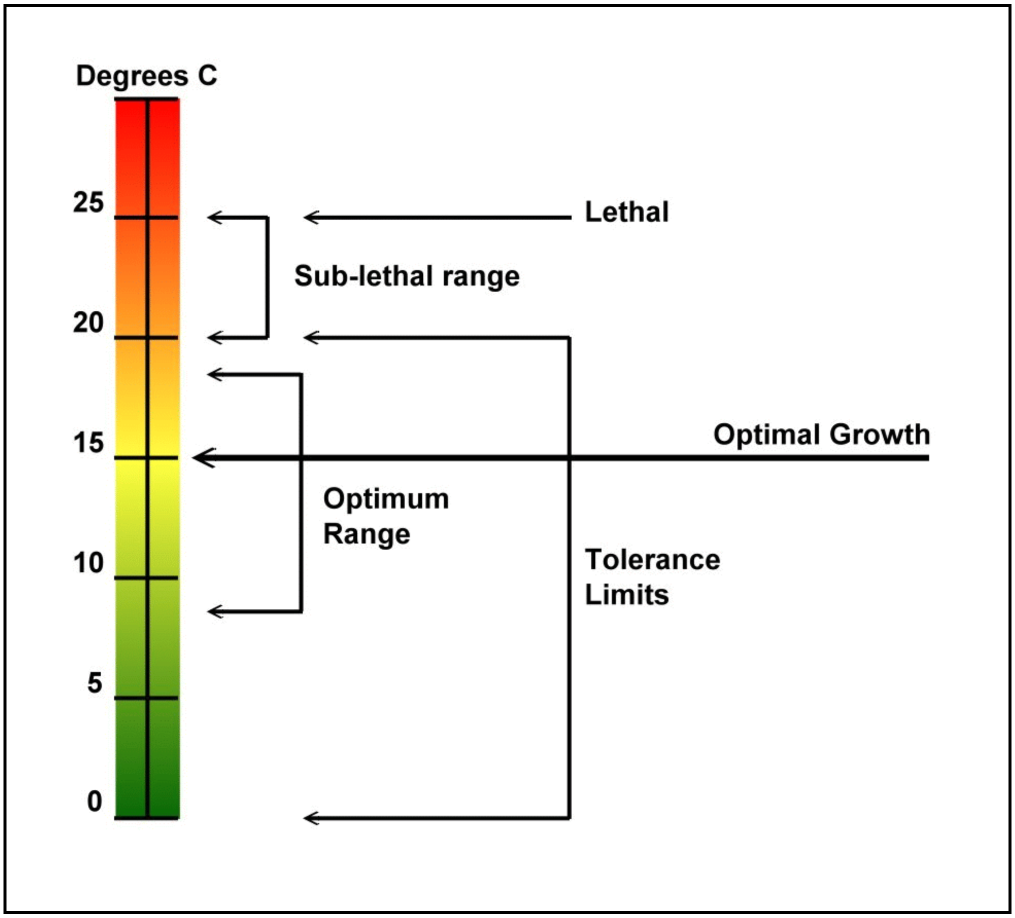

Figure 1. The thermal niche for the rainbow trout as defined by the Michigan Hatchery Manual, 1968. Nomenclature used in this report is presented diagrammatically.

This example is modified from the Michigan Hatchery Manual 1968 and USBOR 1999.

For the Colorado River and its tributaries, there has not been a basin-wide statistical analysis of the thermal conditions and the associated distribution of the native or non-native species such as the analysis conducted by Huff et al. (2005) for western and northern Oregon. That study clearly distinguished the thermal niches of 16 separate species based upon summer maximum temperatures.

There have, however, been several excellent reviews of the observed thermal conditions experienced by the rare fish in the Colorado River. The reader is directed to Joseph et al. (1977) and Miller and Hubert (1990). These citations represent summaries of investigations conducted on a number of the rare and endangered species in the Colorado River.

Most of the information regarding thermal requirements and preferences of the native species in the Colorado River basin have come through field observations of fish assemblage distributions along thermal gradients. In an unaltered condition, seasonal riverine temperatures systematically change with distance downstream (Section 5.0). These temperature changes result in complex bioenergetics changes such as consumption, respiration, excretion, and growth in the fish, as well as ontogenetic shifts in temperature-related physiology between larval, juvenile, and adult fish. These intra-specific changes combined with inter-specific competition and food availability results in the observed fish distributions along thermal gradients. Observations such as those noted by Lamarra (2004) where the density of the two dominant native and the two dominant non-native fish species were strongly correlated with river mile (RM), and presumably temperature are heavily drawn upon by this review. Although it is fully acknowledged that the spatial distribution of any species within a river system is an interaction among a large array of factors, the analysis conducted by Lamarra (2004) indicated that primarily temperature and secondarily habitat were the best predictors of fish densities.

In addition to field observations, some thermal preference studies have been direct laboratory studies under controlled conditions or, fish culture data for several of the native (e.g. pikeminnow and razorback) and non-native fish (e.g. catfish). These studies, combined with the observational data, have resulted in a weight of evidence conclusion about thermal tolerances for the San Juan fishes.

Lastly, this literature review looked at the modification of Flaming Gorge Reservoir thermal outflow characteristics which provided a "field test" of the response of fish assemblages before damming, after damming with cold releases, and after damming with warm releases (Vanicek 1967; Kitcheyan and Montagne 2005).

3.2 Native Species

Colorado pikeminnow (*Ptychocheilus lucius*)

The Colorado pikeminnow has been recognized by the federal government as endangered since 1967 and was one of the original species protected under the Endangered Species Act of 1973 (Federal Register 39(3):1175). Because of the species large size and its wide distribution in the upper Colorado River, the Green River and the Yampa River, the pikeminnow is the most well known and extensively studied of the endemic Colorado River fish (1,181 citations starting in 1952: http://www.mesc.usgs.gov/products/data/COFishBib/cosquaw.asp. Within the San Juan River, all life-history stages except eggs have been found during the Recovery Implementation Program (RIP) investigative period (1991-2005). Most recently, pikeminnow have been stocked as larvae or Age-0 fish in the upper reaches of the river (Ryden 2003) in an attempt to increase population sizes.

Most researchers have found spawning to occur when water temperatures reach 20˚C to 22˚C (Hammer 1981; Haynes et al. 1984; Tyus 1990). Laboratory and field studies suggest that optimal temperatures for hatching are 20˚C to 24˚C with a minimum tolerance limit of 16˚C. Hatching, swimbladder inflation and exogenous feeding occur sooner under fluctuating temperatures than constant temperatures. In addition, no eggs hatch below 14˚C and larvae that were hatched at 30˚C were all abnormal and had 100 percent mortality. The optimum range for growth across all other life stages for the Colorado pikeminnow is 20˚C to 28˚C, with an optimal (maximum) temperature of 25˚C. Laboratory studies found optimum growth at 25˚C with no growth below 13˚C. Optimum sustained swimming speed for adult pikeminnow was found to be 20˚C. Within the San Juan River, 24˚C was the average temperature recorded during field documentation of larval Colorado pikeminnow. In addition, the observed (or estimated) maximum summer temperature in the San Juan River for peak pikeminnow captures was found to be 25.5˚C. [1]

Razorback sucker (*Xyrauchen texanus*)

The razorback sucker was extirpated from the San Juan River prior to its reintroduction in 1994 (Ryden 1997). The species has been found to be spawning in the San Juan River since 1997. Ryden (2001) has noted that field observations of spawning aggregations of ripe females were found in 1997, 1999, and 2001, as well as razorback larvae from 1998 to 2001. An aggressive stocking program (Ryden 2001) has resulted in the razorback being the third most common sucker in the San Juan River.

Field observations in the lower Colorado River Basin found spawning razorback suckers in January to May when temperatures are 10.5˚C to 21˚C. Ripe females were captured in the San Juan arm of Lake Powell (March-April) when water temperatures were 12˚C to 20˚C. A more narrow temperature range for razorback sucker spawning is 15˚C to 18˚C in the Green and Yampa rivers, based upon the collection of ripe fish. Laboratory studies have shown that the optimal temperature for razorback sucker hatching is 20˚C to 21˚C . However, both laboratory studies and field investigations in the Colorado River Basin have documented egg survival across a broader temperature range (8-25˚C). For example, hatching studies found eggs incubated at 10˚C or 30˚C experienced complete mortality. However, if acclimated, eggs were hatched at 10˚C, but had complete mortality at 8˚C. The optimum temperature range for larval and juvenile razorback suckers is similar (9-25˚C), with an optimal temperature of 20˚C to 21˚C. Field investigations have suggested that the optimum temperature range for adult razorback suckers is 8˚C to 26˚C, with an optimal temperature of 21˚C. For the San Juan River, peak captures have occurred where maximum summer temperatures were approximately 22˚C to 23˚C. [2]

Flannelmouth sucker (*Catostomus latipinnis*)

The flannelmouth sucker populations in the San Juan River represent the highest biomass of any of the native species. Although populations have declined and rebounded over the RIP period (1991-2005), the population has retained it dominance within the river system. All life stages have been collected in the river, including eggs.

Laboratory studies and field investigations in the Colorado River Basin have documented egg, larval, and juvenile growth for the flannelmouth sucker across a fairly broad temperature range (11-22˚C). The optimal temperature for larval and

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[1] Colorado pikeminnow temperature sources: Bestgen 1996; Bestgen and Bundy 1998; Bestgen and Williams 1994; Bestgen et al. 1998; Bulkley and Berry 1983; Bliesner and Lamarra 2000; Carter et al. 1985; Clarkson and Childs 2000; Marsh 1985; Hammon 1981; Tyus and Haynes 1991; Black 1982; Hayes and Muth 1984.

[2] Razorback Sucker temperature sources: Bulkley and Berry 1983; Clarkson and Childs 2000; Gorman and Vanhoosen 2001; Marsh 1985; Minckley 1991; Papoulias and Minckley 1992; Valdez 1990; Valentine 1981; Holden 1973.

juvenile flannelmouth suckers is 20˚C to 21˚C. Adult flannelmouth suckers have demonstrated the ability to survive and grow at temperatures as low as 10˚C to 12˚C below Glen Canyon Dam. The optimum temperature range for adult flannelmouth suckers is 10˚C to 30˚C, with an optimal temperature of 25˚C for growth. For the San Juan River, the distribution of adult fish reaches a maximum density where maximum summer temperature was found to be 25˚C. [3]

Bluehead sucker (*Catostomus discobolus*)

This species is the second most common native fish in the San Juan River. Its spatial distribution tends to be further upstream when compared to the other native suckers. All life-history stages have been collected in the San Juan River, with the exception of eggs.

Optimal hatching temperature for the bluehead sucker is 20˚C to 21˚C with a maximum tolerance limit of 26˚C. The temperature range for larval growth is 8˚C to 26˚C. Both larval and juvenile bluehead suckers have a minimum temperature tolerance limit for growth of 8˚C. The optimum temperature range for adult bluehead suckers is 8˚C to 25˚C, with an optimal temperature of 20˚C. For the San Juan River, populations are still trending upward at RM 180 (the uppermost adult monitoring site). Maximum summer temperatures at this location were 20˚C. [4]

Roundtail chub (*Gila robusta*)

Roundtail chub are only found in the mainstem of the San Juan River on occasion (Ryden 2000, Propst and Hobbes 2000), although is was abundant upon the closure of Navajo reservoir (Olsen 1963). At the present time, the species is found in the major tributaries near Farmington, New Mexico (Miller and Rees 2000).

Optimal hatching temperature for the roundtail chub is 23˚C to 26˚C with a minimum tolerance limit of 17˚C. The optimum temperature range for egg survival is 16˚C to 26˚C and for larval fish it is 20˚C to 23˚C. There are no data available on the specific temperature preferences for juvenile or adult roundtail chub. [5]

3.3 Non-Native Species

Channel catfish (*Ictalurus punctatus*)

Channel catfish are the most common non-native fish in the San Juan River and poses one of the greatest biological threats to the re-establishment of Colorado pikeminnow and razorback sucker in the river basin.

The optimum temperature range for hatching and larval success for channel catfish is 21˚C to 29˚C with a maximum tolerance limit of 29˚C. Optimal temperature for juvenile and adult channel catfish is 28˚C. The optimum temperature range for juvenile and adult channel catfish is 21˚C to 30˚C, with a maximum tolerance

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[3] Flannelmouth sucker temperature sources: Bestgen and Crist 2000; Clarkson and Childs 2000; Deacon et al.1987; Holden and Crist 1981; Robins and Childs 2001; Valdez 1990; Ward et al. 2002; Paukert and Rogers 2004.

[4] Bluehead sucker temperature sources: Bestgen and Crist 2000; Gorman and Vanhoosen 2001; Holden and Crist 1981; Robins and Childs 2001; Valdez 1990.

[5] Roundtail chub temperature sources: Bestgen 1985; Chart et al. 1999; Propst; David L. Aquatic Life Habitat Assessment 2007; Southeastern Utah's Fish Species, 2006.

limit of 35˚C. In the San Juan River, maximum densities of channel catfish are well-defined. Juvenile densities in the San Juan River peak at the locations corresponding to a maximum summer temperature of 28˚C corresponding, while adults distributions correspond to maximum summer temperature of 25˚C. [6]

Common carp (*Cyprinus carpio*)

Common carp are the second most common non-native fish in the San Juan River. They are a native to Eurasia and were widely stocked during the first half of the twentieth century throughout the United States as a potential food source.

The optimum temperature range for hatching and larval survival for common carp is 20˚C to 26˚C with a maximum tolerance limit of 26˚C. The mean optimal temperature for egg hatching success is 21˚C. The optimum temperature range for juvenile and adult common carp is 16˚C to 33˚C with a maximum tolerance limit of 35˚C. In the San Juan River, peak densities correspond to 22˚C to 23˚C maximum summer temperatures. [7]

Largemouth bass (*Micropterus salmoides*)

Largemouth bass are found in low densities in the San Juan River Basin in comparison to other non-natives. However, they continue to threaten the recovery of native species.

