2000

NON-NATIVE SPECIES INTERACTIONS: MANAGEMENT IMPLICATIONS TO AID IN RECOVERY OF THE COLORADO PIKEMINNOW *Ptychocheilus lucius* AND RAZORBACK SUCKER *Xyrauchen texanus* IN THE SAN JUAN RIVER, CO-NM-UT

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1 February 2000

SAN JUAN RIVER BASIN RECOVERY IMPLEMENTATION PROGRAM

EXECUTIVE SUMMARY

As part of the San Juan River Basin Recovery Implementation Program (SJRIP), investigations of non-native fishes were conducted during 1991-1997 to characterize interactions with native fishes. The impacts of non-native fish species on natives has often been identified as a key impact, along with habitat alteration, that facilitates loss of native biological diversity. In the San Juan River, the endangered Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*, as well as the other members of the native fish community, are the focus of the SJRIP. A major component of native fish recovery efforts in the San Juan River is the mimicry of the natural hydrograph, and SJRIP studies were designed to assess the response of the resident fish community to variable flow conditions affected the releases from upstream Navajo Dam. Section 5.4 of the SJRIP Long Range Plan identified several informational and action needs regarding non-native fish species: 1) characterize distribution and abundance patters of non-native fishes, 2) characterize habitats used by non-native fishes, 3) describe the food habits of non-native fishes, 4) characterize the response of non-native fishes to varying flow regimes, 5) develop a non-native fish stocking policy, 6) develop regulations to restrict bait-fish species harvest, 7) develop regulations to control importation of non-native fishes, and 8) monitor and evaluate non-native fishes control actions implemented as part of the SJRIP. This report presents results of non-native fishes investigations that address items 1-4 and 8 above.

The distribution and abundance patterns of large-bodied non-native fishes were studied to determine responses to varying flow regimes. Sampling was primarily by raft-mounted electrofishing, but also included limited hoop and trammel netting. Main and secondary channel sampling collected 18 species of non-native fish. Channel catfish *Ictalurus punctatus* and common carp *Cyprinus carpio* were the most abundant and the most widely distributed species. Seasonal movements of striped bass *Morone saxatilis* and walleye *Stizostedion vitreum* out of Lake Powell and upstream into the San Juan River as far as Shiprock, New Mexico were documented. Mark and recapture studies of channel catfish and common carp were used to estimate abundance and to evaluate movement patterns for the entire reach of the San Juan River sampled, Farmington, New Mexico downstream to Clay Hills, Utah. Schnabel population estimates (95% C.I.) for channel catfish ranged from 131,768 (72,143 - 219,393) in 1992 to 274,484 (115,712 - 563,162) in 1995 and for common carp were 26,576 (14,213 - 45,019) in 1992 to 107,268 (61,438 - 172,692) in 1995. The proportional abundance of non-native species sampled during electrofishing surveys in main and secondary channel habitats increased during 1994-1997, after initial declines observed during1991-1994. Implementation of high spring releases from Navajo Dam did not appear to negatively impact non-native species distribution or abundance.

Recapture rates for 3,878 channel catfish and 3,034 common carp tagged with numbered Floy tags were 5.8% and 10.8%, respectively. Neither species exhibited strong movement patterns to or affinities for specific areas of the San Juan River as has been documented in other river systems. The mean distance moved between recapture and original or last capture locations was

12.9 river miles (S.E.=1.5, N=182) for channel catfish and 5.5 river miles (S.E.=0.8, N=281) for common carp. Radio telemetry studies of 18 channel catfish implanted with 40-MHZ tags and equipped with external antennae (400-day tags for fish >550 mm TL, 130-day tags for fish 350-365 mm TL) confirmed the lack of long distance seasonal migrations observed during mark and recapture studies. Adult channel catfish occupied primarily run habitats throughout the year, but during winter base flows a greater number of habitats were selected with eddies, slackwaters, and pools occupied primarily. During high spring flows in June, two of eight individuals still containing transmitters (all others expelled at that time) moved into side channel runs where current velocities were lower than those measured in main channel runs.

Movement (egression/ingression) of native and non-native species between main and secondary channel habitats was studied during 1994-1995. Fish movement at the up- and downstream mouths of secondary channels were sampled by hoop net to measure direction (in,out) and timing of fish movement under varying flow conditions. A total of 841 native and 21,906 non-native fishes were collected in 1994. In 1995, 2,836 native and 6,559 non-native fishes were sampled. Roundtail chub *Gila robusta* was the only rare native species recorded. Speckled dace *Rhinichthys osculus* was the most common native species sampled and non-native samples were primarily red shiner *Cyprinella lutrensis* and fathead minnow *Pimephales promelas*. During July 1994 sampling at high flows, more than 90% of the total specimens were collected. Collections during high August 1995 flows yielded the greatest number of specimens for the year, including 91% of all native specimens. Other than increased movement of native species during high flow conditions, there were no statistically significant differences.

To evaluate piscivory by non-natives on native fishes and commonality of food resource use between the two, we analyzed food habits of San Juan River fishes, 1991-1995. Due to the channel catfish's abundance and widespread distribution, analysis of its food habits was emphasized during 1991-1993. During 1993-1995, we analyzed the food habits of both native and non-native species in association with egression/ingression sampling. All potential large-bodied non-native piscivorous fishes (primarily striped bass, walleye, largemouth bass *Micropterus salmoides*) were sacrificed and stomach contents examined in the field for presence/absence and identification of fishes consumed. Macroinvertebrates were sampled during 1993-1995 to assess abundance and availability of foods for native and non-native fishes. Piscivory in channel catfish was documented in 13.2% of 312 specimens, primarily in catfish >450 mm TL. All stomachs of other non-native piscivores containing food items yielded fish and/or fish remains. We did not document piscivory on rare fishes, and flannelmouth sucker *Catostomus latipinnis* was the most common native species consumed. Examination of stomach contents of small-bodied native and non-native species and young-of-year and juvenile life stages of large-bodied native and non-native species indicated considerable overlap of macroinvertebrate orders consumed. The macroinvertebrate community, when compared to other Colorado River Basin streams, was lower in abundance and diversity (lowest taxonomic level identified was Family). The reduced and abundance of the San Juan River macroinvertebrate community is likely due to the higher frequency and magnitude of late

summer rainstorm events that result in repeated scouring of the substrate and heavy sediment load carried by short-duration flood events.

Mechanical removal of channel catfish, as a potential control measure, was implemented and evaluated during 1995. Passive (hoop and trammel netting) and active (electrofishing) methods were employed, with the latter more effective in capturing channel catfish. Removal efforts employing passive and active methods in discrete reaches (3 river miles) separated by control reaches were unsuccessful due to failure of passive methods to collect adequate numbers of fish and was discontinued after one sampling season. During 1,967 hours of hoop netting only 25 channel catfish and 11 common carp were removed. River-wide removal of all non-native species during spring and fall main channel monitoring surveys, 1995-1997, yielded 22,985 fish. Channel catfish (n=12,660; 5,139 kg) and common carp (n=10,016; 12,433 kg) comprised the majority of fish removed. Analyses of the electrofishing catch per unit effort, mean total length, and biomass of channel catfish in a sub-reach of Reach 6 (PNM Weir to the Hogback Diversion) yielded lower abundance estimates from 1996 to 1997 and may be a response to removal efforts. Transplantation of channel catfish from the San Juan River to isolated recreational angling impoundments is proposed as a means of disposing of non-native channel catfish to minimize interactions with native fishes and increase the quality (size of fish stocked) of current hatchery-supported sport fisheries.

It was hypothesized at the beginning of the SJRIP that mimicry of the natural hydrograph through Navajo Dam releases would benefit native fishes and act to minimize non-native species interactions. Data collected during this study did not identify negative responses of the non-native fish community (channel catfish and common carp) to mimicry of the natural hydrograph (high spring flows timed to coincide with peak Animas River flows). Long-term removal measures to control large-bodied non-native fishes such as channel catfish, however, may successfully reduce abundance and distribution and allow for improved conditions and survival of the native fishes in the San Juan River.

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INTRODUCTION

The role of non-native fishes is often identified, in association with habitat changes, as a major obstacle to conservation of native fish communities. Alteration of riverine habitats by dam construction, water diversion, and bank stabilization have contributed to the establishment and spread of non-native fishes in the San Juan River Basin. Non-native fishes established in the San Juan River include species that occur primarily in lentic environments (mainly centrarchids), as well as more widely distributed species such as the small-bodied red shiner *Cyprinella lutrensis* and large-bodied channel catfish *Ictalurus punctatus*, and common carp *Cyprinus carpio* (Table 1).

The establishment of non-native fishes in lotic habitats of the Colorado River Basin of the American Southwest was widespread by the end of the nineteenth century. Coldwater sport fish, primarily salmonids, were introduced into high-elevation streams resulting in negative impacts on native trout species (Miller 1950, Minckley 1973, Behnke 1992). Warmwater species introduced into lower elevation streams also impacted resident native species, with predation by large piscivores such as channel catfish, flathead catfish *Pylodictis olivaris*, and largemouth bass *Micropterus salmoides* severely reducing formerly widespread distributions of native fishes (Minckley and Deacon 1968, Marsh and Brooks 1989, Tyus and Nikirk 1990). Other non-native species introduced primarily as bait and food fish for non-native sport species, such as red shiner and fathead minnow *Pimephales promelas,* have exerted competitive, as well as predation pressure on native species (McAda and Kaeding 1989, Rupert et al.1993, Douglas et al.1994). Finally, non-native species such as white sucker *Catostomus commersoni* hybridize with native sucker species (Hubbs et al.1943, Miller and Rees 1999).

The result of widespread intentional and accidental stocking of non-native fish species in the western United States, particularly within the Colorado River Basin, is that non-native fish species outnumber native fish species in virtually all artificial lentic habitats. While native species tend to dominate fish communities in lotic habitats that maintain natural flow regimes (Minckley and Meffe 1987, Meffe and Minckley 1987), non-native species can still replace native fishes, as is evidenced in the naturally flowing Salt River in central Arizona (Hendrickson 1993). In the San Juan River, native species numerically dominate the mainstream fish community (Ryden and Pfeifer 1993, 1994, 1995, 1996) while smaller non-native species are more abundant in secondary channels and low-velocity habitats (Buntjer et al. 1993, 1994 Propst and Hobbes 1993, 1994, 1995, 1996, Gido and Propst 1994, Gido et al.1997).

In the San Juan River sub-basin, at least thirty species of non-native fish have been reported (Platania 1990, Sublette et al.1990, Anderson et al. 993, Brooks et al.1994). Of these, four species (red shiner, common carp, fathead minnow, and channel catfish) are comparatively common and regularly collected in the warmwater reaches of the San Juan River downstream of Farmington, New Mexico to Lake Powell, Utah. Channel catfish is the only widely distributed piscivore (Ryden and Pfeifer 1993, 1994). However, lacustrine non-native predatory species such

Table 1. Occurrence of non-native fish species in the San Juan River Basin, CO-NM-UT. Occurrence determinations are based upon 1987-1997 fish collections and by historical Colorado data compilations by Anderson et.al. (1993).

Family	**Species**	**Abbrev.**
Clupeidae	threadfin shad, Dorosoma petenense[1]	DORPET
Salmonidae	brown trout, Salmo trutta brook trout, Salvelinus fontinalis coho salmon, Onchorhynchus kisutch[1] Snake River cutthroat trout, Onchorhynchus clarki spp. rainbow trout, Onchorhynchus mykiss Kokanee salmon, Onchorhynchus nerka[1]	SALTRU SALFON ONCKIS ONCCLA ONCMYK ONCNER
Esocidae	northern pike, Esox lucius[1]	ESOLUC
Cyprinidae	grass carp, Ctenopharyngodon idella red shiner, Cyprinella lutrensis common carp, Cyprinus carpio golden shiner, Notemigonus crysoleucus[1] fathead minnow, Pimephales promelas	CTEIDE CYPLUT CYPCAR NOTCRY PIMPRO
Catostomidae	longnose sucker, Catostomus catostomus white sucker, Catostomus commersoni white x bluehead sucker hybrid, Catostomus spp. white x flannelmouth sucker hybrid Catostomus spp.	CATCAT CATCOM
Ictaluridae[2]	black bullhead, Ameiurus melas channel catfish, Ictalurus punctatus	AMEMEL ICTPUN
Cyprinodontidae	plains killifish, Fundulus zebrinus	FUNZEB
Percidae	Iowa darter, Etheostoma exile yellow perch, Perca flavescens[1] walleye, Stizostedion vitreum[1]	ETHEXI PERFLA STIVIT
Poeciliidae	mosquito fish, Gambusia affinis	GAMAFF
Percichthyidae	striped bass, Morone saxatilis[1] white bass, Morone chrysops[1]	MORSAX MORCHR
Centrarchidae	green sunfish, Lepomis cyanellus pumpkinseed sunfish, Lepomis gibbosus bluegill, Lepomis macrochirus[1] smallmouth bass, Micropterus dolomieu largemouth bass, Micropterus salmoides[1] white crappie, Pomoxis annularis[1] black crappie, Pomoxis nigromaculatus[1]	LEPCYA LEPGIB LEPMAC MICDOL MICSAL POMANN POMNIG

[1] Distribution restricted primarily to reservoir environments.
2 Other species identified, but not verified by voucher specimens were yellow bullhead *Ameiurus natalis.*
as striped bass *Morone saxatilis*, walleye *Stizostedion vitreum* and largemouth bass also occur within the riverine portions of the San Juan River sub-basin on a limited basis (Ryden and Pfeifer 1996).

While other non-native species are common and widespread in the San Juan River, channel catfish are of the greatest concern due to their widespread distribution and high abundance patterns (Sublette et al.1990) and documented predation on native fish communities (Marsh and Brooks 1989, Tyus and Nikirk 1990, Marsh and Douglas 1997). The earliest report of channel catfish in the San Juan basin was 1957 (University of New Mexico, Museum of Southwestern Biology collection), but it is likely the species arrived prior to that date. The establishment of channel catfish in the basin was the result of concerted stocking efforts by state and federal agencies (NMDFG and USFWS files). Although apparently well established, irregular stocking of channel catfish in lotic environments of the San Juan River sub-basin continued into the 1980's. While the New Mexico Department of Game and Fish ceased stocking the species in the river in the early 1980's, it is still stocked in impoundments in the drainage (NMDGF files). There are no official records of its being stocked in the riverine portions of the basin in Utah, at least in the past 30 years (UDWR files). In Colorado, few riverine habitats are suitable for the species, but it does occur in several reservoirs where it continues to be stocked (CDOW files).

Other non-native fish species in the San Juan River, particularly the ubiquitous common carp, likely also play an important role in the restoration and management of the native fish community. Common carp were first introduced into North America in 1831, and in 1879, the U.S. Fish Commission began a stocking program in an effort to address depleted inland fisheries. It is not known when common carp were originally introduced into the San Juan River sub-basin, but Sublette et al. (1990) reported that this species was first introduced into New Mexico waters in 1883. Evermann and Rutter (1895) reported the presence of common carp in the Colorado River Basin during the late 1800's, and it is probable that this species has been in the San Juan River since the turn of the century. The vast reproductive potential and generalist life history patterns for common carp (Panek 1987) imply that this species may be a significant competitor with native fishes for aquatic resources. Minckley (1973) wrote:

> The effects of carp on other fishes are subtle. They are remarkably adaptable animals, with broad spectra of tolerances to chemical conditions, temperatures, currents, foods, and spawning condition, and therefore probably influence most species (directly or indirectly) with which they occur.

With the closure of Glen Canyon Dam on the Colorado River in early 1963, the formation of Lake Powell and associated establishment of lacustrine, non-native piscivore populations began. The periodic occurrence of largemouth bass, striped bass, and walleye in upstream reaches of the San Juan River may increase predation pressure on native species. Largemouth bass and walleye were first collected from the Colorado River reach currently inundated by Lake Powell in 1962, prior to completion of Glen Canyon Dam (Stone and Miller 1966). Striped bass fingerlings were introduced into Lake Powell on an annual basis 1974-1979. Successful reproductive efforts have been documented since, and they maintain a large reservoir population (Gustaveson et al. 1984). Ryden and Pfeifer (1996) have reported on sporadic occurrences of these species in the San Juan River upstream of Lake Powell. While relatively uncommon, these species are all highly piscivorous (Carlander 1950, Minckley 1973, Sublette et al. 1990) and may influence resident native populations, particularly in the lower San Juan River.

The San Juan River Recovery Implementation Program (SJRIP) was established as a response to information needs regarding endangered fish species and proposed development of water resources. Since 1991, the SJRIP has orchestrated the conduct of research to address a variety of questions regarding native fish species recovery and management and water development. The focus of this portion of research funded through the SJRIP is to characterize the interactions between native and non-native fishes under a variety of habitat (flow) conditions. Identifying the mechanisms of interspecific interactions that negatively impact native fishes will allow for the development of management options designed to protect and restore the native fish community. The primary goal of this research is to evaluate and characterize the response of non-native fishes to flow/habitat manipulations designed to benefit the native fish community with emphasis on endangered Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*.

STUDY AREA DESCRIPTION

The Colorado River Basin drains 632,000 km^2 in the western United States and northwestern Mexico (Carlson and Muth 1989) and, for the purposes of water management, is split into upper and lower basins at Lee's Ferry, Arizona (1922 Colorado River Compact). Several large sub-basins are identified within the upper (Green, Colorado, Gunnison, San Juan) and lower (Little Colorado, Virgin, Gila) basins (Figure 1). From the headwaters to its confluence with the Gulf of California, Mexico, the Colorado River flows for a distance of 2320 km, and ranges in elevation from more than 4000 m in headwater reaches to sea level at the terminus. Carlson and Muth (1989) summarized the geologic history and human occupation of the Colorado River Basin.

The San Juan River is a major tributary of the Colorado River and drains 99,200 km^2 in Colorado, Utah, Arizona, and New Mexico (Figure 2). 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 Glen 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

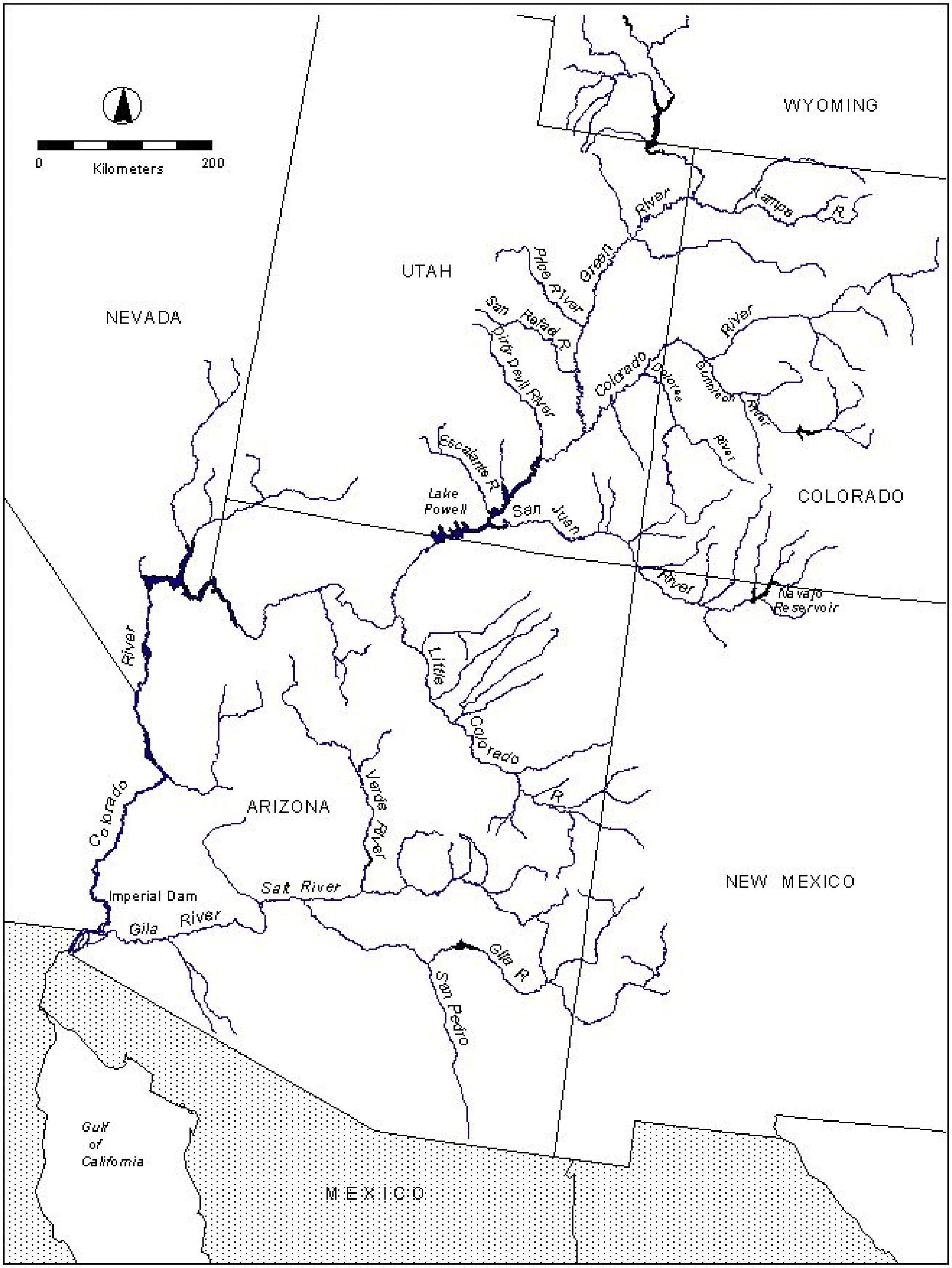
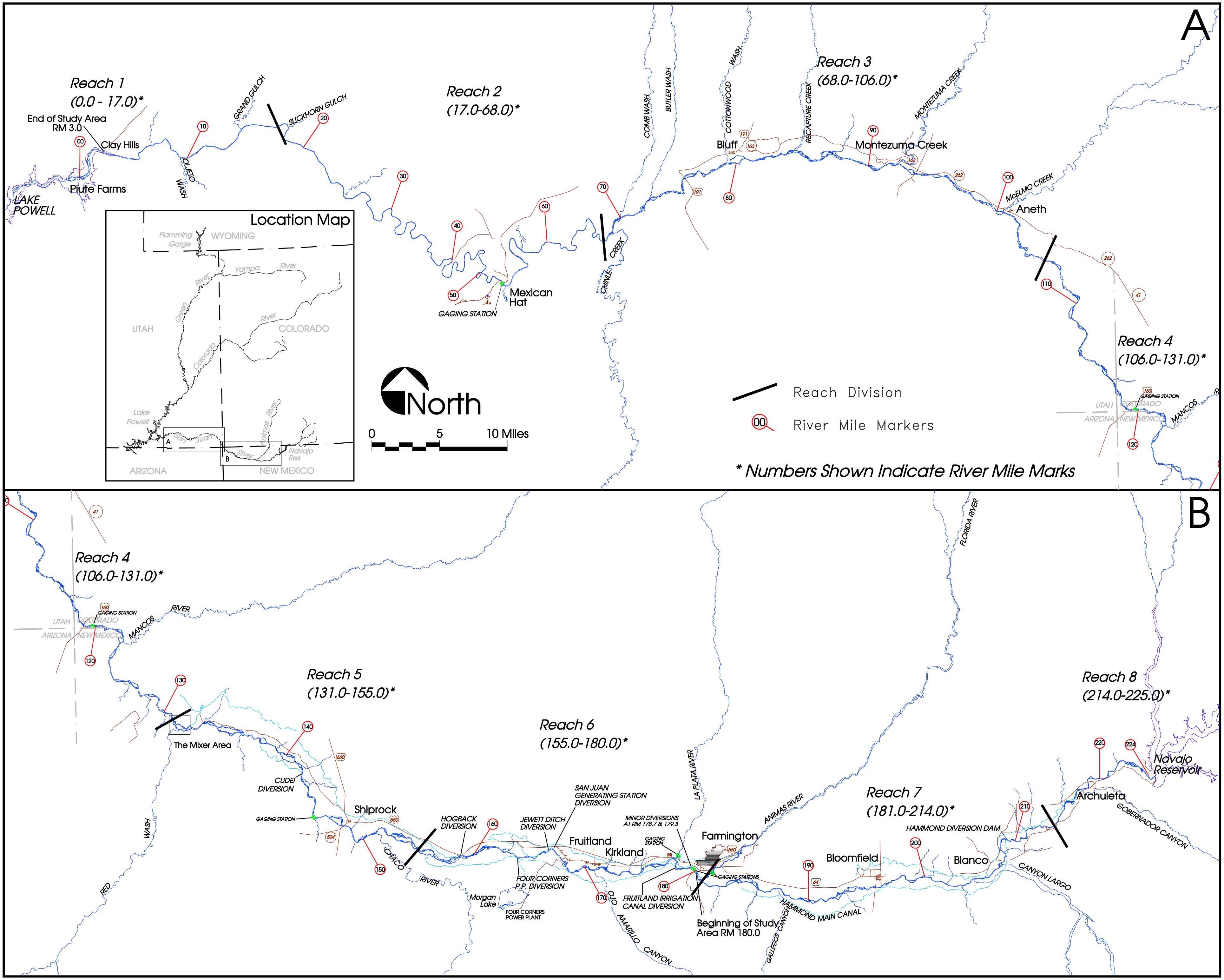


Figure 1. The Colorado River Basin.


A
B
Reach 1
(0.0 - 17.0)*
Reach 2
(17.0-68.0)*
Reach 3
(68.0-106.0)*
Reach 4
(106.0-131.0)*
Reach 5
(131.0-155.0)*
Reach 6
(155.0-180.0)*
Reach 7
(181.0-214.0)*
Reach 8
(214.0-225.0)*
End of Study Area
RM 3.0
Clay Hills
Piute Farms
LAKE
POWELL
GRAND GULCH
SLICKHORN GULCH
OLJETO
WASH
Mexican
Hat
GAGING STATION
CHINLE
CREEK
COMB WASH
BUTLER WASH
COTTONWOOD
WASH
RECAPTURE CREEK
MONTEZUMA CREEK
Bluff
Montezuma Creek
McELMO CREEK
Aneth
Location Map
Flamming
Gorge
WYOMING
Yampa
River
Green
UTAH
COLORADO
Colorado
Lake
Powell
San
Juan
River
Animas
Navajo
Res
ARIZONA
NEW MEXICO
North
0
5
10 Miles
Reach Division
River Mile Markers
* Numbers Shown Indicate River Mile Marks
GAGING STATION
MANCOS
RIVER
The Mixer Area
CUDEI
DIVERSION
Shiprock
HOGBACK
DIVERSION
CHACO
RIVER
JEWETT DITCH
DIVERSION
SAN JUAN
GENERATING STATION
DIVERSION
Fruitland
Kirkland
FOUR CORNERS
P.P. DIVERSION
Morgan
Lake
FOUR CORNERS
POWER PLANT
OJO
AMARILLO
CANYON
MINOR DIVERSIONS
AT RM 178.7 & 179.3
LA PLATA RIVER
ANIMAS RIVER
Farmington
GAGING STATIONS
FRUITLAND IRRIGATION
CANAL DIVERSION
Beginning of Study
Area RM 180.0
GALLEGOS CANYON
HAMMOND MAIN CANAL
Bloomfield
HAMMOND DIVERSION DAM
Blanco
CANYON LARGO
Archuleta
GOBERNADOR CANYON
Navajo
Reservoir
FLORIDA RIVER
RED
WASH

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, Utah, the river is canyon-bound and restricted to a single 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, New Mexico 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*) and Russian olive (*Eleagnus angustifolia*) and 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, and common only on islands free of livestock grazing.

The discharge pattern 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 USGS Bluff, Utah gage) 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, was 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 (Table 2).

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 the 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 the 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 area 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 Gubernador 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.

Table 2. Reach designations for the San Juan River study area based upon Bliesner and Lamarra (1995).

Reach	River Miles	Locality Description
1	0 - 16	Clay Hills - Slickhorn Canyon
2	17 - 67	Slickhorn Canyon - Chinle Wash
3	68 - 105	Chinle Wash - Aneth
4	106 - 130	Aneth - Mixer
5	131 - 154	Mixer - Hogback Diversion
6	155 - 180	Hogback Diversion - Animas confluence
7	181 - 213	Animas confluence - Blanco
8	214 - 224	Blanco - Navajo Dam

CHAPTER I

Distribution, abundance and movement of channel catfish and common carp in the San Juan River, 1991-1997

Introduction

The distribution, abundance, and movement patterns of main channel non-native species, particularly channel catfish and common carp, were the focus of this study segment. Essential to the development of resource management strategies designed to minimize interactions between native and non-native fishes in the San Juan River is the characterization of the spatial and temporal population dynamics of the resident non-native fishes. Data presented and discussed in this chapter emphasize the population dynamics of channel catfish and common carp in main channel and larger secondary channel habitats. Other large-bodied non-natives that inhabit the San Juan River are not as abundant or widely distributed. For lacustrine species that periodically enter the San Juan River, such as striped bass and walleye, interactions with native fishes are temporary and/or occur in restricted reaches of the study area, but may affect native species through predation impacts (see Chapter III, Food Habits).

We hypothesized that the response of non-native species, primarily channel catfish and common carp, to the different flow regimes encountered during 1991-1997 would be negative. Specifically, it was believed that high spring flows would displace adult non-native species and would minimize reproductive success and recruitment of juvenile non-natives. Re-operation of Navajo Dam to mimic a natural hydrograph to allow the San Juan River to function more naturally, particularly for provision of high spring flows, was considered necessary in order to provide for recovery of native fishes (see discussions by McBain and Trush 1997 and Poff et al. 1998). Data analyses for the response of distribution, abundance, and movement patterns of non-native fishes in the San Juan River to flow manipulations by Navajo Dam releases are presented here.

Objectives for this study segment were:

1. Characterize the distribution and abundance patterns of non-native species in main channel habitats.
2. Determine the effects of high spring flows on the abundance of non-native species in succeeding years.
3. Characterize the movement patterns of channel catfish and common carp to identify significant temporal and spatial movement patterns.
4. Characterize the habitat use patterns of channel catfish as a response to habitat availability and flow patterns.

Study Area

The study area for characterization of the distribution and abundance of the non-native fish community encompassed the main and all secondary channels accessible by raft from the confluence of the Animas River downstream to Clay Hills, Utah. The determination of the movement patterns of channel catfish and common carp from mark and recapture data, was conducted in the San Juan River from the weir at Fruitland, New Mexico downstream to Clay Hills, Utah. Radio telemetry studies of channel catfish were conducted in the San Juan River the weir at Fruitland, New Mexico downstream to near the Four Corners area.

Methods

Non-native fishes were collected from main channel and larger secondary channel habitats during adult monitoring surveys. Raft-mounted electrofishing gear (pulsed direct current) was used to sample downstream in 1-river-mile (RM) increments. Attempts were made to net all fish stunned near the front of the raft (anode). Additional fish were occasionally netted by a 'chase' raft and are included in the data compilations. Electrofishing surveys were conducted primarily during daylight hours, but did include some crepuscular collections. For each RM sampled, the location, seconds shocked, and number by species were recorded. At every fifth RM (i.e., a designated mile-DM) the total length (TL), standard length (SL), and weight of each specimen collected was also recorded. Catch per unit effort (CPUE) was calculated as the number of fish collected per minute of electrofishing for all fish species sampled. Catch rates were determined for channel catfish and common carp and compared to the overall catch. Catch data were summarized by reach for the entire river sampled (Farmington, New Mexico to Mexican Hat, Utah), and evaluated for longitudinal trends and anomalies.

Distribution, Abundance, and Movement - Movement of channel catfish and common carp collected by electrofishing was evaluated using Floy anchor tags and recapture of tagged fish. Channel catfish and common carp (>200mm TL) were tagged with sequentially numbered anchor tags 1992-1997 during spring, summer, and fall electrofishing trips. In 1992 and spring 1993 most channel catfish and common carp collected were tagged. During summer 1993 through fall 1995 most channel catfish and common carp collected from DM's were tagged. Additional channel catfish and common carp were tagged in 1995 during a pilot mechanical removal study. In 1996 channel catfish and common carp were tagged upstream of the Hogback diversion as part of a study to evaluate fish passage upstream and downstream of the five identified diversions on the San Juan River. Most non-native fish not tagged were enumerated and released alive 1992 through fall 1995. In 1996, most non-native fish collected downstream of the Hogback diversion were removed from the river and in 1997 most non-native fish collected were removed river-wide (see further discussion in Chapter V, Mechanical Removal). For each fish recaptured the capture location (RM), species, TL, SL, weight, and tag number were recorded. Movement direction and distance and growth data were determined from initial or last capture data. Because anchor tag loss for channel catfish has been reported as high (up to 90%) (Greenland and Bryan, 1974), Brooks et al. (1994) began evaluating tag retention in 1993. All channel catfish and common carp collected and tagged during April and May 1993 electrofishing surveys received two tags and retention was based upon the number of tags remaining at the time of recapture. Fish recaptured through 1997 were used to determine the percent retention for tags implanted during April and May 1993.

Schnabel population estimates (Overton, 1971) were calculated for collections made during 1992-1995 using mark and recapture data collected during main channel electrofishing sampling. Confidence intervals of 95% were calculated for each river reach estimate.

