

EFFECTS OF ELECTROFISHING REMOVAL ON THE CHANNEL CATFISH,
ICTALURUS PUNCTATUS, POPULATION IN THE
SAN JUAN RIVER, NEW MEXICO

by

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ABSTRACT

The introduction of non-native species has been tied to the decline of native species in many areas around the world. The impacts of non-native introductions on native fisheries have prompted the establishment of non-native removal programs to suppress these populations of non-native species. The San Juan River Recovery and Implementation Program was established to mitigate the effects of the non-native channel catfish (*Ictalurus punctatus* (Rafinesque)) on native endangered fishes in the San Juan River. Although the recovery program has removed more than 136,000 channel catfish in the last ten years, a resurgence in endangered fishes has not been observed in the San Juan River. The recovery program personnel determined that population structure and maturation data were needed to establish what the current channel catfish population in the San Juan River looked like. This study evaluated the population structure and reproductive structure of the removed channel catfish population in the San Juan River 2011. The objectives of this study were to establish an age length key and to determine the age at maturation for channel catfish in the San Juan River. Channel catfish were collected between the months of June and August 2011 using raft mounted electrofishing gear. Length and weight were recorded for each fish removed, and samples of pectoral spines and gonads were collected to determine age and maturation. Data suggest that when compared with populations of channel catfish exhibiting normal growth the San Juan River channel catfish population is growing faster and is larger at a given age. However, data also suggest that only a small number of channel catfish are collected reproductively active, and all of these fish are > 400 mm total length (TL). Data also suggest that when compared with other channel catfish populations the San Juan River population is mature at a greater age. Based on these data the channel catfish population in the San Juan River may be compensating for removals and decreased densities by growing more quickly. These data indicate that the removal and recovery program should target large fecund adults to reduce recruitment and suppress the non-native population of channel catfish.

CHAPTER 1

BACKGROUND

Introduction

The San Juan River is a complex system that hosts many unique fish species and a diverse habitat historically governed by drought and floods. Since the 1850's, when European colonization of the area first began, the habitat has been altered and many of the native fish populations have declined. The introduction of channel catfish (*Ictalurus punctatus* (Rafinesque)) to the San Juan River in the 1890's may have caused additional pressure on native fishes through competition for resources. The introduction of nonnative fishes into the San Juan River, NM has been attributed to the decline of many native fish populations. Minckley and Deacon (1991) stated, "Management options may be more limited by the biological pollution of nonnative species than by the vast physical and chemical habitat changes wrought by humans".

Nonnative fish introductions have been associated with the declines in biodiversity and are ranked second to habitat loss and degradation as leading causes for declines in native fish populations (Syslo 2011). Nonnative species can cause declines in native species due to direct competition for resources or indirectly through habitat alterations and altered trophic dynamics (Mueller and Marsh 2002). The nonnative channel catfish in the San Juan River may compete for resources with native predatory fish such as the Colorado pikeminnow (*Ptychocheilus lucius* (Girard)). In addition, population growth of channel catfish could cause competition for suitable habitat with

native fishes, forcing them further into the main stem of the river where they may be more vulnerable.

Nonnative species interactions were not the only challenge for wild native fish populations. Habitat modifications brought about through construction of dams on the San Juan River may also hinder reproductive success. Because of alterations to the system three fish species, Colorado pikeminnow, razorback sucker (*Xyrauchen texanus* (Abbott)), and bonytail chub (*Gila elegans* (Baird and Girard)), are now listed as endangered. Due to extremely low population size and no evidence for naturally spawning populations within the San Juan River, augmentation plans have been established for the razorback sucker and Colorado pikeminnow. The following section provides a description of these two native species and their life history characteristics, a history of water use modifications in the system, and a description of the invasive channel catfish, its life history, and potential impacts on native species. In addition, the establishment of the San Juan River Recovery and Implementation Program has allowed for monitoring and removal of the invasive fish populations since 2001. A description of the program and their findings over the past 12 years have been provided to illustrate the effort to reduce nonnative species population size as well as to quantify the fluctuations that have occurred in the mean total length of channel catfish removed from the population. A final section of this review discusses the augmentation program aimed at re-establishing self-sustaining populations of the endangered fishes.

Introduction to Native and Non-native Fishes

Razorback Sucker (*Xyrauchen texanus*)

The razorback sucker is one of four endangered fishes historically occupying the main stem of the Colorado River. These fish are the largest of the Colorado River suckers, and although they are strongly muscled, they are docile when in nets or being handled (Mueller 2006a). The razorback sucker has had to adapt to these harsh environmental conditions to survive and reproduce in this region. Some of these adaptations are reflected in their reproductive strategies such as the high fecundity (hundreds of thousands of eggs) due to reduced or non-existent recruitment in drought years (Mueller 2006a). Before European settlement of the Colorado River Basin in the 1850's, razorback suckers were abundant and periodically harvested for use as fertilizer or livestock feed (Minckley and Deacon 1991).

Adult razorback suckers have an elongated head and body with a pronounced dorsal keel. The mouth is sub-dorsally positioned with fleshy lips. The scales of the lateral line range in number from 68-87 and are considered moderately small. The dorsal fin is long, consisting of 13-16 fin rays, and is positioned behind the dorsal keel. They have 44-50 slender gill-rakers on the first arch. Their color ranges from olive to brownish-black above the lateral line and lighter yellow below. Dorsal fins are generally dark while anal fins exhibit a yellow hue and caudal fins are light brown to yellow. Breeding males are usually dark dorsally, orange laterally, and have a bright yellow belly. Adult fish can reach lengths of one meter and weigh from five to six kilograms (Minckley 1973).

The razorback sucker was historically one of the more prolific spawning fish in the Colorado River. Fish typically spawn in early January and may continue into April. Males become sexually active at two years of age, but females may take up to five years before they are sexually mature. A large gravid female can lay as many as 200,000 eggs in a single spawning event. Razorback suckers can spawn over a wide range of conditions including lentic and lotic habitats. Despite what system they are spawning in, these suckers prefer clean gravel and cobble. Typical spawning scenarios consist of males positioning themselves over the spawning site where they are eventually met by ripe females. Eggs hatch in three to five days, depending on conducive water temperatures between 23.8-32.2 °C (Swann 1997), and young can grow to more than 300 mm in their first year (Mueller 2002).

Young razorback suckers lack the boney dorsal keel but exhibit this characteristic during development (Muller 2006b). For many years, the keel was thought to aid in hydrodynamic movement, but Portz and Tyus (2004) suggest that it may be used as a mechanism for predator defense, preventing other fish from swallowing it. Larval razorback suckers are phototactic and have been easily collected using dip nets and halogen lights suspended over spawning grounds. Light traps have also been effective in capturing larval fish although significant predation is associated with this method (Mueller et al. 1993; Muth and Haynes 1984).

The razorback sucker was officially designated as an endangered species in 1991 as a result of rapidly dwindling populations (Mueller 2006b). Due to the introduction of nonnative predatory species and the habitat degradation brought on by the damming of

rivers, razorback sucker critical habitat was designated on 21 March, 1994. Although populations of razorback sucker have successfully spawned in the wild, embryo predation, reduction of spawning habitat due to damming of the San Juan River, and potential resource competition has eliminated the potential of self-sustaining populations (Mueller 2006b). Currently, wild razorback sucker have been extirpated from the Salt, Gila, Gunnison, San Juan and Upper Colorado rivers. Wild populations mostly exist in Lake Mohave and Lake Mead and are the source of the majority of broodstock used for stocking efforts (Ulmer and Anderson 1985). The Southwest Native Aquatic Resources and Recovery Center has been one of the more productive facilities for stocking efforts of these endangered fish producing more than 15 million razorback sucker in the last 25 years (Mueller 2006a).

Many sexual dimorphisms exist to separate male and female razorback sucker. The first difference is in the ventral coloration where males are bright orange-yellow on their belly compared with much lighter bellies on female fish (Minckley 1983). Other differences include length and weight, pelvic and anal fin length, urogenital papillae length and morphology and curvature of the last anal fin ray (McAda 1980). Minckley (1983) determined that females were 17% longer and weighed 45% more than their male counterparts. The male anal and pelvic fins were 25% longer in this study, and the papillus in the females were 43% longer than those of the males.

Colorado Pikeminnow (*Ptychocheilus lucius*)

The Colorado pikeminnow is the largest minnow in North America and is found only in the Colorado River drainage. Historically, these fish could grow to 1800 mm long and weigh about 45 kg. Currently, however, it is rare to find a pikeminnow that weighs more than 6.5 kg. These fish were historically distributed throughout the warm water reaches of the Colorado River basin from Wyoming, Utah, and Colorado south to the Gulf of California (Miller 1961).

Adults have a large head and horizontal mouth adapted for grasping prey. Its body shape resembles a northern pike (*Esox lucius* (L.)) in that it is elongated and flattened. The scales are small in size similar to the razorback sucker. Adults exhibit distinct coloration including dark backs, lighter sides, and nearly white bellies. Young are silver in color and have a black, wedge-shaped spot at the base of their tail. Colorado pikeminnow inhabit the main channels and large tributaries throughout the Colorado River Basin. These fish were historically abundant in the lower Colorado River Basin and Delta where backwater habitat and prey were available. Both male and female adults become sexually active after their fifth year (Mueller et al. 2000).

Spawning Colorado pikeminnow may migrate hundreds of kilometers to spawn each year. Adult Colorado pikeminnow in the Upper Colorado River Basin migrate to two known spawning areas in spring. Spawning begins four to six weeks after peak spring runoff, when water temperatures exceed 16 °C, and extends up to six weeks (Bestgen et al. 1998; Nesler et al. 1988; Tyus 1991). Eggs are deposited over cobble bars

and develop in interstitial spaces for four to six days at 18 °C (Bestgen et al. 1994; Hamman 1981).

Emerging larvae are generally seven to nine millimeters in total length and are transported by river currents 40–200 km or more downstream to low-gradient valley reaches. Here, they occupy shallow, low-velocity backwater nursery habitats (Bestgen et al. 1994; Bestgen et al. 1998) for the duration of the growing season (Tyus 1991). These off-channel habitats are typically warmer and much more productive than the main channel. Adults prefer deep stream channels and backwaters where they ambush prey from below. They feed on fish and a myriad of terrestrial animals making them the top native predator in the system (Mueller and Marsh 2002).

