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NONNATIVE FISHES

OF THE

GRAND CANYON

A REVIEW WITH REGARDS TO THEIR EFFECTS ON NATIVE FISHES

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GLEN CANYON ENVIRONMENTAL STUDIES

1992

To Mike
my Beloved Compatriot.
Heros to all the nominatives
in GC, ourselves included

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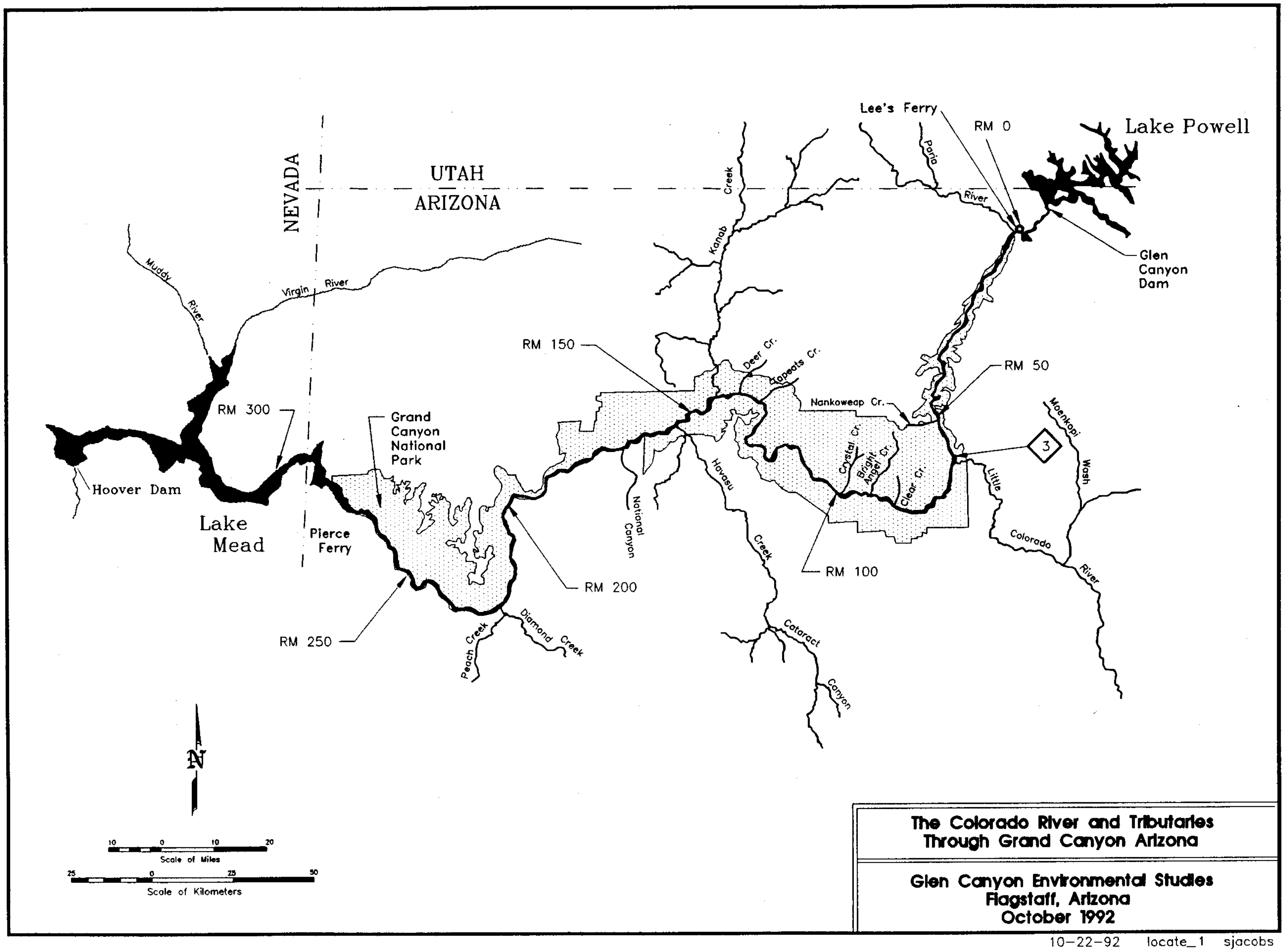
Lake Powell
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I. INTRODUCTION

For the last one hundred years, human activities have influenced the fish fauna of the Colorado River either by manipulation of the water resources, anthropogenic predation pressure or the additions of exotic fish fauna. Since the implementation of the Endangered Species Act of 1973, scrutiny has been given to how habitat alterations impact the well being of native fish populations in the Colorado River.

A major purpose of the Glen Canyon Environmental Studies (GCES) Phase II studies is to address the impacts of Glen Canyon Dam operations on the endangered humpback chub (Gila cypha) and razorback sucker (Xyrauchen texanus) populations in the Grand Canyon. Additional attention is being given to the effects of introduced fish species on populations of native fishes. The effects of nonnatives on native species take on significant proportions in the light of certain operational alternatives and supporting actions being considered in the upcoming Glen Canyon Dam Environmental Impact Statement (GCDEIS), which would alter the physical environment of the existing system. Changes in operating regimen could allow the entry and development of detrimental fish populations in the Grand Canyon system and/or allow an existing nonnative species to gain an ecological advantage over native fish populations. The objective of this paper is to examine, by means of a literature review, the introduction of nonnative fishes into the Grand Canyon aquatic system, and to ascertain what effects nonnative fish have on the native fishes. This report is intended to meet, in part, study review requirements of the Fish and Wildlife Coordination Act and the GCDEIS.

II. THE PRISTINE ENVIRONMENT AND NATIVE ICTHYOFAUNA

The pristine conditions of the Colorado River through the Grand Canyon were much different than the dam influenced river of today. Predam peak discharges during spring runoff events averaged 2400 cubic meters/second. Secondary hydrologic peaks occurred during summer thunderstorm activity. These discharges were not as high as the spring runoff discharges, however they contributed large amounts of silt to the river system. The constant reworking and transportation of these silt deposits created a turbid river with a constantly changing substrate (Howard and Dolan, 1981). Temperature ranges in the pre-dam era ranged from winter lows of just above freezing to summer highs up to 28°C (Stanford and Ward, 1991).

The harsh conditions and isolation of the Colorado River has given rise to a unique fish fauna, which were highly adapted to the Colorado River's extremely variable environment. Although this assemblage consisted of only eight species, it exhibits a high degree of endemism (Minckley, 1982). Historic collection notes and reports from early explorers journals provide an incomplete pre-dam distribution of native Colorado River fish (Cope and Yarrow, 1875; Powell, 1875; Kolb and Kolb, 1914). The interactions of the biotic community in a pristine habitat can only be surmised from general knowledge of the fish populations as we know them today (eg. W. L. Minckley, 1991). In light of historical records, the range and abundance of many native fish have been greatly reduced by introduction of nonnative species and changes in environmental conditions caused by water projects and land use practices. (Miller, 1961).

NATIVE COLORADO RIVER FISH

Common Name	Scientific Name
humpback chub	Gila cypha
bonytail chub	Gila elegans
roundtail chub	Gila robusta
speckled dace	Rhinichthys osculus
Colorado squawfish	Ptychocheilus lucius
flannelmouth sucker	Catostomus latipinnis
bluehead sucker	Catostomus discobolus
razorback sucker	Xyrauchen texanus

III. THE NEW ENVIRONMENTAL CONDITIONS

Hydrologic conditions in the Colorado River in the Grand Canyon reach have been controlled by Glen Canyon Dam and Lake Powell since 1963. Except for short periods in 1965 and 1980, flows in the river have been at or below power plant capacity of 900 cubic meters/second. Beginning in 1983 and extending into 1986 flows exceeded powerplant capacities. These floods were of greater magnitude and longer duration than flows experienced in the post-dam period (Maddux et al., 1987). Sedimentation in the reservoir has reduced the amount of sediment available to the river. Measurements of sediment load at the U.S. Geologic Survey Lees Ferry gauge indicate a pre-dam/post-dam change from an average load of 1500 parts per million (ppm) to 7 ppm (Howard and Dolan, 1981).