Radio telemetry- To supplement Floy tag data and to refine seasonal movement patterns 18 channel catfish were implanted with radio transmitters in September 1996. Two size classes of channel catfish were surgically implanted (350-465 mm and >550 mm TL) using Advanced

Telemetry Systems (ATS), Incorporated, external antennae transmitters. Model 2 (130 day, 11 g, 40 pulses per minute) and model 6 (400 day; 30 g, 55 pulses per minute) transmitters with 30-36 cm teflon coated antennae were used to implant both size classes, respectively. Surgical procedures used to implant channel catfish were identical to those used by Ryden and Pfeifer (1995) to implant Colorado pikeminnow in the San Juan River.

Movement of radio-tagged channel catfish was monitored monthly for one year using both aerial and ground tracking. Aerial tracking was used to determine approximate river mile locations one to five days prior to ground tracking by boat. Radio tracking flights were conducted monthly, October 1996 through September 1997. During each flight for each implanted channel catfish contacted, data were recorded for date, time, river mile, latitude and longitude, and general habitat type. Ground tracking by boat was conducted monthly following each flight and data recorded during initial contact were date, time, river mile, and habitat typed occupied. Radio contact with each implanted fish was continued at 15-20 minute intervals for a minimum of four contacts per fish. During each contact, the location and habitat type occupied were recorded onto an aerial videography sheet for that reach of the San Juan River. Concurrent with the radio tracking, the habitat type from 100 m upstream to 100 m downstream of the most frequent contact location was mapped on each videography sheet to determine habitat availability. Habitat type classifications followed those defined by Bliesner and Lamarra (1999). We also collected data for depth, current velocity, substrate type, water physical chemistry (temperature, salinity, dissolved oxygen, conductivity), proximity to cover, and type of cover available. Habitat use data were analyzed for average distance moved (up- and downstream), monthly habitat selection as calculated by the aggregate percent method (Swanson et al. 1974), and mean habitat complexity (number of habitat types found in the area of the river used by the fish each month).

Results

Distribution, Abundance, and Movement - Non-native fishes, primarily channel catfish and common carp, were widely distributed within the San Juan River downstream of Farmington, New Mexico. During electrofishing efforts in main and secondary channels juvenile, sub-adult, and adult channel catfish were collected from all habitat types sampled. Common carp sampled were primarily adults and were collected in low velocity, shoreline areas over silt/sand substrate with depths < 1 m throughout the reaches sampled. Other non-natives sampled during electrofishing efforts were primarily centrarchids (largemouth bass *Micropterus salmoides*, smallmouth bass *Micropterus dolomieu*, green sunfish *Lepomis cyanellus*). Juvenile centrarchids were usually collected in Reaches 2-4 in low-velocity habitats in association with mouths of dry arroyos, secondary channels, and canals. Sub-adult and adult centrarchids (almost exclusively largemouth bass) were collected primarily in Reaches 4-6.

After spring 1995, adult striped bass *Morone saxatilis* and walleye *Stizostedion vitreum* were frequently collected in the San Juan River downstream in Reaches 1-4, but primarily in 1 and 2. Prior to spring 1995, lowered surface reservoir elevation of Lake Powell had resulted in formation of a barrier to upstream fish movement approximately 3 RM's downstream of Clay

Hill's Crossing, Utah. With the rise in surface elevation during spring 1995, this barrier was inundated and allowed the movement of lacustrine species out of Lake Powell into the San Juan River. Striped bass and walleye were collected in medium velocity runs with depths > 1 m and in eddy and pool habitats along rocky points primarily downstream of Mexican Hat, Utah.

White sucker *Catostomus commersoni* was infrequently collected in the San Juan River downstream of the Hogback Diversion, New Mexico and included hybrids with both flannelmouth and bluehead suckers. While white sucker and associated hybrids were low in abundance (< 0.01% of all fishes sampled), Miller and Rees (1999) reported this species as common in tributaries of the upper San Juan River. A single grass carp *Ctenopharyngodon idella* (517 mm TL, 420 mm SL, 1500 g) was collected from a shoreline, medium velocity run with a depth of 1.5 m and the specimen was retained at University of New Mexico (MSB 14885). Bullhead *Ameiurus* sp. was an infrequently collected ictalurid (< 0.01% of all fishes sampled) and was identified to species as black (*A. melas*), brown (*A. nebulosus*), and yellow (A. *natalis*) during 1991-1993 sampling, but specimens of brown and yellow bullheads were not retained. The only confirmed species identification for *Ameiurus* is of black bullheads (specimens at University of New Mexico, MSB) and is considered here to be the only resident bullhead in the San Juan River study area.

Non-native species generally increased in proportional abundance of all fishes collected during main channel electrofishing sampling efforts, 1994-1997 (Figure 3). Prior to 1994, the pattern of non-native species relative abundance was declining. However, simple linear regression analysis of the 1987-1997 relative abundance values in Figure 3 did not demonstrate a significant change ($R^2 = 0.412$). CPUE for both channel catfish and common carp sampled during main channel electrofishing mirrored the increase in non-native species relative abundance (Figure 4). For channel catfish, overall CPUE increased but individuals > 300 mm TL declined in 1997 after a steady increase during 1994 - 1996 (Figure 5). Results differed for common carp, with the pattern in CPUE increasing throughout the 1994 - 1997 period for all size classes. Longitudinal patterns in the abundance of channel catfish, and, to a lesser extent common carp, are discussed further in Chapter IV, Mechanical Removal, as a response to suppression efforts.

During the 1992-1997 electrofishing surveys of main channel and secondary channel habitats, a total of 3,878 channel catfish and 3,034 common carp were tagged and released (Table 3). Channel catfish recapture rates ranged from 0.7% (n=26) to 2.2% (n=53) and common carp recapture rates ranged from 1.4% (n=42) to 4.7% (n=79). Recapture rates for both channel catfish and common carp were highest in 1993 and lowest in 1997. Recapture rates overall were 5.8% for channel catfish and 10.8% for common carp.

Movement by channel catfish and common carp recaptured during 1992-1997 showed both upstream and downstream movement (Figure 6). Average distance moved (calculated using absolute distance from last capture regardless of direction moved) by channel catfish was higher than for common carp (Table 4). Channel catfish were recaptured an average distance of 12.9 river miles from the original or last capture location between 1992 and 1997: maximum distance

moved upstream was 119.0 river miles and maximum distance moved downstream was 88.0 river miles. Common carp were recaptured an average distance of 5.5 river miles from the original or last capture location between 1992 and 1997: maximum distance moved upstream was 84.0 river miles and maximum distance moved downstream was 126.0 river miles. Average distance moved by year for channel catfish ranged from 7.7 to 20.0 river miles and for common carp ranged from 2.8 to 8.6 river miles. Though average distance moved differed between channel catfish and common carp, 32% of all channel catfish and 33% of all common carp were tagged and recaptured in the same river mile.

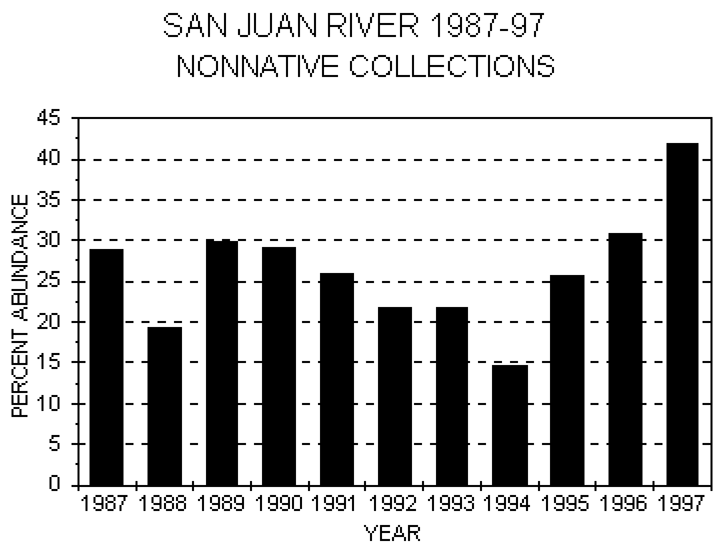


Figure 3. Relative abundance of non-native fish species collected during San Juan River main channel electrofishing surveys, 1987-1997. Results for 1987-1990 were modified from Platania (1990).

Channel catfish and common carp tagged and recaptured in succeeding seasons exhibited distinct movement patterns. Both channel catfish and common carp tagged in spring were typically recaptured in the same river mile or upstream in fall (Figure 7). Conversely, channel catfish and common carp tagged in fall were typically recaptured in the same river mile or downstream in spring (Figure 8). Channel catfish tagged in summer and recaptured in fall showed similar frequency of movement as spring to fall capture-recaptures (Figure 9). Channel catfish tagged in July and recaptured in fall moved furthest on average ($\bar{x}$ = 26 miles, n = 9). Common carp tagged in summer and recaptured in fall had the lowest mean movement and the highest frequency of recapture within the same river mile (Figure 9).

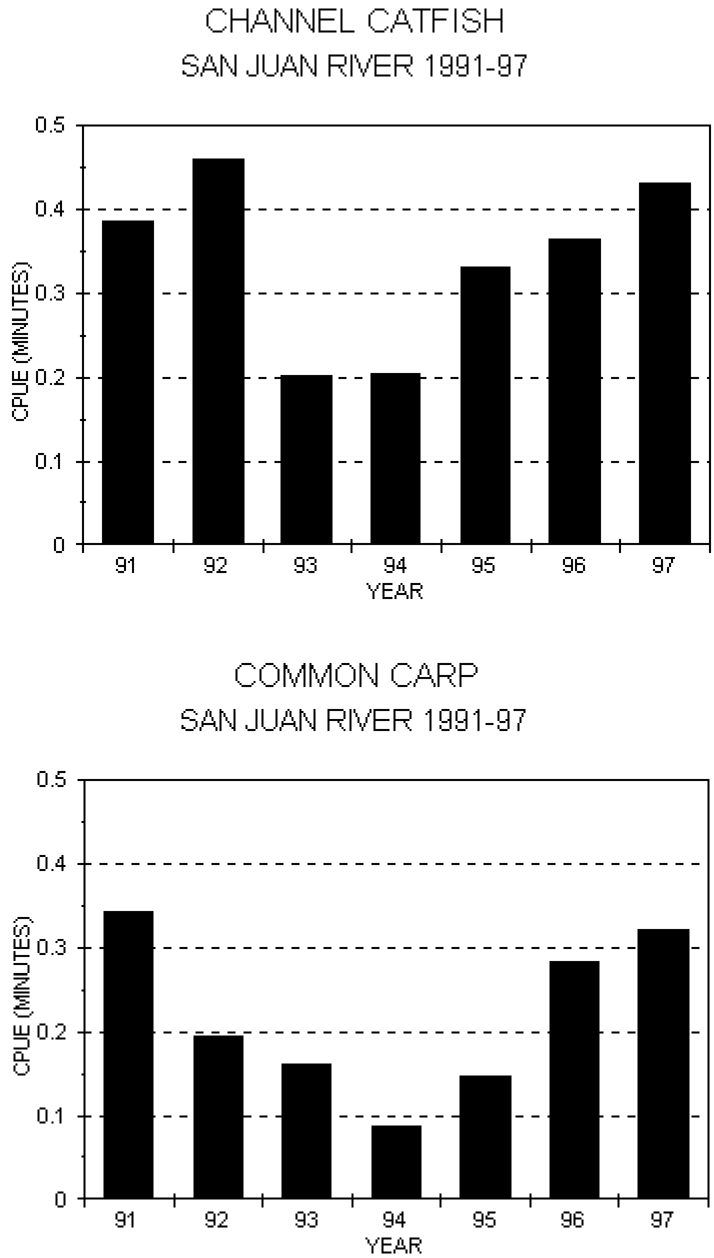


Figure 4. Catch per unit effort (number of fish/minute) for channel catfish (top) and common carp (bottom) collected during electrofishing surveys of the San Juan River, 1991-1997.

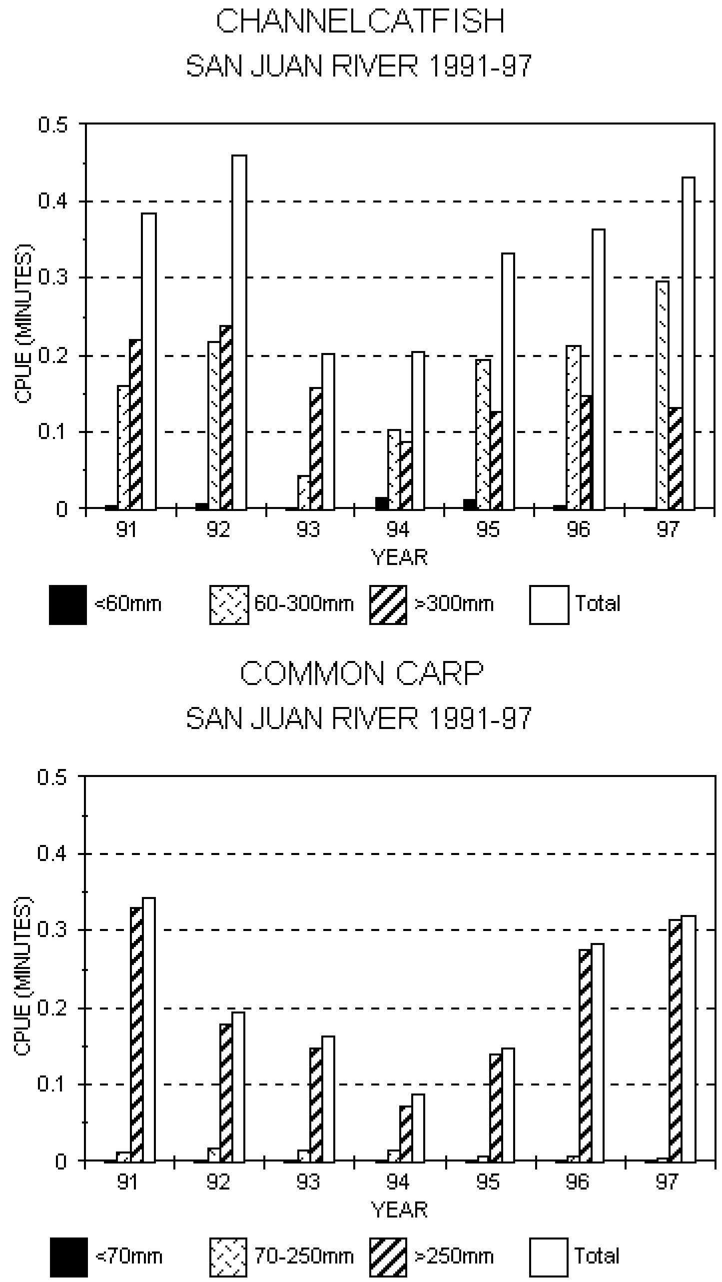


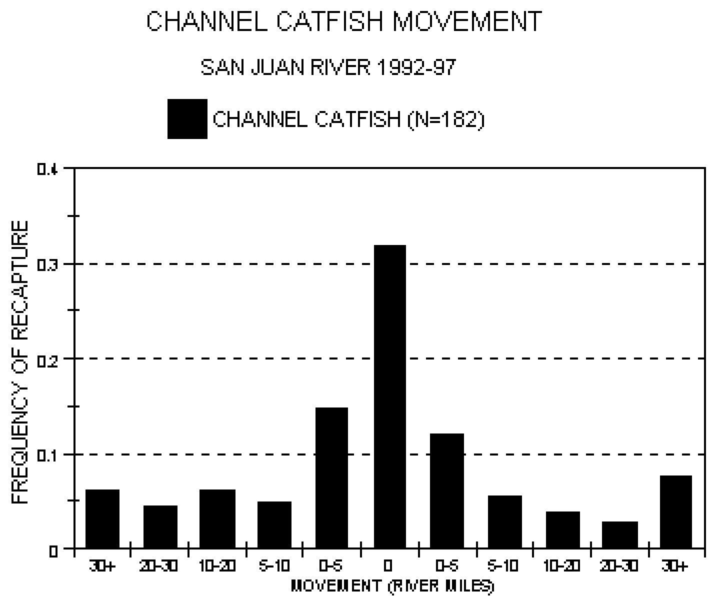
Figure 5. Catch per unit effort (number of fish/minute) for channel catfish (top) and common carp (bottom) by size class and year collected during May and October electrofishing surveys of the San Juan River, 1991-1997.

Table 3. Number of Floy tagged channel catfish (ICTPUN) and common carp (CYPCAR) captured and recaptured in the San Juan River by year, 1992-1997.

	Tagged		Recaptured		% Recaptured	
	ICTPUN	CYPCAR	ICTPUN	CYPCAR	ICTPUN	CYPCAR
1992	1,677	694	32	11	1.9	1.6
1993	752	1,001	53	79	2.2	4.7
1994	341	287	42	64	1.5	3.2
1995	624	667	37	86	1.1	3.2
1996	479	380	33	45	0.9	1.5
1997	5	5	26	42	0.7	1.4
Total	3,878	3,034	223	327	5.8	10.8

Although the number of captures to recaptures between successive seasons was low, there did appear to be some relation between channel catfish movement and flow. Channel catfish tagged in fall and recaptured in spring (prior to runoff: mean flows near 1,200 cfs) had a higher frequency of recapture within the same river mile (86%; 6 of 7) than fish recaptured in spring when mean flows were $\geq$ 3,000 cfs (35%; 8 of 23). Conversely, channel catfish tagged in spring when mean flows were $>$ 5,000 cfs and recaptured in fall had a low frequency of recapture within the same river mile of 14% (12 of 14). In addition, 3 of 3 channel catfish tagged in April and recaptured in May 1993 at flows $>$ 6,000 cfs had moved downstream 5.3 to 7.1 river miles ($\bar{x}$ = 6.5). Mean distance moved did not appear to be related to flow. However, the three furthest distances moved between successive seasons occurred between fall 1995 and spring 1996 following the winter test flows when all three fish moved downstream (49, 72, and 83 river miles; $\bar{x}$ = 68). There did not appear to be any relation between common carp movement and flow.

Between 1992 and 1997 three channel catfish were captured four times and ten were captured three times. Of the three captured on four occasions: one was captured all four times within the same river mile (3-year span; 490-550 mm TL), another was captured within a 3-mile section of river (2-year span; 422-470 mm TL), and one was captured in a 66-mile section of river (3-year span; 448-519 mm TL). The latter was collected twice in a 2-mile section of river in 1992 (4 month span), captured 64 miles downstream (2-year span), and captured a fourth time (7 months later) within the same downstream river mile. These movements are similar to those observed for all channel catfish collectively recaptured from 1992-1997. There did not appear to be any ontogenetic relation with movement, though only eight fish tagged $<$300 mm TL were recaptured (4 of 8 recaptured in same or adjacent river mile).



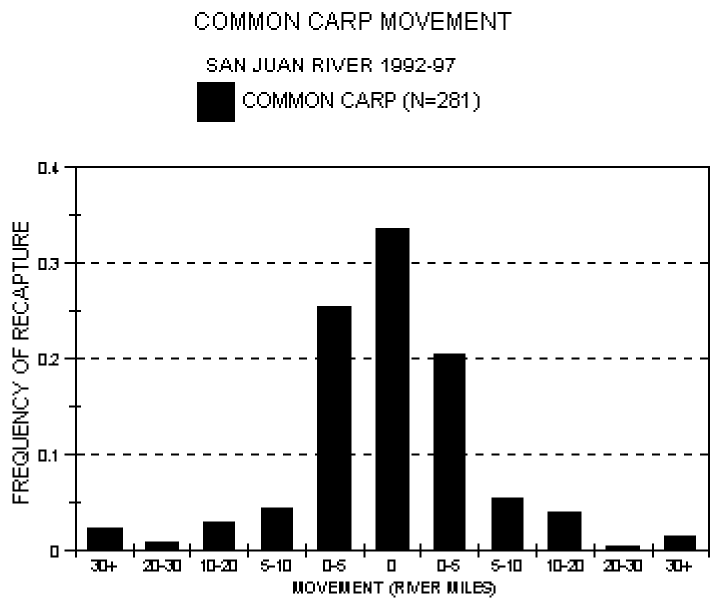


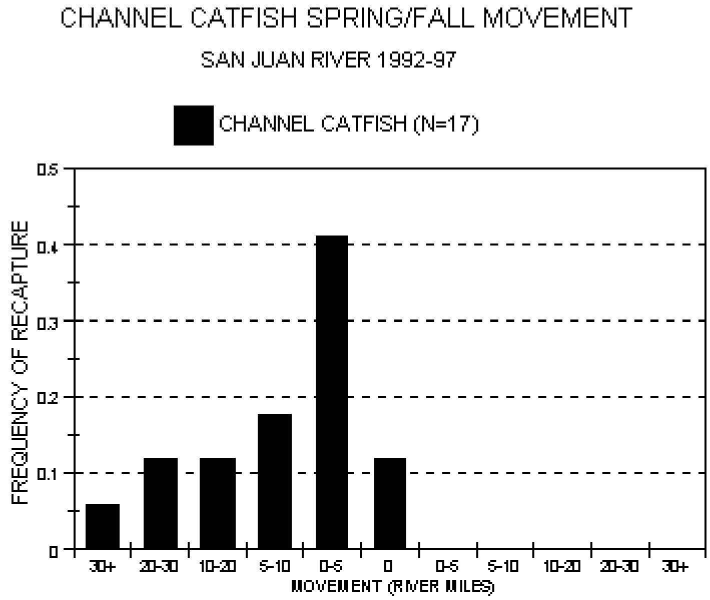
Figure 6. Frequency of recapture by channel catfish (top) and common carp (bottom) upstream and downstream of original or last capture locations in the San Juan River, 1992-1997.

Table 4. Mean distance (river miles) between recapture and original or last capture locations for channel catfish (ICTPUN) and common carp (CYPCAR) in the San Juan River by year, 1992-1997. *N* = sample size, *S.E.* = standard error.

	ICTPUN	*N*	S.E.	CYPCAR	*N*	S.E.
1992	7.7	30	3.1	4.6	10	3.7
1993	9.9	26	2.3	2.8	54	0.9
1994	10.2	31	3.5	3.1	49	0.7
1995	14.0	37	3.1	7.6	82	1.9
1996	15.8	32	4.4	8.6	44	3.3
1997	20.0	26	6.0	4.8	42	2.0
1992-1997	12.9	182	1.5	5.5	281	0.8

One channel catfish (SJR 02180) captured three times in a one year span was collected twice in two successive falls within the same river mile and captured 23 miles downstream in the intervening spring. Another channel catfish (SJR 02501) captured three times in a one year span was captured in three different locations 31 miles apart. Two other channel catfish captured over a 4+ year span (FWS 00843 and SJR 01531) were recaptured within the same river mile. These movements support the overall frequency and mean movement patterns observed for all tagged channel catfish (Figure 8).

There were 27 common carp multiple captures including seven that were captured four times and 20 that were captured three times. Of the seven captured on four occasions: one was captured all four times within the same river mile (5 year span; 442-529 mm TL), three were captured within a 5 mile section of river (2-3 year span), two were captured within a 10 mile section of river (1-2 year span), and one was captured in a 85 mile section of river (4 year span; 501-550 mm TL). Only two of 20 common carp captured three times were captured within the same river mile. Though the frequency of movement was somewhat greater for multiple common carp captures than that observed for all common carp recaptured collectively, the range and average distance moved was similar. We could not detemine any ontogenetic relation with movement since only one juvenile fish (< 250 mm TL) tagged was recaptured .



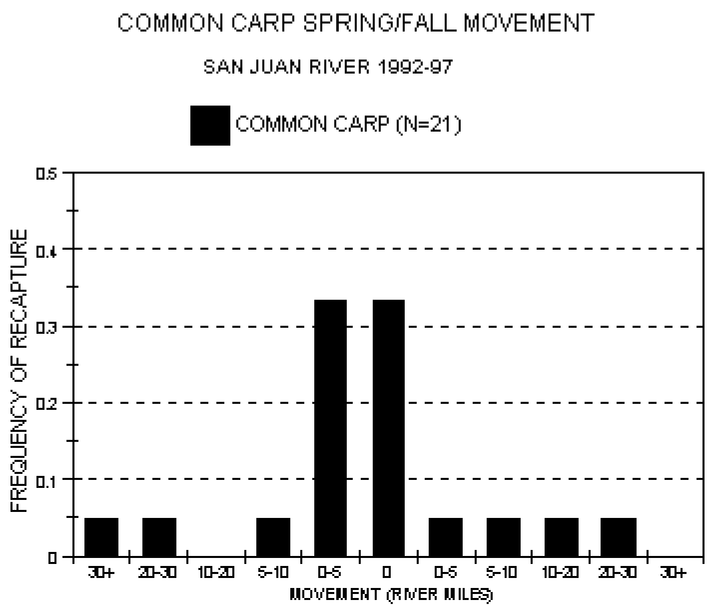


Figure 7. Frequency of recapture by channel catfish (top) and common carp (bottom) upstream and downstream of original capture locations in the San Juan River, between spring and successive falls, 1992-1997.

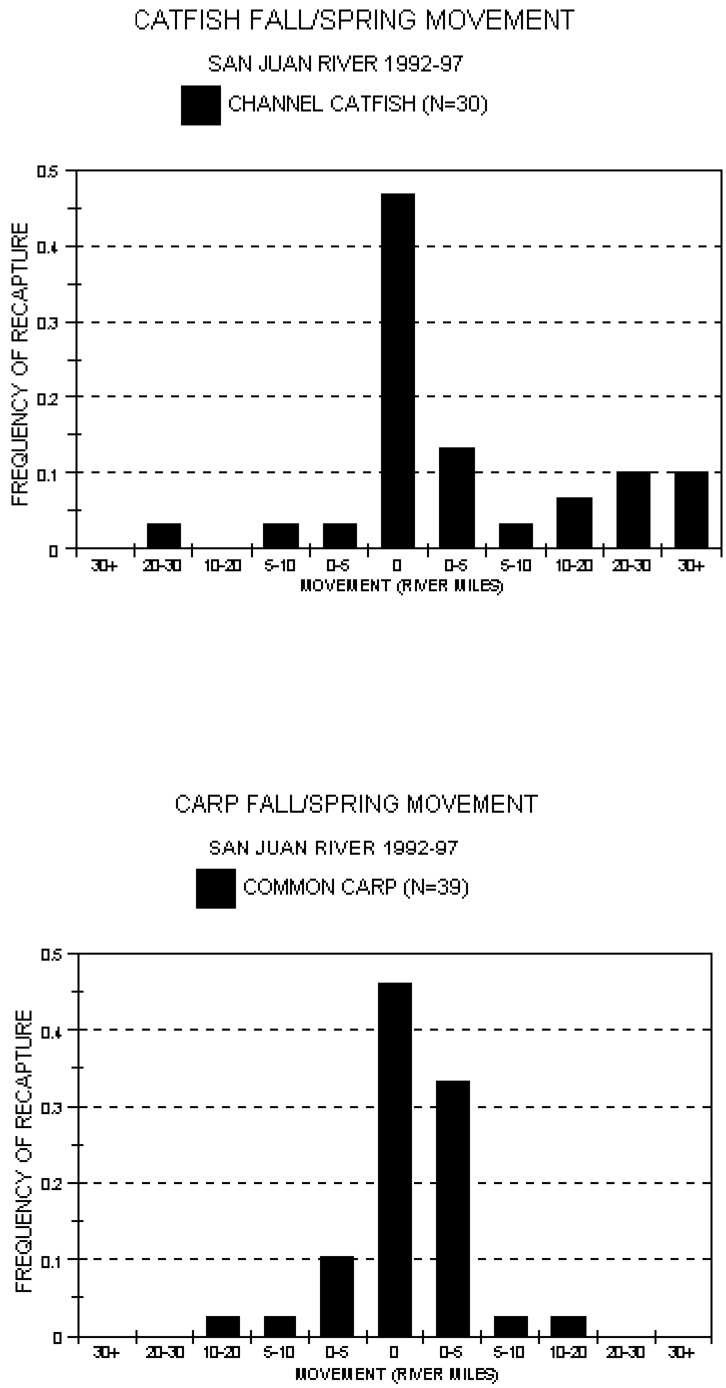
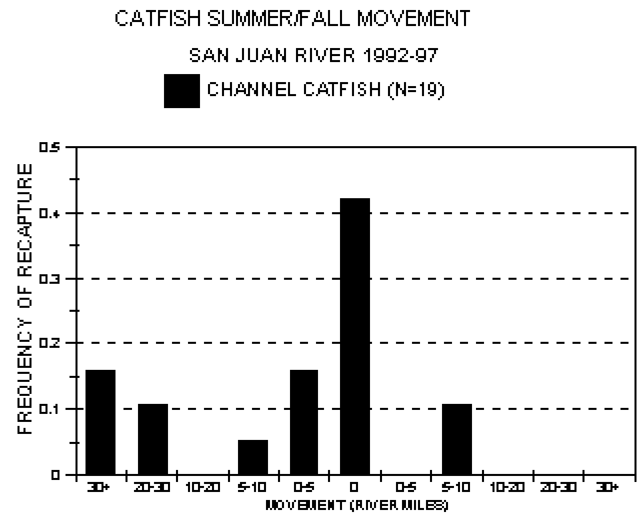


Figure 8. Frequency of recapture by channel catfish (top) and common carp (bottom) upstream and downstream of original capture locations in the San Juan River, between fall and successive springs, 1992-1997.



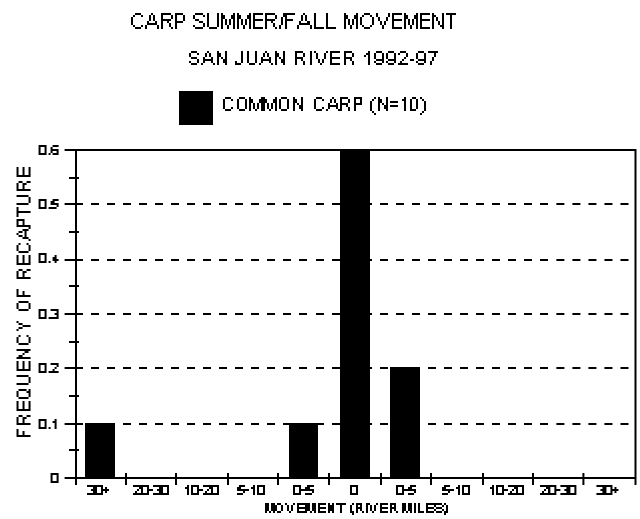


Figure 9. Frequency of recapture by channel catfish (top) and common carp (bottom) upstream and downstream of original capture locations in the San Juan River, between spring and successive falls, 1992-1997.

During April and May 1993 main channel electrofishing, a total of 362 channel catfish and common carp were double tagged in an effort to assess tag loss and resulting impacts on estimates of movement and abundance. During 1993 sampling, 8.5% (31) of the double tagged channel catfish and common carp were recaptured with channel catfish retaining 100% of both tags and common carp retaining 67% of both tags. Only 4.4% (16) of the double tagged fish were recaptured in 1994 with channel catfish retaining 83% (5 of 6) of both tags, while common carp retained only 60% (6 of 10) of both tags. In 1995, 4.1% (15) of the double tagged fish were recaptured with channel catfish retaining only 40% (2 of 5) of both tags and common carp retaining only 20% (2 of 10). In 1996, only one double tagged channel catfish and one common carp were recaptured: each fish had retained both tags. In 1997, 1.4% (5) of the double-tagged fish were recaptured with channel catfish retaining 67% (2 of 3) and common carp 0% (0 of 2). Field observations indicated that the tag placement on common carp, i.e., placement of the anchor between and through the pterygiophores of the dorsal fin, is often not accomplished, likely resulting in subsequent tag loss. In addition, there also appears to be higher tag loss through time.

A total of 36 channel catfish and 5 common carp were recaptured upstream and downstream of the five identified diversions on the San Juan River. Of the 36 channel catfish collected, 4 moved upstream of the Hogback Diversion and 16 moved upstream of the Cudei Diversion (two of these also moved upstream of the Hogback Diversion); one moved downstream of the Four Corners Power Plant, 3 moved downstream of the Hogback Diversion, and 12 downstream of the Cudei Diversion. Of the 5 common carp collected, one moved downstream of the Four Corners Power Plant, one moved downstream of the Hogback Diversion, and three moved downstream of the Cudei Diversion. No common carp recaptured had moved upstream of any of the five diversions.

Schnabel population estimates for 1992 through 1995 showed large populations of both channel catfish and common carp between the Hogback diversion and Mexican Hat (Figure 10). The channel catfish population estimate in 1995 (N = 274,484) was 49% higher than in 1994 (N = 184,285), 75% higher than in 1993 (N = 156,734), and 108% higher than in 1992 (N = 131,768). However, confidence intervals (95%) increased with population size each year (Table 5). The

Table 5. Schnabel population estimates (Overton 1971) by year for channel catfish (ICTPUN) and common carp (CYPCAR) in the San Juan River, 1992-1995.