The optimum temperature range for hatching and larval success for largemouth bass is 20˚C to 30˚C with a maximum tolerance limit of 30˚C. The optimal temperature for egg and larval success is 21˚C. The optimum temperature range for juvenile and adult largemouth bass is 21˚C to 35˚C. The optimal temperature for juvenile and adult largemouth bass is 24˚C to 30˚C. [8]

Striped bass (*Morone saxatilis*)

Lake Powell has a self-sustaining population of striped bass that move out of the lake in the spring and into the San Juan River to spawn (Ryden 2001). Striped bass continue to pose a major threat to recovery of native fish in the San Juan River Basin. Observations by Ryden (2001) in the San Juan River demonstrated that striped bass can move at least 150 miles upstream from Lake Powell and consume native species within the river system.

The optimum temperature range for hatching and larval success for striped bass is 10˚C to 21˚C. Optimal temperatures for egg and larval success are 17˚C to 19˚C. The optimum temperature range for juvenile and adult striped bass is 16˚C to 31˚C with a maximum tolerance limit of 31˚C. The optimal temperature for juvenile and adult striped bass is 16˚C to 25˚C.[9]

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[6] Channel catfish temperature sources: 2007; Buentello et al. 2000; Byerly et al. 2005; Warm Water Fishes Optimal Temperatures, 2006.

[7] Common carp temperature sources: Aquatic Life Habitat Assessment, 2007; Backiel and Stegman 1968; Davies et al. 1986.

[8] Largemouth bass temperature sources: Aquatic Life Habitat Assessment. 2007; Rice et al. 1983; Scheller et al. 1999; Stuber et al. 1982.

[9] Striped bass temperature sources: Aquatic Life Habitat Assessment. 2007; Bettoli 2005; Moss 1985; Southeastern Utah's Fish Species (internet literature).

Rainbow Trout *(Oncorhynchus mykiss)*

Rainbow trout are abundant in the first fifteen miles of the San Juan River below Navajo Dam. The first three miles below the dam is considered one of the best tailwater rainbow trout fisheries in the United States. Rainbow trout exceeding 15 inches in length are consistently caught by recreational anglers in the three mile reach below Navajo Dam (http://www.troutsource.com/RiversFolder/SanJuan.htm).

The optimum temperature range for rainbow trout across all life stages is 7˚C to 18˚C. Temperatures above 25˚C are lethal and 15˚C is the average optimal temperature for larval, juvenile, and adult rainbows. The optimal temperature for hatching success is 13˚C. Tolerance limits are from 0˚C to 20˚C.[10]

4.0 CASE STUDY OF THERMAL MODIFICATION IN THE UPPER COLORADO RIVER

The construction, operation and modification of Flaming Gorge Dam on the Green River in Utah represents an unparalleled case study in the thermal modification of a river system and the subsequent biological implications. Historically, native species including Colorado pikeminnow and razorback suckers were widely distributed in the tributaries of the upper Colorado River basin, including the Green River.

From 1959 to 1962, prior to the closure of Flaming Gorge Dam, there were five fish collection efforts. Observations indicated that native species inhabited the area in large numbers (Vanicek et al. 1970; Modde, 2001). The temperatures near the dam prior to closure ranged from 0.5˚C in January to 21.1˚C in July.

After closure in 1962, Flaming Gorge Dam caused major changes in the ecology of the downstream Green River by altering seasonal flow and temperatures up to 65 miles downstream to the confluence with the Yampa River (Vanicek 1967). After dam closure, river temperatures were modified and reflected the bottom reservoir water temperatures. Although temperatures in the winter increased to 5˚C to 7˚C, maximum summer temperatures decreased down to 6˚C to 10˚C in July. The impact was seen down river as far as the confluence with the Yampa River. The magnitude was dependent upon the water volume released from the dam in the spring and summer.

Vanicek (1967) noted that the native fish community in the immediate vicinity and up to 26 miles below the dam were replaced by rainbow and brown trout. In two of the four years studied after the dam closure, Vanicek (1967) found that there was no reproduction of native species in the Green River above the confluence with the Yampa River. He attributed the lack of reproduction to high flows and lower temperatures.

Further observations by Vanicek et al. 1970 and Holden and Crist 1981 continued to document the decline of the native fish community within the Green River below Flaming Gorge Dam. They concluded that the colder water releases altered the native fish fauna by eliminating most reproduction between the dam and the confluence with the Yampa River.

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[10] Rainbow trout temperature sources: Huff et al. 2005; Stoltz and Schnell 1991; Schneider and Connors 1982.

In 1978, the penstocks at Flaming Gorge Dam were modified to release warmer water in order to improve the non-native tailwater trout fishery. In 1992, flows were re-regulated in order to better reflect a natural hydrograph.

During this process of "fine tuning" the flow and temperature conditions below the dam, the biological response from the native fish community has followed each improvement. For example, with the initial temperature modifications, native species started to return to the lower Green River. Holden and Crist reported in 1981 that they collected two pikeminnow in the Green River. Karp and Tyus (1990) collected three more of the same species several years later. In addition to the rare species (pikeminnow), flannelmouth and bluehead suckers were the most common native species caught in Lodore Canyon. During this same time (1987-1989), trout were at the same densities as flannelmouth suckers in Lodore Canyon.

After re-regulation of flows in 1992, Bestgen and Crist (2000) captured 17 pikeminnow greater than 500 mm in size in the Green River above the confluence with the Yampa River. This alone has indicated that the combination of increased summer temperatures and adjusted flows have allowed a reoccupation of habitat by native species.

More recently, Kitcheyan and Montagne (2005), using a variety of techniques, captured 78 pikeminnows between 2000 and 2002 in the Green River above the Yampa River. In their study, they found that temperatures ranged from1.5˚C to 24.5˚C. The farthest upstream capture was approximately 28 miles below Flaming Gorge Dam. They have hypothesized that pikeminnow may be using the Green River (specifically sites in Lodore Canyon) for spawning. However, no ripe females or larval fish have been caught in the Upper Green River above the Yampa River confluence.

As will be discussed in Section 5.2 of this report, the use of annual thermal units (ATUs) as an integration tool in the assessment of growth for Colorado pikeminnow has value in the analysis of Flaming Gorge thermal modifications and the response of pikeminnow to those alterations. Using the methodology described by Kaeding and Osmundson (1988), ATUs were calculated for the Green River at Browns Park. These data can be seen in Figure 2. This data indicates that from 1992 to 1999, the average annual ATU was 22 units while the period 2000-2005 had 36 ATUs. Inspection of Figure 2 indicates that 2002 was the year with the highest ATUs and corresponded to the time period with highest pikeminnow captures. Kaeding and Osmundson (1988) suggest that 40 ATUs is a threshold level for permanent habitation by pikeminnow.

As noted in the preceding discussion, the initial low downstream temperatures and the ultimate warming due to structural modifications has resulted in the reuse of 50 percent of the habitat lost in the Green River below the dam (30 miles of the original 65 miles) and has directly demonstrated that the initial impacts of a large western dam can be partially offset by structural design modifications and by changing reservoir operations. Furthermore, the Flaming Gorge experience has shown that some degree of thermal modification can accommodate both an outstanding tailwater trout fishery and the native fish community (although displaced 20-30 miles downstream).

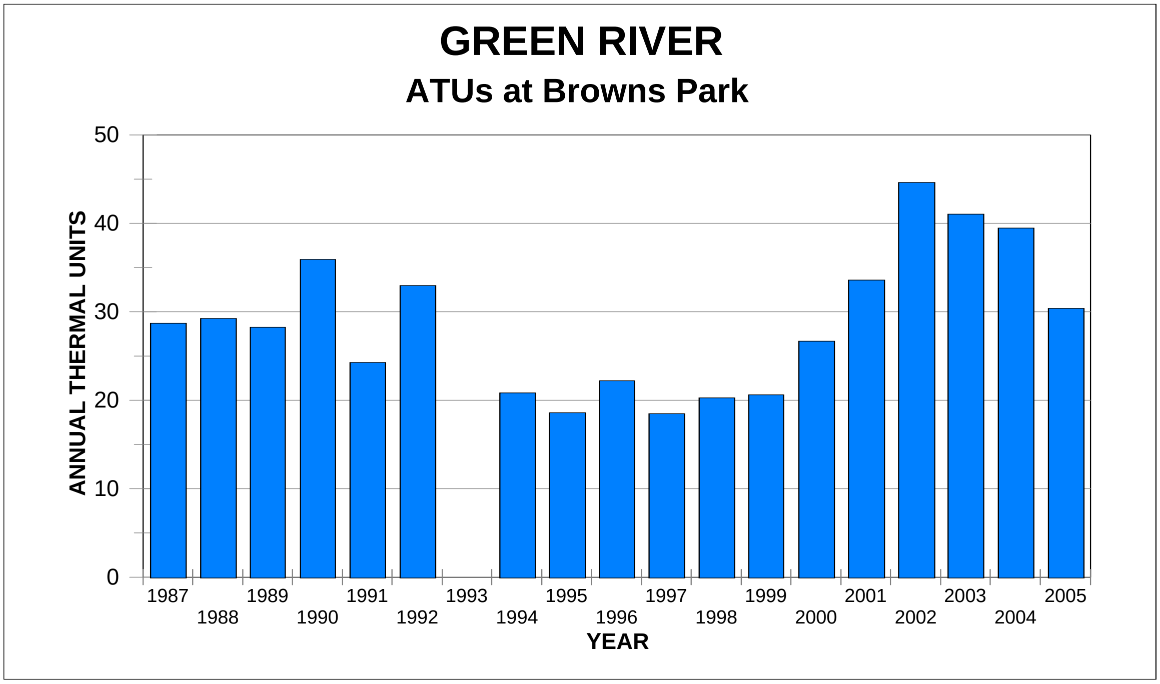


Figure 2. The temporal distribution of annual thermal units calculated from average daily data at Browns Park on the Green River.

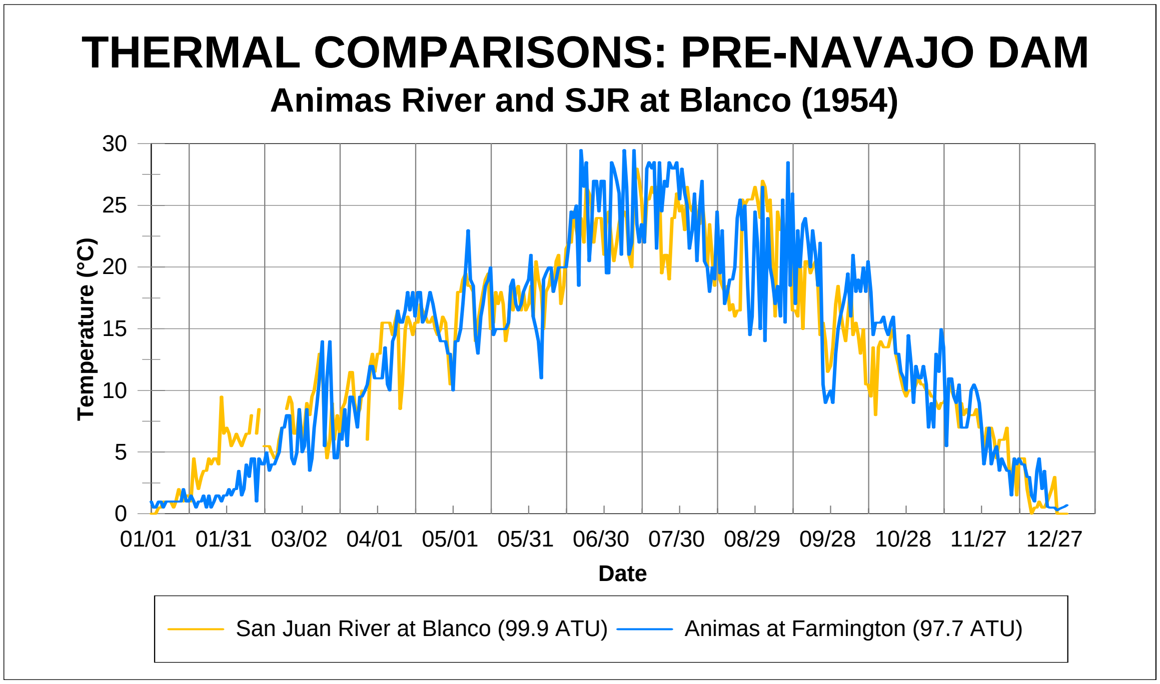


Figure 3. The thermograph data (daily temperature) from the Animas River at Farmington (RM 180) and the San Juan River (RM 205) in 1954 prior to dam closure. Annual thermal units (ATUs) were calculated based upon the methods of Kaeding and Osmundson, 1988.

5.0 OVERVIEW OF THE SAN JUAN RIVER AND NAVAJO RESERVOIR

The San Juan River was impounded by Navajo Dam between 1962 and 1965. The operations of the dam have modified the hydrology and water quality (most notably water temperature) of the downstream San Juan River. The purpose of this section is to describe the historical and current thermal conditions of the San Juan River and to place the possible impacts to fish distributions into perspective.

5.1 San Juan River Thermal History

Historical daily temperature data for the San Juan River was collected and summarized at several locations over the time period from 1949 to 2004. The years when stations have had complete years of daily data were used and can be seen in Table 2. A total of twelve stations were reviewed. Prior to the dam being built, six locations downstream from the dam site had daily data for a year, including the Animas River in Farmington, New Mexico. Beginning in 1962 Navajo reservoir started filling and modified the San Juan River hydrology. After 1965, only one site from the original six (Rosa) had no data. The remaining five stations continued collecting data to some degree after 1965. In addition, six new stations have collected at least one year of daily data after dam closure in 1965. Overall, the most extensive set was from the Animas River in Farmington, New Mexico (RM 180) with data available for 50 of the 54 years. The least extensive data were from Rosa (RM 224) with only two years of data.

Inspection of the thermographs before and after Navajo Dam closure indicated that the Animas River at Farmington (RM 180) and the San Juan River at Blanco (RM 205) had almost identical temperatures prior to the Navajo Dam closure. This can clearly be seen in Figure 3.

