Nonnative Fishes of the Upper Colorado River Basin: An Issue Paper.

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TABLE OF CONTENTS

Page

Page

Page

LIST OF TABLES

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PREFACE

Potential impacts of introduced fishes on endangered and other native fishes in the Upper Colorado River Basin (upper basin) are major concerns of the Biology Committee within the Recovery Implementation Program for Colorado River Endangered Fishes. This committee solicited development of an issue paper to provide necessary guidance for research and management of problems posed by introduced fishes. This report addresses this need. Study objectives were to:

1) assess known or suspected negative impacts of nonnative fishes on the four endangered or threatened fishes,
2) determine avenues of research necessary to provide needed data, and
3) determine management options available to minimize negative impacts and develop an overall strategy for implementation of related recovery efforts.

This paper consists of three parts: a literature review, a summary of expert opinion through a questionnaire, and a synthesis with recommendations. Recommendations for research and management strategies for introduced fishes were derived from the literature review and researcher questionnaire.

The terms *exotic*, *introduced*, and *nonnative* are often used interchangeably when describing a species not historically found in a drainage. The American Fisheries Society (AFS), Exotic Fishes Section (now called Introduced Fishes Section) adopted definitions in 1983 that categorized nonnative fishes by political boundaries of their origin (Shafland and Lewis 1984). An *introduced* or *nonnative* species is a broad category for any animal that occurs in a location due to man's actions. An *exotic* species is "an organism introduced from a foreign country (i.e., one whose entire native range is outside the country where found)". A *transplanted* species is "an organism moved outside its native range, but within a country where it occurs naturally (i.e., one whose native range includes at least a portion of the country where found)". The AFS terminology is followed in this paper. The terms *introduced* or *nonnative* are used over the commonly, although often incorrectly, used term *exotic*. Papers cited may have used the term *exotic* in reference to introduced species, but, except within direct quotes, the correct terminology is used.

EXECUTIVE SUMMARY

Guidance for the study and management of impacts of nonnative fishes on Colorado River endangered fishes was addressed through development of this issue paper. A review of published literature and government reports relating to interactions between native and nonnative fishes in the Upper Colorado River Basin (upper basin) resulted in a reference list of 133 papers. A questionnaire was also developed to establish expert opinion and consensus on various aspects of this issue. Research and management recommendations, and a strategy for implementation of related recovery efforts are also provided.

Increases in the number and relative abundance of nonnative fish species in the upper basin have been documented and shown to be related to habitat alteration and river flows. Predation on endangered fishes in the upper basin has been documented mostly for channel catfish. Nonnative fish predation was identified most frequently in artificial settings where native fish were reared in large numbers, in confined areas, or after stocking of hatchery-reared fish. Studies on diets of native and nonnative fishes have shown dietary overlap between larval or early juvenile Colorado squawfish and juvenile channel catfish, larval to adult red shiner, and juvenile to adult green sunfish, but information on availability of forage items was lacking and conclusive statements about competition could not be made. Spatial competition is also suggested based on habitat-use overlap between young Colorado squawfish, red shiner, sand shiner, and fathead minnow, and between adult Colorado squawfish, channel catfish, northern pike, and walleye. However, in each study, habitat availability was not documented. Introduction of disease to native fishes from introduced fishes was not considered a problem; although, Asiatic tapeworm has recently been found in hatchery-reared Colorado squawfish that were stocked into riverside ponds. Habitat alteration by introduced fishes and hybridization between nonnative and any of the four endangered native fishes have not been documented.

Expert opinion suggested that introduced fishes affecting native fishes are a problem in most Colorado River Basin drainages. Six introduced species of greatest or widespread concern were channel catfish, red shiner, northern pike, common carp, green sunfish, and fathead minnow. Most of these species were considered widespread in distribution, and their impacts on native fishes were considered constant or inversely affected by flow regime. Expert opinion often identified that Colorado squawfish and razorback sucker, their young, and all native fish larvae, were negatively affected by predation or competition from nonnative fishes. Documented evidence of these interactions was limited. Research directed at evaluating predation and competition between the above nonnative fishes and endangered and other native fishes is needed to answer specific recovery questions. Sport-fishery value of introduced fishes was recognized largely for reservoir fisheries, tailwater fisheries, and the Yampa River northern pike fishery. Channel catfish was considered to be supporting the most widespread riverine fishery, but the fishery was of moderate or greater importance only in select localities. Riverine fisheries for all other introduced gamefish were generally considered to be small or inconsequential. Mortality of endangered fishes from incidental take by angling was not considered a significant problem by a majority of respondents.

However, the endangered status of Colorado squawfish warrants close attention by management agencies to potential angling mortality problems. Elimination, reduction, or strict regulation of stocking of nonnative fishes were the most common management options proposed to cope with negative impacts on native fishes. The combination of habitat management and flow manipulation was the next most cited management option considered feasible.

Many respondents expressed a general comfort with their agency internal communication process. As a consequence of legal mandate and recovery programs, communication within agencies between sportfish and nongame sections has been improved. Increasing communication between agencies, biologists, and administrators prior to decision making may be the best means of resolving conflicts between nongame and gamefish management concerns. There was consensus that problems related to introduced fishes are increased in severity by concomitant impacts to the habitat of native fishes. Habitat changes, primarily flow related, were considered a primary problem of greater magnitude than introduced fishes. Some form of habitat manipulation was considered the most likely alternative for maintaining native-fish populations in the face of chronic impacts from introduced fishes. Less than half of the respondents felt that either control of nonnative fishes or augmentation of endangered fishes were viable management alternatives.

If results or interpretations reported here are at significant odds with perceptions of the various agencies and participant groups in the recovery program for Colorado River endangered fishes, further refinement of the issue and consensus opinion through a more rigorous Delphi approach may be a useful next step in providing guidance to the Recovery Implementation Program Biology Committee in managing nonnative fish impact issues.

INTRODUCTION

The native fish fauna of the Colorado River Basin was labeled depauperate by early ichthyologists (Jordan 1891; Miller 1959; 1961). Although the term depauperate was originally used to indicate the low diversity in the basin, it probably also reflected the low value that early residents placed on native fishes. Native Americans apparently valued Colorado squawfish *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, and bonytail *Gila elegans* as a food resource (Miller 1955; Gehlbach and Miller 1961). European settlers, however, saw no tangible value in the original fish assemblage, except in the late 1800s, when locally abundant Colorado squawfish and razorback sucker were captured for use as food or fertilizer (Behnke and Benson 1983). Most residents were nostalgic for the recreational and food gamefish they remembered catching in eastern states or ancestral Europe. In the early 1900s, they stocked gamefish into the Colorado River Basin to create these familiar resources. They attempted to add value to a fish fauna they viewed as basically worthless. Concurrent with these introductions were drastic changes in habitat and flow regimes caused by large dams constructed on the mainstream Colorado River. Decline and extirpation of native fishes quickly followed these introductions (Minckley and Deacon 1968); but it was uncertain if the native-fish fauna declined due to habitat changes, introductions of nonnative fishes, or both (Moyle 1986; Marsh and Langhorst 1988). In North America, extinctions within the past century were mostly attributed, in part, to either detrimental effects of introduced species (68%) or alteration of physical habitat (73%) (Miller et al. 1989).

A total of 55 fish species exists in the upper basin of which 42 are not native to the basin (Tyus et al. 1982; Table 1). Nonnative species comprise 30 to 60% of the fish fauna west of the Rocky Mountains compared to fewer than 10% of the fish fauna east of the Rocky Mountains (Moyle 1986). Eastern fish faunas evolved in complex and shifting assemblages; with few changes to community structures or dynamics due to introductions (Grossman et al. 1982). Moyle (1986) noted that the west had seen wholesale replacement of its native fishes, mostly with eastern species. He identified habitat types in North America that favored establishment of introduced fishes. These habitats included reservoirs and other artificial non-flowing waters, coldwater lakes, coldwater streams, desert streams, isolated habitats, subtropical waters, and large rivers. Success of nonnative fishes also increased in "simple" communities with low native-species diversity (Minckley and Deacon 1968; Shafland 1979) and in areas subjected to physical and biological disturbances (Taylor et al. 1984). The Colorado River Basin has been susceptible to the establishment of nonnative fishes because of the low diversity of its native-fish fauna, the high degree of endemism of this fauna, and its highly altered physical habitat. The Colorado River Basin has the highest level of endemism (74% of the native fishes are endemic species) of any major drainage in North America (Miller 1959), a result of geological isolation from other drainages for a long evolutionary time (Hubbard 1980). In other basins where the native fish fauna is less rich (e.g., the main Mississippi drainage), nonnative fish are also more abundant (Moyle 1986).

Table 1. Fishes of the Upper Colorado River Basin (from Tyus et al. 1982).

Scientific name	Common name	Origin[1]
Clupeidae (herrings)		
Dorosoma petenense	threadfin shad	I
Salmonidae (trouts)		
Oncorhynchus clarki	cutthroat trout	I
Oncorhynchus clarki pleuriticus	Colorado River cutthroat trout	N,E
Oncorhynchus clarki stomias	greenback cutthroat trout	I
Oncorhynchus kisutch	coho salmon	I
Oncorhynchus mykiss	rainbow trout	I
Oncorhynchus nerka	sockeye salmon (kokanee)	I
Prosopium williamsoni	mountain whitefish	N
Salmo trutta	brown trout	I
Salvelinus fontinalis	brook trout	I
Salvelinus namaycush	lake trout	I
Esocidae (pikes)		
Esox lucius	northern pike	I
Cyprinidae (carps and minnows)		
Cyprinella lutrensis	red shiner	I
Cyprinus carpio	common carp	I
Gila atraria	Utah chub	I
Gila copei	leatherside chub	I
Gila cypha	humpback chub	N,E
Gila elegans	bonytail	N,E
Gila robusta robusta	Colorado roundtail chub	N,E
Hybognathus hankinsoni	brassy minnow	I
Hybognathus placitus	plains minnow	I
Notropis stramineus	sand shiner	I
Pimephales promelas	fathead minnow	I
Ptychocheilus lucius	Colorado squawfish	N,E
Rhinichthys cataractae	longnose dace	I
Rhinichthys osculus yarrowi	Colorado speckled dace	N
Rhinichthys osculus thermalis	Kendal Warm Springs dace	N,E
Richardsonius balteatus	redside shiner	I
Semotilus atromaculatus	creek chub	I
Catostomidae (suckers)		
Catostomus ardens	Utah sucker	I
Catostomus catostomus	longnose sucker	I
Catostomus commersoni	white sucker	I
Catostomus discobolus discobolus	bluehead sucker	N
Catostomus latipinnis	flannelmouth sucker	N,E
Catostomus platyrhynchus	mountain sucker	N
Xyrauchen texanus	razorback sucker	N,E

Table 1. continued

Scientific name	Common name	Origin[1]
Ictaluridae (bullhead catfishes)		
Ameiurus melas	black bullhead	I
Ameiurus natalis	yellow bullhead	I
Ictalurus punctatus	channel catfish	I
Cyprinodontidae (killifishes)		
Fundulus sciadicus	plains topminnow	I
Fundulus zebrinus	plains killifish	I
Poeciliidae (livebearers)		
Gambusia affinis	mosquitofish	I
Percichthyidae (temperate basses)		
Morone chrysops	white bass	I
Morone saxatilis	striped bass	I
Centrarchidae (sunfishes)		
Lepomis cyanellus	green sunfish	I
Lepomis macrochirus	bluegill	I
Micropterus dolomieui	smallmouth bass	I
Micropterus salmoides	largemouth bass	I
Pomoxis annularis	white crappie	I
Pomoxis nigromaculatus	black crappie	I
Percidae (perches)		
Etheostoma exile	Iowa darter	I
Etheostoma nigrum	johnny darter	I
Perca flavescens	yellow perch	I
Stizostedion vitreum vitreum	walleye	I
Cottidae (sculpins)		
Cottus bairdi	mottled sculpin	N

[1] N = native species, I = introduced species, E = endemic species.

Populations of nonnative fishes can become established from either intentional or accidental releases. Taylor et al. (1984) listed four reasons for intentional introductions of nonnative fishes:

(1) to add new food, game, or forage species to the native assemblage;
(2) for biological control of unwanted plant or animal pests;
(3) for aesthetic or ornamental reasons; or
(4) to release unwanted pet [or bait] fish.

Accidental releases usually occur from private ponds, stock tanks, and culture facilities as a result of flooding or through improperly designed drainage pipes [or ditches]. Successful establishment of an introduced fish and the affect it will have in a novel environment depends on the physiological, behavioral, and ecological properties of the species, and the physical and biological properties of the ecosystem receiving the introduction. Taylor et al. (1984) also identified that many introduced species persist because they:

(1) are very hardy, survive transport, and thrive in disturbed environments;
(2) are very aggressive and eliminate natives through competition or predation;
(3) are ecologically or behaviorally distinct from natives, and natives do not interact with them or are unable to deal with a new style of predation or competition;
(4) have reproductive strategies that seem to confer on them an unusual degree of "fitness";
(5) are preadapted to distinctive local environmental conditions; or
(6) possess a combination of several of these characteristics.

