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POTENTIAL FOR INTRODUCTION OF THREE SPECIES OF NONNATIVE FISHES INTO CENTRAL ARIZONA VIA THE CENTRAL ARIZONA PROJECT — A LITERATURE REVIEW AND ANALYSIS

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16. ABSTRACT
The CAP (Central Arizona Project) is designed to deliver up to 2.2×10^6 acre-feet per year of allocated Colorado River water to central and southern Arizona for agricultural, municipal, and industrial use. CAP water would be stored in enlarged Lake Pleasant, northwest of Phoenix, and behind Granite Reef Diversion Dam on the Salt River, for later use.

Fish will be pumped from Lake Havasu during operation of CAP and enter central Arizona receiving waters. Water quality changes are also expected. This report documents life history characteristics of three fish species, water quality aspects of CAP source and receiving waters, the existing fisheries of CAP source and receiving waters, physical features of pumping plants, and some life history phenomena of the southern bald eagle.

Striped bass (*Morone saxatilis*) and blue tilapia (*Tilapia aurea*) from Lake Havasu are suspected of having an adverse impact on the existing fishery of Lake Pleasant. These two species, and the white bass (*Morone chrysops*), currently in Lake Pleasant, are suspected of having an adverse impact on the ecology of the Salt and Verde Rivers. If blue tilapia enter Lake Pleasant, they will likely survive and reproduce successfully. Striped bass will be much less likely to reproduce successfully and establish populations.

Recruitment would continue by introduction. Striped bass, white bass and blue tilapia introduced into the Salt and Verde Rivers upstream of Granite Reef Diversion Dam would likely survive, with blue tilapia most likely to reproduce successfully, followed by white bass, and with striped bass least likely to establish populations by successful reproduction. Recruitment by introduction would continue to occur. The degree of impact of blue tilapia and striped bass on the ecology of Lake Pleasant, and of blue tilapia, striped bass, and white bass on the ecology of the Salt and Verde Rivers cannot be predicted with certainty. If these fish become established and their numbers are not controlled by existing predators or environmental pressures, they could have an impact on the fish food base of the southern bald eagles nesting along these rivers.

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Potential for Introduction of Three Species of Nonnative Fishes into Central Arizona via the Central Arizona Project — A Literature Review and Analysis

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June 1984

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Division of Research and Laboratory Services
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METRIC CONVERSION TABLE

Multiply	By	To get
Area:		
acre	0.4047	hectare (ha)
square mile	2.59	square kilometer (km^2)
Energy:		
kilowatt-hour	3.6	megajoule (MJ)
watt-hour	3.6	kilojoule (kJ)
Length		
foot	0.3048	meter (m)
inch	0.0254	meter (m) or
	25.40	millimeter (mm) or
	2.54	centimeter (cm)
mile	1.6093	kilometer (km)
yard	0.9144	meter (m)
Mass		
pound (mass)	0.4536	kilogram (kg)
ounce (mass)	0.0283	kilogram (kg) or
	28.3	gram (g)
Pressure		
lb/in^2	6.8948	kilopascal (kPa)
Temperature		
degree fahrenheit	$t_c = \frac{t_f - 32}{1.8}$	degree Celsius (°C)
Velocity		
foot per second	0.3048	meter per second (m/s)
Volume		
acre-foot	1233.489	cubic meter (m^3)
cubic foot	0.0283	cubic meter (m^3)
Volume/time (flow)		
cubic foot per second	0.0283	cubic meter per second (m^3/s)

INTRODUCTION

The CAP (Central Arizona Project) was authorized September 30, 1968, by the Colorado River Basin Project Act (Public Law 90-537). The project could deliver up 2.714×10^9 m^3 per year of allocated Colorado River water to central and southern Arizona for agricultural, municipal, and industrial use in these areas, to supplement or replace the surface water and continuously diminishing groundwater supplies in Maricopa, Pinal, and Pima Counties (Bureau of Reclamation 1974).

Colorado River water would be pumped out of Lake Havasu at the Havasu Pumping Plant and lifted 244 m to the portal of the 10.5 km Buckskin Mountains tunnel, through which the water would enter the Granite Reef Aqueduct. The Granite Reef Aqueduct would carry the water approximately 304 km to the Salt River, about 40 km east of Phoenix. An inverted siphon under the Salt River, just downstream of the Granite Reef Diversion Dam, would convey water into the Salt-Gila Aqueduct, and eventually into the Tucson Aqueduct to provide water to the Tucson area (fig. 1). The combined length of the Salt-Gila and Tucson Aqueducts is about 155 km. The Granite Reef Aqueduct is essentially complete and is an open, concrete-lined canal with three inline pumping plants (Bouse Hills, Little Harquahala and Hassayampa) and a design capacity 85 m^3/s. The Salt-Gila and Tucson Aqueducts are in various stages of design and construction and are also open canals with design capacities which range from 77.87 m^3/s to 5.66 m^3/s, respectively.

Lake Pleasant, about 48 km northwest of the city of Phoenix, is being investigated as a potential regulatory storage reservoir for CAP water delivered via the Granite Reef Aqueduct. Under normal operating conditions during October to March, CAP water would be diverted into Lake Pleasant through a 6.4-km-long reversible canal. Lake Pleasant would be enlarged for the project by construction of New Waddell Dam. The capacity of the new facility would be about eight times the present capacity of Lake Pleasant. Maximum storage would be in excess of approximately 1,480,186,800 m^3. Water would be withdrawn later as needed to meet downstream demand. Thus, CAP or Lake Havasu water would mix with existing water in Lake Pleasant. Currently, the principal water source for Lake Pleasant is runoff from the Agua Fria River and the surrounding countryside.

The SRP (Salt River Project), a major public utility in the Phoenix metropolitan area, has an allocation of CAP water and will likely transport water for other CAP users. This water would probably be diverted into the Granite Reef forebay through an 22.65 m^3/s interconnection on the south side of the Salt River, just downstream from the inverted siphon under the Salt River. Here again, CAP water would mix with and dilute receiving waters.

The pumping of water out of the Colorado River, with subsequent storage of some of this water in Lake Pleasant and in the Granite Reef forebay on the Salt River, will provide a means for fishes from the Colorado River to enter CAP receiving waters in central Arizona. Concern has been raised by biologists about the impact certain designated fish species would have on the existing ichthyofauna and possibly on any sport fisheries in these receiving waters as well as on bald eagles nesting along the Salt and Verde Rivers. Species of fish considered objectionable by fish and wildlife biologists, in relation to operation of the CAP, and which are the subject of this literature review and analysis, are the striped bass (*Morone saxatilis*), white bass (*Morone chrysops*), and the blue tilapia (*Tilapia aurea*). Information of this sort is required because it is felt that striped bass and blue tilapia will be pumped from the Colorado River at the Havasu Pumping Plant, move down the Granite Reef Aqueduct with its three inline pumping plants (Bouse Hills, Little Harquahala, and Hassayampa), and enter Lake Pleasant and the Granite Reef forebay. Once in Lake Pleasant, there is concern that these two species would become established and interact in a detrimental way with existing populations of white bass and other sport fishes, thereby reducing the sport catch of desirable fish and the overall recreational opportunities for anglers and local residents. The concern also exists that when stored water is withdrawn from Lake Pleasant, striped bass and tilapia, as well as the white bass, would leave the lake, move downstream, and eventually enter the Salt River above Granite Reef Diversion Dam through the SRP interconnection. It is feared that in the Salt River, these three species could become established and interact in a deterimental way with existing fishes in that section of the Salt River below Stewart Mountain Dam and in that section of the Verde River below Bartlett Dam. The Verde River joins the Salt River about 5.6 km upstream from the Granite Reef Diversion Dam. In addition, it is felt that the introduction of these fish species into the Salt and Verde Rivers via CAP operation would have an adverse impact on the fish forage base of southern bald eagles (*Haliaeetus leucocephalus*) nesting along these two rivers.

The historic range of the striped bass and white bass did not include Arizona; these fish were introduced into the State. The striped bass has become established in Colorado River reservoirs

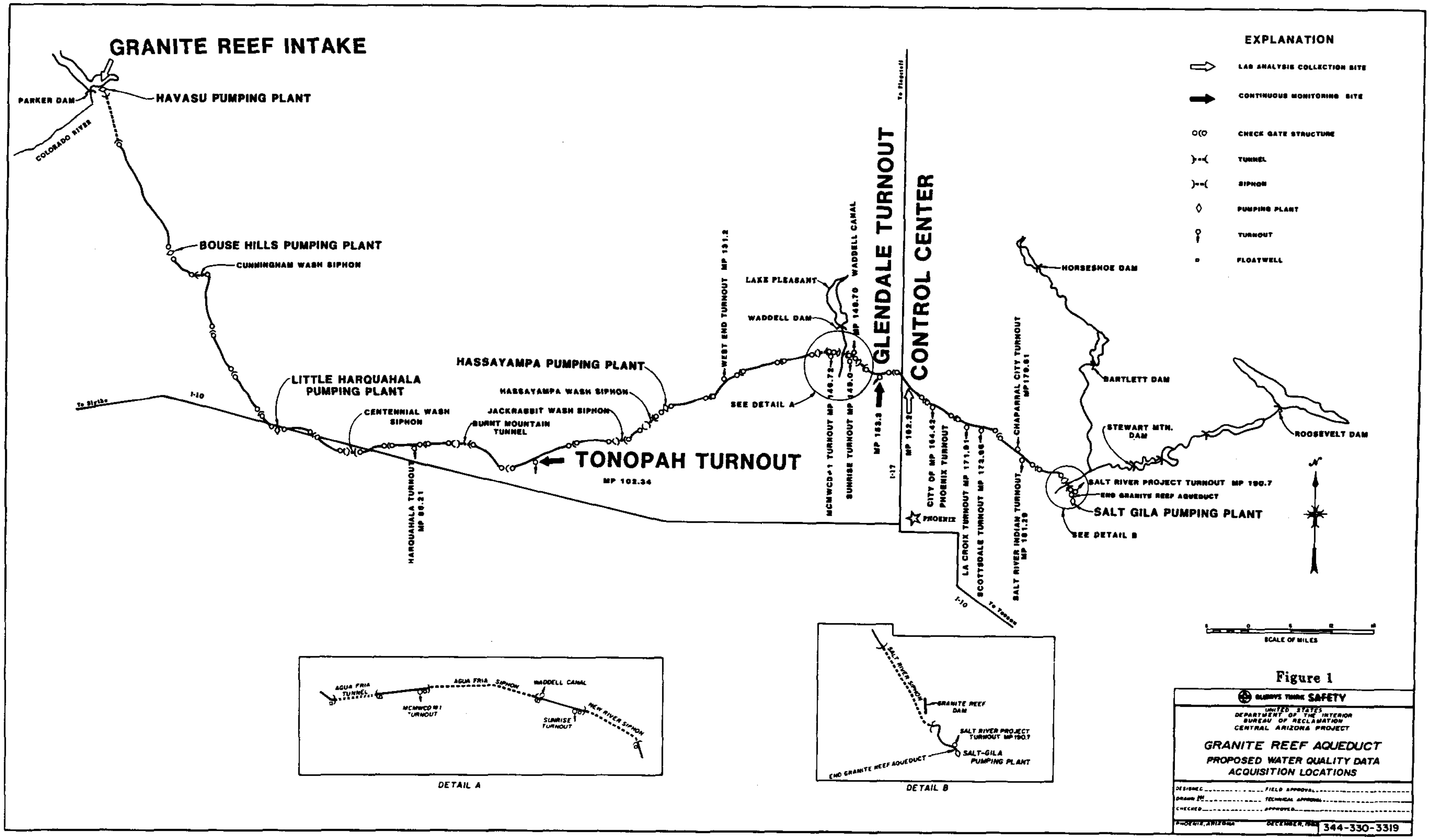

Figure 1. — Map of Central Arizona Project.

and the white bass has become established in Lake Pleasant. The blue tilapia is an exotic cichlid from Africa, which has become established in the lower Colorado River drainage basin. During operation of the CAP, these nonnative and exotic fish species could be introduced into central Arizona into existing, established populations consisting of both native and introduced nonnative fish species.

The purpose of this literature review and analysis is to assess the likelihood of transferring several species of fish from the Colorado River into central Arizona during operation of the CAP, their possible introduction and establishment in CAP receiving waters, and their potential impacts on existing fish populations.

Several objectives were formulated by USBR (Bureau of Reclamation) biologists in consultation with biologists from the USFWS (U.S. Fish and Wildlife Service) and the AGFD (Arizona Game and Fish Department), to address comprehensively, concerns related to potential fish transfer into central Airzona and the impacts of fish transfer on CAP receiving waters. Specific objectives formulated in the Scope of Work by APO, (Arizona Projects Office) include the following:

"1. Compile pertinent data concerning the limnological and water quality aspects of the waters involved. Water chemistry should include, but not necessarily be limited to pH, conductivity, TDS, alkalinity, hardness, calcium, chlorides, dissolved oxygen, sulfates, nitrates, phosphates, iron, and heavy metals. Other parameters to be included on a seasonal basis are: minimum, maximum, and average temperatures; turbidity; depth; flows; and velocity.

"2. Describe the existing fisheries of the systems in question in terms of species present, relative abundance, standing crop estimates, origin of the species present, and creel census data.

"3. Determine the likelihood of biota passing through the CAP intake channel, Havasu Pumping Plant, and inline pumping plants as well as being transported to the receiving waters in a reproductively viable condition.

"4. Compile the biological requirements of the three species with emphasis on those factors which would determine their success in the new waters. Preferred habitat of the species should be identified. The following items should be included: (a) Reproduction — time of year, water temperature, substrate, depth, velocity, spawning behavior, and special requirements; (b) Development — data on time, temperature, size, growth rate, swimming rates, and physiochemical parameters for all life stages from egg to adult; (c) Food habits — data for all life stages; (d) Competition — data on inter- and intraspecific behavior (predation included under food habits). Other biological needs which the investigator deems pertinent may also be included.

"5. Assess the probable establishment of the introduced species in the new waters based on information gathered in items 1 through 4. If establishment is probable, then predict the success of those species and their impacts to the existing aquatic community. Based on current management plans and controls of the AGFD, predict the future aquatic community composition in the absence of CAP. Predict CAP impacts on this future community."

6. Determine impacts on bald eagles nesting along the Salt and Verde Rivers.

Essentially, all information regarding physical, chemical, and biological attributes of the pertinent ecosystems was requested. Significant gaps in the data were to be identified.

METHODS AND MATERIALS

To address the several objectives as listed above, several methods were employed. To address the first objective, water quality and limnological data for the relevant bodies of water were obtained from sources such as the AGFD, USBR, USFS (Forest Service), USGS (Geological Survey), the Salt River Project, CFGD (California Fish and Game Department). Water quality information was examined for Lake Havasu, Lake Pleasant, the Salt and Verde Rivers below Stewart Mountain Dam, and Bartlett Dam, respectively, and Alamo Lake. Relevant water quality parameters for the several water systems were compared to determine if conditions in receiving waters would be suitable or favorable for survival and/or establishment of the three nonnative fishes of concern from source waters.

For the second objective, existing fisheries of the systems, information was obtained from various State and Federal reports, open literature articles, State project completion or progress reports, State stocking records, letter or memorandum reports of fishery survey activities of USBR, USBLM (Bureau Land Management), USFWS, and AGFD personnel, university researchers, and personal communications with individuals knowledgeable about particular fish species or southwestern fisheries. No field sampling was conducted to obtain data for this report. Existing available information on the fisheries of the various water systems was compiled and examined.

Although results of studies reported in State or Federal progress reports, other in-house documents, letters or memoranda, and personal communication, are not subject to peer review, information from these sources was considered pertinent to address the objectives in the Scope of Work and is documented in this report. All information and data available were used in the analysis to evaluate transfer of fish into CAP receiving waters. The blending of biological fact and opinion is an admitted shortcoming of personal communications; these sources are used judiciously where appropriate.

For the third objective, passage of biota through the CAP intake channel and pumping plants, information about pump specifications was obtained from USBR engineers; information about effects of pumping on eggs, larvae, and adult fish was obtained from a review of open literature articles, various State and Federal reports, and personal communication with individuals actively working in the field of fish protection or passage at pumping plants and powerplant intakes.

To address the fourth objective, biological requirements of the striped bass, white bass, and blue tilapia, an extensive computerized library search was conducted by the USBR Engineering & Research Center library in Denver. Data bases searched included NTIS (National Technical Information Service), Biosis, Aquaculture, Aquatic Science and Zoological Record. A less extensive computerized library search related to the three fish species of concern was conducted by the Fish and Wildlife Reference Service, a unit of the Denver City library system. The USBR library search produced 641 citations for striped bass, 147 citations for white bass, and 855 citations for tilapia. These citations were checked and appropriate articles requested through the USBR library. Since many of the articles were in journals or periodicals not held by the USBR library, a large number was requested through interlibrary loan or copy from other libraries. Because of limited availability of some of the articles, such as those in less widely circulated or foreign journals, much time elapsed between the request for an article and its receipt. Life history information was also obtained from various fishery books and miscellaneous publications. Many fishery workers around the country were contacted regarding aspects of the current distributions, life histories, and status of accidental or intentional introductions of the designated fish species.

A complete list of individuals contacted regarding the biology of the three fish species of concern, water quality parameters, and effects of pumping on fish survival is included herein. Information related to pertinent and important life history requirements of the three fish species, especially preferred habitat, reproduction, development, food habits, and inter- and intraspecific competition were compiled and examined to assess potential for survival and establishment in CAP receiving waters.

Information regarding selected life history phenomena of the southern bald eagle, especially food habits, was obtained from available reports and personal contacts with raptor biologists.

To address the fifth objective, assessment of effects on the existing fishery for a future with CAP operations and for a future without CAP operations, pertinent biological requirements for the various life stages of each fish species were compared with available water quality information, probability of survival on passage through pumping plants, and transport through long stretches of open canals to determine the prospects for fish surviving introduction into a receiving water and becoming established and having an impact on the existing fishery. Because of the inherent variability of biological systems, overriding and uncontrollable climatic or meteorological conditions, and uncertainties about misguided but well meaning, or accidental activities of private anglers, predicting the results and impacts of intentional or accidental biological activities (introductions) is inexact. Diversity among the introduced organisms, together with the complexity and resiliency of the ecosystem into which introductions occur, can bring about a range of interactions and impacts. Based on the available data, we describe the probable impact of introduction of the three fish species of concern into CAP receiving waters.

In the Results and Discussion, we will deviate from the order of objectives as listed in the Scope of Work, since we feel that redundancies would occur if we followed that order. We have opted to alter the discussion of the objectives to include:

1. Biological requirements and life history phenomena of the three species of concern;
2. Aspects of the existing fisheries in CAP source and receiving waters;
3. Water quality and limnological aspects of CAP source and receiving waters;
4. Effects of passage through pumping plants on various life stages of the three species;
5. Possible effects of nonnative fish introduction on the southern bald eagle, and;

6. Predictions of the future with and without introduction of CAP water into central Arizona.

This order is a more logical and orderly way to discuss the large quantity of data amassed during this endeavor.

RESULTS AND DISCUSSION

Striped Bass

Description. —The striped bass (*Morone saxatilis*) (*fig. 2*) belongs to the family Percichthyidae and can be distinguished from other percichthyids by the seven or eight black horizontal lines on its sides. The back of the fish is olive-green to almost black with silvery sides and a white belly. The anal fin has 3 spines and 11 soft rays. The two dorsal fins are not joined at the base. The first dorsal fin is triangular in shape with nine stiff spines. The second dorsal fin is graduated in height from front to rear and has 11 or 12 soft rays. The body shape of the fish is elongated and compressed laterally with a small arch and sway belly. There are 67 scales along the lateral line of the fish. The lower jaw distinctly protrudes beyond the upper jaw and the tongue has two patches of teeth on each side (Goodson 1966; Gregory 1968; Minckley 1973).

Distribution. — The striped bass occurs naturally in coastal waters on the Atlantic coast from the St. Lawrence River in Canada to the St. Johns River in Florida, and in some river systems along the Gulf of Mexico, from western Florida to Lake Ponchatrain, Louisiana. The area from South Carolina to Massachussets is regarded as the historic center of abundance (McClane 1974) with especially high populations in Chesapeake Bay and Albemarle Sound.