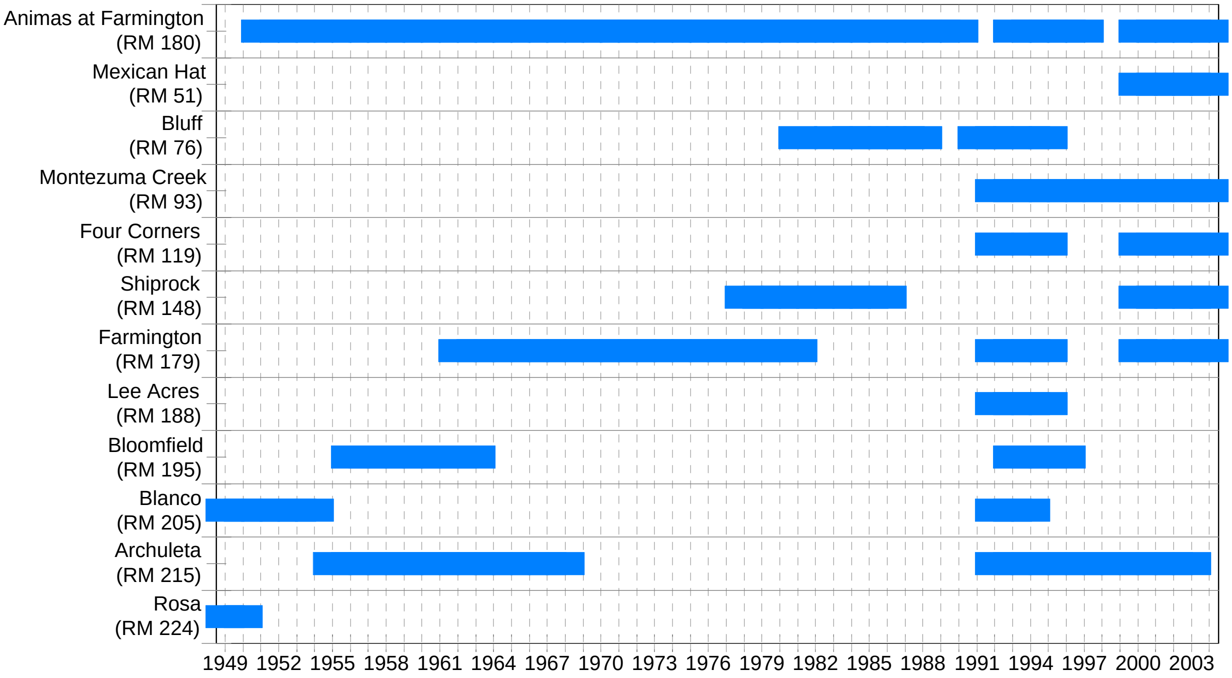
A comparison of the two stations shows that the minimum temperatures occurred in December and January (0˚C) at both stations and both stations had maximums in August (>25˚C). Regressions between the two stations revealed an intercept of 0 and an r^2 of 0.82. This comparison done prior to closure indicates that the Animas River in Farmington at its confluence with the San Juan River had similar thermal conditions as the San Juan at Blanco (RM 205).

Data from 1994 (which represents a post-closure condition in the San Juan at Blanco) was also compared graphically for the same two stations. The results of this comparison can be seen in Figure 4.

The magnitude of differences of the temperatures between these two sites is the result of the closure of Navajo Dam and the subsequent hydrologic modification of the San Juan River. Although the shape of the two curves are remarkably similar, the actual temperatures are greatly reduced at the Blanco site in the summer and higher in the winter. In this respect, the data are similar to water temperatures in the Green River below Flaming Gorge Dam (Vanicek et al. 1970) prior to withdrawal modifications and for the Colorado River below Glen Canyon Dam (USBOR 1999). In both cases, as with Navajo Dam, releases are from the hypolimnetic region of the reservoir.

In order to demonstrate the spatial temperature differences within the San Juan River, a comparison was made between three thermograph stations for 1995. This year was selected because it has

Table 2. The spatial and temporal distribution of temperature data from the San Juan and Animas rivers. Data for the Animas River is near the confluence of the San Juan at RM 180. The data are for daily values over an annual period.



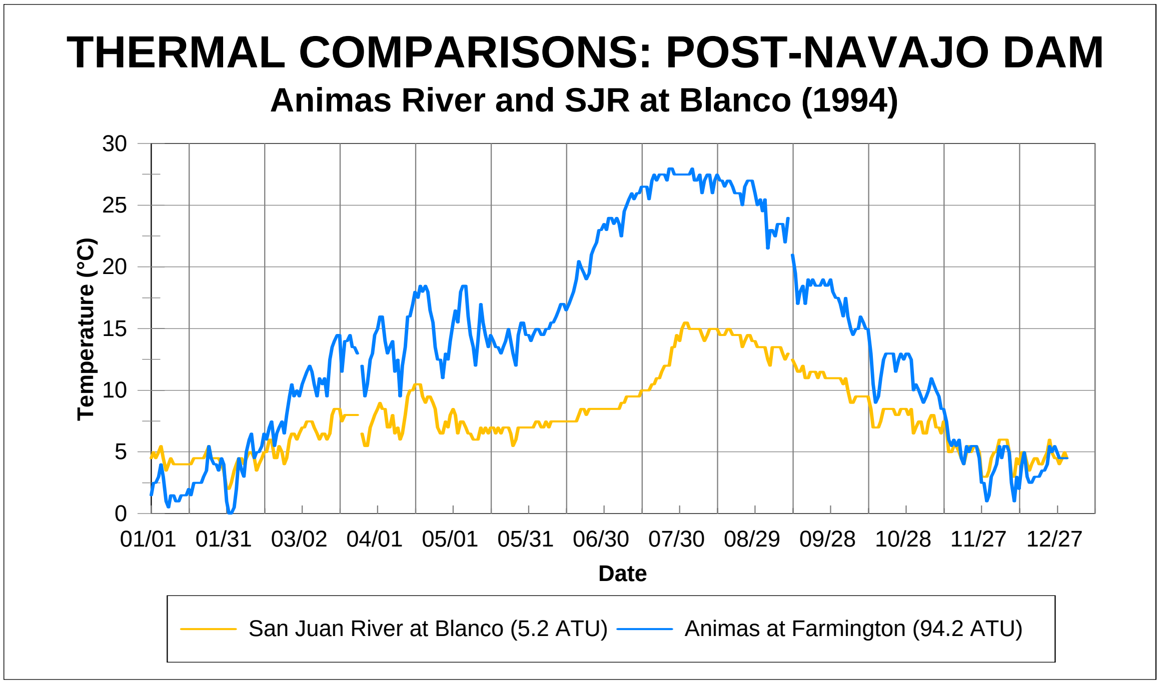


Figure 4. The thermograph data (daily temperature) from the Animas River at Farmington (RM 180) and the San Juan River (RM 205) in 1994 after dam closure. Annual thermal units (ATUs) were calculated based upon the methods of Kaeding and Osmundson, 1988.

been one of three years since 1994 that the primary hydrologic conditions established in the Flow Recommendation Report have been met. As can be seen in Figure 5, the average daily summer temperatures at Archuleta (RM 205), Lee Acres (RM 188) and Montezuma Creek (RM 93) are progressively higher as they move downstream. However, the reverse can be seen in the fall where the site closest to the dam (Archuleta) has the highest temperatures with temperatures decreasing at downstream stations. The important consideration to note is that even after closure of Navajo Dam, there is still a seasonal change that occurs in the temperature of the river and that the magnitude of that change increases with distance from Navajo Dam.

The datasets discussed within this section and illustrated in Figures 3 through 5 demonstrate temporal patterns as well as spatial changes of water temperatures in the San Juan River. However, it should be noted that there is also a diel (daily) variation to temperatures in the San Juan River. Using the August 1995 data from the site closest to Navajo Dam (Archuleta) and furthest downstream (Montezuma Creek), a 4˚C to 5˚C daily variation in temperature can be seen (Figure 6). This variation occurs at both stations in approximately equal magnitude.

5.2 Habitat Availability

To help compare the historical and existing thermal conditions in the San Juan River and its possible effects on habitat availability, an analysis of the spatial distributions of river temperatures as they relate to the potential thermal niche of Colorado pikeminnow was undertaken using the approach developed by Kaeding and Osmundson (1988).

In this approach, mean daily temperatures were converted to thermal unit values (TUs) ranging from 0 to 1.0 based on the growth with Colorado pikeminnow at temperatures ranging from 10˚C to 30˚C (from the laboratory work of Black 1982; Black and Bulkley 1985). In their method (Kaeding and Osmundson 1998), temperatures less than 13˚C were assigned a value of 0. Average daily temperatures of 25˚C were assigned a value of 1.0 (highest value corresponding to a temperature of maximum growth for pikeminnow). The assignment of daily TUs was in the same proportion as the observed growth at the test temperatures over the range of 13˚C to 30˚C. As temperatures increased above 25˚C, the thermal units decreased proportionally. This is shown diagrammatically in Figure 7. The daily TUs were summed to obtain a single annual value (ATUs).

This methodology, based upon the growth of Colorado pikeminnow, represented a systematic way of integrating an annual thermograph into a single number for comparison between sites. Furthermore, the analysis of Kaeding and Osmundson (1988), later confirmed by Osmundson (1999), indicated that a value of 40 ATUs appeared to be associated with the upper riverine distribution of Colorado pikeminnow in the Yampa River and the Upper Colorado River.

Using historical temperature data previously discussed including data collected as part of the SJRIP (Bliesner 1991-2004), ATUs were calculated at those stations in the San Juan River shown in Table 2. The data developed in this analysis allowed inferences as to the habitat available to pikeminnow pre- and post-closure of Navajo Dam.

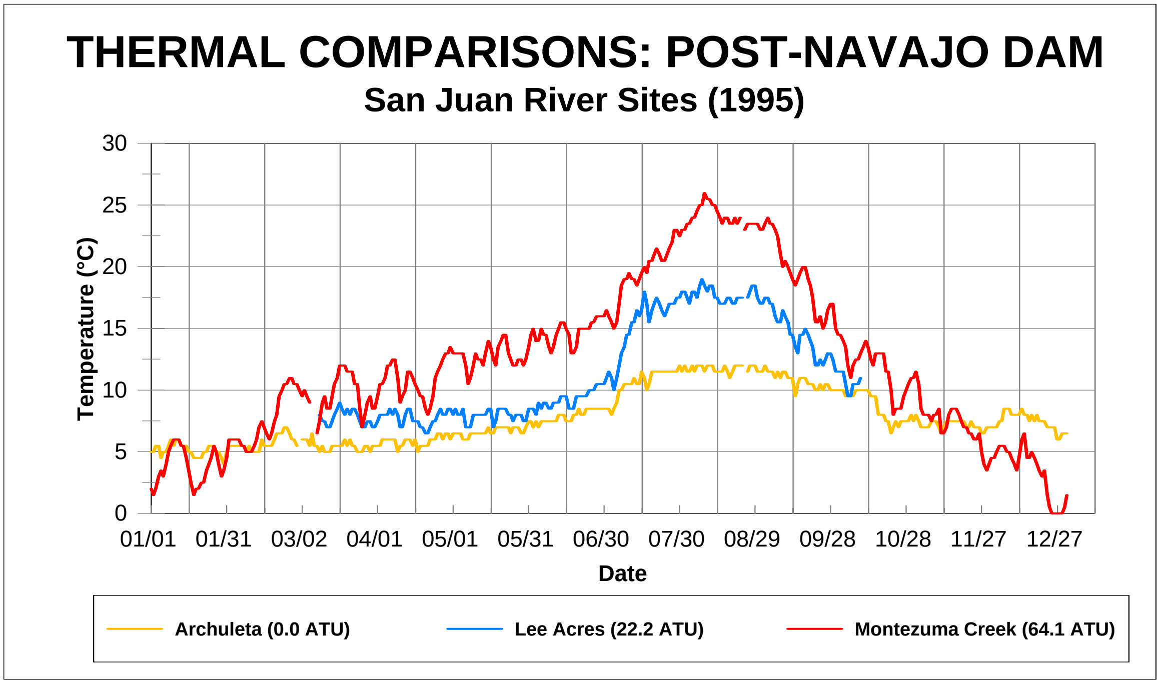


Figure 5. A comparison of the thermographs from three station on the San Juan River in 1995. Annual thermal units (ATUs) were calculated based upon the methods of Kaeding and Osmundson, 1988.

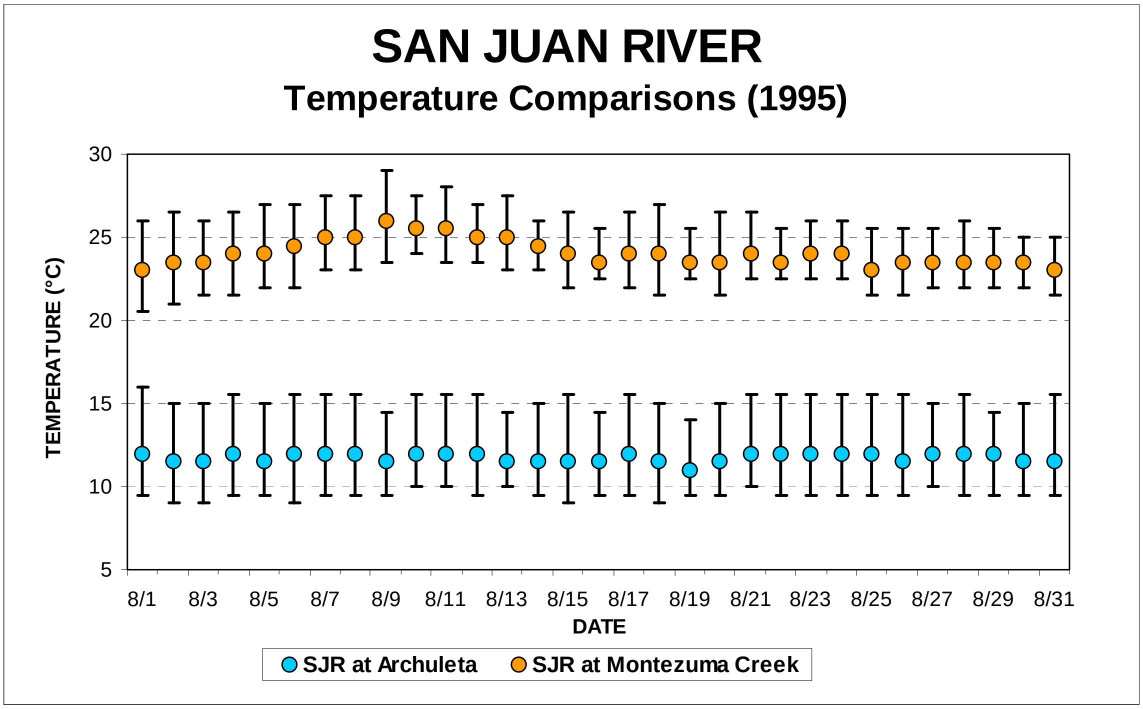


Figure 6. A comparison of minimum, maximum and daily average temperatures in August 1995 at Archuleta and Montezuma Creek in the San Juan River.