The Colorado pikeminnow was listed as a federally endangered species in 1967, (32 Federal Register 4001, 1967) and is protected under the provisions of the Endangered Species Act of 1973 (39 Federal Register 1175, 1973). By the 1970's, they were extirpated from the entire lower Colorado River Basin and sections of the upper basin as a result of alterations to the river system. This accounts for a loss of 80% of the Colorado pikeminnow's traditional habitat. Currently, the Colorado pikeminnow is restricted to the upper Colorado River basin and inhabits warm water reaches of the Colorado, Green, and San Juan rivers and their tributaries. The Green River and its two tributaries (White and Yampa Rivers) support the largest and perhaps most viable population (Tyus 1991), while the San Juan River contains the smallest population (Platania 1991). A third population exists in the upper Colorado River, but relatively low catch rates of adults and young (Osmundson and Kaeding 1989; Valdez and Wick 1982) are suggestive of a

population with limited viability. Decline of the Colorado pikeminnow population in the San Juan River is tied to resource competition with nonnative species, and habitat modifications brought about through the damming of the San Juan River (Mueller and Marsh 2002). Because of the endangered status of this fish, assessing persistence potential of these smaller populations is important in assessing overall species viability (Osmundson and Kaeding 1998).

Channel Catfish (*Ictalurus punctatus*)

Channel catfish are native to North America and historically occupied the Great Lakes, the Mississippi River and its tributaries, and the Gulf of Mexico (Tyus and Nikirk 1990). The channel catfish became popular due to its quality as a sport fish as well as the ease with which they are propagated, transported, and stocked (Tucker and Hargreaves 2004). These qualities are most likely why the channel catfish has been stocked in many river systems across the U.S.

Channel catfish seem to thrive in a wide range of habitat types, although the largest populations of channel catfish observed tend to prefer slightly turbid deeper lake environments with clean substrate such as sand, gravel, or boulders. The channel catfish can also be found in areas with a consistent silt deposition as long as the rate of deposition is low (Pflieger 1997). Channel catfish tend to prefer complex woody habitat types and generally prefer depths of one to two meters during the spring and summer months (Coon and Dames 1991). During the winter, channel catfish tend to seek deeper parts of the main channel in larger streams where rocks and woody debris can break the current. In contrast to channel catfish in reservoir systems, channel catfish that populate

large flood-plain river systems tend to move into the floodplain to feed and use the main stem of the river to move between floodplain habitats (Flotemersch et al. 1999).

The adult channel catfish is a slender scaleless fish with a shallow downward sloping profile anterior of the dorsal fin. It has sharp, strong spines in the dorsal and pectoral fins, and no spines in the pelvic or anal fins. The adipose fin is free lobed while the caudal fin is deeply forked (Pflieger 1997). The color of the channel catfish changes as it grows with the largest fish, > 600 mm TL, dark steel-blue with few if any spots. Breeding males can be distinguished from females by the wider head, bulging cheeks and opercles, and lack of dark spots. A common feature of all channel catfish is that they tend to have eight barbels encircling the mouth at all ages and across sexes (Tucker and Hargreaves 2004).

Channel catfish generally tend to spawn in late spring and early summer in water temperature between 21 to 28 °C. The male will select and clean a confined site and then attract a female to the location (Tucker and Hargreaves 2004). Males and females will meet and swim in circles around one another as the male tries to gently nudge the female toward the cleaned spawning site. Once inside, the male and female will face opposite directions gently flapping their caudal fins upon each other. Females will then lay their eggs, and males will deposit their milt on the spawning site. This process can continue for up to six hours. After the spawning, the males will drive away the females and guard the eggs (Baker 1985).

Young channel catfish resemble adult catfish in many ways including body shape, spines on the dorsal and pectoral fins, and lack of scales. Although they share some

features with adults, juvenile channel catfish tend to be blue or olivaceous dorsally and silvery white ventrally. All smaller channel catfish, < 350 mm TL, will generally exhibit black spots which are distinctive and a means of distinguishing channel catfish from the similar looking blue catfish (Tucker and Hargreaves 2004). Young-of-the-year channel catfish tend to be at the mercy of the currents in large river systems and will drift downstream due to nocturnal feeding activity (Brown and Armstrong 1985). Furthermore, in the absence of shelter, these young channel catfish will aggregate during the day and disperse at night (Brown et al. 1970). Juveniles also tend to occupy the shallower near-shore environments with lower water velocity at night and the deeper main channel of the river system during the day (Irwin et al 1999). Channel catfish were introduced into the San Juan River in the 1890's and have since been attributed to the decline of native species.

Water Use and Modifications

Historically, the Colorado River hosted one of the most diverse fish communities in the world. The survival strategy of these main stem fishes was intimately tied to the harsh environmental conditions rather than interspecies competition as seasonal low flows and drought were the primary causes of fish mortality (Mueller and Marsh 2002). In the 1800's, European settlement brought about extreme alterations to the lower basin and changed the dynamic of both the river and its native fishes. Early settlers realized the impacts that periodic flooding and drought events would have on their ability to sustain crops. In-stream flow during these periods could shift from 1.4 m³/s during droughts to

more than 11,200 m³/s during flooding events (Douglas et al. 2003). Water temperatures also fluctuate drastically in this region from 0 °C to more than 35 °C during a given year (Mueller and Marsh 2002). Initially, small agricultural diversions were installed to provide water to agricultural lands.

As the populations grew throughout the southwest, the demand for a source of water year round became a priority. This brought about the construction of the Theodore Roosevelt and Granite Reef Diversion Dams in the early 1900's to provide flood protection and reservoir storage. From this period on, many more diversions and reservoirs were constructed to keep up with the increasing demand. In the 1930's, the demand for water in the Colorado River Basin exceeded supply and the federal government became involved in water projects. The Colorado River system was drastically altered in 1935 with the construction of the Hoover Dam. At the time of its construction, it was the highest and widest concrete dam in the world. The establishment of dams and water diversions in this region continued throughout the 1900's to meet the needs of the rapidly growing populations in California, Arizona, and New Mexico.

Today, there are more than 20 diversions and storage reservoirs in the lower basin alone. The result of these alterations is a dramatically altered ecosystem where man has dried up hundreds of miles of streams in some areas and permanently flooded other regions. Remaining areas of the river system have been dredged and straightened to such a degree that they resemble canals rather than natural systems. Because of these alterations, the razorback sucker and Colorado pikeminnow are now federally protected as endangered (Mueller and Marsh 2002).

The channelization of the river brought about a reduction in floodplain habitat critical for the development of native aquatic species. Razorback suckers and Colorado pikeminnow traditionally inhabited the broad floodplains that were dominant in the lower Colorado River Basin. The warm productive floodplains of the lower Colorado River Basin were critical to the growth of native larval and juvenile fishes as well as providing habitat for adults. After spawning, both native species move to warmer backwater wetlands that are more productive and use the main stem of the river systems as a corridor to move between habitats (Valdez and Clemmer 1983; Wydoski and Wick 1998). Tagging studies suggest that these two species have the capacity to migrate over large distances to access seasonal habitat (Modde and Irving 1998; Tyus 1987).

Drought cycles limited the availability of floodplain habitat and have historically lasted several years, though they have been periodically broken by spring floods. During floods the river would swell and spread out into floodplains. Larger native females can lay thousands of eggs, and within days, they would hatch and young disperse within flood waters. These habitats are virtually predator free, and survival was probably high for young fish. Razorback sucker and Colorado pikeminnow have developed unique characteristics in longevity and reproductive fecundity. Both of these fishes can live to 50 years and produce tens of thousands of eggs in a single spawning season. In contrast, most other freshwater fishes live fewer than 10 years and can produce only a few hundred offspring each year. These features allowed them to survive through prolonged periods when spawning failed but allowed them to repopulate the river in a single season when conditions were favorable (Mueller and Marsh 2002). Studies have demonstrated that

altered flow regimes, habitat modification, and range fragmentation have contributed to the endangered status of Colorado pikeminnow (Holden 1992). Although the loss of habitat and restricted migration corridors have limited the recruitment of endangered fishes, invasive species interactions may prove to be an equal hindrance to survival of endangered fishes.

The damming of the San Juan River reduced the floodplain habitat available for the native fishes and may have made the river more suitable for channel catfish. Although the razorback sucker is highly fecund, this fish adapted over many years to the San Juan River environment and their reproductive strategies are dependent on drought years followed by years of heavy floods (Mueller and Marsh 2002). Since the river has been dammed it is more channelized with less backwater and floodplain habitat available for native fishes. This habitat alteration may have given the competitive advantage to the channel catfish since native fishes are not adapted to reproduce in this new environment. A map of the river and distinct removal sections is illustrated in Figure 1.

Non-native Fish Removal Program

The San Juan River Recovery and Implementation Program deals with the specific issues of native fish conservation, and nonnative fish removal in the San Juan River. Since the establishment of the program, the main goals have been: 1) protection of genetic integrity, 2) protection, management, and augmentation of habitat, 3) water quality protection, 4) interactions between native and nonnative fish species, and 5) monitoring and data management.

The San Juan River Recovery and Implementation Program operates under an approach known as “adaptive management.” The adaptive management approach allows the San Juan River Recovery and Implementation Program’s Biology and Coordination Committees to make appropriate modifications to annual work plans, field studies, monitoring and augmentation programs, and guiding documents as new information becomes available that would suggest that a change would be advantageous to achieving the recovery goals of the program (Ryden 2005).

To satisfy these goals, nonnative fish removal program plans were established to reduce the populations of channel catfish in the San Juan and Colorado Rivers to re-establish native endangered fish populations. The goals of this removal program are to develop, implement and evaluate the most effective strategies for reducing problematic nonnative fishes and determine the effects of nonnative fish control on distribution, abundance and demographics of nonnative fish populations (Davis et al. 2009).

Mechanical removal of channel catfish, as a potential control measure, was implemented and evaluated during 1998, but was not an established management program until 2001. Both nets and the electrofishing method were initially employed, but evaluations of the methodologies determined that electrofishing was more effective in capturing channel catfish (Brooks et al. 2000). These efforts consist of multiple boats electrofishing the river system in what has become one of the more intensive fish removal programs in the U.S. (personal communication, Mark McKinstry U.S. Bureau of Reclamation). Nonnative fishes are collected using raft-mounted electrofishing units (Smith-Root 5.0 GPP). Rafts sample near each shoreline and netters collect any nonnative fish observed.

The removal program has focused on three individual sections of the San Juan River, New Mexico, Colorado, Utah, encompassing 113.7 river miles.