Striped bass occur along the Pacific coast, from Southern California to Washington, as a result of stocking programs that began during the late 1800's. In 1879 and 1881, a number of yearling bass from Navesink and Shrewsbury Rivers of New Jersey were planted in upper San Francisco Bay, near Martinez, California. By 1889, 10 years after the first fish were introduced, striped bass supported important fisheries in central California. Today, the largest concentrations are found in Coos Bay, Oregon, and in the San Francisco Bay drainage system. Smaller populations exist in the Russian and Columbia Rivers (Setzler et al. 1980). The first known records of striped bass in British Columbia waters were in July 1971, when a specimen was caught by gillnet in Barkley Sound, B.C. (Forrester et al. 1972) and in August 1971, when a specimen was caught off Port San Juan (Hart 1973).

Striped bass are also commonly found in landlocked, freshwater environments. Populations reproduce naturally in such places as the Santee-Cooper River of South Carolina; in Kerr Reservoir, on the headwaters of the Roanoke River of North Carolina and Virginia, in Millerton Lake, California; possibly in Kentucky Lake, in Kentucky and Tennessee; in Beaver Reservoir, Arkansas; in Keystone Reservoir, Oklahoma; Lake Powell, Utah; Lake Mead and Lake Havasu on the Colorado River

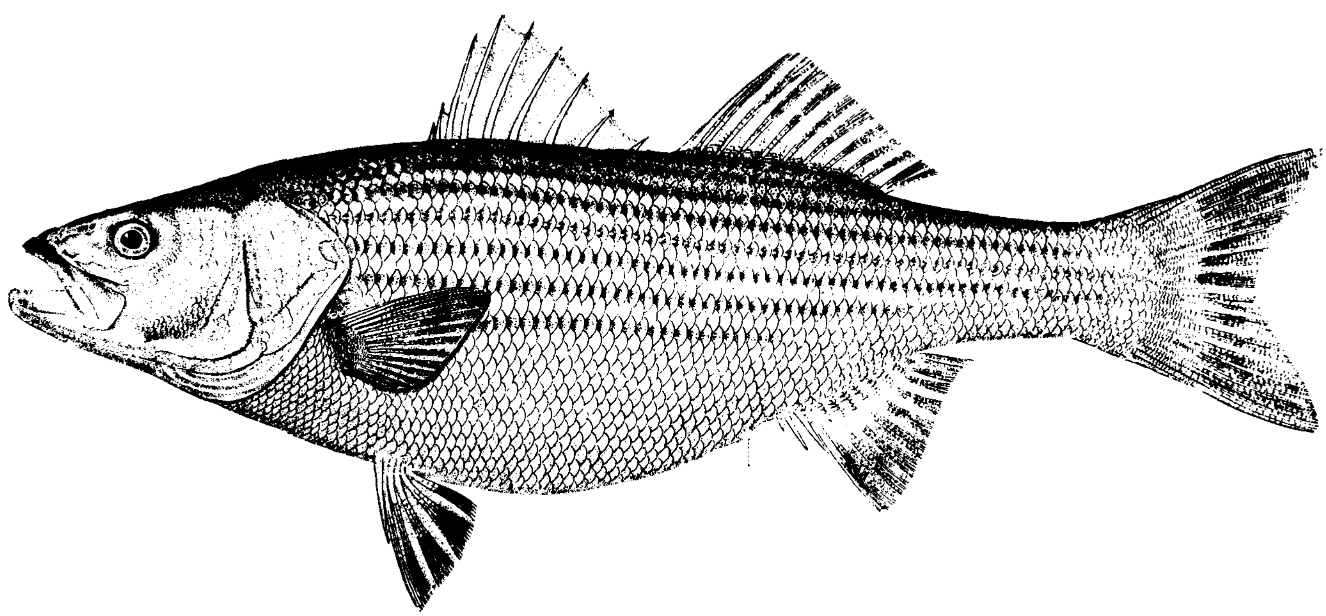

Figure 2. — The striped bass, *Morone saxatilis*.

(Nichols 1966; Smith and Wells 1977; Kilambi and Zdinak 1981; Mensinger 1970, Persons and Buckley 1982; Gustaveson pers. comm.).

Preferred habitat.

Larvae and juveniles.— Raney (1952) reported that eggs are spawned in freshwater and newly hatched striped bass form small schools that live in open waters. Prolarvae prefer subsurface waters. Larvae and young prefer shallow waters with a low current and sand or gravel substrate as nursery areas (Wang and Kernehan 1979). YOY (young-of-the-year) prefer areas with a current (Rathjen and Miller 1957; Woolcott 1962 in Setzler et al. 1980). Juveniles prefer sandy and gravelly bottoms (Merrimer 1937; Raney 1954; Rathjen and Miller 1957; Woolcott 1962; Smith 1971 in Setzler et al. 1980).

Adults. — Adult striped bass are found in freshwater and brackish and estuarine environments. They can be found in large rivers and in small inflowing creeks (Setzler et al. 1980). Combs and Peltz (1982) reported that striped bass in Keystone Reservoir, Oklahoma, distributed themselves along inundated creek channels. In the deeper waters of the reservoir, "stripers" were found along the flooded river channels that have submerged islands and steep dropoffs from shallow flats. They prefer habitats with sandy beaches, rocky shores, and environments that contain rocks or boulders (Bigelow and Schroeder 1953; Pearson 1931 in Setzler et al. 1980).

Water quality requirements.

Temperature.

Adults. —The literature includes inconsistencies in reported optimum temperatures reported for striped bass. Coutant (1980), Coutant and Carroll (1980), Coutant (1981), Schaich and Coutant (1980), and Waddle et al. (1980), reported that temperature is the most important environmental factor affecting striped bass. Coutant (1980) has found evidence that striped bass occupy specified thermal niches which change with age.

Merriman (1941 in Coutant 1980) reported that adult striped bass on the Atlantic Coast occupied only waters below about 25 to 27 °C. Adult striped bass also avoided temperatures greater than 26 °C in the Savannah River, Georgia (Dudley et al. 1977). In Cherokee Reservoir, Tennessee, Waddle et al. (1980), found that adults avoided temperatures above 25 °C. Striped bass in Watts Barr Reservoir, Tennessee, occupied different thermal niches depending on the seasons. Temperatures occupied were less than 25 °C and adults in summer were restricted to two major cool tributaries or a small spring (Coutant 1981). In J. Percy Priest Reservoir, Tennessee, during the summer months, adults occupy narrow thermal niches and in late summer, large striped bass die-offs occur (Coutant 1981). In Elephant Butte Reservoir, New Mexico, some mortality of adult striped bass was observed in 1982 (Dr. Paul Turner, New Mexico State University, Department of Fisheries and Wildlife, pers. comm.). Mortality may have been caused by temperature-dissolved oxygen stress.

Coutant (1980) observed striped bass in Cherokee Reservoir, Tennessee, occupying areas with water temperatures ranging from 10.5 to 15.8 °C during spring months, which corresponded to the warmest temperature available at depths of 1 to 3 m (Schaich and Coutant 1980). During the summer, adult striped bass preferred 15.5 to 25.0 °C temperatures at depths of 8 m and greater. Massive die-offs of adults larger than 4 to 5 kg have occurred because of restricted summer habitat (Coutant 1981). By late July, the fish avoided dissolved oxygen concentrations of less than 3 mg/L near the bottom and epilimnion temperatures greater than 22 °C. The adults moved into refugia which consisted of only about 4 percent of the total reservoir area. These refugia were less than 10 m deep, had temperatures of 15 to 25 °C, and dissolved oxygen concentrations greater than 5 mg/L. Older striped bass preferred cooler temperatures between 16 and 20 °C while younger striped bass preferred 20 to 23 °C (Schaich and Coutant 1980). Coutant (1981) explained the importance of dissolved oxygen as a component of a suitable thermal habitat for adult striped bass. "In eutrophic lakes, high nutrient levels stimulate high organic matter production, which is followed by oxygen-depleting decomposition in deep, cool, water layers. A cool habitat is poorly suited for adults. In nutrient-poor conditions (oligotrophic), there is little organic matter to decompose, and the cool, deep strata, retain enough oxygen in summer to support adult striped bass at suitable temperatures. Eutrophic lakes can thus be seen as a high risk situation for a striped bass population."

Coutant and Carroll (1980) suggested that a temperature-dissolved oxygen "squeeze" exists and may influence behavior and growth of striped bass in warm, eutrophic lakes. Since 1972, annual adult striped bass mortalities have occurred in late summer in Cherokee Reservoir. Magnuson et al. (1979 in Coutant and Carroll 1980) explained that the reduced growth rate of the adult striped bass resulted from high temperature and low dissolved oxygen or power-plant cooling. Some of the reasons are as follows. Hydroelectric dams may deplete oxygen through deep-water withdrawals. Powerplants built on reservoirs stocked with striped bass might adversely affect the distribution of fish populations. Preferred temperature must be considered before striped bass stocking is undertaken in lakes and reservoirs. Also, powerplant site selection and type of cooling system (straight-through or cooling towers) should be considered in relation to thermal tolerance of the striped bass (Schaich and Coutant 1980). Coutant and Carroll (1980) feel that the duration of exposure to stressful conditions and the availability of suitable refugia may determine population survival.

In Cherokee Reservoir, Coutant (1981) showed apparent starvation of adult striped bass even with an abundance of preferred prey in the reservoir. Young gizzard shad were abundant in the 29 to 32 °C layers of water, above the adult striped bass, which occupied cooler, deep water. Adult striped bass preferred to remain in deeper, cooler water than feed on prey in warmer waters. Lakes without well-oxygenated water with temperatures below about 22 °C will be unsuitable for adult striped bass larger than 5 kg (Coutant 1981).

In Lake Powell, Utah, thermal stratification has an unfavorable effect on striped bass in that it seems to segregate the forage fish from the striped bass. Lake Powell is well-oxygenated below the thermocline when the lake is stratified, but contains an oxygen minimum layer in the upper part of the thermocline. During the summer months, adult striped bass must pass through the oxygen minimum layer to forage on shad in the warm epilimnion. The striped bass then return to the cooler hypolimnion (Johnson and Merritt 1979). Striped bass will leave the cool water to forage on a limited number of shad, but the energy expended in the pursuit of food is not replaced by the few shad consumed. Wayne Gustaveson UWR (Utah Wildlife Resources, Page, Arizona, pers. comm.) and Minckley (1973) feel one of the most significant problems affecting the sport fishery of the lower Colorado River system is the limited forage base consisting primarily of the threadfin shad.

Loudermilk (1981) reported that Lake Mead had one of the largest inland sport fisheries for striped bass. The striped bass collected during winter and summer months exhibited poor physical condition, due to a possible thermal separation between the threadfin shad and the adult striped bass or to an actual lack of shad. As seen in Lake Powell, Lake Mead striped bass also showed evidence of starvation. Striped bass were utilizing crayfish to some extent (Cornelio Padilla, NDW (Nevada Department of Wildlife, pers. comm.)

In Lake Havasu, striped bass 40.6 cm or smaller can tolerate the warmer waters above the thermocline. Striped bass greater than 40.6 to 45.7 cm remain in cooler waters below the thermocline and occupy a niche that overlaps with the largemouth bass (Loudermilk pers. comm.). Ponder (1971) reported that in midsummer, Lake Havasu was weakly thermally stratified. Currents occur at depths of 3 to 6 m from water withdrawals and create good dissolved oxygen levels during the summer.

Subadults. —Subadults (2 to 3 year olds) generally occupy temperatures of 20 to 24 °C, slightly higher than adults (table 1). Decreasing average preferred temperature was related to increasing fish size (Schaich and Coutant 1980). Magnuson et al. (1979 in Coutant and Carroll 1980), classifies subadults as cool-water habitat fish. Kokanson (1977 in Coutant and Carroll 1980) puts them in a "temperate mesotherm" category.

Juveniles. —Tagatz (1961 in Otwell and Merriner 1975) reported juvenile striped bass survived a temperature change of from 7.2 to 21.1 °C, but reported mortalities for fish transferred from 21.1 to 12.8 °C. An upper lethal temperature of 35.0 °C was reported by Davies (1973). An optimum temperature range of from 14.1 to 21.0 °C for juveniles was reported by Hester and Stevens (1970). Meldrin and Gift (1971 in Coutant 1980) and Cox and Coutant (1981) reported a higher optimum temperature near 24 to 25 °C (table 1).

Larvae. — Otwell and Merriner (1975) experimented with 28-day-old striped bass and reported "At 12 °C water, the fish went into a shivering, downward-spiraling swim which ended in a momentary motionless posture at the bottom. 'Shock' condition ranged from 30 seconds for 5-day-old fish, to 10 minutes for 28-day-old fish." Davies (1973) reported that larvae acclimated to lower temperature conditions more quickly than did juveniles and at about the same rate as juveniles to higher temperature. For both larvae and juveniles, acclimation was more rapid to higher than to lower temperatures. Larvae and juveniles are limited to the extent that they can adjust to higher temperatures. No greater than 40 percent survival could be obtained for larvae exposed to a test temperature of 26.7 °C. The temperature range for larvae up to 20-mm long was reported to be from 12 to 26.7 °C, and the optimum range was from 16 to 19 °C (table 1) (Albrecht 1964, Tagatz 1961, Regan et al. 1968 in Doroshev 1970; Davies 1973)

Eggs. — Striped bass eggs survived exposure to water temperatures of from 13.3 to 22.5 °C (Barkuloo 1967). All eggs died when temperatures

Table 1. — Tolerance and optimum range of some environmental variables for various life history stages of striped bass

Development stage	Flow rate) (m/s)	Tempera-ature °C)	Salinity (mg/L)	pH	Oxygen (mg/L)	Author
Eggs	0.3-5*	10-27	?-10 000	?	1.5-?	Mansueti (1958)
	1-2	15-20	1000-3000		3-7	Morgan and Rasin (1973)
						Rogers et al. (1977)
						Morgan et al. (1981)
Larvae up to 20 mm long	0-5	12-26.7	?-15 000	6-9	2-20	Tagatz (1961)
	0.3-1	16-19	5000-10 000	7-8	5-8	Albrecht (1964)
						Regan et al. (1968)
						Chittenden (1971)
						Davies (1973)
Juveniles 20-50 mm	0-5	7.2-35	?-20 000	5.3-10	0.8-20	Bogdanov et al. (1967)
	0-1	24-25	10 000-15 000	7-9	6-12	Otwell and Merriner (1973)
						Davies (1973)
						Klyashtorin and Yarzhombed (1975)
						Tatum (1965 in Hill et al. (1981)
						Cox and Coutant (1981)
Subadults 50-100 mm	0-5	?-30	0-35 000	6-10	3-20	Bogdanov et al. (1967)
	0-1	20-24	10 000-20 000	7-9	6-12	Schaich and Coutant (1980)
Adults		10.5-26	Can tolerate estuarine and marine environments		1-?	Schaich and Coutant (1980)
		16-20			5	Hill et al. (1981)
						Coutant (1981)

*Tolerance range in the numerator, optimum range in the denominator

dropped below 12.2 °C and less than 1 percent survived above 22.2 °C. Mansueti (1958) reported a temperature range of from 14 to 23 °C, while Morgan and Rasin (1973) reported a lower lethal temperature of 10.0 °C and an upper lethal temperature of 27 ° C. There was no egg survival above 27 °C (Morgan and Rasin 1973; Shannon 1969). The greatest temperature range for egg survival was from 10.0 to 27 °C.

The optimum temperature range for best survival to hatching was reported as 15 to 18 °C (Rogers et al. 1977). Bayless (1972 in Rogers et al. 1977) reported optimum temperatures from 16.7 to 18.3 °C. Mansueti (1958) reported an optimum range of 17 to 20 °C. Morgan et al. (1981) reported that temperature was the most important factor among several variables affecting development and hatching of eggs with 18 °C the optimum temperature. This optimum temperature corresponds closely to the mean temperature for peak spawning. The reported temperature range for good egg development and high survival was 15 to 20 °C.

Dissolved oxygen.

Adults. — Dissolved oxygen levels for striped bass were studied by Krouse (1968 in Chittenden 1971), who reported complete mortality of striped bass exposed to 1.0 mg/L and partial mortality of fish exposed to 3.0 mg/L dissolved oxygen for 72 hours. Chittenden (1971) also reported death of some striped bass subjected to 3.0 mg/L dissolved oxygen. Doroshev (1970) showed that striped bass tolerated dissolved oxygen levels of 5 mg/L. Hill et al. (1981) reported that 62.9 percent of striped bass remained in areas where dissolved oxygen concentrations exceeded 7.5 mg/L (table 1).

Juveniles. — Dissolved oxygen levels for 0-1-year olds were reported as follows (Dorfman and Westman 1970): 50 percent of the striped bass died when oxygen concentrations remained at 1.0 and 1.5 mg/L for 15 hours. When striped bass were subjected to oxygen concentrations between 2.0 and 3.0 mg/L for 17 hours, 70 percent of the fish died. However, striped bass acclimated to 8.5 and 6.6 mg/L of dissolved oxygen at 20 °C, then transferred to 2.0 and 3.0 mg/L of dissolved oxygen respectively, survived. All striped bass acclimated to an oxygen concentration of 5.9 mg/L at 32.8 °C died when transferred to 2.4 mg/L of oxygen. Overall, the striped bass were affected by exposure to diurnal fluctuations of dissolved oxygen averaging less than 4.0 mg/L (Dorfman and Westman 1970). Klyashtorin and Yarzhombek (1975) found the minimum dissolved oxygen concentration for normal activity of juveniles at 22 °C was 4 to 4.5 mg/L. The minimum dissolved oxygen concentration for survival was reported as 0.8 mg/L at 22 °C. The dissolved oxygen levels for juveniles ranged from 0.8 to 20 mg/L (table 1).

Larvae. — Dissolved oxygen concentrations were tested on striped bass larvae by Chittenden (1971). He found the following effects:

Level of O_2 concentration	Behavior pattern
1.81 ± 0.10 mg/L	Restless
1.28 ± 0.10 mg/L	Inactivity
0.95 ± 0.06 mg/L	Equilibrium loss
0.72 ± 0.04 mg/L	Death

Chittenden (1971) reported that striped bass larvae could survive at a minimum of 3.0 mg/L of dissolved oxygen in 16 to 19 °C water. Klyashtorin and Yarzhombek (1975) reported critical dissolved oxygen levels of 4.0 and 4.5 mg/L at 22 °C.

Eggs. —As dissolved oxygen decreases, survival of striped bass eggs decreases (Turner and Farley 1971). At both 4.0 and 5.0 mg/L dissolved oxygen, less than 50 percent of the eggs survived at 22.2 °C (Setzler et al. 1980). Murawski (1969 in Setzler et al. 1980) reported that the absence of striped bass eggs in the lower Delaware River was probably due to the low level (2.0 to 3.5 mg/L) of dissolved oxygen.

Although the literature documents a wide range of dissolved oxygen tolerances, levels above 5 mg/L are probably most reasonable for survival.

Total Dissolved Solids

Adults. — TDS (total dissolved solids) is probably the least limiting parameter responsible for distribution of striped bass under natural conditions (Hill et al. 1981). Radtke and Turner (1967 in Hill et al. 1981) reported that adult striped bass in a salinity gradient were strongly influenced by the osmotic regime to which they were acclimated. They found that striped bass ready to spawn could not tolerate an increase of about 300 mg/L of dissolved solids. Three-hundred mg/L blocked the spawning run up the San Joaquin River, after the stripers had acclimated first to freshwater. A TDS concentration of 350 mg/L was the critical point above which the striped bass would not migrate. In experiments done by Hill et al. (1981), a range of 3100 to 3300 mg/L TDS was selected by striped bass, after acclimation to 1300 mg/L TDS. When dissolved oxygen concentrations of 7.5 to 7.9 mg/L were included as a variable, striped bass were able to move into a TDS concentration of 1500 mg/L higher (4700 to 5000 mg/L), indicating that at high oxygen levels, striped bass tolerate a higher TDS.

Juveniles. — Juveniles were tested for salinity tolerances and it was found that an increase in salinity of up to 10 000 mg/L increased metabolic rates (Klyashtorin and Yarzhombek 1975). Otwell and Merriner (1973) reported that temperature was more limiting to growth and survival of striped bass than was salinity. Krouse (1968 in Otwell and Merriner 1973) reported higher survival of striped bass at 5000 and 15 000 mg/L than at 25 000 mg/L. Otwell and Merriner (1973) showed higher mortality in striped bass exposed to 20 000 mg/L in 12 and 24 °C waters.