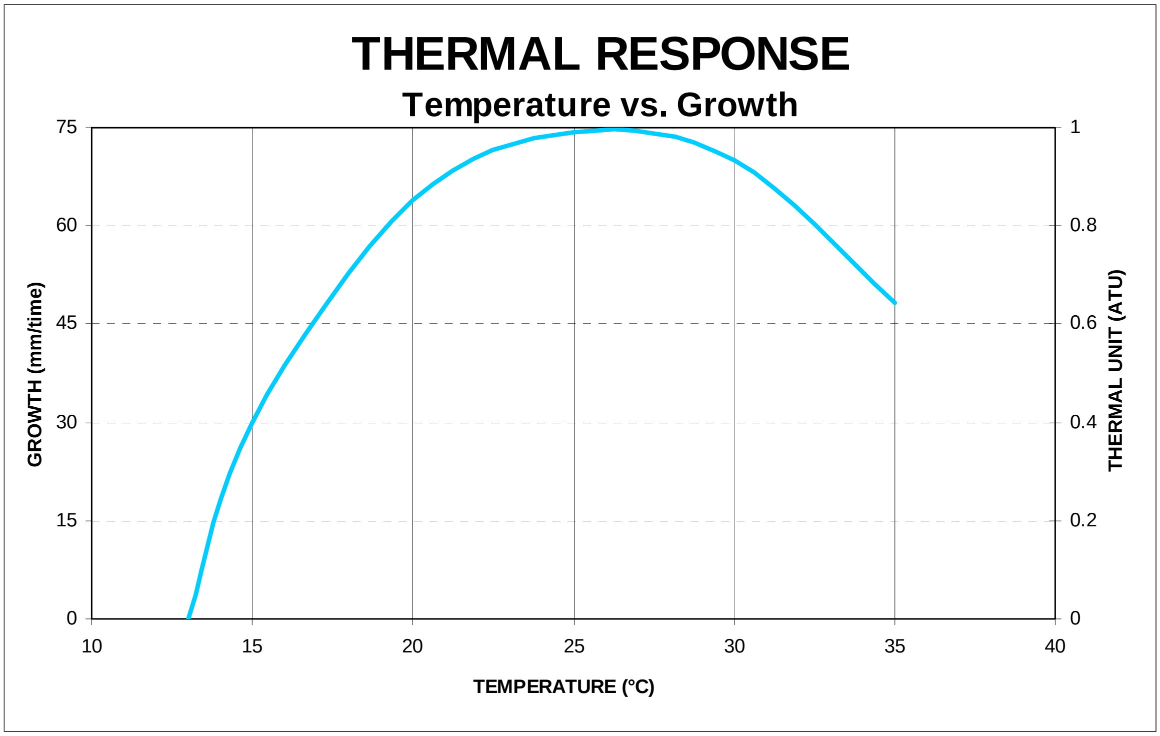


Figure 7. The thermal response (growth) for pikeminnow as determined by Black and Bulkley 1985 and modified by Kaeding and Osmundson (1988) to reflect the corresponding thermal units.

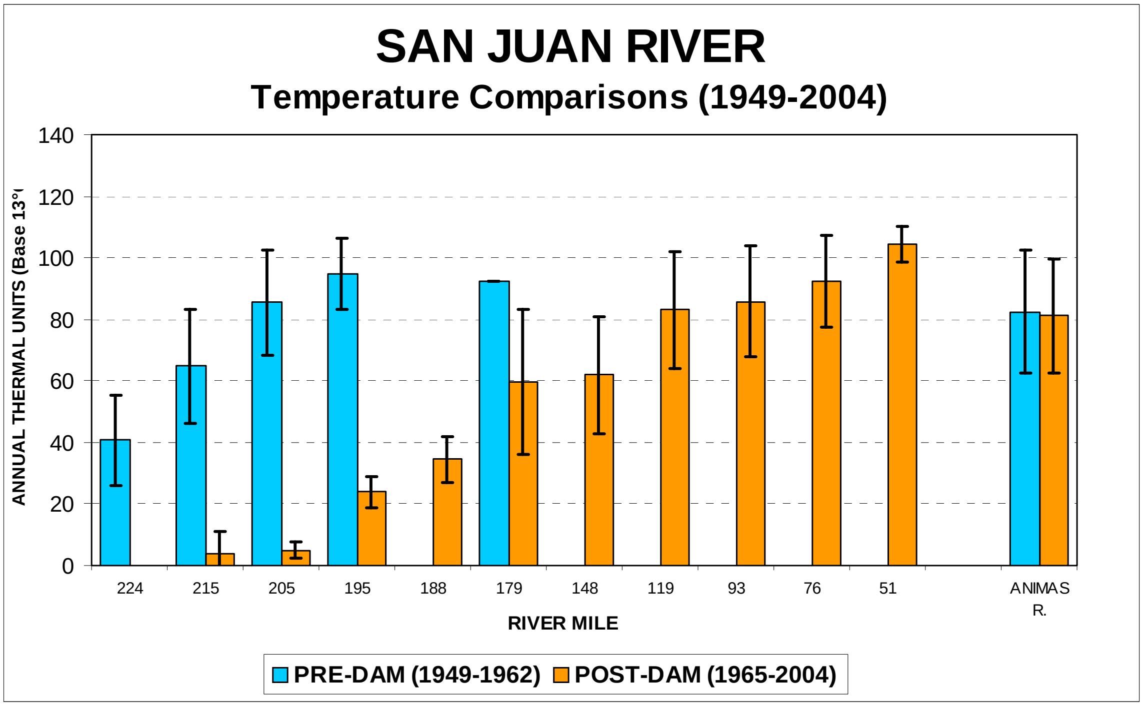


Figure 8. The average annual thermal unit (ATUs) with + one standard deviation for the 11 San Juan River sites and the Animas River at Farmington. Data are overall averages before and after Navajo Dam closure.

The annual average ATUs for each thermograph site shown in Table 2 is graphed in Figure 8. The data shows that if 40 ATUs is a critical thermal criteria for pikeminnow habitation, the pikeminnow could have inhabitated the San Juan River at the location of the Rosa station, as well as the river downstream. Prior to the dam closure, the San Juan River at Rosa was at an ATU value near 40. With distance downstream, the ATUs increased in a linear manner for the next 30 miles. The only other available data in the San Juan before 1965 was data at Farmington (RM 179). The ATUs at Farmington were nearly the same as the upstream location at Bloomfield (RM 195). However, as will be discussed later, the San Juan River temperatures at the Farmington station was and is influenced by the Animas River because the San Juan River site is located below the confluence of the two rivers. As shown in Figure 8, the pre-closure average ATU for the Animas River was less than the San Juan River at Bloomfield, indicating that the Animas River may have slightly cooled the San Juan River prior to 1965.

The post-closure thermal environment based upon the average ATUs is significantly different when compared to the pre-closure averages. Before 1962, 40 ATUs were present at the dam site (RM 224), while after 1965, no (0) ATUs were calculated for this site. At both Archeluta (RM 215) and Blanco (RM 205), the post-closure ATUs were calculated to less than 5 ATUs. From this low level, the river warms continuously (as evidenced by a linear increase of 0.91 ATUs/mile) for the next 86 miles (to Four Corners). Although the ATUs were still increasing down to Mexican Hat (RM 51), the rate of change was reduced to 0.31 ATUs/mile. In the post-closure environment, the 40 ATU level calculates to be at approximately RM 186.9, based upon a best fit polynomial regression noted in Figure 9.

A comparison of thermographs between the Animas River and the San Juan at Blanco before and after closure of Navajo Dam noted thermal changes at Blanco after 1965 (Figures 3 and 4). A review of these figures shows that there are also ATUs provided for each site and condition. This data indicates that in 1954, both sites had approximately identical annual thermal units (99 and 96 ATUs). In 1994, after closure of the dam, the Blanco site had only 5.1 ATUs while the Animas was 94 ATUs (near the 1954 level). Due to Navajo Reservoir releases, the thermal units at Blanco were about 5 percent of pre-closure levels. These data indicate that under post-closure conditions, the potential habitat for Colorado pikeminnow has been reduced.

As noted above, the Animas River had the most extensive temperature data of any location (Table 2). In addition, the average calculated ATU based upon a base level of 13°C was not significantly different between the pre- and post-dam closure periods (Figure 8) at this site. Inspection of the year to year variability for the pre- and post-closure periods shows similar ATU frequency distributions (Figure 10), indicating similar thermal ranges for the years pre- and post-closure. Based upon similar forcing factors (e.g. weather), it is anticipated that the San Juan River would have had similar relative distributions of ATUs.

It is not unreasonable to assume that if responding to some critical thermal regime, pikeminnow would abandon or invade areas depending on thermal conditions. This type of frequency distribution cannot be

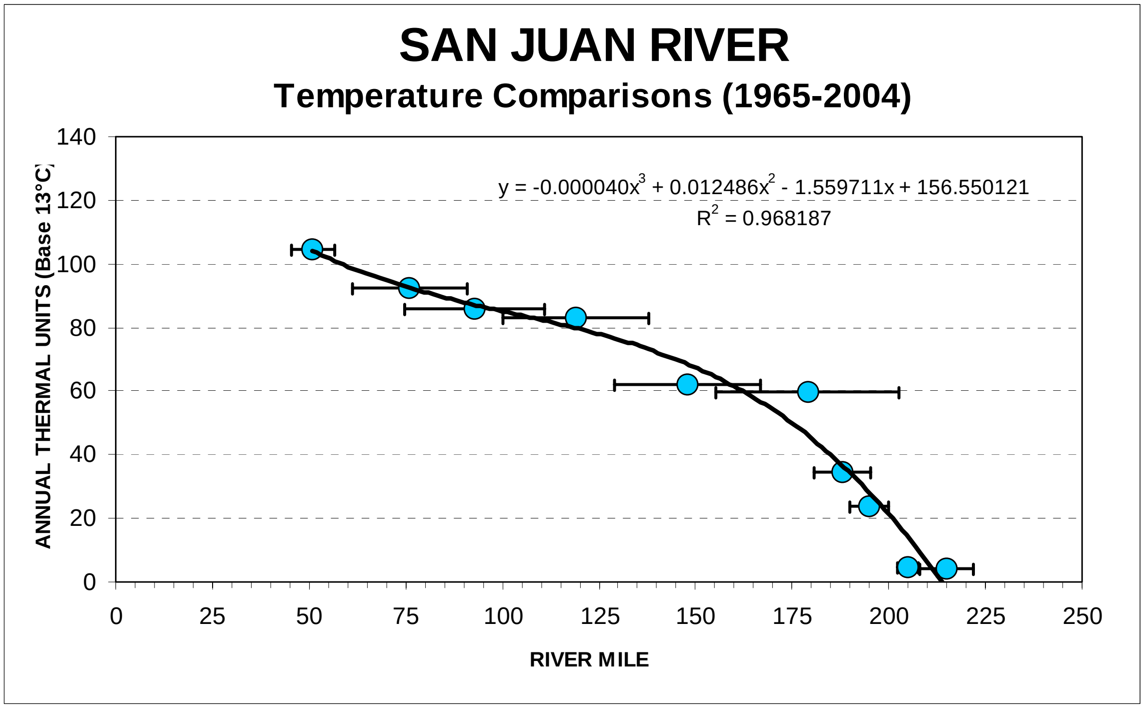


Figure 9. A best fit polynomial regression for determining annual thermal units (above base 13˚C) based upon river location. Data are from 1965 to 2004.

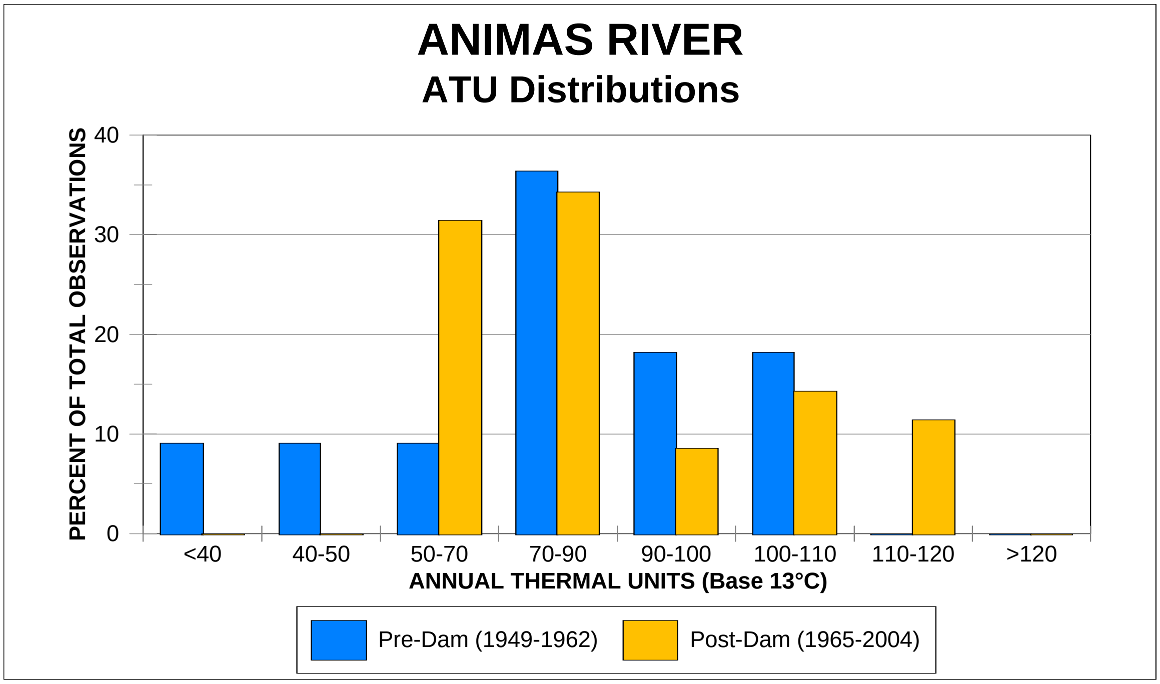


Figure 10. The frequency distribution of annual thermal units in the Animas River before 1962 and after 1965.

calculated for the San Juan River directly because of lack of available data except for Farmington (Figure 11), which is directly effected by discharges from the Animas River. Even so, the ATUs at the Farmington site have been less than the potential 40 ATU threshold 25 percent of the time since 1965. Unlike the pre-dam closure period, where the Animas River was cooler than the San Juan River, in the post-closure period the Animas River is warmer than the river it enters and thus adds thermal units to the San Juan River below its confluence. The San Juan River above the Animas River at Farmington may have less than 40 ATUs more than 25 percent of the years.