Species	Year	N-est.	95% Confidence Interval
ICTPUN	92	131768	72143 - 219393
	93	156734	69830 - 306125
	94	184258	82087 - 359856
	95	274484	115712 - 563162
CYPCAR	92	26576	14213 - 45019
	93	30191	17256 - 48502
	94	41073	22488 - 68387
	95	107268	61438 - 172692

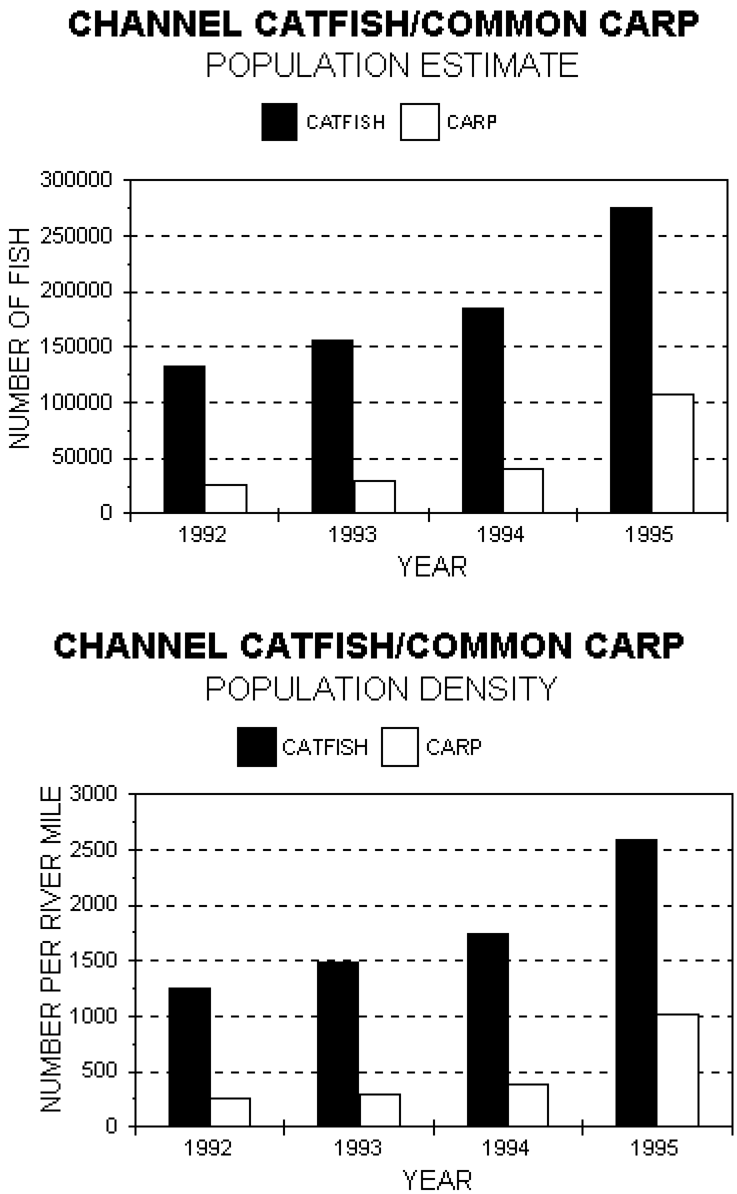


Figure 10. Schnabel population estimates (top) and number of fish per river mile (bottom) by year for channel catfish and common carp for the San Juan River, 1992-1995.

common carp population estimate in 1995 was also higher (161% higher than 1994; 255% higher than 1993; 304% higher than 1992) and also bound by correspondingly larger confidence intervals (95%). There were numerous potential reasons for the low recapture rates and subsequent large confidence intervals, including high tag loss (described above), differential tagging effort, mortality, or immigration. However, these data and CPUE data both indicated that channel catfish and common carp increased in abundance, particularly since 1994.

Radio telemetry - Channel catfish radio telemetry showed similar results as the Floy tag data. Eighteen channel catfish (448-697 mm TL) were implanted with radio transmitters and released within 2 river miles downstream of the capture location except for one individual released 4 river miles downstream of the capture location (Table 6). Surgical procedures were standardized for all fish and the condition of each channel catfish at time of release was stable (Table 7).

Table 6. Channel catfish (*Ictalurus punctatus*) implanted with radio transmitters, 16-18 September 1996.

Collected (RM)	Released (RM)	TL (mm)	SL (mm)	WT (g)	MHZ (40)	Pit tag	Floy tag
136.7	136.6	668	580	3200	011[a]	7F7B0D1D15	07909
156.2	152.2	553	480	2150	041[a]	7F7B19685C	07121
113.9	113.8	640	531	3200	061[a]	7F7B020C5B	07845
136.6	136.6	620	545	2500	081[a]	7F7B143C2A	07906
156.3	155.0	605	505	2900	111[a]	7F7B0D5973	07119
156.3	152.2	637	550	2600	600[a]	7F7D400A05	07120
115.6	115.0	570	466	2100	611[a]	7F7B1B0103	07848
136.0	134.2	697	600	3800	641[a]	7F7B137B3A	07064
115.8	115.0	617	500	2300	650[a]	7F7B074072	07847
157.9	156.4	465	380	1050	671[b]	7F7B143058	07110
116.2	115.0	451	364	900	690[b]	7F7B075175	07849
136.1	134.2	452	375	1000	701[b]	7F7B105B10	07905
156.4	156.4	462	390	1000	791[b]	7F7B0D3441	07113
136.6	134.2	450	370	825	800[b]	7F7B13661C	07908
115.0	115.0	450	354	1100	810[b]	7F7B0D2765	07846
136.6	136.6	460	374	900	821[b]	7F7B074140	07907
157.3	156.4	448	365	980	831[b]	7F7B151772	07111
116.2	115.0	463	369	950	841[b]	7F7B022474	07850

[a] 400 day tags, 56 ppm, no duty cycle (i.e., continuous signal); >550 mm TL
[b] 130 day tags, 40 ppm, duty cycle (i.e., 12hrs on/12hrs off); 350-365 mm TL

Table 7. Channel catfish (*Ictalurus punctatus*) radio telemetry implanting dates, time in MS-222, surgery times, and condition at time of release.

MHZ (40)	Date Implanted	MS-222 In (time)	MS-222 Out (time)	Surgery Begin (time)	Surgery End (time)	Condition
831[a]	9-16-96	1110	1113	1114	1125	a1,b1,c1
791[a]	9-16-96	1126	1128	1129	1137	a2,b2,c2
671[a]	9-16-96	1138	1139	1139	1146	a2,b3,c2
600	9-16-96	1321	1322	1323	1329	a1,b2,c1
111	9-16-96	1330	1331	1331	1341	a1,b1,c1
041	9-16-96	1718	1720	1720	1726	a2,b2,c1
011	9-17-96	1040	1043	1044	1051	a2,b3,c2
081	9-17-96	1054	1057	1059	1106	a2,b3,c2
821[b]	9-17-96	1110	1113	1114	1121	a3,b1,c1
641	9-17-96	1319	1322	1323	1331	a1,b1,c1
701[b]	9-17-96	1338	1340	1342	1349	a3,b3,c2
800[b]	9-17-96	1352	1354	1355	1402	a3,b3,c2
650	9-18-96	1222	1224	1225	1231	a3,b1,c2
611	9-18-96	1312	1313	1314	1321	a3,b3,c2
810[a]	9-18-96	1258	1300	1300	1307	a2,b1,c2
841[a]	9-18-96	1236	1237	1237	1244	a3,b3,c2
690[a]	9-18-96	1211	1212	1213	1218	a3,b3,c2
061	9-18-96	1502	1505	1506	1516	a2,b2,c2

[a] start time for 12 hr duty cycle tag 0730 hrs Mtn Daylight Time
[b] start time for 12 hr duty cycle tag 0940 hrs Mtn Daylight Time

a1 slow recovery time
a2 moderate recovery time
a3 quick recovery time
b1 swam slowly away
b2 swam away at moderate pace
b3 swam quickly away
c1 stable
c2 stable and strong

Channel catfish implanted with radio transmitters did not reveal large scale movement patterns during fall through winter (Table 8) as was indicated by the Floy tagging results. Similar to Floy tagging results there did appear to be some downstream movement in spring and summer (i.e., April and June) when mean flows were >4500 cfs. Interestingly, 2 of 4 larger size class channel catfish did move out of main channel habitats into narrow side channels during peak flows (≥9500 cfs). There appeared to be little difference in average distance or direction moved by size class. However, the larger size class did appear to move more on average during higher flows (i.e., April and June) than did the smaller size class. We did not detect any movement related to spawning activity, though 72% of the implanted channel catfish had expelled their transmitters in late June and July when spawning likely occured.

Adult channel catfish occupied only six habitat types throughout the year including (in order of most frequent use) runs, eddies, slackwaters, run/riffles, pools, and flooded vegetation. Run habitat was the most frequently occupied habitat year-round. However, habitat selection (i.e., habitats with positive electivity values) of radio telemetered channel catfish varied among months (Table 9). During base winter flows adult channel catfish selected the greatest number of habitats, including eddies, slackwaters, and pools. In spring, slackwaters and eddies were still preferred habitats. However, habitat complexity values were highest in spring as different individuals were found in areas with a variety of habitat types (i.e., riffles, run/riffles, and sand shoals) associated with runs. During peak flows in June, two of eight individuals moved into side channel run habitats where water velocities were lower than main channel run habitats. Others remained in runs near the stream margins, including one individual who moved into flooded vegetation. During peak flows, run habitat was the only selected habitat type. In summer, runs were also the only selected habitat and the runs were most often in areas with slackwaters, eddies, and riffles nearby. Habitat use in fall was similar to summer, though runs and eddies were both selected habitats.

Adult channel catfish were most frequently found in run habitats associated with a variety of different habitat types. Most of the areas occupied were relatively simple habitats with low habitat complexity values. They appeared to respond seasonally to changes in temperature and flow preferring areas near slackwaters, eddies, and pools in winter and moving near the stream margins or into side channels, presumably seeking refuge from high water velocities, during spring runoff. There did not appear to be any large scale movement patterns associated with changes in flow. Because radio telemetry data were collected only for one year, it is not possible to state how habitat use would change under different flow regimes. However, because there were only minor differences in seasonal patterns of habitat use and localized movement during high flows we would not expect many changes in habitat use under different flow conditions.

Discussion

Non-native fishes comprised approximately 14-42% of all fishes collected in main channel and larger secondary channel habitats of the San Juan River during 1987-1997. Abundance of non-natives declined 1989 through 1994, but steadily increased in abundance thereafter. Mimicry of the natural hydrography did not significantly reduce the abundance or the distribution of non-native species. Two species, channel catfish and common carp, were the most numerous in

Table 8. Movement by radio telemetered channel catfish (*Ictalurus punctatus*) October 1996 through September 1997 in the San Juan River. RM = river mile, n = number of fish located, * = located during aerial telemetry immediately prior to float trip.

	Capture (RM)	Release (RM)	Oct 96 (RM)	Nov 96 (RM)	Dec 96 (RM)	Jan 97 (RM)	Feb 97 (RM)	Apr 97 (RM)	May 97 (RM)	Jun 97 (RM)	Jul 97 (RM)	Aug 97 (RM)	Sep 97 (RM)
011[a]	136.7	136.6	136.5	135.2	135.2	135.2	135.2	134.4	127.6*	111.8	111.8		
041[a]	156.2	152.2	152.0	151.6	151.6*	151.6*	151.6	151.5	151.5				
061[a]	113.9	113.8	113.7										
081[a]	136.6	136.6	133.5	125.2	125.2	125.2*	125.3	124.8	124.5	115.0			
111[a]	156.3	155.0	154.3	154.6	154.4*	154.3*	154.3	121.0	121.0				
600[a]	156.3	152.2	155.0	155.6	155.6*	155.8	155.8	155.8	155.6	155.4	155.7	155.7	
611[a]	115.6	115.0	116.0	116.0	116.0	115.8*	116.1	116.1	116.1	115.4	114.1		
641[a]	136.0	134.2	134.3	133.3	133.5	133.4	133.5	133.4	136.7				
650[a]	115.8	115.0	115.0	115.2	115.3*	115.4*	115.3	115.7	115.9	107.6	108.2	108.0	
avg distance moved			0.9	1.5	0.1	0.1	0.1	4.4	1.4	6.9	0.6	0.1	
671[b]	157.9	156.4	157.3	157.6	156.4*	156.6	156.6	158.0	157.9				
690[b]	116.2	115.0	114.4	114.4	114.4*	114.3*	114.4						
701[b]	136.1	134.2	118.6	109.8	108.1*	97.0*	85.0*	84.4*					
791[b]	156.4	156.4	155.6	155.2	155.2*	155.3	155.3	154.2	156.8				
800[b]	136.6	134.2	135.2	135.3	135.3	135.3	135.3	135.2	135.0	134.2			
810[b]	115.0	115.0	114.8	114.8	114.7*	114.7*							
821[b]	136.6	136.6	138.8	138.3	138.3	137.8	137.8	135.9	136.1	134.4			
831[b]	157.3	156.4	156.3	156.2	156.2*	156.0	156.0	156.2	156.2	155.8	155.1		
841[b]	116.2	115.0	114.8	114.5	114.5*	114.6*	114.6	114.6	114.6	114.6			
avg distance moved			2.2	1.2	0.2	1.4	1.5	0.8	0.5	0.7	0.7		
n =		18	18	17	17	17	16	15	14	9	5	2	0

Table 9. Habitat selection[1] for radio-tagged channel catfish in the San Juan River, October 1996 through September 1997. Monthly habitat selection was calculated by the aggregate percent method (Swanson et al. 1974). Mean habitat complexity is the number of habitat types found in the area of river being used by the fish each month.

Habitat Type	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Eddy	50		47		27						74
Pool	50										
Slackwater		95	50		66						
Run						100	100	100	100	91	26
Run/Riffle					8					9	
Mean Habitat	5	2	4		5	4	3	4	3	3	

[1] Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974).

main channel collections and were widely distributed throughout the San Juan River downstream of Farmington, New Mexico (channel catfish below the PNM weir at Fruitland, New Mexico). For study purposes in the SJRIP, annual spring hydrographs, 1992-1997, included peak release patterns from Navajo Dam timed to coincide with peak spring flows in the tributary Animas River (Bliesner and Lamarra 1999). Provision of a high spring release (an ‘engineered’ flood stage) from Navajo Dam to mimic a natural hydrograph was believed to be useful in suppression of non-native species abundance in downstream reaches, as has been proposed elsewhere (Meffe and Minckley 1987, Minckley and Meffe 1987, Poff et al. 1998). Spring peaks ranged from a low of 3500 cfs in 1995 to a high of 12,000 in 1995. Regardless of the peak, non-native proportions after 1994 steadily increased.

The year-round occupation, widespread distribution , and abundance of channel catfish and common carp during the study period illustrate the success of non-native fishes in the San Juan River. Neither species demonstrated seasonal migrations from or within main channel environments. In their native range, channel catfish have been observed to move out of large, main channel rivers after winter into smaller tributaries during spring, presumably to spawn and then return in autumn to the larger riverine environment (Pellet et al. 1998, Dames et al. 1989, Newcomb 1989). Our data for smaller sized individuals were sparse and ontogenetic relationships to movement patterns were not characterized. However, smaller sized channel catfish (< 300 mm TL) and common carp (< 250 mm TL) would represent primarily sexually immature fish which would not move similar to adults (McKeown 1984). Irving and Karp (1990) observed similar movement patterns for channel catfish and common carp in the Yampa River, Colorado. Observed movement of common carp has generally been restricted to winter aggregations in deep, low velocity habitats (Panek 1987). It is possible the lack of movement observed for channel catfish may be explained by the absence of a larger, warmwater stream tributary to the San Juan River.

Based upon recapture locations for tagged and radio-telemetered channel catfish, high spring flows tended to displace individuals downstream some few river miles. Larger channel catfish (> 550 mm TL) were usually recaptured within the same river mile and, based upon telemetry data, some individuals move into secondary channels during high flow events. In general, channel catfish demonstrated more fidelity for discrete reaches and the largest individuals moved the least. This pattern is similar to that noted for channel catfish within its native range (Pellet et al. 1998). Common carp did not appear to be affected by high spring flows and recaptured adults were found consistently within the same 2-4 river mile reach.

Both channel catfish and common carp were general in their selection of habitats, with channel catfish widely distributed in all available habitats. Common carp were found more often in shallow, low velocity habitats along stream margins where overhanging salt cedar and Russian olive branches afforded overhead cover. Tyus and Nikirk (1990) similarly found channel catfish widely distributed in the Green and Yampa rivers, occupying essentially all available habitats. The channel catfish was considered a "broad-niched species" by Layer and Maughan (1985) and further illustrates this species' adaptive capabilities. Common carp observed in the Yampa River were similar in habitat use observed in the San Juan River (Irving and Karp 1990) and elsewhere (Panek 1987). Thus, these species are able to occupy all riverine habitats and are able to withstand, possibly even flourish, in annual discharge patterns designed to mimic natural flow conditions for the benefit of native species in the San Juan River.

The presence of lacustrine non-native species such as the striped bass and walleye in the San Juan River are seasonal, occurring primarily in spring through summer and concentrated in the lower portion of the study area near Lake Powell. As these species enter the San Juan River, presumably for spawning (Persons and Bulkley 1982, Gustaveson et al. 1984, Sublette et al. 1990), they exert predation pressure on native fishes (see discussion in Chapter III, Food Habits). Both species, when resident in large reservoirs, also show a strong fidelity for inflowing rivers (Sublette et al. 1990, Wilkerson and Fisher 1997). While this interaction is short-lived and restricted to generally the lower portion of the San Juan River, temporary impacts to native species may include reduction of numbers in a reach where numbers are already low (Ryden 1999).

Striped bass were introduced into Lake Powell in 1974, reproduction was first noted in 1979, and the population is currently self-sustaining (Gustaveson et al. 1984). Walleye were not stocked into Lake Powell, but were first collected within Glen Canyon in 1962 (Stone and Miller 1966). Presumably, walleye occurring in Lake Powell were descended from individuals escaping from Duchesne River reservoirs. The barrier to upstream movement of fish out of Lake Powell, located downstream of Clay Hill's Crossing, Utah, was inundated in 1995 by the rising lake level and the hiatus in collections of striped bass and walleye upstream in the San Juan River since the late 1980's (Platania 1990) came to an end. Future considerations for operation of Lake Powell may include deliberations regarding maximum reservoir elevation to maintain the barrier. However, there are tradeoffs to maintaining a barrier to upstream movement of fish out of Lake Powell. Ryden (2000) emphasized the need to maintain access for endangered Colorado pikeminnow inhabiting the lower San Juan River and Lake Powell. Thus, any consideration of fish movement barriers should address both the avoidance of non-natives and the movement patterns of native species.

Mimicry of the natural hydrograph to improve and provide greater habitat diversity within the San Juan River channel downstream of Farmington, New Mexico has been proposed as a means to improve conditions for native fishes (summarized by Holden 1999). While habitat conditions in main channel habitats for native fishes have improved during the course of this study (Bliesner and Lamarra 1999), non-native species abundance has also increased. This is likely due to the similarity in habitat use patterns of natives and non-natives in the San Juan River (see also discussion in Chapter III, Food Habits). In support of this, McAda and Kaeding (1989) cautioned that merely providing more habitat would not necessarily result in an increase in the abundance and distribution of native species. This was based upon the observed considerable overlap between native and non-native species in resource use patterns. Further, Karp and Tyus (1990) characterized the potential negative effects of non-native species interactions on the growth and survival of Colorado pikeminnow due to similarities in resource use patterns and the aggression of non-natives.

Flow manipulations designed to improve habitat conditions for native fishes, alone, will not recover the endangered Colorado pikeminnow and razorback sucker in the San Juan River through reduction of non-native species. However, improved habitat conditions in the San Juan River since implementation of dam-controlled releases to provide for spring peak flows may partially explain the high survival rates noted thus far for hatchery-reared Colorado pikeminnow and razorback sucker stocked into the San Juan River and should not be discounted. Other manipulations of the San Juan River environment, including higher summer baseflow conditions (Propst and Hobbes 1999) and mechanical removal of certain non-native species (see Chapter V, Mechanical Removal) may act in concert with mimicry of the natural hydrograph to improve chances for recovery and maintenance of the native fish community.

Conclusions

- The relative abundance of non-native species sampled during main and secondary channel electrofishing surveys varied, but was not statistically different from early efforts begun in 1987 until completion of this sampling in 1997.
- Channel catfish and common carp were the most abundant and widely distributed large-bodied non-native species present in the San Juan River, 1991-1997.
- Mimicry of the natural hydrograph (particularly for high spring flows) did not reduce the abundance or alter distribution of channel catfish and common carp.
- Non-native species abundance in main channel collections increased from 1994 through 1997, but for the period 1987-1997 did not significantly increase.
- Tagging study results for channel catfish and common carp did not demonstrate strong temporal and/or spatial movement patterns and most recaptured individuals remained within 10 river miles of original capture locations.
- Movement of striped bass and walleye upstream into the San Juan River out of Lake Powell occurred on an annual basis after inundation of a waterfall barrier downstream of Clay Hills, Utah. Striped bass were more widely distributed, occurring upstream to Shiprock, New Mexico.
- Channel catfish used primarily run habitat, the most common available, during all flow conditions and large adults demonstrated movement patterns into secondary channels during high flow events.

CHAPTER II

Egression and ingression of native and non-native fishes between main and secondary channels of the San Juan River, 1994-1995

Introduction

The study of egression and ingression by young-of-year and juvenile large-bodied native and non-native fishes and juvenile and adult small-bodied native and non-native fishes between secondary channel and main channel habitats was conducted during 1994-1995. Secondary channels provide for low-velocity habitats in the San Juan River where backwater habitats occur less frequently than elsewhere in the Colorado River Basin (Bliesner and Lamarra 1999). Changes in flow alter low-velocity habitats available to resident fishes in secondary channels (Gido and Propst 1999, Gido et al. 1997), and movement into secondary channels from main channel environments may provide escape from less hospitable conditions, such as higher current velocities.

Altered flow regimes due to regulation in rivers of the American Southwest have provided for more favorable conditions for non-native species (Douglas et al. 1994), and re-operation of Navajo Dam to mimic a natural hydrograph has been proposed as a means of improving riverine habitats and the associated survivability of native species in the San Juan River. In order to assess the response of the resident fish community to changes in flow and relate to observations reported by Gido and Propst (1999) and Gido et al. (1997) for secondary channel fish communities, this study segment measured movement between main and secondary channels on a seasonal basis.

The study objectives were:

1. Determine seasonal patterns in movement of native and non-native fishes into and out of secondary channels under high- and low-flow conditions.
2. Determine daily (dawn, day, dusk, night) patterns in movement of native and non-native fishes into and out of secondary channels under high- and low-flow conditions.
3. Relate movement patterns of native and non-native fishes to water temperature differences between main and side channel habitats under high- and low-flow conditions.

Study Area

A total of six sites (four secondary channels) were selected to monitor diel, seasonal, and site-specific movement patterns: RM 128.2, RM 127.2, RM 134.2, RM 133.8, RM 82.8, RM 82.6. Sites were selected that could be sampled at a variety of flows and were accessible by all-terrain vehicles (ATVs) to allow for transport of sampling gear.

Methods

Four sampling efforts were conducted between early spring and late fall (late-March/early-April, mid-July, late-August/early September and late-October), 1994-1995. Fish movement was monitored using both hoop nets and minnow traps. The hoop nets used for sampling were 3 m long, with 0.6-m diameter hoops, two 1.2-m wings, and treated 0.3-cm black mesh. The minnow traps were aluminum 0.3-cm mesh (two sizes: 0.6 m x 0.6 m x 0.3 m and 0.5 m x 0.4 m x 0.2 m) with 2.5-cm and 3.2-cm diameter openings, respectively. The choice of hoop nets or minnow traps depended upon the depth and size of the secondary channel at the time of sampling. Hoop nets and minnow traps were placed in the secondary channel near the confluence with the main channel and secured with t-posts. Traps were oriented upstream and downstream (i.e., parallel to shore) to collect fish moving into and out of the secondary channel. Nets were set for 24-hour periods and checked every 5 to 7 hours. The time

intervals sampled included dawn, day, evening, and dusk.. Fish specimens collected were identified, enumerated by species, measured (TL), and released near shore. Fish collected entering the secondary channel were released in the secondary channel and fish collected exiting the secondary channel were released in the main channel. Specimens not identified or released in the field were preserved in 10% formalin and returned to the laboratory for later identification.

Movement data were analyzed and compared for number of native and non-native fish moving into and out of secondary channels at dawn, mid-day, dusk, and midnight. The movement of native and non-native species between side and main channels was evaluated using the non-parametric Mann-Whitney U-Test. Replicates were considered to be fish trapped in the six hour interval (dawn, day, dusk, night) in the upstream or downstream trap. Each site was used separately as a replicate for a maximum of 6 replicates for each interval. Thus, movement data were compared between movement in and out of the channels within the appropriate six hour interval in the same time of year (i.e. dawn in vs. dawn out during the April sample). Native and non-native fish movements were considered separately. Differences in movement patterns were considered significant at $P \leq 0.05$.

Water temperatures in main and secondary channel habitats were measured during fish sampling to determine differences that might affect fish movement patterns, such as avoidance or preference for a specific temperature regime. Water temperatures were measured in the main channel immediately upstream of the confluence with the secondary channel, and at an approximate midway point in the secondary channel at dawn, mid-day, dusk,and midnight. Differences between main and side channel mean water temperatures were evaluated by a paired t-test. Replicates were considered water temperatures at each site separated into the time of day and year the measurement was made. Water temperatures were compared between main and side channels within each time interval for the same time of day and season (i.e. dawn main channel water temperature vs. dawn side channel water temperatures for April). Values were considered significant at $P \leq 0.05$.

Results

During 1994, a total of 841 native and 21,906 non-native fishes were collected during egression/ingression sampling in secondary channel habitats (Table 10). Mid-July collections, when flows were highest (ca. 2800 cfs), accounted for more than 90% of the total specimens collected. Late-October sampling accounted for approximately 7% of the total specimens collected and late-March/early-April samples had the fewest specimens collected (one flannelmouth sucker *Catostomus latipinnis* and 7 fathead minnows *Pimephales promelas*). Six roundtail chubs *Gila robusta* were the only rare fish collected and were sampled at RM 128.2 in mid-July during early morning and late afternoon sampling.

In 1995, a total of 2,836 native and 6,559 non-native fishes were collected during egression/ingression sampling in 1995 (Table 11). More than 60% of the total non-native specimens collected were sampled during mid-July when flows were highest (3000 to 3800 cfs) and 91% of the native specimens were collected during August sampling when flows were 1600 to 2300 cfs. Approximately 17% of the total specimens were collected in late-October (ca. 1000 cfs) and <3% were collected in April (2800 to 3300 cfs). The only rare species, a roundtail chub, was collected at RM 128.2 in late-August during mid-day sampling. Native speckled dace *Rhinichthys osculus* and bluehead sucker *Catostomus discobolus*, and

non-native red shiner *Cyprinella lutrensis* and fathead minnow were the most commonly collected species moving into and out of secondary channels. All four species' movements occurred primarily in July and August.

Table 10. Total number of fish collected during hoop net egression/ingression sampling for the San Juan River, March through October, 1994.

	Mar/Apr	Jul	Aug/Sep	Oct	Total Range
Mean discharge (CFS)	600	2800	340	1400	340-2800
Temperature range (˚C)	3-18	17-23	17-33	8-14	3-33
Natives:					
roundtail chub	0	6	0	0	6
speckled dace	0	623	28	58	709
flannelmouth sucker	1	68	4	13	86
bluehead sucker	0	39	1	0	40
TOTAL	1	736	33	71	841
Non-natives:					
common carp	0	17	36	3	56
red shiner	0	18354	111	657	19122
fathead minnow	7	1582	137	827	2553
plains killifish	0	7	3	3	13
channel catfish	0	0	4	95	99
mosquitofish	0	3	44	5	52
largemouth bass	0	11	0	0	11
TOTAL	7	19974	335	1590	21906

Table 11. Total number of fish collected during hoop net egression/ingression sampling for the San Juan River, April through October, 1995.

	Apr	Jul	Aug	Oct	Total Range
Mean discharge (CFS)	3080	3450	1867	990	990-3450
Temperature range (˚C)	7.5-12.5	16.1-22.2	21.0-26.1	5.8-16.5	7.5-26.1
Native species					
roundtail chub	0	0	1	0	1
speckled dace	15	132	819	50	1016
flannelmouth sucker	2	54	449	2	507
bluehead sucker	0	0	1312	0	1312
TOTAL	17	186	2581	52	2836
Non-native species					
common carp	0	72	141	0	213
red shiner	156	3085	41	480	3762
fathead minnow	82	929	1142	59	2212
plains killifish	0	3	0	1	4
channel catfish	8	10	295	8	321
black bullhead	0	0	32	0	32
mosquitofish	0	5	5	1	11
largemouth bass	0	4	0	0	4
TOTAL	246	4108	1656	1590	6559

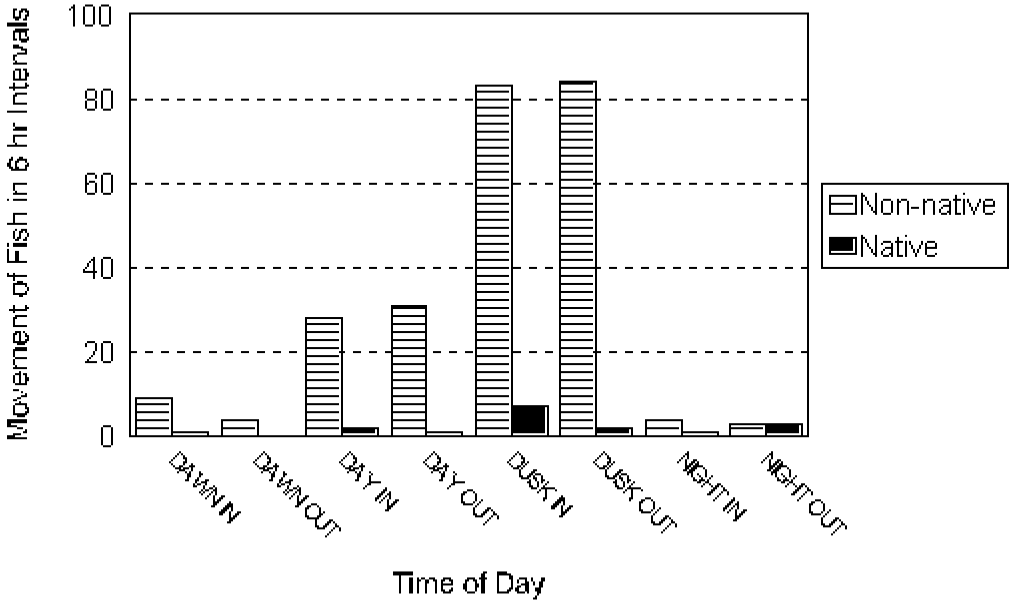


Figure 11. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during April 1995.

March/April Movement

Initial sampling in 1994 resulted in the capture of only seven fish (Table 10). Flow was low (600 cfs) and daily water temperature ranged 3-18 °C. Flow was approximately five times higher in 1995 and water temperatures were cooler and less variable (Table 11). A total of 246 fish were sampled moving into and out of secondary channels in 1995. Non-natives (red shiner and fathead minnow) comprised 90.5% of the fish sampled. Speckled dace was the most common native species sampled. Movement occurred primarily during day and dusk sampling periods (Figure 11). The least amount of movement was detected during night sampling. Direction of movement was approximately equal for into and out of secondary channels.

July Movement

The largest number of fish sampled during this study were collected in July 1994 (Table 10). Flow was ca. 2800 cfs and daily water temperatures ranged 17-23 °C. Overwhelmingly, red shiner was the most abundant species collected, representing 88.6% of all fish sampled and 91.9% of all non-natives. Overall, non-natives were 96.4% of the fish during this period. Speckled dace was the most common native species sampled and represented 86.4% of all native species collected in July 1994. During July 1995 sampling, flow was higher and water temperatures were slightly cooler (Table 11). Non-native species dominated collections and were 95.7% of all fish sampled. Red shiner and speckled dace were, respectively, the most common non-native and native species . Juvenile common carp *Cyprinus carpio* were 4.2 times more common in 1995. Juvenile largemouth bass *Micropterus salmoides* were only collected in July during this study and occurred in samples for both years. Young-of-year and juvenile flannelmouth suckers were the only other native species collected in 1995, unlike in 1994, when a total of four native species was sampled (Table 10).

Direction of movement during July 1994 was generally out of secondary channels, with the exception of night (Figure 12). The greatest amount of movement occurred during day and dusk sampling. Movement measured for native species sampled occurred primarily during daylight and was out of secondary channels. In 1995, movement patterns were somewhat different with most movement into secondary channels during day, dusk, and night sampling (Figure 13). Most movement measured occurred during the dusk sampling period. The least amount of movement occurred during nighttime for both non-native and native species. In 1995, native species movement patterns were uniform throughout all time periods sampled.

August Movement
The greatest disparity in environmental conditions between years occurred during August sampling. Flow was nearly 5.5 times higher in 1995 (Table 11) than in 1994 (Table 10) due to a late summer peak in flow caused by rainstorm activity (Bliesner and Lamarra 1999). Water temperatures were more variable in 1994 when flow was lower, measuring as high as 33 °C (Table 10). August water temperatures had a range of 5.1 °C (Table 11).