Larvae. — Auld and Schubel (1978 in Setzler et al. 1980) reported suspended sediment concentrations of 500 and 1000 mg/L reduced the survival of yolksac larvae after being exposed to these concentrations for 48 to 96 hours.

Optimuim salinities for rearing striped bass larvae (from Lal et al. 1977):

Optimal growth		Optimal survival	
age (days)	salinity (mg/L)	age (days)	salinity (mg/L)
1-9	6750	1-6	3370
10-19	13 490	7-13	6750
20-29	20 240	14-20	13 490
30-35	26 980	21-29	20 240
36	Seawater	30-35	Seawater

Eggs. — Morgan and Rasin (1973) tested tolerances of striped bass eggs to salinities. They found that development was significantly higher at 0.1 to 0.5 mg/L than at 2000 mg/L. Hatch varied from 73 percent survival at 2000 mg/L to

86 percent at 8000 mg/L. Albrecht (1964 in Setzler et al. 1980) showed that low salinities, 1690 to 1740 mg/L, enhanced egg and larval survival but moderate salinities, 8320 to 8580 mg/L, were not detrimental to survival.

Turner and Farley (1971) found highest survival occurred at 1000 mg/L salinity and 18.3 °C. None of the eggs survived above salinities of 1000 mg/L at 22.2 °C. Increased survival of striped bass eggs and larvae has been reported for periods up to 3 weeks in diluted seawater ranging from 3 percent (Albrecht 1964 in Lal, et al. 1977) to 30 percent (Doroshev 1970). Lal et al. (1977) found that survival of 1-day-old striped bass eggs was greater in salinities ranging from 10 to 50 percent seawater than in freshwater. Mortalities occurred and survival declined for eggs hatched in salinities greater than 10 percent seawater.

Striped bass eggs were not affected by concentrations of 500 mg/L of fine-grained sediments. Above 1 000 mg/L, hatching success did decline (Schubel and Auld 1974 in Setzler et al. 1980).

pH.

Juveniles. — A pH range of 7.06 to 8.35 was reported for juveniles (Hester and Stevens 1970) although Bogdanov et al. (1967 in Doroshev 1970) reported a wider pH range of 6.0 to 10.0). Davies (1973) calculated an optimum pH for juveniles as 7.5. Tatum et al. (1965 in Hill et al. 1981) reported a pH of 5.3 to be a lower lethal pH. Doroshev (1970) showed that juveniles are sensitive to pH changes of less than 1 pH unit, while Humphries and Cummings (1973 in Hill et al. 1981) found that fluctuations in pH caused mortalities in hatchery situations. Hill et al. (1981) reported "Avoidance of all conditions of pH lower than 6.6 in experiments agrees with onset of shift in fish blood oxygenation in which pH below neutrality results in sharp drop in oxygen-carrying capacity." Hill et al. (1981) found that the hydrogen ion was more influential in determining the location selected in the water than were dissolved oxygen or TDS.

Table 1 (adapted from Doroshev 1970) summarizes the tolerance and optimum range of some environmental factors for various life history stages of striped bass.

Powell (1973) reported optimum values for several environmental parameters for eggs and larvae (table 2). His optimum dissolved oxygen values differ considerably from optimum values reported in table 1.

Food and feeding habits.

Adults. — Striped bass feed avidly in the evening just after dark and may also feed just before dawn (Raney 1952). Adults in freshwater habitats feed primarily on clupeid fishes when they are present (Barkuloo 1967; Smith and Wells 1977). When clupeids are unavailable, the bass may be unable to utilize alternate forage. Striped bass generally congregate where there are concentrations of threadfin shad (Minckley 1982a). Striped bass are voracious predators and are capable of reducing and controlling clupeid populations (Stevens 1958).

In selected lakes in Florida, shad were the primary food source for adult striped bass. In Lake Julianna, Florida, threadfin shad were virtually eliminated within 2 years after establishment of striped bass, while gizzard shad were reduced by 80 percent from 1972 to 1974. Improvements in the initially poor bluegill population occurred as a result of reduced competition by shad (Ware et al. 1974) Generally, threadfin shad populations seem to be more affected by striped bass predation than gizzard shad populations. Ware et al. (1977) reported striped bass feeding habits in Lake Hunter, Florida. Striped bass stomachs contained 59.2 percent shad, 12.1 percent *Tilapia aurea*, and 2.2 percent centrarchids. Striped bass from 356 to 533 mm in length utilized *T. aurea*. In Lake Hunter, the gizzard shad population was reduced to one-half its original size, and the threadfin shad population declined each winter (Ware et al. 1974).

Table 2. — Optimum range of some environmental factors for hatching periods of striped bass eggs and larvae (from Powell 1973)

Development stage	O_2 (mg/L)	CO_2 (mg/L)	pH	Temperature (°C)	Total hardness	Salinity (mg/L)
Eggs	8.0-10.1	0.0-0.6	7.8-8.1	18.6-20.5	100.0-120.0	1500-1700
Larvae	8.2-10.2	0.0-4.0	7.6-8.2	17.2-18.5	100.0-120.0	1400-1500

In Hollingsworth Reservoir, Florida, stomachs from 127 striped bass, 15.2 to 28.0 cm in length, contained 32.9 percent shad, 15.9 percent mosquitofish, 10.5 percent freshwater shrimp, 7.0 percent bream with about 33 percent unidentifiable fish remains (Ware 1969).

Santee-Cooper Reservoir, South Carolina, is also a situation where the striped bass population drastically reduced the shad population, but was unable to shift its diet to alternate forage. In the 1950's, the bass population multiplied and utilized clupeid fishes as a forage base. The striped bass population peaked about 1960 but then declined 30 to 50 percent when the clupeid population declined. Although the reservoir contained a diverse fauna of cyprinids, catostomids, and centrarchids, this alternate forage was scarcely utilized, and the striped bass population began to decline (Stevens 1958). Stevens (1958) found that in Santee-Cooper Reservoir, clupeid fishes supported the striped bass population most of the year but in April, May, and June, mayfly nymphs were the dominant food source. Game fishes and rough fish were consumed in insignificant numbers by the stripers.

In Kerr Reservoir, Virginia-North Carolina, stripers also ate mainly clupeids. In the summertime when YOY shad were scarce, striped bass ate crappie (Domrose 1963 in Goodson 1966).

In Toledo Bend Reservoir, Louisiana, striped bass predominantly fed on sunfish and bluegills during both cool and warm months (Walker 1977). One hundred eighty-seven striped bass stomachs were examined; 104 stomachs contained the following food items:

Food	Percent occurrence
Sunfish and bluegill	61.51
Shad	33.33
Brook silversides	4.70
Log perch	0.44

In D'Arbonne Lake, Louisiana, 61 striped bass stomachs were examined. Twenty-nine stomachs contained the following food items (Walker 1977):

Food	Percent occurrences
Shad	90.00
Unidentifiable sunfish and bluegill	6.67
Brook silversides	1.11
Largemouth bass	1.11
Crawfish	1.11

Striped bass populations introduced in Lake E.V. Spence, a west Texas reservoir, exhibited a decline in growth rate when the gizzard shad and threadfin shad populations declined. Reduced growth rates of striped bass coincided with the reduced abundance of 76- to 178-mm-long gizzard shad and 76- to 102-mm-long threadfin shad. The number of striped bass stomachs examined that contained food declined from 79 percent in 1972 to 25 percent in 1977. The threadfin shad population was drastically reduced by striped bass predation. The gizzard shad population was less affected by predation since individuals grew too large to be utilized by the striped bass (Morris and Follis 1978).

Johnson and Calhoun (1952) examined stomachs of 229 adult striped bass from summer and fall fisheries around San Francisco Bay and found:

Food	Percent occurrence
Shrimp	53
Anchovy	39
Isopods	1
Crabs	2
Mysid shrimp	1
Bullhead	2
Flat fish	1
Smelt	0.3

Stomach contents of 158 striped bass from winter and spring fisheries contained:

Food	Percent occurrence
Neomysis	20
Shrimp	13
Isopods	< 1
Smelt	2
Stickleback	< 1
Remains of small fish	64

In Millerton Lake, California, 39 bass stomachs were examined. The stomachs contained 1 bluegill, 2 unidentifiable fish, and 1,239 threadfin shad.

Striped bass stomachs from the lower Colorado River were examined (February through November 1969) by Edwards (1974); threadfin shad were the most common food item found in the stomachs.

Persons and Buckley (1982) examined 321 striped bass stomachs from Lake Powell. They found 70 percent empty stomachs, 28 percent containing threadfin shad, 4 percent red shiners, 2 percent unidentifiable. The threadfin shad, which was introduced into this reservoir, is the major food source for the bass. Threadfin shad attain adult size in their first year of growth. Adult threadfin shad do not grow large enough to avoid predation by striped bass and intense predation could reduce the threadfin shad broodstock, and as a consequence, reduce reproductive success. Since the threadfin shad population has declined in Lake Powell, the adult striped bass feed on crayfish but apparently do not eat crappie or other game fish. Adult striped bass appear to be undernourished and body condition declined to 0.85 in 1982. Fish that normally should weigh about 5.4 kg now weigh about 3.6 kg (Gustaveson pers. comm.).

In Lake Mead, threadfin shad are important in the diet of striped bass from July to January. Zooplankton, crayfish, and midge larvae predominate in the diet of 381 to 660 mm striped bass from February to July. Low numbers of centrarchids occurred in the stomachs of striped bass (Padilla 1983). From 1976 to 1979, die-offs of striped bass (560-710 mm) occurred in the spring. Examination of dead fish revealed that a nutritional problem existed and that food was probably limiting (Baker and Paulson 1981).

Downstream from Lake Mead, in Lake Havasu, adult striped bass utilize the threadfin shad for food. The striped bass also eat crayfish on the bottom of the reservoir. The striped bass in the lake apparently compete with largemouth bass for threadfin shad (Mr. Bill Loudermilk, Fisheries Biologist, California Department of Fish and Game, pers. comm.).

The optimal growth rate of the adult striped bass has been affected in Lakes Powell, Mead, and to a lesser extent, Havasu, presumably due to a decline in available forage (Padilla 1983). The Ad Hoc Striped Bass Committee of the Colorado River Wildlife Council suggested criteria of a desirable forage fish for introduction into the lower Colorado River system to supplement the threadfin shad. These include a fish that would be a prolific, schooling, 76- to 178-mm planktivore, that would inhabit the thermocline area (15.5 to 21 °C), be vulnerable to predation, survive to 4 °C, not be an early spring spawner, and fit into the existing food chain (Padilla 1983). Some of the fishes considered include the rainbow smelt, gizzard shad, silversides, Delta smelt, blueback herring, American shad, and the various sculpins.

Bailey (1975) studied the effects of established striped bass populations upon pelagic forage fishes (table 3). Of all reservoirs listed in the southeastern United States, only two lakes, Lakes Hunter and Julianna in Florida, reported a drastic reduction in the shad population. J. Percy Priest Reservoir, Tennessee, had significant reduction in the shad population. Toledo Bend and D'Arbonne, Louisiana, had slight reductions in the population, and Maumelle Reservoir, Arkansas, had possible shad reduction. Bailey (1975) reported that striped bass introductions have had no noticeable effects on other native fishes in any reservoir.

Table 3. — Effects of established striped bass populations upon clupeid fishes.

Reservoir	State	Effects on shad population
Norfolk	Arkansas	None
Beaver	Arkansas	None
Greeson	Arkansas	None
Maumelle	Arkansas	Possible reduction
Martin	Alabama	No data
Lay	Alabama	No data
Jones Bluff	Alabama	No data
Jordan	Alabama	No data
Hunter	Florida	Drastic reduct.
Julianna	Florida	Drastic reduct.
Sinclair	Georgia	No data
Herrington	Kentucky	None
Ross R. Barnett	Mississippi	None
Badin	North Carolina	None
Norman	North Carolina	None
Greenwood	South Carolina	No data
Murray	South Carolina	No data
Hartwell	South Carolina	None
Clark Hill	South Carolina	None
Toledo Bend	Louisiana	Slight reduction
D'Arbonne	Louisiana	Slight reduction
J. Percy Priest	Tennessee	Significant reduction
Norris	Tennessee	No data
Cherokee	Tennessee	None
E.V. Spence	Texas	No data
Navarro Mills	Texas	None

Juveniles. — The diet of juvenile striped bass includes crustaceans (Raney 1952; Chadwick 1960; Goodson 1966; Gregory 1968; Minckley 1973; and Gomez 1970), insect larvae (Minckley 1973; Boynton and Polgar 1981; Nichols 1966; Raney 1952), copepods (Chadwick 1960; Goodson 1966), aquatic insects (Heubach 1963), and fish larvae (Van Den Avyle et al. 1983).

Gomez (1970) reported the following food items present in stomachs of young striped bass from Canton Reservoir, Oklahoma:

Crustacea
Copepoda, Malacostraca, Branchiopoda, Branchiura, unidentified.

Insecta
Aquatic: Diptera, Ephemeroptera, Odonata, Trichoptera.
Terrestrial: Orthoptera, Hymenoptera, unidentified.

Arachnida
Acarina, Aranea

Pisces
Clupeidae, Cyprinidae, Centrarchidae, Atherinidae, unidentified.

Of 99 fish stomachs examined, insects predominated at 79.7 percent, followed by crustaceans (46.5 percent), fish (16.1 percent), and arachnids (3.0 percent).

Larvae. — Doroshev (1970) studied feeding habits of larvae and found the following:

Days after hatching	Length (cm TL)	Weight (mg)	Food preferred	Diameter or length (cm)
9	0.6-0.7	1-5	*Cyclops* nauplii *Brachionus* *Artemia* nauplii	0.015-0.03
15	0.9-1.5	8-14	*Cyclops* III-V; *Moina* sp.	0.030-0.06
22	1.8-2.2	15-80	*Cylops; Moina,* *Chaoborus*	0.080-0.15

At Front Royal Fish Cultural Station, Virginia, the contents of 213 striped bass stomachs were examined in 1969 and 1970. Cladocerans constituted the major portion of the diet, with copepods and insects also important food organisms. Bass that were 30 to 40 mm long increased their intake of cladocerans, while copepod abundance decreased and insect abundance remained relatively stable. *Daphnia* and *Bosmina* were positively selected and *Cyclops* were eaten in relation to their abundance in ponds (Humphries and Cumming 1971).

Information is unavailable about specific food habits for juvenile and larval striped bass in the lower Colorado River.

Spawning. — Anadromous adult striped bass migrate from the sea upstream into larger rivers to spawn from February to July and randomly release gametes in areas of moderate to strong current. In California, adult striped bass migrate from the tidal estuaries of the Sacramento and San Joaquin River systems, upstream to rivers for spawning (Chadwick 1965, Miller and McKechnie 1969). Chadwick (1965) stated that since 1958, the spawning potential of striped bass in the San Joaquin River system has declined, while the spawning potential of striped bass in the Sacramento River has increased. In freshwater impoundments, adults migrate upstream until suitable habitat is found or further upstream movement is blocked by dams (Higginbotham 1979). The number of eggs produced varies with size; a 1.4-kg female can produce 14,000 eggs while a 22.7 kg specimen can produce nearly 5,000,000 (Raney 1952). The semibuoyant eggs are spherical, transparent, nonadhesive, and relatively large when compared to the eggs of other estuarine and anadromous fish. Unfertilized eggs are about 1.3 mm in diameter and about 2.4 to 3.9 mm when fertilized and fully water hardened. Egg diameter usually ranges from 3.0 to 4.0 mm (Mansueti 1958). Striped bass eggs have an unusually large oil globule, contributing over 50 percent of the egg's dry weight (Rogers and Westin 1981). Eldridge et al. (1977 in Rogers and Westin 1981), reported that the oil globule was an important energy source for larval development. Average specific gravity of eggs from Sacramento-San Joaquin River Systems were found to be approximately 1.0005, with a range of 1.0003-1.0007 (Albrecht 1962). Albrecht (1964 in Wang and Kernehan 1979) reported that a moderate current of greater than 0.3 m/s was necessary to keep the eggs suspended. Eggs need a long stretch of water and a current to remain suspended for the 2 to 3 days needed for incubation. In southern states, hatching requires 36 to 48 hours but requires 60 hours in California (Gregory 1968). The eggs will generally smother on the bottom if they sink because of silt or low quality water (less than 3 mg/L dissolved oxygen) (Minckley 1973).

Spawning is controlled by water temperature and usually takes place from February through July. Table 4 summarizes the range of the striped bass spawning season (Scruggs 1955; Lewis 1962; Nichols and Miller 1967; Turner 1976 in Kilambi and Zdinak 1981).

Edwards (1974) reported that the minimum temperature of the water must be 14.5 °C and that peak reproductive activity occurred between 15.6 to 18.4 °C. Hardy (1978 in Persons and Buckley 1982) and Talbot (1966 in Persons and Buckley

Table 4. — Striped bass spawning, adapted from Hardy (1978 in Setzler et al. 1980)

Location	Time	Author
Gulf of Mexico	Peak in June	Raney 1952
Mississippi	Mid-February to mid-March (on basis of well-developed roe)	McIlwain 1964
Alabama	April	Raney 1952
Eastern Florida	Mid-February to end of May	Barkuloo 1970
	"probably nearer mid-winter in St. John River"	McLane 1955
South Carolina	April to mid-May	Scruggs 1957
North Carolina	Late April and May	Chapoton and Sykes 1961
Chesapeake Bay region	Mostly April, May, early June	Chapoton and Sykes 1961; Dovel 1971
Delaware	Late May to mid-July, peak June	Raney 1952
Hudson River	Mid-May to mid-June,	Raney 1952
	peak last 2 weeks of May	Rathjen and Miller 1957
New England	June and early July	Bigelow and Schroeder 1953
Canada	June and July	Bigelow and Schroeder 1953; Pearson 1968; Raney 1952
California	Mid-March to late July, peak May and June	Scofield 1928 Calhoun et al. 1950

1982) reported temperatures for spawning between 10 to 25 °C but most frequently between 15.6 to 17.8 °C. Wang and Kernehan (1979) also reported spawning activity between 10.0 to 25.0 °C with peak activity of 15.0 to 18.0 °C. Morris (1979) found that female striped bass held in water as low as 6 °C and then raised to normal spawning temperature developed eggs to the same degree of maturation as females held in water of 16 to 19 °C. The reported optimum temperature range for spawning is 15.0 to 18.4 °C.

During spawning activity, "rock fights" occur when one female is pursued by several males. Much splashing accompanies spawning (Wang and Kernehan 1979). During the spawning act, a group of three or four fish mill in a circle and splash for about 1 minute. Water is thrown as high as 1.5 m into the air and then the fish abruptly submerge (Morgan and Gerlach 1950 in Edwards 1974).

Ovaries from female striped bass from the Colorado River during March and April were found to be cream colored and contained ova having a mean diameter of 0.77 mm. During May and June, ovaries were green and contained type 3 ova, ranging in size up to 1.35 mm with a mean of 1.02 mm. These ova had reached their maximum growth, and the eggs were ready to be spawned (Edwards 1974). Lewis (1962 in Kilambi and Zdinak 1981) reported type 2 ova (0.16 to 0.30 mm) and type 3 ova (0.33 to 1.00 mm) were maturing and the fish were potential spawners during the next spawning season. Chadwick (1965) felt that Lewis' criteria, used in the North Carolina River System, were not satisfactory for determining state of maturity of female striped bass in San Pablo and San Francisco Bays during the spring. Chadwick found ova that developed a year or more before they ripened and ova present in an intermediate developmental stage between these and the mature ova Lewis described. From the Colorado River, a high percentage of female striped bass have type 3 ova and green color ovaries in their fourth year. These fish are ready to spawn. A mean of 231,643 mature ova have been recorded for female striped bass from the Colorado River. This high percentage of mature age-class IV females and the number of mature ova present is far greater than reported from other regions (Edwards 1974).

In Coos Bay, Oregon, Scofield found in 1931 (Edwards 1974) that 35 percent of the females were mature and had spawned in their fourth year. Morgan and Gerlach (1950 in Edwards 1974) noted 68 percent of fourth year females were mature in Coos Bay.