Water release temperatures from Glen Canyon Dam are much less variable than the temperature fluctuations in the pre-dam river. River water temperatures have not ranged much from 8.8°C. Temperatures in the mainstem change very little as releases travel through the canyon. Temperatures have been recorded between 5 and 15°C at the Grand Canyon gauging station (RM 87) (Stanford and Ward,1991). However, certain flow scenarios combined with weather conditions may influence local temperatures. Temperatures observed in backwaters in the western end of Grand Canyon exceeded 25°C under steady flows while the main channel remained cold (Maddux et al., 1987). The level of storage in Lake Mead affects the distribution of warm water in the lower end of the canyon. The point of influence may vary from around Separation Canyon (RM 240) during high lake elevations to Pierces Ferry (RM 280) at low lake elevations.

Productivity of the river is now almost entirely autochthonous. The clear water releases from Glen Canyon Dam allow more light to penetrate the water column, providing more energy for primary and secondary production. The basic primary producer is the abundant green algae, Cladophora glomerata. Diatoms and other periphyton living attached to the Cladophora, aquatic diptera and an introduced amphipod, Gammarus lacustris, form the aquatic food base for fish in the river. (Usher et. al., 1988; Leibfried, 1988).

Currently, four of the native fish species in the Grand Canyon are listed as Federally Endangered: Gila cypha, Gila elegans, Xyrauchen texanus and Ptychocheilus lucius (U. S. Fish and Wildlife Service, 1991). Both the bonytail chub (Gila elegans) and the Colorado River Squawfish (Ptychocheilus lucius) are believed to be extirpated from the Grand Canyon reach of the Colorado River. The last reported capture of a squawfish was in 1975 at the mouth of Havasu Creek (Smith et al., 1979 as reported by W.L. Minckley, 1991).

Table 1. Relative abundance of fish species in the Colorado River between Glen Canyon Dam and Diamond Creek - predam to present day.

Species	1958 - 1959	1967 - 1968	1968	1967 - 1973	1975	1976	1977 - 1978	1984 - 1986	Present
NATIVE									
Colorado squawfish	R	R	-	-	R	-	-	-	-
Razorback sucker	R	-	-	-	-	-	R	R	-
Bluehead sucker	-	C	C	C	A	C	C	C	C
Flannelmouth sucker	C	A	C	C	A	C	C	C	C
Humpback chub	-	C	R	R	R	R	LC	R	LC
Speckled dace	A	-	C	A	A	A	C	A	A
NONNATIVE									
Cutthroat trout	-	-	-	-	-	-	I	R	R
Rainbow trout	-	A	C	C	C	C	A	A	A
Brown trout	-	R	-	-	C	-	C	C	LC
Brook trout	-	-	-	-	-	C	C	C	R
Coho salmon	-	-	-	I	R	R	-	-	-
Virgin River spine dace	-	-	-	-	-	R	-	-	-
Common carp	C	A	C	C	C	A	A	A	A
Utah chub	R	-	-	-	-	-	-	R	-
Fathead minnow	A	-	A	R	A	-	C	A	C
Red shiner	-	-	C	-	C	R	-	-	-
Redside shiner	-	-	-	-	-	-	-	-	-
Golden shiner	-	-	-	-	-	R	R	R	-
Channel catfish	A	A	A	R	R	-	C	R	LC
Black bullhead	-	-	-	-	C	-	-	R	-
Yellow bullhead	-	-	-	-	-	-	-	R	R
Striped bass	-	-	-	-	-	-	R	R	R
Killifish	R	-	-	-	LC	C	LC	R	LC
Walleye	-	-	-	-	-	-	-	-	R
Woundfin	-	-	-	I	-	-	R	-	-
Largemouth bass	-	-	-	-	-	-	R	R	R
Green sunfish	-	-	-	-	LC	-	R	R	-
Bluegill	-	-	-	-	-	-	R	-	R
Threadfin shad	-	-	-	-	LC	R	-	-	-

A = Abundant
C = Common
LC = Locally Common
I = Initial Introduction
– = No Record

* 1958 – 1959 from McDonald and Dotson, 1960 (Glen Canyon only)

1967–1968 from Stone and Rathbum, 1968

1968 from Miller and Smith, 1968

1967–1973 from Holden and Stalnaker, 1975

1967 – 1973 from Minkley and Blinn, 1976

1975 from Miller, 1975

1976 from Suttkus et al., 1976

1977 – 1978 from Carothers et al., 1981

1984 – 1986 from Gustveson, et al., 1987

Present from AGF and Bio/West, Inc. preliminary data, unpublished.

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The status of the razorback sucker (Xyrauchen texanus) is unknown. Numbers are so reduced that it is only rarely seen in the river. Arizona Game and Fish Department researchers captured a razorback in the Grand Canyon in 1984 near Shinumu Creek. (Maddux et al., 1987). Recent collections around the mouth of the Little Colorado River (LCR) have also reported razorback suckers or hybrids (C. O. Minckley, 1990). Humpback chub (Gila cypha) are common in the Little Colorado River and around its confluence with the main Colorado. Three native fishes, speckled dace (Rhinicthys osculus), bluehead sucker (Catostomus discobulus), and flannelmouth sucker (Catostomus latipinnis) are present throughout the river.

The status of endangered fish species in the Grand Canyon is given below (U.S. Fish and Wildlife Service, 1991).

STATUS OF FEDERALLY PROTECTED COLORADO RIVER NATIVE FISH

SPECIES	DATE LISTED	STATUS
Colorado River Squawfish (Ptychocheilus lucius)	March 11, 1967	endangered
Humpback chub (Gila cypha)	March 11, 1967	endangered
Boneytail chub (Gila elegans)	April 23, 1980	endangered
Razorback sucker (Xyrauchen texanus)	October 17, 1991	endangered

IV. INTRODUCED FISHES

In addition to the native species still inhabiting the Grand Canyon there are capture records for at least 24 introduced species. These species have been introduced via efforts to create sport fisheries, by immigration from Lake Mead and Lake Powell, or by "bait bucket" introductions. Each introduced species has a unique history in the Grand Canyon and each will be discussed separately in regards to its impact on the native fish fauna of the existing river system. Spawning requirements and food habits are discussed briefly to provide insight into each species impact on native species.

Since 1968 there have been eight icthyological studies of the Grand Canyon region, including the current studies under the aegis of the Glen Canyon Environmental Studies. A ninth study, McDonald and Dotson, 1958, was conducted in Glen Canyon and is included because of its close proximity to the study area. These studies were conducted by different organizations with varying goals and methods. It is impossible to arrive at specific trends for fish populations by comparing data sets. Each sampling method works best in specific types of habitat and accordingly is biased towards species using that habitat. Each researchers interpretation of species abundance rather than specific catch rates or densities were used to track population trends for each species (See Table 1). Accounts for each species found in the Grand Canyon are organized under family sections and a separate section for incidental species.

CYPRINIDAE

Common carp

Common carp (Cyprinus carpio) were among the first species to be introduced into the Colorado River. The U.S.Fish and Wildlife Service (1980) list the introduction of this species into the Colorado River system in 1890.

During this period the U.S. Fish Commission planted carp into many different drainages throughout the country as a game fish. Carp have since spread in the Colorado River drainage and are one of the most abundant fish through out the river system. In the Grand Canyon, catch rates for carp in the mainstream increase below the confluence of the Little Colorado River (Maddux, et al., 1987; Bio/West unpublished data, 1991). C.O. Minckley (1990) found carp to be one of the most abundant nonnative fish in the LCR during the months of April and May. In the river above the LCR, congregations of carp have been observed around springs or tributary mouths where warmer water comes into the main stem. In addition to tributaries, submerged vegetation along the banks also seems to be a favored habitat in the lower river (Carothers and Minckley, 1981).

Carothers and Minckley (1981) indicated carp spawning occurred in Grand Canyon from late winter through August. They noted a preference for low gradient streams with temperatures between 19 and 22°C. Temperatures are favorable for spawning in the LCR as well as Kanab Creek. Successful spawning in the LCR was verified when young-of-the year (YOY) carp were captured (C.O. Minckley, 1989). Fish present in the canyon are also thought to be migrants from Lake Mead or from the LCR (Carothers and Minckley, 1981).

Carp are omnivorous, feeding on a variety of plant or animal detritus found either floating on the surface or in bottom ooze (Scott and Crossman, 1973). Predation on early life stages of native fishes has not been documented in the Grand Canyon. However, carp have been observed feeding immediately downstream of spawning bluehead suckers in Kanab Creek (M. Yard, pers. com, 1991). C.O. Minckley (1990) speculated that large schools of carp, observed congregating in the LCR, were feeding on the eggs and larval stages of native fish. Total loss of an introduced stock of larval razorback suckers in Lake Mohave was attributed to an invasion of a breeding pond by carp and green sunfish (Lepomis cyanellus) (Marsh and Langhorst, 1988).