According to Pimm (1987) there are two important questions regarding effects of introduced species. First, what determines if an introduction will be successful, and second, what determines if a successful introduction will have an impact on the community it invades. Impacts of nonnative fishes on a native fish are measured by identifying effects relative to either the individual or the population. A nonnative may create stress on an individual and cause a change in behavior or even death, eventually affecting population health. The impact that an introduced species will have on a native species is determined by examining the interactions between the two. Taylor et al. (1984) stated;

> The *impact* of an exotic fish species on a freshwater community is defined as any effect attributable to that exotic that causes - directly or indirectly - changes in the density, distribution, growth characteristics, condition, or behavior of one or more native populations within that community. The definition is independent of human judgments as to the "value" of an introduction; impacts are nothing more than the *changes* in native populations brought about by the activities of an exotic species. A demonstration of impact implies verification of a causal relationship between changes in a native population and the presence of an exotic.

The disappearance of native species is often attributed to predation and competition by introduced fishes, but unequivocal examples are few (Taylor et al. 1984; Moyle et al. 1986). Evidence of direct impacts of introduced species on native fishes is difficult to obtain (Schoenherr 1981) and is often masked by severe man-caused habitat alterations (Moyle 1976). Laboratory experiments may eliminate some confounding factors, but may not reflect natural conditions. Field studies often imply interactions between nonnative and native fishes, but most have not been designed to study this problem and many researchers obtain their interaction data as an afterthought.

Taylor et al. (1984) outlined the ecological effects of introduced fishes on native fishes in native aquatic communities:

A. Trophic interaction
    1) Predation by introduced fishes,
    2) Competition for food, or
    3) Introduced fishes as a forage base.
B. Spatial interactions (aggressive effects or overcrowding)
    1) Competition for habitat,
    2) Competition for spawning space, or
    3) Competition for feeding station.
C. Habitat alteration
    1) Removal of vegetation by
        a. consumption,
        b. uprooting, or
        c. increasing turbidity.
    2) Degradation of water quality by
        a. siltation,
        b. substrate erosion, or
        c. eutrophication.
D. Hybridization, and
E. Disease or parasite introduction.

METHODS

Information from 133 papers about interactions between native and nonnative fishes in the upper basin was categorized based on the above outline from Taylor et al. (1984). When applicable, related information from the Lower Colorado River Basin (lower basin) or other drainages was included. Although the focus was on interactions with endangered species, interactions with other native fishes were included. Only warm-water species were considered; coldwater, native trouts and their introduced relatives were not discussed because upper basin endangered fishes are not usually found in sympatry with coldwater fishes.

Another source of information existed in the accumulated experience of biologists and other fishery professionals working within the Colorado River Basin. Their perspective of the issue was obtained to supplement the literature review. This included their knowledge of relevant unpublished data or in-house agency reports not readily available. A questionnaire concerning the issue of impacts of nonnative fishes on native fish was developed to acquire related information from sources of biological expertise present in the Colorado River Basin (Appendix A). This approach was a modified Delphi technique for acquiring consensus from existing experts in a particular field (Zuboy 1981). The approach used here departed from that described in Zuboy (1981) because the objective was to query biologists and look for consensus on various aspects of the issue.

A draft questionnaire was developed and circulated among members of the Recovery Implementation Program Biology Committee in January 1990 for comment. The finalized questionnaire included participant background information and 17 questions. It was sent 24 April 1990, to 40 persons in Colorado, Utah, New Mexico, Arizona, and Nevada representing fish management and endangered fish research expertise in the Colorado Division of Wildlife (CDOW), Utah Division of Wildlife Resources (UDWR), New Mexico Game and Fish Department (NMGF), Arizona Game and Fish Department (AGF), U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Reclamation (USBR), National Park Service (NPS), Colorado State University (CSU), University of New Mexico (UNM), Arizona State University (ASU), and BioWest, Inc. A reminder notice with questionnaire was sent 24 September 1990, to non-respondents. Responses from participants were compiled for background data and consensus or majority opinions for each question were identified.

LITERATURE REVIEW

General trends in abundance of nonnative fishes

Distributions of fishes introduced into the upper basin were shown on maps provided by Tyus et al. (1982) and further discussed by Carlson and Muth (1989). Documented reports of decreasing numbers of native and increasing numbers of nonnative fish are numerous; however, it is unclear whether direct cause and effect relationships exist. Several examples follow that identify an increase of nonnative fishes concurrently with a decrease of native fishes

In three study areas on the upper Colorado and lower Gunnison rivers, Colorado, Osmundson and Kaeding (1989a) noted that young native fishes progressively decreased in abundance from 1986 through 1988, while introduced fishes, especially red shiner, fathead minnow, and larval sand shiner, progressively increased in abundance. These trends in abundance may have been related to annual differences in flow, i.e., 1986 was identified as a high flow year, 1987 an average flow year, and 1988 a low flow year.

Behnke (1980) noted that an increase in redside shiner abundance occurred concurrently with the decline of Colorado squawfish in the Green and Yampa rivers, Utah and Colorado, and suggested that redside shiner had caused the decline. Holden (1977) disagreed with this conclusion by noting that redside shiner were abundant in the 1960s when Colorado squawfish reproduction was apparently successful.

The introduction and increase of northern pike and walleye in the Green River, Utah was documented by Tyus and Beard (1990). Originally introduced into a Yampa River tributary reservoir in 1977, northern pike invaded the Green River by 1981. Since that time, they have increased in both range and abundance. Walleye were presumably established in the Green River drainage in the 1960s by fish stockings in Duchesne River, Utah reservoirs. Although widely distributed in the Green River, their numbers remain low but stable (Tyus and Beard 1990).

The Yampa River provides another example of the abundance and distribution of nonnative fish species. Miller et al. (1982b) studied the lower 206 kilometers (km) of the Yampa River to its confluence with the Green River. Of 24 fishes collected, 15 were introduced. Native fishes were more common within Yampa Canyon in Dinosaur National Monument than other areas. Species diversity increased upstream as more nonnative fishes were collected. They disagreed with Joseph et al. (1977) who implied that lack of documented Colorado squawfish reproduction since 1969 was correlated with increasing numbers of redside shiner, the dominant species in 1975-1976. Implications made by Joseph et al. (1977) were questioned because all collections were made in upper reaches, upstream of documented Colorado squawfish reproduction (Miller et al. 1982b). The most abundant species collected in Dinosaur National Monument by electrofishing and angling between 1987-1989, were common carp and channel catfish (Karp and Tyus 1990b).

Miller et al. (1982a) studied the lower 241 km of the White River to its confluence with the Green River. Of 15 fishes collected, eight were nonnative. Red shiner was the most common and widely distributed of the introduced fishes. Miller et al. (1982a) observed that red shiner juveniles and adults had greatest abundance at lower sites and decreased in numbers at upper sites. *Gila* spp. abundance was the opposite, with greatest number at upper sites. They postulated this could indicate that either habitat was more suitable for natives in the upper strata or competition existed between *Gila* spp. and red shiner at lower strata, with *Gila* spp. apparently losing the battle.

Relationship between abiotic parameters and abundance of nonnative fishes

The literature surveyed often revealed apparent relationships between abiotic factors and the abundance of introduced fishes. The most common abiotic factors mentioned were habitat alteration and flow events. Several examples follow.

In the San Rafael River, Utah, a tributary to the Green River, McAda et al. (1980) found native fishes only at upstream stations. Introduced fishes were found at downstream stations near the Green River. This was attributed to differences in habitat between the two sections. The lower section was dewatered, less diverse, and more uniform than the upper section. A similar pattern was noted by Deacon and Bradley (1972) in the Moapa River, Nevada.

Lanigan and Berry (1979, 1981) studied the White River (106 km) in Utah from 1978-1979. Red shiner was the most commonly collected species (62%) of all fish collected. They cited a study by (Crosby 1975) in 1974-1975 that collected similar numbers of red shiner (52%). Lanigan and Berry (1979) noticed that introduced fishes had replaced endemic fishes in the lower White River and were becoming more numerous in upstream reaches. They also suggested that the fish fauna may have been influenced by habitat alterations because numbers of nonnative fish increased as habitat diversity decreased.

In the Colorado River, Colorado, low spring flows apparently benefitted nonnative fishes that were adapted to stable environments (Osmundson and Kaeding 1991). High spring flows, however, flushed nonnatives from backwater habitats and into the main channel. Turbulent riverine conditions and delayed warming probably interfered with nonnative reproduction (Valdez 1990; Osmundson and Kaeding 1991).

Abundance of fathead minnow, sand shiner, and red shiner larvae decreased with increased peak flow in three Grand Valley, Colorado, reaches in the Colorado and Gunnison rivers (Osmundson and Kaeding 1991). Numbers of other introduced fishes (mosquitofish, green sunfish, and largemouth bass) were also negatively correlated with peak flow, but correlations were not strong enough to be significant given the small sample size of years in which sampling was conducted.

Valdez (1990) found that densities of red shiner, sand shiner, and fathead minnow increased with decreasing flow peak, but concluded that management of flows would only temporarily control these nonnative fishes because their high reproductive potential would enable them to recover within 2-3 years.

Information from other basins substantiates how nonnative fishes are influenced by the environment. For example, Cooper (1983) sampled fish populations in the Pit River in northeastern California. Introduced fishes dominated lower river reaches that had been altered by human activity. The lower reach had been altered by impoundments and diversions and had sluggish flows and low gradient. Upper undisturbed reaches contained native fish assemblages. The upper reach was characterized as unaltered with high stream velocity, steep gradient, and riffle, run, and pool habitats. The altered habitat was ecologically similar to the natural environment of the introduced species.

Organisms living in habitats subject to frequent perturbations may evolve strategies or behaviors that minimize the impact of, or exploit, the natural disturbance (Meffe 1984). Fishes that evolved in Southwestern streams would be expected to have evolved mechanisms to avoid or utilize frequent flash floods. Meffe (1984) found that introduced mosquitofish incurred greater loses during floods than native Sonoran topminnow *Poeciliopsis occidentalis*. Native topminnows exhibited behaviors such as quick response and proper orientation to flood events that enabled them to persist. Flood events were augmented in the last 80-90 years by arroyo cutting which deeply entrenched many streams. Where topminnows and introduced mosquitofish were sympatric, mosquitofish were usually eliminated within a few months by floods. He suggested that apparent coexistence of topminnow and mosquitofish was allowed by periodic flash flooding that removed large numbers of predatory mosquitofish. He supported this by comparing fish community structures in several flooding and non-flooding habitats. Topminnow were eliminated or severely reduced in areas not prone to flooding, but coexisted with mosquitofish in areas that frequently flooded.

In arid, mountainous regions of Arizona and New Mexico, nonnative fishes that evolved in lowland, mesic conditions were intolerant to natural southwestern flooding regimes whereas native species resisted floods (Minckley and Meffe 1987). They hypothesized that different responses probably reflected different evolutionary histories. Nonnatives were displaced during floods from narrow canyon reaches to wider floodplain reaches where they persisted. A few species affected by high-intensity flooding included: common carp, red shiner, fathead minnow, mosquitofish, largemouth and smallmouth bass green sunfish, bluegill, and catfish. Red shiner and mosquitofish rapidly reestablished populations due to high reproductive potentials. Smallmouth bass and green sunfish, both stream adapted fish, reappeared within weeks after flooding. Regulated releases in low, controlled volumes apparently had little affect on nonnative fishes.

Native fishes might not always be at an evolutionary advantage during perturbations, such as flood events. If introduced species evolved within an area that was also subject to flooding, then the introduced fish might be at an adaptive advantage over native fishes.

Castleberry and Cech (1986) found that introduced arroyo chub *Gila orcutti* displaced native Mojave tui chub *Gila bicolor mohavensis* from its fluctuating habitat, a desert river. Arroyo chub had a longer evolutionary history in fluctuating stream environments than native tui chub. Tui chub probably existed in these habitats due to absence of similar fish. Arroyo chub maintained position and exhibited better swimming performance than native tui chub during flood events. Thus, differential responses to abiotic factors were important in the outcome of the biotic interaction.

Interactions between native and nonnative fishes

Trophic interactions

Nonnative fishes can interact on a trophic level with native fishes in several ways. Nonnatives may directly decrease numbers of native fish by predation. The threat alone of predation may cause stress or behaviors in native fishes that are detrimental. Nonnative fishes may also compete with native fishes for food. If nonnative fishes are better able to catch or utilize a limited food resource, then native fishes may obtain less quantity or lower quality foods. Finally, a positive relationship may occur if introduced fishes serve as forage for native species. This interaction will be negative if the introduced prey has an anti-predatory defense that could harm or kill the native predator, especially if this defense is novel to the evolutionary history of the native.