Nearly five times more fish were collected in ingression/egression study sampling in 1995 (Table 11) than in 1994 (Table 10). In 1994 , non-native species were 91% of all fish collected and fathead minnow, for the first time, was the most numerous, comprising 40.9% of all non-natives. Non-native mosquitofish were more abundant for this sampling period than observed at any other time and represented 13.1% of all fish. Speckled dace was the most common native species, but represented only 8.4% of all fish collected. Native species numerically dominated samples in July 1995, the only time this occurred during this study (Table 11). Of 4,237 fish sampled, native species were 60.9% of the sample. For all species sampled, bluehead sucker young-of-year and juveniles (31%) and fathead minnow (27%) were

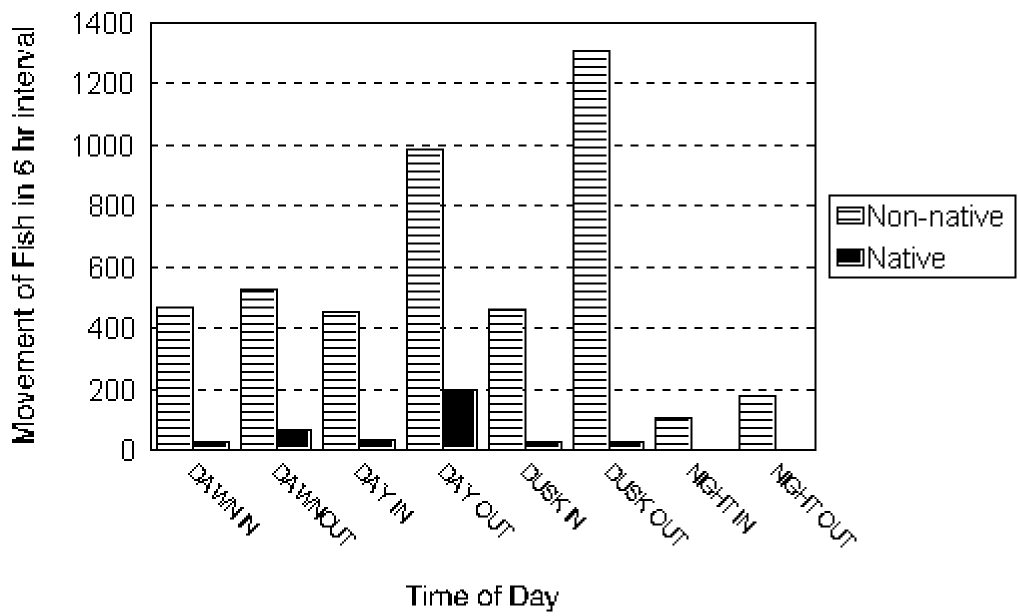


Figure 12. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during July 1994.

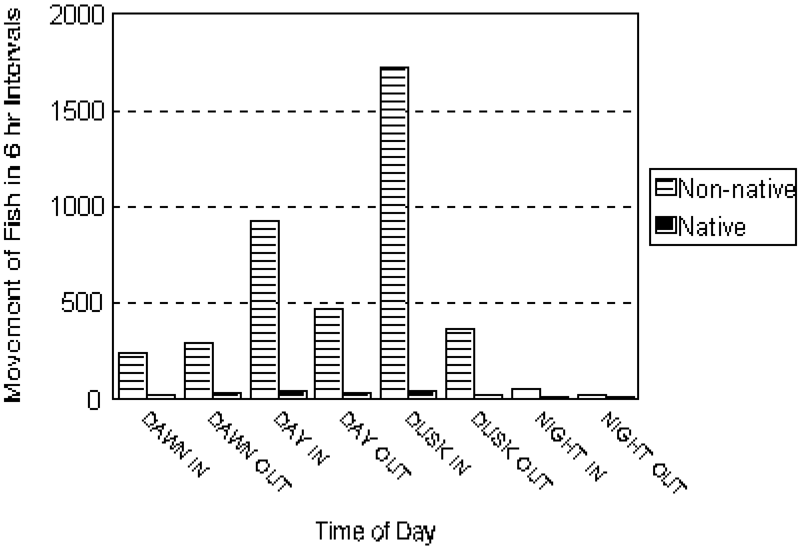


Figure 13. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during July 1995.

the most abundant. Speckled dace and flannelmouth sucker were more abundant in July 1995 and were 80.6% and 88.6%, respectively, of the total number for each species sampled during the two-year study.

Several non-native species were most abundant in August 1995 ingression/egression samples. However, red shiner collections were lowest for all sampling periods, except April 1994 when few fish were sampled in this study. In August 1995, young-of-year channel catfish (*Ictalurus punctatus*) were 91.9% of the total number collected but were only 4% of the total in 1994. Numbers of common carp young-of-year and juveniles collected in August 1995 were nearly two times greater than the next highest period and represented 66.2% of the species' total catch that year. The only collection of black bullhead (*Ameiurus melas*) occurred during August 1995.

With the exception of daytime sampling, direction of movement observed in August 1994 was primarily out of secondary channels (Figure 14). Conversely, direction of movement by fishes sampled was into secondary channels in August 1995 when flow was higher (Table 11). In 1994, most movement occurred during dusk and nighttime sampling and the greatest movement observed for native species was into secondary channels during dawn. Sampling in 1995 yielded the largest data set for native species. With the exception of dusk sampling, natives moved into secondary channels and most movement occurred during nighttime and slightly less so during dawn (Figure 15). Non-natives similarly moved most often during nighttime and dawn periods.

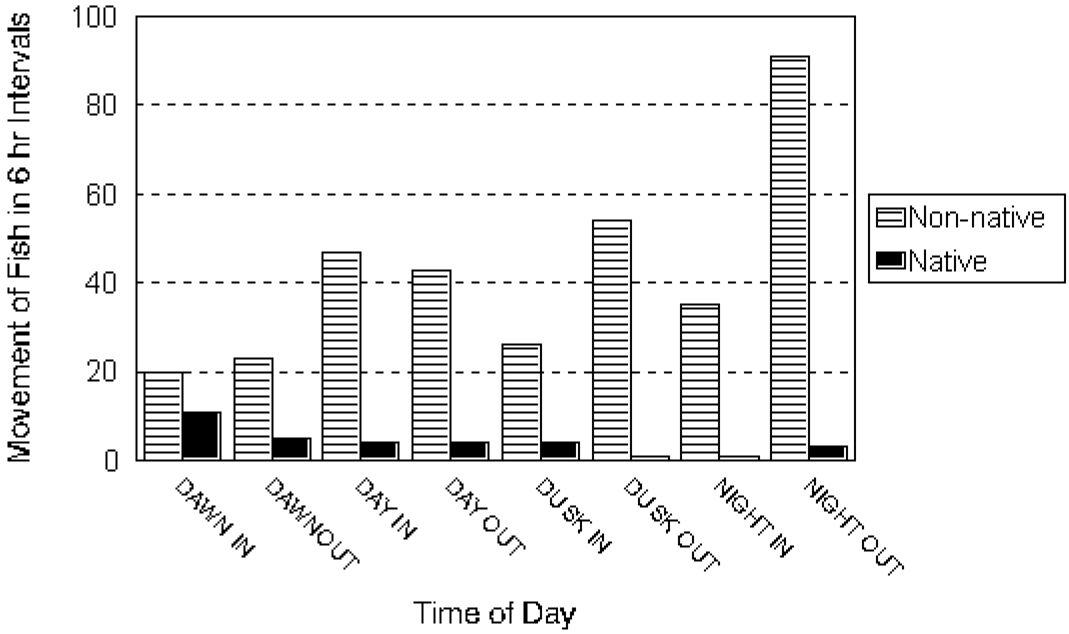


Figure 14. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during August 1994.

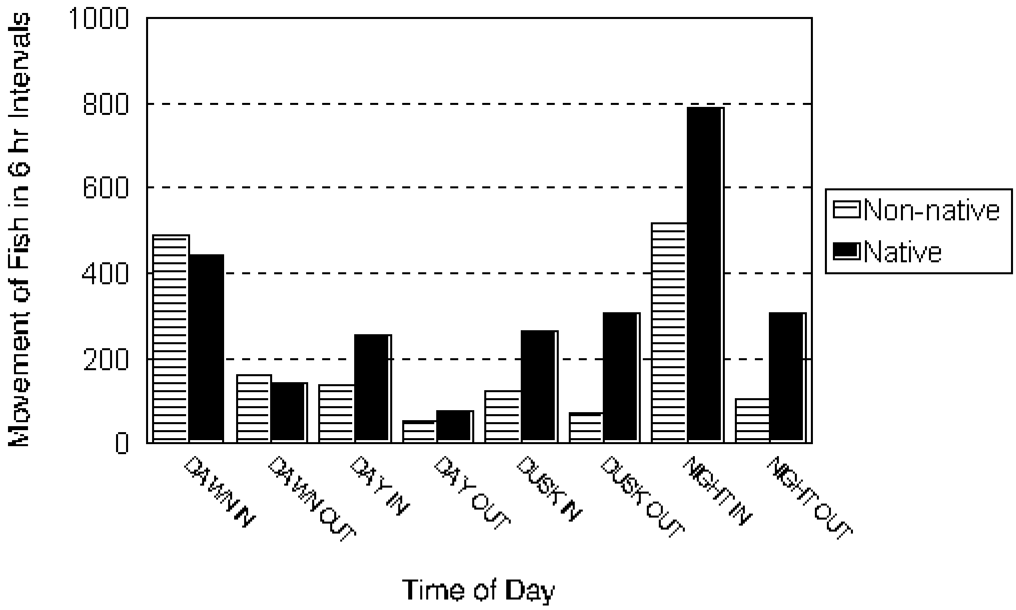


Figure 15. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during August 1995.

October Movement

Flows were greater during 1994 (Table 10) than in 1995 (Table 11) and water temperatures were more variable and slightly warmer during 1995. For both years, non-native species were

most common in collections and were nearly three times more abundant in 1994, while native species comprised a larger proportion of fish sampled in 1995 (8.7%) than in 1994 (4.3%). Fathead minnow (52%) and red shiner (41.3%) nearly equally dominated the sample of non-natives in 1994 and the order of abundance was dramatically switched in 1995 with red shiner (87.4%) more abundant than fathead minnow (10.7%). Channel catfish young-of-year and juveniles were proportionately four times more abundant for all non-native species sampled in 1994 than in 1995. Native species collected during both years were speckled dace and flannelmouth sucker; numbers and proportions sampled were similar, with speckled dace being more common.

The direction and time of day of movement were remarkably different for 1994 (Figure 16) and 1995 (Figure 17). In 1994, observed movement for non-native species was primarily out of secondary channels, except for dusk samples, and was primarily during dawn. Native species numbers sampled were consistent through all sampling periods and movement was generally out of secondary channels, except for daytime when direction of movement was approximately equal. Movement during 1995 was primarily into secondary channels for non-native species and was generally even for native species. Non-native fish generally moved during daytime and dusk and movements were nearly absent during nighttime. Native species were primarily sampled during daytime and dusk and were not collected moving out of secondary channels at night.

Results of the Mann-Whitney U-Test for movement of non-native and native fish into and out of side channels for time of day and season yielded few significant differences (Table 12). Native fish in the day sample of July 1994 and the dusk sample in April 1995 had significant differences in movement between channels. In July 1994, native fish moved out of the side channel, and in April 1995 native fish moved into the side channel. The primary native fish in both of these samples was speckled dace. Both of these observations occurred during high flow conditions (Tables 10-11).

There were no significant temperature differences between main and secondary channels with the exception of one sample (Figure 18). The water temperature was higher in the main channel compared to the side channel in the August 1994 night sample. Secondary channel maximum daily temperatures were lowest in April in both years (Tables 10, 11), were warmer in 1994, and the lowest (3 ° C) recorded temperature occurred also in April 1994 during pre-spring release conditions.

Discussion

During 1994 sampling, flows were low, particularly during April and August sampling and fish movement detected was primarily out of secondary channels. In 1995, flows were higher and movement was primarily into secondary channels. Presumably, fish moved out of secondary channels into main channel habitats to avoid diminishing available habitats as flows declined, in spite of increasing habitat complexity (Gido et al. 1997). With higher flows in 1995, greater movement into secondary channel habitats likely occurred as fish

sought lower velocity habitats even though available habitats increased in uniformity (Gido and Propst 1999, Gido et al. 1997). While non-native species were the primary source of observed movements throughout the study period, native speckled dace, bluehead suckers, and flannelmouth suckers exhibited extensive movement during high flow conditions measured in August 1995 sampling.

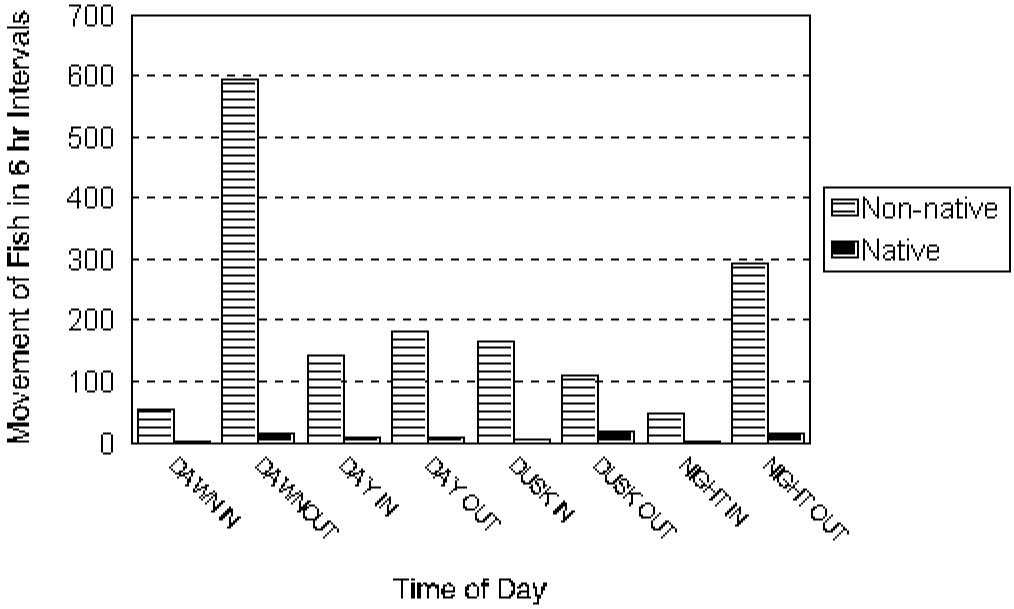


Figure 16. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during October 1994.

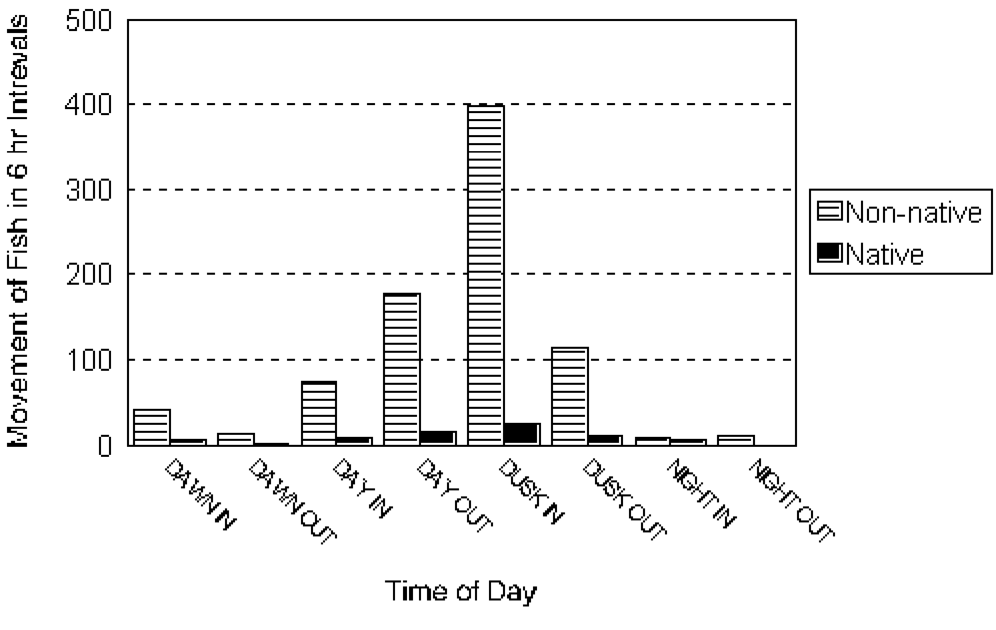
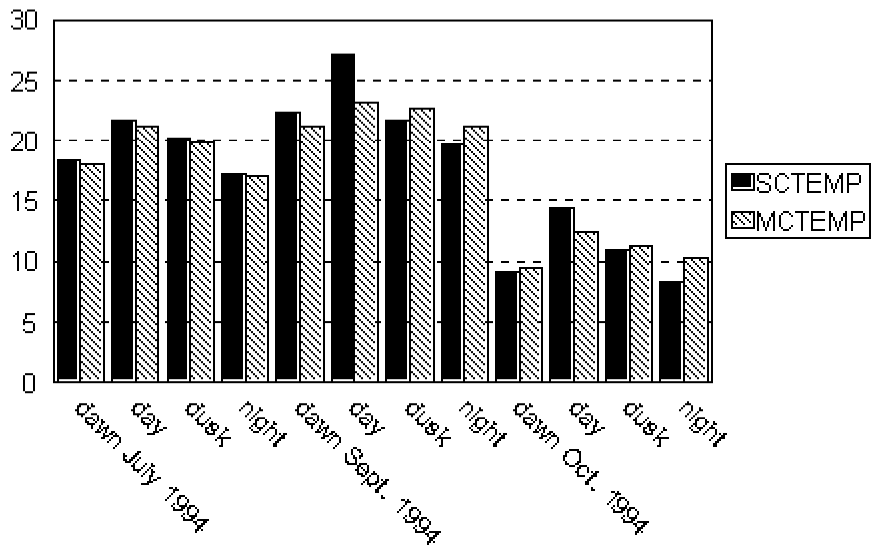


Figure 17. Daily movement of fish in and out of secondary channels by month and year at river miles 82.6-82.8, 127.2-128.2 and 133.8-134.2 during October 1995.

1994



1995

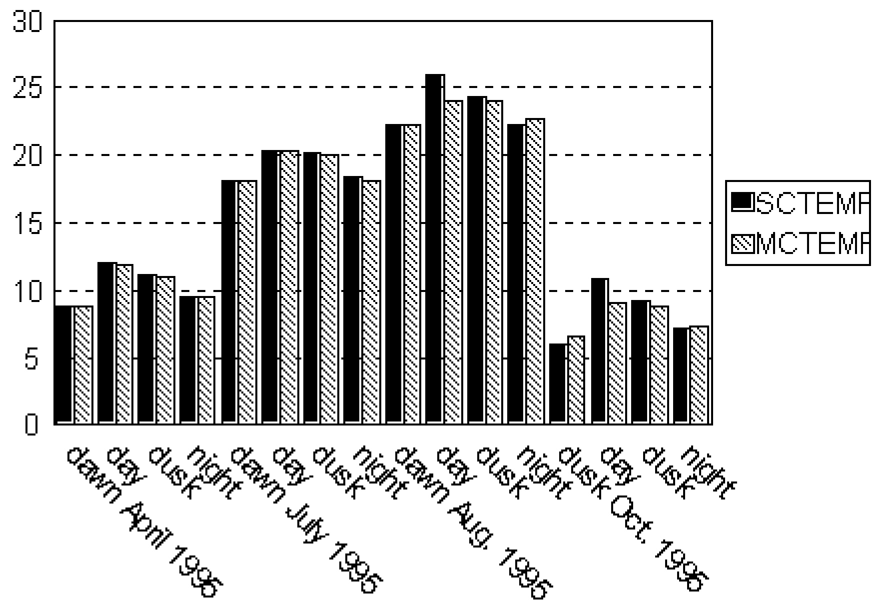


Figure 18. Mean water temperature for all sample sites relative to time of day for egression and ingression sampling for movement between secondary and main channels in the San Juan River.

Table 12. Results of Mann-Whitney U-Test for movement of non-native and native fish into and out of side channels for time of day and season, 1994-1995.

Time of Year	Time of Day (in vs. out)	p value non-native	p value native
July 1994	dawn	0.686	0.686
July	day	0.343	0.029*
July	dusk	0.343	0.886
July	night	0.886	equal
August 1994	dawn	equal	0.421
August	day	equal	0.486
August	dusk	0.421	equal
August	night	0.421	equal
October 1994	dawn	0.937	0.394
October	day	equal	equal
October	dusk	0.818	0.093
October	night	0.589	0.93
April 1995	dawn	0.485	0.699
April	day	0.589	0.699
April	dusk	0.132	0.041**
April	night	0.589	0.394
July 1995	dawn	0.937	0.589
July	day	0.699	0.589
July	dusk	0.699	0.818
July	night	0.589	0.818
August 1995	dawn	0.31	0.31
August	day	0.18	0.24
August	dusk	0.699	0.394
August	night	0.394	0.485
October 1995	dawn	0.69	0.548
October	day	0.537	0.792
October	dusk	0.792	0.429
October	night	0.69	0.69

*significant movement of fish into the side channel
** significant movement of fish out of side channel

The direction of movement between main and secondary channels varied with time of day, season, and flow. Most fish moved during daytime and dusk. Movement in early spring, prior to runoff and peak flow conditions, was minimal. For both native and non-native species, more movement out of secondary channels occurred during low flow conditions for 1994-1995. It is probable that as flows declined in secondary channels resident fish, both natives and non-natives, sought larger habitats. Conversely, higher flows in the San Juan River generally resulted in movement of fish primarily into secondary channels, regardless of season. The increased abundance of native fishes in August 1995 samples during elevated flow conditions was remarkably different from all other periods sampled, including August 1994 sampling.

The increased number of native fishes moving into secondary channels in August 1995 during elevated flows due to summer rainstorm flooding may reflect an avoidance response by native species to less hospitable main channel conditions or an attraction for conditions provided by secondary channels. With the regulation of San Juan River flows by Navajo Dam, the high frequency and magnitude of late summer rainstorm activity and associated flooding (Bliesner 1999) may play an important role in the structuring of the fish community. Gido and Propst (1999) observed the overlap in habitat use patterns for native and non-native species in secondary channel habitats of the San Juan River. Juvenile life stages of native fishes were more interactive with non-native fishes than were adults and were likely negatively impacted by the overlap in resource use. Higher flows through secondary channels in the San Juan River, however, appeared to reduce the abundance of non-natives, thereby allowing native fishes a temporary opportunity to use habitats not dominated by non-natives (Gido et al. 1997). The relatively large number of native fishes moving into secondary channels during elevated flow conditions in August 1995 may explain, in part, why post-high flow secondary channel fish communities in the San Juan River were comprised of a larger proportion of native fishes.

The low numbers of red shiner moving into secondary channels during the elevated flow conditions sampled in August 1995 were markedly different than other sampling periods in this study. Combined with apparent displacement due to more uniform habitats and higher velocities, these data may help to explain reduced abundance of this species observed by Propst and Hobbes (1999) after elevated flow conditions during summer 1995. The increased number of channel catfish young-of-year being transported into secondary channels, as was observed in August 1995, may illustrate that for some species elevated flows may result in an increase in juvenile non-natives in secondary channels following summer high flow events of short duration. This may also explain why, regardless of the preceding flow conditions, autumn and spring fish communities are consistently dominated by non-native species (Propst and Hobbes 1999).

The importance of natural flood events to maintenance of native fishes coexisting with non-natives in altered habitats has been documented and discussed by several authors (Douglas et al. 1994, Minckley and Meffe 1986, Meffe and Minckley 1987). Flood or other high flow events may be important to maintenance of native fishes in the San Juan River (Gido et al. 1997). While the reduction in non-native species abundance following spring high flows was temporary (Propst and Hobbes 1999), subsequent elevated summer flows continued to suppress non-native numbers (Propst and Hobbes 1999). While mimicry of the spring hydrograph is important to maintenance and development of habitats (Bliesner and Lamarra 1999) and reduced non-native numbers in secondary channels (Propst and Hobbes), elevated

summer base flow conditions may also assist in reducing the recruitment success of non-natives and allow for increased survival by native species.

High spring flow conditions are necessary to maintain connection between main and secondary channels in the San Juan River (Bliesner and Lamarra 1999). The ability of native fishes to move from the main channel to secondary channels during flood events may increase native species survival and assist in the maintenance of the native fish community in the San Juan River. In addition, elevated base flow conditions and summer rainstorm flood events likely result in reduced recruitment success for non-native species, such as the red shiner. Mimicry of the natural spring hydrograph and continuation of late summer flood events that elevate base flow conditions and reduce non-native species numbers are important components to consider when managing dam releases and considering future water development scenarios.

Conclusions

- Movement of both native and non-native species into and out of secondary channels was approximately equal, with a few exceptions.
- Movement of both native and non-native species occurred primarily during dusk and night-time sampling.
- Non-native species were more abundant in samples taken during low to moderate flow conditions for movement both into and out of secondary channels.
- Native species were more common in samples collected during high flow conditions in August 1995 for movements both into and out of secondary channels.
- Measured water temperature differences between main and side channels were greatest during dusk sampling.
- Study results suggested that native species more actively used secondary channels during high flow events and, combined with results of secondary channel ichthyofaunal studies, may illustrate a competitive edge of native species over non-natives during high flows.

CHAPTER III.

Food habits of San Juan River fishes, 1991-1995

Introduction

Non-native species predation on native species may be a major obstacle to recovery and management of native fish communities. The introduction and establishment of non-native species in the Colorado River Basin has generally occurred after habitat alteration by dam construction and alteration of stream flows. Mimicry of the natural hydrograph with re-operation of Navajo Dam was proposed as a necessary tool to reduce non-native species interactions and assist in recovery of the native fishes. It was believed that suppression of non-native species would reduce predation and other negative interactions with native species.

Commonality of resource use by native and non-native species and the resulting competitive interactions have been identified as a major impact to the fish fauna of the American Southwest (reviewed by Douglas et al. 1994). However, specific interactions between native and non-native species vary and food habits studies for the San Juan River community were lacking. The primary purpose of this study segment was to characterize the food habits of all San Juan River fishes, evaluate predation by non-natives on natives, and evaluate food availability (macroinvertebrates) for young-of-year (YOY) and subadult large-bodied native fish species and all life stages of small-bodied native and non-native fish species.

In order to characterize the use and availability of food items and ascertain limiting factors that would contribute to development of recovery strategies for the San Juan River native fish community, the following objectives for this study component were identified:

1. Characterize of the extent of piscivory by non-native predatory fish species on native species.
2. If possible, document direct predation upon Colorado pikeminnow and razorback sucker.
3. Characterize the food habits of native and non-native species to assess resource use overlap in foods consumed.
4. Characterize the temporal and spatial patterns of the benthic macroinvertebrate community in main and side channel habitats.
5. Compare and contrast the abundance patterns of the benthic macroinvertebrate community of other rivers and streams within the Colorado River Basin to assist in determination of limitation of the food base to resident fishes.

Study Area

Studies of piscivory were conducted in main channel environments throughout the study area, from the Hogback Diversion, New Mexico, downstream to Clay Hills, Utah for channel catfish *Ictalurus punctatus* (ICTPUN) food habits and downstream of Bluff, Utah for walleye *Stizostedion vitreum* (STIVIT) and striped bass *Morone saxatilis* (MORSAX). Sampling to characterize the food habits of small-bodied native and non-native species and young-of-year stages of large-bodied native and non-native species was conducted in main and side channel habitats in three discrete reaches: RM 82.6-82.8, RM 127.2-128.5, and RM 133.8-134.2. All three reaches include areas where main and secondary channels were confluent and offered the opportunity sample both habitats within a discrete time period.

Benthic macroinvertebrate sampling was conducted in main and side channel habitats in three discrete reaches: RM 82.6-82.8, RM 127.2-128.5, and RM 133.8-134.2. All three reaches

included areas where main and secondary channels were confluent and allowed for sampling of main and side channel habitats within a discrete time period.

Methods

Food Habits - Piscivory by non-native fish species on the native fish community was the focus of data collection efforts during 1991-1993. Channel catfish and other less abundant non-native piscivores (primarily centrarchids) were collected by electrofishing during main channel adult monitoring trips and data recorded for total and standard lengths, weight, and date collected. Individual fish >150 mm TL were eviscerated: stomachs removed, preserved in 10% formalin, and returned to the laboratory for content analysis. Specimens <150 mm TL were preserved whole in 10% formalin and returned to the lab for stomach content analyses. Time of day for collection of channel catfish stomach samples occurred primarily during early daylight hours (0800-1100 hours). October 1991 samples collected after 1200 hours were primarily empty. Based upon the nocturnal feeding habits and success of stomach content analyses for this species in the Gila River, Arizona (Marsh and Brooks 1989), the change to earlier daylight sampling was instituted during spring 1992. Other non-native piscivorous species (black bullhead *Amerius melas* (AMEMEL), green sunfish *Lepomis cyanellus* (LEPCYA), bluegill *Lepomis macrochirus* (LEPMAC), smallmouth bass *Micropterus dolomieu* (MICDOL), largemouth bass *Micropterus salmoides* (MICSAL), and brown trout *Salmo trutta* (SALTRU)) were uncommon. All individuals collected, regardless of time of day, were retained for stomach content analysis. While other potentially predatory non-native species periodically occur within the study area, notably striped bass and walleye, we did not collect any during the 1991-1993 study period. Ryden and Pfeifer (1996) reported on the collection of 34 striped bass and 26 walleye in 1995 after inundation of a barrier falls located downstream of Clay Hills by the rising surface elevation of Lake Powell. During 1995-1997, we opportunistically performed field examinations of stomach contents for individual fish obviously having full guts, to determine prey species and ontogenetic stage consumed (YOY, juvenile, adult).

Efforts were begun in 1993 to evaluate the food habits of YOY and juvenile native fishes and co-occurring non-native fishes, primarily red shiner *Cyprinella lutrensis* (CYPLUT) and fathead minnow *Pimephales promelas* (PIMPRO). These two-fold efforts were designed to evaluate both dietary overlap (inferring competition) and piscivory by non-native species on natives. Emphasis was placed upon sampling Reaches 4 and 5 because YOY and juvenile life stages of native fishes were common and abundant (Buntjer et al. 1993, 1994; Propst and Hobbes 1995), and there was a greater potential for analyses of resource overlap for all life stages of non-native fishes and all native fishes, including Colorado pikeminnow and roundtail chub. Sampling efforts and locations were accomplished in conjunction with egression and ingression studies. Sampling was conducted by seining downstream in discrete mesohabitats. Most specimens collected were preserved in 10% formalin and returned to the laboratory for identification, enumeration, and size measurement. If abundant in the collections (>10 individuals), only 10 individuals of each species were analyzed for stomach contents. If not abundant (≤ 10 specimens), all individuals of that species were analyzed. Stomach contents were identified according to food item categories listed in . Macroinvertebrates were identified to Order since many of those individuals consumed were partially digested and further definition of taxonomic classification would have been of questionable accuracy.

Table 13. Key of food items and other taxa including abbreviations used in food habits studies for San Juan River fishes.

Order / or Family	Abbreviation
Ephemeroptera	ephem
Odonata	odon
Plecoptera	pleco
Hemiptera	hemip
Megaloptera	mega
Coleoptera	coleo
Trichoptera	tricho
Lepidoptera	lepid
Diptera	dipt
Decapoda	deca
Gastropoda	gastr
Nematomorpha	nmrph
Ostracoda	ostra
Nematoda	nema
Annelida	annel
Araneidae	arane
Isopodidae	isopo
Chilopidae	chilo
Orthoptera	ortho
Isoptera	isopt
Hymenoptera	hymen
Russian olive	R.olive
Any other vegetation	veg
Fish	fish
Other vertebrates	other verts
Terrestrial	terr
Unidentified organics	UnOrg

Annual and seasonal stomach contents of non-native piscivores were summarized by percent frequency of occurrence of individual food item categories and average number of individuals in each category (Table 13) per stomach. Empty stomachs were excluded from analysis. Channel catfish were divided into three size categories (<300 mm TL, 301-450 mm TL, >450 mm TL) and results of stomach contents listed by year (1991, 1992, 1993) for all specific food item categories and by season (spring, summer, autumn) for general food item categories (aquatic invertebrates, terrestrial invertebrates, fish, other vertebrates, Russian olives, other vegetation). Other non-native predators were grouped together for all three years and stomach contents were summarized by season and general food item categories (aquatic invertebrates, terrestrial invertebrates, fish, other vertebrates, Russian olives, other vegetation). The diversity of the food items consumed most frequently was evaluated by use of the index, Hill's family of diversity numbers (Ludwig and Reynolds 1988). For food habits analyses, these diversity numbers represent the effective number of food item categories, in other words the degree to which proportional abundances are distributed among food item categories. To compute Hill's diversity numbers for the most abundant food item categories, we generated Shannon's Index diversity values for inclusion in the formula,

$$N1 = e^{H'}$$

where N1 is Hill's number of most abundant food item categories and H' is Shannon's Index. The diversity of abundant food items consumed by YOY and juvenile native and non-native species (also included adults for small-sized taxa) was also determined by Hill's family of diversity numbers as described above.

Food Availability - To assess the potential for competition between native and non-native fishes for available food resources, sampling was conducted to determine the diversity and abundance of different taxa of macroinvertebrates occurring in secondary channel and adjacent main channel shoreline habitats occupied by YOY and juvenile native fishes. Sampling for food availability was conducted in close proximity to samples collected for food habits analysis of co-occurring native and non-native fishes as specified above.

Macroinvertebrate sampling employed three gear types: Surber and Hess samplers for moderate to high velocity run and riffle habitats over coarse substrate (predominantly gravel and cobble), and Ekman dredge in low velocity run, pool, and eddy habitats over gravel, sand and/or silt bottom. Three replicates were collected at each site sampled within Reaches 4 and 5. Samples were preserved in 95% ethanol and returned to the laboratory for analysis. Macroinvertebrates were identified to Order in 1993 and to Family in 1994-1996. Data were combined for all habitat types sampled and sampling methods and were analyzed for number per square meter expressed as an average of the three replicate samples collected at each site.