Generally, females mature in 4 to 7 years and may not spawn every year (Raney 1952). Gregory (1968) reported that less than half of the females mature and spawn during their fourth year, but all are sexually mature by their sixth year. Merriman (1941 in Edwards 1974) found that only 25 percent of the females spawned at 4 years in Connecticut waters.

Males generally mature by their third year and by their fifth year are capable of reproducing (Gregory 1968). Most males spawn at a length of 254 mm or more (Raney 1952).

Prolarvae are initially planktonic and prefer subsurface waters. Later, the larvae and young prefer shallow waters with low current and sand or gravel substrate as nursery areas (Wang and Kernehan 1979). Spawning occurs in freshwaters with a salinity of less than 3000 mg/L over variable substrate.

Natural reproduction with completion of entire life cycles has occurred in freshwater environments, such as 64 954 ha Santee-Cooper Reservoir, South Carolina. Fishing is maintained on a year-round basis in this reservoir largely from spawning of resident fish (Scruggs 1957). Santee-Cooper Reservoir consists of two separate but connected bodies of water. Lake Marion was formed by construction of a dam across the Santee River. An 11-km-long canal from Lake Marion diverts water into Lake Moultrie, formed by construction of Pinopolis Dam on the nearby Cooper River.

In the early 1950's, the Pinopolis Dam permitted migration of fish through the lock at the dam (Scruggs 1955). Soon after impoundment of the reservoir, congregations of striped bass were observed in the tailrace area below Pinopolis Dam. The striped bass population of the reservoir was recruited from the Santee River by impoundment and possibly from migration through the Pinopolis lock from the Cooper River. From 1954 to 1957, the lock operations were greatly reduced and the striped bass were found to spawn successfully within the reservoir system (Stevens 1958; Surber 1958).

Scruggs (1957) found that striped bass were not migrating from the Cooper River to coastal waters but were remaining in the area of the Santee-Cooper Reservoir. Scruggs noted than 95 percent of the striped bass, after migrating to the upper 48 km of the Cooper River, had returned to the area and, in fact, little recruitment occurred from the Cooper River into the reservoir through the Pinopolis lock.

In 1954, egg samples were taken from tributary streams of the reservoir. Eggs were collected during the spawning season from the Congaree River which flows into Lake Marion. The river was very turbid from red clay and had a flow of 62 to 1107 m^3/s. Scruggs (1957) concluded that the Congaree River was the most important spawning area for striped bass because of the greater number of eggs collected there than from any other sampling area. It was thought that spawning probably occurred over a long stretch of river. From three smaller tributaries where striped bass spawned, Scruggs (1957) concluded that the duration of spawning was from April 6 to June 2, 1955, with a peak in late April. Other spawning areas included the area below the Pinopolis Dam. YOY striped bass were collected in both 1954 and 1955 from widely scattered areas along the shore of both lakes, supporting the conclusion that the life cycle of striped bass had been completed in the Santee-Cooper Reservoir or its tributaries (Scruggs 1957).

Striped bass have reproduced naturally in some other reservoirs as well.

Beaver Reservoir, on the White River in Arkansas, was impounded in 1963 and covers 11 420 ha. Since 1975, the reservoir has been stocked annually with striped bass. Kilambi and Zdinak (1981) reported that striped bass mature and are capable of spawning there. Striped bass were collected that had type 2 and 3 ova with yolk. This is an indication of spawning capability, and natural reproduction may have occurred since mature males have been collected frequently (Kilambi and Zdinak 1981). Pledger (1976 in Kilambi and Zdinak 1981) stated that some of the Beaver Reservoir striped bass population may be of Santee-Cooper-Reservoir stock. Pledger stated "If fish from Beaver Reservoir are from this population, they are genetically similar and may be able to reproduce in a totally freshwater environment."

Kentucky and Barkley Reservoirs, on the Cumberland and Tennessee Rivers in Tennessee, are both located adjacent to powerplants. There were no introductions of fertile striped bass eggs or larval striped bass into the river systems in 1975 (Hogue et al. 1977). Fry were introduced into the reservoirs, but it was concluded that the 49-mm total length juvenile collected in Barkley Reservoir was produced naturally (Hogue et al. 1977). Spawning was thought to take place above damsites, upstream from the reservoirs. Hogue et al. (1977) reported "All of the striped bass larvae identified were not developed to a degree that they could be capable of upstream movements, even during periods of low flow. It is logical to assume that spawning occurred between collection sites and the upstream dams, Cheatham and Pickwick. There is an outside possibility that spawning occurred at some point above the dams, and developing eggs and/or larvae survived dam passage, but when consideration is given to the damages expected upon passage resulting from abrasion, general trauma, shear forces, and pressure changes, likelihood for survival is low." A striped bass egg was collected below Pickwick Dam in 19.5 °C water. The velocity of 0.64 m/s was adequate to keep the egg suspended. Hogue et al. (1977) concluded that spawning was likely to occur in tailraces below Cheatham and Pickwick Dams.

In Keystone Reservoir, Oklahoma, a reproducing population of striped bass has developed as a result of a fingerling stocking program (Mensinger 1970). From 1965 to 1969, 2.75 million striped bass were stocked into the reservoir. Natural reproduction was first verified in 1970 (Mensinger 1970) and has occurred for consecutive years since 1970 in the Arkansas River tributary of Keystone Reservoir (Combs 1979). Spawning activity occurred from 1976 to 1978 on the Arkansas River when water temperatures reached 15.5 to 18.5 °C and terminated when water temperatures reached 17.0 to 26.5 °C. Spawning ranged from 27 to 51 days. Spawning success depended upon the velocity of the river. Arkansas River velocities during the 1976-78 spawning seasons ranged from 0.503 to 0.725 m/s in 1976, 0.500 to 0.573 m/s in 1977, and 0.558 to 0.835 m/s in 1978. The minimum distance above Keystone Reservoir needed to allow for hatching ranged from 60 to 74 km during the years of 1976 to 1978. The Arkansas River has a swift flow during the spawning season over a substrate of fine gravel with rock riffles. The river has suitable turbulence for spawning to occur, and natural reproduction continues to take place in this area (Combs 1979).

Prior to initial stocking of striped bass into Lake Powell in 1974, it was thought that striped bass would not reproduce; however, they have apparently spawned successfully. The waters of Lake Powell do not seem to be an impediment to striped bass spawning because the oxygen level in the substrate is sufficient to prevent the eggs from smothering on the bottom after they settle (Gustaveson pers. comm.). On April 26, 1980, surface water temperature in Gypsum Canyon, at the head of the reservoir, was 13 °C. Sexually mature males were collected in April, but females were not found to be sexually mature until May 20, 1980, when the water temperature reached 16 °C. Spent females were first captured on June 11, and spent males were collected later. Eggs were found nearly 160.9 km from any tributary and midlake spawning was suspected. During 1981, sampling began on May 26, when the water temperature was 16 °C. Spawning had already begun (table 5) (Persons and Buckley 1982). It can be concluded that Lake Powell striped bass spawned in 1980 and 1981 and have produced a naturally reproducing population. Fingerling stocking in Lake Powell was terminated in 1979 (Persons and Buckley, 1982), because successful spawning has occurred in three different locations: a short run 20.0 km above the lake in Cataract Canyon on the Colorado River, the San Juan River (tributary on the lower lake), and midlake spawning in Wahweap Bay (Loudermilk 1982). Natural reproduction has also occurred in Lake Mead (Gustaveson pers. comm.; Mr. Cornelio Padilla, Nevada Department of Wildlife, Las Vegas, Nevada, pers. comm.). The settling of striped bass eggs on an oxygen rich substrate for incubation is thought to allow successful reproduction of striped bass in Lake Mead (Gustaveson et al. in press). Striped bass in Lake Mead spawn directly in the lake.

Table 5. — Stage of maturity of adult striped bass captured at Gypsum Canyon, Lake Powell in 1980 and 1981

Sex and stage of gonads	1980		*1981		Totals	
	No. captured	percent of total	No. captured	percent of total	No. captured	percent of total
Male						
Immature	9	4.5	3	1.5	12	3.0
Maturing	6	3.0	2	1.0	8	2.0
Ripe	**121	61.1	89	43.4	210	52.1
Spent	1	0.5	51	24.9	52	12.9
Totals	137	69.2	145	70.7	282	70.0
Female						
Immature	6	3.0	8	3.9	14	3.5
Maturing	15	7.6	4	2.0	19	4.7
Ripe	25	12.6	8	3.9	33	8.2
Spent	15	7.6	40	19.5	55	13.6
Totals	61	30.8	60	29.3	121	30.0
Grand totals	198		205		403	

*Does not include 23 fish of undetermined sex and stage of maturity that were released.
**Includes some partly spent fish.

In the Havasu section of the Colorado River system, female striped bass migrate upstream annually to the tailwaters of Davis Dam. It was first documented that a strong-year class was produced in 1970 (Edwards 1974). Reproduction is probably limited in this area because of the absence of long reaches of flowing water (Minckley 1979). Reproduction occurs from Davis Dam to approximately 16 km downstream. In 1969, 53 percent of the bass sampled in this stretch were females. This area provides strong and turbulent currents similar to spawning waters in California (Edwards 1974; McClane 1978).

Since 1978, spawning has occurred upstream from Lake Havasu and possibly along the shoreline (Mr. Richard Beaudry, Arizona Game and Fish Department, Havasu City, Arizona. pers. comm.; Mr. Brad Jacobson, Arizona Game and Fish Department, Yuma, Arizona, pers. comm.; Gustaveson pers. comm.; Loudermilk 1982). In June 1982, several large females (22.7 kg) were caught on the lower end of Topock Gorge. Also, ripe males and females were found throughout the lake during spawning, but the spawning locations are still unknown (Loudermilk 1982a).

Age and growth.— Smith and Wells (1977) reported the length of larvae at several periods after hatching. These are:

Age	Length
2-5 days	0.5 cm
10-15 days	0.8 cm
20-30 days	1.0 cm
50-70 days	2.0 cm
60-80 days	2.5 cm

Ware (1969) reported lengths for 1-year-old striped bass from different locations around the country:

Location	1-year-old
Lake Hollingsworth, Florida	241 mm
Santee-Cooper, South Carolina	216 mm
Kerr Reservoir, Virginia North Carolina	130 mm
Millerton Lake, California	132 mm
Atlantic Coast	125 mm
Pacific Coast	104 mm

Striped bass increase in length most rapidly during the first 4 years. In the California Delta Area (Moyle 1976), Keystone Reservoir, Oklahoma (Mensinger 1970), and the lower Colorado River (Edwards 1974) the following values were reported for growth in length:

Age (yr)	California delta area (Moyle 1976) (length)	Keystone Reservoir Oklahoma (Mensinger 1970) (length)	Lower Colorado River (Edwards 1974) (length)	
	(cm)	(cm)	(cm)	(cm)
			Males	Females
1	* 2.0- 3.0	25.9	16.2	17.7
2	23.0-35.0	45.5	43.3	44.0
3	38.0-39.0	54.1	56.8	60.6
4	48.0-50.0	60.7	66.5	71.8

*Possible typographical error in Moyle (1976).

After the fourth year, striped bass will add 10 to 30 mm to their length annually (Moyle 1976) and 0.9 to 1.4 kg to their weight (Bailey 1975). The 2.0 to 3.0 cm length reported for 1-year-old striped bass by Moyle (1976) seems to be inconsistent with other data. The data probably should read 20 to 30 cm for 1-year-old striped bass. Striped bass in the lower Colorado River seem to grow faster in their third and fourth year than striped bass in either Keystone Reservoir or the California Delta area.

In Millerton Lake, California, by the fourth year, striped bass are 550 to 560 mm in length and add 40 to 50 mm per year. In the California area, striped bass will reach about 1250 mm in length and weigh 41 kg as compared to the Atlantic Coast where they reach 1800 mm in length and weigh 56 kg (Moyle 1976).

A record striped bass reported from Edenton, North Carolina, in 1891, was 1830 mm (6 ft) in length and weighed 57 kg (125 lbs) (McClane 1978).

McClane (1978) reported average weight and length for striped bass, 2-18 years old:

Age (yr)	Length (mm)	Weight (kg)
2	305-330	0.34
3	457-508	1.2-1.4
4	610	2.3
5	762-813	4.5-6.8
6	838-914	8.2-9.1
7	914	9.1
10-11	965	13.6
14	1016-1067	18.1
17-18	1270	22.7

In Louisiana, growth and weight were recorded for striped bass collected from D'Arbonne Lake and Toledo Bend Reservoir (Walker 1977). In both impoundments, the greatest growth rate was found among 1-year-old fish. Average annual growth rates, in kg, for Toledo Bend Reservoir was 0.9 to 1.1; for D'Arbonne Lake, the average growth was 0.9 to 1.2 kg.

Striped bass in landlocked environments seem to have a greater potential for growth. California fishermen catch stripers ranging from 1.4 to 13.6 kg. Fishermen in South Carolina catch fish weighing about 3 kg (Gregory 1968; Goodson 1966). Minckley (1973) reported that growth rates of striped bass in the Lower Colorado River seem high and striped bass show greatest growth rates in landlocked situations.

Competition. — Limited information is available on inter- and intraspecific competition of striped bass and deals mainly with competition for food. Few reports mention coexistence of striped bass and white bass in freshwater environments. The reservoirs where coexistence of these two species does occur are usually over 11 000 ha and interspecific competition has not been reported to be a problem.

Watts Barr Reservoir, Tennessee (15 628 ha) is a case where yellow, white, and striped bass coexist and are segregated in part by their more or less nonoverlapping food habits. YOY striped bass consumed large invertebrates and fish larvae; whereas, YOY white bass were more opportunistic feeders and ate fish and dipteran larvae when abundant. Yellow bass fed mainly on zooplankton. Differences in the food used were related to preferred prey size (Van Den Avyle et al. 1983). Van Den Avyle et al. (1983) observed that differences in food habits of the yellow, white, and striped bass were a consequence of different prey-size preferences rather than an outcome of competition. All three bass species occupied nonsegregated shoreline habitat and interspecific competition was not observed in the reservoir.

Lake of the Ozarks, Missouri (24 282 ha) is another large lake where white bass and striped bass coexist. Hanson and Dillard (1975) did not report any adverse effects that the striped bass might have had on the other fishes. The lake remained a good fishery for white crappie and white bass following the introduction of the striped bass in 1967. The abundant gizzard shad population was able to support the pelagic fish in the reservoir.

Keystone Reservoir, Oklahoma (10 643 ha), has a naturally reproducing population of striped bass. The native species present in the lake include black bass, white bass, channel catfish, crappie, sunfish, and gizzard shad. The white bass and crappie populations fluctuated widely and Combs (1980) speculated that this may be the cyclic nature of the fishes rather than the effects from the striped bass population. Important native fishes in Keystone Reservoir showed few effects that could be attributed to the striped bass population.

Elephant Butte Reservoir, New Mexico (6680 ha), also has white and striped bass. Gizzard and threadfin shad are abundant in the reservoir and provide forage for both species of bass. Turner (pers. comm.) feels that striped bass will outcompete white bass for food, if the preferred food becomes limited. There has been no evidence of competition between the white and striped bass for food since striped bass introductions in the early 1970's.

Predator-prey interactions are sometimes reduced in intensity because of the limitations of the preferred temperature requirements of the species involved. Threadfin and gizzard shad, freshwater drum, juvenile carp, and sunfishes may become thermally isolated from adult striped bass during the summer months. At the same time, yellow perch, white crappie, black crappie, rainbow trout, walleye, and sauger, which generally occupy the same thermal niche as striped bass, may compete for prey or be preyed upon. These interspecific interactions could be intense if suitable refugia are limited (Coutant and Carroll 1980). Coutant and Carroll (1980) explain that "Accelerated predation forced by advanced eutrophication could logically cause large striped bass predators to overtake populations of smaller game fish."

Claytor Lake, Virginia, presents a good case for interspecific competition. The lake is classified as a marginally eutrophic reservoir, and anoxic hypolimnic conditions occur in summer. The adult sport fish present from 1977 to 1979 included walleye, white bass, striped bass, black bass, and crappie. The self-sustaining populations in the lake includes black bass, white bass, channel catfish, crappies, bluegill, and yellow perch. Striped bass and walleye are stocked. The principal pelagic forage species in Claytor Lake, prior to a severe die-off in the winters of 1977 to 1978, was the alewife. In 1979, this fish became abundant again. Alewives were seldom eaten by littoral piscivores (black bass and crappie), but were utilized by walleye, white, and striped bass. Competition for food in the lake probably occurred when the alewife population crashed. Pelagic piscivores began to feed on centrarchid fishes and yellow perch but preyed again on the alewife when its population increased. Striped bass consumed the largest number of alewives of all the piscivores in Claytor Lake (Kohler and Ney 1981).

In 1969, rainbow trout were originally stocked into Lake Mead to help utilize the large limnetic population of threadfin shad. The rainbow trout subsequently became prey for the striped bass, which were also introduced to utilize shad, and in response to a decline in largemouth bass (Baker and Paulson 1981). The utilization of trout by the striped bass reduced the trout harvest and resulted in almost complete loss of the rainbow trout fishery. From 1970 to 1975, rainbow trout occurred in 23 percent of the striped bass stomachs examined, but threadfin shad still comprised 50 percent of their diet (Baker and Paulson 1981). The result was a decline in both the rainbow trout and threadfin shad populations because of striped bass predation.

Downstream from Lake Mead, in Lake Havasu, adult striped bass utilize threadfin shad and crayfish for food. The striped bass in the lake apparently compete with largemouth bass for threadfin shad if the shad population is reduced in abundance (Loudermilk pers. comm.).

Introductions of striped bass outside their native range. — Introductions of striped bass have been attempted with some success in freshwater environments throughout the United States. The first known successful introduction was during the period from 1879 to 1881, when 432 striped bass from New Jersey were shipped to California and stocked in San Francisco Bay. Within 10 years, a commercial fishery developed as a result of the stocking. Estimates in 1971 showed that there were about 1.5 million adult striped bass in the Sacramento-San Joaquin Delta area. Annual recruitment remained fairly high from 1969 to 1971 and survival rate was about 50 percent (Stevens 1974). In the mid-1930's, a stocking program of young striped bass in New Jersey reservoirs resulted in failure (Surber 1957 in Bailey 1975).

In the mid-1950's, it was a general practice to stock adult fish in landlocked environments. The fish were expected to spawn within a year or two and eventually create a fishery. However, collection of adults with gillnets or hook and line caused shock and handling stress. Some adults died in ponds from diseases and some could not survive the transport (Gray 1957 in Bailey 1975). Adult striped bass have been stocked in three localities in Florida since 1961, mainly to control gizzard and threadfin shad populations. Lake Talquin was stocked with 97 stripers and Lake Ivanhoe was stocked with 61 adult stripers. There was no evidence that these adult striped bass survived. The St. Lucie River was stocked with 477 adult striped bass. Evidence showed that survival had been good, perhaps because of the access to saltwater (Barkuloo 1967). Bailey (1975) reported that some stockings of adult striped bass into freshwater reservoirs in Southeastern United States were not successful. Lake Ouachita, Arkansas, was stocked from 1956 to 1960 with 870 adults, 195 subadults, 7 yearlings, and 27 fingerlings, without success. Selected lakes in the States of Kentucky, Maryland, North Carolina, South Carolina, and Georgia were stocked with adult wild fish, again unsuccessful, as measured by reproduction.

From the mid-1950's to 1970, striped bass fry were stocked in reservoirs in Arkansas, Alabama, Kentucky, Louisiana, North Carolina, Virginia, South Carolina, Tennessee, and Texas. In general, survival was poor. Fisheries were established in only two reservoirs, Kerr Reservoir, North Carolina-Virginia and Clark Hill Reservoir, South Carolina. Kerr Reservoir lies 64 km above a major natural spawning area of striped bass. YOY were found in the reservoir in 1956 (Surber 1957 in Bailey 1975) and probably were produced naturally from the original population of fry that were introduced there in 1953.

Fingerling stocking seemed to be more successful than adult or fry stocking in establishing striped bass populations in southeastern reservoirs. Dardanelle, Arkansas; Jones Bluff, Alabama; Norman, North Carolina; Greenwood, South Carolina; Hartwell, South Carolina; J. Percy Priest, Tennessee; Norris, Tennessee, Cherokee, Tennessee; and Navarro Mills, Texas; are reservoirs that have established striper fisheries probably because of fingerling stocking rather than fry stocking.