Predation. -- Predation was one of the most cited negative effects of nonnatives on native fishes. Although predation by nonnative fishes has contributed to at least local reductions in populations of native fishes, it is difficult to demonstrate as a cause of species elimination (Moyle 1976). Because nonnative fish predation on endangered fishes is difficult to confirm in natural conditions, predation was documented most frequently on natives raised in large numbers, in confined areas, or after stocking. Most predators are opportunistic and will consume any prey available in large numbers. Many nonnatives in the upper basin are known predatory species and create an obvious concern. Of 37 native fishes from the southwestern United States, only four (10.8% of all species) are piscivores; of 57 introduced fishes, 26 (45.6%) are piscivores (Meffe 1985). They include egg, juvenile, and adult predators such as largemouth and smallmouth bass, green sunfish, northern pike, walleye, channel catfish, common carp, and mosquitofish.

Because western fishes evolved with few predacious fishes, they may have a naivete towards predators and probably lack anti-predator traits (Minckley 1983; Meffe 1985). This is because they have been free of the influence of other major groups of fishes, especially the Perciformes for millennia. Many introduced predators are also small enough to infiltrate shallow backwater habitats that historically provided refugia from larger native piscivores (Meffe et al. 1983).

The decline of Colorado squawfish and razorback sucker has often been attributed to increased rates of mortality on early life stages by predation (Minckley 1983; Kaeding and

Osmundson 1988; Lanigan and Tyus 1989; Marsh and Minckley 1989; Osmundson and Kaeding 1989b). McAda and Wydoski (1980) attributed reproductive failure as the major factor in the decline of razorback sucker. Lanigan and Tyus (1989) hypothesized that the lack of recruitment in the Green River was due to predation on young razorback sucker by introduced fishes. Kaeding and Osmundson (1988) suggested that Colorado squawfish were vulnerable to increased early life mortality by introduced fishes because of their unusually slow growth in the upper basin. If razorback sucker spawn in gravel pits connected to the mainstream Colorado River, Osmundson and Kaeding (1989a; 1991) predicted young would be subject to predation from common carp, green sunfish and largemouth bass. Osmundson and Kaeding (1989a) also suggested that predatory introduced fishes "probably have important negative effects on the endangered fishes in the 15-mile [24 km] reach and elsewhere in the Colorado River", but which introduced fishes were a problem was unknown. Common carp, the most abundant nonnative fish in Dinosaur National Monument, was suspected of having a negative impact on native fishes by egg predation (Karp and Tyus 1990b).

Predation on endangered fishes has been documented in the upper and lower basins. Coon (1965) found Colorado squawfish in two of 58 stomach samples of channel catfish collected from the Dolores River in 1963. Catfish sizes ranged 130-452 mm TL; prey sizes were not reported. Taba et al. (1965) found Colorado squawfish and *Gila* spp. in the stomachs of black bullhead from the Colorado River near Moab, Utah.

Other native species are also vulnerable to the effects of predation. Remains of humpback chub have been found in stomachs of channel catfish collected from the Little Colorado River (W. L. Minckley, personal communication in Karp and Tyus 1990b). Crescent shaped wounds were found on some humpback chub from the Little Colorado River, Arizona and were attributed to channel catfish; suggesting failed attempts by channel catfish to prey on humpback chub (Kaeding and Zimmerman 1983). Similar bite-like marks were observed on humpback chub collected in Dinosaur National Monument and were attributed to channel catfish, the only piscivorous fish capable of such marks (Karp and Tyus 1990b).

Nonnative predator fishes were implicated in the decline of roundtail chub in the Gila River Drainage, New Mexico (Bestgen and Propst 1989). Deleterious effects were inferred by past and current distributional patterns of roundtail chub and introduced fishes. Roundtail chub, once common in the study area, were apparently displaced by smallmouth bass that were common. Smallmouth bass were restricted from further upstream distribution in one tributary creek by barrier falls. Although rarely found below the falls, large roundtail chub populations were abundant above the barrier falls where bass were absent. Floods in 1983 and 1984 severely reduced smallmouth bass and channel catfish populations, concurrent with an increased abundance of native fishes in 1985.

Several studies attempted to document predation by examining stomach contents of predacious nonnative fishes. Most of these have been unable to provide evidence of predation. Colorado squawfish were considered potential prey for northern pike and walleye, but none were found in 123 pike and 61 walleye stomach samples examined from fish collected from the Green River, Utah (Tyus and Beard 1990). Grabowski and Hiebert (1989) also found no predation of Colorado squawfish based on stomach analysis of juvenile channel catfish, black bullhead, green sunfish, and largemouth bass. But, they suggested that the potential for predation still existed. Persons and Bulkley (1982) examined stomach contents of striped bass from Lake Powell during their spawning run up the Colorado River and did not detect predation on Colorado squawfish. Colorado squawfish of suitable prey size were present in the area sampled, but, of 321 striped bass stomach examined, none contained native threatened or endangered fishes. Striped bass utilized the most abundant prey source available, threadfin shad. They determined that adult striped bass would probably not prey heavily on endemic fishes during spawning as long as threadfin shad are abundant and as long as bass spawning occurs below Cataract Canyon rapids.

Inability to detect predation does not mean that it is not occurring. It may be due to small sample size of predator stomachs, rarity of endangered fish, or inability to identify fish remains (Tyus and Beard 1990). Meffe (1985) cautioned on the use of gut-content analysis to infer population effects of predation. Stomach contents would need to be analyzed soon after the initial colonization of the predator in order to observe actual predation effects on the native population. Once predation has lowered the population, few natives would be available for predation and would not be detected in gut analysis. In lab studies, prey were identifiable for only 4 hours after ingestion. Even if predation rate is calculated, the impact on the prey population would be difficult to predict because a low rate can have a large impact on a species with low fecundity (Meffe 1985).

Osmundson (1987) confirmed predation as a significant mortality factor of young-of-year (YOY) and yearling-sized Colorado squawfish stocked in riverside ponds along the Colorado River, Colorado. Colorado squawfish were preyed upon by largemouth bass, green sunfish, black crappie, and black bullhead. Predation by channel catfish was suspected but not confirmed. Colorado squawfish were stocked into ponds with different predator densities and even low numbers of predators had a significant impact on reducing numbers of stocked Colorado squawfish. Laboratory studies identified that largemouth bass selected Colorado squawfish for prey over green sunfish and red shiner. Selection was equal for Colorado squawfish and fathead minnow, but, under pond conditions, abundant fathead minnow did not decrease predation on Colorado squawfish. After stocking, largemouth bass completely switched from other forage fish to Colorado squawfish. Small Colorado squawfish were preferred over larger ones. Based on predator to prey size relationships, Colorado squawfish over 250 mm TL were believed invulnerable to largemouth bass predation. In aquaria studies of interactions between young Colorado squawfish and several nonnative fishes, Karp and Tyus (1990a) did not observe predation, but attributed this to the lack of a size advantage by the nonnatives.

Predation has been identified on many endangered fishes in the lower basin because of widespread stocking programs there and the occurrence of numerous predators.

Hendrickson and Brooks (1987) documented predation by yellow bullhead and largemouth bass on Colorado squawfish stocked in the Verde River, Arizona. Marsh and Brooks (1989) reported that catfish predation significantly reduced number of stocked razorback sucker (45-168 mm TL) during a 3-year stocking program in the Gila River, Arizona, even though channel and flathead catfish *Pylodictis olivaris* were a small portion of the total fish fauna. Other forage available included red shiner and other native suckers. Razorback sucker were probably vulnerable to predation because of disorientation from transport, stress, and novel surroundings. Marsh and Minckley (1989) suggested that the hypothesis that lack of recruitment is attributable to predation is enhanced by high survival of razorback sucker in predator-poor canal habitats.

Marsh and Langhorst (1988) concluded predation was the cause for loss of young razorback sucker in an isolated backwater on the shores of Lake Mohave. High water levels and storm-driven waves breached the isolated backwater allowing invasion of nonnative fishes including threadfin shad, common carp, channel catfish, largemouth bass, green sunfish, and bluegill. Predation was documented with the discovery of an average of four razorback sucker larvae in nearly 40% of the green sunfish collected during a 24-hour period. One month after the invasion of nonnatives, razorback sucker larvae could no longer be collected; total mortality was attributed to predation.

Marsh and Brooks (1989) suggested that self-sustaining populations of razorback sucker were unlikely in areas of abundant, nonnative predators. However, once beyond the size range of abundant smaller predators like green sunfish, razorback sucker probably attain capabilities to avoid predation from larger predators like largemouth bass and catfish (Marsh and Minckley 1989). Brooks (unpublished data in Marsh and Langhorst 1988) found a direct relationship for predation of razorback sucker and density of green sunfish at Dexter National Fish Hatchery.

In Lake Mohave, common carp were observed feeding in redds immediately after razorback sucker had spawned, but of 201 common carp stomachs examined, none contained eggs. Razorback sucker eggs were found in four of 63 channel catfish stomachs; no other species examined contained either eggs or larvae. Species examined included largemouth bass, rainbow trout, cutthroat trout, and striped bass. Egg predation by common carp was considered insignificant given the large number of eggs available and the lack of eggs in any common carp stomach. The lack of eggs in predator stomach samples may also have been due to mastication, rapid digestion, or regurgitation (Bozek et al. 1984).

Competition for food. -- Li (1979) identified three requirements for competition to occur between two species: (1) the resource must be limited, (2) the resource must be shared, and (3) the sharing of the resource results in a negative influence on one of the two species. Competition for food is often identified by measuring the amount of dietary overlap of two species and then determining the availability of the food. If food is in limited supply and overlap is high, then competition may be occurring. Field documentation of food competition is often difficult to obtain. Miller and Hubert (1990) identified several recent studies that contained information on feeding habits of introduced fishes. Many studies have examined dietary overlap but none have concurrently identified whether food resources were in limited supply.

Jacobi and Jacobi (1981) examined stomach contents of five introduced fishes (YOY, juvenile, and adult) and six native fishes (YOY and juvenile) to identify dietary overlap and possible competitive interactions. Introduced species included channel catfish, fathead minnow, sand shiner, red shiner, and an unidentified killifish *Fundulus* spp. Native fishes included Colorado squawfish, roundtail chub, possible humpback chub, flannelmouth sucker, bluehead sucker, and Colorado speckled dace. Food item preference was determined for each species and whether preference was significantly different between native and other species. There was dietary overlap for all species except adult killifish, YOY bluehead sucker, and adult fathead minnow. Only native species consumed fish. YOY squawfish apparently chose fish (YOY red shiner) over invertebrates.

Grabowski and Hiebert (1989) identified dietary overlap between Colorado squawfish and many introduced fishes sampled from backwaters on the Green River. Overlap occurred between Colorado squawfish and sand shiner, common carp, channel catfish, green sunfish, and black bullhead. They suggested that if chironomids, the major food item, became limited then competition could occur.

McAda and Tyus (1984) found high dietary overlap for Colorado squawfish (22-40 mm TL), small channel catfish (15-53 mm TL), and red shiner. Overlap decreased as squawfish became larger. There was no significant overlap between squawfish and fathead minnow. Although dietary overlap supported the hypothesis that competition was occurring, they cautioned that food availability was not measured and it was unknown if resources were limited. They warned that dietary overlap may have reflected common use of an abundant food rather than competition. Tyus and Nikirk (1990) suggested negative interactions between channel catfish and native fishes were likely due to the abundance and omnivory of channel catfish in the Green and Yampa rivers.

Karp and Tyus (1990b) identified a potential for competitive interaction between humpback and roundtail chub with channel catfish. They based their theory on the high number of channel catfish in habitats used by chub and overlap of food consumed. Tyus and Karp (1989) believed dietary overlap identified by Jacobi and Jacobi (1981) and McAda and Tyus (1984) indicated the potential for significant interspecific interaction between channel catfish and Colorado squawfish.

Forage supplementation. -- The abundance of nonnative prey species in the upper basin may provide native fishes with an unconventional source of food. Whether or not this food source is now actually necessary or beneficial for the native species is difficult to determine. Colorado squawfish is the only endangered fish species that is piscivorous. Karp and Tyus (1990a) suggested that growth of juvenile Colorado squawfish may be enhanced by an abundance of nonnative prey fishes. YOY Colorado squawfish feed on red shiner (Jacobi and Jacobi 1981; McAda and Tyus 1984). One or more of the following species; redside shiner, common carp, white sucker, or fathead minnow; were identified in different studies as prey consumed by yearling, juvenile, or adult Colorado squawfish (Vanicek 1967; Grabowski and Hiebert 1989; Osmundson and Kaeding 1989b).