The San Juan River Recovery and Implementation Program initially began removals of channel catfish due to the presumed direct impact of predation on the endangered razorback sucker and Colorado pikeminnow (Davis 2003). Although Brooks et al. (2000) had determined that piscivory only occurred in 13.2% of channel catfish stomachs, all fish exhibiting piscivory were > 450 mm TL. It was thought that the suppression program would reduce the number of channel catfish > 450 mm TL and therefore reduce the predation on the endangered species enough to allow for wild spawning populations. Between the years of 2003 and 2011, more than 136,000 channel catfish have been removed from the San Juan River (Figure 2). However, there has been no evidence for successful recruitment in the wild endangered fish populations. Because intensive removals have not aided in the recovery of the endangered fishes, the San Juan River Recovery and Implementation Program determined that evaluations of the current population structure of channel catfish are necessary. A recent analysis of 1000 channel catfish stomachs showed that, even after the stocking of 350,000 razorback suckers, no endangered fish were being preyed on by channel catfish (unpublished data Patton et al.).

An evaluation of the current channel catfish population structure will allow management personnel to determine if the channel catfish population in the San Juan River is similar to other systems with ongoing suppression efforts. In addition, an evaluation of channel catfish maturity based on total lengths and associated ages can be

used to determine if maturity is occurring at a different length or age than in other systems where channel catfish reside.

Endangered Fish Stocking

Colorado Pikeminnow

The stocking of Colorado pikeminnow (*Ptychocheilus lucius*) in the San Juan River facilitates both the expansion of the population size of these fish as well as providing a means to assess movement and recruitment within the river. In 1996, stocking of endangered Colorado pikeminnow began and was aimed at meeting the primary goal of re-establishment of persistent wild populations of endangered fishes in the San Juan River. The Southwest Native Aquatic Resources and Recovery Center has been the primary source of stocked Colorado pikeminnow since 1996 in the Animas and San Juan Rivers. Between the years of 1996 and 2000, 832,449 larval and age-0 fish have been stocked in the San Juan River by the Utah Department of Wildlife Resources (Ryden 2003b).

The stocking of endangered fishes less than a year old has been tied to increased catch per unit effort of these species in the San Juan River. In 1997 and 2001, 49 and 148 adult Colorado pikeminnow were released, respectively (Ryden 2010). In subsequent years of monitoring, several hundred of these released fish have been recaptured through seining or electrofishing practices, 19 of these recaptures had recruited from the sub-adult to the adult stage (Ryden 2008a). In 2003, an Augmentation Plan for Colorado Pikeminnow in the San Juan River was finalized. This plan called for the annual stocking

of > 300,000 age-0 Colorado pikeminnow into the San Juan River for seven years (2003-2009) to facilitate establishing a population of > 800 adult Colorado pikeminnow in the San Juan River between the Animas River confluence and Lake Powell. An amendment to this plan also called for the stocking of 3,000 age-1 Colorado pikeminnow annually beginning in 2006 (Ryden 2005).

In 2009, significantly higher catch per unit effort of Colorado pike minnow was observed (Davis et al. 2009). In 2009, another augmentation plan was established through 2020 and called for the continued release of > 300,000 young-of-year Colorado pikeminnow (Furr 2011). In 2010, there were issues with largemouth bass virus that eliminated the ability of the Southwest Native Aquatic Resources and Recovery Center to release its reared fishes. In 2011, the plan was to move forward with phase II of the Augmentation Plan which calls for the release of $\geq 400,000$ Colorado pikeminnow in the San Juan and Animas Rivers (Furr 2010). Although the plan called for the release of age-0 fish only starting in 2011, the inability of the Southwest Native Aquatic Resources and Recovery Center to stock fish in 2010 resulted in the release of age-1 and age-2 fish in 2011 (Furr 2010). In 2011, stocking of 250,000 Colorado pikeminnow occurred at the PNM weir on the San Juan River, and another 150,000 Colorado pikeminnow in an area of the Animas River near its confluence with the San Juan River. Fish and Wildlife personnel seined the areas where Colorado pikeminnow were stocked to remove any predatory fishes. Next, block nets were set in place to confine the stocked fish to acclimate for approximately 24 hrs. The block nets were then removed and fish were

allowed to drift downstream naturally (Weston Furr, Personal Communication, October 2011).

Razorback Sucker

One of the goals of the San Juan River Recovery and Implementation Program is to establish self-sustaining populations of endangered razorback suckers and Colorado pikeminnow. Due to the lack of detection of wild razorback suckers through an extensive evaluation of all life stages in 1991-1993, the San Juan River Recovery and Implementation Program initiated experimental stocking of razorback suckers (Furr 2011). From March 1994 to October 1996, 942 razorback suckers were stocked between four stocking sites on the San Juan River (RM 158.6, 136.6, 117.5 and 79.6). Information from these released fish helped to identify year round habitat use, growth, survival and movements. Due to the success of these efforts, an augmentation plan was established for the annual stocking of razorback suckers by the San Juan River Recovery and Implementation Program beginning in 1997.

The augmentation plan called for the establishment of 15,900 razorback suckers, and it was estimated that to reach this goal within the river, 73,482 fish would need to be stocked between 1997 and 2001 (Ryden 1997). However, only 5,896 razorback suckers were stocked in the river at RM 158.6 due to inability of the program to acquire adequate numbers of fish from hatcheries. In an attempt to alleviate this problem, the San Juan River Recovery and Implementation Program acquired ponds for use at the Navajo Agricultural Products Industry. These ponds have since been used for the rearing of young razorback suckers and have been the primary source of stocked fish. The

razorback suckers are stocked in the ponds in the spring each year, and ≥ 300 mm fish are harvested in the Fall for stocking (Furr 2011). Although these ponds have increased the numbers of available razorback suckers for stocking, the numbers continue to fall short of management goals due to the unpredictability of production and growth. Despite numbers of stocked fish being limited, important information about movement and recruitment have been observed from recapture of razorback sucker in spring and fall monitoring trips (Ryden 2001).

Larval razorback sucker have also been observed in the San Juan River, but recruitment to the juvenile stage has not been observed (Ryden 2008a). Based on the information acquired an addendum to the augmentation plan was established in 2003 and called for an 8-year period of stocking from 2004-2011 (Ryden 2003b). Between 2002 and 2008, 52,084 razorback suckers were stocked owing to the stocking of all razorback suckers harvested from the ponds. Although there were a large number of razorback sucker stocked, many of them fell short of the target size of ≥ 300 mm. Due to the issues with the augmentation plan, the full 8-year plan was not initiated until 2009 and will continue through 2016 (Furr 2011).

Conclusions

Although removal efforts of invasive channel catfish and augmentation plans for the Colorado pikeminnow and razorback sucker have been established in the San Juan River recovery of these native fish has not been observed. In order to develop the most efficient strategy to mitigate the effects of the non-native species and allow for recovery

of the endangered fishes, an evaluation of the current population dynamics of the non-native fishes is necessary. This study evaluates the population structure and reproductive potential of the non-native channel catfish population in the San Juan River. These data will then be used by management personnel to develop a strategy targeting vulnerable life history stages of the non-native fishes and allowing for the recovery of the native fishes. The following chapters establish the population structure and condition of the channel catfish, as well as establishing a length at maturity matrix and reproductive potential analysis.

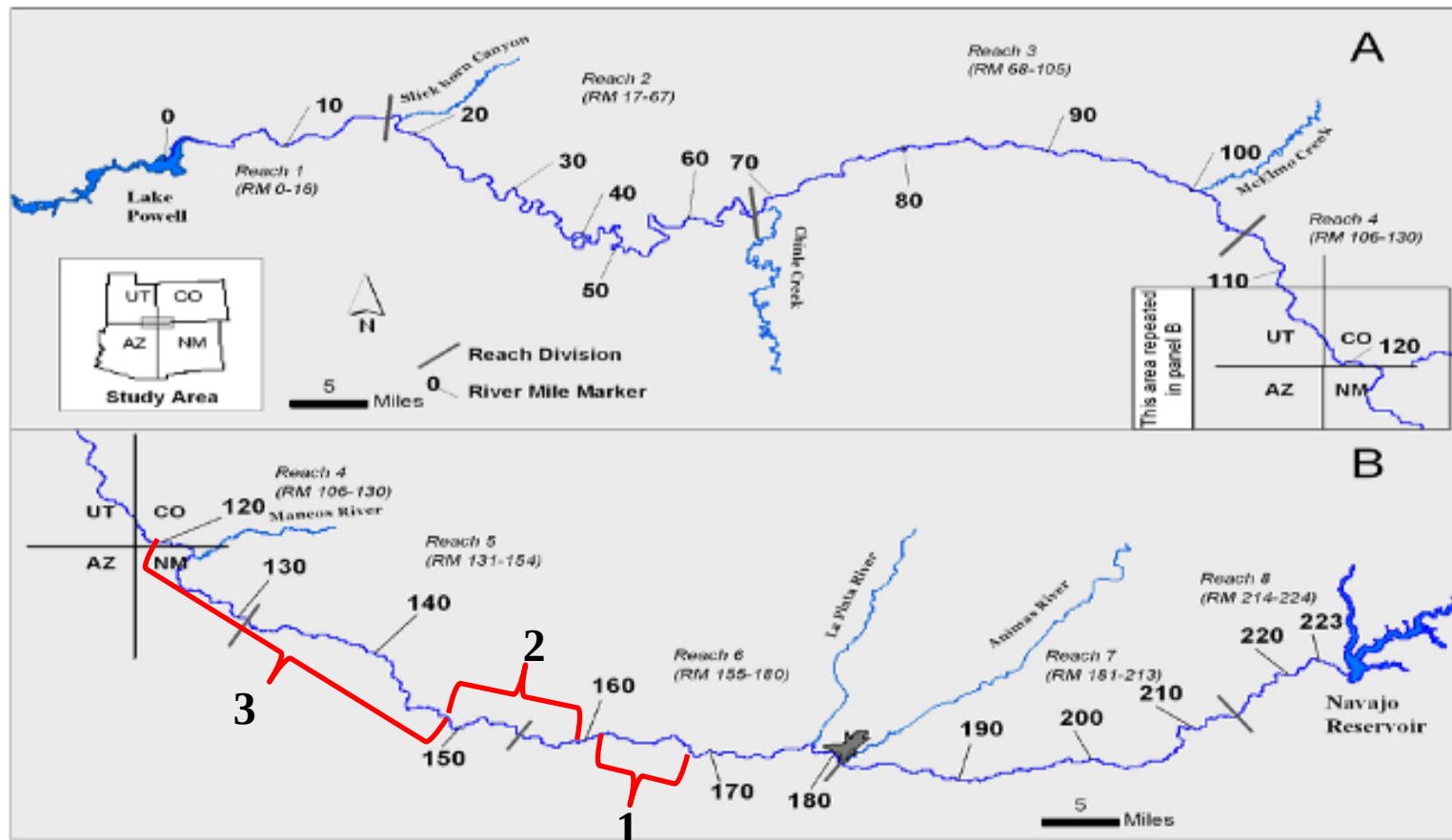


Figure 1: Map of study area and distinct sections sampled. Sections include section 1, PNM Weir to Hogback Diversion, section 2 Hogback Diversion to Shiprock Bridge and section 3, Shiprock Bridge to Mexican Hat.