Macroinvertebrate numbers varied widely within and among sample locations and nonparametric statistical analyses were employed to further describe results. To detect any significant variation in macroinvertebrate diversity between years, the Kruskal-Wallis test (Zar 1984), which analyzes the variance of individual taxon ranking, was used to test the null hypothesis that macroinvertebrate diversity did not differ between years. Comparison of the most abundant macroinvertebrate taxa diversity in main and side channel habitats between years was evaluated by Hill's diversity index (Ludwig and Reynolds 1988). Hill's diversity numbers (= number of species) are a measure of the number of species in the sample where each species value is weighted by its abundance and requires the use of Shannon's index

values to account for the more abundant species without excluding rarer forms. To test for significant differences in macroinvertebrate density between years, the Mann-Whitney U-test compared densities for combined results of main and side channel sampling between years.

<u>Results</u>
Food Habits - To characterize the potential piscivory by non-native fish species on native species, we examined stomach contents from 312 channel catfish and 37 individuals representing six species (3 black bullhead *Ameiurus melas*, 3 green sunfish *Lepomis cyanellus*, 1 bluegill *Lepomis macrochirus*, 2 smallmouth bass *Micropterus dolomieu*, 23 largemouth bass *Micropterus salmoides*, and 5 brown trout *Salmo trutta*). We also performed field examinations of the stomach contents of 11 striped bass *Morone saxatilis* and 19 walleye *Stizostedion vitreum* collected during main channel electrofishing in June 1996, after inundation of the barrier falls downstream of Clay Hills, Utah in 1995.

Seasonal food habits analyses for channel catfish *Ictalurus punctatus* stomachs containing food were for 173 specimens in spring, 69 during summer sampling, and 70 individuals collected during autumn (Tables 14-16). The majority of channel catfish specimens examined were 300-500 mm TL and and the overall range was 57-742 mm TL (Figure 19). The overall diet of channel catfish was omnivorous. Aquatic macroinvertebrates were the most commonly consumed food items by all sizes of channel catfish throughout the sampling period, although a similarly high frequency of Russian olive fruits and other flora, primarily filamentous green algae *Cladophora* sp. was also consumed. Piscivory was documented in all seasons sampled and the highest frequency of occurrence for fish remains in stomachs examined was during summer. Of the 312 stomachs containing food, 13.7% (n=42) contained fish or fish remains and the native flannelmouth sucker was the most commonly consumed species.

Table 14. Stomach contents of channel catfish sampled during 1991.

Food Item	Fall 1991 (n=9)		
	Percent Occurrence	$\bar{X}$±SD	Range
ephem	11	0.22±0.6	0-2
tricho	22	0.55±1.2	0-4
lepid	11	0.11±0.3	0-1
dipt	55	62.5±99.9	0-319
R.olive	33	9.2±16.4	0-50
other veg	66	-	-

Channel catfish <300 mm TL (n=63) consumed almost exclusively macroinvertebrates and Russian olives for all seasons sampled (Figures 21-25). Of 13 Orders of macroinvertebrates consumed, those occurring most frequently in stomachs containing food items were

Ephemeroptera, Trichoptera, and Diptera (Tables 15,16). Dipterans were the most frequently occurring food item in spring samples, ephemeropterans and trichopterans were the most frequently consumed in summer, and trichopterans were numerically dominant in autumn samples. Filamentous green algae occurred in >30% of the individuals examined for all seasons, but was highest in spring samples (51.5%). Russian olive fruits were consumed in all seasons, but did not occur at higher frequencies as observed for larger channel catfish. Piscivory, while documented for channel catfish <300 mm TL, was minimal occurring in <10% of spring and autumn samples and absent in summer stomach content analyses. Those identifiable species consumed were speckled dace *Rhinychthys osculus* (RHIOSC) and non-native red shiner and fathead minnow, all <85 mm SL.

Food habits of channel catfish 300-450 mm TL were similar to smaller-sized individuals, but a greater diversity in diet was observed (Figures 21-25). Seven more Orders of macroinvertebrates were consumed , but ephemeropterans, trichopterans, and dipterans remained those most frequently consumed (Tables 14,15). Terrestial insects (primarily Hymenoptera) were consumed at higher frequencies (19-30%) than for smaller channel catfish and were highest in spring samples. Filamentous green algae and Russian olive fruits were also more frequently consumed, occurring most frequently in autumn stomachs at 86.5% and 50.7%, respectively. Piscivory was documented for all three seasons sampled and highest in summer (18.5%). Identifiable fish species consumed were native speckled dace and flannelmouth sucker *Catostomus latipinnis* (CATLAT) (<150 mm SL), and non-native red shiner.

Piscivory occurred most frequently in channel catfish >450 mm TL (n=103 stomachs, Figures 19-25). The highest frequency of occurrence for nearly all food item categories was in summer. While ephemeropterans, trichopterans, and dipterans remained the most abundant and frequently consumed macroinvertebrates, terrestrial invertebrates were more common in the diet, particularly for adult coleopterans during spring (32%, n=16). Both filamentous green algae and Russian olive fruits were consumed nearly as frequently and the most frequently consumed food in autumn samples was filamentous algae (80%, n=28). Documented piscivory was highest in summer samples (31.4%, n=11) and identifiable fish remains were almost exclusively flannelmouth sucker, while native speckled dace and bluehead sucker *Catostomus discobolus* (CATDIS) and non-native red shiner were also eaten. Measurable flannelmouth sucker ranged 211-315 mm SL and the largest flannelmouth sucker occurred in the stomach of the largest channel catfish (742 mm TL). Piscivory for channel catfish >450 mm TL was noted primarily for RM 101-104 (near Aneth, Utah) and RM 128-132 (The Mixer).

With the exception of bluegill, all other non-native predator species examined from 1991-1993 demonstrated piscivory. The frequency of occurrence of fish and/or fish remains was 35.1% (n=13) and higher that the next most frequently consumed food item, Ephemoptera (24.3%, n=9, Table 17). Black bullhead consumed the greatest diversity of food items (Hill's number of abundant species = 3, Figure 21). Bluegill (n=1) and smallmouth bass (n=2) were not included in these analyses. Identifiable fish species consumed were native speckled dace and flannelmouth sucker and non-native red shiner, fathead minnow and mosquitofish *Gambusia affinis* (GAMAFF).

Table 15. Stomach contents of channel catfish sampled during 1992.

Food Item	Spring 1992 (n=46)			Summer 1992 (n=21)		
	Percent Occurrence	$\bar{x}$ ±SD	Range	Percent Occurrence	$\bar{x}$ ±SD	Range
ephem	57	2.5±6.2	0-39	76	8.4±16.2	0-62
odon	4	0.04±0.2	0-1	10	0.09±0.3	0-1
pleco	19	0.2±0.5	0-2	-	-	-
hemip	6.5	0.04±0.2	0-1	19	0.3±0.7	0-3
coleo	35	0.9±2.6	0-17	24	0.4±0.7	0-2
tricho	82	7±9.8	0-41	71	4±3.6	0-11
lepid	30	0.6±1.5	0-9	4.8	0.05±0.2	0-1
dipt	93	23±35	0-154	81	29±58.4	0-213
deca	15	0.2±0.7	0-4	-	-	-
gastr	2	0.02±0.1	0-1	10	0.2±0.5	0-2
nmrph	2	0.1±0.4	0-3	-	-	-
ostra	-	-	-	5	0.05±0.2	0-3
nema	-	-	-	5	0.2±07	0-3
arane	4	0.04±0.2	0-1	-	-	-
isopo	9	0.2±0.6	0-4	5	0.19±0.9	0-4
chilo	4	0.04±0.2	0-1	-	-	-
hymen	24	0.6±2	0-13	14	0.4±1.1	0-5
R. olive	41	2.6±6.2	0-30	38	4.8±13	0-59
flora	60	-	-	29	-	-

Table 16. Stomach contents of channel catfish sampled during 1993.

Food item	spring 1993 (n=103)			summer 1993 (n=42)			fall 1993 (n=59)		
	%	$\bar{x}$±SD	Range	%	$\bar{x}$±SD	Range	%	$\bar{x}$±SD	Range
ephem	33	0.6±1.2	0-7	71	47±79	0-302	19	0.3±0.7	0-3
odon	10	0.1±0.3	0-1	7	0.1±0.5	0-3	2	0.01±0.1	0-1
pleco	12	0.2±0.5	0-4	12	0.2±0.5	0-2	7	0.07±0.3	0-1
hemip	6	0.1±0.2	0-1	-	-	-	3	0.03±0.2	0-1
coleo	43	1.3±2.3	0-12	2	0.02±0.2	0-1	15	0.4±1.6	0-12
mega	-	-	-	5	0.1±0.3	0-2	-	-	-
tricho	63	5±9.3	0-58	71	6.7±10	0-36	29	0.8±2.2	0-12
lepid	34	1±2.5	0-18	-	-	-	2	0.02±0.1	0-1
dipt	62	2.4±3.3	0-37	29	4.3±114	0-66	31	1±1.7	0-10
deca	5	0.1	0-2	-	-	-	2	0.02±0.13	0-1
nema	9	0.4±2.5	0-25	-	-	-	2	0.1±0.4	0-3
annel	6	0.4±3.2	0-32	-	-	-	-	-	-
arane	-	-	-	-	-	-	5	0.05±0.2	0-1
isopo	17	0.8±2.3	0-12	-	-	-	5	0.05±0.2	0-1
ortho	1	0.01±0.1	0-1	5	0.04±0.2	0-1	3	0.03±0.2	0-1
isopt	1	0.02±0.2	0-2	-	-	-	3	0.03±0.2	0-1
hymen	32	0.8±2	0-13	7	0.1±0.4	0-2	15	0.5±2	0-17
fish	11	0.2±0.6	0-5	26	0.5±0.9	0-4	12	0.2±0.6	0-3
R. olive	52	4.8±10	0-63	24	5±13	0-63	32	1.4±4	0-24

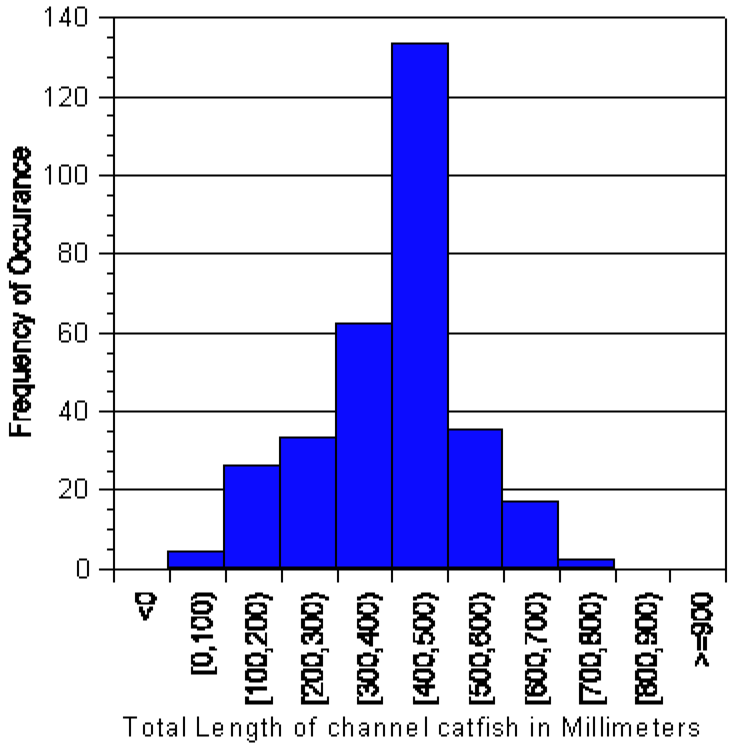


Figure 19. Size class structure (total length, mm) of channel catfish used in stomach analyses.

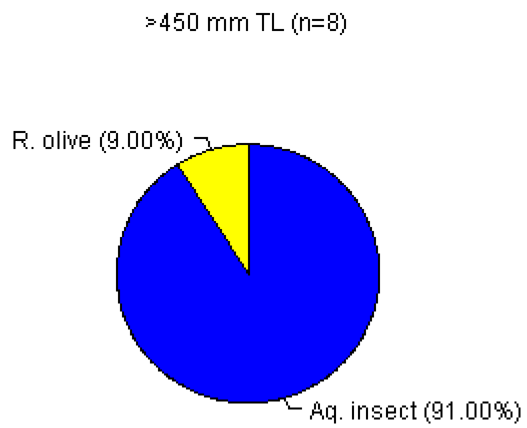


Figure 20. Diet of channel catfish >450 mm TL sampled during Autumn 1991.

Table 17. Stomach contents of all other non-native species sampled during 1991-1993.

Food Item	Other non-native fish 1991-1993		
	Percent Occurrence (n=24)	$\bar{x}$±SD	Range
ephem	37	1.3±2.9	0-12
tricho	12	0.16±0.48	0-2
odon	4	0.04±0.2	0-1
dipt	17	0.21±0.5	0-2
pleco	4	0.04±0.2	0-1
hymen	4	0.04±0.2	0-1
fish	54	1.12±1.6	0-7

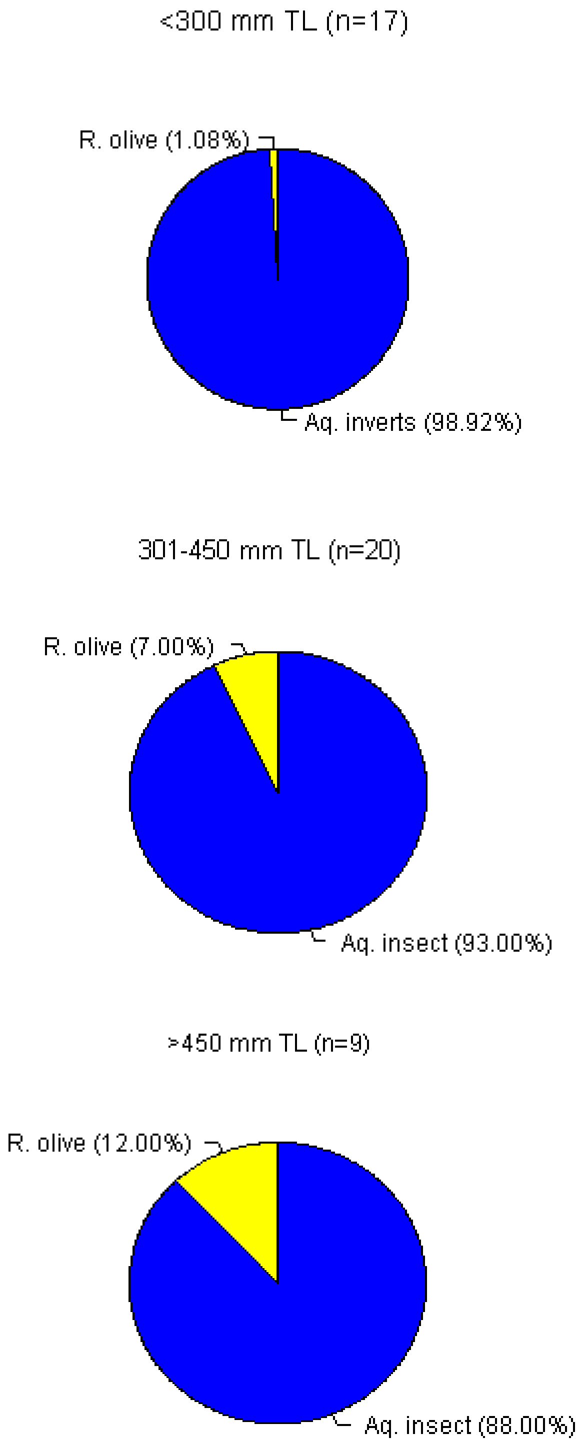


Figure 21. Diet of 3 size classes of channel catfish sampled during Spring 1992.

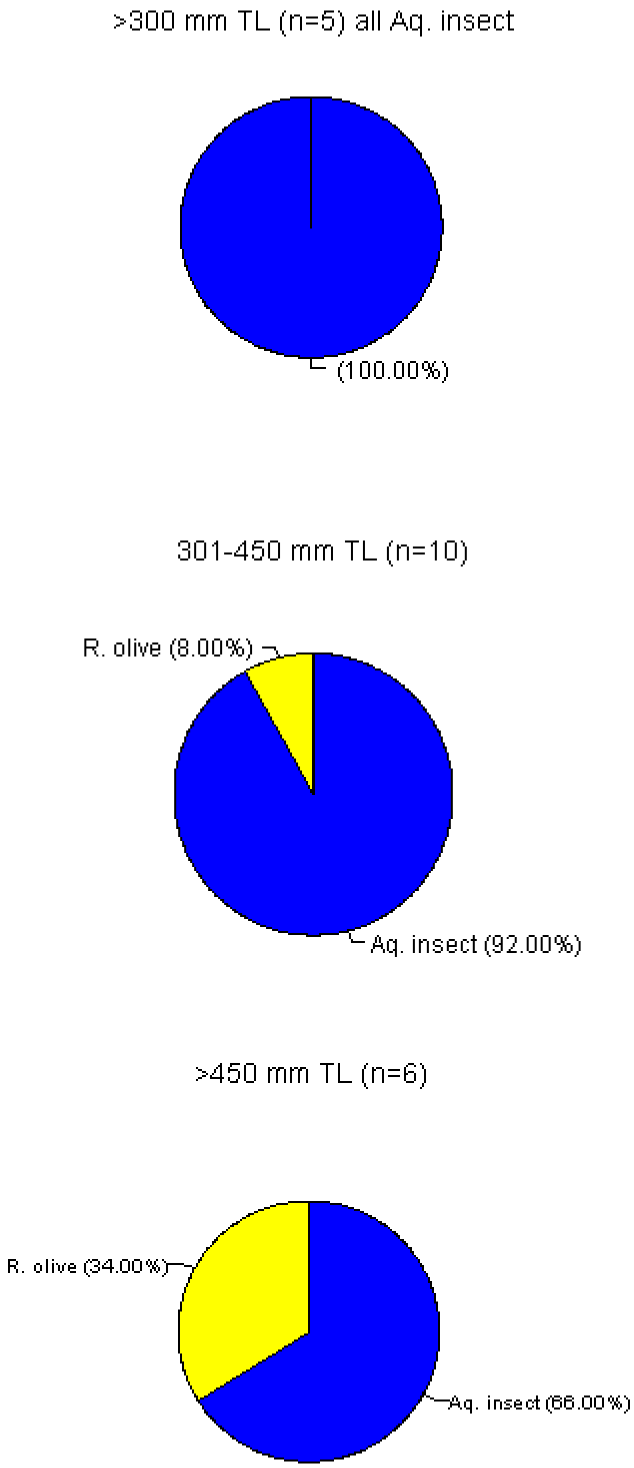


Figure 22. Diet of 3 size classes of channel catfish during Summer 1992.

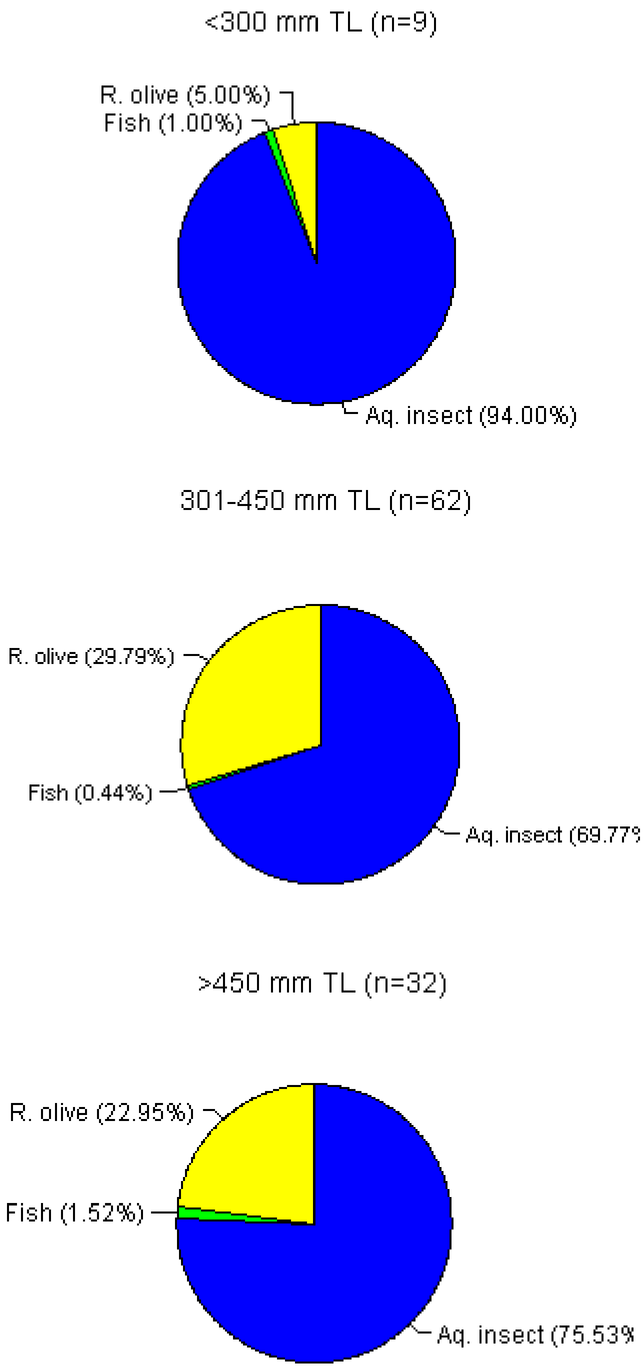


Figure 23. Diet of 3 size classes of channel catfish sampled during Spring 1993.

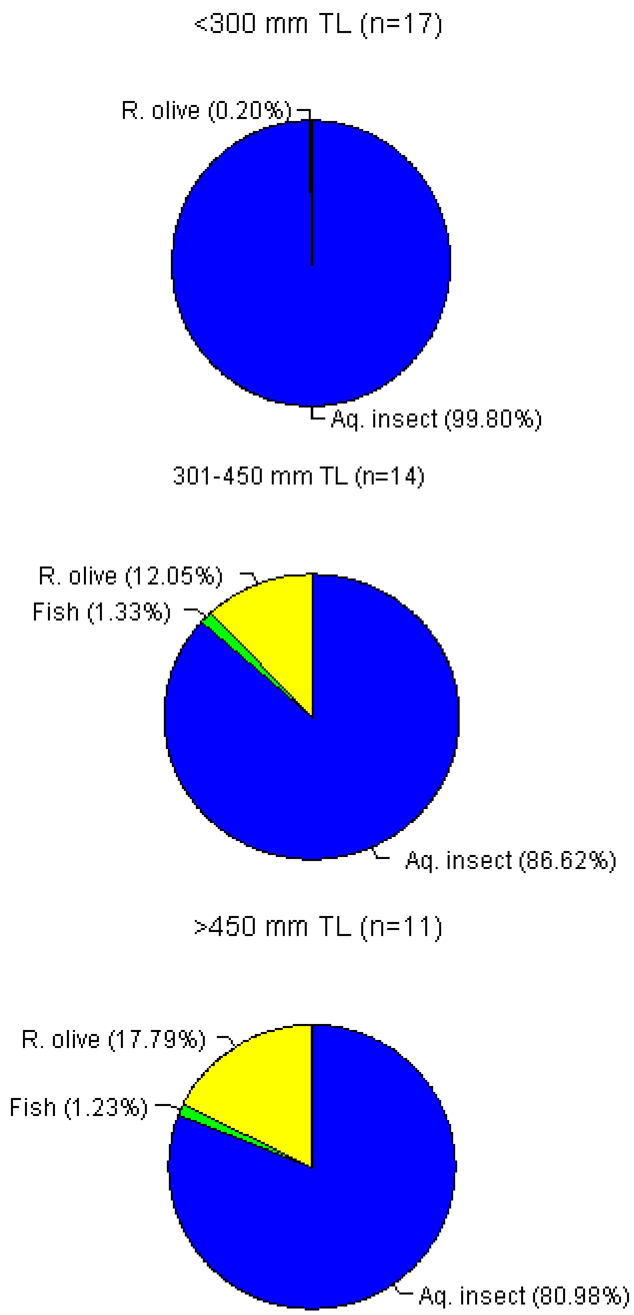


Figure 24. Diet of 3 size classes of channel catfish sampled during Summer 1993.

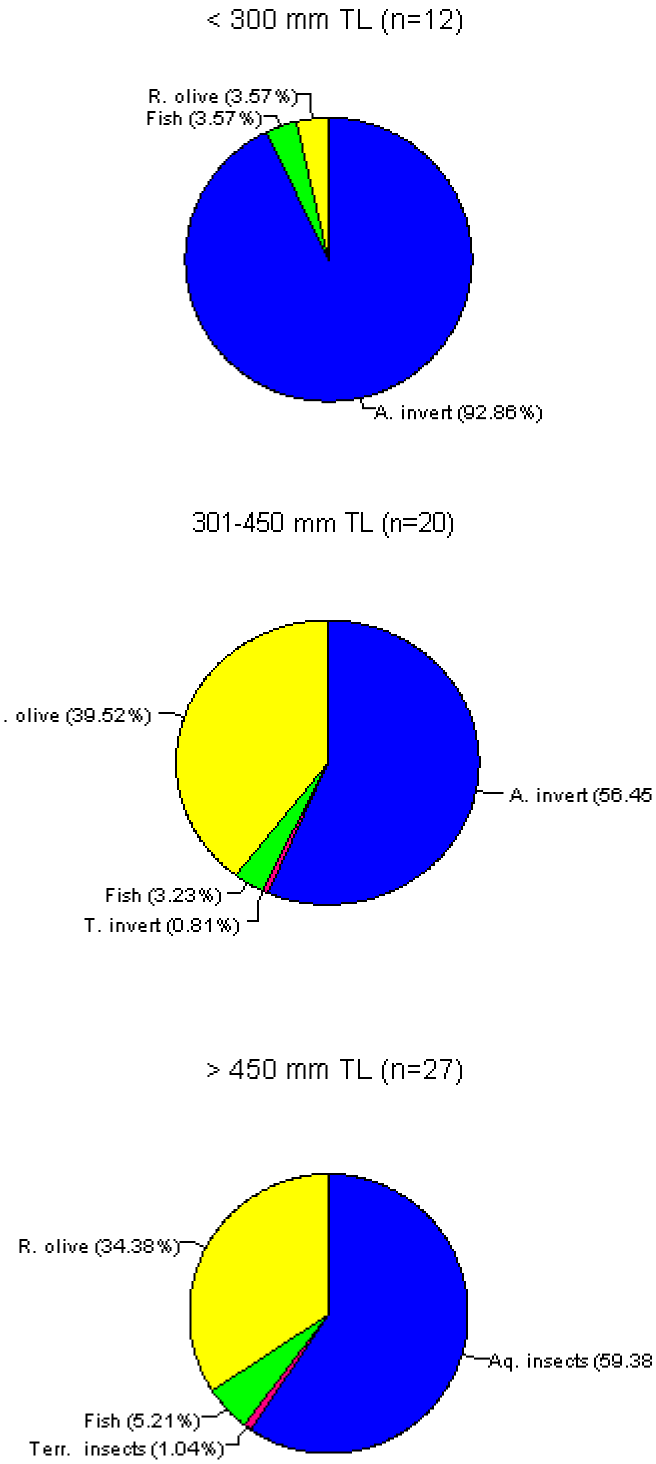


Figure 25. Diet of 3 size of classes of channel catfish sampled during Fall 1993.

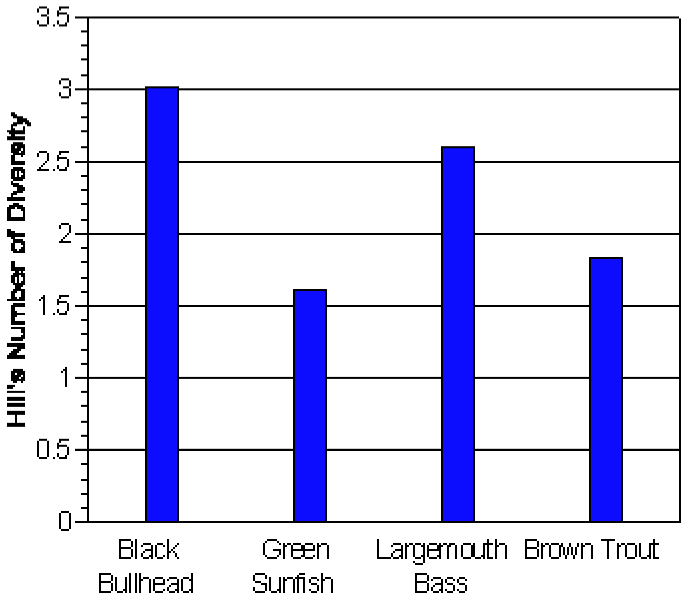


Figure 26. Diet diversity of other non-native predatory species sampled during 1991-1993 in the San Juan River.

Prior to 1995, striped bass and walleye had not been collected in the San Juan River since 1988 (Platania 1990; Ryden and Pfeifer 1996). After the inundation of the waterfall barrier downstream of Clay Hills, Utah during spring 1995, these two species reappeared. The stomach contents of 11 striped bass (398-610 mm TL) and 38 walleye (407-646 mm TL) collected during 1995 and 1996 main channel electrofishing efforts were examined. Striped bass were collected from river miles 2.9 to 91.2. Walleye collections were made primarily in the San Juan River between river miles 5.0 and 53.0, but also included a few individuals from river miles 77.4 to 108.3. Water conditions were generally turbid with zero or near zero visibility and 45.5% of striped bass and 44.7% of walleye (both sight feeders) stomachs were empty (Table 18). Flannelmouth suckers (132-280 mm SL) and threadfin shad *Dorosoma petenense* (DORCEP) (not measured) were the exclusive food items in striped bass stomach contents. Striped bass stomachs containing threadfin shad were collected downstream of River Mile 20.2, the upstream distributional limit of for threadfin shad documented during this study. For walleye, fish and/or fish remains occurrence was 100% for those stomachs containing food, and a greater variety of fish species and sizes were consumed. Flannelmouth sucker (150-260 mm SL) were the most common fish species consumed. Other fish species consumed were channel catfish (30-72 mm SL), largemouth bass (not measured, but was a YOY), and red shiner (70-80 mm SL).

Table 18. Stomach contents of striped bass and walleye collected by electrofishing during June 1996 in the San Juan River between Clay Hills, Utah and Mexican Hat, Utah.

Species	n	Stomach Contents Empty	With Food	%Freq. Occurrence	Prey Species
striped bass	11	6	5	100	flannelmouth sucker
walleye	38	21	17	100	channel catfish largemouth bass red shiner flannelmouth sucker

A total of 3,604 stomachs were examined from small-sized native and non-native species sampled 1994-1996. Only 21 percent of these fish were native. The most abundant native fish caught was speckled dace, consisting of 78 percent of the total native catch. Flannelmouth sucker and bluehead sucker consisted of 14 percent and 7 percent of the remaining native catch, respectively. One roundtail chub was examined over the three year study and the stomach was empty. Red shiner comprised 63 percent of the total non-native catch. The remaining non-native fish stomachs examined were fathead minnow (27%), channel catfish (5%), mosquitofish (3%), common carp (0.5%), and plains killifish *Fundulus zebrinus* (FUNZEB) (0.3%).

Of the native species examined, speckled dace consumed the greatest diversity of food items (Tables 19-21). Dipterans and ephemeropterans were the macroinvertebrates most often consumed by speckled dace during all three years sampled, although the Order Trichoptera was an important food item measured during 1995. Macroinvertebrates consumed by flannelmouth and bluehead suckers were primarily dipterans during all three years. Flannelmouth suckers also consumed ephemeropterans and, during 1996, consumed coleopteran larvae. The diet of bluehead sucker demonstrated the lowest diversity. All three native species consumed detrital materials at a relatively high rate. During 1996, diet diversity for all three species was lower, a year in which spring runoff and late summer rainstorm-caused flows were lower than in 1994-1995.

Channel catfish and red shiner consumed the greatest variety of macroinvertebrates (Tables 18-20). As with the native fishes, dipterans were the primary macroinvertebrate consumed and, with a few exceptions, detritus consistently occurred in all non-native species examined. Young of year common carp stomachs examined were generally empty and primarily contained dipteran larvae and, minimally, unidentified vegetation. Plains killifish and mosquitofish also consumed a low diversity of food items consuming almost exclusively dipteran larvae, likely due to their surface-feeding habits.

Table 19. Percent frequency of occurrence of food items from stomachs of fishes collected in low velocity habitats of the San Juan River between Shiprock, NM and Bluff, Utah 1994.

	Native fish				Non-native fish						
	GILROB	RHIOSC	CATDIS	CATLAT	CYPCAR	CYPLUT	PIMPRO	FUNZEB	ICTPUN	GAMAFF	LEPMAC
No.	1	135	7	9	5	378	246	6	27	52	1
Amphi	0	0	0	0	0	0	<1	0	0	0	0
Annel	0	0	0	0	20	<1	0	0	4	2	0
Coleo	0	0	0	0	0	0	0	0	7	10	0
Dipt	0	31.8	29	67	80	20	9	83	41	29	100
Ephem	0	15.6	0	11	0	11	0	0	15	2	100
Hemip	0	<1	0	0	0	<1	0	0	7	4	0
Hymen	0	<1	0	0	0	<1	<1	0	0	2	0
Odon	0	2	0	0	0	4	0	0	0	2	0
Pleco	0	4	0	0	0	5	0	0	4	0	100
Tricho	0	7	0	0	0	4	0	0	7	0	0
Terr	0	2	0	0	0	3	0	0	7	14	0
Veg	0	4	14	11	20	7	2	0	0	2	100
Detrit	0	54	71	78	20	40	81	50	15	29	100

Spearman Rank Correlation Coefficients were calculated between the relative abundance of fish and mean number of all macroinvertebrates of each order found in the stomachs of each species of fish. All fish stomachs were included in this test even if they were empty. We accepted significant values of <99%. Two native fish, flannelmouth suckers (P=0.001) and bluehead suckers (P= 0.009), were found to have a positive correlation with the Order Diptera. Only one non-native fish, the mosquitofish, was found to have a positive correlation with the Order Hemiptera (P =0.004). Speckled dace, plains killifish, red shiner, common carp, and fathead minnow were not found to have any strong correlations with any order of macroinvertebrates.