In addition to growth effects as noted above, the thermal modifications of the San Juan River by the construction and operation of Navajo Reservoir may effect other life history requirements of the rare fishes in the San Juan River. To this end, an analysis of potential spawning effects was undertaken using the work of Trammell and Chart (1999). In their 5-year study (1992-1996) of pikeminnow larval production in the Colorado River, they found a correlation coefficient of 0.99 between the degree days (DD) to spawn (starting on January 1) and the catch rate of larval pikeminnow (numbers per 1000 cubic meters) in the Moab area. A re-analysis of their data indicated a threshold value of 1,575 DD was necessary for successful capture of larval pikeminnow. If one assumes that 1,575 DD represents the cumulative thermal history necessary for successful spawning of pikeminnow, degree days can be calculated for the San Juan River prior to and after closure of Navajo Dam. This analysis can be seen in Figure 12. Before the closure of the dam, the San Juan River attained on average 1,575 DD by August 6 at Rosa, July 11 at Archuleta, June 24 at Blanc, June 19 at Bloomfield and June 14 at Farmington. The Animas River attained 1,575 DD by June 24 for the years prior to Navajo Dam closure. The amount of time necessary to attain 1,575 DD in the San Juan River has been significantly altered by Navajo Dam releases. For example, at Archuleta it now takes on average an additional 32 days to attain 1,575 DD. The same is true for Blanco (37 days), Bloomfield (48 days) and Farmington (10 days). Because there is no temperature data before 1962 prior to Navajo Dam for Shiprock, inspection of the pre-dam Farmington data can indicate the potential changes. Considering that Farmington was, on average, attaining 1,575 DD on June 14 prior to Navajo Dam closure which was very similar to the San Juan River from Four Corners and downstream (Montezuma Creek, Bluff and Mexican Hat) post-closure with a date of June 12-14. Based upon this data, it is very possible that Shiprock's cumulative thermal structure (cumulative degree days) is being altered by Navajo Dam release temperatures by delaying the attainment of 1,575 DD by an estimated 13 days.

Temperature is an important component in the spawning activity of Colorado pikeminnow (Hammer 1981; Haynes et al, 1984; Trammell and Chart, 1999). The quantitative effects of the thermal conditions necessary for spawning are poorly understood. Hammer (1981) has suggested that 20-22˚C is the optimal temperature for spawning, while Hayes et al (1984) observed spawning at temperatures as low as 18˚C. Trammell and Chart (1999) suggest that the 18˚C threshold has little biological significance. Their data indicates that thermal history may provide a better indication of

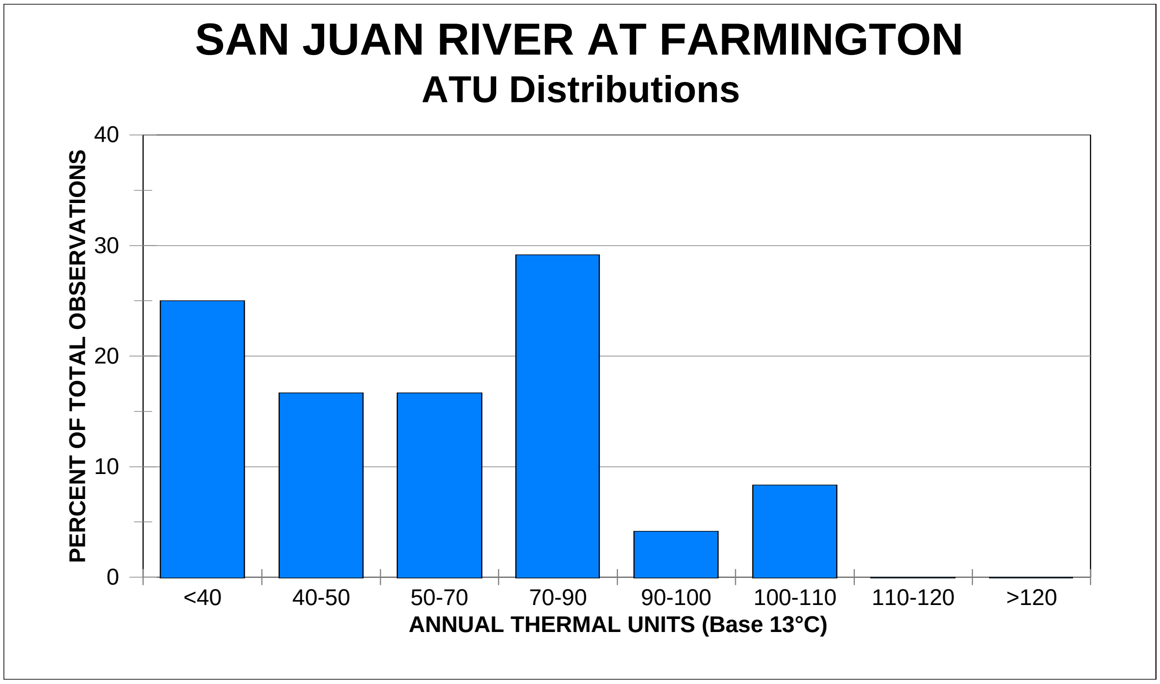


Figure 11. The frequency distribution of annual thermal units in the San Juan River for years after 1965.

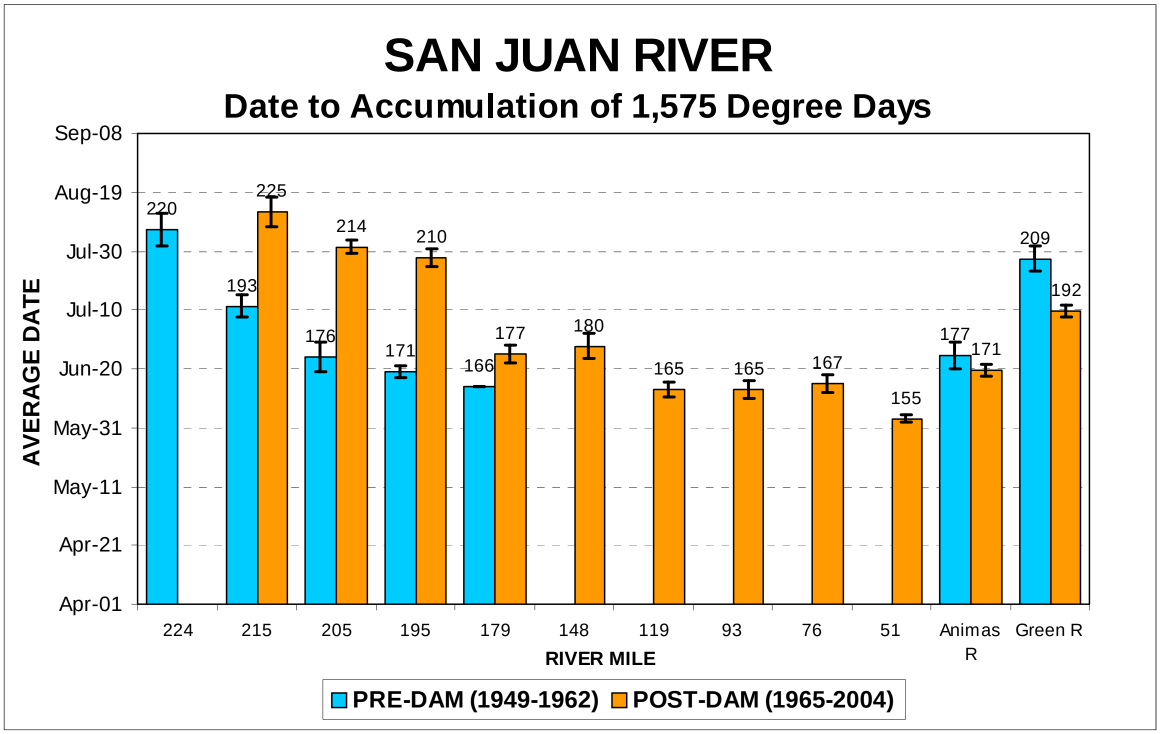


Figure 12. The date to reach 1575 calculated cumulated degree days (from January 1). The 1575 DD is assumed to be a threshold value for pikeminnow spawning based upon the data collected by Trammell and Chart (1999). Data are averages (+/- standard errors) for the time periods in the San Juan River before and after closure of Navajo Dam.

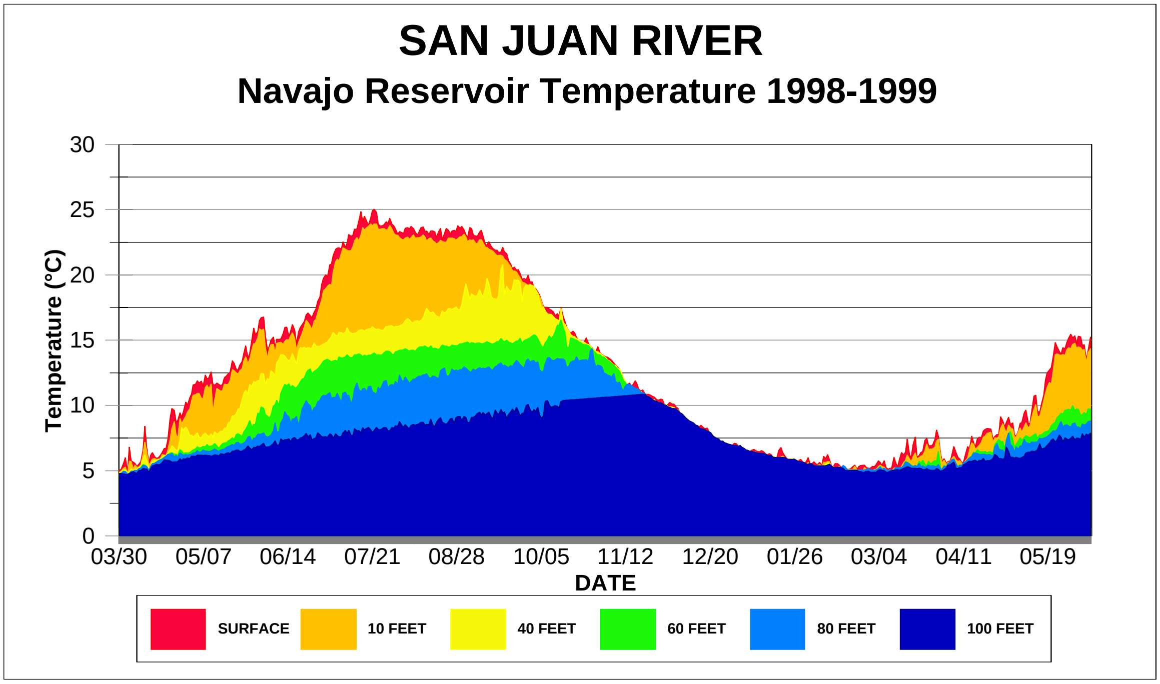


Figure 13. The spatial and temporal distribution of temperatures (˚C) in Navajo Reservoir during 1998 and 1999.

reproductive timing when combined with the magnitude of flow. In the San Juan River, the cumulative thermal history as determined by cumulative degree days has been significantly altered as far downstream as Farmington and quite possibly Shiprock.

From March 1998 to June 1999, Lamarra (1999) collected hourly temperature data at seven depths (surface, 10 feet, 20 feet, 40 feet, 60 feet, 80 feet, and 100 feet). These data can be seen in Figure 13. For analysis purposes, the 40-foot depth strata was used as an example of an optimum temperature for rainbow trout as a hypothetical thermal release from Navajo Reservoir. The resulting thermograph would produce (at the dam) approximately 10 ATUs. This release pattern would improve the trout fishery (e.g. Flaming Gorge thermal modification) by providing temperatures within their optimum growth range (Figure 1), as well as provide significant thermal units downstream for Colorado pikeminnow. These thermal modifications may improve the habitat conditions for Colorado pikeminnow as far upstream as Bloomfield (RM 195). This same release pattern would also result in a July 14 date to attain 1,575 DD, however the absolute temperature with this release pattern would never exceed 15˚C and thus never attain the 18˚C threshold suggested by Haynes et al (1984).

6.0 SPATIAL DISTRIBUTION OF SAN JUAN FISHES

The existing literature on the thermal requirements of the major species in the fish community of the San Juan River has been reviewed in this report. In addition, the environmental conditions prior to and after the closure of Navajo Dam have been briefly described. An attempt has also been made to infer the changes in Colorado pikeminnow habitat that could have occurred as a result of the reservoir's placement and operation and that could occur if thermal modifications were made to the dam. Based upon the above information, as well as the exhaustive amount of fishery and temperature data between Farmington and Lake Powell, it was felt that a comparison of the San Juan River fish thermal regimes to those found in the literature was warranted. This may then allow inferences to be drawn about possible changes to the fish community (other than rare species) with thermal modification at Navajo Dam.