Fathead minnow

Fathead minnow (Pimephales promelas) have become widespread throughout the lower Colorado River system primarily through their use as a bait fish. Researchers have found them to be common in the Little Colorado River (Minckley, 1990). Fathead minnows increase in abundance towards the western end of the canyon (Maddux et al., 1987), favoring more turbid waters. Most collections made in the Grand Canyon are from backwaters, quiet eddies and submerged vegetation with slowed current velocities. Hubbs and Cooper (1936) found that this fish was relatively intolerant of other species and achieved its greatest abundance when isolated.

Fathead spawning occurs at temperatures at or above 15.6°C. Maturity can be reached in less than a year under optimum conditions. Fish hatched in spring could be spawning by the end of the summer (Markus, 1934). Arizona Game and Fish researchers felt that although this introduced species had persevered through the closure of Glen Canyon Dam, fluctuating flows might hinder its reproduction by flushing young fish from warmer backwaters out into the main river (Maddux et al., 1987).

Fatheads are not considered piscivorous. Their food consists of detritus, algae and other microscopic items (Scott and Crossman, 1973). Fathead minnows have been shown to behave aggressively towards young native fishes in backwater situations. This was considered to be a factor in the decline of Colorado River squawfish in the Upper Basin of the Colorado River (Karp and Tyus, 1990). The same interactions can be expected for fatheads and young humpback chubs occupying backwater habitats in the Grand Canyon. Holden and Stalnaker (1975) felt that due to low densities in Grand Canyon fatheads did not present a serious threat to native fish populations.

Red shiner

Red shiner (Cyprinella lutrensis) was first introduced into the Colorado River in the late 1940's, escaping from bait rearing ponds along the river, and further spreading through "bait bucket" introductions. (Hubbs, 1954). Red shiners were reported as common in the main river between Lees Ferry and Diamond Creek during 1968 (Miller, 1968). This species was common in the Glen Canyon Dam tailwaters area up until the 1967 - 1968 sampling season after which they were not collected. (Stone and Rathbun, 1968). In later years, only a few individuals were reported in the lower end of the river near Lake Mead (Sutkus, 1976). McCall (1981) hypothesized this decline as related to cold water releases from Glen Canyon Dam. Currently, red shiners are one of the most abundant fishes in Lake Mead occurring as far upstream as Spencer and Surprise Canyons (McCall, 1981).

Red shiners spawn at temperatures between 15 and 30° C. They mature in the first year and seldom reach a size of more than 80 mm or exceed 3 years in life (Scott and Crossman, 1973). McCall (1981) reports that they are opportunistic feeders, feeding in schools on plankton and insects both at the surface and in the benthic zone of Lake Mead.

The red shiner has proven to be a highly competitive nonnative displacing other native minnows where it becomes established. Minckley and Deacon (1968) reported the displacement of the spikedace (Meda fulgida) from its native habitat in the Verde River. McCall (1981) reports a similar interaction with the loachminnow (Tiaroga cobitis) in the Gila River.

CYPRINODONTIDAE

Rio Grand killifish

Rio Grande killifish (Fundulus kansae) has been in the Little Colorado drainage since before 1938, presumably the result of a 'bait bucket' introduction (Miller and Lowe, 1967). They were found at the mouth of the LCR in 1975 (Miller, 1975) and Stone (1964,1965) found them below Glen Canyon Dam in limited numbers. They are now most commonly found in springs or at the mouths of tributaries to the main channel. McCall (1983) attributes this decline in the main channel to cold releases from Glen Canyon Dam. The killifish prefer small open, sandy bottom streams and are tolerant of high concentrations of salinity and alkalinity.

Killifish spawning occurs in April and May (Minckley, 1973). Water temperature of 27.7° C was noted at the time of spawning by Koster (1948). The spawning needs of this fish are assumed to be met around tributary mouths within the canyon since several populations with juveniles have been found (Minckley and Blinn, 1975).

Killifish, in general, are omnivores. They consume both bottom and top dwelling insects as well as detritus and plant material when necessary. Hubbs and Wauer (1973) found them to compete successfully with native fish populations in Texas, where killifish and native minnows shared limited breeding and wintering habitat. Their distribution within the canyon seems to be limited by the available habitat and their numbers are low. They are not a serious competitor with native fish populations at this time.

ICTALURIDAE

Channel catfish

Channel Catfish (Ictalurus punctatus) were first introduced into the lower Colorado River in the 1890's (Miller and Alcorn, 1943). They were also introduced about the same time in the Moab, Utah area, upstream from the Grand Canyon. These introductions were apparently successful, as evidenced by their presence throughout the Colorado River system. They have been collected during every fish survey of the Grand Canyon region since records have been kept. Once abundant throughout the Grand Canyon reach, catfish numbers have seemingly decreased since the closure of Glen Canyon Dam. Miller and Smith (1968) found channel catfish to be abundant while Holden and Stalnaker (1975) found them to be rare or only locally abundant. Alan Kinsolving of Arizona Game And Fish Department and Rich Valdez of BioWest, Inc. have found them locally common around the confluence of the Little Colorado River and increasing in numbers towards the western end of Grand Canyon below Lava Falls. Catfish have also been collected around the confluence area of the LCR and in the LCR by C. O. Minckley,(1990) and Carothers and Minckley, (1981).

This distribution information is probably best explained by their preference for warm water for spawning. Channel catfish spawn at temperatures between 23.9 and 29.5° C, which would make spawning possible in the LCR and possibly in the lower end of the river towards Lake Mead. Carothers and Minckley (1981) verified spring and summer reproduction in Kanab Creek and the Little Colorado by collection of YOY fish. Decreases in abundance may be related to the fact that recent fish surveys have not relied heavily on angling, which is one of the most efficient means of sampling for catfish. Netting and electrofishing are not as efficient for the collection of this species and their widespread use in the latter surveys may skew the catch rates and underestimate populations of this species in the Grand Canyon.

Channel catfish are omnivorous in their feeding habits, but they are known to be piscivorous upon reaching adulthood. Stomach contents taken from the LCR and Colorado mainstem show the presence of native fishes as well as insects and Cladophora. Predation upon humpback chubs has been documented by Minckley (pers. comm., 1990) and Kaeding and Zimmerman, (1983). Minckley found predation on juvenile humpbacks trapped in a hoopnet and Kaeding noticed crescent shaped marks on larger humpbacks, which he attributed to predation attempts by catfish. Catfish predation on fingerling razorback suckers introduced into the Gila River was sufficiently high to affect reintroduction efforts where catfish densities where high (Marsh and Brooks, 1989). Channel catfish may be a serious threat to native fish populations, especially in the LCR where catfish occur with YOY and juvenile stages of native fishes.

Black bullhead

Black bullhead (*Ictalurus melas*) has been reported in the Grand Canyon reach sporadically. Researchers collecting this species have listed it as rare and it probably never has been abundant in the Grand Canyon. (Stone and Rathbun, 1968; Holden and Stalnaker, 1975). The species prefer warmer, low velocity waters which probably kept it from proliferating in the Colorado River since its original introduction to Lake Mead in 1904. (U.S.Fish and Wildlife Service, 1980). A juvenile black bullhead has been collected in the LCR which would indicate that this species is capable of reproduction in that system (A. Haden pers. obs.). Black bullheads have similar dietary habits to channel catfish (Sublette, et al, 1990) and an increase in the abundance of this species in the LCR could have a negative affect upon native fish populations in that system.

PERCICHTHYIDAE

Striped bass

Striped bass (*Morone saxatilis*) have been a concern to fisheries investigators in the Grand Canyon, since they were introduced into Lake Mead in 1969. The primary foragebase for striped bass in Lake Mead and Lake Powell is threadfin shad (*Dorosoma petenense*). Successful spawning in Lake Mead was first documented in 1973 (McCall, 1979). This species was introduced into Lake Powell in 1974 and was found to be reproducing there in 1979 (Gustavson, et al., 1990). Concern has arisen in recent years as striped bass have been collected in the Colorado River in the Grand Canyon. C.O. Minckley (1990) captured one striped bass, with fish remains in its stomach, in the LCR while sampling for humpback chubs and has reported others from that vicinity.

Striped bass have been considered rare above Diamond Creek (RM 225) by most fisheries researchers that have sampled in the canyon. Most collections have been in the lower end of the Grand Canyon below Havasu Creek (RM 156). Numerous anecdotal observations of striped bass throughout the river corridor were made by commercial boatmen and passengers during 1989 and 1990 (A. Haden, pers. obs.). Minckley (1990) reported a striped bass caught at 24.5 mile rapid in May of 1990.