Table 20. Percent frequency of occurrence of food items from stomachs of fishes collected in low velocity habitats of the San Juan River between Shiprock, New Mexico and Bluff, Utah 1995.

	Native fish			Non-native fish					
	RHIOSC	CATDIS	CATLAT	CYPCAR	CYPLUT	PIMPRO	FUNZEB	ICTPUN	GAMAFF
NO	291	40	64	9	467	168	1	75	8
Amphipod	0	0	0	0	<1	0	0	0	0
Annel	3	0	3	0	<1	0	0	0	0
Coleo	1	0	0	0	3	0	0	3	0
Dipt	42	18	66	11	22	5	100	83	12
Ephem	11	2	16	0	4	0	100	23	0
Hemip	1	0	0	0	<1	0	0	1	0
Hymen	0	0	0	0	<1	0	0	0	0
Odon	<1	0	0	0	1	0	0	0	0
Pleco	3	0	2	0	2	0	0	1	0
Tricho	12	2	6	0	9	<1	0	21	0
Nema	0	0	0	0	<1	0	0	0	0
Terr	2	0	0	0	3	0	0	0	0
Fish	0	0	0	0	0	0	0	0	0
Veg	2	4	3	0	4	3	0	1	0
UnParts	33	0	14	0	41	2	100	51	0
Detritus	67	95	86	67	52	90	0	64	0

Table 21. Percent frequency of occurrence of food items from stomachs of fishes collected in low velocity habitats of the San Juan River between Shiprock, NM and Bluff, Utah 1996.

	Native fish			Non-native fish					
	RHIC OSC	CAT DIS	CAT LAT	CYP CAR	CYP LUT	PIM PRO	FUN ZEB	ICT PUN	GAM AFF
Number	156	11	31	5	957	359	2	51	17
Amphipo	0	0	0	0	0	0	0	0	0
Annel	0	0	0	0	0	0	0	4	0
Coleo	6	0	32	0	< 1	0	0	0	0
Dipt	38	11	54	0	40	20	100	74	23
Ephem	20	0	3	0	1.5	0	0	21	0
Hemip	0	0	0	0	< 1	0	0	0	0
Hymen	0	0	0	0	0	< 1	0	0	0
Odon	0	0	0	0	0	0	0	0	0
Pleco	0	0	0	0	0	0	0	8	0
Tricho	0	0	0	0	10	2	0	69	0
Nema	0	0	0	0	0	0	0	0	0
Terr	0	0	0	0	< 1	0	0	0	0
Fish	0	0	0	0	0	0	0	0	0
Veg	< 1	27	0	0	< 1	19	0	0	71
UnParts	40	18	45	0	27	15	0	86	88
detritus	9	18	39	0	7	20	50	5	100

Diversity indices were calculated for the number of orders of macroinvertebrates consumed by all species of fish captured during this study. The diversity of the diets for all species examined was relatively low using the Shannon index converted to Hill's numbers (Table 22). Channel catfish and red shiner had the most diverse diet of non-native species, consuming two orders of macroinvertebrates while speckled dace had the most diverse diet of the native fish, also consuming two orders macroinvertebrates. For both native and non-native species, the orders Dipteran and Ephemeroptera were important foods.

Table 22. Diversity of the observed diets of native and non-native species for 1994-1996 collections in the San Juan River.

Species	Status	Shannon index	Hill's Number of Abundant Species
CYPLUT	Non-native	0.729	2.07
CYPCAR	Non-native	0.305	1.30
PIMPRO	Non-native	0.128	1.13
RHIOSC	Native	0.712	2.03
CATDIS	Native	0.179	1.19
CATLAT	Native	0.581	1.79
ICTPUN	Non-native	0.754	2.13
FUNZEB	Non-native	0.414	1.5
GAMAFF	Non-native	0.443	1.55

Food Availability - Macroinvertebrates were sampled during August and October 1993 and March/April, July, August and October from 1994 to 1996.

During 1993, a total of 54 Surber and 42 Ekman dredge samples were collected in Reaches 1, 3, 4, and 5. Six orders of macroinvertebrates were collected by each method (Table 23). The mean total number of macroinvertebrates was low (163.2 per m^2) for August, and Ephemeroptera was the most common taxon sampled. During October sampling, Ephemeroptera and Diptera were approximately equal in numbers, but the overall macroinvertebrate density was extremely low (19.3 per m^2). Two orders present in August samples were absent in October (Plecoptera, Coleoptera).

A total of 107 macroinvertebrate collections, including 36 Surber samples, 21 Hess samples, and 50 Ekman dredge samples were collected during 1994. Eleven orders of macroinvertebrates were collected by all gear types (Table 24). Density was highest in spring sampling (3623.8 per m^2, 15 taxa) and declined to a low in October (130.5 per m^2, 11 taxa).

Table 23. Macroinvertebrate densities (number per m^2)for combined collections by Surber and Ekman samplers for 1993. Numbers are mean ± S.D. (range).

Taxa	August (n=68)	October (n=28)
Ephemeroptera	103.07±324.6(0-2023)	9.82±17.4(0-65)
Odonata	1.2±4(0-19)	0.38±2(0-11)
Plecoptera	0.72±4.8(0-38)	-
Trichoptera	8.27±21(0-134)	0.38±2(0-11)
Coleoptera	0.32±1.83(0-11)	-
Diptera	49.62±134.8(0-823)	8.67±15.1(0-54)
TOTAL	163.2	19.3

Chironomidae represented more than 95% of all invertebrates sampled in spring collections and continued to dominate remaining season samples, but at a lower level. Of the remaining taxa sampled, ephemeropterans (5 families) and trichopterans (1 family) were the most common. The Order Diptera was represented by the most diversity with 7 families and one unidentified taxon.

One hundred forty-one macroinvertebrate samples including 36 Surber samples, 42 Hess samples, and 63 Ekman dredge samples were collected in 1995. Twelve orders of benthic macroinvertebrates were collected by all gear types (Table 25). Spring samples resulted in collection of the fewest taxa (n=19) and lowest density (51.2 per m^2) of benthic macroinvertebrates. Thereafter, the macroinvertebrate community recovered and peak density (283.2 per m^2) and taxonomic diveristy (n=19) were recorded in July samples. Density declined to a low of 143.3 benthic macroinvertebrates per m^2 in October samples while the diversity of taxa sampled was identical to July. Generally, Diptera was the dominant order for all seasons sampled except July when 5 ephemeropteran families comprised 68.7% of macroinvertebrates sampled. The Order Trichoptera was represented by four families, unlike 1994 samples, when only the family Hydropsychidae was collected.

A total of 120 macroinvertebrate samples including 42 Surber samples, 42 Hess samples, and 36 Ekman dredge samples were collected in 1996. Thirteen orders of aquatic macroinvertebrates were collected by all gear types (Table 26). Spring density was the highest (7308 per m^2) for all seasons sampled during 1993-1996. Mean densities of macroinvertebrates were also relatively high in July (2212 per m^2) and August (1809 per m^2) samples when compared to other years. Number of taxa sampled was highest in July (n=23) and declined to a low diversity in October (n=12). The diversity of families representing the order Trichoptera increased from 1995 to five families with Hydropsychidae consistently the most common. Unlike all other sampling seasons for the study period, trichopterans numerically dominated July samples of macroinvertebrates (59.2%). For the remainder of the year, dipterans (primarily Chironomidae) were numerically dominant in samples.

Table 24. Macroinvertebrate densities (number per m^2) for combined collections by Surber, Ekman, and Hess samplers for 1994. Numbers are mean ± S.D. (range).

Taxa	March/April(n= 18)	July(n= 23)	August(n= 30)	October(n= 37)
Ephemeroptera				
Siphlonuridae	-	-	-	-
Baetidae	0.59± 2.5(0-11)	199.3± 484.6(0-1944)	0.4± 2.2(0-12)	7.8± 27.1(0-154)
Heptagentiidae	0.59± 2.5(0-11)	2.3± 7.4(0-34)	4± 15.2(0-79)	0.27± 1.7(0-10)
Tricorythidae	4.7± 9.2(0-9)	4.8± 10.7(0-35)	1± 10(0-53)	0.9± 3.7(0-21)
Leptophlebiidae	-	-	1± 3.9(0-18)	3.7± 17.9(0-107)
Ephemeridae	45.4± 74(0-290)	-	11.3± 33.5(0-161)	0.29± 1.7(0-11)
Odonata				
Gomphidae		0.83± 3.9(0-19)	1.3± 6(0-32)	-
Plecoptera				
Perlodidae	5.3± 13.4(0-53)	0.5± 1.9(0-7)	0.2± 1.1(0-6)	0.2± 1.7(0-10)
Hemiptera				
Naucoridae	-	-	0.04± 2.2(0-12)	-
Trichoptera				
Hydropsychidae	65.7± 113.2(0-387)	36.0± 102(0-458)	20.2± 53.4 (0-236)	6.7± 6.8(0-86)
Coleoptera				
Elmidae	0.59± 2.5(0-11)	-	-	-
Diptera				
Tipulidae	2.7± 6.5(0-19)	-	-	6.2± 12.2(0-51)
Ceratopogonidae	7± 18.5(0-77)	1.1± 4.2(0-19)	-	-
Simulidae	5.9± 20.2(0-86)	42.6± 96.4(0-305)	3.7± 19.6(0-107)	31.2± 123(0-645)
Chironomidae	3447.6± 3160 (409-12419)	260± 406.7 (0-1569)	15.4± 54.6(0-293)	6.2± 12.3(0-51)
Anthericidae	-	-	0.04± 2.2(0-12)	-
Empididae	1.9± 3.5(0-11)	-	-	-
Unkown	17± 63.2(0-267)	-	-	-
Hymenoptera				
Unknown	2.9± 8.1(0-32)	-	-	-
Annelida				
Oligochaeta	15.9± 20.2(0-32)	12.1± 28.5(0-114)	75.9± 278.3 (0-1498)	67± 209.9 (0-1088)
Amphipod		-		-
Hyallela	-		0.2± 1.1(0-6)	
Terrestrial	-	-	0.35± 1.9(0-11)	-
TOTAL	3623.8	559.3	135	130.5
No. Taxa	15	10	15	11

Table 25. Macroinvertebrate densities (number per m^2)for combined collections by Surber, Ekman, and Hess samplers for 1995.

Taxa	March/April(n= 36)	July(n= 36)	August(n= 36)	October(n= 33)
Ephemeroptera				
Siphlonuridae	-	-	-	0.3± 1.8(0-11)
Baetidae	-	42± 79.9(0-461)	13.1± 28.1(0-129)	6.6± 13.8(0-54)
Oligoneuridae	-	1.2± 4.4(0-22.5)	0.3± 1.8(0-11)	-
Heptagentiidae	0.6± 2.5(0-11)	25.3± 48.7(0-202)	13.1± 34.9(0-180)	10.3± 28.6(0-151)
Tricorythidae	-	9.1± 21.8(0-112)	10.9± 21.9(0-75)	1.3± 5.3(0-23)
Leptophlebiidae	-	117± 370.7(0-2135)	12± 37.4(0-215)	-
Ephemeridae	1.2± 4.3(0-21)	-	-	2± 6.2(0-32)
Odonata				
Gomphidae	-	-	0.5± 3.1(0-19)	1.2± 4.6(0-19)
Plecoptera				
Perlidae	-	0.6± 3.7(0-23)	-	-
Perlodidae	1.2± 3.5(0-11)	5.9± 14.6(0-67)	1.5± 6.3(0-32)	0.3± 1.8(0-11)
Chloroperlidae	-	2.5± 8.4(0-45)	0.3± 1.8(0-11)	1± 4.1(0-22)
Hemiptera				
Homoptera(suborder)			0.3± 1.8(0-11)	0.3± 1.8(0-11)
Naucoridae	-	-	-	-
Megaloptera				
Corydalidea	-	0.3± 1.8(0-11)		-
Trichoptera				
Hydropsychidae	8.1± 17.5(0-65)	19.9± 41.4(0-225)	93.6± 335.5(0-1883)	50.7± 159.8(0-797)
Hydroptilidae	-	-	-	0.3± 1.8(0-11)
Brachycentridae	-	0.3± 1.8(0-11)	-	-
Lepidostomatidae	-	1.6± 4.7(0-23)	-	-
Coleoptera				
Haplidae	-	0.3± 1.8(0-11)	-	-
Elmidae	-	0.6± 2.6(0-11)	-	-
Diptera				
Tipulidae	0.3± 1.9(0-11)	-	1.2± 4.2(0-22)	1± 3.1(0-11)
Ceratopogonidae	0.6± 2.6(0-11)	-	0.5± 3.1(0-19)	1.7± 7.2(0-38)
Simulidae	-	35.4± 88.3(0-112)	0.3± 1.8(0-11)	-
Chironomidae	24.1± 49.3(0-215)	16.4± 26.9(0-112)	32.2± 69.3(0-280)	61.3± 119.2(0-463)
Dolichopodidae	-	-	0.9± 3.9(0-22)	-
Anthericidae	-	-	0.3± 1.8(0-11)	0.7± 2.6(0-11)
Empididae	-	-	-	-
Unkown	0.5± 3.2(0-19)	-	-	-
Hymenoptera				
Unknown	0.3± 1.9(0-11)	0.6± 2.5(0-11)	-	0.3± 1.8(0-11)
Annelida				
Oligochaeta	14.3± 32.3(0-134)	2.6± 7.2(0-38)	3.7± 11.8(0-57)	1.7± 7.2(0-38)
Amphipod				
Hyallela	-	-	-	-
Gammarid	-	-	0.3± 1.8(0-11)	-
Nematoda	-	1.6± 5.4(0-23)	-	1.7± 5.5(0-19)
Terrestrial	-	-	-	0.6± 3.3(0-19)
TOTAL	51.2	283.2	185	143.3
No. Taxa	10	19	18	19

Table 26. Macroinvertebrate densities (number per meter^2) for combined collections by Surber, Ekman, and Hess samplers for 1996. Numbers are mean ± S.D. (range).

Taxa	March/April(n= 36)	July(n= 27)	August(n= 26)	October(n= 28)
Ephemeroptera				
Baetidae	0.4± 2(0-11)	78.3± 131.2(0-473)	17.7± 26.9(0-90)	0.8± 2.8(0-11)
Oligoneuridae	-	0.4± 2(0-11)	-	-
Heptageniidae	11± 24(0-101)	16.2± 26.2(0-101)	5± 18.9(0-97)	1.2± 3.3(0-11)
Tricorythidae	33± 60.5(0-236)	135.1± 208.7± (0-990)	15.3± 76.6(0-398)	-
Leptophlebiidae	-		21.2± 56(0-269)	0.4± 2(0-11)
Ephemeridae	-	87.7± 165.6± (0-657)	-	-
Odonata				
Gomphidae	0.4± 2(0-11)	-	2.6± 6.3(0-20)	-
Cordulidae	-	-	3.7± 15(0-77)	-
Calopterygidae	-	-	0.8± 2.9(0-11)	-
Plecoptera				
Perlodidae	55.6± 117.8(0-495)	1.2± 4.5(0-22)	0.4± 2.1(0-11)	-
Hemiptera				
Corixidae	-	2.1± 10.8(0-57)	9.6± 34.1(0-172)	0.4± 2.1(0-11)
Homoptera(suborder)	-	-		
Naucoridae		0.4± 2(0-10)	2.1± 8.5(0-43)	-
Megaloptera				
Corydalidea	-	-	0.4± 2.2(0-11)	-
Trichoptera				
Hydropsychidae	536.7± 1183.4(0-5705)	1221.7± 281 (0-12260)	378.2± 938.4 (0-4294)	4.2± 6.7(0-22) -
Hydroptilidae			2.1± 10.3(0-54)	-
Brachycentridae	0.4± 1.9(0-11)	86.5± 173.4(0-743)	-	-
Helicopsychidae	-	0.4± 2(0-11)	-	-
Lepidostomatidae	0.4± 1.9(0-11)	0.4± 2(0-11)	-	-
Taliridae	-	0.8± 2.8(0-11)	0.8± 2.9(0-11)	-
Lepidoptera				
Pryalidae	1.8± 5(0-22)	1.2± 4.5(0-22)	2.1± 5.2(0-22)	-
Noctuidae	0.6± (0-19)	-		0.4± 2(0-11)
Coleoptera				
Elmidae	3.3± 8.4(0-43)	4.8± 10.7(0-32)	3.7± 16.6(0-86)	0.4± 2(0-11)
Diptera				
Tipulidae	0.7± 2.7(0-11)	-	0.4± 2.1(0-11)	-
Ceratopogonidae	7.3± 10.6(0-38)	41.5± 102(0-402)	178.4± 476(0-2296)	37.1± 77.5(0-270)
Simulidae	8.7± 19.2(0-75)	106.6± 446(0-2368)	424.3± 1499.5 (0-7707)	14.6± 39.9(0-183)
Chironomidae	5009.9± 6569.6 (0-28094)	369.8± 702.6(0-2679)	738.5± 1157.8 (0-4876)	38.8± 60.4(0-258)
Anthericidae	1.1± 3.2(0-11)	-	-	-
Empididae	30.4± 47.4(0-204)	-	0.8± 2.9(0-11)	-
Unkown				1.6± 6.5(0-33)
Hymenoptera				
Unknown	0.4± 1.9(0-11)	0.4± 2(0-11)	-	
Annelida				
Oligochaeta	1604.3± 242(0-9816)	51.9± 116(0-459)	-	13.9± 31.9(0-151)
Amphipod				
Gammarid	-	0.4± 2(0-11)	-	-
Nematoda	10.1± 24.8(0-112)	-	-	-
Terrestrial	-	3.2± 9.2(0-43)	-	-
TOTAL	7308	2212	1809	118
No. Taxa	20	23	21	12

The pattern of seasonal density of macroinvertebrates was of a consistent decline from spring to autumn sampling, with the exception of Spring 1995 (Figure 27). It is likely that the relatively high frequency of late summer rainstorm events that result in short-term flooding in the San Juan River, when compared with the rest of the Colorado River basin (Bliesner 1999), reduce macroinvertebrate numbers from spring to autumn. In 1995, a storm event within the Basin produced a short-term flood event that peaked near 170 $m^{3 - sec}$ (6000 cfs) at the Four Corners Streamflow Gage (Bliesner and Lamarra 1999). The substrate scour produced by that flow event, when compared to higher densities of macroinvertebrates in 1994 and 1996, apparently reduced macroinvertebrate numbers. By July 1995, macroinvertebrate densities had increased to near July 1994 conditions. The greatest density of macroinvertebrates was observed during spring 1996 sampling (Table 26, Figure 27), a year where the peak spring discharge, measured at the Four Corners Streamflow Gage, was less than 113 $m^{3 - sec}$ (4000 cfs) (Bliesner and Lamarra 1999). The absence of high spring flows in 1996 resulted in macroinvertebrate density estimates greater than all other years sampled for April, July and August. October 1996 macroinvertebrate densities were similar to other years' density estimates. Thus, regardless of the shape of the annual hydrograph for 1993-1996, autumn macroinvertebrate density estimates were similar.

Comparison of between-year differences in macroinvertebrate density estimates by Mann-Whitney U-Test indicated no significant difference between 1994 and 1995 ($P=0.372$). Density estimates for 1996 were significantly greater ($P> 0.90$) than in 1994 ($P=0.093$) and in 1995 ($P=0.021$). The differences in macroinvertebrate density estimates between main and side channel habitats for all years were not statistically significant (1994, $P=0.686$; 1995, $P=0.686$; 1996, $P=0.486$).

The diversity of macroinvertebrates sampled during 1994-1996 did not vary significantly between years (Kruskal-Wallis test, $P=0.514$). Differences in macroinvertebrate diversity between main and side channel habitats were not statistically significant for all years sampled (1994, $P=0.886$; 1995, $P=0.343$; 1996, $P=0.343$). The diversity of abundant taxa sampled (Hill's diversity index) was similar between main and side channel habitats for all years (Figure 28). Hill's values generally remained static from spring to autumn sampling except for the increasing trend noted in 1994, when the hydrograph included a relatively short duration spring hydrograph and minimal summer storm runoff event activity (Bliesner and Lamarra 1995).

Discussion

Predation on (Meffee 1985, Tyus and Nikirk 1990, Marsh and Douglas 1997) and competition with (reviewed by Douglas et al. 1994) native fishes have contributed to the decline of western North American fishes, particularly those species native to the Colorado River Basin. Nearly all introduced species in the San Juan River that pose threats to native fishes are from more speciose environments where evolutionary adaptations resulted in inherent abilities to survive interactions such as higher predator diversity (Johnson et al. 1993). Even the piscivorous Colorado pikeminnow may be negatively impacted by the

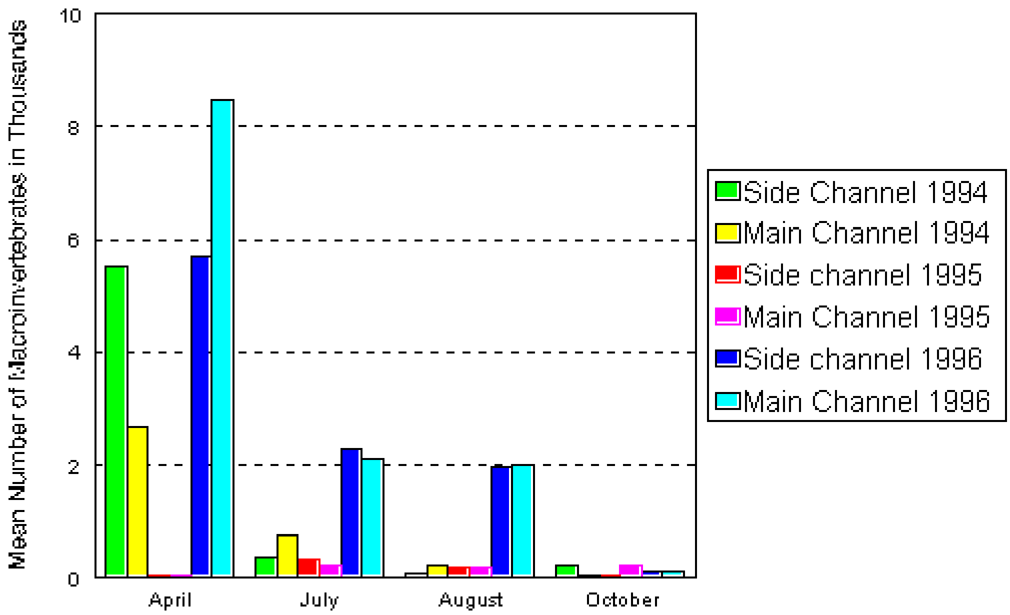


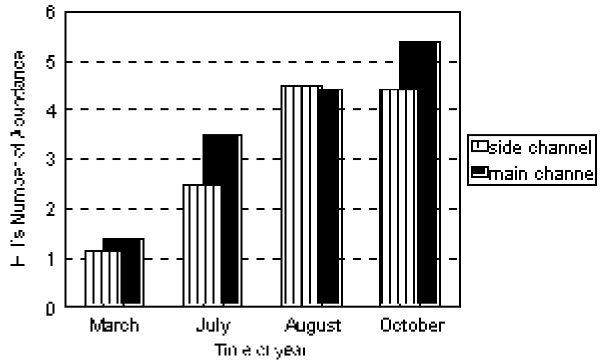
Figure 27. Macroinvertebrate density in main and side channel habitats for sampling during 1994 through 1996.

consumption of some non-native species that pose risks, such as the pectoral spines of young channel catfish (McAda 1985, Pimental et al. 1985).

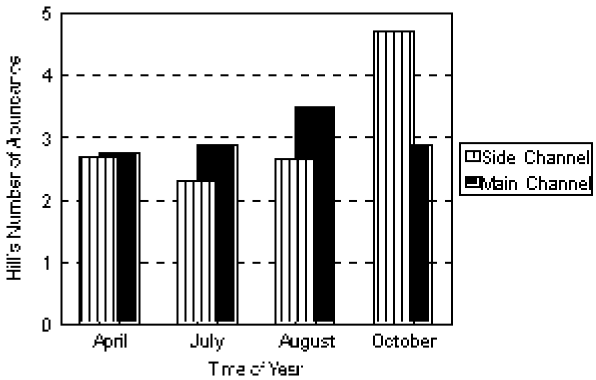
Piscivory by non-native channel catfish was only documented for large adults >450 mm TL. However, the low level of piscivory, if combined with the known distribution and estimated abundance of channel catfish reported in Chapter I, may limit the recruitment and survival of native species. Marsh and Douglas (1997) estimated that in spite of the low level of piscivory noted for abundant non-native species in the Little Colorado River , the rate of predation posed a serious threat to the resident humpback chub *Gila cypha* population. Adult channel catfish will prey upon a variety of fish species (Carothers and Minckley 1981, Tyus and Nikirk 1990) and have the potential to impact all native species, not just those that are rare. In at least one situation, intense predation by channel and flathead catfish was documented to have caused the failure of efforts to re-establish razorback sucker in the Gila River Basin of Arizona (Marsh and Brooks 1989).

Concern about piscivory on native fishes is not limited to channel catfish. Non-native lacustrine species, primarily from Lake Powell, may pose a serious threat to native species in the lower portion of the San Juan River. Both striped bass and walleye are highly piscivorous (Minckley 1973, Jones et al. 1994) and enter the lower San Juan River periodically. Prior to 1995, a waterfall barrier existed downstream of Clay Hills and prevented the upstream movement of fishes out of Lake Powell. After inundation of the waterfall in spring 1995, both striped bass and walleye became frequent in lower San Juan River fish collections. Striped bass moved further upstream than did walleye, and were

1994



1995



1996

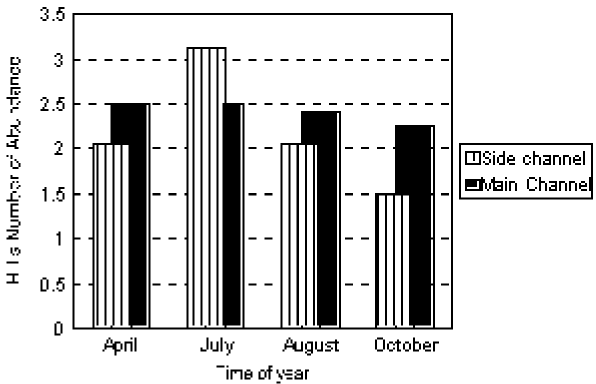


Figure 28. Overall macroinvertebrate diversity in main and side channel samples taken seasonally, 1994-1996.

frequently caught by anglers fishing the San Juan River between the Four Corners area and the Hogback Diversion, New Mexico (Bob Culp, New Mexico Department of Game and Fish, personal communication). Stomach content analysis of striped bass and walleye from Autumn 1995 through Autumn 1996 illustrated the piscivorous nature of both species. It is likely that both non-native predators enter the San Juan River during spring high-flow conditions for the purposes of undertaking spawning runs and following the preferred food fish, threadfin shad (Minckley 1973, Ryden 1999). While threadfin shad were relatively uncommon, native catostomids were not and comprised a large percentage of the fishes ingested by striped bass and, to a lesser extent, by walleye. The exposure of the native fish community to predation pressure exerted by lacustrine non-native species should be considered an additional threat to that imposed by non-native species resident to the riverine environment.

Non-native piscivory on larval or other early lifestages of native fishes was not documented during this study. However, these study efforts were not designed to assess predation impacts on early life stages of native fishes. Food habits data for all non-native species examined indicated that a diversity of foods was consumed. Marsh and Langhorst (1988) observed predation on larval razorback suckers by green sunfish and discussed the difficulties in the detection of such predation due to the fragility of larval forms. Predation on larval native fishes by red shiner in the upper Colorado River was documented in areas where endangered Colorado pikeminnow and razorback sucker occurred (Ruppert et al. 1993). Brandenburg and Gido (1999) documented predation by non-native fishes (red shiner, largemouth bass, black bullhead) on native larval fishes (speckled dace, flannelmouth and bluehead suckers), but the rate of predation was lower than that reported by Rupper et al. (1993). The current rarity of the endangered fishes in the San Juan River does not lend itself to documentation of predation by non-native species, but may with attainment of increased abundance and distribution through recovery efforts. The widespread distribution and abundance of red shiner in the San Juan River and documented piscivorous food habits elsewhere give evidence of additional predation pressure on native fishes not restricted to large-bodied non-native forms.

Food habits of non-native fishes, primarily younger age classes of channel catfish, indicated that a variety of food items, primarily aquatic invertebrates were consumed. Similar food habits have been reported elsewhere in the Colorado River Basin (Carothers and Minckley 1981, Minckley 1982, Tyus and Nikirk 1990) and in other river basins (Larson and Propst 1999). Other non-native species, notably red shiner, common carp, and fathead minnows also consumed a variety of foods and all consumed primarily aquatic macroinvertebrates (dipteran larvae). Native speckled dace and flannelmouth and bluehead suckers consumed similar foods to non-natives and, like non-natives fed primarily upon the most abundant aquatic macroinvertebrates. We did not observe food resource partitioning for most species in this study, likely due to the relatively low diversity and abundance of the aquatic macroinvertebrate community in the San Juan River and our inability to identify gut contents to the lowest taxonomic level.

Deacon and Minckley (1974) characterized most native fishes of the Southwestern United States as opportunistic, with specific foods consumed based largely upon abundance or availability. Further, it was considered that partitioning of niches in functioning large

rivers where species diversity was typically higher was more easily attained. With the alteration of the San Juan River channel morphology due to a variety of factors (Bliesner 1999), dependent biotic communities were likely forced to abandon some niche partitioning in order to adapt to changing conditions. In the case of native fishes in the San Juan River, the introduction of non-native fishes that feed upon the same foods exacerbated responses to changing environmental conditions. In general, the introduction of non-native fishes into a stream fish assemblage after habitat degradation results in the decline of the native species (Ross 1991). In the San Juan River, the regulation of flows ameliorated extreme environmental conditions under which native species evolved. The loss of extremes removed environmental conditions that may not have allowed non-native species to become established and more uniform flow conditions allowed non-native species to successfully compete for available resources. As discussed by Douglas et al. (1994), the removal of extremes under which the depauperate and endemic fauna evolved would allow for either of two processes to eliminate or reduce native species: displacement or replacement.

Food Availability - The benthic macroinvertebrate community in the San Juan River downstream of Navajo Dam represents a transition from low diversity and high abundance in the tailwaters immediately downstream of Navajo Dam (Dubey and Jacobi 1996, Holden et al. 1980) to a community of high diversity and low abundance in downstream reaches below Shiprock, New Mexico (Sublette 1977, Holden et al. 1980, this study). The distribution, adundance and diversity of benthic macroinvertebrates are important issues regarding food availability and use for resident San Juan River fishes. Identification of the temporal and spatial variations in the macroinvertebrate community and their effects on food availability for fishes is an important consideration in the identification of flows for recovery of the native fish community. Given that non-native fishes are syntonic in all reaches of the San Juan River and consume similar food items as do non-natives, the availability (=abundance) of macroinvertebrates as food may serve as a limitation or a benefit to native species.

In the San Juan River, the density and diversity of benthic macroinvertebrates are lower than reported elsewhere in the Colorado River basin (Holden and Crist 1981, Rader and Ward 1988) and in other lotic waters (Ward 1974, Munn and Brusven 1991). The seasonal decline from spring to fall of macroinvertebrate abundance is also different than reported elsewhere in the Colorado River basin (Holden and Crist 1981) and is likely related to the hydrology on the San Juan River.

Bliesner (1999) reported that both the suspended sediment concentration and magnitude and frequency of summer and autumn rainstorm events were significantly higher in the San Juan River than in either the upper Colorado or Green rivers. The low density of macroinvertebrates observed in autumn samples in San Juan River collections during 1993-1996 are likely due to the high frequency of late summer flooding caused by rainstorms. Hynes (1970) and Ward (1992) reviewed the deleterious impacts of catastrophic floods to invertebrate communities and Meffee and Minckley (1987) measured the reduction of densities after floods and subsequent increases during recovery periods. This is likely similar to the San Juan River where the cessation of late summer and autumn rainstorm events, followed by relatively quiescent winter flows, allows the

macroinvertebrate community to recover to higher densities observed in spring samples. The life history patterns, including time of emergence, for San Juan River macroinvertebrates have evolved to avoid unfavorable physical conditions, such as the high magnitude and frequency of late summer rainstorm events. It may be that the macroinvertebrates sampled in the San Juan River represent taxa that oviposit in spring/early summer and have a relatively short incubation and hatching period (Anderson and Wallace 1984); both requisites to avoid late summer and autumn flooding impacts.

While the impacts of late summer and autumn rainstorm events likely reduces macroinvertebrate numbers, a high degree of physical variability is important in order maintain high diversity and the resulting biological stability of the system. A widely fluctuating physical system is much more likely to encompass the optimum habitat conditions for a larger number of species (Vannote et al. 1980). In a naturally functioning river system, the total continuous absence of a species or population is rare since there is a process of continuous species replacement based upon a temporal sequence in life histories (Hynes 1970, Vannote et al. 1980, Anderson and Wallace 1984, Ward 1992). This can be complicated in regulated river reaches where species loss or rarity is an artifact of dam construction (Ward 1974,1976, Rader and Ward 1988, Munn and Brusven 1991). Unregulated inflowing tributaries, such as the Animas River, are important in ameliorating the negative impacts of dam regulation to macroinvertebrate communities (Rader and Ward 1988, Munn and Brusven 1991). In the San Juan River, Holden et al. (1980) measured increased species diversity downstream of the Animas River confluence.