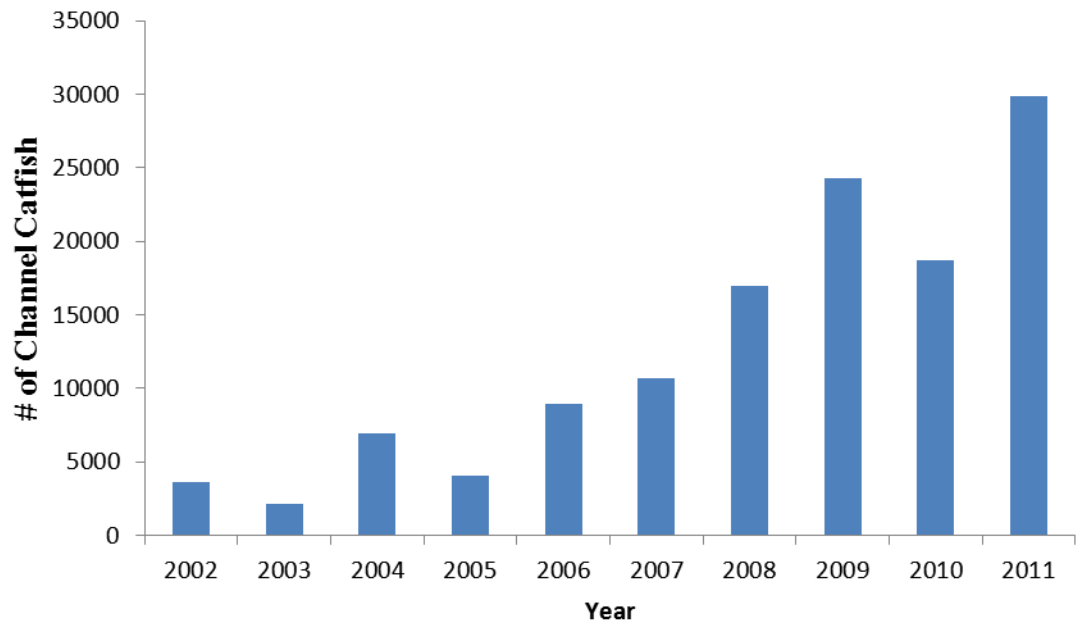


Figure 2: Total number of channel catfish removed from the San Juan River from 2002 to 2011.

CHAPTER 2

CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, POPULATION STRUCTURE
AND CONDITION IN THE SAN JUAN RIVER, NEW MEXICOAbstract

The San Juan River Recovery and Implementation Program has removed more than 136,000 channel catfish from the San Juan River from 2002 to 2011, but recovery of native fishes has not been observed. To assess the effects of removals on the population of San Juan River channel catfish, population structure and length at age data are needed. This information will allow the removal program to quantify the proportional contributions of fish from each year to the population and determine if channel catfish are responding to removal efforts. Since previous data are not available on the age length and condition of channel catfish in the San Juan River, these data will allow for future comparisons of the San Juan River channel catfish population to determine if there is a population response to removals. This study evaluates the structure of the channel population through determination of length frequency distributions, age at length determination and condition in the San Juan River, New Mexico in 2011. Channel catfish were removed using standard electrofishing practices and calcified structures were collected and analyzed for age determination. The majority of the fish removed were between 200-350 mm total length (TL) skewing the population size structure towards smaller individuals. The channel catfish population is truncated with 71% of fish age 3 or younger and less than 1% of fish age 10 and 11. Condition of the removed population

based on relative weights demonstrated that the channel catfish population is in better condition ($W_r=113$) than the standard condition for channel catfish of the same length in an unexploited environment. These data suggest that channel catfish are compensating for reduction in density with increased growth.

Introduction

Nonnative fish species can impact native fish species through direct and indirect competitive resource interactions or direct predation (Franssen et al. 2006). In the San Juan River system common carp (*Cyprinus carpio* L.), and channel catfish were introduced in 1880 and were commonly seen by 1910 (Grinnell 1914). Channel catfish in particular are an omnivorous species and may compete with native species for the same resources such as macro-invertebrates (Brooks et al. 2000). The success of these introduced species has been associated with the decline of native species and by 1960 the razorback sucker (*Xyrauchen texanus* Abbot) and Colorado pikeminnow (*Ptychocheilus lucius* (Girard)) were rarely seen in the lower portion on the river basin (Miller 1961). Since 1960, wild populations of razorback suckers and Colorado pikeminnow have continued to decline and the last razorback sucker taken from the upper portion of the Colorado River basin was in 1995 (Mueller 2006a).

Although many nonnative species are now common in the San Juan River, channel catfish are of the greatest concern due to their widespread distribution, high abundance and predation on native fishes (Sublette et al. 1990). Monitoring studies of adult fish in the San Juan River demonstrated that channel catfish accounted for the

largest percentage of large-bodied fish in the system (47.6% of total catch) (Ryden 2010). Monitoring and removal efforts on the main stem and secondary channels of the San Juan River sub-basin supported this notion as channel catfish and common carp were the most abundant and the most widely distributed of the 30 species collected (Brooks et al. 2000). However, although predation of channel catfish is a concern, especially due to high abundance of channel catfish in the system, studies have suggested that it may not be the cause of declining native populations. A study conducted to quantify piscivory of channel catfish (n=1000) on the San Juan River in 2011 failed to document any piscivory based on pharyngeal tooth counts (Patton unpublished data). Two hundred of these channel catfish were captured one week after the stocking of 350,000 endangered fish.

Due to the decline of the endangered razorback sucker and Colorado pikeminnow, the San Juan River Recovery and Implementation Program was established to mitigate the effects of nonnative fishes, and to quantify impacts of nonnative fish piscivory. Since 2001, efforts have been aimed at removal and monitoring of the channel catfish and other nonnative species in the San Juan River. Although the San Juan River Recovery and Implementation Program has been successful at removing more than 136,000 channel catfish, populations of native fishes such as the razorback sucker and Colorado pikeminnow have not recovered.

Although removal efforts have been successful in reducing the number of large channel catfish (> 300 mm TL) in the San Juan River system (Davis et al. 2009), populations of stocked endangered fishes still struggle with successful recruitment. This may be tied to a number of effects that can cause shifts in the age structure and

abundance of channel catfish in the San Juan River. Due to the plasticity of fish populations channel catfish may exhibit a range of responses to exploitation (Rose et al. 2002). Gerhardt and Hubert (1991) reported that in the Powder River drainage, the Ricker and Thompson-Bell model indicated that population structure and abundance of channel catfish would change considerably as exploitation rates increased. They reported that an annual exploitation rate of 22% would result in a 75% reduction in overall abundance of fish ≥ 300 mm TL and cause a substantial shift towards smaller individuals. Similar shifts in yield and population structure have been observed in sport and commercial fisheries as the rate of exploitation increased (McHugh and 1984; Pitlo 1997). Bonvechio et al. (2011) determined that the age structure of an exploited catfish population became truncated, with few larger individuals and a greater abundance of smaller individuals, but that there was evidence for higher recruitment and earlier maturation demonstrating the plasticity of catfish populations.

Because channel catfish removals are not allowing for a resurgence of native fish populations it is imperative that the population structure and reproductive potential (chapter 3) of channel catfish be quantified. These data will allow for comparisons with the channel catfish population in future years and enable the removal program to determine how the population is responding to removals. The objectives of my study are to determine the age/length structure of the channel catfish population in the San Juan River in 2011 and quantify the condition of the removed population of channel catfish. Lengths, weights, and pectoral spines were collected on channel catfish removed from the San Juan River from June to August 2011. Age was evaluated through analysis of

calcified pectoral spines and used with associated length, and weight data to determine the population structure. Condition was assessed by comparing the weights of the channel catfish with relative weights for channel catfish under normal growth conditions.

Materials and Methods

Study Area

The San Juan River is part of the Colorado River Basin which drains 632,000 km² in the western United States to the Gulf of California and northwestern Mexico (Carlson and Muth 1989). Several large sub-basins have been identified within the upper basin (i.e. Green, Colorado, Gunnison, San Juan). The San Juan River is a major tributary of the Colorado River and drains 99,200 km² in Colorado, Utah, Arizona, and New Mexico (Brooks et al. 2000). With the completion of the Navajo Dam in 1963, the upper 124km of river was isolated from the lower portion, and caused partially regulated 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 (Brooks et al. 2000).

The primary study area is divided into three removal sections, PNM (Power New Mexico) Weir to Hogback Diversion (River Mile (RM) 167.5-159), Hogback Diversion to Shiprock Bridge (RM 158.8–147.9) and Shiprock Bridge to Mexican Hat (RM 147.9–120.2). The section of river between PNM Weir and Hogback Diversion is relatively stable, with predominantly embedded cobble substrate and few secondary channels. Between Hogback diversion and Shiprock Bridge, cobble substrate still dominates,

although it is less embedded. Between Shiprock and Mexican Hat, the cobble substrate becomes mixed with sand to an increasing degree with distance downstream, resulting in decreasing channel stability. Except in canyon-bound sections, the river is bordered by nonnative salt cedar (*Tamarix chinensis*) and Russian olive (*Eleagnus angustifolia*) and native cottonwood (*Populus fremonti*) and desert willow (*chilopsis linearis*).

Population Sampling

In 2011, the three removal sections of the San Juan River were electroshocked for nonnative removal six times from June to August. Channel catfish were collected using raft-mounted electrofishing gear (pulsed direct current ~1.2 volts/cm). Electrofishing removals were conducted during daylight hours when stunned fish are most visible. Attempts were made to net all fish stunned near the front and sides of the raft (anode) with a three meter long dip net. Channel catfish collected during the removal efforts were held in oxygenated live wells aboard the removal vessels. When the live well became crowded fish were removed from the boats and euthanized in MS-222 solution. For each fish, the location, date, total length (TL), weight and sex were recorded. Total length was measured to the nearest one millimeter using a 1000 mm measuring board, and weight was measured to the nearest five grams using a range of spring scales. Both pectoral spines and otoliths were removed for aging.