The trend in striped bass catches indicates a concentration of fish during April through July below Havasu Creek. This indicates that there may be a seasonal migration up the Colorado from Lake Mead. Data based on angling is skewed towards seasonal sightings since most anglers are on the river during the summer. However, recent BioWest, Inc. unpublished data, based on September 1990 to September 1991 sampling effort, indicate that striped bass catches in the river did not begin until April and persisted through July. No fish were captured above river mile 156. This trend is consistent with that of previous years. Another potential source of striped bass is Lake Powell during high water flows through the spillways or hollow jet tubes at Glen Canyon Dam. Persons et al. (1985) reported catches of both striped bass and walleye after such a release in 1980. Reports of these catches continued into the fall of that year well after the spillways had closed.

Natural populations of striped bass are anadromous. Under most conditions their semi-buoyant eggs need current from 12.2 to 88.4 centimeters/second to keep them from settling to the bottom and becoming silted in (Crance, 1984). Landlocked populations show a proclivity for this spawning behavior (Persons, 1982). Persons (1982) indicated that spawning began when temperatures in the Colorado River above Lake Powell reached 16°C. Spawning in other areas has been reported between 12 and 24°C (Hill, 1989) and between 14 and 20°C (Talbott, 1966 as reported by McCall, 1981). McCall (1981) reported that conditions in Lake Mead were most favorable for spawning from April through mid-July.

Persons (1982) also indicated that most (70%, n=320) individuals in the Lake Powell headwaters were not feeding during the spawning run. The majority of striped bass stomachs examined by BioWest researchers during the last year were empty (93%, n=15) (B. Leibfried, Bio/West, Inc., pers. com.). This may not be a good indicator of their activities in the river. Striped bass are not steady feeders, but are apt to gorge themselves then stop until digestion is complete (Allan and Roden, 1978; Scott and Crossman, 1973).

Striped bass are piscivorous in a reservoir environment. This is illustrated by the decimation of shad populations in Lakes Powell and Mead (McCall,1981; Gustavson, et al. 1990; Baker and Paulson, 1983). The diet of adult striped bass in the Lake Powell and Lake Mead consists almost entirely of threadfin shad; however they are known to be opportunistic. Baker and Paulson (1983) reported high incidence of predation upon rainbow trout (Oncorhynchus mykiss) when shad populations were low in Lake Mead. A rainbow was found in the stomach of a striped bass captured in 1991 below the mouth of Havasu Creek (B. Leibfried, pers. comm.). C. O. Minckley (1981) found carp remains in the stomach of a striped bass captured in the lower end of the river which would indicate that these fish are able to switch diets to less preferred species as they leave the reservoir (McCall, 1981).

McCall (1981) gives three arguments against striped bass having a major effect on native fish populations in the Grand Canyon. He argues that striped bass are sight feeders and the high silt load from the river keeps the water turbid enough to greatly reduce their effectiveness as a predator on native fish which are highly adapted to a turbid environment. Workers in California estuaries find that most striped bass are caught in waters where light transmission is essentially zero. This indicates that these fish are not entirely dependant on visual senses to capture prey (O'Conner, 1991). McCall's also argues that forage fish are scarce in the river. He is correct in the assumption that the lower portion of the Grand Canyon reach seems depauperate of fishes. However, striped bass may not be interested in forage fish if they are fasting while migrating to spawn. If fish are only moving through the system, native fish populations may not be threatened. It would be a much different scenario if striped bass establish themselves in the upper river, possibly in the LCR's warmer water, where there is a larger supply of forage. Lastly, McCall points out that temperatures in the river are at the lower limit for survival of eggs. This is probably the controlling factor limiting the colonization of these fish into the river system. Of the fish captured within the Grand Canyon reach, none displayed a high degree of gonadal development. While this indicates limited successful reproduction in the river, the question of why striped bass migrate so far upstream remains unanswered.

PERCIDAE

Walleye

Walleye (Stizostedion vitreum) have never been stocked in Lake Powell or Lake Mead, but are currently common in Lake Powell. This population presumably expanded from individuals migrating downstream from the upper portions of the river (Gustavson, et al., 1990). No researchers have reported them in significant numbers in the Grand Canyon reach or in Lake Mead. However there have been occasional captures throughout that area. Recent Arizona Game and Fish Department researchers captured an adult in the Glen Canyon tailwaters area (Sue Morgenson, Arizona Game and Fish Department, pers. comm., 1991) and BioWest, Inc. captured an adult below Lava Falls (RM 179). (Bill Leibfried, pers. comm., 1991). Presumably these captures over the years are a result of recruitment from water being diverted around Glen Canyon Dam, since there has been no documentation of spawning activity in the river.

Spawning in Canada occurs in rivers at temperatures between 5.6 and 11.1° C (Scott and Crossman, 1973). Given these environmental conditions spawning could occur in the river below Glen Canyon Dam. However, walleye require extended periods of low temperatures (minimum 10° C) and gradual warming for gonadal development. Sudden shifts in temperatures during spawning can lead to lower survival rates for eggs and larvae (Sublette et al, 1990). In lake environments high winds strand eggs by floating them ashore (Kallemeyn, 1987). Fluctuating flows would likely have the same effect and thereby limit production.

Walleyes are opportunistic piscivores and have been reported to feed on any species available. Some adult populations have been known to feed on emerging mayflies and chironomids when they are available. (Scott and Crossman, 1973; Sublette et al., 1990). Cannibalism in some populations has been reported (Scott and Crossman, 1973). Since walleyes are sensitive to high light intensities, feeding is restricted to evening or night in clear waters. This same sensitivity to light makes the walleye an effective predator in turbid systems. Currently, extremely low numbers of introductions and barriers to spawning success have kept this predator from becoming more common.

SALMONIDAE

Several species of salmonids have also been introduced into the Colorado River in Grand Canyon. In the early 1900's both the National Park Service and Arizona Game and Fish Department have actively stocked these fish in the Colorado River and its tributaries. Since 1964, the Arizona Game and Fish Dept. has managed the section of river between Lees Ferry and Glen Canyon Dam as a trout fishery. The National Park Service no longer has a policy of stocking nonnative species (Leopold, et al., 1963). Trout have been repeatedly introduced into the system to supplement their populations and with the river environment now modified to their advantage trout are widespread and numerous throughout much of the river between the dam and Lake Mead (Maddux et al., 1987; Carothers and Minckley, 1981).

Brook trout

Brook trout (Salvelinus fontinalis) were first introduced into Bright Angel Creek in August of 1920. Havasu and Clear Creeks were planted in subsequent years (Stricklin, 1950; Arizona Game and Fish Department, 1950). The last known stocking of Brook trout in Clear Creek was in 1934 by the National Park Service. In 1977 and 1979, Brook trout were released into the main channel above Lees Ferry. They have not been reported in great numbers by most researchers. Carothers and Minckley (1980) found this species to be common in the main river but their captures were made soon after the stocking in Glen Canyon and they were considered rare by subsequent researchers. This species has very low tolerances for warm water, generally seeking temperatures below 20° C. (Scott and Crossman, 1973).

Brook trout spawn in the fall. The lethal temperature for eggs is upwards of 11.7° C. (Scott and Crossman, 1973). No documentation exists of successful reproduction in the tributaries or the main river below Lees Ferry.

Brook trout are carnivorous feeders. Adults in other systems in Arizona are know to prey on other small fishes (Minckley, 1973); however their diet in the Grand Canyon consists mainly of larger aquatic invertebrates (Carothers and Minckley, 1981).

Brook trout apparently do not make up a large proportion of the fishery in the Grand Canyon. Even above Lee's Ferry (RM 0) they do not represent more than a few percent of the fishery (McCall,1983). Studies carried out in the Lees Ferry reach indicated that brook trout were dependant on stocking to maintain their population (Maddux et al., 1987). Without stocking, it does not seem likely that this species can exert much impact on native fish populations.

Brown trout

Brown trout (Salmo trutta) were first introduced into the Grand Canyon in Shinumo Creek (RM 109) in 1926 (Stricklin 1950; Arizona Game and Fish Department, 1950). They were subsequently planted in Bright Angel and Garden Creeks (RM 88). The last stocking of this species in the Grand Canyon was in 1934. In the pre-dam era this fish was probably restricted to the tributaries during the warmer months, venturing into the main river only during the winter when temperatures decreased. Currently it resides in the mainstem as well as the tributaries. The heaviest mainstem concentrations of these fish occurs between Clear and Kanab Creek (RM 144). However they are occasionally reported in Glen Canyon (Sue Morgenson, Arizona Game and Fish Dept., pers. comm.) Brown trout are more tolerant of warmer, poor quality water than most salmonids. (Allan and Roden, 1978).