Any flow regime that is regulated or altered reduces habitat variability and detrimentally affects the macroinvertebrate community diversity (Ward 1976, 1992, Vannote et al. 1980). In the San Juan River, macroinvertebrate densities and community diversity are relatively low and further regulation of the system, i.e. reduction in flow variability in the Animas River, may further exacerbate low densities caused by late summer and autumn rainstorm events. Maximizing habitat conditions to allow for biologically stable macroinvertebrate communities in the San Juan River will allow for increased food availability to resident fishes and may assist in minimizing deleterious interactions between native and non-native fish species.

<u>Conclusions</u>

- Predation by non-native species (channel catfish, striped bass, walleye) upon native fishes (speckled dace, flannelmouth and bluehead suckers) was documented.
- Piscivory by channel catfish occurred primarily in individuals >450 mm TL for all size classes was at a low level (13.7%) and when combined with estimated abundance of channel fish (Chapter I) may be considered a significant impact to the native fish community.
- Striped bass and walleye were not abundant but were exclusively piscivorous and consumed primarily native catostomids.
- Predation on Colorado pikeminnow and razorback sucker was not observed.
- Small-bodied native and non-native species and young of year and juvenile large-bodied non-native fishes all consumed similar foods during all seasons sampled.

- Benthic macroinvertebrates were consumed by native and non-native fishes in relative proportion to temporal patterns of availability.
- The relative abundance of benthic macroinvertebrates in the San Juan River was low when compared to other streams of the Colorado River Basin.
- The frequency and magnitude of late summer rainstorm events that frequently cause short-duration flood events reduce the abundance of macroinvertebrates and may limit food resources for fishes in the San Juan River.
- The benefit of mimicry of the natural hydrograph to food resource use by native species was not demonstrated.
- Based upon previous studies of San Juan River macroinvertebrates and longitudinal patterns in macroinvertebrate communities in other altered river systems, maintenance of natural flows in the Animas River are important to maximize the diversity of abundance of food items for resident fishes.

CHAPTER IV

Mechanical removal of non-native fishes from the San Juan River, 1995-1997

Introduction

The control of non-native species to accomplish reduction in distribution and abundance is a primary concern to be addressed as part of recovery programs for rare native fishes. In the San Juan River, the widely distributed and abundant channel catfish poses a major obstacle to recovery of the Colorado pikeminnow and razorback sucker. While other large-bodied non-native species occur within the San Juan River, the channel catfish occupies essentially all available habitat types on a year-round basis, larger individuals prey upon native fishes, and overlap with resident native fishes in other resource uses is high. Recreational angling in the San Juan River downstream of Farmington, New Mexico appears low based upon personal observations of the authors, other San Juan River researchers, and regional New Mexico Department of Game and Fish. However, no data regarding angler use were available to quantify use and exploitation of the San Juan River channel catfish population by anglers.

The apparent absence of substantial angler exploitation of the channel catfish population, combined with the prevalence of common carp and periodic invasion of warmwater lacustrine species upstream from Lake Powell were the focus of efforts in this study segment to evaluate suppression of non-native fishes by mechanical removal. All non-native fishes were the target of removal efforts, however, channel catfish were emphasized due to the species' magnitude of potential negative impacts to native fishes and due to the potential use of removed channel catfish in recreational angling programs isolated from the San Juan River. We report upon the results of mechanical removal efforts (primarily by electrofishing) for all non-native fishes. The relationship of removal to changes in population dynamics of channel catfish is presented and discussed in detail.

The study objectives were to:

1. Evaluate the efficacy of passive (netting) and active (electrofishing) mechanical methods for removal of large-bodied non-native fishes.
2. Characterize changes in the abundance and distribution patterns of channel catfish as a response to mechanical removal efforts.
3. Determine changes in the biomass of channel catfish in discrete study reaches as a response to mechanical removal efforts.
4. Assess the feasibility of a transplantation program to remove channel catfish from the San Juan River and relocate them to isolated impoundments currently used for recreational fisheries.
5. Compare the costs of transplanting channel catfish to those incurred by captive propagation and stocking.

Study Area

The entire San Juan River, including accessible secondary channels, from Farmington, New Mexico downstream to Clay Hill's Crossing, Utah was sampled for this study segment. Removal efforts were concentrated from the PNM powerplant weir near Fruitland, New Mexico downstream Mexican Hat, Utah. Initial removal efforts in 1995 evaluated the use of

hoop nets in seven contiguous reaches, RM 142-121. In spring 1996, removal efforts were initiated for river-wide sampling activities.

Methods

Evaluation of the efficacy of mechanically removing channel catfish from selected reaches of the San Juan River was initiated in 1995. The study area consisted of seven contiguous 4.8 km (3 mi) test reaches from the Cudei Diversion (RM 142.0) downstream to approximately 2.5 km (RM 121.0) upstream of the Four Corners bridge. In the uppermost test reach, all captured channel catfish were weighed (g), measured (TL and SL mm), tagged with a Floy tag (only specimens >200 mm TL), and released. This procedure of weighing, measuring, tagging, and releasing was followed in every other test reach (four reaches total). In the three intervening reaches, all channel catfish captured were weighed (g), measured (TL mm), and removed from the river.

Three principal methods of capture were used: raft-mounted electrofishing, hoop netting, and trot lining. Electrofishing efforts were primarily incorporated into the regularly scheduled adult monitoring trips. Two additional electrofishing efforts in 1995 were conducted, one in April, and one during a hoop net sampling trip in July. Two separate sampling trips in 1995 using baited and unbaited hoop nets (10 m long x 1 m aperture, no wings) were conducted in July (descending limb of spring hydrograph) and September (late summer monsoonal season). In addition, hook-and-line sampling was used during the July 1995 hoop net trip and trotlining was employed during September 1995 hoop netting efforts.

Baited hoop nets were set parallel to the shoreline in a variety of habitat types for 24 to 36-hour periods and checked at roughly 6, 12, and 24-hour intervals. Approximately 6 hoop nets were set within each 4.8 km test reach. Several types and combinations of bait were used including beef liver, beef kidney, cheese, dogfood, and ivory soap. Beef liver was also used as bait for the trotline and hook-and-line sampling. Trotlines (18 hooks each) were set in a variety of habitat types at varying angles from the shoreline including perpendicular and parallel sets. Approximately 3 trotlines were set within each 4.8 km test reach for 24-hour periods and checked every 4 to 12 hours.

Mechanical removal using hoop nets and trotlines within the seven contiguous test reaches was discontinued after September 1995. In April 1996, mechanical removal efforts were expanded to include removal of all non-native fishes collected during routine adult monitoring sampling by electrofishing downstream of the diversion at the Hogback Diversion, New Mexico and further expanded river-wide in 1997.

Data are presented for numbers and total weight of each non-native species for all removal methods employed. Additional data analyses were conducted to assess the response of the channel catfish population to removal efforts. Electrofishing data were not normally distributed, owing to variable field conditions caused by the differences in flows, type of

electrofishing raft (three different boats used), personnel (experience, competency), and habitat differences between geomorphic reaches that affected fish distribution patterns. Ryden (1999) discussed these sampling aspects in more detail. The non-parametric Mann-Whitney U-Test was used to evaluate differences between years and reaches for both CPUE and mean total length data and P-values less than 0.05 were considered significant.

We used data for all river miles sampled, including those from non-designated river miles where channel catfish were only enumerated prior to 1994. After 1994, channel catfish were enumerated and classified according to life stage: young-of-year, <60 mm TL; sub-adult, 60-300 mm TL; adult, >300 mm TL. We used trend data to detect changes in CPUE for all reaches for 1991-1997. For 1994-1997, data were analyzed by geomorphic reach, by year, and by size class to detect statistically significant changes in CPUE as a response to mechanical removal efforts.

We analyzed total length data for geomorphic reaches for 1991-1997 to determine changes in mean total length as a response to mechanical removal of channel catfish. Length frequency distribution and relative skewness of data were determined for each year for the combined sample of all channel catfish measured. Mean total length frequency was determined for each reach by year except for Reach 1, due to low sample sizes. Significance of annual changes in mean total length for each reach were analyzed by Mann-Whitney U-Test and characterized as one of three responses: decrease, similar, increase. The biomass (kg) of channel catfish collected during all electrofishing efforts was estimated for each reach from the average weight of all individuals weighed at designated river miles and multiplied by the total number of channel catfish collected within each reach. This weight was then converted from grams to kilograms, which was used for all analysis. We used simple linear regression analysis with reach and year as the independent variables and estimated biomass as the dependent variable. Observations were considered significant if the R-squared value exceeded 0.95.

Results

A total of 335 channel catfish (163 Floy tagged; 158 removed), 303 common carp (240 Floy tagged), and 11 black bullhead (7 Floy tagged; 2 removed) were collected during sampling efforts designed to specifically address mechanical removal in 1995. Twenty-five channel catfish and 11 common carp were collected during 1,967 hours of hoop net sampling, 235 channel catfish and 292 common carp were collected during 35.2 hours of electrofishing, 65 channel catfish were collected during 306 hours of trotlining, and 10 channel catfish were collected during 10 angler-hours of hook-and-line sampling. An additional 423 channel catfish (222 Floy tagged; 180 removed) and 376 common carp (269 Floy tagged) were collected during routine adult monitoring sampling (within the seven test reaches). Due to inconsistent collecting success within the seven test reaches and the small number of channel catfish sampled, primarily due to poor success of netting efforts, discrete test reach analyses

could not be conducted and these data were grouped with those reported below for Reaches 1-6.

During main channel electrofishing surveys, a total of 22,985 non-native fish were collected and removed from the San Juan River 1995-1997. In 1995, 522 channel catfish, 75 common carp, four walleye, and two black bullhead were removed: total biomass for channel catfish was 289 kg and 72 kg for common carp. In 1996, 6,319 channel catfish (2610 kg), 5,084 common carp (6319 kg), 33 walleye (51 kg), 20 largemouth bass (0.4 kg), 17 striped bass (32 kg), 17 green sunfish (0.3 kg), and 11 black bullhead (0.6 kg) were removed. In 1997, 5,819 channel catfish (2240 kg), 4,857 common carp (6042 kg), 9 walleye (3 kg), 2 largemouth bass (4.4 kg), 6 green sunfish (0.1 kg), and 11 black bullhead (0.7 kg) were removed.

Although hoop net sampling has been shown to be an effective means of selectively capturing channel catfish in the Mississippi drainage (Dames et al., 1989), it was not an effective technique for capturing channel catfish (.01 fish/hr) in the San Juan River. The relative abundance of fish collected during hoop net sampling showed a predominance of native flannelmouth sucker in the collections (Figure 29). Catch rate data by gear type showed electrofishing to be the most effective technique for capturing channel catfish (Figure 29).

Changes in CPUE for Channel Catfish

Results of analyses of channel catfish population dynamics for 1991-1997 are presented by reach. Reach 1 was sampled relatively few times during the seven year study period and was not included in analyses of within and between year differences. Reach 1 CPUE was included for the summary analysis of CPUE for 1991-1997 combined.

Reach 6 - CPUE for channel catfish decreased each year between 1991 and 1993 (Figure 30) and remained similar from 1993 to 1994. Thereafter, CPUE was variable between 1995 and 1997. There was a slight decrease in CPUE between 1996 and 1997, but the decrease was not significant (Table 27). Reach 6 had the second highest overall CPUE for1991-1997.

Reach 6 CPUE was similar to other reaches within years, but varied widely. In 1994, 1995, and 1997, Reach 6 CPUE was similar to Reaches 5 and 4 (Figure 30). There was a significant decrease in catch rates between 1991-1992 and 1992-1993 (Table 27). CPUE was similar from 1993 to1994. CPUE of channel catfish 60-300 mm and >300 mm increased significantly between 1994 and 1995 (Figure 31). CPUE for all size classes were similar from 1995 to 1997. For 1996 to 1997, there was a slight decrease in CPUE for channel catfish >300 mm, a slight increase in the CPUE of channel catfish 60-300 mm, and the overall CPUE declined; none of the changes were significant (Table 27).

Reach 5 - CPUE fluctuated widely between years. Reach 5 had the highest CPUE in 1993 for all reaches, a year with an overall low CPUE (Figure 30). In 1994, there was a marked decrease in CPUE in this reach. CPUE remained low into 1995, but increased again starting in 1996. The overall CPUE of Reach 5 remained most similar to Reaches 2 and 6.

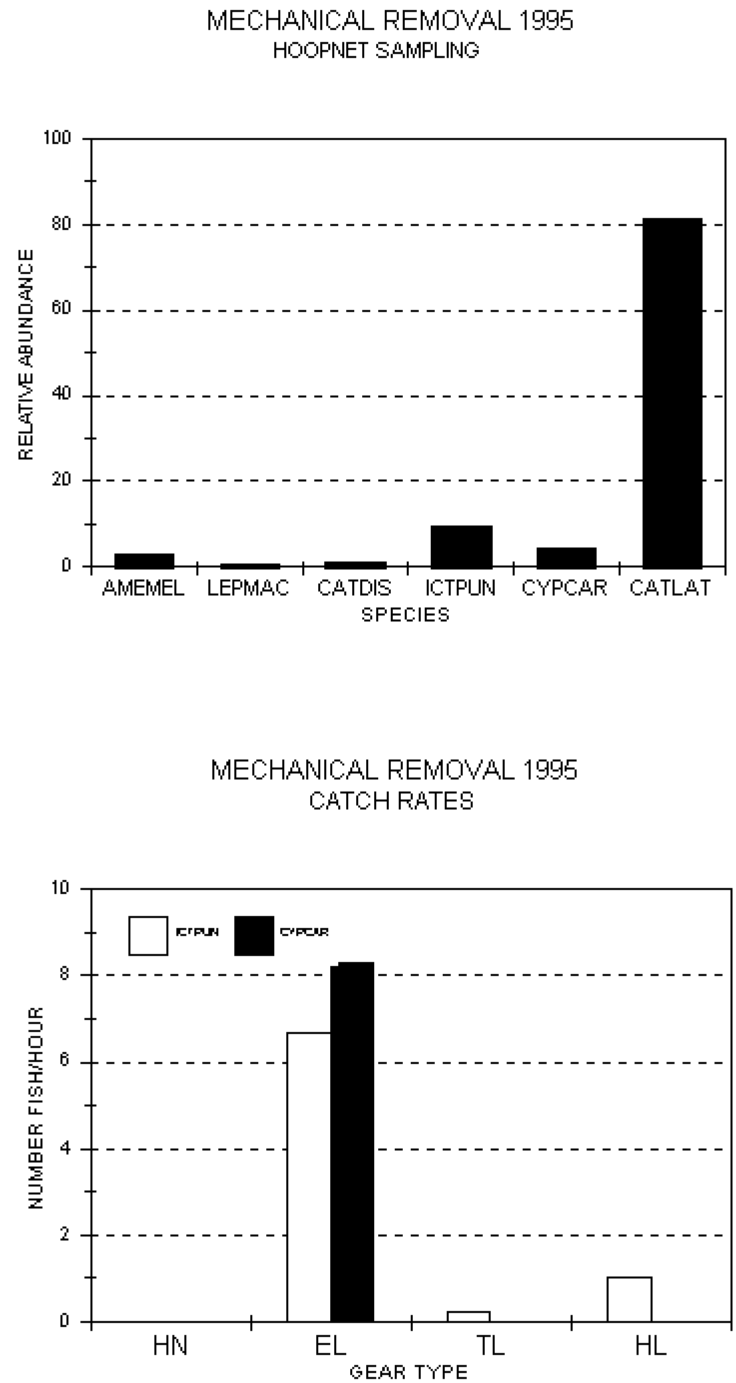


Figure 29. Relative abundance by species of fish collected using hoop nets (top) and catch per unit effort (number of channel catfish/hour) by gear type (bottom), 1995. HN = hoop net, EL = electrofishing, TL = trotline, HL = hook-and-line.

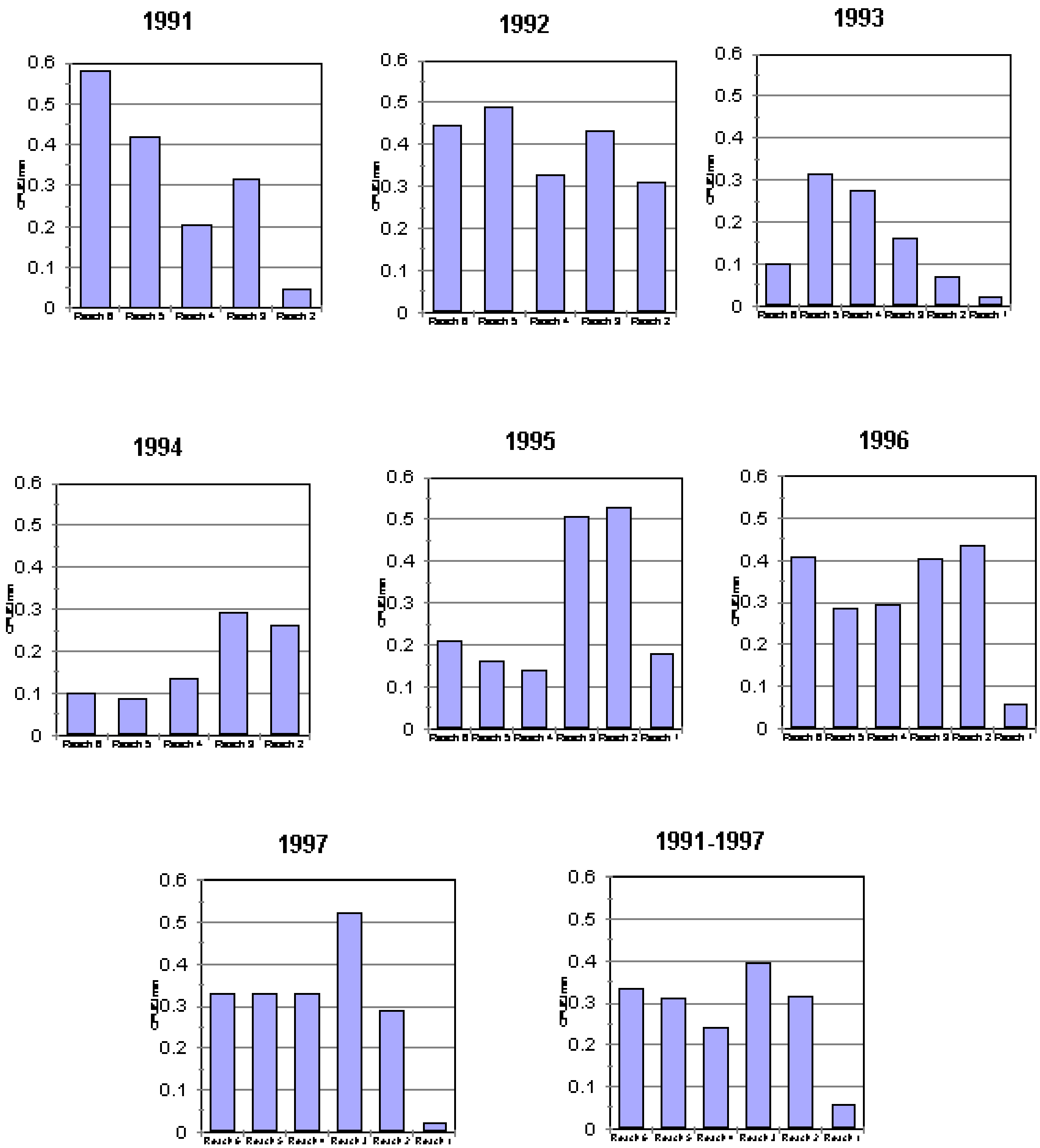


Figure 30. CPUE for channel catfish collected by main channel electrofishing in the San Juan River. Data are presented by geomorphic reach for each year and for all years combined.

Table 27. Differences in catch rates of channel catfish between years by size class for geomorphic Reach 6 determined by the Mann-Whitney U-Test.

Reach 6 Years	<60 mm	Class response between years	60-300 mm	Class response between years	>300 mm	Class response between years	Total catch	Class response between years
1991-1992	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	decrease
1992-1993	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	decrease
1993-1994	N/A	N/A	N/A	N/A	N/A	N/A	p<0.82	similar
1994-1995	p=0.25	similar	p<0.05	increase	p<0.05	increase	p<0.05	increase
1995-1996	p=0.08	similar	p=0.69	similar	p=0.07	similar	p=0.14	similar
1996-1997	p=0.99	similar	p=0.07	similar	p=0.37	similar	p=0.87	similar

CPUE remained similar for 1991-1992 and 1992-1993, but decreased significantly between 1993-1994 (Table 28). The CPUE for channel catfish 60-300 mm and >300mm increased each year from 1994 to 1996 (Figure 31). There was a significant increase in CPUE for all size classes of catfish from 1994 through 1997 (Table 28). There was significant increase in CPUE of channel catfish 60-300 mm between 1996 and 1997, but CPUE for <60 mm and >300 mm remained similar.

Table 28. Differences in catch rates of channel catfish between years by size class for geomorphic Reach 5 determined by the Mann-Whitney U-Test.

Reach 5 Years	< 60 mm	Class response betw een years	60-300 mm	Class response betw een years	> 300 mm	Class response betw een years	Total catch	Class response betw een years
1991-1992	N/A	N/A	N/A	N/A	N/A	N/A	p= 0.88	similar
1992-1993	N/A	N/A	N/A	N/A	N/A	N/A	p= 0.52	similar
1993-1994	N/A	N/A	N/A	N/A	N/A	N/A	p< 0.05	decrease
1994-1995	p< 0.05	decrease	p< 0.05	increase	p< 0.05	increase	p< 0.05	increase
1995-1996	p< 0.05	increase	p< 0.05	increase	p< 0.05	increase	p< 0.05	increase
1996-1997	p= 0.26	similar	p< 0.05	increase	p= 0.08	similar	p< 0.05	increase

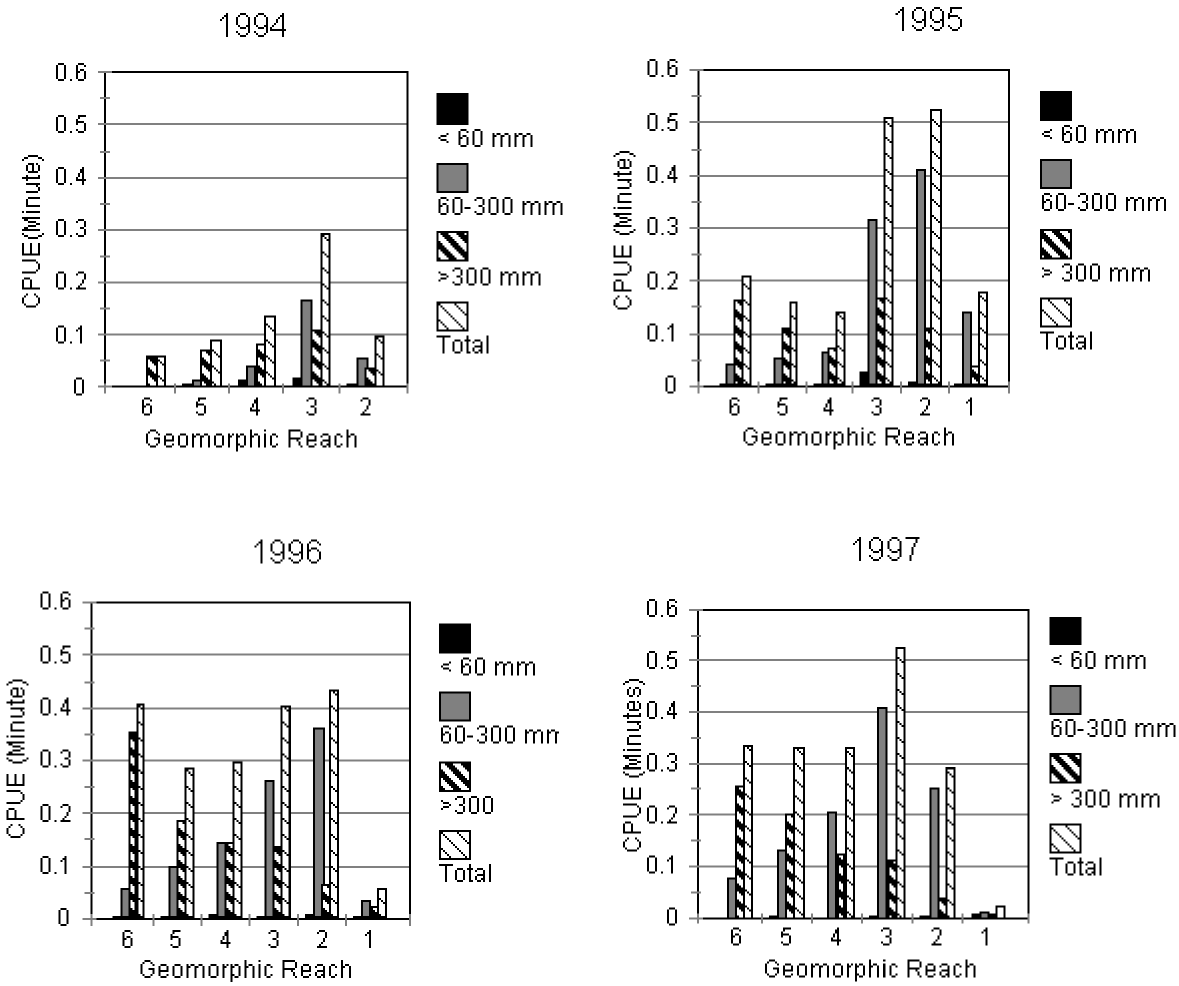


Figure 31. CPUE for individual size classes of channel catfish collected by main channel electrofishing in the San Juan River, 1994-1997. Data are presented by geomorphic reach.

Reach 4 - CPUE in Reach 4 was variable from 1991 to 1995 (Figure 30). In 1996, the CPUE increased sharply and then remained relatively unchanged through 1997. Reach 4 had the second lowest CPUE of all years combined.

CPUE increased significantly from 1991 to1992. For 1992-1993 CPUE did not change, but decreased significantly between 1993 and 1994 (Table 29). CPUE for all size classes changed little until a slight increase was measured in 1996. In 1997, there appeared to be an increase in catfish 60-300 mm, the highest CPUE for this size class between 1994 and 1997. The

CPUE for channel catfish <60 mm decreased between 1994 and 1995 (Table 29). The CPUE for channel catfish < 60 mm was similar between 1995 and 1996 and decreased significantly from 1996 to 1997. The other size classes varied between years in significance, but between 1996 and 1997 catch rates for catfish 60-300 mm, >300 mm, and the total catch were similar.

Table 29. Differences in catch rates of channel catfish between years by size class for geomorphic Reach 4 determined by the Mann-Whitney U-Test.

Reach 4 Years	< 60 mm	Class response between years	60-300 mm	Class response between years	> 300 mm	Class response between years	Total catch	Class response between years
1991-1992	N/A	N/A	N/A	N/A	N/A	N/A	p< 0.05	increase
1992-1993	N/A	N/A	N/A	N/A	N/A	N/A	p= 0.09	similar
1993-1994	N/A	N/A	N/A	N/A	N/A	N/A	p< 0.05	decrease
1994-1995	p< 0.05	decrease	p= 0.28	similar	p= 0.45	similar	p= 0.05	similar
1995-1996	p= 0.23	similar	p< 0.05	increase	p< 0.05	increase	p< 0.05	increase
1996-1997	p< 0.05	decrease	p= 0.07	similar	p= 0.939	similar	p= 0.25	similar

Reach 3 - The highest CPUE for this reach was measured in 1994 and 1997 (Figure 30). The lowest CPUE was in 1993, a year for overall low catch rates river-wide. The CPUE for all reaches for 1991-1997 was highest in Reach 3.

CPUE in this reach was similar from 1991 to 1992 and from 1993 to 1994, but decreased significantly from 1992 to 1993 (Table 30). Between 1994 and 1995 channel catfish 60-300 mm, >300 mm, and the total catch increased significantly. CPUE for channel catfish <60 mm and >300 mm decreased significantly between 1995 and 1996, while the CPUE for 60-300 mm fish significantly increased. The overall CPUE between 1995 and 1996 remained similar. The only significant increase between 1996 and 1997 was in catfish 60-300 mm (Table 30, Figure 31).

Reach 2 - The highest CPUE for Reach 2 was in 1995 and 1996 (Figure 30). Similar to other reaches for all years, CPUE was lowest in 1993. CPUE increased significantly from 1991 to 1992 and 1993 to1994, but decreased 1992 to1993. Between 1994 and 1995 all size classes increased significantly. CPUE for channel catfish >300 mm decreased significantly between 1995 and 1996, but other size class catches remained similar. All catch rates dropped significantly between 1996 and 1997 in Reach 2 (Table 31).

Reach 1 - So few channel catfish were collected in Reach 1 during 1991-1997 that CPUE data were not analyzed for between year differences. Trend data only were used to make inferences regarding response of channel catfish to removal efforts.

Table 30. Differences in catch rates of channel catfish between years by size class for geomorphic Reach 3 determined by the Mann-Whitney U-Test.

Reach 3 Years	<60 mm	Class response between years	60-300 mm	Class response between years	>300 mm	Class response between years	Total catch	Class response between years
1991-1992	N/A	N/A	N/A	N/A	N/A	N/A	p=0.11	similar
1992-1993	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	decrease
1993-1994	N/A	N/A	N/A	N/A	N/A	N/A	P=0.11	similar
1994-1995	p=0.06	similar	p<0.05	increase	p<0.05	increase	p<0.05	increase
1995-1996	p<0.05	decrease	p<0.05	increase	p<0.05	decrease	p=0.98	similar
1996-1997	p=0.25	similar	p<0.05	increase	p=0.06	similar	p<0.05	increase

Table 31. Differences in catch rates of channel catfish between years by size class for geomorphic Reach 2 determined by the Mann-Whitney U-Test.

Reach 2 Years	<60 mm	Class response between years	60-300 mm	Class response between years	>300 mm	Class response between years	Total catch	Class response between years
1991-1992	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	increase
1992-1993	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	
1993-1994	N/A	N/A	N/A	N/A	N/A	N/A	p<0.05	increase
1994-1995	p<0.05	decrease	p<0.05	increase	p<0.05	increase	p<0.05	increase
1995-1996	p=0.44	similar	p=0.21	similar	p<0.05	decrease	p<0.05	decrease
1996-1997	p<0.05	decrease	p<0.05	decrease	p<0.05	decrease	p<0.05	decrease

Reach 1 CPUE did not substantially change between 1996 and 1997 (Figure 30). There was an increase in CPUE between 1993 and 1995 (no 1994 sampling) and CPUE declined in 1996. There was a decrease in all size classes from 1995 to 1997 (Figure 31).

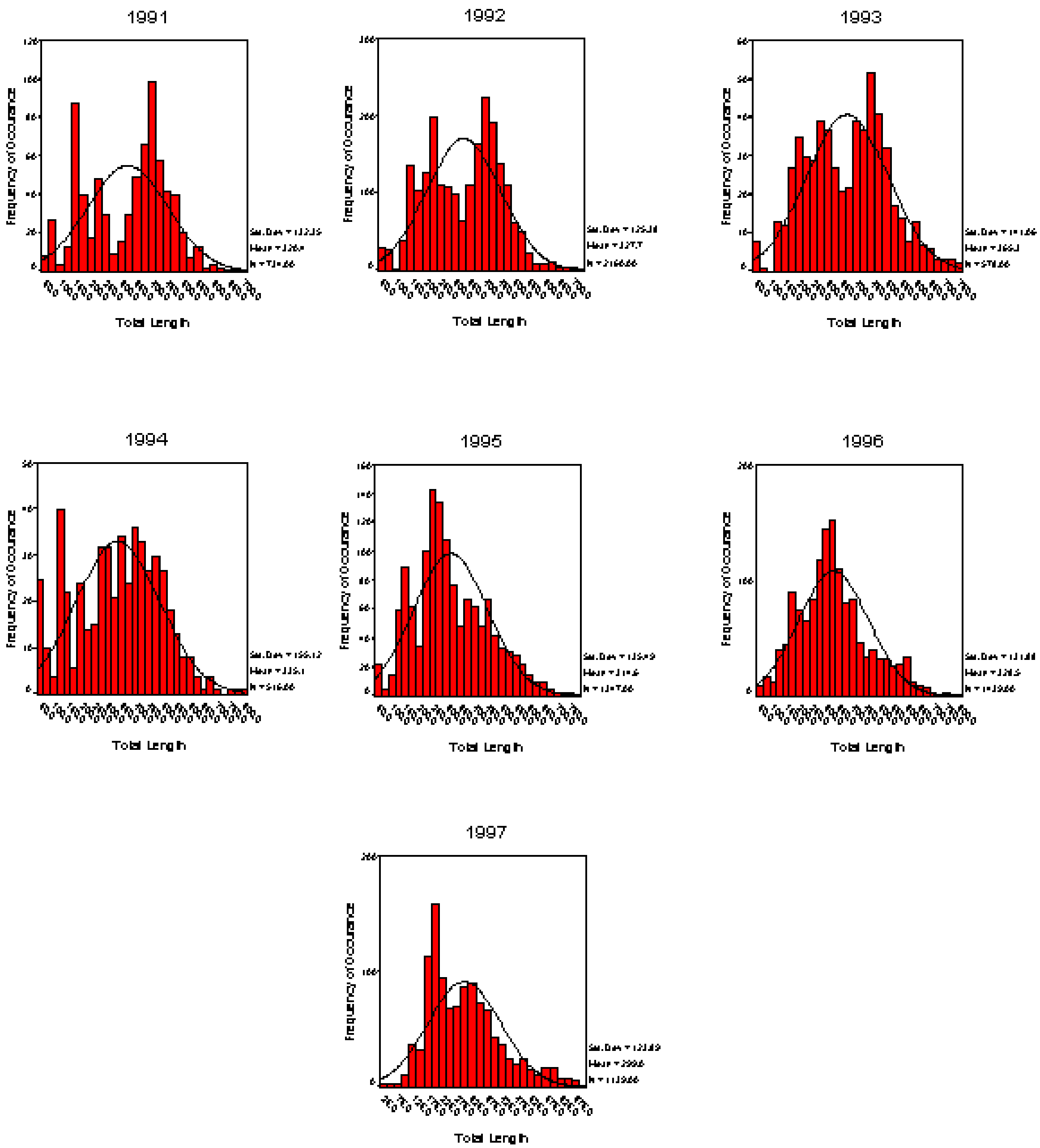


Figure 32. Length (mm TL) frequency histogram for channel catfish collected by main channel electrofishing in the San Juan River, 1991-1997.