By 1970, fisheries were definitely established in 7 out of 36 southeastern reservoirs that had been stocked with fingerlings (Bailey 1975). Three of these reservoirs had been stocked with fingerlings only, two had been stocked with fry and fingerlings, and two with fry, fingerlings, and yearlings. By 1973, after 3 more years of fingerling stocking efforts, 23 out of 53 lakes had established fisheries.

Striped bass eggs and fry were first introduced into 15 628 ha Watts Barr Reservoir, Tennessee, in 1964. From 1964 to 1978, 3,500,000 eggs, larvae, and fingerlings had been stocked (Higginbotham 1979). Fingerlings have been stocked annually since 1971. The reservoir contains many fish species including largemouth bass, smallmouth bass, white bass, yellow bass, white crappie, black crappie, walleye, sauger, sunfishes, gizzard shad, threadfin shad, buffalofish, carp, freshwater drum, and catfish. Van den Avyle and Higginbotham (1979) evaluated relationships among growth rates, survival, numbers stocked, and size of stocking for 7 year-classes of striped bass during 1977 and 1978. They found fingerlings stocked during June and July 1978 dispersed rapidly but tended to remain within the general area into which they had been introduced. Striped bass in the reservoir preferred sandy shoreline habitats. Stocking has continued in the reservoir, but striped bass have not become abundant. There is speculation that a commercial net fishery, which has existed throughout the stocking program, could be preventing the establishment of a substantial adult striped bass population (Heitman 1979).

One area where a naturally reproducing population has developed from introduced fish is the Arkansas River system. Keystone Reservoir (Mensinger 1970) in Oklahoma and Dardanelle Reservoir in Arkansas are both located on the Arkansas River (Bailey 1975). Santee-Cooper, South Carolina, and Kerr Reservoir, North Carolina-Virginia, both contain naturally reproducing populations of striped bass but had native populations before impoundment (Goodson 1966). Keystone Reservoir in Oklahoma had approximately 2.75 million striped bass ranging in size from fry to adults stocked during 1965-1969. The reservoir covers 10 643 ha and impounds the Cimarron and Arkansas Rivers. The impoundment was constructed for hydroelectric power, navigational purposes, and for flood control. Natural reproduction of striped bass was not found in 1969, but spawning activity was apparent in the Cimarron and Arkansas Rivers and below Keystone Dam in 1970 (Mensinger 1970). Since 1970, a successful naturally reproducing population has become established.

Striped bass fisheries were established in Toledo Bend Reservoir, Louisiana-Texas, and D'Arbonne Lake, Louisiana. Toledo Bend Reservoir has a surface area of 73 490 ha and a maximum depth of 27 m and an average depth of 8 m. Two million six hundred forty-two thousand striped bass were stocked there from 1965 to 1977 (Walker 1977). D'Arbonne Lake has a surface area of 6071 ha and is 26 km long with a maximum depth of 9 m and an average depth of 3 m. From 1965 to 1977, 723,000 striped bass were stocked there. Fisheries have been established and maintained by continued stocking, but natural reproduction has not been verified.

Striped bass were stocked in 24 282 ha Lake of the Ozarks, west-central Missouri, from 1967 to 1974, to control the gizzard shad population (Hanson and Dillard 1975). The maximum depth of the lake is 33.5 m. The average annual flow through the powerplant at the dam is 142 m^3/s. White bass were abundant in the lake, along with bluegill, channel catfish, and white crappies. The repeated introduction of striped bass and establishment of a population did not seem to affect the other species of fish in the lake. The catch of white crappie and white bass remained good, but striped bass angling success depended on clarity of the water with striped bass generally avoiding turbid water conditions (Hanson and Dillard 1975).

In the Western United States, striped bass were introduced into a number of freshwater environments. Early attempts included an experimental introduction of striped bass in the lower Colorado River on April 15, 1959, to enhance the fishery (Minckley 1973). Nine hundred and thirty-eight small stripers that averaged 86 mm in length were planted in the river near Blythe, California (St. Amant 1959). In California, striped bass were introduced into Millerton Lake in 1955 and stocked from 1955 to 1957 (Cloyd and Ehlers 1960 in Goodson 1966). Millerton Lake had a reproducing population of striped bass from 1958 to 1960 (Goodson 1966). Striped bass were introduced into Modesto Reservoir in California in 1964, but the success of the introduction is unknown.

Striped bass were successfully introduced into Lake Powell, Utah, to enhance fishing opportunity for anglers and to utilize the abundant shad population (Wayne Gustaveson pers. comm.).

From 1974 to 1979, Lake Powell was stocked annually with striped bass (Hopeworth 1978). Most fish were stocked at the south end of the reservoir in Wahweap Bay. Bullfrog Bay, midway up the lake, was also stocked during 1976-1977. Table 6 shows records of the striped bass stocked into Lake Powell from 1974-1977. Since 1974, a total of 815,000 fry have been introduced. Stocking was terminated in 1979 because natural reproduction was sufficient to maintain recruitment.

Table 6. — Stocking records of Lake Powell, 1974-1977

Year	Wahweap	Bullfrog	Total
1974	49,885	0	49,885
1975	94,878	0	94,878
1976	35,752	19,305	55,057
1977	86,003	52,650	138,653
	266,518	71,955	338,473

Total sport catch estimates for 1979 and 1980 were 8,000 and 17,000 fish, respectively, with the majority of the fish caught in the summer months. In 1982, 54,000 fish were harvested (Loudermilk 1981).

In 1969, striped bass were introduced into Lake Mead to provide another sport fish in a response to the declining largemouth bass (*Micropterus salmoides*) fishery and to utilize the threadfin shad population (Baker and Paulson 1981). Lake Mead, formed by Hoover Dam, is considered an oligotrophic-mesotrophic lake. The lake is 183 km long, has a maximum depth of 180 m, with a surface area of 660 km^2. Creel census data from 1978, 1979, and 1980, indicated that striped bass contributed 4.1 percent, 40.1 percent, and 50+ percent to the harvest, respectively. YOY were observed near the sandy beaches of Lake Mead during July to August (Loudermilk 1981). Spring die-offs were common from 1976 to 1979 because food was probably limiting, but no die-offs have occurred since 1980 (Baker and Paulson 1981).

Striped bass have never been stocked in Lake Mohave, but low numbers of bass were present there in 1981 (Padilla pers. comm.). Lake Mohave is formed by Davis Dam on the Colorado River. It has a maximum depth of 30.5 m (Allan and Roden 1978). Recruitment of larvae and eggs into Lake Mohave is thought to be through Hoover Dam. The presence of 1- and 2-year-old striped bass was documented from June 1981 (bass 356 mm in length) to November 1982 (bass 482 mm in length).

Lake Havasu, formed by Parker Dam, 81.0 km below Davis Dam, also has a striped bass fishery. Lake Havasu has an area of 7038.5 ha with depths ranging from 0.6 to 22.8 m. There are seven other species of game fish present in Lake Havasu; largemouth bass, black crappie, bluegill, green sunfish, redear sunfish, channel catfish, and yellow bullhead (Ponder 1971).

Striped bass recruitment in Lake Havasu is thought to originate around Bullhead City, Arizona, and at Parker Dam (Loudermilk pers. comm.) because ripe fish have been observed at both locations about the same time of year.

California Fish and Game Department conducted summer gillnet surveys on the lake. Striped bass from the 1978 or younger year classes represented 19 percent of the total catch from point and cove sets. The average total length of 56 striped bass collected during late June was 346 mm. The Bullhead City Striped Bass Derby in 1980 showed an average weight for striped bass of 4.8 kg (Loudermilk 1981). In 1981, two striped bass tournaments were held on February 28 and March 14. The winning fish weighed 4.1 kg and 7.7 kg. respectively.

In Lake Havasu, the summer months of June and July were the peak months for striped bass angling. Creel surveys during April to July 1981 showed that channel catfish and largemouth bass were collected more than striped bass (Loudermilk 1982b).

Loudermilk (1982a) reported that from 1979 to 1981, gillnetting along shorelines 8.2 m or less in depth produced the best catch of subadult striped bass. Two-year-old fish were predominant in the samples in each of the 3 years of sampling.

During July 1982, Arizona Game and Fish Department sampled the Arizona side of Lake Havasu, with only 8.6 percent of the total catch being striped bass. U.S. Fish and Wildlife Service personnel found that 75 percent of the stripers caught during spring were subadults (160 to 597 mm). Late fall surveys showed that 65 percent of the fish caught were subadults, ranging from 210 to 803 mm.

Conditions in the Colorado River below Lake Havasu are conducive for warm-water fishes because of warm epilimnetic penstock intakes in Parker Dam (Minckley 1982a). The Colorado River Wildlife Council Ad Hoc Committee on Striped Bass (Loudermilk 1982) reported that striped bass fishing is generally successful in the lower Colorado River system, including the area below Parker Dam, Headgate Rock Dam, Palo Verde Diversion Dam, Imperial Dam (All American Canal), and Rockwood Heading (Yuma Division). Stripers weighing 13.6 kg have been reported, but the source of recruitment for this area is still unknown. During the period 1962 to 1969, 93,000 striped bass fingerlings and yearlings from South Carolina were introduced into the river system (Edwards 1974).

On August 13, 1962, 17 000 fingerlings (average length 51 mm) and 200 yearlings (average length 158 mm) were stocked between Blankenship Bend and Topock, Arizona. In 1962, 1963, and 1964, additional fingerlings and yearlings were stocked, bringing the total to 82,935 fingerlings and 896 yearlings, respectively (table 7). Fish for these introductions were collected from the Tracy fish screen at Tracy, California.

Stocking at Bullhead City, Arizona, was carried out in October 1969 when 9,175 (9,000 fish,

Table 7. — Stocking records of striped bass — sites between Davis and Parker (adapted from Edwards 1974)

	Number	Length (mm)	
Aug. 13, 1962	17,000	50	Topock area
Aug. 13, 1962	200	177	Topock area
Aug. 14, 1962	21,025	50	Davis Dam to Needles
Aug. 29, 1963	3,080	50	Blankenship Bend, Topock Gorge
Aug. 29, 1963	125	76-177	Blankenship Bend, Topock Gorge
Aug. 20, 1964	14,950	50	1.6 km south of Devil's Elbow, Topock Gorge
Aug. 20, 1964	150	177	1.6 km south of Devil's Elbow, Topock Gorge
Aug. 21, 1964	9,000	50	0.8 km north of Topock Bridge
Aug. 21, 1964	421	177	0.8 km north of Topock Bridge

102 mm in length; 175 fish, 178 mm in length) striped bass from South Carolina were introduced. A total of 93,000 were planted into the Colorado River (Edwards 1974). Table 8 shows the overall record of fish stocked in the lower Colorado Region by the different agencies (Fish and Wildlife Service 1980, Arizona Game and Fish Department 1980) between 1959 and 1972. There appears to be a hiatus between the years 1964 and 1969 when either records were incomplete or striped bass introductions did not occur.

Other striped bass introductions include Lake Hollingsworth, Florida. Lake Hollingsworth is a 144-ha, hypereutrophic lake, with an average depth of 1.2 m. Water discharges at an average of 36 m^3/s. The lake contains a heavy accumulation of organic muck and detritus estimated at 60 to 70 percent of the total bottom area. Dense phytoplankton blooms persist year-round. Lake Hollingsworth was selected for stocking for three reasons: (1) the eutrophic conditions support a dense shad population characteristic of problem lakes in Florida, (2) the closed ecosystem prevented emigration, and (3) high stocking rates could be accomplished. The overall fishery in 1968 to 1969 was described as poor and consisted of gizzard and threadfin shad, brown bullhead, stunted bluegill, and low numbers of *Tilapia aurea*, not considered a contributor to the sport fishery. On June 5, 1968, 15,597 2-month-old striped bass were stocked into the lake at a rate of 17 fish/ha. Ware (1969) reported that the striped bass were successfully established, but Bailey (1975) reported that the striped bass in Lake Hollingsworth were killed off by parasites.

Table 8. — Stocking of striped bass from Lake Mead to Imperial — Lower Colorado River

Year	Location	Number	Agency
1959	Palo Verde to Imperial	1,590	CFG*
1961	Palo Verde to Imperial	3,327	CFG
1962	Below Davis Dam	40,025	CFG
1963	Below Davis Dam	54,035	USFWS
		7,441	CFG
1964	Below Davis Dam	331	CFG
1969	Lake Mead	20,000	NFG
1969	Colorado River	9,145	AGF
1970	Lake Mead	16,300	NFG
1971	Lake Mead	1,034	NFG
1972	Lake Mead	3,000	AGF

* CFG = California Fish and Game.
* USFWS = United States Fish and Wildlife Service.
* NFG = Nevada Fish and Game.
* AGF = Arizona Game and Fish.

Beaver Lake in Arkansas is another case where striped bass failed to become established after repeated introductions and where the effects of a changing habitat on fish populations were evaluated (Rainwater and Houser 1982). The 11 420-ha reservoir was studied after impoundment in 1963 until 1980; it has a mean depth of 18 m with a maximum depth of 62 m and an outlet depth of 42 m. The fishery consists of 38 native and 5 introduced fish species (Rainwater and Houser 1982). The striped bass were initially stocked in 1968, with subsequent stockings during 1970 to 1980. Striped bass succeeded in becoming established only three times. The white bass population fluctuated periodically. Gizzard shad constituted 60 to 100 percent of the total weight of shad in samples. The majority of these individuals was too large to be eaten by most predators. Striped bass contributed less than 1 kg/ha in any one year and were collected in less than 5 of the 18 years of sampling. White bass, a native species, did succeed better than the striped bass (Rainwater and Houser 1982).

In August 1969, 3,500 fingerlings were introduced into Sterling Reservoir, Colorado. In 1971, 10,938 fingerlings were planted (Powell 1972; Larry Finnell, Colorado Division of Wildlife, pers. comm.). Only 18 striped bass were recovered from Sterling Reservoir during 1970 to 1973 (Imler 1976). Sterling Reservoir fluctuates about 9 to 12 m annually and is about 18 m deep at the dam. In September, the reservoir is at its lowest, and it fills during the winter. In 1977, 5 percent of the striped bass catch averaged 660 mm in length. Other fish species present in Sterling Reservoir include walleye, yellow perch, and white suckers. In the early 1970's, the gizzard shad population crashed and, as a result, there are few stripers in Sterling Reservoir (Jay Stafford, Colorado Division of Wildlife, pers. comm.). It is not known for certain whether the voracious habits of the striped bass caused the gizzard shad population to crash, followed by the decline of the striped bass, or whether some environmental or climatic factor was responsible independently for the decline of the gizzard shad, which resulted in a decline of the striped bass population.

Elephant Butte Reservoir, New Mexico, was first stocked with striped bass in the early 1970's (Turner pers. comm.) along with largemouth bass. Striped bass were first caught in Elephant Butte Reservoir in 1976, and periodic stocking has been carried out since 1977. There is also an abundant white bass population in Elephant Butte Reservoir. The primary forage there consists of gizzard and threadfin shad. Striped bass mortalities were observed in 1982, probably the result of stress caused by a temperature-dissolved oxygen "squeeze" (Turner pers. comm.). This phenomenon has been discussed elsewhere. Natural reproduction of striped bass has not been observed in Elephant Butte Reservoir. The normal spawning season for striped bass coincides with spring runoff, and water is too turbid and cold during this time for natural reproduction to take place (Turner pers. comm.).

A summary of the successful reservoir and lake introductions of striped bass includes (adapted from Setzler et al. 1980):

- Martin, Lay, Choctawhatachee River and Bay, Jones Bluff and Jordan in Alabama
- Norfolk, Beaver, Greeson, Dardanelle, Maumelle in Arkansas
- Hunter and Julianna in Florida
- Sinclair in Georgia
- Hartwell and Clark Hill in Georgia-South Carolina
- Herrington in Kentucky
- Toledo Bend and D'Arbonne in Louisiana
- Ross R. Barnett in Mississippi
- Bardin and Norman in North Carolina
- Greenwood and Murray in South Carolina
- Norris, Cherokee, and J. Percy Priest in Tennessee
- E. V. Spence and Navarro Mills in Texas
- Santee-Cooper in South Carolina
- Kerr Reservoir in Virginia-North Carolina
- Keystone in Oklahoma
- Lake of the Ozarks in Missouri.

In addition, successful introductions have occurred in:

- Lake Mead in Arizona-Nevada
- Lake Powell in Utah
- Lake Havasu in Arizona.

Striped bass were unsuccessfully introduced or survival was questionable (Setzler et al. 1980) in Sterling Reservoir, Colorado; Hawaii; Kentucky; Ohio River; western Maryland; New Jersey; and Lake Ontario.

Localized or landlocked populations of striped bass exist in (Setzler et al. 1980):

- Santee-Cooper Reservoir in South Carolina*
- Keystone Reservoir in Oklahoma*
- St. Johns River in Florida
- Roanoke River in North Carolina
- Kentucky and Barkley Reservoirs in Tennessee*
- Beaver Reservoir in Arkansas*
- Kerr Reservoir in Virginia
- Colorado River in Arizona, California, Nevada, and Utah*
- Elephant Butte Reservoir in New Mexico.

* Denotes reproducing populations of striped bass.

Excerpts and summaries from Arizona Game and Fish Department Federal Aid to Fish Restoration reports relative to Central Arizona Project Waters. — The following section is a chronological summary of narrative statements regarding introduction, status, and effects of striped bass in Arizona, gleaned from an examination of various Arizona Game and Fish Department progress and completion reports (principally F-7 reports, Federal Aid in Fish Restoration) for the period 1959 to 1982. The particular report from which information was obtained is indicated and any material quoted is so indicated.

1. F-7-R-4, January to October 1961, work plan 4, job No. A-1, by R. D. Ringo

Lower Colorado River, Imperial: "Introduction of new fish species has been numerous in this area. Some of the most recent have been the threadfin shad (*Dorosoma petenese*) 1954, redear sunfish (*Lepomis* *macrolophus*), date undetermined, striped bass (*Roccus saxatilis*) 1959 and 1961, and proposed is the flathead catfish (*Pylodictis olivaris*)."

2. F-7-R-5, November 1961 to October 1962, work plan 4, job No. B-1, by R. D. Ringo

Imperial Dam Area: "Most recent introduction has been the striped bass (*Roccus saxatilis*). This fish was planted by the cooperative efforts of both California and Arizona in 1959 and 1961. Since its introduction, only a few specimens have been reported or personally seen for this area. The following is a list of observed specimens:

Date	Total length (cm)	Weight (kg)	Sex
3/30/60	39.4	0.7	M
9/28/60	50.8	1.5	F
9/30/61	64.8	2.7	F
11/28/61	65.5	3.2	M
5/04/62	68.6	4.0	M
5/11/62	70.0	4.2	F

The last recorded female specimen was reabsorbing the gonad tissue, indicating the reproductive potential to be problematical."

3. F-7-R-6, November 1962 to October 1963, work plan 4, job No. B-1, by D. Smith

"During this project, a joint stocking of striped bass (*Roccus saxatilis*) was made by California and Arizona Game and Fish Departments. Twenty-thousand fingerling bass were planted in the Blythe area. During the project period, only one confirmed striped bass was taken by an angler. This specimen was 45.7 cm in total length and weighed 1.6 kg."

Summary of striped bass fingerling plantings, Colorado River:

Month and year	Numbers	Area
April 1959	1,000	Blythe
December 1959	600	Ferguson Lake
December 1961	1,737	Blythe
December 1961	1,500	Martinez Lake
August 1962	25,000	Davis Dam
August 1962	38,225	Needles
August 1963	20,000	Blythe
Total	105,062	

4. F-7-R-6, November 1962 to October 1963, work plan 4, job No. G-1

"Lake Havasu fishing has declined over the past 20 years (1943–1963), generally speaking. Bass and bluegill are the species which show the most decline. This lake and river above the lake received approximately 40,000 striped bass in 1962 and again in 1963. Plans call for 40,000 to be planted in 1964. It is felt that 3 years stocking at this rate will be sufficient to indicate if the striped bass will increase the quality of fishing in Lake Havasu."