Introduced fishes used as prey may pose a threat if they have anti-predatory mechanisms that are deadly to their predators, especially if native predators are naive to this defense. Several authors have noted the occurrence of channel catfish lodged in the throats of Colorado squawfish. Apparently, pectoral fins of catfish lock out and become lodged in the esophagus of squawfish (Vanicek 1967). McAda (1983) collected a Colorado squawfish (550 mm TL) with a 120 mm TL catfish in this condition in 1974. He believed it was a rare occurrence based on the large number of Colorado squawfish collected without this problem and considered this to have had little influence on the decline of Colorado squawfish. Wick et al. (1985) also collected a Colorado squawfish (591 mm TL) with a 174 mm TL channel catfish lodged headfirst in its throat.

Pimentel et al. (1985) reported three occurrences of Colorado squawfish choking on channel catfish in the Green River in 1982 and 1983. They also performed laboratory studies of adult Colorado squawfish (mean TL = 444 mm) and small channel catfish (mean TL = 77 mm). Colorado squawfish that did consume channel catfish were not injured and catfish did not lodge in their throats. A possible explanation for the lack of lodging was that Colorado squawfish in this study were considerably larger than the prey. Colorado squawfish did not prefer channel catfish and fed on other species when possible. Removal of spines did not enhance predation on channel catfish and Colorado squawfish fed on them only after being starved for over 5 days. Pimentel et al. (1985) suggested that environmental conditions, such as cold water, might make channel catfish sluggish and more vulnerable to predation.

Spatial interactions

Any desirable space in limited supply can be contested, creating competition between nonnative and native species. There can be competition for habitat, feeding station, or spawning space. Using a preferred space and protecting it from others might benefit a fish that is resting, feeding, spawning or performing any necessary activity. Benefit may be obtained from an area that provides better water quality, depth, velocity, substrate, or some other parameter. Spatial competition is often tested by determining overlap of microhabitat use between two species. A high degree of overlap may indicate competition for a defined space, but for competition to occur microhabitat must be limited. Habitat use of some introduced fishes in the upper basin was summarized by Miller and Hubert (1990) and Valdez (1990) summarized additional information on nonnative distribution and life history.

Holden (1977) suggested possible competition based on similar microhabitat use by rare and introduced species. His collections of YOY squawfish and humpback chub on the Green River were dominated by young nonnative species. McAda and Tyus (1984) examined habitat data from fish collections on the Green River. They identified high spatial overlap in habitat use between young Colorado squawfish, red shiner, and fathead minnow and little overlap between squawfish and channel catfish. McAda and Kaeding (1989) also showed complete habitat overlap between YOY Colorado squawfish and red shiner, sand shiner, and fathead minnow collected from the Green and Colorado rivers, Colorado and Utah. Habitat parameters analyzed were depth, velocity, and substrate averaged from each seine haul.

Adult and juvenile Colorado squawfish were collected in association with both native and nonnative fishes in the White River. Introduced species associated with Colorado squawfish were common carp, channel catfish, fathead minnow, and red shiner. Colorado squawfish between 116-172 mm total length (TL) were collected with red shiner, fathead minnow, and common carp (Miller et al. 1982a). Adult Colorado squawfish apparently used the same habitats as northern pike, walleye, and channel catfish suggesting the potential for competitive interactions especially during periods of limited resource availability (Wick et al. 1985; Tyus and Karp 1989; Tyus and Beard 1990).

Karp and Tyus (1990a) studied young Colorado squawfish interactions with six species (five introduced) of similar size in aquaria. All nonnatives exhibited relatively high amounts of interspecific aggression, including green sunfish, black bullhead, fathead minnow, redside shiner, and red shiner. Green sunfish, fathead minnow, or red shiner were frequently observed chasing smaller Colorado squawfish. Territorial behavior was observed only for green sunfish and fathead minnow. Fathead aggression was attributed to breeding behavior. They observed one incident of aggression resulting in physical injury with a fathead minnow nipping a small Colorado squawfish. Colorado squawfish may be competitively inferior in a crowded or resource-limited environment based on its non-aggressive nature and slower pursuit of prey items.

Habitat alterations by introduced fish

Habitat can be altered by consumption, uprooting, or increased turbidity as a result of nonnative fish activities. Water quality can be degraded by siltation, substrate erosion, or eutrophication. Some species may cause habitat degradation by uprooting vegetation or consuming large numbers of aquatic plants. These feeding strategies may be novel to the biotic system and increase turbidity and siltation or cause degradation of water quality. No incidents of habitat alteration by exotics in the upper basin have been reported. Common carp have been implicated in the removal of aquatic vegetation in other systems but their affect on vegetation in the upper basin is unknown. Moyle (1976) reported carp decreasing the clarity of a lake in California due to uprooting vegetation.

Hybridization

Hybridization with native species can occur between closely related species. This usually occurs through interbasin transfer of a nonnative from an adjacent basin. One species may eliminate another through genetic swamping (Moyle 1976). The resulting hybrids may also out-compete the native parent species or dilute wild genetic stocks with continued hybridization. Introduced white sucker hybridize with native flannelmouth or bluehead sucker (Wick et al. 1981, 1985, 1986; Valdez et al. 1982a and b), and flannelmouth sucker hybridize with razorback sucker (Hubbs and Miller 1953; Tyus and Karp 1990), but there are no known wild hybrids between introduced fishes and the four endangered species.

Disease or parasite introductions

New diseases or parasites can be carried and introduced by nonnative species. Native fish may also become more susceptible to natural disease or parasites when stressed by interactions with nonnatives.

Flagg (1981) conducted a survey of disease agents in native and introduced species in the Colorado River Basin. One objective was to determine if disease agents associated with introduced species adversely affected endangered species. Pathogens were identified from seven native and six introduced species. These included the four endangered species, green sunfish, smallmouth and largemouth bass, channel catfish, black bullhead, and red shiner. Disease agents associated with introduced species did not appear to adversely impact endemic species. Native fishes harbored a distinctly different pathogen group than did the introduced fishes. Flagg (1981) suggested that disease was probably not a factor in the decrease in endangered fish populations.

Osmundson (1987) reported the first occurrence of Asian tapeworm in the upper Colorado River basin and determined that it came from Colorado squawfish raised at Dexter National Fish Hatchery. Osmundson and Kaeding (1989b) identified the negative impact parasites like Asian tapeworm can have on Colorado squawfish and the importance of screening forage fish for parasites prior to their introduction into grow-out ponds.

Incidental take by angling

Osmundson and Kaeding (1989a) noted the significant threat posed by high angler activity for channel catfish within the 15-mile (24 km) reach of the Colorado River. Vulnerability of Colorado squawfish increased with decreased flows which concentrated Colorado squawfish and increased fisherman access. Vanicek (1967) noted the ease of hook and line take of Colorado squawfish, and the heavy exploitation of this species by local fishermen. Wick et al. (1985) reported capturing a Colorado squawfish on the Yampa River by angling with cut sucker meat, a bait often used when fishing for channel catfish. Review of tagging records (Wick et al. 1985) indicated that Colorado squawfish were often collected by researchers using angling gear in Colorado, on the Yampa, Gunnison, and Colorado rivers. In some years up to 10% of all Colorado squawfish Carlin tagged have been recaptured by fishermen (Tyus and Karp 1989).

Management recommendations

Management recommendations from the literature included suggestions for flow maintenance or regulation, habitat enhancement, preservation of natural habitats and reaches, stocking endangered fish large enough to avoid predation, and protocols for stocking and control of nonnative gamefish.

Several recommendations in the literature warned of altering flow regimes that native fishes coevolved with while other recommendations suggested that flow regimes could be regulated to the advantage of native fishes and a disadvantage of nonnative fishes. Karp and Tyus (1990b) warned that alterations of natural flows in the Yampa River might enhance the further proliferation of nonnative species. They suggested protecting natural flows of the Yampa River. Osmundson (1987) suggested that upstream dams on the Colorado and Gunnison rivers, Colorado, should be discouraged from moderating natural spring flooding that may be useful in controlling nonnative fishes.

Osmundson and Kaeding (1989a) suggested that "flows might be controlled to increase temperature and promote spawning earlier in the year" which might improve growth and survival of larval squawfish. High flushing flows during spring may be the only means to control introduced species (Osmundson and Kaeding 1989a; 1991). Osmundson and Kaeding (1991) recommended peak spring flows for the 15-mile (24 km) reach of the upper Colorado River, Colorado, that they hoped would decrease introduced fishes. Higher flows were suggested based on the negative relationship between peak flow and nonnative abundance and the positive relationship between peak flow and native abundance. Grabowski and Hiebert 1989) warned that increased water levels might increase shoreline habitat for young native fish, but might also provide habitat for larger predatory introduced fish in backwaters. Valdez (1990) believed that management of flows would only temporarily decrease densities of many nonnatives because of their high reproductive potential.

Minckley and Meffe (1987) suggested that regular flood events might decrease nonnatives and allow natives a chance to recover from predation or competition, allowing the two faunas to coexist. Regular floods would shift the advantage to native fishes that could probably survive this type of event better than most nonnatives. Although they were directing this action toward small streams the applicability for larger rivers and spring run-off flooding remains to be shown. Several predatory centrarchids and ictalurids have been reduced or eliminated by flooding in Arizona streams while natives were little affected. However some extreme flood events may decrease or even decimate native populations and drastically alter habitat by bank cutting (Meffe 1984).

Habitat enhancement has was also recommended as a method to enhance native fish populations, but any habitat modification must account for the affects on nonnative fishes. Behnke (1980) suggested the creation of backwaters for mitigation of development. The backwaters would serve as nursery grounds of rare fishes and control structures could be installed to exclude nonnative predators and competitors. Johnson (1980) warned that these backwaters might actually enhance exotic fish populations by providing a haven and increasing competition.

Valdez and Wick (1981) suggested that backwater habitats created for endangered fish should function like natural backwater habitats to avoid becoming refugia for nonnative fishes. Backwaters formed at high flow should drain with descending flow and low flow backwaters should be inundated and flushed at high flows. Backwaters created from gravel pit ponds and connected to the river tended to be permanent and provided refugia for nonnative competitors by sheltering them from the riverine environment. These should be sealed to prevent immigration of nonnatives into the river. Osmundson (1987) suggested that gravel-pit ponds be zoned away from the river or that very secure dikes be required to prevent sportfish from entering the river during high water events.

Molles (1980) suggested the establishment of a semi-natural preserve for native fish fauna with natural flows and the exclusion of exotics. He suggested preservation of the entire community, not preservation of individual species. He admitted such an undertaking would be ambitious; but, once established it would require less management input than the continual stocking of hatchery populations. He admitted the major obstacle would be the elimination of exotics. Hubbard (1980) agreed, suggesting the "primeval-like" habitats found in the Yampa River within the upper basin made this river most suitable as a preserve. Hubbard (1980) believed that natives could probably cope with most nonnative fishes if provided with natural habitats.

There appeared to be a need for standard protocols and review of stocking programs for nonnative fishes. Pimm (1987) suggested three rules for introductions to reduce severe impacts. Don't introduce species where predators (or competitors) are absent. Don't introduce highly polyphagous species. Don't introduce species into relatively simple communities. Osmundson (1987) recommended that nonnative fish stocking by private citizens and public agencies into the river system should be discouraged.

If endangered fish are stocked in the upper basin they should be large enough to avoid predation. Osmundson (1987) recommended stocking fingerling Colorado squawfish into predator-free, grow-out ponds in the early spring and transferring them to the river in the fall. Size at release should be 200-250 mm TL to avoid most predators. Razorback sucker also should be stocked at a size (> 300 mm TL) relatively immune to predation (Marsh 1987; Marsh and Langhorst 1988; Marsh and Brooks 1989). Marsh and Langhorst (1988) pointed out that this might establish adult stocks but self-perpetuation would not occur if predation on larvae continued. Stocking in the late winter (January) helped razorback sucker acclimate to riverine conditions, find cover, and avoid predation (Marsh 1987). Marsh and Langhorst (1988) believed that recovery of razorback sucker "may best be achieved in backwaters, oxbows, and smaller tributary habitats amenable to substantial, perhaps repeated, removal of nonnative fishes". They suggested a reduction of established populations of known predators through ichthyocides to remove catfish from selected streams before stocking of razorback sucker.

EXPERT OPINION QUESTIONNAIRE

Twenty-six people participated in the questionnaire. From the original 40 persons queried, three changed jobs and locations prior to responding, and were unavailable to participate. From 37 potential participants, there was a 70% response rate. Participants included 7 representatives from USFWS, 7 from UDWR, 3 from CSU, 3 from NMGF, 2 from BioWest, Inc., and 1 each from ASU, CDOW, UNM, and USBR.

Job type categorization showed 54% of the respondents were biologists, 38% were researchers, 27% were managers, and 31% considered their jobs to be some combination of these three job types. Eighty-five percent of the respondents overall placed part of their expertise in one or more of these job types. Twenty-seven percent of the respondents were in administrator, supervisor, college professor, or other categories.