6.1 Fish and Temperature Distributions

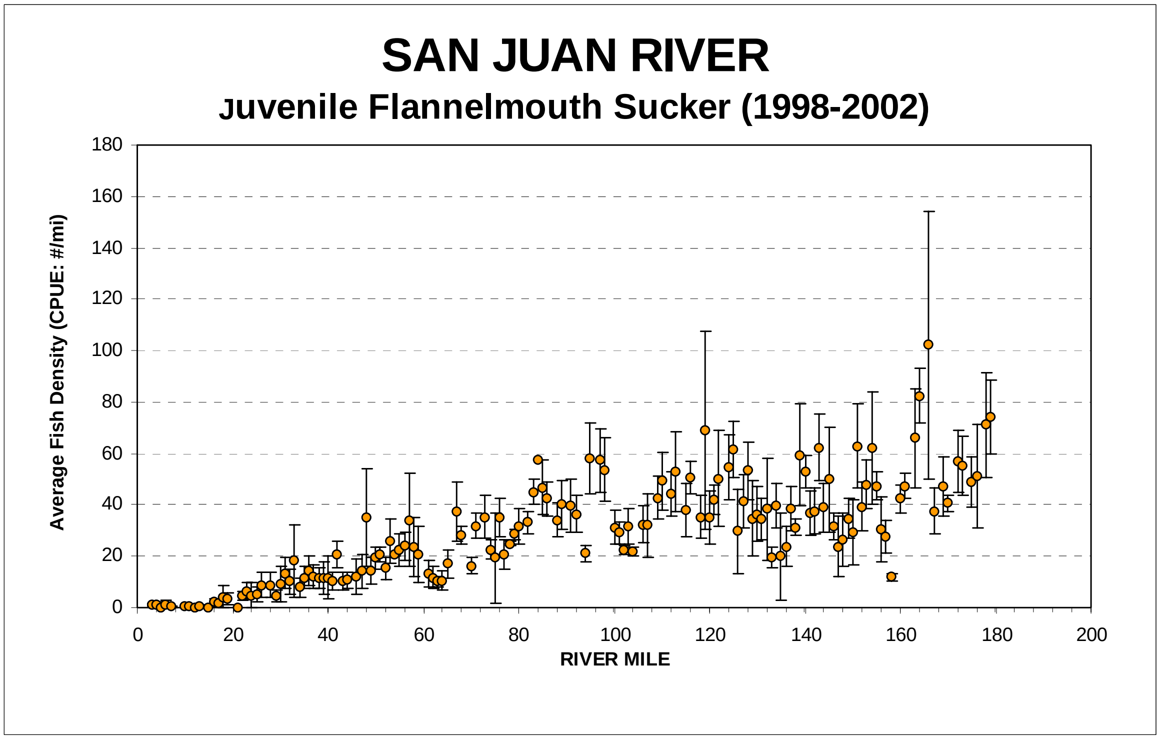
Adult monitoring catch-per-unit-effort (CPUE) data from 1998 to 2002 was used to summarize the longitudinal distribution of the major species in the fish community of the San Juan River. These data are best suited to describe the river-wide spatial pattern because they cover the entire river from RM 180 to RM 2, and all the CPUE collections were made at comparable times (fall of the year).

To further simply the analysis, single species distribution was obtained by averaging the five years of CPUE data for each river mile for each of the four numerically dominant species (Figures 14-17). In addition, standard errors for each river mile was also calculated for this 5-year period and distributional data for Colorado pikeminnow (Figure 18) and razorback suckers (Figure 19) were obtained from an analysis conducted by Bliesner 2006. Because of the low number of captures, a summation of captures by river mile from 1994 to 2004 during adult monitoring was used as a distributional index (rather than an average CPUE and the associated standard error).

A previous analysis conducted by Lamarra (2004) using step-wise multiple regressions and Principals Component Analysis indicated that when using the dominant habitat types as well as temperature (river mile location), the dominant factor predicting fish density was temperature (river mile designator). This river-wide analysis further indicated that the level of correlation with temperature varied by life-history stage and year. The goodness-of-fit value (r^2) between river mile or temperature and the location of bluehead and flannelmouth suckers ranged between 0.87 and 0.54, indicating that location (RM) or temperatures were a significant factor in determining longitudinal densities of these native species in the San Juan River, more so than any other habitat factor.

Inspection of the distributional pattern of the fish in Figures 14 through 19 indicates that for juvenile flannelmouth, juvenile and adult blueheads, and possibly razorback suckers, the full distributional pattern was not available from the adult monitoring data. In the case of the noted species, it appears that their densities are still increasing above RM 180, the upper end point of adult monitoring. Peak population sizes (as estimated by CPUE) for these fish are more than likely higher than at RM 180. Given this disclaimer, the temperature preference analysis for these fish assumed that their distributions peak near RM 180.

As noted by a number of authors (Deacon et al. 1987; Scheller et al. 1999; Huff et al 2005), ambient temperatures for riverine species can define the species range limits. Because fishes in western rivers experience a wide range of temperatures, especially low winter extremes (nearing 0˚C), low winter temperatures do not appear as a factor in the longitudinal



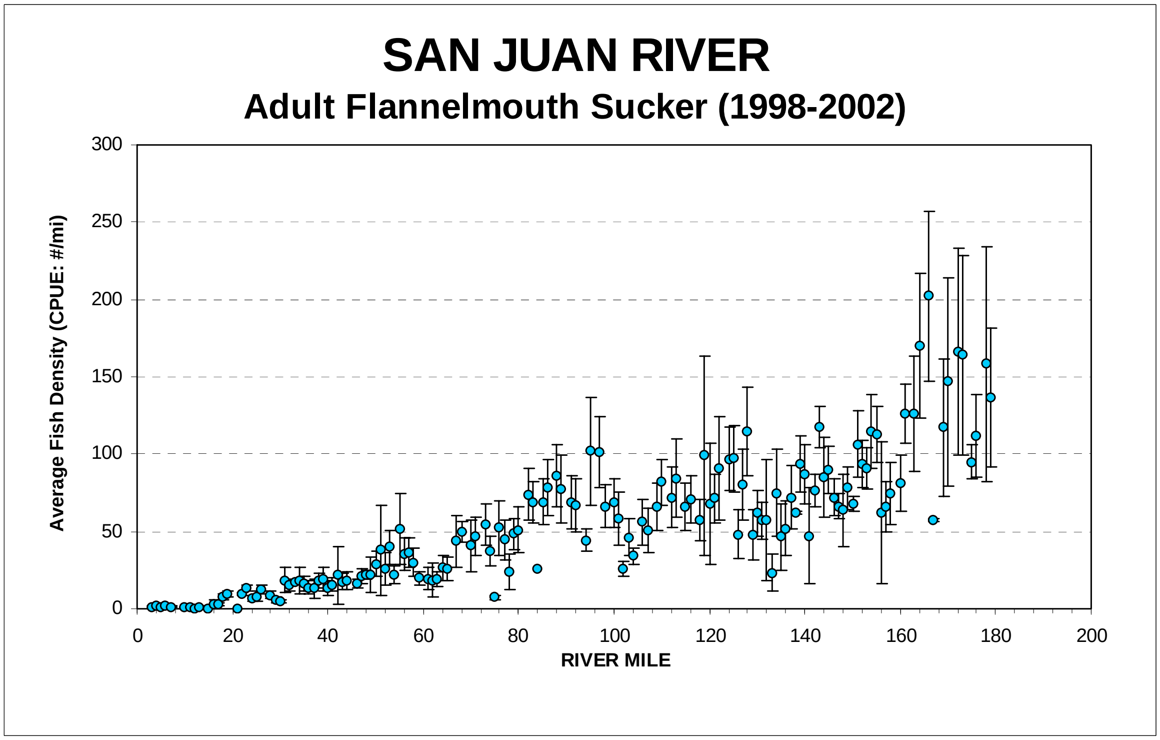
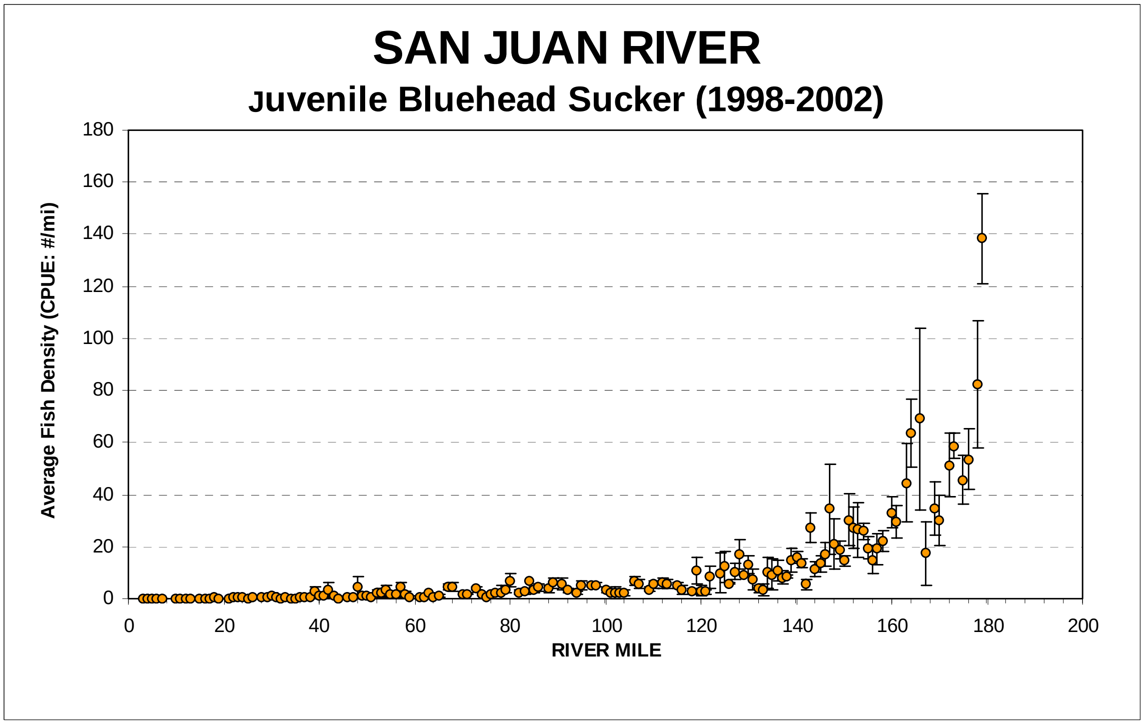


Figure 14. The average (1998-2002) CPUE (fish/mile) for flannelmouth sucker juvenile (top) and adult (bottom) in the San Juan River. Data are from Ryden 2002.



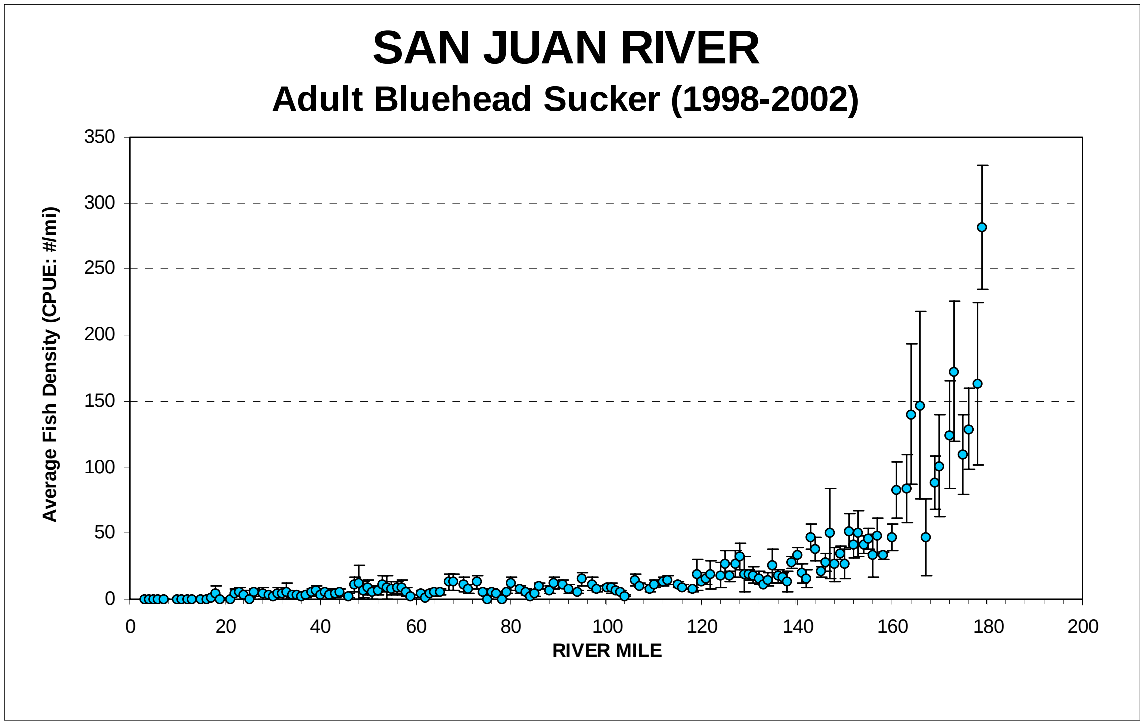
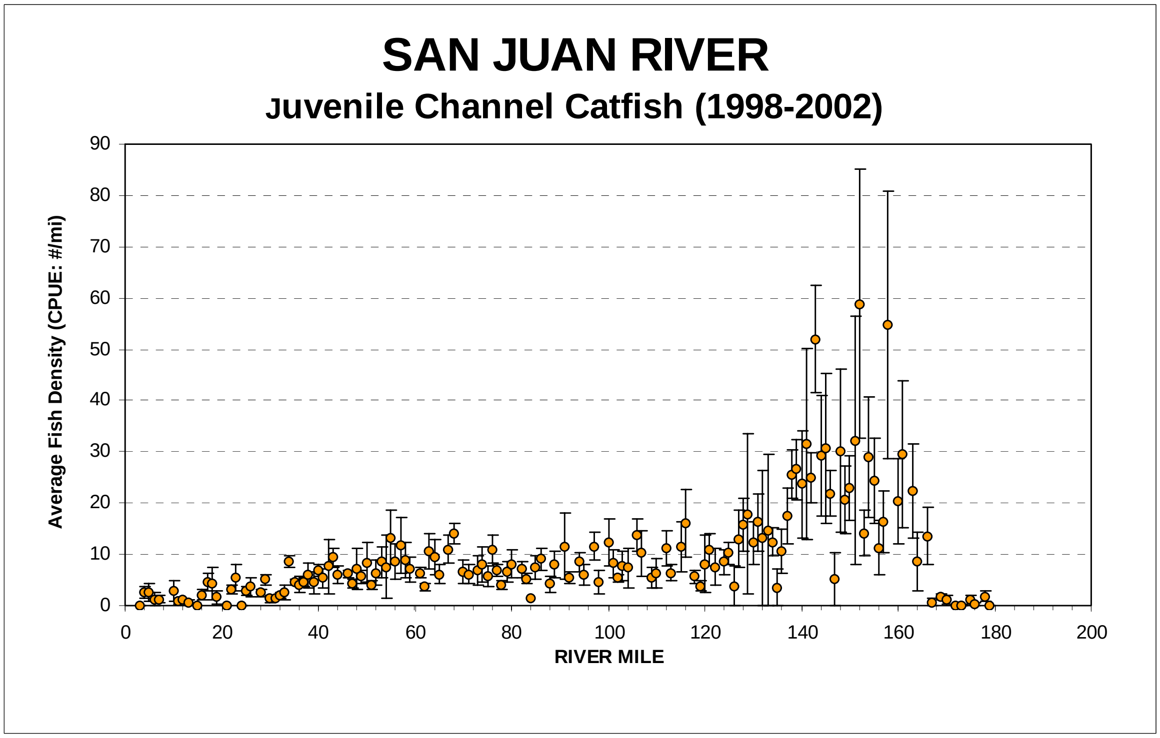


Figure 15. The average (1998-2002) CPUE (fish/mile) for bluehead sucker juvenile (top) and adult (bottom) in the San Juan River. Data are from Ryden 2002.