Brown trout are fall and winter spawners. Scott and Crossman (1973) report spawning between 6.7 and 8.9°C. Concentrations of reproductively colored browns migrate up Bright Angel Creek during late November through January. (Allen Haden, pers. obs.). Considering the present numbers of brown trout now in the system and the fact that they have not been stocked since 1934, it safe to say that reproduction is successful in the Grand Canyon.

The diet of brown trout in the Grand Canyon consists of a wide variety of invertebrates, their respective larvae and speckled dace (Carothers and Minckley, 1981). Brown trout are highly piscivorous when they attain a large size. They have been known to feed heavily upon suckers and chubs, to the point where they are used by managers to control fish numbers (Walden, 1964).

Brown trout may be an important predator on native fishes. Adult native fishes are too large to serve as prey for all but the largest brown trout, but juvenile and younger life stages may be susceptible as they are in close proximity to established concentrations of brown trout in and around Shinumo and Bright Angel Creeks. This is especially important as researchers document small populations of humpback chub using the areas around these tributaries. If efforts are made to establish chub populations around these streams, consideration must be given to the presence of brown trout.

Rainbow Trout

Rainbow trout (Oncorhynchus mykiss) have been repeatedly stocked in the Colorado River and its tributaries. They were first introduced to Tapeats Creek in 1923 by the National Park Service (Stricklin, 1950; Arizona Game and Fish Department, 1950). Introductions into Bright Angel, Havasu, and Clear Creeks followed. The last stocking of rainbows in the Bright Angel Creek was in 1964. Diamond Creek was stocked by the U.S. Fish and Wildlife Service in

1970 and 1972. Stocking the tailwaters of Glen Canyon Dam by Arizona Game and Fish Department began in 1964. Continual stocking and management have produced a productive trout fishery within the Lee's Ferry area. Stocking efforts have been successful in spreading this species throughout the Grand Canyon. Numbers are highest above Lee's Ferry with a general decline with distance from the dam. There are population concentrations around tributary confluences especially during winter spawning runs into those tributaries.

Reproduction and recruitment of rainbow trout occurs in the Grand Canyon. Rainbow trout present in Glen Canyon primarily spawn during fall and winter (McCall, 1983). Carothers and Minckley (1981) reported spawning from late fall to early spring with peaks in winter when water temperatures were between 7 and 12°C. These authors also reported that most spawning below Lees Ferry took place in high gradient tributaries.

Much attention has been given to the diet of rainbow trout in the Grand Canyon (Leibfried, 1988 and Carothers and Minckley 1981). A synopsis of this information indicates that rainbow trout are opportunistic omnivores. Their success in establishing themselves in this system is sufficient evidence of their opportunistic feeding habits.

While their diet does not generally include other fishes, it is apparent through observations over the years that rainbow trout affect native fish populations. Carothers and Minckley (1981) documented trout eggs and speckled dace remains in rainbow trout stomachs. Minckley (1978) found trout eggs and larval bluehead suckers in rainbow trout stomachs from tributaries. Alex Laweka of U.S. Fish and Wildlife Service reported a juvenile humpback chub in the stomach of a rainbow at the confluence of the LCR (M. Douglas, Arizona State University pers. comm., 1991). Miller (1968) noted the complete disappearance of speckled dace from Tapeats Creek after the introduction of rainbow trout there. Studies of Nutrioso Creek in Arizona showed that rainbow trout there negatively influenced the distribution of the Little Colorado River spinedace, Lepidomeda vittata by predation (Blinn and Runck, 1990). Because large numbers of rainbow trout are present in the river, this species has potential to have a significant impact on native fish species there.

INCIDENTAL SPECIES

There have been a number of other introductions and incidental catches of nonnative fish in the Grand Canyon than those previously mentioned. They are condensed into one section because the low number of observations. These species have either disappeared from the system or they do not persist in the system long enough to make a significant impact, therefore a full treatment of their impact on native fishes is not presented. They are identified in an effort to have as complete a summary as possible and to emphasize the fact that potential for their accidental reintroduction into this aquatic system do exist. In addition, their presence in the system may allow population growth should the proper conditions become available.

Cutthroat trout (Salmo clarki) were introduced into the Lees Ferry region in 1978 and 1979. The population declined and this species comprised less than 5% of the creel count in 1983 (McCall, 1983).

Coho salmon (Oncorhynchus kisutch) were introduced into both the Lees Ferry reach and Lake Mead in 1970 and 1971 respectively. One was found by Suttkus (1976) at Whitmore Wash (RM 185).

A single specimen of golden shiner (Notemigonus crysoleucas) was found by Suttkus (1976) in Kanab Creek. Another specimen was reported above the mouth of the Little Colorado River in the 1977 to 1979 sampling period (Carothers and Minckley, 1981). More recently, an individual was found at river mile 74 by Arizona Game and Fish Department personnel during the 1984-1986 sampling program (M. Yard pers. comm.). Golden shiners are a popular bait minnow. These isolated individuals were probably the result of bait introductions.

Limited numbers of largemouth bass (Micropterus salmoides), Utah chub (Gila atraria) and green sunfish (Lepomis cyanellus) were found in the Glen Canyon area during 1984-1986. This was a period of high runoff when water was diverted around Glen Canyon Dam through the spillways. One specimen of green sunfish was reported from the LCR confluence area in 1991 (Douglas and Marsh, 1992). Additionally, threadfin shad (Dorosoma petenense) were found in the river during these periods (Maddux, et al. 1987). One specimen of yellow bullhead (Ictalurus natalis) was also found in the lower portion of the river during the 1984-1986 sampling program. (M. Yard pers. comm. 1991). Another specimen of yellow bullhead was captured in the LCR in 1991 (Douglas and Marsh, 1991).

Woundfin (Plagopterus argentissimus) were introduced into the Paria River by Arizona Game and Fish Department in 1972. None have been recaptured.

A single specimen of Virgin River spinedace (Lepidomeda mollispinis) was collected near the mouth of the Paria in 1972 (Sutkus et al, 1976). This specimen was probably inadvertently introduced during the woundfin stocking earlier that year (Carothers and Minckley, 1981).

Redside shiners (Richardsonius balteatus) have been reported twice at the LCR (J. Brooks, U.S. Fish and Wildlife Service pers. comm., 1991 and Kaeding and Zimmerman, 1983).

There is one verbal account of smallmouth bass (Micropterus dolomieui) from the mouth of Spencer Creek (RM 246) (A. Kinsolving, Arizona Game and Fish Dept. pers. comm.). Both largemouth bass (Micrpterus salmoides) and blue gill (Lepomis macrochirus) were found in limited numbers below Lava Falls (RM 179) (Carothers and Minckley, 1981).

PROPOSED INTRODUCTIONS

Rainbow smelt

Rainbow smelt (Osmerus mordax) have been proposed for introduction into Lake Powell as a supplemental forage fish for the declining striped bass fishery there. This is a pelagic species preferring temperatures around 7.2° C, with a preference for low light intensities (Scott and Crossman, 1973). They are anadromous, spring spawners in much of their historic range, requiring temperatures below 15° C. (Scott and Crossman, 1973).

Rainbow smelt are carnivores, feeding mainly on plankton and amphipods. They are known to feed upon smaller fishes, even of their own kind. (Scott and Crossman, 1973).

If introduced into Lake Powell they are expected to establish themselves as far downstream as Lake Hávasu. Water temperature and chemistry will not impede their invasion into this system. Entry into the LCR and other tributary systems would only be impeded by hydrologic and physical barriers greater than 2 feet in height (Gustavson and Bonebrake, 1989).

Their effect on native fishes can only be surmised at this point. If young life forms of native fish occur in the main river along with smelt it seems likely that they would be affected. As yet no one has studied the impact these fish may have on the riverine food web, especially as it concerns the amphipod, Gammarus lacustris. For a more detailed summary of the possible impacts see Gustaveson and Bonebrake, (1989).