Responsibility categories showed 65% of the respondents dealt with threatened and endangered (T&E) species, 58% dealt with nongame species, 46% dealt with sport fisheries, and 42% dealt with gamefish species. Thirty-one percent of the respondents dealt with both game and nongame species, 46% dealt with nongame or T&E species only, 23% dealt with T&E species only, and 12% dealt with gamefish species only. Responsibilities for 54% of the respondents were regional in scope, 15% were statewide in scope, 4% were district oriented, and 27% were not bounded by any geographical boundaries.

Question 1: *What rivers, lakes, or drainages have you had experience with, or that you are currently responsible for resource management within? (e.g., Yampa, Green, White, Colorado, Lake Powell, Gila, Dolores, San Juan, Salt, etc.).*

Answers to this question showed the combined experience of the respondents included 32 river drainages and 5 reservoirs within the Colorado River Basin, the southwestern United States, and the Missouri and South Platte basins (Table 2). Sixty-five percent of the respondents had experience in the Green River, 58% in the Colorado River, 42% in the White and San Juan rivers, 38% in the Yampa River, and 27% in the Gunnison River. Nineteen percent of the respondents indicated their experience base included Lake Powell.

Question 2: *Are impacts from introduced fish species upon native fish species a problem in any of these waters? If so, please identify which waters.*

The majority of the respondents (81%) answered this question with a "yes" or some qualified form of "yes". Most of the drainages listed in Table 2 were included as having native fish species impacted by introduced fish species. Respondents identified the Green, White, Yampa, Colorado, Little Snake, San Juan, Salt, Gila, Virgin, Pecos, Rio Grande and Rio Chama rivers. Some respondents included all waters in New Mexico except the Tularosa, all waters in Utah, all waters in the Lower Colorado River Basin, or all waters in the Colorado River Basin. Thirty-five percent of the respondents indicated impacts of

Table 2. Drainage basins in which questionnaire respondents have developed expertise as fish biologists and fishery managers. Number of respondents indicates number of person listing experience in that basin.

Drainage basin	No. of respondents
Arkansas	1
Canadian	3
Cimmarron	1
Colorado (upper, lower, and Grand Canyon reaches)	13
Colorado River Basin (all inclusive)	1
Dolores	3
Duchesne	3
Flaming Gorge Reservoir	2
Gila	5
Green (upper and lower reaches)	15
Gunnison	6
Lake Havasu	1
Lake Mohave	1
Lake Powell	5
Little Colorado	3
Little Snake	2
Mill Creek	1
Mimbres	1
Missouri	1
Muddy	1
Navajo Reservoir	2
Pecos	4
Plateau Creek	1
Price	1
Rio Chama	1
Rio Grande	4
Rio Yaqui	1
Salt	3
San Francisco	1
San Juan	9
San Rafael	1
South Platte	1
Tularosa	1
Uncompaghre	1
State of Utah, all	1
Verde	2
Virgin	1
White	9
Yampa	9

introduced fishes upon native fishes should be qualified by statements like "remain to be proven, are difficult if not impossible to define, still need good documentation, are difficult to validate, and lack corroborative research evidence". Other qualifications included impacts were "likely, probable, possible, and presumed". The responses concerning degree of impact ranged from "severe" to "moderate" to "small" to "any negative impact should be considered a problem".

Question 3: Which introduced species do you consider to be presenting a problem?

Seventy-seven percent of the respondents listed introduced fish species they considered to be presenting a problem to native fish species. Twenty-eight species were named, and channel catfish, red shiner, northern pike, common carp, green sunfish, and fathead minnow comprised a group considered by 35% or more of the respondents to be a problem (Table 3). Over half the respondents listed channel catfish and red shiner as problem species and northern pike was listed by 46% of the respondents. Some respondents did not provide species names, but referred to "catfish species", "bullheads", "all centrarchids", "all centrarchids and percichthyids", "nonnative salmonids", "*Notropis* spp.", "topminnows", and "any which compete with or prey upon the native species". Salmonid species listed in Table 3 were proposed solely by respondents from New Mexico, or who had experience in New Mexico.

A general statement provided here was that probably all nonnative species that exist in the Colorado River Basin and southwestern United States present a problem given the right conditions, certain situations, or create problems in localized areas. One respondent considered this question as too broad and simplistic, and that case by case analysis was required with consideration of related factors besides the presence of a particular species. Another respondent indicated this was a loaded question based on conjecture. Other respondents stated they were "not sure", or that insufficient evidence existed for most introduced species, or those species that had been investigated did not appear to be abundant in the river (i.e. largemouth bass), or only presented a small problem (channel catfish). One respondent also listed Asiatic tapeworm as an introduced species presenting a problem.

Question 4: What native fish species do they affect, and what is the nature of the impact(s) (e.g., predation, competition for food or habitat, disease, etc).

This question was aimed at identifying specific interactions between introduced and native fish species. Many respondents approached this question from a theoretical perspective. Some respondents indicated all native species existing where nonnatives occur are affected. Depending on species, life stage, and the "right conditions", each introduced species can negatively affect each native species. Predation and competition were considered the primary types of interaction occurring, though some considered predation the primary interaction in effect. Most respondents indicated they felt small-bodied introduced

Table 3. Nonnative fish species listed as presenting problems for native fish fauna in the Colorado River Basin and southwestern United States. Species are ranked by number of respondents listing the species as a problem.

Species	Common Name	No. votes	Rank
1) *Ictalurus punctatus*	channel catfish	16	1
2) *Cyprinella lutrensis*	red shiner	14	2
3) *Esox lucius*	northern pike	12	3
4) *Cyprinus carpio*	common carp	10	4
5) *Lepomis cyanellus*	green sunfish	9	5
6) *Pimephales promelas*	fathead minnow	9	5
7) *Notropis stramineus*	sand shiner	6	6
8) *Micropterus salmoides*	largemouth bass	5	7
9) *Ameiurus melas*	black bullhead	5	7
10) *Gambusia affinis*	mosquitofish	4	8
11) *Morone saxatilis*	striped bass	4	8
12) *Catostomus commersoni*	white sucker	4	8
13) *Stizostedian vitreum*	walleye	3	9
14) *Pylodictus olivarus*	flathead catfish	3	9
15) *Oncorhynchus clarki*	Snake River/Yellowstone cutthroat	3	9
16) *Oncorhynchus mykiss*	rainbow trout	3	9
17) *Salmo trutta*	brown trout	3	9
18) *Salvelinus fontinalis*	brook trout	3	9
19) *Ameiurus natalis*	yellow bullhead	2	10
20) *Richardsonius balteatus*	redside shiner	2	10
21) *Micropterus dolomieui*	smallmouth bass	2	10
22) *Hybognathus placitus*	plains minnow	1	11
23) *Ambloplites rupestris*	rock bass	1	11
24) *Cyprinodon variegatus*	sheepshead minnow	1	11
25) *Gila atraria*	Utah chub	1	11
26) *Lepomis macrochirus*	bluegill	1	11
27) *Fundulus zebrinus*	plains killifish	1	11
28) *Pomoxis annularis*	white crappie	1	11

species affected the early life stages of native fishes and adult native fishes were affected by large introduced, predaceous species. One respondent indicated the converse of this question should be asked: "which native species are not affected by the presence of nonnative species." One respondent felt all native species were affected at earlier life stages. Some respondents felt all natives were "undoubtedly" affected, others were not sure. Some felt the interactions were potential in nature, and more or less significant in degree. Similar to Question 3, some respondents indicated any interactions were not well documented, and thus were unknown in natural environments. One respondent indicated this question was only conjecture. The abundance and widespread distribution of introduced fish species were cited as reasons why predation and competition were probably occurring.

Numerous specific interactions between native and nonnative fish species were provided by the respondents. Using the priority listing of nonnative fishes provided in Table 3, the input of the respondents is summarized below by interaction and nonnative species:

Predation

Channel catfish: -- all native species affected, especially from larvae through juvenile stages. Colorado squawfish and razorback sucker were identified as affected species, especially early life stages of both. Two respondents indicated other native species were affected including roundtail chub, flannelmouth sucker, bluehead sucker, and all *Gila* spp. life stages. One respondent indicated this species as prey affected Colorado squawfish; another indicated this was not an important interaction.

Red shiner: affected all native fishes in the larval stage; especially young of Colorado squawfish and razorback sucker.

Northern pike: all native fishes affected, including YOY and juvenile forms. Colorado squawfish, razorback sucker, roundtail chub, flannelmouth sucker, and bluehead sucker were specifically named.

Common carp: eggs and larvae of all native fishes affected, especially razorback sucker and Colorado squawfish. Eggs, larvae and young of razorback sucker were mentioned numerous times as a specific impact.

Green sunfish: mostly larvae and young of all native fishes, but particularly Colorado squawfish and razorback sucker were impacted. This impact was exerted primarily in backwater habitat.

Fathead minnow and sand shiner: these two species affected young forms of razorback sucker and Colorado squawfish, but included all larval native fish as probable prey.

Largemouth bass: all YOY and juvenile forms of native fishes were affected. Razorback sucker young and Colorado squawfish were again specifically identified.

Black bullhead: affect native fish larvae, YOY and juvenile forms, especially in backwater habitat.

Mosquitofish: affect all larval native fish. The Gila topminnow was specifically identified.

Striped bass: razorback sucker young and Colorado squawfish were identified in particular, and all native fish life stages occurring in Lake Powell.

Walleye: razorback sucker young and Colorado squawfish were specifically identified, though all native fish were considered vulnerable.

Flathead catfish: not specifically identified by respondents in this question, though literature provides evidence of impact to stocked razorback sucker young.

Brown trout: affect Rio Grande cutthroat and Gila trout.

Yellow bullhead and smallmouth bass: affect all endemic fishes in the Gila River Basin.

Redside shiner: affect all larval native fishes.

Rock bass: specific impacts to Pecos gambusia, roundnose minnow, Mexican tetra, and greenthroat darter identified.

Plains killifish: affects all larval native fish.

Black crappie: affects all native fish young.

White bass: June sucker specifically affected.

Competition

Each introduced species identified as a competitor was listed below followed by affected native species and life stage.

Channel catfish: Colorado squawfish, razorback sucker, all *Gila* spp. were specifically identified. Many other native species were considered affected, including flannelmouth sucker, bluehead sucker, and headwater catfish (New Mexico only).

Red shiner: Colorado squawfish young were specifically identified, as were *Gila* spp. and spikedace. All native species were considered affected, especially larval forms.

Northern pike: listed primarily as competitor with Colorado squawfish, but razorback sucker and all native species were also identified.

Common carp: Colorado squawfish and razorback sucker were identified along with roundtail chub, flannelmouth sucker, bluehead sucker, and June sucker. All native species were considered to be affected.

The following species were all listed as competitors with native species in general or Colorado squawfish in particular (denoted by "*"):

Green sunfish
Largemouth bass*
Walleye*
Striped bass*
Black bullhead
Bluegill

The following species were all listed as competitors with all larval or young natives fishes, but Colorado squawfish in particular (denoted by "*"):

Fathead minnow*
Sand shiner*
Redside shiner

Mosquitofish: Pecos gambusia listed specifically.

White sucker: all native species, but flannelmouth listed specifically.

Brown and brook trout: Rio Grande cutthroat and Gila trout listed specifically.

Plains minnow: Rio Grande silvery minnow listed specifically.

Hybridization

Hybrids identified as occurring between native and nonnative fishes are listed below. Native species are provided first, followed by the nonnative species.

Flannelmouth sucker x white sucker
Bluehead sucker x white sucker
Rio Grande cutthroat trout x Snake River cutthroat or Yellowstone cutthroat trout or rainbow trout (New Mexico and Utah specifically identified this interaction).
Gila trout x Yellowstone cutthroat or rainbow trout.
Pecos gambusia x mosquitofish
Headwater catfish x channel catfish
Rio Grande silvery minnow x plains minnow

Disease

Fathead minnow was specifically identified as a possible disease source for native fishes by one respondent. Another identified Asiatic tapeworm as a disease problem.

Habitat Alteration

The common carp was listed by two respondents as having an impact upon native fishes through habitat alteration.

Question 5: Are you aware of any documented evidence, published or not, in the Colorado River Basin demonstrating:

-predation upon endangered fishes, in general, selectively, or as a threat to population survival?

-a competitive advantage of an introduced fish species over an endangered or other native fish species?

-a beneficial effect of an introduced species upon the native fish fauna?

If the answer is yes to any of the above, please summarize below and cite the appropriate literature reference, or, if possible, please provide us with copies of unpublished reports. If the evidence exists as unpublished raw data, please specify as such.