Age Determination

Pectoral spines were sectioned below the basal groove using an 8000 series cordless Dremel tool with a #426 reinforced cutting wheel. Spine sections were sanded

down using #4 grit sandpaper, and sections were mounted on slides using Loctite® instant mix epoxy. Digital images were taken with a Leica® DM 2000 microscope and an attached RT KE Spot digital camera at 5x magnification. For each spine section, age was determined by counting the number of annuli from the middle to the perimeter of each spine following the technique of Campana et al. (2001). Two blind readers then aged the channel catfish spines and recorded their ages in a spreadsheet. Once ages were established, a length frequency histogram and age length key was constructed to quantify the population structure of the channel catfish population in the San Juan River, New Mexico.

Analysis

Population Structure. Data were tested for normality using the Leven's test, Gastwirth (2009), and data met the assumptions of normality. A length frequency histogram was constructed to demonstrate the distribution of total lengths of the removed channel catfish population. This length frequency histogram was used to compare the channel catfish population structure in the San Juan River with that of other exploited populations of catfish.

Length at Age. An age/length key was constructed for the 2011 San Juan River channel catfish population based on the proportional distributions of lengths for an estimated age. This table demonstrates the probability of a fish of total length "x" being of age "y". Each length group is associated with a probability of age and all samples within a row represent a single age class. Twelve distinct age categories were observed in

the channel catfish populations, but very few fish were captured of ages 10-12 (3, 1, and 0 fish respectively).

Condition and Relative Weight. Because of the curvilinear relationship of length to weight all length and weight data were log transformed. These data were used to construct a condition regression and determine the condition of the sampled population. Condition of channel catfish was calculated as $K = (W \cdot 100 / L^3)$, where W is the weight of the fish in grams and L is the length of the fish in cm. The relative weight of channel catfish was calculated using the standard weight equation. The standard weight equation for channel catfish, $\log_{10} W_s(g) = -5.800 + (3.294 \cdot \log_{10} TL(mm))$, established by Brown et al. (1995) was used to compare the relative weights of the removed channel catfish population in the San Juan River with that of standard weights for fish of equal size.

Age Bias. Due to bias that may exist in an age estimation of a single reader, or age estimator, it is important to validate ages by quantifying the amount of bias and precision that exists between readers. Ideally, validation is a comparison between fish of a known age relative to the estimated ages of the samples collected from a population, allowing for an estimation of accuracy. Because fish of known ages were not available for the population of channel catfish that were sampled for this study, a measure of bias and precision between readers was more appropriate for this study (Campana 2001; Campana et al. 1995). An age difference plot and an age bias graph were used to assess the bias between readers based on the methods of validation suggested by Campana et al. (1995).

Results

Population Structure

A total of 428 channel catfish were removed from the San Juan River for this study. Proportions of males and females in the removed population were 51.2% males ($n = 219$) and 48.8% females ($n = 209$). Average total lengths of males and females were 328.5 mm (± 6.22 SE), and 336.4 mm (± 6.47 SE), respectively. In 2011 the channel catfish population in the San Juan River was dominated by fish < 400 mm TL (80% $n = 341$). Fish < 300 mm TL comprised 44 % of the removed population ($n = 188$). Lengths of removed channel catfish ranged from 83-650 mm TL. A length frequency histogram illustrates the distribution of total lengths for the removed channel catfish population (Figure 3). The mean total length for channel catfish was 334.1 mm TL in 2011. With the exception of age 6 fish, the mean total length increased with age (Table 1). Total number of fish and average total length were calculated for each section sampled (Table 2). The uppermost section of the river, PNM to Hogback Diversion, had the fewest fish removed ($n = 64$), but had the highest average total length (380.1 mm) and the highest average weight (687 g). In the lower most section, Shiprock to Montezuma Creek, fish had the lowest average total length and weight (307.1 mm, 397.3 g, $n=101$). In the middle section of the river the average weight and length was between that of the upper and lower most sections (333.2 mm, 495.2 g, $n=263$), but yielded 61% of the total fish removed. Average age for channel catfish was highest in the upper most section, PNM to Hogback Diversion (4.7 years), and showed a decreasing trend in sections 2 (3.7 years) and 3 (3.1 years).

Length at Age

All channel catfish collected on the San Juan River in 2011 were between one and 11 years old. The differences in distributions of total lengths and ages are illustrated in age length key constructed for 2011 (Table 3). This key shows the probability of a fish of age “x” being of length “y”. Most fish collected in the San Juan River were three years old or younger (72%, n = 307). Less than 1% of the fish collected were of the ages 10 and 11 (3 and 1, respectively).

Condition and Relative Weight

The condition factor of the channel catfish population sampled in 2011 was 1.14. Condition factor for five of the seven 100 mm length groups was greater than one indicating that fish are of a healthy weight, and are not malnourished (Table 4). Condition of 100-300 mm fish was below one indicating these individuals are not of a healthy weight for their length. Condition was assessed using a condition regression analysis (Figure 5). The relative weights for the channel catfish population in the San Juan River in 2011 were greater than expected from a normal population for all 20 mm length categories except 170-189 mm (Figure 4). The overall relative weight for the removed channel catfish population was greater than would be expected from normal growth rates ($W_r = 113$, n = 428).

Age Bias

Evaluation of age estimation by two blind readers failed to demonstrate differences in ages based on reader bias. The age bias graph (Figure 6) shows the average

age assigned by reader 2 based on the age assigned by reader 1. The mean and 95% confidence intervals show that the variation in the ages assigned by reader 2 is small compared with reader 1. To quantify the amount of variation that exists between readers, the coefficient of variation was 17.76%.

Discussion

In 2011, the population of the San Juan River channel catfish was dominated by smaller channel catfish, < 400 mm TL (80%). In addition the age structure of the removed channel catfish population was heavily reliant on fish of age 3 or younger (72%). The distribution of total lengths is indicative of an exploited fish population where the reduction of larger size classes of fish causes a shift towards smaller fish dominating the population (Bonvechio et al. 2011). Similar to the exploited population studied by Bonvechio et al. (2011), the age structure of the population of San Juan River channel catfish was truncated resulting in many age 3 or younger individuals (n=307) and few individuals of age four to eleven (n = 121). The absence of larger size classes of channel catfish, and the presence of many smaller size classes also support the findings of Gerhart and Hubberd (1991), who suggested that moderate exploitation rates of fish populations would reduce the abundance of fish > 300 mm TL by 75%.

An evaluation of total lengths between the three removal sections shows that sections were not similar. The uppermost section of the river, PNM to Hogback Diversion, had the fewest fish removed, but had the highest average total length and the greatest average weight. These data show that the largest fish being removed from the

system are in the uppermost reach of the San Juan River. These findings suggest that channel catfish are occupying small home ranges in the upper most portions of the river as spawning sites during the spring and summer months as suggested by Pellett et al. (1998). In contrast, in the lower most section, Shiprock to Montezuma Creek, the lowest average total length and weight of all three sections (307.1 mm, 397.3 g, $n = 101$). However, the middle section of the river had average weight and length was between that of the upper and lower most sections (333.2 mm, 495.2 g, $n=263$), but yielded 61% of the total fish removed. There is a non-selective fish barrier at the Hogback Diversion which is essentially a shallow spot dominated by large cobble stone and boulders. This may be a bottle neck in the river for the channel catfish population since so many individuals were removed from this section. Average age of channel catfish was highest in the upper most section of the river and showed a trend of decreased average age in the two downstream removal sections. This suggests that channel catfish are moving farther upstream as they get older, which may be in response to reproductive age (chapter 3) and suitable spawning habitat.

Although we know the average total length of channel catfish in the sampled population it is important to compare these data with the total removed population of channel catfish from the San Juan River ($n=29,881$) to determine if the sample is representative of the population. The average TL of the removed channel catfish population in the San Juan River was 316 mm TL ± 3.6 (Duran et al. 2012). The average TL estimated for the population based on my analysis was 326 mm TL ± 4.2 . These data suggest that my estimate of TL based on my sampled population of channel catfish is

slightly higher than the mean of the total removed population. Because of this, I believe my sample population is a good representation of the removed channel catfish population in the San Juan River, NM. To be successful at suppressing an exotic fish population the primary effort must be aimed at reducing the number of large fish with high reproductive potential (Syslo et al. 2011). Therefore, determining where these large fish are residing as the seasons change is critical to establishing a successful removal effort. One factor to consider is that these fish may not be migrating the full length of the river every year, but may be residing in backwater and tributary habitats. Dames et al. (1989) found that 41% of channel catfish marked and released moved to tributary streams and of these most were > 250 mm TL. In addition, of the fish that were marked and released in tributary streams where they were collected, 79% of the movements recorded were within the tributary as opposed to from tributaries into the Missouri River. These data suggest that removing fish from the main stem of the San Juan River may not be the most efficient means of reducing the overall channel catfish population. Evaluations of tributaries and backwater habitats of the San Juan River should be conducted to determine the proportion of large channel catfish residing in these areas. If large adults are residing in backwater habitats for most of the year and reproducing, then they will be unaffected by current removal efforts and continue to contribute to the total channel catfish population of the San Juan River.

The plasticity of fish populations allows for compensation in growth, fecundity, and survival as a density dependent response to removals (Rose et al. 2000). In the San Juan River, the goal of the program is to reduce the population size of the channel catfish

to allow for successful reproduction and survival of wild populations of endangered fishes. To evaluate the success of this effort it is beneficial to determine if the suppressed population is compensating for a reduction in density by quantifying the response to removals.

The condition of the channel catfish population was greater than one indicating that fish have adequate resources to grow. Although stomach content analysis has determined that channel catfish are not preying on endangered fishes they may still be competing for resources with the native predatory Colorado pikeminnow. Another possibility is that the channel catfish has found some other source of nutrition not utilized by the native species such as the seeds of the non-native Russian olive tree (*Elaeagnus angustifolia* L.). Studies are currently underway to determine if channel catfish can derive nutrients from the Russian olive seeds as stomach content analysis found stomachs packed with the seeds (Tim Patton, unpublished data).