V. DISCUSSION

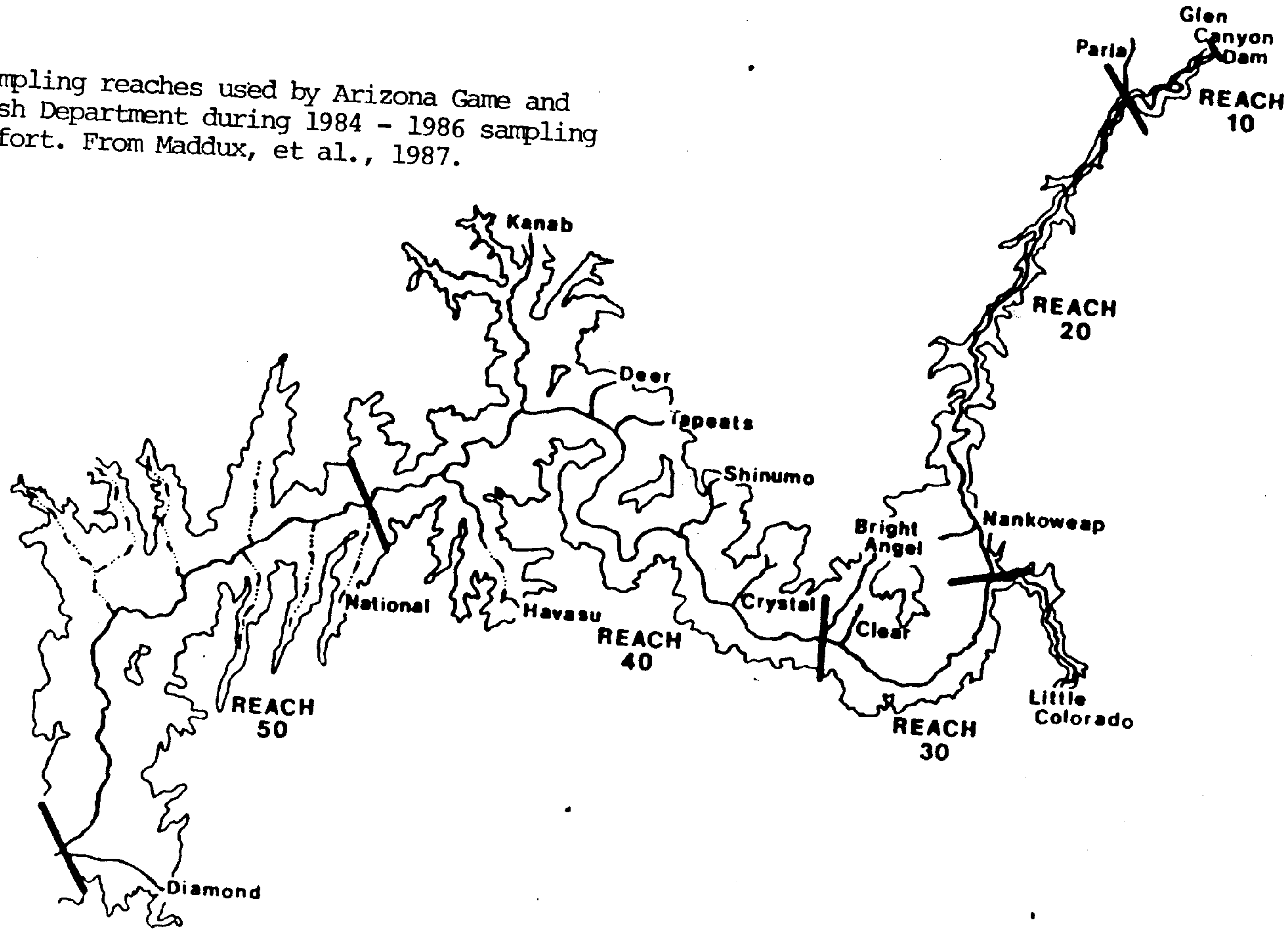
Twenty-four (24) different species of introduced fishes have been collected in the Colorado River between Glen Canyon Dam and Lake Mead. Of these, seven (7) are established in numbers sufficient enough to affect the native fish fauna. The others reflect the ease with which fish can overcome barriers such as dams and rapids and expand their ranges.

Distributional patterns of native and nonnative fish during the 1984-1986 sampling effort are shown in Table 2. Species favoring cold water are concentrated in the eastern portion of the Grand Canyon in closer proximity to Glen Canyon Dam. Species preferring warmer waters are concentrated around tributaries or in the western end of the canyon where water temperatures are slightly higher. The presence of several warm water species (largemouth bass, green sunfish and Utah chub) in the Glen Canyon reach can be attributed to

Table 2. Fish species present by reach in the Colorado River. 1984 - 1986. P = present. * = native. From Maddux, et al., 1987; M. Yard pers. comm, 1991.

SPECIES	REACH 10	20	30	40	50
CATASTOMIDAE					
* Bluehead sucker	P	P	P	P	P
* Flannelmouth sucker	P	P	P	P	P
* Razorback sucker				P	
CENTRARCHIDAE					
Green sunfish	P				
Largemouth bass	P				
CYPRINIDAE					
Common carp	P	P	P	P	P
Utah chub	P				
* Humpback chub		P	P	P	P
Golden shiner			P		
Fathead minnow		P	P	P	P
* Speckled dace		P	P	P	P
CYPRINODONTIDAE					
Plains killifish			P		P
ICTALURIDAE					
Black bullhead			P		P
Yellow bullhead					P
Channel catfish			P	P	P
PERCHTHYIDAE					
Striped bass					P
SALMONIDAE					
Cutthroat trout	P				
Rainbow trout	P	P	P	P	P
Brown trout		P	P	P	P
Brook trout	P	P	P	P	

Map 2. Sampling reaches used by Arizona Game and Fish Department during 1984 - 1986 sampling effort. From Maddux, et al., 1987.



introductions from Lake Powell through the spillways at Glen Canyon Dam. These species have not persisted in this area since use of the spillways has stopped.

Documentation of actual competition with and predation upon native fishes is difficult to quantify. Predation on native fishes by nonnative species in the Grand Canyon has been observed by many researchers. Unfortunately, the sporadic nature of these reports makes it impossible to make quantitative predictions of their influence upon the native fishes.

Compelling circumstantial evidence can be deduced using a general knowledge of fisheries ecology and the Colorado River ecosystem (Kaeding, 1986). Successfully introduced species are by nature aggressive and adaptable. They must be so, in order to become established in a new habitat. They are also freed from any ecological constraints in their home range. Colorado River native fishes have evolved in a unique and isolated system. Species from naturally developed systems are often highly adapted to the physical environment but unable to cope with introductions of exotic species (Shoenherr, 1981; Karp and Tyus, 1990). Introductions into such systems often result in the extirpation of native species from that system (Shoenherr, 1981; Moyle, et al., 1985).

The effects of introductions of nonnative fish into an aquatic system can be categorized as: (1) elimination of the native species, (2) reduced growth and survival rates, (3) changes in community structure, and (4) no impact (Moyle et al., 1985).

Observations of no impact by introduced species upon native species are viewed with suspicion by Moyle et al. (1985), who suggest thorough study before conclusions be made.

Six general mechanisms have been identified by which introduced fishes can displace native species. Impacts on growth and survival and subsequent impacts on community structure are reflected in these general mechanisms. These are (1) competition, (2) predation, (3) inhibition of reproduction, (4) environmental modification, (5) transfer of parasites and diseases, and (6) hybridization. (Moyle, et al. 1985).

In the Grand Canyon, native/nonnative interactions exhibit all of these mechanisms except for hybridization. Some mechanisms such as competition and inhibition of reproduction are hard to quantify, but may be assumed, given a general knowledge of ecology. Predation on native fishes is documented, yet difficult to quantify. Environmental modification is attributed to human endeavors and not directly to introduced fish. These mechanisms for displacement occur within habitats that native fish need to complete their life cycles; habitats that are already rendered marginal by the dam induced environmental modifications. Evidence of complete elimination of native species by nonnative species in the Grand Canyon is limited. The only recorded incident would be the absence of speckled dace in Tapeats Creek after the introduction of rainbow trout (Miller, 1975).

Reduced growth and survival of native fishes has been attributed to changes in environmental conditions brought about through human endeavors. However there is evidence that nonnative species have a secondary effect on survival of young fishes. Channel catfish and carp densities are high in the Little Colorado River. Since spawning of the majority of the humpback chub population is restricted to this system, their eggs, YOY and juvenile life stages are vulnerable to predators.