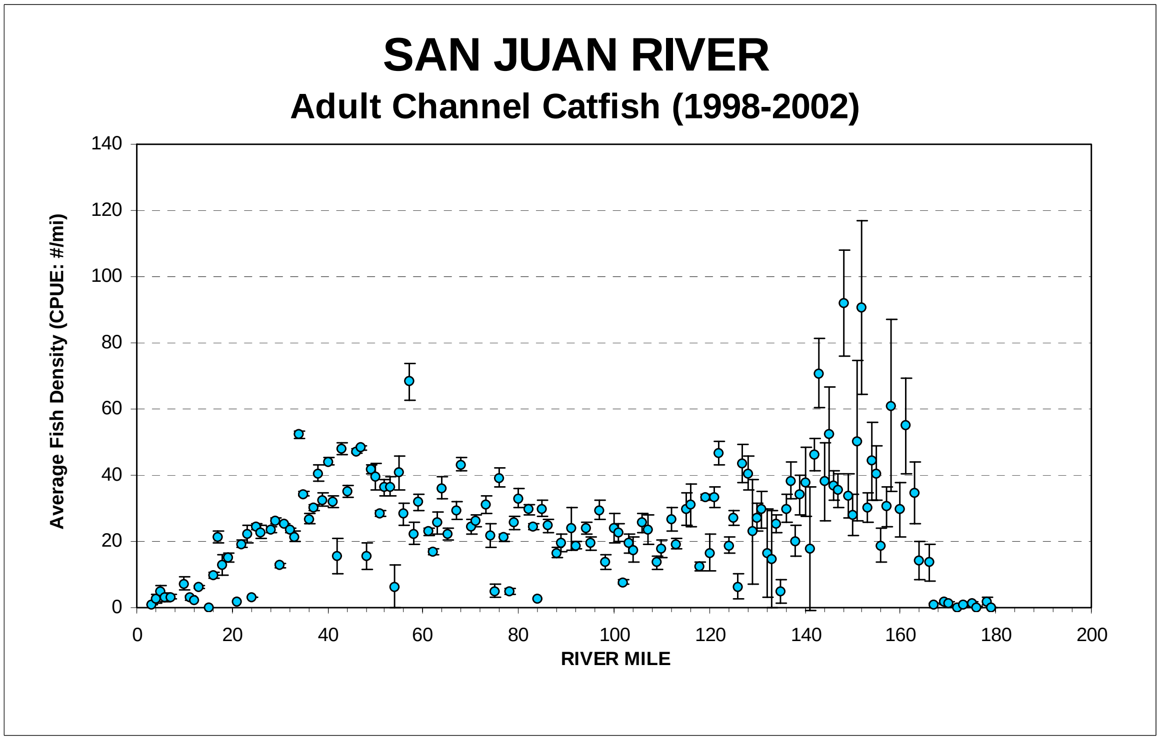
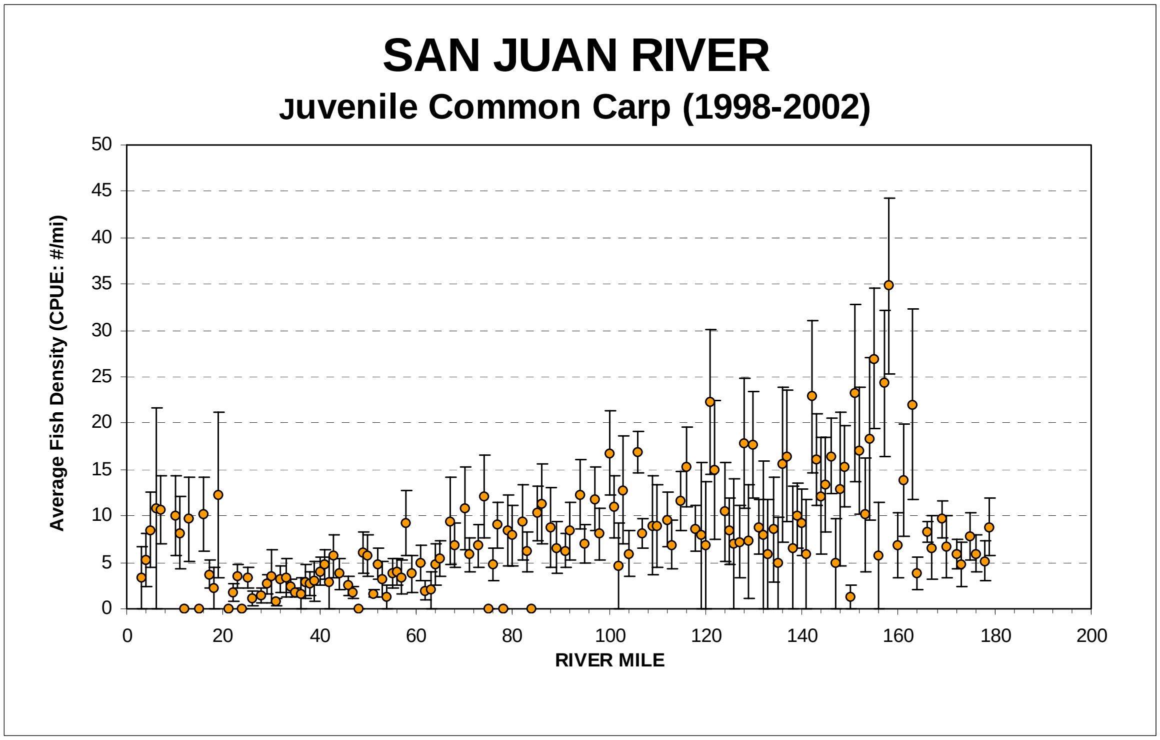


Figure 16. The average (1998-2002) CPUE (fish/mile) for channel catfish juvenile and adult in the San Juan River. Data are from Ryden 2002.



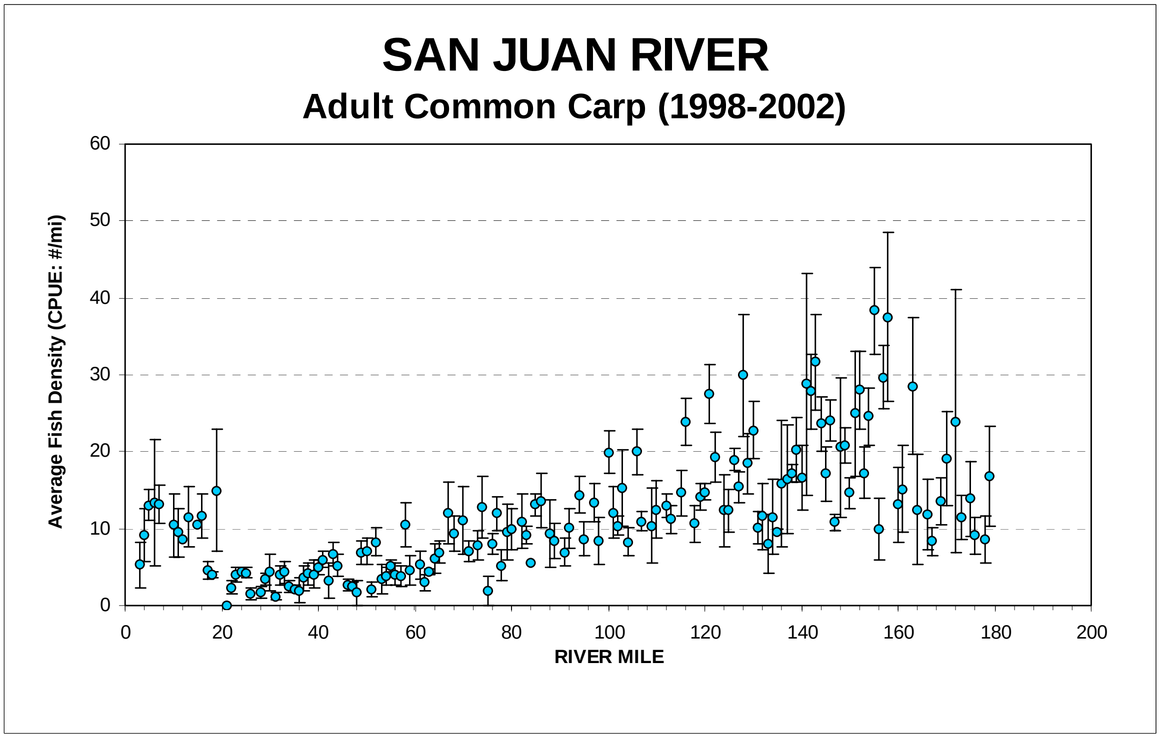


Figure 17. The average (1998-2002) CPUE (fish/mile) for common carp juvenile and adult in the San Juan River. Data are from Ryden 2002.

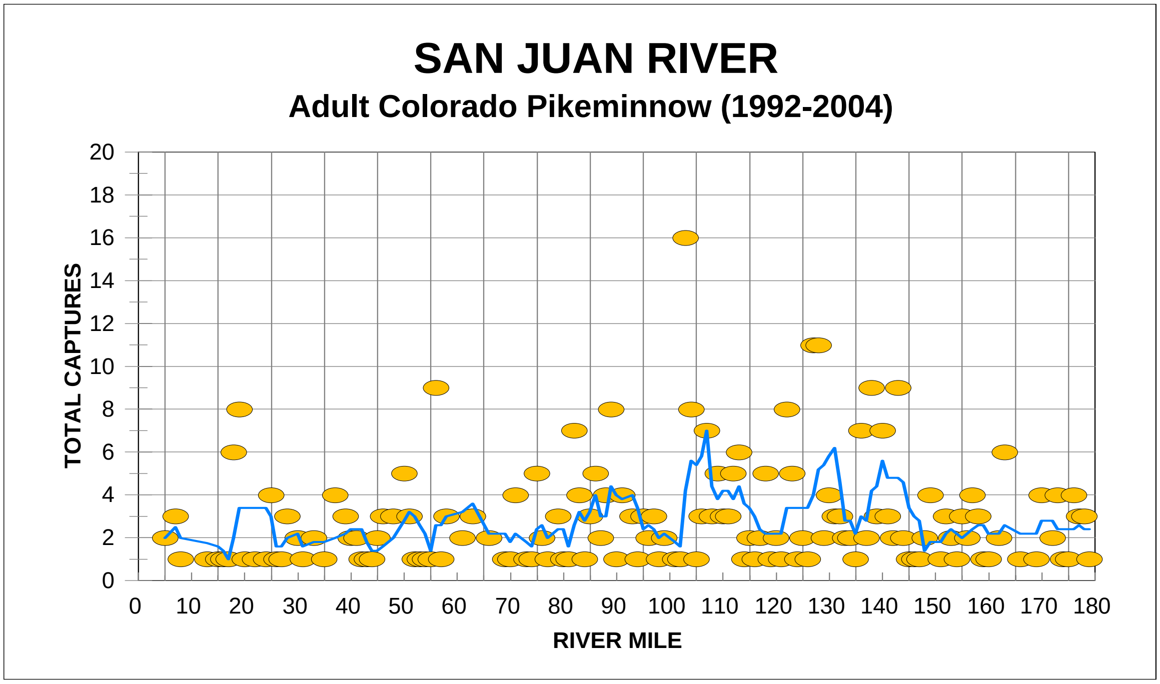


Figure 18. A summary of total captures from 1992 to 2004 for Colorado pikeminnow in the San Juan River by river mile location. Data are from Ryden 2005.