5. F-7-R-7, November 1963 to December 1964, work plan 4, job No. S-1

"Attempts were made to procure striped bass larva in mid-May, but it is felt that the plankton drift nets were fished somewhat prior to the period when larval fish would normally be expected. Large numbers of adult striped bass were reported caught (California Department of Fish and Game) in the vicinity of the Palo Verde Weir in late May indicating a possible spawning run at that time."

6. F-7-R-8, January 1965 to December 31, 1965, work plan 4, job No. S-1

"During the last week of May, large numbers of adult striped bass were reported by the California Department of Fish and Game and were being caught by anglers below the Palo Verde Weir. This is an indication that the spawning run for these fish occurred in late May."

7. F-7-R-10, January 1967 to December 1967, work plan 3, job No. S-1

"Limited netting investigations failed to provide any evidence of quantity striped bass reproduction, although one 43.2 cm specimen with two annuli indicated that some reproduction has been successful in Lake Mead and Lake Mohave."

Recommendations were listed:

Sample fish populations by use of nets and electrofishing equipment between Davis Dam and Lake Havasu, with special emphasis on striped bass reproduction. Continue scale sampling for age composition in the Davis Dam, Lake Havasu area.

Davis Dam to Lake Havasu

"Nets and electrofishing were utilized in the Colorado River between Davis Dam and Lake Havasu in an effort to sample striped bass and determine possible striped bass reproduction. No striped bass or evidence of reproduction was found with the use of the above techniques. As the last plant was made in 1963, it is apparent that no reproduction has occurred."

Striped bass scales sample data, Davis Dam to Lake Havasu, Colorado River:

Number of species	Age	Average wgt. (kg)
1	2 years (female)	3.2
6	3 years (male)	4.1
1	3 years (female)	5.4
3	3 years (no sex)	4.1
3	4 years (female)	5.4
Total 14		

8. F-7-R-11, January 1968 to December 1968, work plan 3, job No. R-3

   "During 1968, 86,291 rainbow trout were stocked in the Colorado River between Fort Mohave and Davis Dam. It has been determined that striped bass have some detrimental effect on trout populations immediately below Davis Dam. Because of this effect, and the relatively high striped bass population present during June through September, it is felt that no trout stocking should be conducted there during that period."

A stomach analysis of 23 striped bass caught by anglers between Bullhead City and Davis Dam showed:

Stomach contents	Percent occurrence
Crayfish	17.4
Threadfin shad	47.8
Rainbow trout	4.3
Empty	30.4

9. F-7-R-11, January to December 1968, work plan 3, job No. S-2

   "Underwater observations of striped bass movements and locations were made. Striped bass were first sighted on May 9 in the river between Fort Mohave and the California-Nevada border. Between June 1-November 18, striped bass were observed in the fast water directly in front of the outlet gates."

10. FS-4, January to December 1968, work plan 4, job No. S-1

    "Some reproduction of striped bass was noted in Senator Wash Reservoir. The lakes inlet-outlet into Imperial Reservoir was sampled for evidence of striped bass reproduction. One 24.1 cm striper was collected June 26, 1968. Several fishermen reported catching sublegal striped bass in the reservoir."

11. FS-5, January to December 1969, work plan 4, job No. S-1

    "Striped bass in Senator Wash Reservoir (190. 3 ha, 24.4 m deep) are just attaining legal size."

12. F-7-R-14, January 1971 to June 1972, work plan 3, job No. R-3

    "To determine striped bass predation on newly stocked trout, stomachs from 20 striped bass were examined over a 13 day period following stocking of tagged trout below Davis Dam. A total of 24 trout were found, 18 of which were tagged."

13. F-7-R-20, July 1977 to June 1978, job No. 3

Temple Bar at Lake Mead:

"Striped bass checked increased from 94 in 1976-1977 to 113 in 1977-1978, and average length increased by 2.5 cm to 54.0 cm. May-June 1978, yearling fish (<17.5 cm) comprised 65.4 percent of the catch by electroshocking. The striped bass population of Lake Mead appears to continue to expand with good recruitment of 1- to 2-year old fish. A total of 50 striped bass (30.9-94.0 cm) were collected from the surface in either a dead or moribund condition."

14. F-7-20, July 1977 to June 1978

Colorado River-Parker Strip:

Out of 77 fish caught by anglers, only one 88.9 cm striped bass was caught.

Lake Havasu:

Out of 634 fish caught by anglers, 35 were striped bass for about 6 percent of the total.

Lake Havasu, February 23, 1977:

Method: electrofish

Striped bass	Length (cm)	Weight (kg)
	65.2	2.62
	54.3	1.74
	47.5	1.31

15. F-7-R-21, July 1979 to June 1980, work plan 1, job No. 3

Annual growth increments for striped bass, Colorado River below Davis Dam

1976-1980	Fork length						
	I	II	III	IV	V	VI	VII
Samples (n = 123)	244.1	460.3	586.8	664.3	722.3	838.7	923.3
Edwards study (n = 55)	203.1	438.5	574.3	588.4	650.0		

Age growth analysis of striped bass showed a greater growth rate than previously reported by Edwards (1974).

16. F-7-R-23, June 1980 to June 1981, work plan 1, job No. 3

"Two surveys were completed, April 30 and May 8, 1981, in the lower Colorado River area. In April, a 1.5 km stretch along the Arizona side was surveyed. River flow was 308 m³/s, and temperature was 19.0 °C. Sixty-six striped bass of the dominant 1978 age class were seen in groups of 8 to 12 fish cruising approximately 1 m from the shoreline in 1 m of water. Nine stripers ranging from 70.0-76.0 cm were observed.

"May survey was conducted along the Arizona side for a distance of 2.5 km. Twenty-eight smaller (50.0 cm) fish and 18- 70.0 cm fish were observed. Although the majority of male stripers checked by creel census during the survey period were ripe, no spawning behavior was observed.

"Internal analysis of 65 striped bass belonging to 1 age class was made. Zooplankton was the most common item (73.0 percent)."

An overall species composition of the creel reflects significant changes from 1980 to 1981.

Comparison of species composition percentages below Davis Dam:

Fiscal year	Percent largemouth bass	Percent bluegill	Percent channel catfish	Percent carp	Percent rainbow trout	Percent striped bass
1980	0.4	0.0	4.9	0.3	91.7	2.7
1981	1.4	0.2	60.8	1.2	17.2	19.2

"An apparent shift occurred from rainbow trout (91.7 percent FY80) to channel catfish and striped bass (80.0 percent combined FY81)."

17. F-7-R-23, (July 1980 to June 1981), work plan 1, job No. 4

Lake Havasu:

"A total of 573 fish were collected during survey operations on Lake Havasu. Sunfish were predominate (44.3 percent), followed by largemouth bass (35.1 percent), and carp (16.2 percent). Four species (channel catfish, striped bass, goldfish, and black crappie) accounted for the remaining 4.4 percent of the fish collected. The striped bass collected averaged 25.9 cm in length."

Striped bass:	Length (cm) min.	Length (cm) max.	Weight (kg) min.	Weight (kg) max.
	19.3	32.5	0.08	0.34

White bass. —

Description. — The white bass (*Morone chrysops*) (fig. 3) belongs to the temperate bass family Percichthyidae. It is considered a landlocked form of sea bass and is closely related to the striped bass. White bass have, in the past, been placed in the genera *Lepibema* and *Roccus*, as well as *Morone*. *Chrysops* means "golden eye" although the eye is not conspicuously golden. Other common names of the white bass include silver bass, white lake bass, barfish, rock bass, striped bass, stripe, gray bass, and sand bass (Cloutman and Olmsted 1983).

The color of the white bass is silvery, with whitish underparts and about six to eight dark and narrow lateral stripes which are frequently interrupted (Pflieger 1975; Koster 1957; Scott and Crossman 1973; Chadwick et al. 1966).

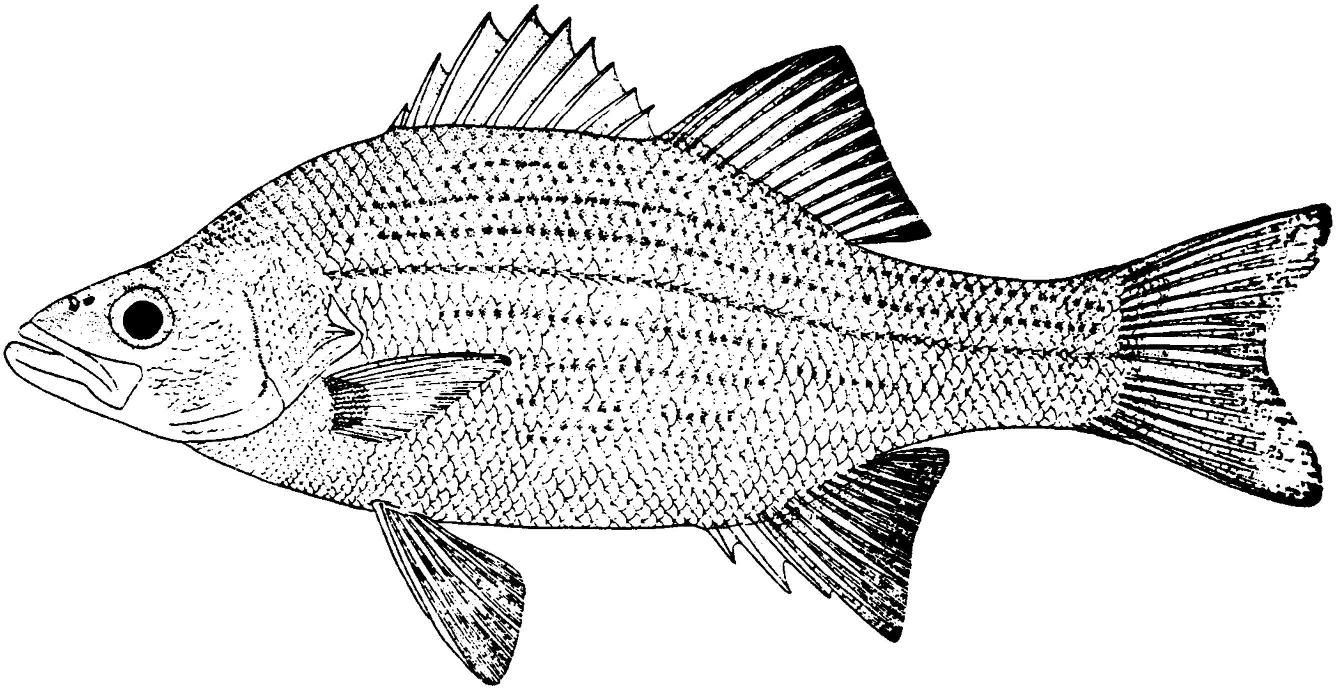

Figure 3. — The white bass, *Morone chrysops*.

White bass are deep bodied with a laterally compressed body and a back rising steeply behind the head. The dorsal fins are separate, with 9 spines in the first and 1 spine and usually 13 rays in the second. The anal fin has 3 spines, distinctly graduated in size, and 11 to 13 rays (Miller and Robison 1973). The pelvic fins have 1 spine, 5 rays, and the pectoral fins have 15 to 17 rays (Moyle 1976). They are distinguished from striped bass mainly by their deeper bodies (Chadwick and Von Geldern 1964).

The caudal fin is large and forked and the lateral line has 55 to 65 scales. Hyoid teeth (teeth on the base of the tongue) are in a single patch and pseudobranchiae (small gill filaments under the gill cover) are well developed and conspicuous (Minckley 1973).

Maximum size is near 50.8 cm and 2.27 kg. However, the average size range of white bass taken by anglers is 28 to 38 cm and 0.45 to 1.4 kg (Pflieger 1975; Scott and Crossman 1973).

White bass are generally not long-lived fish, but a 10-year-old specimen has been reported at Oneida Lake, New York (Forney and Taylor 1963 in Duncan and Myers 1978). Fish over 8 years old are rarely observed.

Distribution. — The original range of white bass was along the Mississippi River system from Minnesota and Wisconsin south to Mississippi and east Texas. Included here are the Great Lakes and all major stream systems south to the Gulf of Mexico (Sumner 1973). In Canada, the white bass has long been known to occur in Lake Ontario, Lake Erie, Detroit River, Lake St. Clair, Lake Huron, and Lake Nipissing. It apparently has recently (1944) extended its range into the Quebec waters of the St. Lawrence River. In 1963, a white bass specimen was caught in Lake Winnipeg, the first capture of the species from Manitoba waters (Scott and Crossman 1973).

Historically, white bass in the Sandusky River, Ohio, were quite abundant. Prior to 1850, erosion in the Sandusky River watershed was kept to a minimum because soils were tied down by forests and prairies (Trautman 1975). Apparently, the waters were rarely turbid. Decomposing vegetation in the water precipitated solids which assisted in clarifying the water, and decomposing vegetation furnished both food and cover for the young (Trautman 1975). Because of the apparent great clarity of the water, the fish fauna were composed of many species intolerant to turbidity and silted substrates (Trautman 1975).

I.M. Keeler, a journalist, wrote in 1840 that in the spring, white bass filled the whole channel and he frequently saw three or four wagon-loads of white bass taken out of the water with one draw of the seine (Trautman 1975).

Its range in the United States has been greatly increased by introductions into warm waters along the Missouri River and in several southern and southwestern states. White bass have developed large populations in large lakes having a wide range of limnological conditions. River populations of white bass are generally not as large nor considered as important as lake populations (Chadwick and Von Geldern 1964).

Preferred habitat. — White bass generally prefer relatively clear water and pools of streams and open still waters of lakes and reservoirs deeper than 3.05 m, usually over firm sandy or rocky bottoms. Mr. William Keith (Chief of Fisheries, Arkansas Game and Fish Commission, Little Rock, Arkansas, pers. comm.) stated that "white bass do best in a reservoir system with a good inflowing stream." Observations of white bass fry revealed largest concentrations associated with rock substrate areas (Winget et al. 1981 in Radant and Sakaguchi 1981) in Utah Lake, Utah. This preference is not unexpected since the principal spawning areas are over rocky substrates, and young larvae do not have the ability to move too far from the nursery area. YOY fish (fingerlings) were initially concentrated over rock substrates but quickly dispersed throughout Utah Lake. The bay areas appear to be important areas for early development of white bass (Radant and Sakaguchi 1981), possibly because of food availability. Statistical comparison of catch rates recorded from sand-silt and rock substrates in Utah Lake showed significantly higher catches of YOY fish in the main lake over rock substrates than in the main lake over sand-silt substrates. Data collected from Utah Lake, 1978 to 1979, suggest a general movement of young white bass away from the shoreline areas during the fall. This movement is most likely a result of increased pelagic tendencies of white bass as they grow older and/or a response to cooling water temperatures during the fall (Radant and Sakaguchi 1981). Young bass avoid dense vegetation and shallow areas with organic bottoms (Bailey and Harrison 1945 in Chadwick et al. 1966). White bass older than late YOY are commonly found in open water of lakes and reservoirs rather than littoral areas. The white bass tend to be in deep offshore water during the day and come into shallow areas at dusk where they follow the shoreline foraging for food (Moyle 1976; Sigler and Miller 1963).

In a study of larval white bass in Rough River Lake, Kentucky, Kindschi (1979) found that during daylight hours, white bass were taken primarily in deep, cool water, and at night apparently came to the surface to feed. For the period April 30, 1978 to May 30, 1978, white bass prolarvae were taken primarily along the eastern shoreline which had a more gravelly or rocky bottom, a substrate over which white bass have been known to spawn (Pflieger 1975). For the remainder of the sampling period, individuals were found more in limnetic regions feeding in small schools away from the shoreline. Wissing (1974) also reported YOY white bass swimming and feeding in large schools.

In limnetic larval studies on two tributaries of Lake Erie (Maumee and Sandusky Rivers) Cooper et al. (1981) noted that when collections were made with high larval densities (greater than 100 larvae/100 m^3) significantly more larval gizzard shad and white bass were found in the sheltered low flow portions of the river than in midchannel sampling locations, indicating a preference for lower flows and more cover.

Although white bass normally prefer deep water, their spawning areas are located in shallow shoals, many times in the slow-moving water over a firm bottom. Hasler et al. (1965) reported in a study of open water orientation of white bass in Lake Mendota, that in displaced white bass, orientation is nonrandom with a directional bias toward the spawning ground. Once the displaced fish was near the littoral spawning ground, additional information concerning location (currents, wind, sun, etc.) lead the fish toward its preferred habitat in the lake.

Spawning. — White bass spawn from March through June, depending upon latitude and water temperatures. "Adult white bass migrate up large tributary streams, or if lake dwellers, seek out stream inlets. Several references are found which indicate these fish also spawn around seeps, springs, or other well aerated portions of lakes" (Sumner 1973). Spawning in the Pecos River in New Mexico takes place in late spring (Koster 1957). White bass normally become sexually mature and spawn in the second year of life (Moyle 1976; Newton and Kilambi 1969). Almost all 1-year-old males longer than 230 mm were sexually mature in Center Hill Reservoir, Tennessee, (Webb and Moss 1967). These fish gather in large unisexual schools prior to spawning (Baglin 1977; Riggs 1955; Vincent 1968; Wissing 1974). In Utah Lake, signs of unisexual schooling first appeared when water temperature reached 11.1 °C (Vincent 1968), and Riggs (1955) noted unisexual schooling of white bass started when water temperatures ranged from 12.8 to 15.6 °C in Shafer Lake, Indiana.

These unisexual schools of fish move into the spawning areas and spawning generally occurs when temperatures range from 13 to 23 °C

(Chadwick et al. 1966; Moyle 1976). Meyer et al. (1973) reported that white bass began spawning when water temperatures reach 12.8 to 14.4 °C and may spawn over a 2- to 3-week period. Spawning started in Center Hill Reservoir, Tennessee, after water temperatures reached 11.7 °C. White bass ceased spawning and moved downstream when the temperatures dropped below 11.7 °C. The duration of the period between the start of schooling migration and the start of spawning is related to and/or dependent upon the time at which the critical water temperature for spawning is reached (Webb and Moss 1967).

Females release relatively few eggs at a time and each fish's spawning takes place over a period of several hours (Dietz 1967). Several males surround one female as she swims about scattering semibouyant eggs. The males expel milt over the eggs as they are released; the eggs then sink to the bottom (Dietz 1967). The adhesive fertilized eggs stick to gravel, rocks, and vegetation. In the major tributary streams into Lake Oahe, South Dakota, spawning took place over submerged dead vegetation or debris. Eggs spawned in flowing water will drift downstream of the actual spawning site (June 1977).

Temperatures between 10 to 18 °C are necessary for spawning to ensure the perpetuation of the species (Vincent 1968), although the fish will tolerate temperatures beyond this range.

Males ripen much earlier than females, sometimes reaching the point of sperm emission by late October. Females never reach a comparable stage of ripeness until April or later (Chadwick et al. 1966). Spawning takes place in waters 1 to 3 m deep (Moyle 1976), but usual spawning depths are 0.9 to 1.8 m deep (Riggs 1955). Spawning activity lasts from 5 to 15 days (Vincent 1968).

Bonn (1953) reported that sexually mature fish in Lake Texoma, Texas, congregate near the tributary streams and await a water level rise so that they can travel over silt bars into the streams. However, in 1950 and 1951, no water rise occurred and after waiting past their normal spawning date, the fish returned down the lake and spawned off windswept points. White bass spawned in tributaries of Grand Lake, Oklahoma, when flows were only 10 to 20 ft^3/s (Jenkens 1964 in Chadwick et al. 1966).

After spawning, females and males abandon the spawning ground within 1 week (Ruelle 1977). The fecundity of white bass ranges from 242,000 to over a million eggs (Riggs 1955; Ruelle 1977). "Female white bass produce more ova than they bring to maturity. Females spawned only about 50% of their ova; large ova were shed during spawning and smaller ova were retained and reabsorbed by late summer in Lewis and Clark Lake" (Ruelle 1977). The minimum size of mature white bass eggs in Lewis and Clark Lake, South Dakota, is 0.60 mm (Ruelle 1970 in Baglin and Hill 1976). Eggs, 0.57 mm in diameter, were used in mature egg fecundity estimates in Beaver Reservoir, Arkansas (Newton and Kilambi 1973 in Baglin 1977). After spawning and water hardening, the diameters of white bass ova were 0.70 mm to 1.18 mm (Ruelle 1977). The eggs hatch in 46 hours at 15.6 °C (Riggs 1955). Dorsa and Fritzsche (1979) reported the size at hatching of larvae to be 1.71 to 2.81 mm TL and body depth behind yolk-sac 0.26 to 0.95 mm.