Sixty-two percent of the 26 respondents answered yes to the predation segment of the question. Apart from the eight references cited by numerous respondents, references were also made in two instances to unpublished file data in Utah DWR and at Arizona State University. Personal communication was cited several times regarding predation upon razorback sucker larvae or humpback chub. One respondent was confused by what defined "documented evidence" and two indicated they did not have time to adequately answer this question. Northern pike were listed as a possible "undocumented" threat to T&E species in the Green, White, and possibly Duchesne rivers. Smallmouth bass, flathead catfish and channel catfish were listed as predation problems for all native fish species in the Gila River basin. Two respondents indicated predation problems occurring primarily in impoundments. One respondent indicated predation by Colorado squawfish on channel catfish was a threat.

Fifty percent of 20 respondents answered yes to the competition segment of the question, though few sources of evidence were cited. One respondent indicated northern pike were dominating clear backwater habitat in the upper Yampa. Several respondents referred to the competitive impact of red shiner upon spikedace and loach minnow documented in draft recovery plans for the two species in the lower Colorado River Basin. One respondent cited the increased catch/unit effort index for nonnative species relative to native species as circumstantial evidence. One respondent felt red shiner undoubtedly had a competitive advantage over native species and that evidence existed but was unable to cite it. Evidence of competitive interaction between headwater trout species was also suggested as a generally accepted and documented fact.

Forty percent of 20 respondents answered yes or "perhaps" to the beneficial effect segment of the question. Most of these respondents suggested one or more of the introduced assemblages of red shiner, sand shiner, fathead minnow, and redside shiner provided food for Colorado squawfish. One respondent indicated this aspect of native fishes had not been adequately investigated.

Answering this question was more imposing to respondents than intended due to our inability to provide respondents with the literature synthesis and citation list that was part of this study. Our intention was to provide our literature base to other experts for their review. Answering this question would then have provided respondents the means for filling in gaps in our literature review. The literature base was later provided with a draft copy of this report to all respondents for review.

Question 6: *For problematic introduced fish species, what is your evaluation of their abundance, and the magnitude of their impact(s)-increasing, decreasing, constant, fluctuating with environmental variables, etc.? (please identify environmental influences if known)*

For small-bodied fish species including red shiner, sand shiner, redside shiner, and fathead minnow, one or more of these species were considered by consensus to be widespread and abundant within many drainages. Thirty-eight percent of the respondents cited the abundance and impact of these small species to be inversely influenced by flow regime and associated environmental variables. In most cases, the impact of smaller species was judged to be constant, but fluctuating in severity with abundance as influenced by flow. Red shiner was noted as the most likely single, small-bodied species to be exerting a negative impact.

Northern pike, channel catfish, and common carp were most often listed as specific problematic large fish species. Four of five respondents considered pike abundance to be increasing in the upper basin except within the upper Colorado River. Catch rate statistics were provided indicating northern pike in the Green River have increased since 1975 and equal the catch rate of Colorado squawfish in 1986-1988. Channel catfish were considered to be very abundant and fluctuating in year class strength with flow and temperature regime. The impact of channel catfish was considered to be at a constant level. Common carp were considered very abundant to the point of ubiquitous, and their impact at a constant level. Carp were considered to be very opportunistic with changing habitat availability. Centrarchids, especially largemouth bass, green sunfish, and smallmouth bass; and walleye were considered to be common in the upper basin with areas of local abundance and impact. One respondent listed that the predaceous impacts of largemouth bass may be relatively great even though abundance is low. The impact of white sucker was listed as increasing in the Rio Grande basin due to widespread distribution and abundance. Sheepshead minnow and plains minnow were identified as specific problems in the Pecos River basin (New Mexico-Texas).

Several respondents indicated they were not sure, that introduced fish have not been determined to be problematic, or that they could not pinpoint any problematic species at present. One respondent considered this question to be too broad; another considered it to be conjecture. One respondent indicated he did not have time to answer this question.

Question 7: Do any of the introduced fish species support sport fisheries, and are these fisheries large, moderate, inconsequential?

Wildlife agencies are increasingly faced with potentially conflicting demands of providing sport fisheries as well as maintaining native fish populations in their natural habitat. The intent of this question was to point out what appears to be at stake for wildlife agencies on the sport fishery side of the issue as they pursue the recovery of endangered native fishes. If a gamefish species is determined to present an unacceptable threat to the recovery of endangered fish species, polarity of the management issue will intensify with the popularity of the gamefish and size of associated fishery. Conversely, attempts to negatively manage carp and small cyprinids to benefit native fishes will be met with indifference or applause by the public since they have no sport fishery value. Only three respondents indicated introduced species supported no sport fisheries in the Colorado River Basin. Presumably these persons were referring to riverine fisheries exclusively.

Channel catfish

Several respondents considered this species to provide moderate level fisheries overall in the Colorado River Basin. One respondent considered channel catfish to be probably the most popular riverine gamefish present, but another considered their populations were generally unexploited overall. In Utah, channel catfish fisheries in the Green and Colorado rivers were considered moderate. One respondent considered catfish fisheries in Utah to be inconsequential from an economic perspective while another considered this species to provide substantial opportunity locally in Utah near towns like Vernal and Moab. In Colorado, channel catfish fisheries were considered moderate to large in the Colorado, Gunnison, White, Yampa, Dolores, and Little Snake rivers. Differences in assessment were noted between respondents for all these rivers in Colorado. The Little Snake River catfish fishery was deemed inconsequential by one respondent. In New Mexico, fisheries for this species were considered large overall, but small in the San Juan River due to low public access.

Northern pike

Fisheries for northern pike were deemed moderate overall by one respondent. In Utah, the species population was considered to have excellent potential for supporting a moderate fishery in the Green River but was rated inconsequential at present. A small, local fishery for northern pike was identified in the Green River near Jensen. In Colorado, northern pike were considered by one respondent to support a moderate fishery in the upper Yampa and in off-channel impoundments in both the Yampa and White rivers. Another respondent considered the northern pike fishery in the Yampa to be large, but nonexistent in the Gunnison, Colorado, White, and Green rivers within Colorado.

Centrarchids

For largemouth bass, smallmouth bass, and green sunfish, riverine fisheries for these species in Colorado and Utah were considered inconsequential in the Green, Colorado, Dolores, Gunnison, and White rivers. One respondent listed the smallmouth bass fishery in the Yampa River as inconsequential while another listed this fishery as moderate. In standing water habitats, however, from small off-channel, gravel pit ponds to moderately-sized Elkhead Reservoir in Colorado to large impoundments like Lake Powell and Flaming Gorge, one or more of these species were considered to support moderate to large fisheries. This was considered so in New Mexico also. Bluegill and crappie fisheries were considered inconsequential in all cases except in Rio Blanco Lake near the White River in Colorado.

Walleye and Striped bass

Fisheries for these two species were considered large or substantial only in Lake Powell, and for striped bass in Lakes Mojave and Mead. Walleye in the Green River was considered inconsequential.

Bullhead species

In Colorado, fisheries for black bullhead were considered inconsequential in the Dolores, Yampa, and Little Snake rivers; and moderate in the Gunnison, Colorado, White, and Green rivers. In New Mexico, the yellow bullhead fishery was considered large.

Trout species

Fisheries for salmonid species are relevant when they exist in impoundments or their tailwaters that occur within the historic range of native warmwater species, or in river reaches above this historic range, but may also be affected by reservoir operations. As such, respondents considered large to world class brown and rainbow trout fisheries existed in the tailwaters below Flaming Gorge Reservoir on the Green River, Navajo Reservoir on the San Juan River, Ruedi Reservoir on the Fryingpan River (upper Colorado mainstem), below the

Aspinall Unit reservoirs on the Gunnison River, and below McPhee Reservoir on the Dolores River.

Question 8: *Do you consider angling mortality related to incidental catch of endangered fishes by anglers pursuing gamefish species a significant source of mortality? If so, what is your estimate of the incidence of "harvest" mortality, and what gamefish species is the target of the fishery?*

Thirty two percent of the 25 respondents answered yes to the question, particularly in regard to angling mortality for Colorado squawfish. Opinions differed strongly between respondents from federal and state agencies. Three more respondents indicated angling mortality may potentially be affecting the endangered fishes. Two estimates of 10% angling mortality were proposed. Angling mortality to Colorado squawfish and humpback chub was associated with incidental captures by persons seeking northern pike, smallmouth bass, or channel catfish; angling mortality to bonytail was associated with incidental capture by persons seeking rainbow trout. The significance of angling mortality was not necessarily associated with numbers caught, but three respondents based their judgement upon the likely size of Colorado squawfish that are affected, the fish's older age, vulnerability to angling prior to sexual maturity, and replacement time needed to recruit another younger fish. The long-lived nature of adult Colorado squawfish also extends the period these fish are vulnerable to angling. It was hypothesized that angling mortality may be responsible for the absence of larger adult fish in river reaches receiving greater fishing pressure, such as the Grand Valley reach of the Colorado River in Colorado.

Respondents offered several reasons why angling was not a significant source of mortality to endangered fish. One was the relative abundance of the endangered fishes and low fishing pressure were attributes of the system, and did not lead to conclusions of significant loss. Other reasons provided included 1) creel survey data collected by Utah DWR, 2) the effectiveness of the catch and release recommendation for native fishes provided to the public by Utah DWR through creel survey contacts, signing, and its fishing proclamation, 3) the persistence of endangered species in areas of increasing angler activity, and 4) reported evidence from anglers of caught/released adult Colorado squawfish with prior, multiple hook wounds. All were suggested as supporting evidence that many anglers are aware of the endangered status of these species and are releasing endangered fish that they capture.

In New Mexico, harvest of bait minnows for sportfishing was also listed as a problem.

Question 9: In your opinion, what are possible field techniques or other approaches that wildlife management agencies might use to lessen, or eliminate problems or impacts created by introduced species?

Five respondents suggested a philosophical assessment was in order prior to any discussion of active negative management of problematic introduced species. These are paraphrased below:

* Honestly assess relative values. If native fish are valued higher, explore means to remove nonnatives and prevent re-establishment. This is very difficult and costly, however.

* Assess whether introduced species are the primary or secondary cause of the impacts. Attempt removal of nonnatives only if they are the primary cause.

* We must identify problems first and attempt to target vulnerable life stages (of nonnatives).

* The real question ought to be: "Can we restore the habitats in the Green and Colorado rivers to their original conditions, which would favor the needs of endemic fishes?" The answer is obviously no, due to the dams! A further issue, assuming interspecific competition from exotic fishes, is how to maintain or reduce the exotic population numbers?"

* We may be able to more effectively manage for endemics and against introduced fishes.

Five respondents provided a philosophical perspective based on what they perceived as the reality of problems posed by introduced species. Several indicated no practical, realistic, or effective solutions existed for eliminating or solving these problems. Two other responses suggested these problems are permanent and recovery efforts or management should be targeted at determining the extent of the impacts and the efficacy of control measures.

Remaining responses offered approaches which could be grouped into five major categories. These were sport fishery regulation, sportfish stocking, eradication, habitat management, and hatchery augmentation. In almost all cases, these approaches were not offered as singular techniques, but as elements of a comprehensive approach using multiple techniques from one or more categories.

Sport fishery regulation

Opinions were divided on several techniques proposed as means of reducing problems associated with introduced gamefish species. One respondent indicated angling was a potential way to reduce abundance of targeted gamefish species, while another respondent stated the reduction of gamefish predators through sport harvest was not possible. Six respondents offered regulation changes as means of reducing problematic introduced gamefish species or minimizing incidental capture of native fish. These changes were:

* Restrictions on sport harvest of endemics.

* In the Yampa River, manipulate fishing regulations to encourage fishing for northern pike during periods when Colorado squawfish are not present; discourage fishing when Colorado squawfish are vulnerable to capture.

* In the Colorado River, conduct intensive surveys to determine to what extent incidental take is a problem (i.e. Grand Valley reach), and (if this take is judged unacceptable), create a seasonal closure (in the river reach) to channel catfish fishing and prevent fishing during the time when adult Colorado squawfish are most vulnerable to angling. This is suspected to be during spring when adults are concentrated near shore in backwater areas.

* In New Mexico, allow trot and set lines for catfish (generally not allowed in southwestern states). Allow spearfishing for sportfish. Allow commercial harvest of reservoir sport fisheries.

* In Utah, biologists recommended the use of set or trot lines not be allowed, a gear restriction they have implemented on the Colorado and Green rivers for several years.

Five respondents offered techniques related to public information and education. These included continuing efforts to educate anglers about the need to help protect endangered fish and encourage anglers to recognize (be able to identify) and release native fish. Part of the public relations process recommended by one respondent was to publicize fines and penalties associated with violating the law (protecting endangered wildlife). Utah considered the signing and pamphlet program targeted at anglers that is currently in place to be effective. In both the Colorado Fishing Map and the State fishing season information pamphlet, color pictures and descriptions of endangered Colorado River fishes are prominently displayed; and in the latter, river reaches in the state where an angler might encounter one of these fishes is also prominently displayed. A program of signing prominent public access points on Colorado's river reaches where anglers may encounter endangered fishes has also been initiated. Enforcement and prosecution under the law with accompanying media coverage was also recommended as a means of reducing incidental take of endangered fishes.