Changes in community structure are hard to determine since we do not have a comprehensive knowledge of the population structure that existed before human perturbation of the Colorado River system. There are some unanswered questions regarding the physical and biological aspects of the river as well as nonnative fish populations that lead to possible impacts to the native fish community. (1) Why isn't there more spawning by humpback chub in tributaries other than the LCR, especially when temperatures favorable to spawning exist in other tributaries in the Grand Canyon? Are there other physical factors preventing successful spawning or are there biotic interactions between natives and salmonids competing for limited space in the tributaries? (2) Why aren't adult humpback chubs more plentiful in the lower portions of the river where physical parameters are more similar to pre-dam conditions? The last 100 miles of the Colorado River between Kanab Creek and Lake Mead is warmer and more turbid than the rest of the system. One would expect humpback chub to inhabit this area of the river in greater numbers than the upper region which is colder and less turbid. This is not the case. Is this a problem of food availability or is it due to nonnative warmwater species utilizing this area? If these questions could be adequately addressed, the underlying reasons for the existing community structure might be revealed. Ongoing Glen Canyon Environmental Studies Phase II research is directed at answering these questions.

Fish communities are capable of adjusting quickly to additions of new species by extirpation of one species or niche shifts among existing species to make room for the newcomers. It was found that community structures similar to coevolved communities develop in less than 20 years after introduction of new species (Moyle et al., 1985). This is an important concept for application in the Grand Canyon. It has been 29 years since the closure of Glen Canyon Dam. A new set of environmental conditions in the Grand Canyon has been established. Many of the introduced warmwater species already in the river have been removed from the system or now have reduced their range and abundance while cold water salmonid species have expanded their range and abundance. Native fish populations have been greatly diminished or eliminated, but some reduced populations still persist in restricted areas. Predation and competitive interactions between native and nonnative fishes, while still important today, may have been more important in the period immediately following introduction of a new species or modification of environmental parameters (Carothers and Minckley, 1981). Information on the population trends of humpback chub and other native species to support this theory are sorely lacking. Moyle's et al. (1985) conclusions would suggest that the Grand Canyon fish community is stabilizing, but if so the stability will be very tenuous. Productivity shifts and the unstable nature of an ecosystem driven by fluctuating discharges will continue to disrupt trends in population dynamics and impact the number of habitat niches available. Fish population stability is further decreased by continual stocking of trout into the Glen Canyon reach of the river which migrate into the lower reaches (Carothers and Minckley, 1981).

INTRODUCED PARASITES

Evidence of impacts from parasites introduced by nonnative fishes has been documented for the Grand Canyon. *Lernea cyprinacea* have been found on juvenile native fish in the LCR and Kanab Creek. This parasite is a native of Europe and is thought to be transported into this system by fish from Lake Mead or a hatchery (Kaeding and Zimmerman. 1983; Carothers and Minckley, 1981). Mortality for infected fish is unknown, however infected fish are expected to lose the parasite upon entering the cooler waters of the mainstem (Carothers and Minckley, 1981). Recently concern has arisen over the occurrence of asiatic tapeworm (*Bothriocephalus acheilognathi*) in humpback chubs taken from the LCR. The extent of this infection among the native fish population is unknown at this time, but a heavy infestation could seriously affect that population. This parasite is not native to the Colorado River and was probably introduced through the introduction of infected nonnative fish species (J. Landye, Arizona Game and Fish Dept., pers. com., 1991).

AFFECTED HABITATS

Low velocity backwater habitats are important to all lifestages of native fishes in the Colorado river (Maddux, et al., 1987; Karp and Tyus, 1990; Valdez and Wick, 1981). These same authors found that backwaters were an important habitat to nonnative fishes. Predation, competition for space and food is likely to occur with the occurance of both native and nonnative fishes in these low velocity habitats.

Warmwater, low gradient tributaries, such as the LCR and Kanab Creek, are important habitat to native fishes in the Grand Canyon. They provide warmwater spawning and nursery areas for humpback chub and other natives species (Carothers and Minckley, 1981; Maddux et al, 1987; Kaeding and Zimmerman, 1983). Just as the tributaries provide a haven for native species they also provide habitat for warmwater nonnative species. It also provides habitat for catfish, carp and fathead minnows (Minckley, 1990). The probability of negative native/nonnative interactions seems likely considering the close proximity of aggressive introduced species to young native fish in the LCR.

Native/nonnative interactions in high gradient, cooler tributaries, such as Bright Angel, Shinumo and Havasu Creeks, involve primarily salmonid fishes. Competition for space in the tributaries may occur during spawning runs of salmonids. Seasonal differences in fish populations have been reported by several researchers (Minckley, 1978; Maddux, et al., 1987; Carothers and Minckley, 1981). Native species numbers were highest in the tributaries during spring and summer months while trout numbers were highest in the fall and winter. This pattern was explained by the seasonal differences in spawning behavior of natives and nonnatives and no habitat overlap was assumed. (See Figure 1, from Maddux, et al., 1987). However, other researchers surmised that the aggressive nature of spawning trout displaced native fishes and smaller trout from the tributary or sent them into hiding where they were not sampled (Minckley, 1978; Carothers and Minckley, 1981). More information on the fate of young fish displaced from tributaries into the main river is needed before these interactions can be fully evaluated.

DAM MANAGEMENT

The task of effectively managing releases from the dam to enhance populations of native fishes in the canyon is extremely difficult. Cold releases from the dam have restricted the spawning of humpback chub to one or possibly a few tributaries that meet the required temperature regime. This may have greatly restricted the range and numbers of this fish species. Proposals have been made in conjunction with the GCDEIS to modify the dam to allow release of warmer waters from the surface of the impoundment. On the other hand, if the water in the river was warmed sufficiently to enhance reproduction of humpback chub, exotic fishes requiring warm water may invade the Grand Canyon region or increase their abundance in areas where they already exist. (See Table 3.) The consequences of an action that did not consider limiting nonnative species could be dire. Therefore, the use of any river water warming scenario should be flexible to allow for intermittent use during certain periods of the year. Immigration of predators from Lake Mead and Lake Powell could overwhelm any population increase of humpback chub. The Colorado River in the Upper Basin contains reaches that have not had their flow, or water quality significantly altered. In these areas a decline of native fishes is occurring, which is attributed to the successful colonization of these reaches by nonnative species (Kaeding, 1986).

Large numbers of warmwater species are readily available in Lake Mead for immigration into the Grand Canyon region. Many are species that have proven to have negative effects on native species in other areas. Two aspects of the Colorado River ecosystem may be keeping them from entering the river. The first obstacle would be the cold water released from the dam. The highest rates of invasion by striped bass are during periods when water temperatures are highest in the lower portion of the river. The cold water is probably a deterrent to successful reproduction in the river by most fishes. (See Table 3.) However, adults of the larger species are able to withstand river temperatures.

A second detriment to upstream travel is suggested by McCall (1979) as being the low productivity of the lower Grand Canyon. The area from Havasu Creek down to Diamond Creek is depauperate of fish biomass. Large numbers of adult fish do not exist and water temperatures are marginal for reproduction. This 'biological desert' may not provide a forage base that would allow predators from the lake to colonize in this area and establish the stock