The relative weight for the removed channel catfish population ($W_r=113$) is similar to that of the exploited catfish population studied by Bonvechio et al. (2011) where the relative weight increased from 93 to 103 in just two years of intensive fish removals. Relative condition factors > 100 indicate that the removed population of channel catfish is in better condition than a population of catfish exhibiting normal growth rates. Bonvechio et al. (2011) suggested that the increase in relative weights of channel catfish was due to a compensatory growth response to exploitation. Although conditions of channel catfish could not be compared between years on the San Juan

River, the high relative weight of this population suggests that removal may be causing a density dependent response in growth.

If the channel catfish population did not exhibit a response in condition and reproductive potential (chapter 3), and the population remains dominated by smaller fish then removal efforts will be successful at reducing the population size (Knutsen and Ward 2011). However, in the San Juan River the population structure and relative condition of the removed channel catfish suggests that growth is similar to systems where intensive removals exist, in that the population is compensating for the reduction in density by growing quicker than fish in non-exploited systems. It is important however to compare population structure and condition of the San Juan River channel catfish over time to define the effects of removals. Because no data were available on fish collected at a similar time of year before removal, this comparison could not be made.

Table 1: Mean total length at age of channel catfish in the San Juan River, NM 2011.

Age (YR)	# at age	Mean TL (mm)	SD	Min	Max
1	18	203.6	19	156	226
2	140	256.3	30	180	333
3	149	325.9	36	228	523
4	25	385.3	48	322	512
5	8	449.8	36	409	530
6	14	438.5	38	379	512
7	29	455.8	63	283	581
8	26	476	46	379	579
9	15	516.7	46	457	650
10	3	536.7	58	499	604
11	1	555	0	555	555
Total	428				

Table 2: Average weight, total length, and age of channel catfish removed by section in the San Juan River, NM, 2011.

	PNM to Hogback	Hogback to Shiprock	Shiprock to Montezuma
Total Number Removed	64	263	101
Avg. Total Length (mm)	380.1	333.2	307.1
Avg. Weight (g)	687	495.2	397.3
Section length (km)	13.7	17.5	44.6
Fish per kilometer	4.67	15.03	2.26
Average Age	4.4	3.7	3.1

Table 3: Probabilities that removed channel catfish within a given length group is a certain age.

Total Length (mm)	Age (yrs.)											N
	1	2	3	4	5	6	7	8	9	10	11	
150	5.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
170	16.67	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
190	27.77	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
210	50.00	15.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
230	0.00	27.14	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
250	0.00	23.57	3.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
270	0.00	16.43	9.40	0.00	0.00	0.00	3.45	0.00	0.00	0.00	0.00	
290	0.00	7.86	13.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
310	0.00	5.71	23.49	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
330	0.00	0.71	26.18	20.00	0.00	0.00	3.45	0.00	0.00	0.00	0.00	
350	0.00	0.00	13.42	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
370	0.00	0.00	7.38	24.00	0.00	7.14	6.90	3.85	0.00	0.00	0.00	
390	0.00	0.00	0.67	16.00	12.50	28.57	3.45	0.00	0.00	0.00	0.00	
410	0.00	0.00	0.00	0.00	12.50	0.00	20.69	7.69	0.00	0.00	0.00	
430	0.00	0.00	0.00	8.00	37.50	28.58	6.90	19.23	0.00	0.00	0.00	
450	0.00	0.00	0.00	4.00	25.00	21.43	10.34	11.54	13.33	0.00	0.00	
470	0.00	0.00	0.00	4.00	0.00	0.00	13.78	15.37	13.33	0.00	0.00	
490	0.00	0.00	0.00	0.00	0.00	7.14	17.24	19.23	26.67	66.67	0.00	
510	0.00	0.00	0.67	4.00	0.00	7.14	6.90	11.54	6.67	0.00	0.00	
530	0.00	0.00	0.00	0.00	12.50	0.00	0.00	3.85	33.33	0.00	0.00	
550	0.00	0.00	0.00	0.00	0.00	0.00	6.90	7.70	0.00	0.00	100.00	
590	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.33	0.00	
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	0.00	0.00	
Total number	18	140	149	25	8	14	29	26	15	3	1	428

Table 4: Condition of the San Juan River channel catfish population in 2011

	Length Categories (mm)						
	0-100	101-200	201-300	301-400	401-500	501-600	601-700
Condition	1.75	0.79	0.93	1.03	1.13	1.10	1.29
# of Fish	1	10	172	148	67	28	2

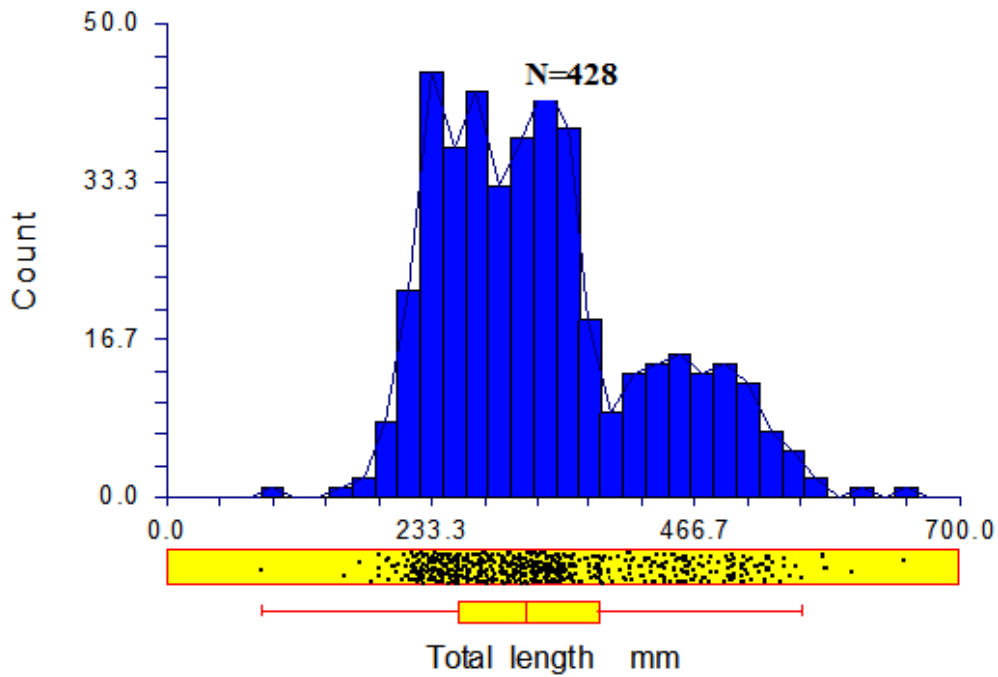


Figure 3: Length frequency histogram for the removed channel catfish population in the San Juan River 2011.

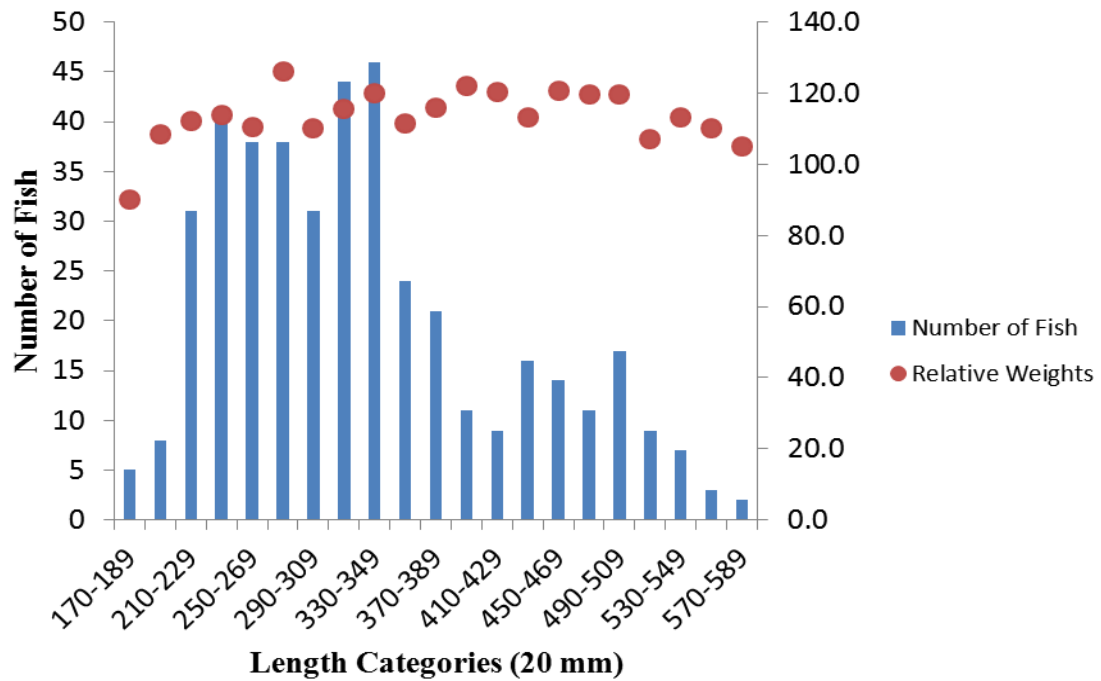


Figure 4: Graph of relative weights of channel catfish removed from the San Juan River, NM based on total lengths in 20 (mm) groups. Columns represent number of fish within each length category.

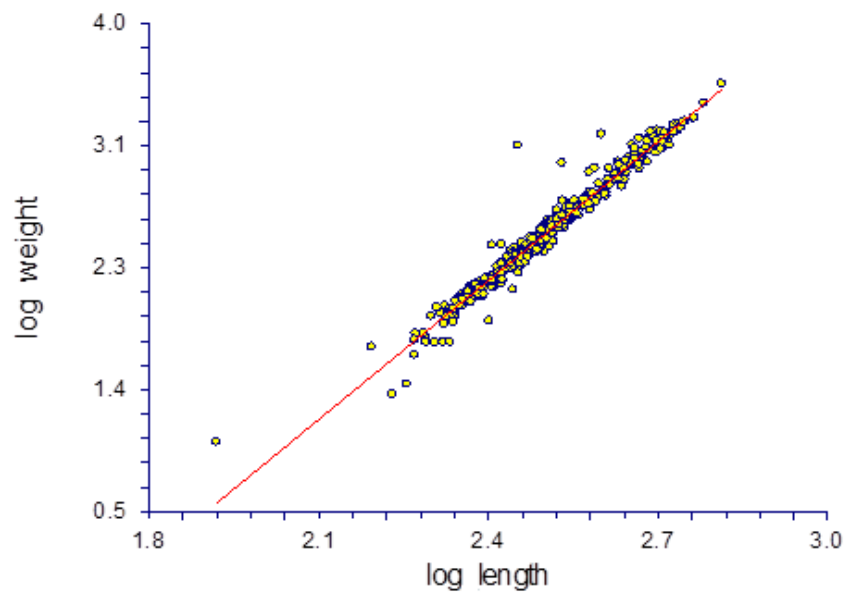


Figure 5: Condition regression for the channel catfish population in the San Juan River.