Populations are often unstable or cyclical in nature (Minckley 1973). In Beaver Reservoir, Arkansas, white bass reach a peak abundance every 4 years (Yellayi and Kilambi 1975). In Degray Lake, Arkansas, there were no reproductive failures since the year after first stocking, 1970, and there were strong year classes of white bass in 1971, 1974, and 1977 (Moen and Dewey 1980). Year class strength was not correlated with instream flows during the spawning period in this study. White bass populations in the TVA system tend to run in 3-year cycles, but they do not fluctuate as drastically there as in more northern water (Hall 1964 in Chadwick et al. 1966).

McClane (1974) stated that white bass require a nearly perfect combination of spawning conditions (substrate, current or wave action, and steady temperatures of around 14.4 to 17.8 °C) to reproduce successfully, and that a lack of one or more of the required conditions may explain why successful reproduction occurs only once in a 3-to 4-year period. Mr. Bill Silvey (Fishery Biologist, Arizona Game and Fish Department, Phoenix, Arizona, pers. comm.) stated that white bass in Lake Pleasant have strong year classes correlated with high spring inflows in the Agua Fria River; there is also some spawning of white bass in the reservoir almost every year.

Reproductive success appears to increase when spring water levels are high and to decrease when they are low in Lake Francis Case, South Dakota (Martin et al. 1981). Mr. Monte Leishman (New Mexico Game and Fish Department, pers. comm.) stated that in the Pecos River Lakes in New Mexico (Sumner Lake, Santa Rosa Lake, McMillan Lake, Avalon Lake, Red Bluff Lake) there has always been higher reproductive success of white bass in high water years than in low water years. Greater abundance of food in higher water years when forage fish production increases could also be responsible for better growth and greater subsequent bass populations.

Water quality requirements. — White bass do well over a wide range of limnological conditions and types and sizes of water bodies. The smallest body of water that white bass have been introduced into and survived is the 0.809 ha Sudik Pond in Oklahoma (Jenkins and Elkin 1957), but the smallest reported impoundments where this species has prospered are Lakes Duncan (162 ha) and Clinton (134 ha) in western Oklahoma. White bass seem to do best in warm, slightly alkaline lakes and reservoirs (Moyle 1976). Chadwick et al. (1966) reported fish in Oklahoma living in 80 to 110 mg/L alkalinities and white bass introduced into North Carolina living in alkalinities less than 30 mg/L. Arnold (1960 in Vincent 1968) reported turbidity reached a maximum of 45 mg/L SiO_2 equivalents in Utah Lake during normal winds in August 1959. [Limited information is available on how SiO_2 relates to aquatic life or JTU, but McKee and Wolf (1963) reported that 50 mg/L SiO_2 can cause difficulties arising from turbidity].

Formerly clear waters of the Sandusky River, Ohio, now carry an increased load of suspended and dissolved solids. Average turbidity of the surface water in 1974 was 22.1 JTU and average bottom water was 33.2 JTU with the highest values in the spring and summer. In terms of relative abundance, white bass have declined from being the most abundant species (1840) to a position of reduced abundance (Hartly and Herdendorf 1975). Environmental changes such as deforestation, plowing of virgin prairie, draining of land, construction of mill dams, introduction of exotic organisms, and intensified commercial fishing have been factors that have contributed to the changes observed in white bass population (Hartly and Herdendorf 1975).

Lake McConaughy, Nebraska, behind Kingsley Dam on the North Platte River has aggregations of warm, cool, and cold water fishes. Among these are white bass and striped bass. The gizzard shad is the primary forage species. White bass are doing well in the 14 164 ha lake (Taylor and Hams 1981). The lake has maximum and mean depths of 53 and 22 m, respectively, and is considered eutrophic, based on chemical and physical characteristics. Alkalinities ranged from 145 mg/L to 260 mg/L and total hardness from 170 mg/L to 440 mg/L.

Temperature. — Yellayi and Kilambi (1969) found that the early developmental stages of white bass were sensitive to temperature with developmental rates too slow at 12.8 °C and too fast at 20 °C.

Conductivity and temperatures were measured in Utah Lake. Conductivities in the lake and bays ranged from 450 μS/cm to 1,700 μS/cm and temperatures at a depth of 1 m ranged from 23 °C down to 5 °C during the month of November (Radant and Sakaguchi 1981). Utah Lake has a maximum depth of 4.2 m at the maximum lake level (Fuhriman et al. 1974 in Radant and Sakaguchi 1981).

Reutter and Herdendorf (1976) conducted thermal preference, cold shock tests, and heat shock tests on several species of young fish from Lake Erie, including white bass. They reported that summer preferenda were approximately equal to or slightly higher than lake temperatures for all species including white bass. Summer preferendum for white bass was 27.8 °C with 35.3°C being the critical thermal maximum (the temperature at which the fish loses locomotor control). Adult seasonal temperature perferenda are (Barans and Tubb 1973 in Reutter and Herdendorf 1976): winter preferenda, 12 to 17 °C; spring preferenda, 12-17 °C; summer preferenda, 28-30 °C; fall preferenda, 16 to 17 °C. YOY white white bass preferenda in the same report are winter preferenda 10 to 13 °C; spring preferenda, 16 to 18°C; summer preferenda, 31 °C; and fall preferenda, 28 °C, indicating that in general, young white bass prefer higher temperatures than adults.

Reutter and Herdendorf (1976) discussed white bass living in a powerplant discharge which could be subjected to a maximum temperature of 11.1 °C over ambient. Ambient lake temperatures ranged from 0.5 to 25.6 °C. Results from tests starting at 5.5 °C or lower were considered winter results, tests starting from 5.5 to 20.0 °C were considered spring and fall temperatures, and tests starting at over 20.0 °C were considered summer ambient temperatures. White bass would be one of the few species that live in the 11.1 °C discharge plume due to their high temperature preferences during summer. In cold shock tests conducted by Reutter and Herdendorf (1976), white bass were held in water 11.1 °C degrees over ambient then placed in ambient lake water of 1.0 °C on up. The white bass was one of the two most stressed species along with gizzard shad (*Dorosoma cepedianum*) in cold shock test when the ambient lake temperature was 1.0 °C or less. At ambient lake temperatures of 3.0 °C, stress was seldom observed in the test specimens during cold shock tests.

In studies of effects of temperature on hatching and survival of white bass larvae, McCormick (1978) found that normal larvae hatched at temperatures between 18 and 26 °C, and one group hatched at 14 °C. Water quality during these tests was: total hardness, 43-47 mg/L; total alkalinity, 42-43 mg/L; pH, 7.1-7.3; and dissolved oxygen at least 7 mg/L, up to 104 percent saturation. Photoperiod was normal for the time of year.

Rates of development increased directly with temperature. Time from fertilization to hatching was about 4.5 days at 14 °C, but only 1 day at 26 °C. The thermal tolerance of newly hatched larvae did not change with acclimation apparently because they were unable to make the necessary physiological changes. All larvae tested by McCormick (1978) had 24 hour TL 50's near 31 °C. Larvae did not hatch at 6, 10, and 30 °C, and hatching was significantly reduced at 28 °C and at 14 °C in one group tested.

The lower limit of 12.8 °C reported by Yellayi and Kilambi (1969 in McCormick 1978) seems to be a good estimate of expected 100 percent mortality of larvae. The high and low temperature limit of successful incubation is close to lower temperature limits for initiating spawning (Riggs 1955), and upper limits of spawning of 26 °C found by McCormick.

In Cvancara et al. (1977), no YOY white bass survived water temperatures of 35 °C. In experiments in the summer, YOY white bass would survive temperatures of 30 °C over a prolonged period of time provided other conditions were favorable.

Dissolved oxygen. — Siefert et al. (1974) conducted tests on the effects of reduced oxygen concentrations on early life stages of white bass and two other fish species. The water used for tests was from Lake Superior and had a total alkalinity of 40-43 mg/L, a total hardness of 42-45 mg/L, sodium concentration of 1.2-1.4 mg/L, potassium level of 0.5 mg/L, calcium level of 11.8-14.0 mg/L, magnesium level of 2.5-2.9 mg/L, and a pH of 7.6-7.8. They reported that white bass at 16 °C were not significantly affected at hatch in regard to decreasing oxygen concentration. At the end of the test (7 days posthatch), there was a significant reduction in survival at 20 percent saturation (a mean of 1.8 mg/L dissolved oxygen) at 16 °C, and larvae did not reach a stage of horizontal swimming until the 5th day.

They found that at 19 °C, white bass hatched earlier and larvae maintained at 19 °C and 20 percent oxygen saturation died before they reached the horizontal swimming stage. Water at 20 percent oxygen saturation is therefore unsuitable for young white bass. At 35 percent oxygen saturation, there is an apparent inhibition of yolk-sac absorption, but larvae otherwise behaved normally until they start to search for live food.

Since white bass occur in rivers along the Gulf Coast, they obviously can tolerate brackish water. Jenkins (in Chadwick et al. 1966) reported that white bass die when chlorides reached 6000 mg/L in Great Salt Plains Reservoir, Oklahoma, but he is not sure if the chlorides caused the deaths directly or not.

Food and feeding habits. — In 11 425 ha Beaver Reservoir in northwest Arkansas, Newton and Kilambi (1969) reported that fish comprised 99 percent by weight of the diet of immature white bass (129 to 260 mm) in winter, summer, and fall. In the spring, the diet of immature white bass consisted of about 99 percent Diptera, Ephemeroptera, and Plecoptera. Cladocerans and amphipods accounted for the remaining 1 percent of the diet. These studies also reported that adult white bass ate fish (predominantly gizzard and threadfin shad) in winter, summer, and fall. In adult white bass, spring was the only period when crustaceans contributed significantly to the diet. Fish and crustaceans accounted for 60.1 percent and 35.6 percent of the diet by weight, respectively. Centrarchids (*Micropterus* spp.) and cyprinids (*Notropis* spp.) were the important groups of fishes in the spring diet and shad were completely absent from stomachs during this period. Insects accounted for 4.3 percent by weight in the spring diet of the adults.

This tendency to rely on insects and crustaceans during the spring can be partially attributed to shortage of edible size forage fish (shad) during that time of year. Water temperature and dissolved oxygen did not appear to affect the feeding intensity of the white bass significantly. Conductivity and transparency both showed a direct influence on feeding intensity while pH (hydrogen ion concentration) was shown to have an inverse relationship to feeding intensity (Olmsted and Kilambi 1971). The evening crepuscular period appears to be the time of heaviest feeding of adult white bass in Beaver Reservoir. This report suggested that white bass feed more voraciously at lower pH conditions in the range of 5.9 to 7.8. Threadfin shad were more important than the gizzard shad in the diet because of their greater abundance and smaller size. Larval threadfin shad were more numerous in the surface waters than larval gizzard shad (Kersh 1970 in

Olmsted and Kilambi 1971). There was a cycle in the species of centrarchids utilized by white bass in Beaver Reservoir, Arkansas. Black bass were most often consumed in spring and early summer with sunfish (mainly bluegill) being the principal centrarchid consumed in late summer and fall. There was no significant difference in the feeding intensities of the male and female white bass. Olmsted and Kilambi (1971) also reported that feeding intensity was very low during spawning season and increased greatly following spawning. The feeding intensity decreased in July and maintained a moderate level until the following spawning season.

In comparisons of growth of white bass between several years' catches in Beaver Reservoir, a slow growth for all age groups except 1-year-olds occurred when there was a drastic reduction of threadfin shad. The reduced biomass of juvenile shad adversely affected the growth of adult white bass (Yellayi and Kilambi 1969). Since immature white bass fed more heavily on insects during spring and on fishes in other season, their growth was not greatly affected by the reduction in shad.

Kindschi (1979) studied the larvae of some species of fish in 2345 ha Rough River Lake, Kentucky, and found that after gizzard shad larvae reached 10.5 mm total length, the frequency of these shad larvae in the stomachs of white bass increased until the shad reached a length of 20 mm. After the shad larvae reached 20 mm in length, these larvae became less abundant in white bass stomachs and eventually were not consumed by white bass between 25-30 mm total length.

This abrupt change in the diet was likely due to the lack of larval fish vulnerability and abundance at this time, or because of the increase in zooplankton concentrations. Stomachs of white bass collected from Rough River Lake contained no other food items when shad were present, possibly indicating satiation. The energy saved in consuming one large item rather than several small items could imply greater survival at these early stages. Zooplankton appeared to dominate the stomach contents of individuals between 25-30 mm total length and those white bass larvae not having shad in their stomachs. There appeared to be no day-night preference as to when shad were consumed (Kindschi 1979).

Bonn (1953) found that young white bass fed principally on crustaceans, insects, and fish in Lake Texoma, Texas. Crustaceans were found in the stomachs of young white bass every month of both years of the study. Mayfly nymphs and damselfly adults formed the largest percentage of volume of insect food. Of the fish found in the stomachs, gizzard shad were the most abundant. Other species found occasionally were brook silversides (*Labidesthes sicculus*), white crappie (*Pomoxis annularis*), and various cyprinids. In Spirit Lake, Iowa, Sigler (1949) found white bass fed to a small extent on black crappie (*Pomoxis nigromaculatus*).

Mr. Richard McCleskey (Chief of Fish Management, New Mexico Game and Fish Department, Santa Fe, New Mexico, pers. comm.) stated that threadfin shad were introduced 4 years ago in Elephant Butte Reservoir, New Mexico. White bass and gizzard shad were then present and now the white bass are almost exclusively feeding on threadfin shad because of their size and pelagic nature.

In an apparent exception to the usual piscivorous feeding habits of white bass, McNaught and Hasler (1961) found *Daphnia* to be the dominant food of adult white bass in Lake Mendota, Wisconsin.

Griswold and Tubb (1977) reported that small minnows were the primary food of white bass in Sandusky Bay, Lake Erie, with Cladocera and Diptera (chironomids) also contributing to the diet in May, June, and July. Shad were not mentioned as a component of the diet.

White bass apparently feed more by sight than by scent in tests by Green (1962). Feeding by sight was also suggested by Olmsted and Kilambi (1971) in that although white bass feeding was probably not exclusively by sight, the positive influence of transparency on feeding intensity was probably related to improved visibility.

Voigtlander and Wissing (1974) reported major feeding activity of young fish and yearlings occurred prior to sunset in Lake Mendota, Wisconsin. YOY fish apparently ceased feeding 2 to 3 hours after sunset, while yearlings continued to feed at low levels throughout the night.

Voigtlander and Wissing (1974) also stated that young white bass depended highly on cladocerans and chronomids. Young white bass and, to a somewhat lesser extent, yearlings in the northern portion of their range, seem to depend heavily on zooplankton, while young and yearlings in the southern portion of their range seem to be primarily piscivorous (Bonn 1953; Olmsted and Kilambi 1971). This is due to availability of small gizzard and threadfin shad and more rapid rates of growth in the southern waters. Wissing (1974), McNaught and Hasler (1961), and Olmsted and

Kilambi (1971) indicated that YOY white bass in Lake Mendota had at least two periods of intense feeding (early morning and late afternoon). Young fish usually exhibit a high growth efficiency; however, as they grow older and larger, the ability to convert food energy into new tissue declines continuously (Ivlev 1945, Gerking 1955, 1959 in Wissing 1974).

Alewife (*Alosa pseudoharengus*) was the principal pelagic forage fish for pelagic piscivores including white bass in Claytor Lake, Virginia, before a severe die-off in the winter of 1977 to 1978 (Kohler and Ney 1981). The pelagic piscivores, including the white bass, returned to an alewife diet within 1 year of the die-off during which time they preyed mainly on various centrarchids and yellow perch. It appeared that these fish were able to shift their diet to alternate prey with little adverse affects; however, the fish did seem to prefer a certain species that they consume until energy used during foraging is greater than energy gained from preferred food. The results of reducing alternate prey species by predation could be drastic and could have a severe impact on the white bass. White bass prefer shad (Toole 1952, Riggs in Chadwick et al. 1966). Ruelle (1971 in Radant and Sakaguchi 1981) noted that when forage fish are abundant, YOY white bass fed on young fish but when forage fish were absent, the young white bass ate zooplankton and insects. Bonn (1953) and Webb and Moss (1967) reported that forage fish in the diet of young white bass produced the greatest growth.

Cannibalism by white bass is uncommon; however, in Utah Lake, few forage fish are present, and the only abundant forage was young white bass (Radant and Sakaguchi 1981). Cannibalism occurs because young white bass are the only suitable forage fish available in sufficient numbers. Young white bass, however, quickly grew beyond suitable forage size by fall and were no longer taken by adult white bass.

Age and growth. — White bass in northern waters generally live longer than those in southern waters. For example, in northern Iowa, 7 and 8 year olds are common, while in Oklahoma, 5 and 6 year olds are rare (Sigler and Miller 1963). In general, the life expectancy of white bass is short. Few live more than 3 to 4 years in the south or 4 to 5 years in the north. Even in the north, maximum age is 7 to 9 years, while in the south it is 6 to 7 years (McClane 1978). Ralph Little (New Mexico Game and Fish Department, pers. comm.) estimates that in white bass populations in Elephant Butte Reservoir, New Mexico, the average lifespan is 16 to 18 months.

For both male and female white bass in Center Hill Reservoir, Tennessee, where shad were the primary forage fish, the greatest increase in average length was during the first year of life. The greatest increase in weight came during the second year of life in the same reservoir (Webb and Moss 1967). Drawdowns seem to affect white bass size (Little pers. comm.). New Mexico Game and Fish Department observations indicate that white bass caught by anglers are smaller in the spring following a winter when the reservoir was low going into the winter.

In Lake Wapepello, Missouri, white bass reach a length of about 18.3 cm the first year and average 30.2, 33.8, and 35.8 cm by the end of succeeding years (Pflieger 1975).

Jenkins and Elkin (1957) found that white bass in Oklahoma grow faster in reservoir habitats during the first year of life than in river habitats, and females weighed slightly more than males of equal length.

Competition. — Competition may exist between white bass and other fish species, such as walleye, for spawning areas. In Center Hill Reservoir, Tennessee, walleye (*Stizostedion vitreum*) spawned in the same headwater areas at approximately the same time as white bass (Webb and Moss 1967). James (1979) indicated that competition may exist between the white bass and yellow bass for habitat during spawning and early development and to some extent for food in the early life stages. James (1979) stated that coexistence of these two species over the same habitat may be possible due to the variation in sizes of organisms consumed by these two species. The white bass diet was composed of larger invertebrates and shad, while the yellow bass consumed greater portions of smaller organisms such as copepods, cladocerans, and smaller fishes (minnows, silversides).

Van Den Avyle et al. (1983) reported habitat preferences and food habits of YOY striped, white, and yellow bass in Watts Bar Reservoir, Tennessee. They stated "Prediction of the extent of overlap in resource use among these three species is further hampered by the lack of comparative information on food habits and distributrion patterns in reservoirs or other systems where these species occur together." YOY of all three species were widely distributed, and there was no pronounced segregation of the species along the shoreline. It is possible that the three species were separated to some extent along vertical or inshore/offshore habitats, but their sampling techniques and design could not detect these variations. Differences in food habits of the three YOY basses in Watts Bar Reservoir were related to prey size. Striped bass fed on relatively large fish and invertebrates, while yellow bass ate primarily zooplankton. White bass appeared to be more opportunistic and consumed fish and dipterans when available and fed on smaller prey at other times.

Van Den Avyle et al. (1983) reported that their hypothesis was consistent with other reports that stated fishes with similar distributions must have different or highly flexible feeding preferences in order to exist. Differences in the three observed basses were likely a consequence of having different prey-size preferences rather than a result of competition. Van Den Avyle et al. (1983) stated that their findings should be applied cautiously since other reservoirs have different ecologies and published information generally is insufficient to predict prey use, distribution patterns, or species interaction.

Competition of white bass with striped bass is not very well documented. Turner (pers. comm.) suggested that striped bass will outcompete white bass when food is limiting. Elephant Butte Reservoir, New Mexico (6680 ha), has striped bass, white bass, and abundant populations of gizzard and threadfin shad. No competition between these two species has been observed in the years since striper introductions in the early 1970's.