Hatchery augmentation

This approach was listed by two respondents, and in both cases, augmentation was listed in conjunction with other means listed above. A specific criterion was suggested for a 180 mm length minimum for stocking hatchery-reared endemics (presumably referring to the four endangered big river species).

Question 10: Have you, your agency, or associates attempted any of the above, and with what success (or failure)?

Nine of the respondents answered in the negative for this question. The remaining responses were grouped by the same categories in Question 9:

Sport fishery regulation

Few of the approaches suggested by the respondents in the previous question have been attempted or evaluated. Other than obvious restrictions on harvest of endangered fishes, no regulations have been created or evaluated to limit the take of endemic species or promote the harvest of nonnative species within the Colorado River Basin. Conflicting recommendations from respondents on the use of trotlines for the harvest of catfish underscores the need for better information regarding the incidental take of endangered fishes caused by this angling method. In order to manipulate angling regulations through seasonal closures, reach closures, or tackle restrictions, the degree and timing of potential angling impact should be evaluated. Emergency closure of the tailwaters of Taylor Draw Dam on the White River, Colorado, to angling, which is now a continuing regulation, is a case in point of remedying a recognized, specific impact. Several respondents cited a recent creel survey conducted in Utah on the Colorado River suggesting incidental take of endangered fishes was nonsignificant. A 1987 creel survey conducted on the Yampa River indicated daytime angling pressure on reaches containing endangered fishes was too low to generate harvest estimates for gamefish species (CDOW, unpublished data). In Utah, the program for educating anglers to release captured endemics fishes, including the signing program, was considered very successful. No evaluation of the information and education program within Colorado has been undertaken.

Concerning baitfish regulations, Utah suggested the regulations prohibiting seining have had some success. No evaluation of similar regulations in Colorado have been undertaken. Implementation of stricter regulations regarding baitfish and seining has generally occurred too late, according to one respondent, to make a difference in drainages where problems already occur. Regulations serve only to discourage further introductions and the harvest of juvenile endangered native fishes.

in the Virgin River drainage for largemouth bass broodstock, ponds also inhabited by spikedace, desert suckers, woundfin, and other native fishes. Another example of conflict in management programs was the proposed introduction of rainbow smelt into Lake Powell, but the perception of respondents was that review of the proposal by both game and nongame sections was more evident.

In Colorado, a management philosophy expressed was that efforts to recover endangered fish should proceed via augmentation and artificial habitat enhancement so that aggressive sportfish management can proceed thereafter. A perception outside the state agency was CDOW was not pursuing the potential problem of incidental take of endangered fish by angling in the Grand Valley and enforcement of laws prohibiting harvest of these fish was insufficient.

Responses suggested an internal communication process was evolving within Colorado, Utah, and New Mexico. One observation on this communication process was: "The philosophies tend to diverge, and it is hard to have a true dialogue. Recovery biologists in general seem very unwilling to sit down and discuss the true issues. Management biologists are willing to sit down and discuss, but are not always sympathetic. When dialogue is forced to happen, we have had some success."

On the federal level, respondents stated that long range planning documents requiring strict compliance with the National Environmental Protection Act (NEPA) provided the mechanism for achieving a balance between the harvest of sport and native fish and introductions of "new" sport species. Another respondent acknowledged that even though their agency goal was to enhance all fishery resources, sport or game fish species must take a lower priority when endangered species are concerned.

Question 13: Do you feel the problems posed by introduced fishes upon native fishes have been exacerbated by other problems such as aquatic habitat change/loss, water quality degradation, land use practices, etc.? Is there any documented evidence of this you are aware of (please cite)?

All 25 respondents answered affirmatively to this question (one did not answer). Forty-eight percent listed habitat loss or changes, 28% listed flow reductions or pattern changes, and 20% listed water quality deterioration or water temperature changes as the primary "other" problems that initiate or increase the severity of problems related to introduced fishes. Four respondents indicated documented evidence was not known, while seven provided some form of evidence.

Federal agency respondents indicated avoidance of conflict with threatened and endangered species through NEPA compliance was standard policy. Concern was expressed that the lack of regulation of stocking by private landowners by Colorado was a primary flaw in the government regulatory structure.

Question 15: In practice, do you feel these policies/protocols are effective, are they selectively implemented, are they ignored?

Ten of 16 respondents felt the policies or protocols in place within their states or between agencies were generally effective. Only one federally-employed respondent indicated the policies and protocols were generally not effective due to the lateness of concern. This respondent felt implementation was selective, and largely dependent upon communication and cooperation between native and sport fish biologists. Other reservations were expressed. The strength of these agreements was considered to be subject to changes in public/political opinion and cooperation. If the potential impact to recreation or economics was too great, political processes would engage to dictate agency activities and direction. Another respondent felt initial communication between fisheries and nongame sections was good, but was unsure of how long the communication link held up. One respondent felt that sportfish biologists held little sympathy for the native fish fauna and their riverine habitat if their presence conflicted with sportfishery desires. The proposed rainbow smelt introduction in Lake Powell by Utah DWR was described as a test case. One respondent used the regulation prohibiting seining for bait within drainages in New Mexico as an example of a confounding state policy. In an effort to reduce incidental take of endangered fishes through bait seining within their native range, the policy permits the use of bait from outside the drainage and has resulted in the introduction of other nonnative fishes. Another respondent felt state policy was largely ignored by the public until recent prosecution in criminal court resulted in public education and better compliance.

Question 16: What do you see as likely management alternatives for maintaining native, threatened, or endangered fish fauna in waters where problematic introduced fish species cannot be eliminated or their adverse impacts ameliorated?

Twenty of 26 persons provided answers here. Responses to this question could be categorized into six alternatives. Areas of potential management, listed in order of most cited to least cited alternative, included habitat management, control of nonnative fishes, augmentation, refugia, angler harvest, and unknown. Eighty percent of the responses included some form of habitat management, 45% included control of nonnative fishes, 40% included augmentation, and 15% included refugia. Only one respondent (and perhaps the six others providing no answer) indicated no solution was apparent to the scenario described in this question. Most of the respondents suggested a management strategy consisting of several approaches from the major categories. The alternatives are listed below along with more specific comments provided by the respondents.

introduced species. The barrier effect of dams and the change in water flow regime and quality is certainly the largest single physical impact to native species.

-With the exception of construction of large mainstem dams like Flaming Gorge, introduced species are at least equal among other impacts listed.

-Nonnative fishes play a significant role in the life history of native fishes.

-Introduced fishes could have the most detrimental effect on razorback sucker. It appears this species may successfully spawn but young are eaten. However, loss of habitat obviously is a factor also. Our job of helping these fish would be much easier and probably much more successful if we did not have to deal with introduced fishes.

-Totally underestimated! We have done a considerable amount of work in the area of determining habitat changes and effects of habitat changes on native species, but only given lip service to the problem of nonnative impacts. The problem is, it is difficult to do, the outcome is slow, and likelihood of successful removal or elimination is difficult at best.

-The effect of introduced species is one of the major impacts to native species. All these impacts are cumulative, however, and "recovery" will entail dealing with all simultaneously.

-Impacts from introduced fishes may be as or more important. You have to view all changes as acting in a synergistic manner; it is difficult to separate one from the other.

-Again, it is just one of many. In the case of Lake Powell, altered habitat and predation are having a major impact.

-Impacts from introduced fishes are very important because introductions are irreversible usually and results are unpredictable. They constitute a confounding variable in most studies.

-All impacts are intertwined and you cannot separate one from the others.

-Because these fish are present now, our efforts to negatively impact them, especially sportfish, will certainly encounter special interests that will insist or ensure that desirable sportfish persist in the system. Something is broken out there that affects rare native fishes. Mark-recapture of stocked individuals of various sizes is the only way to gain insight to the problem in a reasonable time period (15 yr). Sure, there are probably impacts due to nonnatives, but much of the perceived problem will remain emotional in spite of the data. There is no doubt that nonnatives are part of the spectrum affecting threatened and endangered fish, but is it part of the addressable spectrum that we can in reality do something about?

DISCUSSION AND SUMMARY

Literature Review

Increases of number of nonnative fish have been documented in the Colorado River (Osmundson and Kaeding 1989a), Green River (Behnke 1980; Holden 1980; McAda et al. 1980), Yampa River (Joseph et al. 1977; Miller et al. 1982a), and White River (Crosby 1975; Lanigan and Berry 1979, 1981; Miller et al. 1982b).

The abundance of nonnative fishes has also been shown to be related to abiotic factors such as habitat alteration and flow events (Cooper 1983; Meffe 1984; Castleberry and Cech 1986; Minckley and Meffe 1987; Valdez 1990; Osmundson and Kaeding 1991).

In the upper basin, predation has been documented on wild Colorado squawfish by channel catfish (Coon 1965) and black bullhead (Taba et al. 1965). In the lower basin, channel catfish consumed humpback chub (W. L. Minckley, personal communication in Karp and Tyus 1990b) and there is evidence of other predation attempts by channel catfish on humpback chub (Kaeding and Zimmerman 1983; Karp and Tyus 1990b). Razorback sucker eggs have been found in channel catfish stomachs in Lake Mohave (Bozek et al. 1984). Stomach contents from one or more of the following species; channel catfish, common carp, northern pike, rainbow and cutthroat trout, green sunfish, black bullhead, largemouth bass, striped bass, or walleye; were examined by several researchers who failed to find eggs or remains of rare fish (Person and Bulkley 1982; Bozek et al. 1984; Grabowski and Hiebert 1989; Tyus and Karp 1990).

Inability to detect predation through stomach content analysis does not discount predation of endangered fishes. Inability to detect predation may be due to small sample size of predator stomachs, rarity of endangered fish, rapid digestion, mastication, or regurgitation of prey (Bozek et al. 1984; Tyus and Beard 1990). Even if predation is documented, its affect on the prey population may be difficult to predict, especially in wild, natural situations.

Several studies have shown the negative affect that predation can have on fish numbers. Because of the difficulty of documenting predation on wild, rare species, nonnative fish predation effects were documented most frequently on native fishes reared in large numbers, in confined areas, or after stocking (Hendrickson and Brooks 1987; Osmundson 1987; Marsh and Langhorst 1988; Marsh and Brooks 1989). Predation was confirmed as a significant source of mortality for artificially propagated YOY and yearling Colorado squawfish raised along the Colorado River in riverside ponds (Osmundson 1987). Predation was also confirmed as a significant source of early life mortality on razorback sucker reared in an isolated backwater in Lake Mohave (Marsh and Langhorst 1988). The backwater was invaded by exotic predators that eliminated the razorback sucker population. Exotic fishes identified as major predators in the two studies were largemouth bass, green sunfish, black crappie, black bullhead, channel clearly documented. They were in disagreement with wholesale changes or negative management directions being expressed toward sportfisheries impinging upon river reaches inhabited by endangered fishes. Conflicts arising within and between agencies regarding game and nongame management concerns may be best dealt with by promoting increased opportunities for communication between field biologists and administrative managers prior to decision-making.

There was consensus on the perception that problems related to introduced fishes were increased in severity by other concomitant impacts to the habitat of native fish. Habitat changes, especially flow related, were considered a primary problem by respondents. They also considered some form of habitat manipulation as the most likely alternative for maintaining native fish populations in the face of chronic impacts from introduced fishes. Half of the respondents considered negative impacts to native fish habitat to be the greatest problem and restoration or enhancement of that habitat the most feasible solution to reducing introduced fish problems. Slightly less than half the respondents considered nonnative fish control and augmentation as viable management alternatives.

The objectives and guidelines described for the Delphi technique were followed in the development of the questionnaire and the list of experts asked to participate. These guidelines targeted expertise, anonymity, and consensus opinion of the respondents. Because the objective of this project was the development of issues pertaining to nonnative fishes and impacts to native fishes, the questions were not constructed for specific quantitative answers and analysis as illustrated in Zuboy (1981). Given the subjective nature of the issues, answers, and interpretations provided in the discussion, the results may not be free of bias. As indicated in Zuboy (1981), however, the selection of experts is the key to success, and if the experience of the experts is appropriate to the problem at hand and of sufficient breadth, the results should tend to be unbiased. Despite its obvious departure from the true Delphi approach, this report does however represent a step toward systematic refinement of the issues at hand. If results or interpretations reported here are at significant odds with perceptions of the various agencies and participant groups in the recovery program for Colorado River endangered fishes, further refinement of the issue and consensus opinion through a more rigorous Delphi approach may be a useful next step.