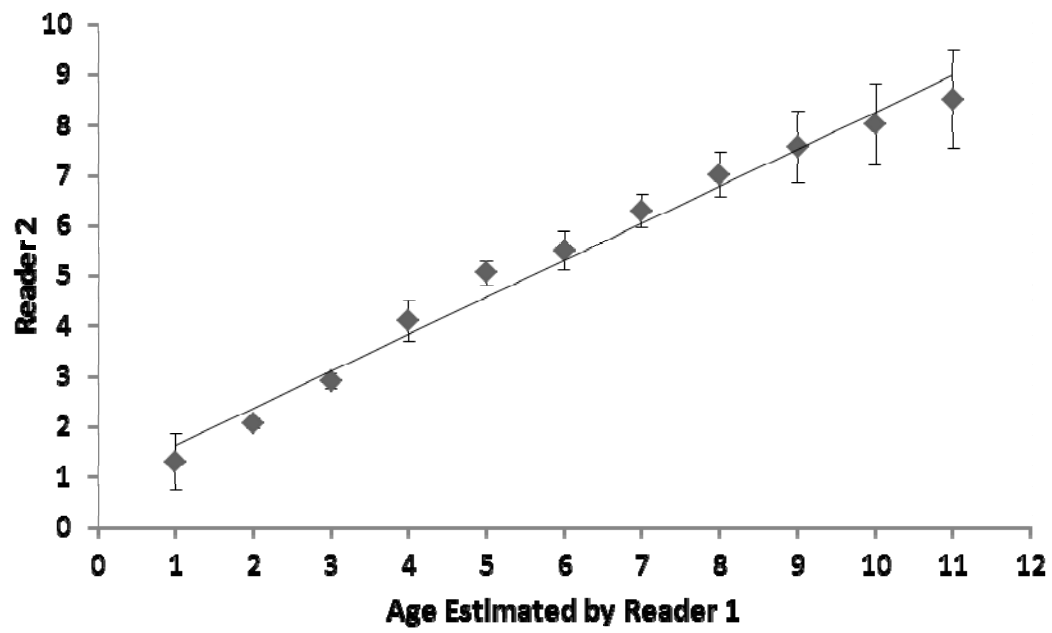


Figure 6: Plot of age estimated by reader 1 against age estimated by reader 2 with 95% confidence interval.

CHAPTER 3

EVALUATION OF CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, OVARIAN
MATURATION IN THE SAN JUAN RIVER, NEW MEXICOAbstract

Although the interactions between non-native and native fish species have been tied to the decline in the native populations, the impacts of the mitigation techniques for exotic species are not well understood. In the San Juan River, electroshock removal efforts have been established for more than 10 years. Although removal programs for exotic species have been successful at removing adult fish, few of these programs have evaluated the efficacy of these practices in reducing the overall population. An evaluation of removal programs allows for strategic implementation of removal based on targeting life history stages that are most closely tied to population growth. Although the electroshock technique is more effective at capturing channel catfish (*Ictalurus punctatus* (Rafinesque)) > 300 mm total length (TL), there have been no studies evaluating at what length the San Juan River channel catfish are reproductively active. This study evaluates the reproductive potential of the removed female channel catfish population in the San Juan River in relation to total length. Ovaries from 190 female channel catfish were collected in June 2011 and analyzed histologically to determine gonadal maturation. Only a small portion of the removed female population had the potential for reproduction in the San Juan River, and of these fish, all were > 400 mm in TL. Although suppression efforts have been most effective at removing channel catfish > 300 mm TL, the proportion of the

removed population that is reproductively active is small (3.6%). These data suggest that the San Juan River Recovery and Implementation Program should target reproductively active individuals more heavily to suppress the channel catfish population most efficiently. This information will act as a baseline for future research on the maturity status of the channel catfish population in the San Juan River and allow for comparisons between years.

Introduction

The introduction and establishment of non-native fish species in the Colorado River Basin in the late 1800's is the basis for ongoing research and removal efforts in the region today. There are many effects that non-native predators can have on the native biota which is dependent on the nature of the interactions between these species and their environment. In the San Juan River, the removals of channel catfish are aimed at suppression of the population of channel catfish to allow for the re-establishment of wild reproducing populations of the endangered razorback sucker and Colorado pikeminnow. Although approximately 30,000 channel catfish are removed every year from the San Juan River, the endangered populations have not exhibited resurgence (Duran et al. 2012).

Use of electric fields is an accepted approach for invasive fish removal because the strength of the electric field can be controlled, and there are no residual implications (e.g., piscicides, toxicants, etc.) after completion of electrofishing. Removal efforts for channel catfish on the San Juan River implement electrofishing rafts along the river

throughout summer months. Effects of electroshocking as a removal effort may have reproductive effects that have not been documented. A comparison of the stage of maturation based on total length between the years before to removal efforts and the current population would have allowed for determination of the extent of these effects. However, due to a lack of data and established protocols for evaluating maturity of the channel catfish in the San Juan River, it is currently impossible for this comparison to be made.

Electroshocking practices have been shown to be size selective, and in the San Juan River, the electrofishing gear is most effective on channel catfish > 300 mm total length (TL) (Davis et al. 2009). Although electrofishing gear is targeting fish > 300 mm TL, there are no data on the stage of maturity of these fish. Female channel catfish become reproductively active at age 3 in most systems (Davis 2009). However, factors affecting puberty in channel catfish include age, size, and number of annual cycles (Shepard and Jackson 2005). The normal spring reproductive pattern of the channel catfish occurs in May and June, with spawning only occurring once per year in natural environment (Davis 2009).

To successfully suppress exotic fish species in large bodies of water, reproductively active fish must be targeted and removed from the system (Syslo et al. 2011). In Yellowstone Lake, scientists have determined that population growth of the exotic lake trout was most sensitive to reproduction. As a result, Syslo et al. (2011) suggested that an increase in fishing selectivity towards mature adult lake trout may increase the success of suppression efforts. Since no studies have evaluated the

reproductive potential or structure of the removed channel catfish population in the San Juan River, it is unclear if removal efforts are targeting the fish with the highest reproductive contributions to the population. Based on these data, fish removed from the San Juan River in June were sampled to determine reproductive potential.

This study aims to establish the reproductive structure and potential and a probability matrix for stage of maturity based on TL of the removed population of channel catfish of the San Juan River. The probability matrix establishes the probability of a fish of length “x” being of maturity stage “y”. This will allow the removal program to determine the proportion of reproductively active fish being removed based on an evaluation of the TL of fish removed. These data establish a baseline for the current population of female channel catfish removed from the San Juan River and allow for future comparisons of stage of maturity to determine if shifts in size at maturity are occurring in response to electrofishing removal efforts.

Materials and Methods

Field Protocols

Three sections of the San Juan River are electro shocked multiple times during the course of a year for non-native fish removal. These sections are: PNM to Hogback (RM 167.5-159), Hogback Diversion to Shiprock Bridge (RM 158.8–147.9) and Shiprock Bridge to Mexican Hat, Utah (RM 147.9–52.9). During the month of June 2011, channel catfish removed from these sections were sampled. Channel catfish were collected using raft-mounted electrofishing gear (pulsed direct current ~1.2 volts/cm). Electrofishing

surveys were conducted during daylight hours when stunned fish were most visible. Attempts were made to net all fish stunned near the front and sides of the raft (anode) with a three meter long dip net. Channel catfish collected during the sampling efforts were held in oxygenated live wells aboard the removal vessels. When the live well became crowded, fish were removed from the boats and euthanized in a 200 ppm MS-222 solution. For 190 channel catfish, the location, date, TL, weight and sex, based on macroscopic observations, were recorded. Total length was measured to the nearest one millimeter using a 1000 mm measuring board. Whole body weight was measured to the nearest five grams using a range of spring scales. Gonads were removed from the female fish by cutting open the abdomen with a scalpel. Gonads were fixed in 10% phosphate buffered formalin, and stored in 500 ml plastic bottles. These ovarian samples were shipped to the Bozeman Fish Technology Center for further histological analysis.

Histological Analysis

Degree of maturation was determined through histological analysis of ovaries collected in the field. Gonadal tissue was embedded in paraffin and sectioned at five micrometers. Duplicate slides were made for each female. One slide was stained with Hematoxolin and Eosin and the other stained with Periodic Acid Schiff reagent (Luna 1968). Slides were examined under a compound scope (Leica DM 2000, Wetxlar, Germany, 100x-400x), and the germ cells were scored for stage of maturation. Nine stages were established based on the work of Quagio-Grassiotto et al. (2011), which evaluated oocyte development in freshwater catfish. The stages are shown in Table 3.

Fish were assigned to a stage based on the furthest developmental stage observed in the histological sample.

Probability Matrix

The established stages of maturation were used with the associated TL for each fish to construct a probability matrix for length at maturity. This table shows the proportion of fish of size “x” that are of maturation stage “y”. The purpose of the probability matrix is to allow management personnel to determine the proportion of reproductively active individuals they have removed from the population using TL as an indicator of stage of maturity in the female channel catfish removed from the San Juan River. This table can also be used with the previously mentioned age/length key to evaluate the estimated age at maturity for the female channel catfish (chapter 2).

Results

The reproductive structure of the removed population of female catfish was 0% Stage 1, 51.6% Stage 2, 18.4% Stage 3, 13.2% Stage 4, 0% Stage 5, 10.5% Stage 6, 2.6% Stage 7, 3.7% Stage 8 and 0% Stage 9. No fish were observed to have ovaries with only primary oogonia (Stage 1), as all fish collected were beyond this stage of ovarian development. No fish collected had ovaries containing ovarian follicles in the initial phase of yolk platelet deposition (Stage 5) or post ovulatory follicles (Stage 9). The developmental stage of the majority of the fish sampled ($n = 158$ or 83%) were at or before the pre-vitellogenic stage (Stage 2-Stage 4).