Changes in Total Length of Channel Catfish

The distribution of total lengths of channel catfish varied between years. A bimodal distribution in total length was evident in 1991, 1992, and 1993 (Figure 32). In 1994, the total length distribution was skewed slightly toward larger fish, while in 1995 the total length distribution skewed toward smaller individuals. The total length distribution in 1996 appeared to more even, but in 1997 was skewed back toward smaller individuals.

The mean total lengths of channel catfish declined from up- to downstream each year. Exceptions were in 1991 when Reach 2 higher mean total length, and Reach 3 channel catfish were slightly larger than those in Reach 4. In 1993 and 1996, Reach 1 had a higher mean total length than some upstream reaches (Figure 33). Reach 6 had the highest mean total length over the seven year study, with the exception of 1991. Channel catfish in Reach 5 were slightly smaller, but were consistently larger than all other reaches, also with the exception of 1991.

The general pattern for mean total length of channel catfish sampled in each reach in the San Juan River was of an initial increase in size from 1991 to 1994 (Figure 34). After 1994 and with few exceptions, mean total lengths declined in all reaches. Somewhat different than the other reaches, Reach 2 mean total lengths declined throughout the entire sampling period and were noticeably lower in 1992 and 1994. Larger channel catfish (>450 mm TL) were abundant in Reach 6 , but declined in 1995 after initiation of selective removal of large individuals upstream of the Hogback Diversion in 1994. With the exception of 1991, Reach 2 channel catfish were smaller than those sampled in all other reaches.

Comparison of mean total length data by reach and year by Mann-Whitney U-Test excluded Reach 6 due to inadequate sample sizes related to inconsistent sampling efforts prior to 1994. The mean total length of channel catfish significantly increased or remanded similar in reaches 5, 4, and 3 until 1994 (Table 32). Mean total length variably increased and decreased in Reach 2 until 1995. From 1994 to 1995 the length of channel catfish decreased significantly in all reaches except Reach 2. Between 1995 and 1996 channel catfish mean total lengths were similar. The mean total length of channel catfish decreased significantly between 1996 and 1997 in Reaches 4, 3, and 2 and did not significantly change in Reach 5.

Table 32. Differences in mean total length of channel catfish within each reach between years. Reach 6 was excluded from analyses due to significantly smaller sample sizes.

Reach	1991 to 1992 p value and response	1992 to 1993 p value and response	1993 to 1994 p value and response	1994 to 1995 p value and response	1995 to 1996 p value and response	1996 to 1997 p value and response
5	$p < 0.05$ increase	$p < 0.05$ increase	$p = 0.051$ similar	$p < 0.05$ decrease	$p = 0.124$ similar	$p = 0.442$ similar
4	$p < 0.05$ increase	$p = 0.159$ similar	$p < 0.05$ increase	$p < 0.05$ decrease	$p = 0.11$ similar	$p < 0.05$ decrease
3	$p = 0.668$ similar	$p < 0.05$ increase	$p = 0.763$ similar	$p < 0.05$ decrease	$p = 0.893$ similar	$p < 0.05$ decrease
2	$p < 0.05$ decrease	$p < 0.05$ increase	$p < 0.05$ decrease	$p < 0.05$ increase	$p = 0.744$ similar	$p < 0.05$ decrease

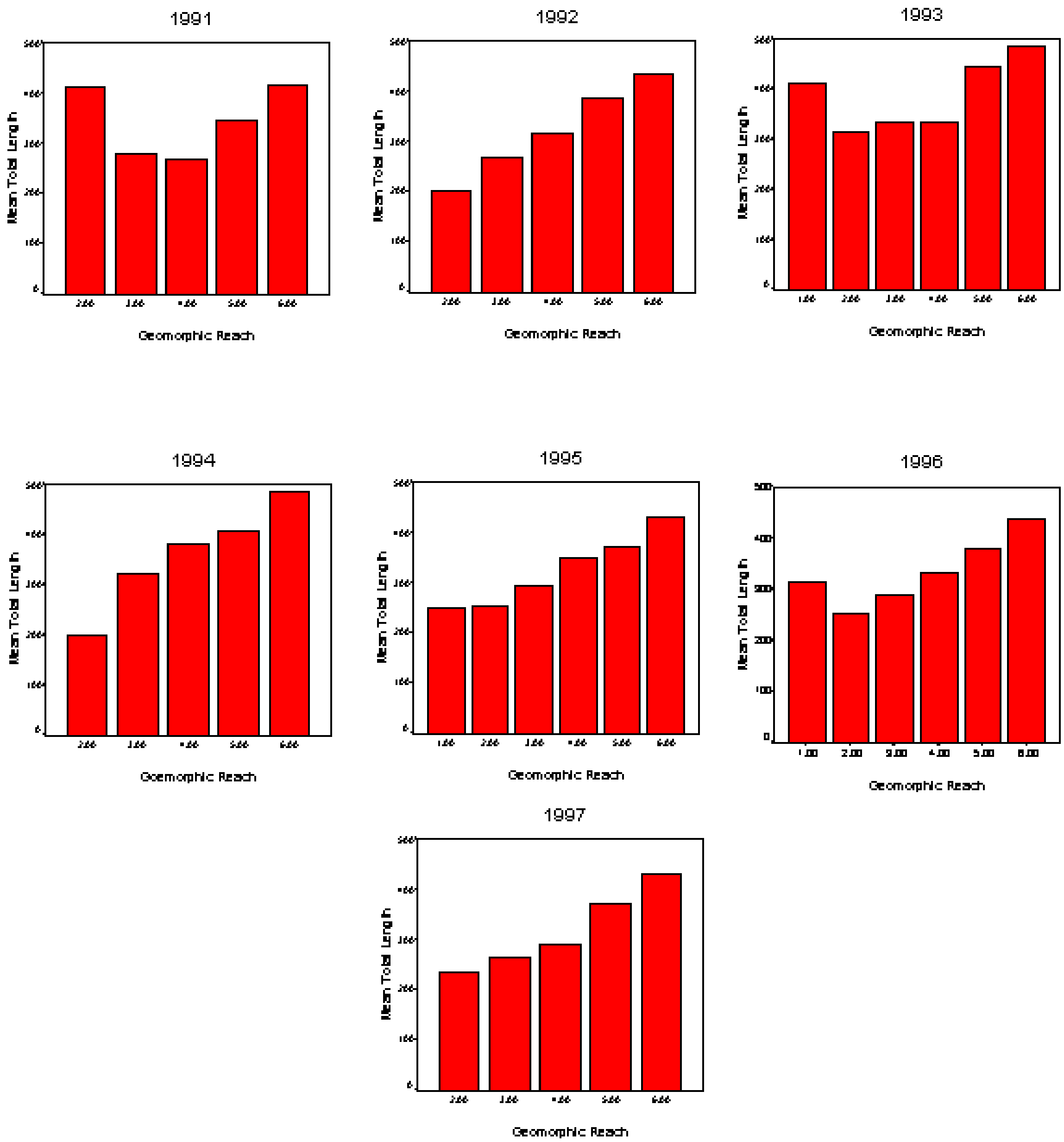


Figure 33. Longitudinal patterns for mean total length for channel catfish collected by main channel electrofishing in the San Juan River for each year,1991-1997

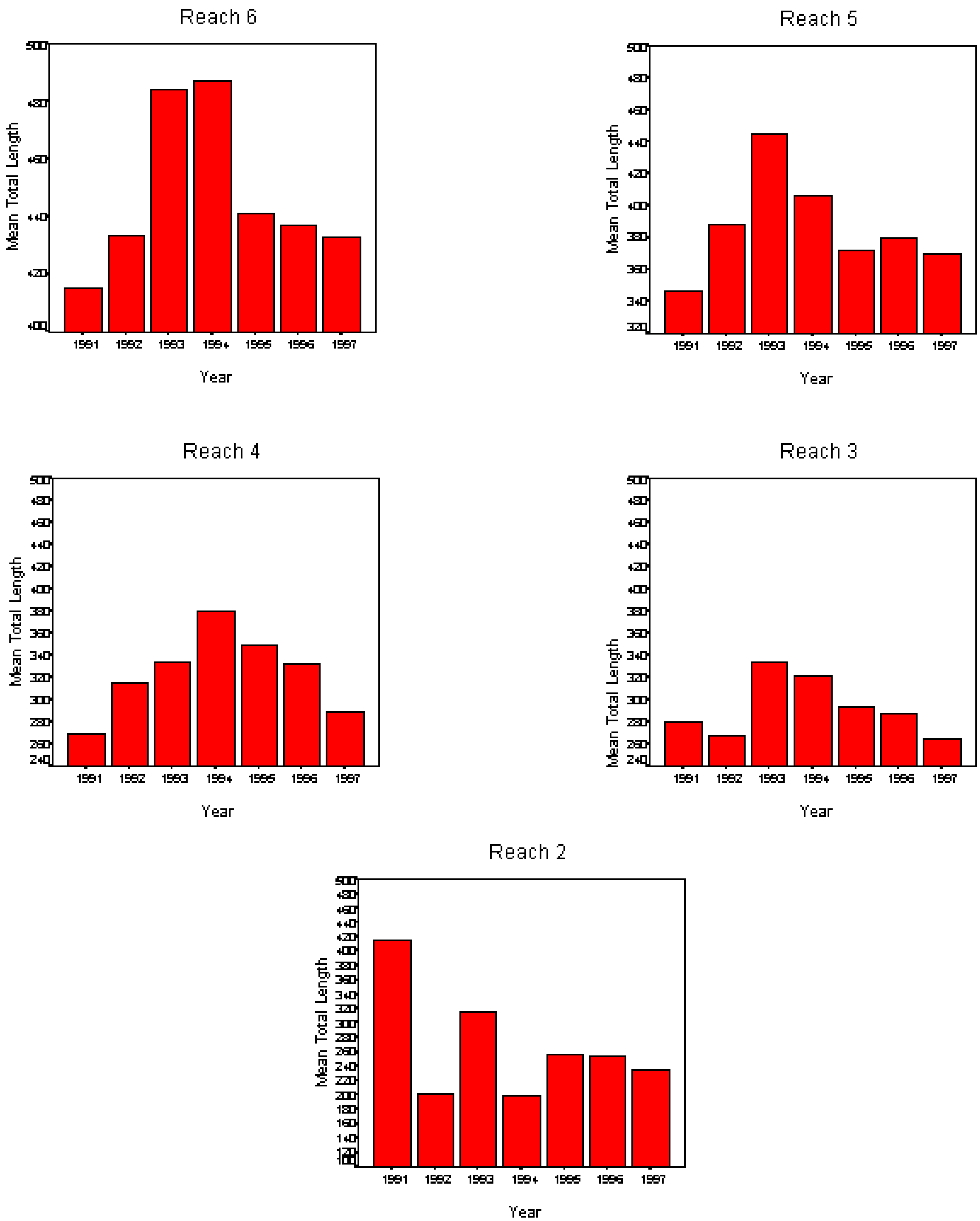


Figure 34. Annual patterns changes in mean total length for channel catfish collected by main channel electrofishing in the San Juan River for each reach,1991-1997.

Biomass Estimates for Channel Catfish

Biomass estimates for channel catfish collected by electrofishing varied between reaches within years (Figure 35). The total estimated biomass for all reaches combined also varied between years. The highest estimated biomass was measured in 1992 samples and was a result of the high biomass in Reach 5 of the same year (Figure 36). There were no statistically significant increases or decreases in biomass within reaches between years (Table 33). The total biomass (all reaches combined) was not statistically significantly between years (R^2 = 0.08). Estimated biomass decreased in all reaches during 1997 sampling efforts, with the lone exception of estimates for Reach 5 (Figure 35). The total estimated biomass of channel catfish sampled by electrofishing for all reaches decreased in 1997 from 1996 estimates, but was nearly equal to 1995 (Figure 36).

Table 33. Results of simple linear regression analysis of channel catfish biomass estimates within reaches and between years,1991-1997.

Reach	R^2
6	0.3
5	0.2
4	0.593
3	0.339
2	0.026
1	0.02

Discussion

Catch rates for channel catfish varied between years and reaches. The combined catch rates for all seven years showed that Reach 3 consistently had the highest catch rate. The river channel in this reach was in a broad floodplain with high sinuosity and low gradient (Bliesner and Lamarra 1999). This reach in medium to low flow years may provide better nursery habitat for young-of-year and juvenile channel catfish. Drifting larval channel catfish from upstream reaches and larvae produced within this reach may be retained due to the suitability of available nursery habitat. Low velocity habitat conditions provided in Reach 3 likely serve to maintain a relatively high abundance of channel catfish.

Though not significant ($P<0.05$), there was a decrease in CPUE for channel catfish >300 mm TL and the total CPUE for all size classes of channel catfish in Reach 6 ($P=0.87$). We believe that the decreased CPUE for channel catfish >300 mm TL in Reach 6 may be a response to intensive removal efforts initiated during Autumn 1995 in a discrete reach bounded by impediments (diversion structures) to fish movements. Larger channel catfish are easily

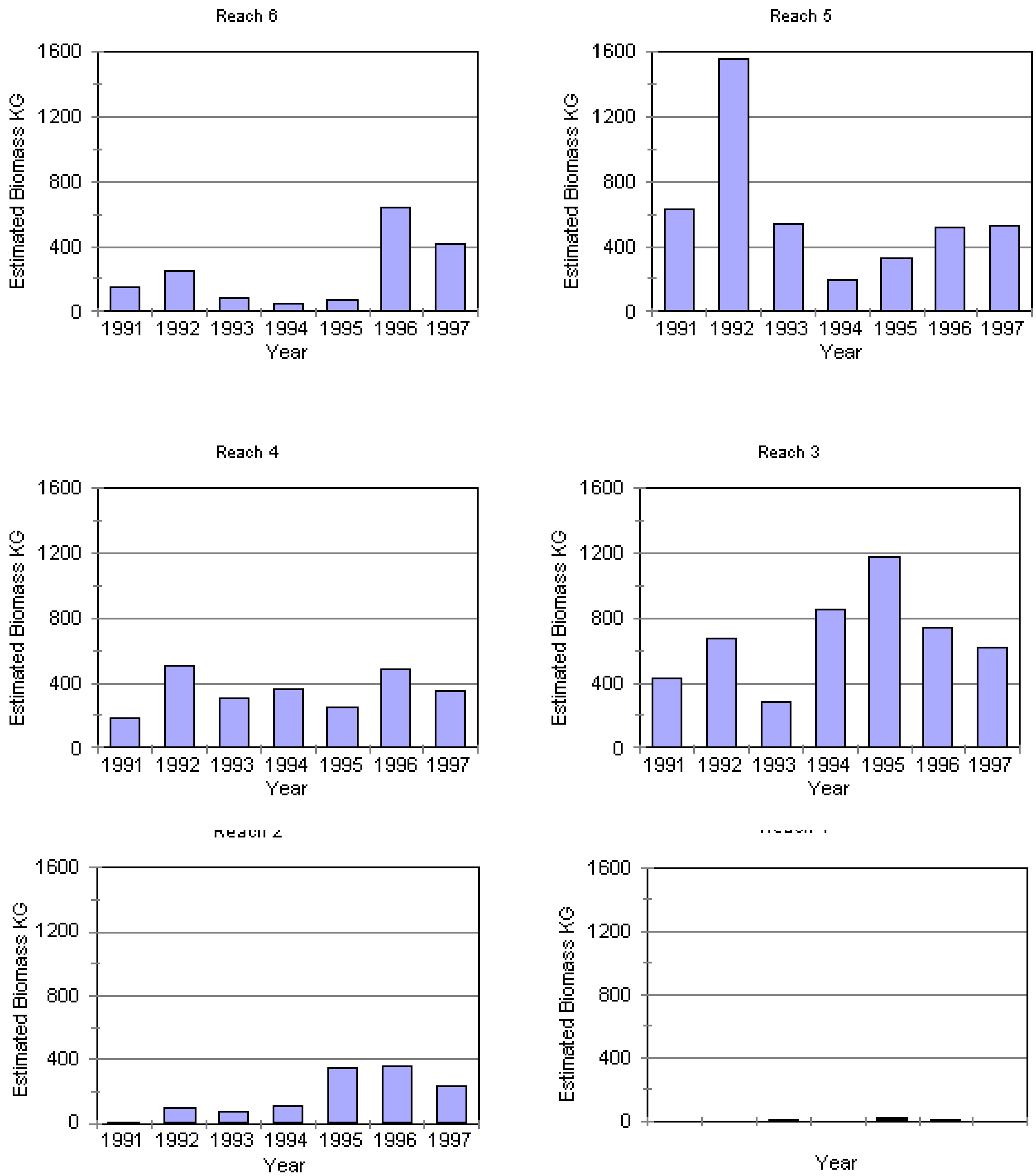


Figure 35. Estimated biomass (kg) of channel catfish collected by main channel electrofishing by reach and year.

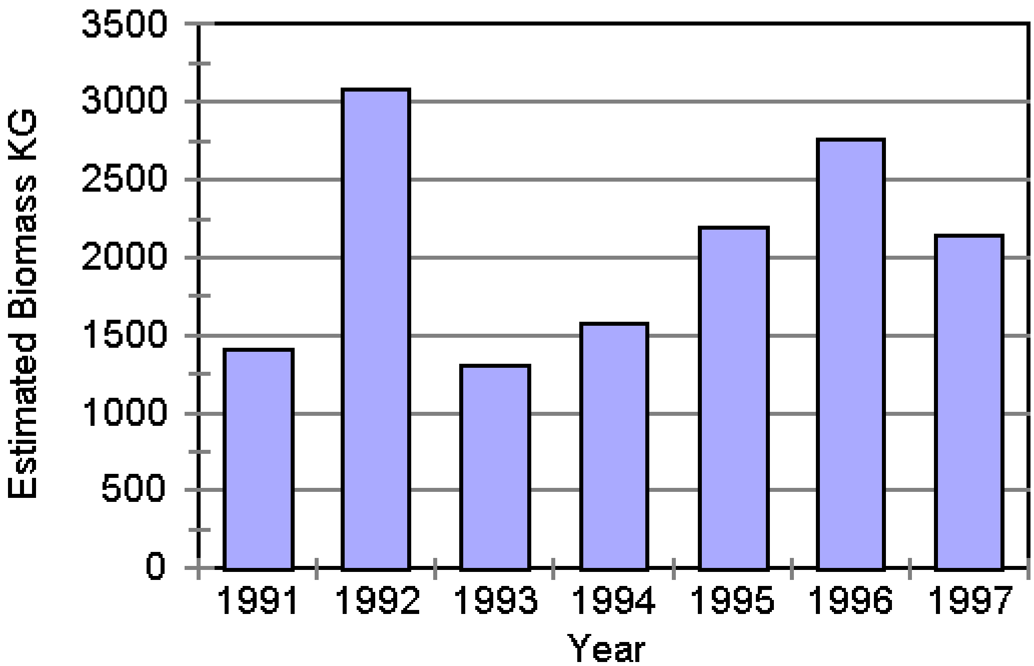


Figure 36. Estimated biomass (kg) of channel catfish collected by main channel electrofishing for all reaches combined for each year.

detected when stunned and netters tend to focus on these fish. The increase in CPUE for channel catfish 60-300 mm in Reach 6 between 1996 and 1997 may be a response to the reduction of the larger size class, thus allowing these fish to become more abundant. Small channel catfish (<60 mm) were not retained within this reach, likely due to lack of low-velocity habitat (Bliesner and Lamarra 1999) and the drifting nature of larval channel catfish (Platania et al. 1999).

Downstream of Reach 6, the changes in channel catfish population dynamics were variable. In Reach 5, the total catch continued to increase from 1994 to 1997, channel catfish 60-300 mm continued to increase, and between 1996 and 1997 the catch rate of channel catfish >300 mm remained constant. This response is similar to the over harvesting of channel catfish by commercial fishermen in Mississippi river (Pitlo 1997). The increase in channel catfish 60-300 mm between 1994 and 1997 may be a response to the removal of larger channel catfish in Reaches 6 and 5.

In Reach 4, catch rates varied between years and changes related to mechanical removal were not apparent. In Reach 3, CPUE for channel catfish 60-300 mm increased significantly each year between 1994 and 1997. The CPUE for channel catfish >300 mm varied between 1994 and 1996, but did not increase in 1997. The CPUE for all size classes of channel catfish in Reach 2 either remained similar or decreased after implementation of removal efforts, 1995-1997, in spite of the presence of the relatively strong 1994 year class.

Changes in the length frequency distribution of channel catfish also illustrated that mechanical removal affected the population. Between 1991 and 1993, the length frequency distribution was bimodal, a size structure observed in a lightly exploited channel catfish population in the Powder River system, Wyoming-Montana (Gerhardt and Hubert 1991). Individual year classes of channel catfish were easily identified for 1991-1994, with the 1994 year class being particularly strong. This also illustrated strong recruitment of channel catfish into the next larger size class each year. Beginning in 1995, the population structure shifted toward smaller individuals, with channel catfish >725 mm absent from collections in 1997. This change in size structure has been linked to over harvest of larger individuals in the Mississippi River (Pitlo 1997).

In 1994 large channel catfish (>500 mm TL) were removed from throughout the San Juan River study area, but not on a consistent basis. It was not until Autumn 1995 that consistent and systematic removal efforts were initiated. Beginning in 1994, larger channel catfish were exploited more readily, thus initiating the skew of the population toward smaller individuals. The overall decrease in mean total length in Reaches 2 to 4 between 1996 and 1997 illustrated the reduction in abundance of larger individuals. Though smaller individuals were removed, the effect of mechanical removal did not suppress their abundance. This is a typical response in other fish populations where individuals over a certain length are continuously harvested (Pitlo 1997, Slipke et al 1998). Nonetheless, the channel catfish population continued to shift to smaller individuals through 1997, an indication that even the smaller size classes of channel catfish were affected by mechanical removal.

In the San Juan River, channel catfish did not move substantially (Chapter I). The presence of numerous diversion structures may act as impediments to movement of fish, further restricting movement patterns of channel catfish. Fewer than 20 individuals have been collected upstream of the PNM weir near Fruitland, New Mexico and the weir bounds a reach on the upstream end that concentrated channel catfish, including a relatively high percentage of large individuals (Ryden 1999). Approximately 9 river miles downstream, the Hogback Diversion isolates this reach and, given the lack of movement by channel catfish, provides for the opportunity to attempt suppression within a discrete reach. Given the proclivity for downstream drift of channel catfish larvae and the attainment of sexual maturity for channel catfish not usually before a total length of 300 mm is attained (Jearld and Brown 1971), removal of channel catfish from upstream reaches may reduce numbers throughout the San Juan River.

The role of mechanical removal in the control of non-native species in the Colorado River Basin has received moderate notice. Lentsch et al. (1996) considered this method of control as minimally useful and not efficient in the removal of non-natives. Nesler (1995) supported mechanical removal as a viable means to suppress northern pike *Esox lucius* and proposed efforts for channel catfish, as well. Mechanical removal by itself usually does not successfully reduce non-native numbers. Data discussed here, however, would argue that there is some merit to continuation of removal efforts. While mechanical removal is minimally effective in lacustrine environments (Houser and Grinstead 1961), Pitlo (1997) illustrated the ability of commercial fishing to reduce the channel catfish population in a large riverine environment. Suppression of channel catfish abundance in the San Juan River will result in a response from the other members of the fish community (Roell and Orth 1998). Presumably, native fishes should increase in abundance in response to suppression efforts. However, other non-native fishes, particularly small-bodied species, may also respond in a positive manner to channel catfish removal efforts. Concurrent efforts to control small-bodied species such as red shiner would assist in promoting a positive response by the native fish community to mechanical removal of channel catfish.

We initiated a channel catfish transplantation project during 1997 to provide these fish to lentic systems, isolated from the San Juan River for recreational angling use. This program is supported by both the Navajo Nation and the State of New Mexico. Past removal efforts relied solely upon sacrifice of removed non-native fish. Transplantation of large channel catfish (up to 15 X larger than typical hatchery-reared fish) into lakes on the Navajo Nation and in the Farmington, New Mexico area where angling pressures are relatively high provide improved quality. Within the Southwest Region of the Fish and Wildlife Service, the total expenditures for culturing channel catfish exceeds one million dollars. A shift in the allocation of funds, from hatchery propagation, to mechanical removal and transplantation would allow for increased removal efforts and may result in long-term suppression of channel catfish abundance in the San Juan River.

While the relative cost of removing and transplanting channel catfish by electrofishing is high ($3.15/kg) compared to hatchery production and stocking ($0.31 - 1.25/kg, FWS records), reduction of non-native species may lessen the need for culture of endangered fish species at federal and State hatcheries ($6.82 - 7.73/kg, FWS records). In addition, the cost comparison for wild versus hatchery channel catfish does not account for the disparity in average size of fish stocked. Wild channel catfish transplanted in this study were 3 - 15 times larger and the production of larger individuals at cultural facilities greatly increases facility demands and cost while number of individuals produced decreases.

Mechanical removal of channel catfish from the San Juan River is not proposed as a means to eliminate this non-native species. Rather, it is postulated that active management to promote recovery of endangered fish species should include long-term suppression of non-natives, such as mechanical removal, that minimizes impacts to remaining native species.

Conclusions

- Electrofishing was the most efficient method of removing channel catfish.
- Hoop and trammel netting were not effective methods of removal, likely due to lack of slow, deep (> 1 m) habitats in the San Juan River.
- Striped bass and walleye were highly susceptible to removal by electrofishing.
- The abundance of large (> 400 mm TL) channel catfish was significantly reduced by electrofishing removal efforts in the river reach between the PNM Weir and Hogback Diversion.
- Agency and angler support for transplantation of channel catfish from the San Juan River to isolated impoundments was high.
- The cost of transplanting channel catfish versus hatchery production and stocking was 2.5 - 10 times greater, but individual channel catfish were 3 - 15 times larger. Large channel catfish are not available from current hatchery sources.
- Mechanical removal of channel catfish by electrofishing is proposed as a long-term action to suppress channel catfish abundance. Periodic removal efforts will not significantly affect numbers and biomass of channel catfish in the San Juan River.

MANAGEMENT IMPLICATIONS

Recovery of the Colorado pikeminnow and razorback sucker in the San Juan River will require the implementation of a variety of management programs. Control of non-native species should be the focus of intensive efforts through flow manipulation, selective removal programs, strict management procedures for recreational angling and various private uses (e.g. vegetation control, vector control, ornamental), and public education. Hendrickson (1993) considered the control of non-native fishes to be one of the more important activities in attempted efforts to recovery Colorado pikeminnow and razorback sucker in the Gila River basin, Arizona.

Through the conduct of intra-Service Section 7 consultations, ESA, recreational fishing programs administered by the State and Federal agencies are required to be analyzed for potential impacts on listed species. Formerly, channel catfish were stocked into the main San Juan River in the Farmington, New Mexico reach until 1988 (New Mexico Department of Game and Fish files) before discontinuation due to the rediscovery of Colorado pikeminnow downstream. All State-regulated stockings, tribal recreational fisheries programs and Federal activities have been reviewed through the Section 7 process to avoid conflicts between recreational angling and endangered fishes recovery.

The introduction of small non-natives for use as bait is restricted by State and Tribal laws. Only specific non-natives are allowed for use as live baitfish by State agencies and the use of live baitfish is not allowed in any tribal waters of the San Juan River Basin. No new species are allowed to be introduced into the San Juan River basin.

Restoration of the natural flow regime is recognized as the focal point of river restoration and the associated native fish communities (Vannote et al. 1980, Poff et al. 1997). In the San Juan River, mimicry of the natural hydrograph appears to be improving and maintaining suitable habitat conditions for various lifestages of native fishes (Bliesner and Lamarra 1999). Coincident to the improvement of habitat conditions, some non-native fishes have also increased in abundance. Maintenance of the natural flow regime, including tributary flows from the Animas River are important components in the SJRIP. The low abundance of benthic macroinvertebrates that serve as a primary food source for both native and non-native species may be reduced even further with continued water development within the basin. The importance of tributary inflows to maintenance of the food base for resident fishes should be incorporated into future native fish and water development strategies.

Mechanical removal and selective fish passage implemented in an incremental fashion may assist in the further reduction of non-native species. For example, the placement of a large diversion dam with fish passage, as is currently planned at the Hogback Diversion, New Mexico, will further isolate the reach upstream to the PNM Weir. Given the demonstrated lack of significant movement by channel catfish in the San Juan River and low occurrence in the bypass channel at the Redlands Diversion on the Gunnison River (Frank Pfeifer, FWS,

personal communication), repetitive mechanical removal efforts in this reach may substantially reduce the abundance of channel catfish. If institutionalized as on ongoing management program, particularly as a replacement for hatchery-reared fish, it is conceivable that a program can be successfully implemented to incrementally reduce channel catfish numbers from up- to downstream in discrete reaches separated by diversion structures. However, it is not likely that this removal program will succeed without a long-term commitment for operation, similar to the current support that hatchery programs receive.

Relationship to Long Range Plan

Section 5.4 of the Long Range Plan addresses the roles of non-native species in the decline of native fishes and potential management actions designed to avoid or lessen negative interactions. Four milestones were listed within this section:

5.4.3 Describe food habits of non-native fish species and evaluate for predation and competition impacts on the native fish species.
5.4.5 Develop a non-native fish stocking policy.
5.4.6 Develop and implement regulations to restrict baitfish species harvest within appropriate habitats.
5.4.7 Develop and implement regulations to restrict import of non-native fish species.

The food habits of non-native fishes were described in detail. Predation of non-native species on natives was documented for channel catfish, striped bass, and walleye. While the level of predation by channel catfish was low, the widespread distribution and high abundance of this species indicated that negative impacts to the native fish community were plausible. The highly piscivorous striped bass and walleye, while not as abundant or widespread, also exert negative pressures upon the native fish community in the lower San Juan River. Of all striped bass and walleye stomachs examined and that contained food, fish remains were consistently present. Efforts for reduction of channel catfish throughout the San Juan River and of striped bass and walleye in lower reaches are warranted to assist in recovery of the Colorado pikeminnow and razorback sucker. All fishes present in the San Juan River otherwise consumed similar foods and the macroinvertebrate community, the primary food, was low when compared to streams elsewhere in the Colorado River Basin. Future studies that evaluate the spatial and temporal availability and use of macroinvertebrates are necessary to further define relationships between native and non-native species under and as a response to differing flow conditions.

A policy regarding the stocking of non-native fish has not yet been developed. Current regulations by the states of Colorado, New Mexico, and Utah restrict stockings within waters under State jurisdiction. Tribal (Jicarilla Apache, Navajo, Southern Ute, Ute Mountain Ute) activities are strictly controlled and nearly all fish for recreational angling programs are provided by Fish and Wildlife Service hatcheries. Stocking sport fish species under the jurisdiction of the Fish and Wildlife Service require the conduct of intra-Service Section 7

consultation, Endangered Species Act, to ensure compliance with existing law and avoidance of impacts to native species. This also applies to State stockings conducted under the Federal Aid Program. Thus, while no policy regarding the stocking of non-native fish in the San Juan River Basin exists, future efforts should parallel those of the Upper Colorado River Basin Recovery Implementation Program to develop such guidance. Specifically, guidelines should be developed regarding limited allowance of stockings in isolated waters and should prohibit the introduction of new non-native species to the San Juan River Basin.

Regulations for the harvest of baitfish species are controlled by the State agencies and by the Tribes. Within Tribal waters, the harvest and/or use of live baitfish is not allowed. Harvest and use of live baitfish in waters under State jurisdiction are allowed throughout the San Juan River Basin, except in selected impoundments. The transport of live baitfish species taken from one water to another are not allowed. The further definition and specificity of pertinent regulations should be applied to all restrictions to ensure prohibition of movement of species between waters and to protect rare and endangered fishes in the San Juan River.

Regulations that cover the importation of non-native fish species are restricted to State, Tribal and Fish and Wildlife Service jurisdiction. Generally, importation is strictly controlled and disallowed for prohibited species that are identified in State and Tribal regulations and by the Colorado River Wildlife Council (membership is the seven Colorado River Basin states). Completion of requirements under the National Environmental Policy Act address potential biological and social impacts. However, further recommendations by the SJRIP to affected natural resource management agencies should be developed to ensure avoidance of introductions of new species to the San Juan River Basin.

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