Research recommendations

1.) Rate nonnative and native fish interactions as a high priority area of investigation.

2.) Direct research towards specific questions of interactions, rather than general studies that infer effects as an afterthought.

3.) Direct research at the most abundant or potentially harmful species. These include channel catfish, northern pike, green sunfish, red shiner, common carp, and fathead minnow.

4.) Suspected negative interactions should be confirmed with laboratory or controlled field settings when feasible, followed by field investigations to confirm results in the wild.

5.) Initial research on predatory or competitive interactions should be targeted at simple investigations between one native and one introduced species.

6.) Laboratory research should focus on sequential testing from simple confirmation of a predatory or competitive interaction between two species to repetitions of experiments under expected field conditions (e.g. temperature, substrate, current velocity, turbidity, cover, prey and predator density, alternate prey choices).

7.) Research should target a) impacts of small bodied forms of introduced fishes to the reproductive success and YOY survival of native fish, and b) field-oriented manipulation/response experiments using adult fish in important habitats (e.g. removal of introduced predators from spring backwaters).

8.) Research establishing the cause-effect relationship between reproductive success, spawning, or other life history activities of small-bodied introduced species with major flow regime events should be pursued to validate the use of flow manipulation or instream flow acquisition/protection to reduce reproductive success and early life survival of these abundant species.

9.) The effect of habitat enhancement or restoration favoring native endangered fishes should also be evaluated for expected negative impacts to introduced species via abundance and habitat use patterns.

10.) If endangered fishes are stocked within the upper basin, it is important to ascertain the level and effect of predation on their numbers. This information would be useful for future stocking and may indicate problems with wild fish recruitment.

11.) Research using razorback sucker should seek to build upon the nucleus of results of previous studies in the lower basin that confirmed predation upon this species by various introduced species.

12.) Existing research results confirming wild predation by various introduced species upon Colorado squawfish, humpback chub, and bonytail chub were exceedingly scarce. Field investigations should verify, replicate, or expand upon results from controlled field and lab studies.

Management recommendations

1.) Agencies should not seek to enhance or promote river-based, non-salmonid fisheries for introduced species, particularly channel catfish, northern pike, smallmouth bass and walleye until specific research investigations can confirm or deny suspected negative interactions.

2.) Agencies should seek to maintain and safeguard native fish faunal assemblages in their native habitat by restricting use of gamefish predators to off-channel water bodies that are secure from escapement, and identifying and isolating sources of gamefish escapement from river access. Increased isolation of offstream impoundments is recommended to prevent escapement of exotic fishes during high flow events.

3.) Agencies should seek to confirm the optimistic estimate of incidental catch of endangered fishes in the Colorado River in Utah and expand the evaluation to areas of high angler use in occupied endangered fish habitat elsewhere. Creel survey sample techniques should be modified with respect to time of day and seasons of highest angler effort and catch.

4.) Agencies should continue public relations efforts to promote catch and release of native fish by anglers, and target specific angler groups that have a higher probability of capturing endangered species.

5.) Agencies should initiate or continue to identify and monitor river reaches in occupied endangered fish habitat that are susceptible to periodic and extraordinarily high incidental catch of endangered fishes, and move to protect these areas from angler use (e.g. White River closure below Kenney Reservoir).

6.) Agencies should facilitate and promote internal and interagency communication between nongame/native fish and gamefish management sections to encourage optimal management guidance for both elements of the aquatic wildlife resource.

7.) Agencies should continue to review proposed and existing stocking practices for both new and indigenous gamefish, forage fish species, and sport fisheries with regard for potential negative impacts to native and endangered fish communities both on and off-site. Research should be required to confirm or deny suspected negative interactions.

8.) Agencies should seek to establish regulatory review procedures regarding stocking of private waters and baitfish commerce to prevent undesirable introductions of nonnative fish species.

9) Endangered fish that are stocked should be large enough to avoid predation by most fishes. Minimum size should be determined by existing predator conditions and sizes. Predator free grow-out ponds should be used to obtain fish of suitable size.

10) Establish river reaches or entire rivers as natural preserves. Attempt to maintain these as refugia by providing historic flows and if possible exclusion of exotic fishes.

Implementation strategy

One of the objectives of this issue paper was to provide the Recovery Implementation Program (RIP) with guidance on how to approach the issue of nonnative fish impacts upon the recovery of endangered native fishes. A primary result indicated that documented evidence was severely lacking on the impacts and control of nonnative fishes. Given the 15 yr time frame set for the RIP, we are faced with two alternatives to proceed:

1) Accept the conceptual understanding that negative impacts of introduced fishes in the Colorado River Basin are significant without scientific documentation and proceed to negatively manage populations of introduced fish species perceived to be most harmful to the native fish fauna, or

2) Target research on introduced fish species perceived to be harmful and identify which life stages and in which habitats introduced species negatively affect endangered fishes; then manage toward reducing or eliminating the negative effect.

The choices, however, are not as simple as selecting (1) or (2). Inherent within both alternatives is a subsequent decision as to whether management alternatives and field techniques exist, or can be developed, to reduce or eliminate the negative interaction. Most of the introduced fishes exist in the Colorado River Basin due to some human-related activity. Some of the nonnative species represent popular gamefish species; some represent selected species for management of forage bases for sport fisheries or common commercial bait products. In conjunction with conservation of the wildlife resource, an important mandate for state wildlife agencies is to provide public fishing recreation. Similar to water and land management activities, correction of perceived negative impacts from introduced fishes will undoubtedly restrict or eliminate certain human activities and choices, and will require documentation in order to proceed.

Recommendations provided here comprise a strategy for approaching the issue of introduced fish impacts. Recommendations 1-6 for research attempt to direct this activity toward areas of major concern in a logical sequence. These activities start to answer which nonnative species affect which endangered species and how. Recommendations 7-10 provide further guidance regarding research activities that would document negative impacts to recruitment, negative competitive interactions, and the utility of flow-related management, habitat enhancement, or fish control efforts in reducing the abundance and effects of introduced fishes or enhancing the survival of native fishes. Recommendations 11-12 encourage better research planning and design based on previous research results.

Currently, research is ongoing that addresses some of the concerns and recommendations above. Results from these studies will provide further guidance of a more specific nature regarding problem species, interactions with native fishes, and effects of environmental manipulations. Decisions concerning future research needs or field management activities can be refined when these studies are completed.

Until research documentation provides the necessary direction, specific management activities targeted at negatively affecting introduced fish species should be selected carefully. Negative management activities directed at introduced fish species with little sportfish value can probably proceed without arousing opposition. In the meantime, agencies can seek to minimize suspected negative impacts from nonnative fishes by more conservative management of certain predaceous gamefish species in select, or restricted aquatic habitat. This is the essence of management recommendations 1-2. Agencies can also manage for identifying and reducing incidental harvest of endangered and native fishes via angling by continuing to monitor river reaches via creel survey, protecting endangered fishes and select river reaches vulnerable to angling pressure, and continuing public relations and education efforts aimed at promoting identification and release of endangered and native fishes. This is the intent of management recommendations 3-5.

Recommendations 6-8 suggest means of improving management for nongame and native fish fauna via better communication between nongame and gamefish interests, review of present stocking programs and goals, and expanded regulatory procedures for preventing undesirable introductions of non-native fish species. Reintroduction or augmentation of native endangered fishes are potential management options applicable in the field. Research results have suggested this approach can be severely affected by the presence of predaceous fish species in the receiving waters. Recommendation 9 suggests a protocol and procedure for reintroduction or augmentation in riverine habitat affected by introduced predaceous fishes.

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APPENDIX A

1. Cover letter for expert opinion questionnaire.

2. Expert opinion questionnaire.

AQUATIC RESEARCH
317 West Prospect
Fort Collins, CO 80526

DATE

Dear Colleague and Participant,

Enclosed is a questionnaire we have developed regarding introduced and native fishes and their interactions, and we are requesting your assistance with any information you may have. We are preparing an issue paper on the management of introduced fish species with respect to the conservation of endangered fishes and native fish fauna. The paper is being prepared at the request of the Technical Group for use in the Upper Colorado River Basin endangered fishes recovery implementation program. This questionnaire complements an ongoing review and synthesis of published and available in-house literature. We are hoping you will add to this knowledge base with your personal-professional experience.

There are 17 questions as well as some preliminary biographical information we need to categorize results. Names and individual responses will be kept confidential if requested. Many of the questions may be answered with a detailed response so we ask that you strive for concise, complete, but brief answers. You need answer only those questions you feel comfortable and qualified in responding to, but opinions, when stated as such are welcome. If additional space is needed, attach additional sheets of paper, and identify your answer(s) according to the number of the question.

We have included a distribution list so you are aware of associates in your state/agency that have also received this questionnaire. We are interested in your individual responses more than a collective group answer, but you are welcome to confer with colleagues if you wish to clarify facts or other details. If you would like a copy of the questionnaire results and/or the final draft of our report (including the literature synthesis), please indicate so when you return the completed questionnaire.

We would like to receive your completed questionnaire by May 30. If you would like to participate, but constraints imposed by the upcoming (or ongoing) field season or other responsibilities mean that you will need more time, please contact us. Completed forms may be mailed to either of us at the addresses below.

Regards,

Thomas P. Nesler
Colorado Div. Wildlife
317 W. Prospect
Fort Collins, CO 80526
303-484-2836

John Hawkins
CSU Larval Fish Lab
33 Wagar, CSU
Fort Collins, CO 80523
303-491-5475

QUESTIONNAIRE

Name: (optional/confidential)

Job type: Fisheries: Biologist ___
related Manager ___
Researcher ___
Technician ___
Supervisor ___
Administrator ___
College professor ___
Other (specify) ___ Title__________
Other: (please specify)______________________

Are your responsibilities associated with:
___sport fisheries
___gamefish species
___nongame fish species
___T&E fish species
___other (please specify)____________________

___a district or area
___a region or drainage basin
___statewide
___other (please specify)____________________

1.) What rivers, lakes, or drainages have you had experience with, or that you are currently responsible for resource management within? (e.g., Yampa, Green, White, Colorado, Lake Powell, Gila, Dolores, San Juan, Salt, etc.)

2.) Are impacts from introduced fish species upon native fish species a problem in any of these waters? If so, please identify which waters.

3.) Which introduced species do you consider to be presenting a problem?

4.) What native fish species do they affect, and what is the nature of the impact(s) (e.g. predation, competition for food or habitat, disease, etc.)

5.) Are you aware of any documented evidence, published or not, in the Colorado River Basin demonstrating:

-predation upon endangered fishes, in general, selectively, or as a threat to population survival?

-a competitive advantage of an introduced fish species over an endangered or other native fish species?

-a beneficial effect of an introduced species upon the native fish fauna?

If the answer is yes to any of the above, please summarize below and cite the appropriate literature reference, or, if possible, please provide us with copies of unpublished reports. If the evidence exists as unpublished raw data, please specify as such.

6.) For problematic introduced fish species, what is your evaluation of their abundance, and the magnitude of their impact(s)-increasing, decreasing, constant, fluctuating with environmental variables, etc.? (please identify environmental influences if known)

7.) Do any of the introduced fish species support sport fisheries, and are these fisheries large, moderate, inconsequential?

8.) Do you consider angling mortality related to incidental catch of endangered fishes by anglers pursuing gamefish species a significant source of mortality? If so, what is your estimate of the incidence of "harvest" mortality, and what gamefish species is the target of the fishery?

9.) In your opinion, what are possible field techniques or other approaches that wildlife management agencies might use to lessen, or eliminate problems or impacts created by introduced species?

10.) Have you, your agency, or associates attempted any of the above, and with what success? (or failure?)

11.) Are you aware of any institutional management programs or large scale approaches that have successfully eliminated an undesirable introduced fish species or reduced their negative impacts on a native fish species within a drainage basin?

12.) How is your agency, or the state wildlife agency in your area or state attempting to balance demands for sport fishing recreation and demands for conservation of endangered fishes and native fish fauna?

13.) Do you feel the problems posed by introduced fishes upon native fishes have been exacerbated by other problems such as aquatic habitat change/loss, water quality degradation, land use practices, etc.? Is there any documented evidence of this you are aware of (please cite)?

14.) What is your state's policy regarding introductions of non -native fish species into the state, and are there policies or protocols for stocking gamefish predator species or fish forage species in waters or drainages that may adversely affect threatened or endangered fishes?

15.) In practice, do you feel these policies/protocols are effective, are they selectively implemented, are they ignored?

16.) What do you see as likely management alternatives for maintaining native, threatened, or endangered fish fauna in waters where problematic introduced fish species cannot be eliminated or their adverse impacts ameliorated?

17.) How do you view the relative effect of impacts of introduced fishes in the spectrum of other potential impacts to the habitat or life history requirements of endangered fishes (e.g., flow depletion/alteration, habitat/water quality degradation due to water development, land use practices, or other identifiable human-related activity?