Probability Matrix

The probability matrix illustrates the proportional probability of a fish of length x being in Stage y of development (Table 4). The majority of the female channel catfish removed from the population (83%) had ovaries where yolk platelet deposition had not yet occurred (Stage 2-Stage 4). All fish designated as Stages 2 or 3 were between 200-400 mm TL, and all fish designated as Stage 4 were between 300-500 mm TL. No fish were Stage 5 as all ovaries examined were before or beyond early yolk platelet deposition. Only 12 of the 190 fish were sufficiently mature to spawn at the time they were collected. The fish that did have ripe ovarian follicles (Stage 7 and 8) were all > 400 mm in TL, with the exception of one fish that was stage 7 at 309 mm TL (Figure 5). All individuals found with ripe ovarian follicles were collected in June. Variability in the average total length of ripe (Stage 7 and 8) individuals may be due to the low sample size for those individuals (i.e., $n = 5$ and 7 fish, respectively).

Discussion

Based on the histological evidence from the channel catfish ovarian samples, 0 Stage 1, 98 Stage 2, 35 Stage 3, 25 Stage 4, 0 Stage 5, 20 Stage 6, 5 Stage 7, 7 Stage 8 and 0 Stage 9 females were removed from the channel catfish population of San Juan River. Since only Stage 7 and 8 fish are capable of successfully spawning, this demonstrates that although many channel catfish are being removed each year, few are mature enough to reproduce. The probability matrix suggests that female channel catfish are able to spawn at > 400 mm in TL as 11 of the 12 fish with mature ovaries were

between 400-600 mm TL. There was one channel catfish in Stage 7 of development that was 309 mm TL. In addition, the probability matrix demonstrates a trend towards larger fish size at further developmental stages, as the majority of Stage 2 fish (55.1%) were between 200-300 mm TL, Stage 3 fish (48%) were between 300-400 mm TL, Stage 4 fish (44%) 300-400 mm TL, Stage 6 fish (70%) 400-500 mm TL, and Stage 7 fish (80%) 500-600 mm TL.

No fish were observed to have ovaries with only primary oögonia (Stage 1), as all fish collected were beyond this stage of ovarian development. This demonstrates that the removal efforts are targeting channel catfish that have initiated gametogenesis, but few of these fish are reproductively active. No fish collected had ovaries containing ovarian follicles in the initial phase of yolk platelet deposition (Stage 5) indicating that vitellogenesis may be initiated earlier in the spring or in the fall. This is indicative of most channel catfish populations as oocyte development begins in late April and May and samples were collected in late June (Banks et al. 1999). The lack of post ovulatory follicles (Stage 9) in June suggests spawning has not yet occurred. Since spawning occurs in June and July for channel catfish populations, with water temperatures between 23-32 C°, (Banks et al. 1999; Wellborn 1988), these fish most likely have not yet spawned (Davis 2009). However, it is also possible that the reproductively active channel catfish in this population are utilizing backwater habitat during spawning and are missed during sampling. Since removal efforts target the main stem of the San Juan River, it is possible that many reproductive individuals are missed in June when spawning occurs.

The majority of the fish sampled ($n = 158$ or 83%) were at or before the pre-vitellogenic stage (Stage 2-Stage 4). These fish are of adequate TL for sexual maturity (Shepard and Jackson 2005), however a study evaluating the predictability of channel catfish maturation based on age and size determined that age is a better indicator of spawning readiness in this species (Davis et al. 2005). Based on the age/length keys constructed for this removed population in the previous chapter, fish that were mature enough to spawn were > 400 mm TL. Fish of this TL coincides with fish of age 3 or greater, but of the fish from the sampled population that were > 400 mm TL, only two of the 72 age-3 female channel catfish were mature enough to spawn in 2011. Most reproductively active channel catfish were age 7 or greater (67%). As female channel catfish in most systems are reproductively active at 3 years of age (Davis 2009; Banks et al. 1999), the female channel catfish in the San Juan River appear to be reproductively active at an older age.

Although channel catfish > 400 mm are readily being removed from the population, very few of the individuals removed are reproductively active. However, one means by which to assess the reproductive potential removed is to quantify the number of eggs removed through adult fish removals. Walser and Phelps (1993) suggested that female channel catfish produce 7,759 eggs/kg of body weight. Based on the weights of the reproductively active channel catfish removed (16.2 kg) 125,618 channel catfish eggs were removed from the system. The concerns with removal of reproductively active fish in the San Juan River are similar to the concerns of the lake trout suppression group in Yellowstone Lake. The suggestion was made to increase net size to remove larger lake

trout and therefore a greater amount of reproductive potential from the population (Syslo et al. 2011). Although the San Juan Rive Recovery and Implementation Program does not use netting as its means of removal for channel catfish, it is suggested that the removal techniques used be modified to target a larger number of reproductively active fish (400 mm TL). This may include removals in tributary streams and backwater habitat during spawning season to ensure capture of reproductive individuals.

In Oregon, predation of salmon smolts has led the department of fish and game to establish a suppression effort for northern pikeminnow (Friesen and Ward 1999). Pikeminnow >250 mm fork length were exploited by 10-20% to allow for higher survival of the salmon smolt. Similarly, predation was the initial rational behind the establishment of the removal program in the San Juan River. However, Knutsen and Ward (2011) evaluated the population pre and post exploitation to determine if fecundity had changed. Due to lack of data on pre-removal channel catfish, this is not possible for the channel catfish population in the San Juan River. Knutsen and Ward (2011) acknowledged that removals would have little benefit if exploited northern pikeminnow populations exhibit increased fecundity (Knutsen and Ward 2011). When evaluating the fecundity of the northern pikeminnow, there was no evidence for increased fecundity, and therefore removals should continue to diminish the population (Knutsen and Ward 2011). However, in the San Juan River, this analysis has yet to be conducted due to the lack of data on the pre-removal population of channel catfish. To better assess the effectiveness of suppression efforts for the channel catfish population in the San Juan River, an evaluation of changes in fecundity due to exploitation of fecund individuals must be

conducted. Understanding the relationship between numbers and sizes of channel catfish removed and the reproductive potential of those removed is critical to establishing a successful suppression program.

Table 5: Stages of gonadal development identified from gonadal biopsies of channel catfish removed from the San Juan River, NM.

	Developmental Stage	Description
Females		
Differentiation	1	Clusters of oogonia in a nest
Primary Oocyte	2	Not separate from the nest
Ovarian Follicle	3	Fully formed follicular layer; separate from the nest
Zona Pellucida	4	Zona Pellucida fully formed
Early Vitellogenesis	5	Few yolk platelets formed
Mid Vitellogenesis	6	Fully packed with yolk platelets; central nucleus
Post Vitellogenesis	7	Nucleus migrating toward animal pole
Oocyte Maturation	8	No nucleus present
Post ovulatory Follicle	9	Remnant follicular layers and primary oocytes

Table 6: Probability of maturation Stages 1-9 based on total lengths of channel catfish removed from the San Juan River, NM.

Maturation Data for 2011 Based on Length							
	Total Length (mm)						#Fish
Stage	0-100	101-200	201-300	301-400	401-500	501-600	
1	*	*	*	*	*	*	0
2	*	5.1%	55.1%	37.8%	2%	*	98
3	*	*	37.1%	48.6%	5.7%	8.6%	35
4	*	*	8%	44%	36%	12%	25
5	*	*	*	*	*	*	0
6	*	*	*	*	70%	30%	20
7	*	*	*	20%	*	80%	5
8	*	*	*	*	85.7%	14.3%	7
9	*	*	*	*	*	*	0

CHAPTER 4

CONCLUSIONS

The results of my study suggest that the channel catfish population in the San Juan River may be compensating for numbers of removed individuals over the past decade. Channel catfish in 2011 were in better condition than would be expected for channel catfish of the same length under normal growth conditions. Maturation data suggest that channel catfish may be maturing at an older age than catfish in unexploited systems. These data show that, although some compensation to removal efforts may be occurring in the San Juan River, there is no evidence for earlier maturation as a response to removals. However, only 12 of the 190 channel catfish were capable of spawning in 2011. Due to the low number of sexually mature channel catfish in my sampled population and the abundance (83% of total catch) of non-reproductive channel catfish < 300 mm TL, I believe that there are many reproductive individuals that were not adequately sampled in 2011. Since removals are spatially limited to the main channel of the river, it is likely that older and larger individuals were not removed because they move out of the main channel to spawn or feed.

With so many small, young individuals being recruited into the population every year it is unlikely that there are so few reproductively active adults in the system. I believe that the majority of the reproductively active adult channel catfish are residing in tributary streams and backwater habitat and that juvenile fish are entering the main channel of the San Juan River from these unexploited areas. I suggest that a telemetry

study be conducted to determine the location of the spawning population of channel catfish. Telemetry data may also aid in our understanding of the movement patterns of the spawning portion of the channel catfish population. This information will allow management personnel to determine if removal efforts on the main channel of the San Juan River will be effective at reducing the proportion of reproductive individuals and the overall population size.

To aid in the recovery of the native endangered species, 13 new off channel habitats are being constructed on the San Juan River from 2011-2012. Although the goal of this project is to increase habitat availability for native species it is likely that the non-native channel catfish will utilize these new sites as well. It will be important to sample these newly established sites to determine if this new habitat is more beneficial to the native or non-native fishes. Evaluating these sites may also allow for some insight into how channel catfish may be competing with native fishes. In addition, sampling these areas may help to determine which fish species are able to utilize these new habitats first and if they are able to continue to reside there or are forced out.

In 2011, a mark recapture study was initiated by the San Juan River Recovery and Implementation Program for channel catfish in the San Juan River. These data will be critical in determining any patterns in occupancy and seasonal site selection that could lead to a more efficient removal of larger channel catfish. Although capture efficiency is low in the San Juan River due to high turbidity, mark recapture estimates may also aid in determining a population estimate for channel catfish in the San Juan River. However, for

this to be effective it is necessary to determine if a large proportion of the population is residing in off channel habitat.

Although mean total length of channel catfish sampled for this study (326 mm TL) was slightly higher than the mean total length of the total removed channel catfish population (316 mm TL), I believe that I have a good representation of the removed population. Because of this, I have confidence that the increased length at age observed in my sample is representative of the population. In addition, I believe that the relative weight data strengthen the point that fish are larger at a given age than would be expected under normal growth rates. Although these data suggest that some responses to removals are occurring on the San Juan River, a comparison of channel catfish population structure and age at maturation between years is necessary to determine significant responses of the channel catfish population to removals.

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