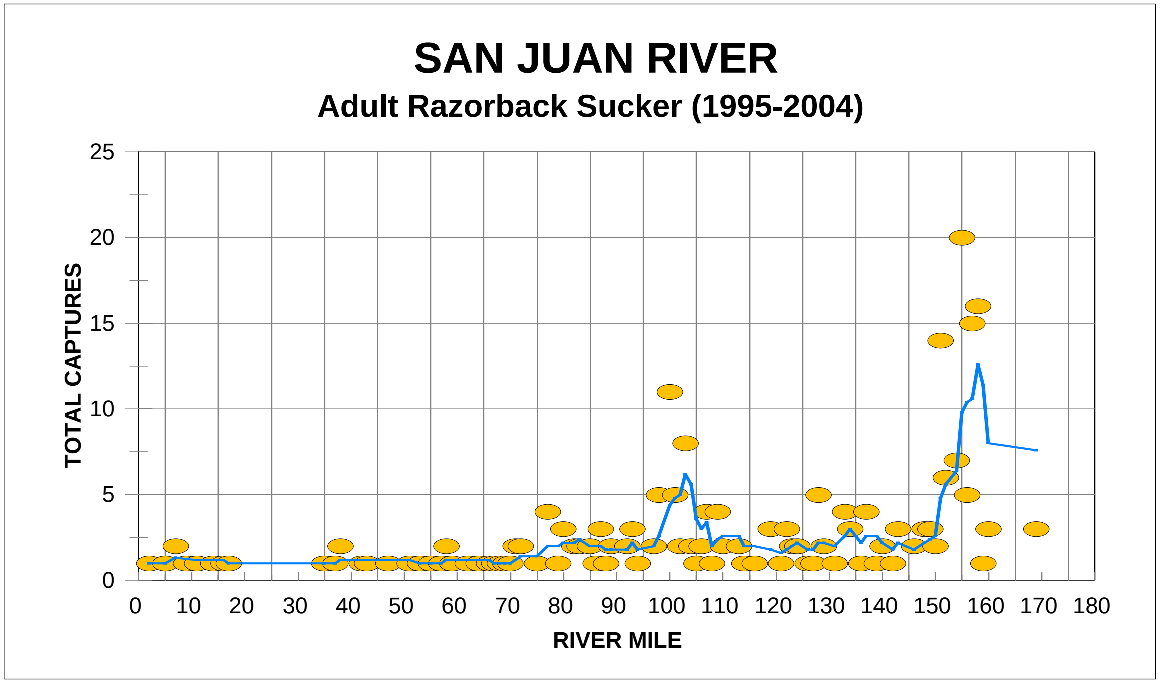


Figure 19. A summary of total captures from 1995 to 2004 for razorback sucker in the San Juan River by river mile location. Data are from Ryden 2005.

distribution of fish. For both warm and cold water species, their upper thermal ranges will most likely define their downstream distributions (Osmundson 1999). Therefore, the use of maximum summer temperatures (which do change with distance upstream) seems a reasonable approach to help estimate the preferred temperature for these species. In the case of the San Juan River, maximum temperatures occur in the middle of August and fish surveys occur in September and October. A comparison was therefore made between the maximum observed temperatures at seven stations in the San Juan River (Figure 20) and the distribution of fish over the same area. The location of peak populations densities (CPUE or total captures) were then compared to the maximum temperatures near that location. These data have been summarized in Table 1. The assumption made in this analysis is that the fish are distributed longitudinally based upon temperature (Lamarra 2004) and that the maximum observed temperature (at the location of highest density) corresponds to the preferred temperature and optimum growth (Jobling 1981) for that species. The author does however acknowledge that other factors do play an important role in the observed distributions of these fish, however, the analyses conducted to date indicates that temperature plays a dominant role and that factors such as food, inter and intra specific competition as well as predator avoidance although not analyzed could be factors regulating the fish distributions observed in the San Juan River.

The distribution of juvenile and adult flannelmouth suckers is shown in Figure 14. The adult fish have an increasing density with distance upstream reaching a maximum at about RM 135, after which it remains relatively constant. Based upon the inflection point of this distribution and the data in Figure 20, it was inferred that the optimum temperature for adult flannelmouth is approximately 25˚C. This is consistent with the literature values noted in Table 1. Juvenile flannelmouth are continuing to increase past RM 180. For the purpose of this analysis, the preferred maximum temperature is less than or equal to 20˚C for juvenile flannelmouth suckers.

Bluehead sucker distributions are shown in Figure 15. In both life stages shown in the figure the distributions are increasing past RM 180. For the purpose of this analysis, the preferred maximum temperature is less than or equal to 20˚C for both stages of this species. The 20˚C temperature as a preferred thermal maximum is consistent with the literature values in Table 1.

For both catfish (Figure 16) and common carp (Figure 17), the maximum densities by river mile form distinct maximums in their longitudinal distributions. For catfish adults this corresponds to approximately 25˚C and for juveniles, 28˚C. These values are consistent with the literature search noted in Table 1. Adult common carp peaked at RM 155, which corresponded to a maximum temperature of 22˚C to 23˚C. As with the other species noted above, this was consistent with literature values for preferred temperatures.

The spatial distribution of Colorado pikeminnow (Figure 18) and razorback sucker (Figure 19) based upon the location of captures from 1995 to 2004, do not have as clear a pattern as the two nonnatives. In part this is due to the fewer number of captures compared to the other more common species. In looking at an upper

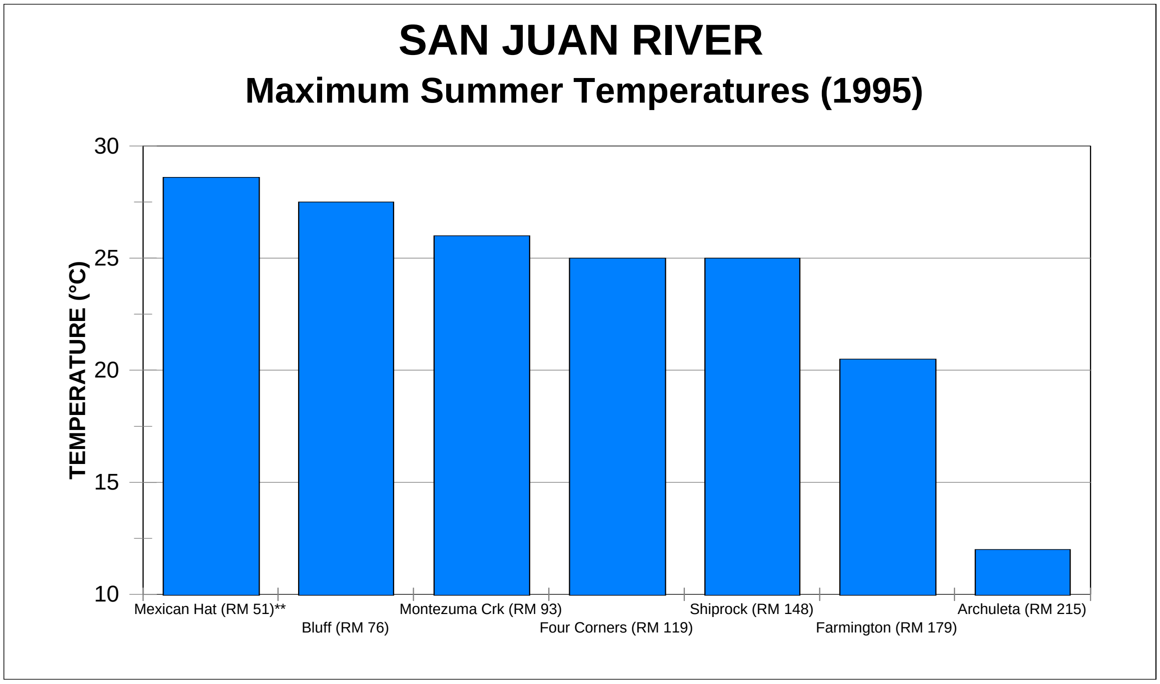


Figure 20. The maximum observed daily average temperature at seven locations in the San Juan River in 1995. Data for Mexican Hat is averaged from 2001-2002.

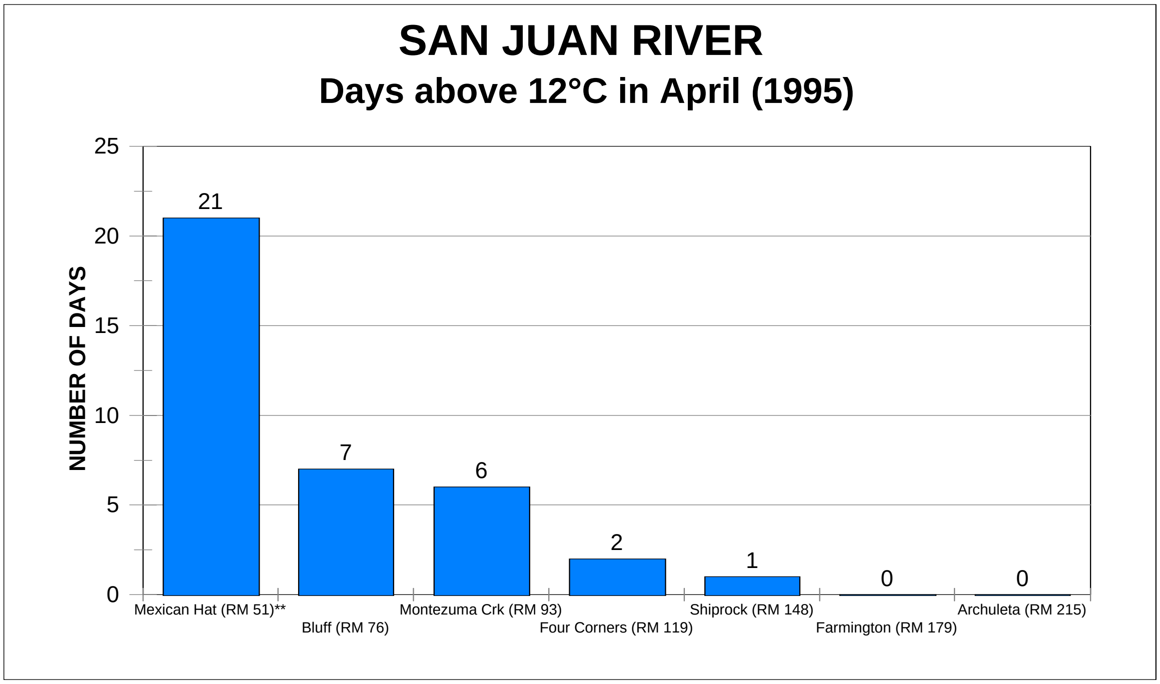


Figure 21. The number of days in April where the average daily water temperature was above 12˚C at each station in the San Juan River during 1995. Data for Mexican Hat are averages from 2001-2002.

envelope of captures by river mile, the highest densities are near RM 100 (16 captures). Considering that river location as having the highest densities, the corresponding maximum temperature would be near 25.5˚C. This is consistent with literature temperatures inferred as the preferred temperatures for Colorado pikeminnow.

Razorback sucker spatial distributions based upon total captures from 1995 to 2004 during the adult monitoring can be seen in Figure 19. As with pikeminnow, the razorback sucker distributions are not clear-cut. Using a 3-point moving average, two peak distributions emerge, one at RM 100 and the second at RM 150-160. Because there are lower capture densities above RM 160, it is assumed that the RM 150-160 reach is the preferred thermal optimum. This corresponds to a maximum summer temperature of 22˚C to 23˚C, which also corresponds to literature values for preferred temperatures for razorback suckers.

Although comparing the distributional pattern of the fishes found in the San Juan River with maximum observed temperature has produced temperatures noted in the literature as optimum temperatures, it does not fully explain the distributional patterns.

During the initial phases of building the Population Carrying Capacity Model, a preliminary analysis of the young-of-year (YOY) fishes (Buntjer et al. 1993; Buntjer et al. 1994) was undertaken in order to develop hypotheses regarding potential physical forcing factors (Lawrence 2002) on fish growth and distribution. This initial analysis focused on YOY fish densities as determined by the river-wide systematic investigations of low velocity habitats. A variety of forcing factors were investigated, including temperatures and winter/spring storm perturbations (as defined by Bliesner in the San Juan River Flow Recommendation Report 1995).

For the native bluehead sucker, the densities (#/100 m^2) between RM 2 and RM 158 in August were found to be negatively correlated with the number of days the maximum daily temperatures exceeded 12˚C during the previous April. It appears that this may also be a partial reason for the longitudinal distribution observed for this species (Figure 15). At least for 1995, the number of days exceeding 12˚C increases with distance downstream (Figure 21).

Inspection of both Figure 15 and Figure 21 indicates that bluehead sucker densities start to increase at about RM 130, which corresponds to the location where the number of days above 12˚C approaches zero. This analysis may indicate that elevating temperatures during this time period (at least above 12˚C) negatively impacts the potential recruitment of bluehead suckers at that location in the river.

In a similar manner, Lawrence (2002) looked at the factors related to the observed condition of the native suckers in the San Juan River based upon the adult monitoring program. That analysis indicated that both temperature and the perturbation frequency (storms) significantly predicted the condition factor of the flannelmouth sucker juveniles and adults. In the case of temperature, the flannelmouth sucker condition factor determined in August was higher if average temperatures in March and April were warmer. The number of perturbation events from October to April also predicted August condition (more storms resulted in lower fish condition). The preceding analysis indicates that although maximum temperature may affect or contribute to the longitudinal distribution of fish, other seasonal temperatures may also play an important role in survival and growth. These temperatures, if defined, should be included in an evaluation of potential thermal benefits to native species through Navajo Dam modifications. This is consistent with the opinion that temperature and food are two dominant factors regulating growth of riverine fishes (Weatherley 1972).

7.0 CONCLUSIONS

A review of the available literature has helped define the thermal niche of the native and dominant non-native species found in the San Juan River.

In addition, the site-specific analysis of the inferred temperature optima for the six species undertaken in this report appears to provide good agreement between this analysis and literature values for the same species (Table 1). Based upon all the evidence in this review, it is hypothesized that warmer summer temperatures in the San Juan River above the confluence with the Animas River over current conditions will result in an upstream movement of all the species discussed. The relative proportions and spatial distributions of the members of the fish community under the current thermal gradient should be the same, but located further upstream under a new thermal gradient.

Joseph et al. (1977) does an excellent job of describing the longitudinal distribution of the native species within the Upper Colorado River. Prior to man's influence, the Colorado River and its tributaries generally had headwater streams ("trout waters") which were cold, clear water, high gradients streams with rocky or gravelly substrate. These systems had a transition zone towards large, warm, and turbid rivers. Drawing upon observations of Jordon (1891), he describes the species that should be present in each major zone.

For example, Colorado cutthroat trout, speckled dace, mottled sculpin and mountain whitefish would be in the upper high gradient reaches. In the transition reach, bluehead suckers and roundtail chub would be major components, along with speckled dace. In the lower larger river reaches, flannelmouth sucker, razorback sucker and Colorado pikeminnow would be present. Based upon early investigations, speckled dace, flannelmouth sucker, and to a certain extent, bluehead sucker were found in both the transition and the lower zones of these river systems. The fall distributional pattern for razorback suckers was not described.

For the San Juan River, a similar distribution of species is present, although compressed due to cool water releases from Navajo Reservoir. Modification in temperatures released from Navajo Dam could allow those species in the San Juan River below the Animas River to increase their populations further upstream. This would include both the permanent presence of pikeminnow as well as the potential use of the river for spawning by this species. Under the current thermal conditions in the San Juan River above the confluence with the Animas, it is doubtful that pikeminnow would establish a permanent presence or attempt to spawn.

With selective passage at the P&M weir, the non-native component (primarily catfish and carp) of the current fish community can be limited in their upstream movement by allowing only selective fish passage and an aggressive removal program. This would allow a dominance of the native fish community which would be utilized by Colorado pikeminnow. Negative impacts of a new thermal regime can be mitigated by keeping spring temperatures moderate and by moving the native fish community upstream closer to Navajo Dam, which would maximize community net production by lessening the magnitude of storm perturbations that effect growth and condition factor of the native community.

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