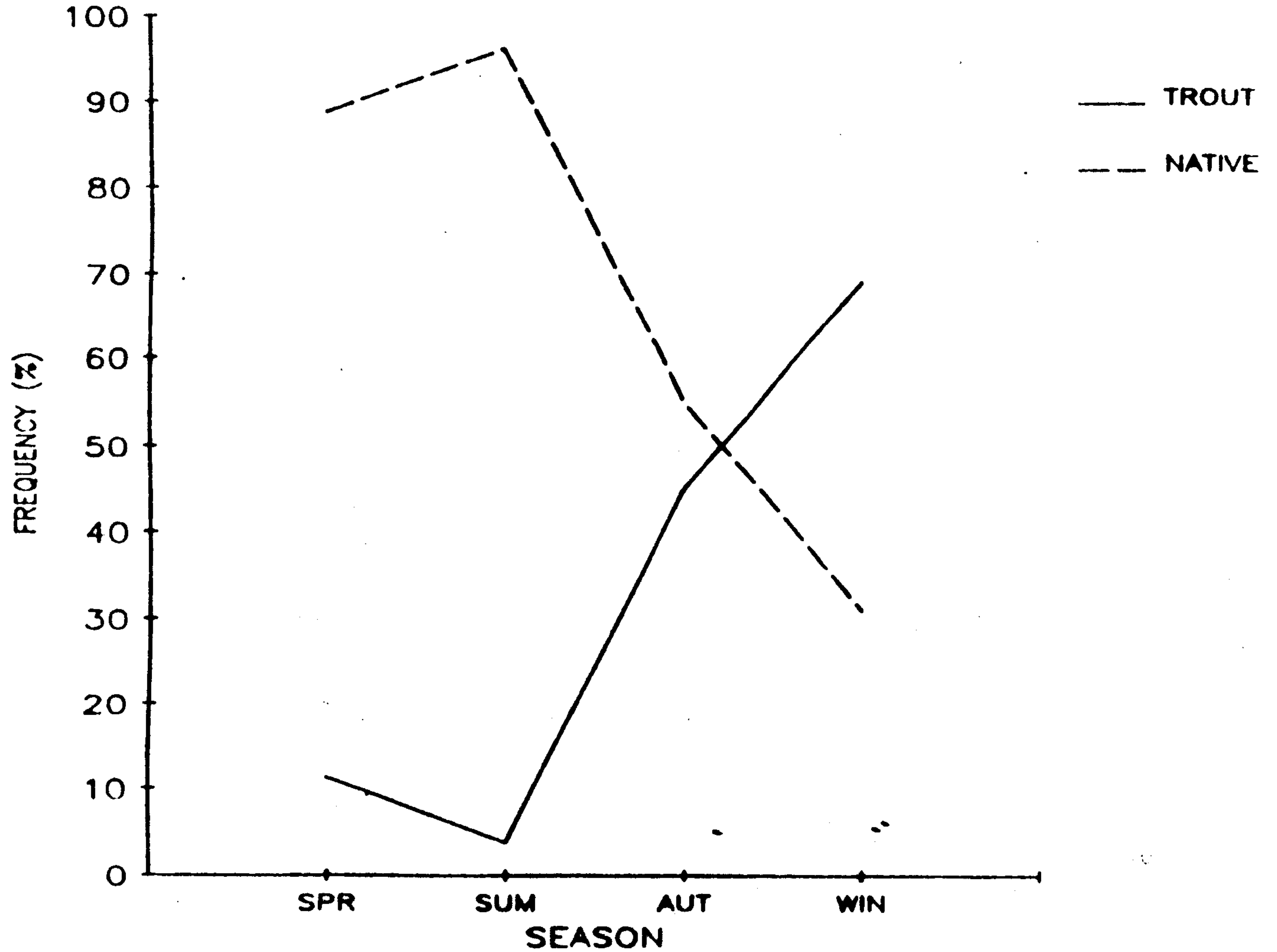
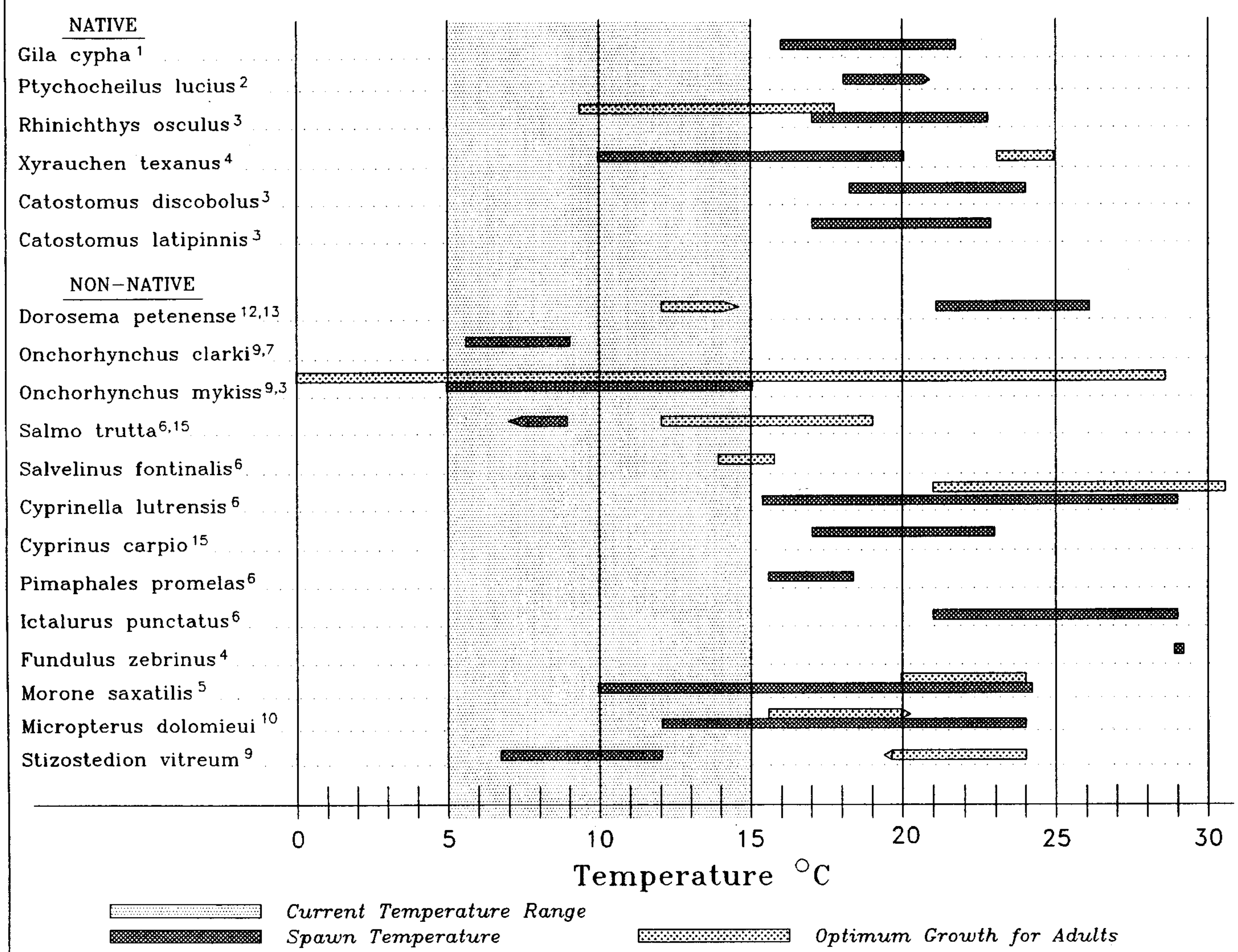


Figure 1. Relative frequency of all trout species and native species (flannelmouth sucker, bluehead sucker, humpback chub, and speckled dace) by season from tributaries (excluding fish captured by larval seine). From Maddux, et al., 1987.

Table 3. Temperature Requirements for Colorado River Fishes



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7. *Cross, 1967*
8. *Koster, 1948*
9. *Sublet et al, 1990*
10. *Clark, 1967*
11. *Jenkin, 1975*
12. *Griffith, 1978*
13. *Johnson, 1971*
14. *Deacon et al, 1987*
15. *Lubinski et al, 1984*
16. *Stanford & Ward, 1990*

necessary to continue the population expansion upstream. The low productivity of this area has been attributed to lower nutrient levels and longer periods of sediment in the river which leads to lower primary production. Careful attention should be given to the productivity of this section of river and the subsequent expansion of fish populations. Recent investigations under GCES have found seasonal increases in insect production in this area (L. Stevens pers. comm., 1991) and, as stated before, catfish and other deep dwelling species abundances may be underestimated by recent sampling techniques.

VI. CONCLUSIONS

The existing literature on native and nonnative species of the Colorado River, coupled with an understanding of basic ecology, illustrate that native fish populations in the Grand Canyon are suffering from pressure exerted by both nonnative species and physical environment modifications. In order to preserve these unique and valuable native species the pressure must be decreased on both fronts.

Suggestions have been made to alter the present temperature regime of the river, thereby increasing the amount of habitat for spawning and maturation for native fishes. If such a plan is undertaken it must include considerations for nonnative fish. Large numbers of warmwater species in Lake Mead await an opportunity to immigrate into the Grand Canyon. The timing of releases and temperature must be carefully regulated to limit establishment and population growth of competing fish species. Releases that benefit native fish should be timed to coincide with low abundance for nonnatives that could also benefit or they must be timed not to coincide with spawning season for nonnatives.

Existing stocks of native species centered around tributaries should be protected. Every effort should be made to protect these important spawning and nursery habitats from invasion by nonnative species and efforts should be made to reduce populations of nonnative piscivores already present within those systems.

Concern should be noted towards no more purposeful introductions of new species into the Grand Canyon. New species would only further disrupt a system that has yet to find a status quo. Managers of the trout fishery in Glen Canyon should not stock any strains of piscivorous trout that could migrate downstream and become established there.

Any plan to re-introduce natives into tributaries within the Grand Canyon should also include a plan to protect natives from nonnative competition and predation.

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