In a comparison of the mouth size of white bass and striped bass, the white bass have the smaller mouth (Douglas 1974). This, along with the single patch of hyoid teeth in the white bass, seems to indicate that white bass cannot eat as large a prey as the striped bass.

In Lake McConaughy, Nebraska, Madson (pers. comm.) reported competition for forage (gizzard shad) between white bass and striped bass. Adult white bass were introduced in Lake McConaughy in 1944 and became an important component of the creel in the early 1950's. Striped bass were introduced in 1965 and were stocked intermittently as fingerlings through 1978. Very little reproduction of stripers was observed. The overall fishery in Lake McConaughy began declining about 1975, with a game fish food deficiency suspected as the problem. The gizzard shad are at the northern edge of their range in Lake McConaughy and intermittent, local winter kills occur. This fact, along with the intense feeding behavior of striped bass, was believed to be the cause of the decline of the fishery. Nebraska has since discontinued their striped bass stocking program, and the white bass fishery, along with the gizzard shad, have made a noticeable recovery. Walleye also utilize gizzard shad for forage.

Bailey and Harrison (1945) found white bass and yellow bass (*Morone mississipiensis*) were abundant in deeper portions of 1475 ha Clear Lake, Iowa, and along sandy and gravel littoral zones where they fed at night. In general, the white bass diet was similar to the yellow bass, but the white bass was noticeably more piscivorous. Also, its greater average size and relatively larger mouth compared to the yellow bass permitted predation on larger fish. Shad were not present in this reservoir, and young game and pan fish (black bullhead, yellow bass, yellow perch, black bass, bluegill, crappie) were the major forage fish for the white bass and to a lesser degree, the yellow bass.

Yellow bass are currently found in the Salt River. These were introduced in 1931 in the Salt River Reservoirs (Miller and Lowe 1964 in Marsh and Minckley 1982), and may have entered the Salt River with floodwaters in 1972 and 1973 (USFWS 1976). They also may have entered the Salt River during extensive flooding in 1978 and 1979 (Marsh and Minckley 1982).

Examination of stomach contents of large walleye collected in Colorado reservoirs where white bass were introduced showed that walleye consumed white bass. Largemouth bass also were reported as taking white bass (Lynch 1955). McCleskey (pers. comm.) stated that white bass and largemouth bass do not compete directly. There is a pelagic separation between these two species.

Little (pers. comm.) reported that striped and white bass prey on each other's fry, as well as on shad fry, in Elephant Butte Reservoir.

Meyer et al. (1973) reported that certain zooplankton organisms (e.g., the copepod *Cyclops*) prey on very small white bass fry.

Introductions of white bass into the southwest. — White bass were first introduced into Arizona in March 1959 by AGFD (Arizona Game and Fish Department) personnel into Lake Pleasant on the Agua Fria River. Miller and Lowe (1967) reported white bass were introduced in 1960, but no supporting records were found in Arizona Game and Fish stocking reports. Arizona Game and Fish Department stocking records show that 160 254 to 305 mm white bass were planted in Lake Pleasant on March 1, 1961, and an additional seventy-eight 51 to 254 mm white bass were planted on August 11, 1961. The only other recorded plant in Arizona was of a 381-mm white bass into Cortez Lake from Lake Pleasant on November 13, 1975 (table 9). The white bass essentially disappeared in Lake Pleasant for a time, but apparently reproduced successfully and became a popular fishery in the period after 1967 (Minckley 1973).

White bass were introduced into the lower Colorado River near Yuma, Arizona, in 1968. Later in 1969, two more white bass plants were made by CFGD (California Fish and game Department) below Parker, Arizona, one of 300 fish and one of 427 (USFWS 1980). Essbach (pers. comm.) reported the planting of one-hundred to one-hundred twenty 0.68-to 1.6-kg white bass in backwaters of the Colorado River near Blythe, California in the mid-1960's. For unknown reasons, these white bass stockings were not successful and the species failed to become established (Shapovalov et al. 1981).

In the 1940's, there existed a need for a fast growing, prolific, predacious fish which could survive in large numbers under conditions (hard, alkaline water) prevailing in Colorado east slope reservoirs. White bass were selected and introduced from Texas into Colorado's John Martin Reservoir in 1948 (Lynch 1955). These fish reproduced successfully in 1949, 1950, and 1951, and made up over 30 percent of the total game fish harvest during 1951 and 1952. Unfortunately, drought conditions forced the draining of the reservoir, and the population was eliminated. Lynch (1955) stated that the white bass are unable to reproduce successfully in Colorado unless there is an inflow of freshwater into a reservoir during June or the first of July each year. Natural reproduction has been excellent in impoundments which have inflows during these months.

Table 9. — White bass (*Morone chrysops*) stocking activities of the Arizona Game and Fish Department, 1961 through 1980. Compiled from a review of departmental stocking records.

Year	Receiving water	Dates	Numbers	Source	Size (mm)
1961	Lake Carl Pleasant	3-01-61	160	?	254-305
	Lake Carl Pleasant	8-11-61	78	?	50-254
1975	Cortez Lake (35th and Dunlap, Phoenix)	11-13-75	1	Lake Pleasant	381

A stocking of 206 white bass averaging 18 cm in length was made into Holbrook Lake, Colorado 1953 (Lynch et al. 1956). In this 7,472-acre-foot irrigation lake, white bass were part of the creel for a few years, but because of drawdowns and possible total draining, no fish have been netted in recent samplings (C. Bennett, Colorado Division of Wildlife pers. comm.).

Other introductions of white bass in eastern Colorado irrigation reservoirs in the 1950's have been moderately successful with remnant populations in Boyd Lake, North Sterling Reservoir, Prewitt Reservoir, Blue Lake, and Neogha Lake. The lack of spawning habitat is the main reason for the white bass population remaining fairly low (Stafford, pers. comm.). Inflows into these reservoirs are interrupted by irrigation demands; also, spawning substrate along shorelines is sparse. The water in all these eastern Colorado lakes is considered very hard. TDS are over 800 mg/L and alkalinities are over 110 mg/L (C. Bennett pers. comm.). Bonny Reservoir, in eastern Colorado, probably has the best population of white bass because it does not fluctuate nearly as much as other eastern Colorado reservoirs (C. Bennett pers. comm.).

White bass were planted at Bitter Lakes National Wildlife Refuge and Bottomless Lakes, New Mexico, in 1959. The fish planted at Bitter Lakes reproduced successfully and the fish planted in Bottomless Lakes survived, but there was no evidence of successful reproduction (Navarre 1962).

In spring 1960, adult white bass from Red Bluff Reservoir, New Mexico/Texas, were stocked in McMillan and Avalon Reservoirs and the Pecos River in New Mexico. These fish spawned the following spring and had good survival (Navarre 1962). Excellent fisherman catches of white bass occurred in the two reservoirs and the river. There have also been some apparent failures in white bass plants in New Mexico but it is not clearly understood why (Navarre 1962). Brood stock obtained from Red Bluff were planted in Municipal Lake, Six-Mile Reservoir, and Ten-Mile Reservoir, New Mexico. All these plants apparently failed (Navarre 1962).

White bass were also stocked in Caballo Reservoir on the Rio Grande in the fall of 1960 and supplemented by another plant in the spring of 1961 (Navarre 1962). Some of these white bass were apparently transferred upstream into Elephant Butte Reservoir by fishermen (Little pers. comm.).

Once the white bass were found in Elephant Butte Reservoir, the NMGFD (New Mexico Game and Fish Department) made two supplemental stockings, one stocking of 2,200 in 1964 and one of 25 in 1965. These introductions of white bass into Elephant Butte Reservoir were successful (Jester 1971).

The first recorded attempts to establish white bass in Oklahoma include the stocking of Lake Overholser (688 ha) and Duncan Lake (162 ha) in 1941. Both of these attempts were successful (Jenkins and Elkin 1957). Following the impoundment of Lake Texoma (37 684 ha) in 1944, white bass, which occurred naturally in the Red River above the dam, were sufficiently numerous to establish a population in the lake. Jenkins and Elkin (1957) reported that 10 lakes 40.5 to 202.5 ha in size were stocked in the 1950's, but reproduction had not been successful.

White bass were introduced in Utah Lake, Utah, in 1956, and by 1967, had become the most abundant fish in the lake. Prior to the mid-1960's, there had been intensive agricultural and industrial development in the watershed. This fact, along with drastic fluctuations and extensive commercial fisheries, had reduced the native salmonid population to extinction. The cold water fishery was replaced by introduced warmwater species (Heckmann et al. 1981). Other introduced fish species that were successful in Utah Lake include carp, black bullhead, channel catfish, and walleye. The factor limiting game fish production in Utah Lake is the lack of forage fish. Largemouth bass were abundant in the lake until the 1920's and 1930's when drought and winter oxygen depletion killed tons of largemouth bass. Since then, largemouth bass populations have never recovered and are infrequently observed in fish sampling (Heckmann et al. 1981). White bass in Utah Lake have apparently not had an adverse effect on carp, which still provide a large commercial harvest annually.

Excerpts and summaries from Arizona Game and Fish Department Federal Aid to Fish Restoration reports relative to Central Arizona Project waters. — The following section is a chronological summary of narrative statements regarding introduction, status, and effects of white bass in Arizona, gleaned from an examination of various AGFD progress and completion reports (principally F-7 reports) for the period 1959 to 1982. The particular report from which the information was obtained is indicated and any material quoted is so indicated.

(1.) F-7-R-2, January 1959 to January 1960, Work plan 4, Job No. C-1, by R. Gruenwald

"If and when the white bass becomes established, it is hoped the slack production periods will be strengthened by white bass harvests."

White bass introduction was made in early March 1959. To date (January 1960), no reproduction of white bass has been observed. It is recommended that further brood stock be secured in an endeavor to establish them as an additional game fish.

Recommendations: Continue creel census through 1961, so if white bass do become prevalent, they may be evaluated as to their effect upon the reservoir fishery.

(2.) F-7-R-3, January 1960 to January 1961, work plan 4, job No. G-1, by R.J. Gruenwald.

Lake Pleasant White Bass

Present: Extended efforts have been made with the shocker and in cove renovations to discover the brood stock or evidences of reproduction of this species to no avail.

Future: The procurement of additional brood stock is now in progress and it is hoped that it will be placed into this lake in time for the spring spawning activity.

(3.) F-7-R-4, January 1961 to October 1961, work plan 5, job No. G-1, by R.J. Gruenwald

Lake Pleasant White Bass

Past: Several attempts to start this species have ended in failture

Present: Another attempt was made this year by placing brood stock into the reservoir.

Future: It is hoped that spawning will occur this coming spring. If not, one more attempt at stocking brood individuals will be made.

(4.) F-7-R-5, November 1961 to October 1962, work plan 5, job No. G-1, by W.G. Gaylor

Lake Pleasant White Bass

Past: Several attempts have been made to establish this fish with no success.

Present: There are no indications that any spawn has occurred. The plans for an additional stocking were dropped.

Future: Future plants will depend on the water conditions.

(5.) F-7-R-8, January to December 1965, work plan 5, job No. S-1

"The one outstanding event that we are particularly pleased with is the reproduction of white bass in Lake Pleasant. Anglers began to take 203 to 229 mm white bass in early September. Average length of white bass of the year in the angler's creel on October 9 was 252 mm, and average weight was 240 g. Largemouth bass of the same year class were slightly smaller.

"The brood stock of white bass was first introduced in the spring of 1959. A second plant was made in 1961, but the success of these plants was thought to have been a failure as no reproduction was observed until this year (1965). Hopes are high that they will provide an excellent addition to the warm water fishery of Arizona" (presumably Lake Pleasant).

(6.) F-7-R-9, January to December 1966, work plan 5, job No. S-1

"Lake Pleasant was nearly dry in 1963 and 1964, and almost became defunct as a fishery." Good runoff in the winter of 1964 to 1965 provided excellent conditions for spawning that spring. "White bass and walleye were taken by the shocker for the first time. White bass were planted in Lake Pleasant in 1959 and again in 1961, and no reproduction was apparent until 1965." Seventeen white bass were collected with the shocker.

Summary of fishery: Lake Pleasant returned to top fishing form in 1966 after 2 years of poor fishing due to low water levels. During the spring, white bass in the 254- to 305-mm size class were easily caught by anglers, with some anglers catching 20 or more in a few hours. Only a few white bass were taken during the summer and fall months.

(7.) FS-2, February to October 1966, work plan 5, job No. C-1

The introduction of white bass in Lake Pleasant made a marked contribution to the fisherman creel this year (1966). Most white bass were taken in March and April, with success figures indicating a catch of 0.086 and 0.087 white bass per hour, respectively. Only a few were caught during the remainder of the year.

In 1965, white bass length averaged 226 mm while in 1966, length averaged 287 mm.

(8.) F-7-R-10, January to December 1967, work plan 5, job No. S-1

Only five white bass were collected by the shocker in 6 days of work in January 1967. In 2 days of shocking at the end of March, one hundred forty-one 330- to 381-mm white bass were collected with the shocker. This indicated that white bass were moving into the shoal areas preparatory to spawning. Examination of some individuals showed that spawning may have already occurred.

(9.) FS-3, January to December 1967, work plan 5, job No. C-1

Harvest of white bass in Lake Pleasant experienced a sharp unexpected drop over previous years. This appears to indicate the harvest in 1965 and 1966 was from a very limited spawn in 1965. Possibly, a few spawners from the original plants in 1959 or 1961 were successful. Most white bass in 1966 averaged about 279 mm. In 1967, the white bass averaged 320 mm, and none appeared to have been from a 1966 spawn. Electrofishing surveys in February and November 1967 indicated that no successful spawn had occurred since 1965.

(10.) F-7-R-11, January to December 1968, work plan 8, job No. S-1

Lake Pleasant was shocked for 7 days in mid-November. Only five white bass were taken, although two averaged about 254 mm, indicating that at least some spawning had occurred in 1968. Only a few white bass were taken by anglers in 1968. Estimated harvest dropped to 640 fish in 1968.

(11.) FS-4, January to December 1968, work plan 5, job No. C-1

In 1968, Lake Pleasant was again full and conditions seemed suitable for another successful spawn, but by the end of the year, there was no evidence that spawning was successful.

(12.) F-7-R-12, January to December 1969, work plan 8, job No. S-1

Only 22 white bass were taken by shocking, but angler success indicated a more substantial population.

(13.) FS-7, January 1, 1971, to December 31, 1971, work plan 4, job No. S-1

It was noted that "No white bass, sturgeon, striped bass, mollies, trout, smallmouth bass, Tilapia, plains red shiner, or striped mullet were taken in the spring electrofishing survey. All these species are known to have inhabited Imperial Reservoir in the past ten years."

(14.) F-7-R-17, July 1, 1975, to June 30, 1976, job No. 5

Anglers harvested large numbers of white bass, but since the bass stay deep most of the time, they are almost impossible to sample with the shocker. The lake was low again this year, which made white bass more susceptible to the angler.

(15.) F-7-R-21, July 1, 1979, to June 30, 1980, work plan 1, job No. 4

Nineteen white bass were collected in Lake Pleasant in the spring of 1980, presumably by electrofishing.

Table 10 shows angler harvest of white bass in Lake Pleasant through 1969.

Table 10. — Angler pressure and white bass harvest estimates for the period February 1 to October 31, 1964 to 1969, in Lake Pleasant.

Year	Hours angled	Number anglers	White bass number	Average white bass length
1964	59,505	21,252	1	
1965	62,410	18,356	187	8.9
1966	83,832	22,061	3,689	11.3
1967	92,808	29,002	1,114	12.6
1968	71,136	20,324	640	11.1
1969	71,538		858	11.0

Blue tilapia. —

Nomenclature and description. — The blue tilapia [*Tilapia aurea* (Steindachner)] (fig. 4) has in the past been confused with *Tilapia nilotica* Linne (Armbrester 1971; Spataru and Zorn 1978; and Trewavas 1965). Confusion has also existed in identifying other tilapia species used in experimental work,

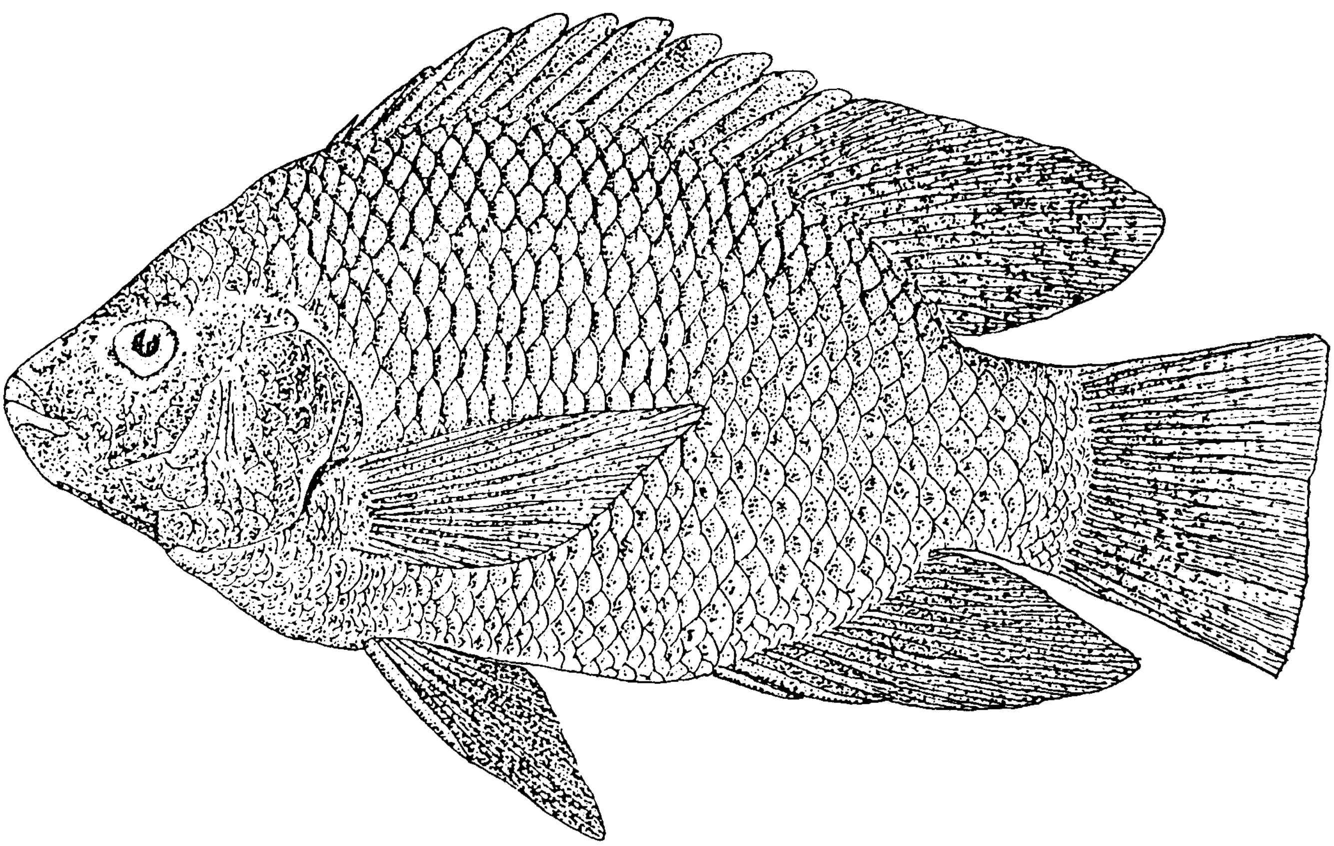

Figure 4. — The blue tilapia, *Tilapia aurea*.

due to the similar morphology of the many species (Lowe-McConnell 1959). Recent studies of morphological and ethological characteristics have led to a separation of the substrate brooders and mouthbrooders into the genera *Tilapia* and *Sarotherodon*, respectively (Trewavas 1973). Trewavas (1982a) has further elevated the subgenus of maternal mouthbrooders (*Oreochromis*) to generic status, and now refers to the blue tilapia as *Oreochromis aureus*. Bond (1979) did not accept revisions to the status of the genera. Here we retain the name *Tilapia aurea* for general discussion, rather than *Sarotherodon aureus* or *Oreochromis aureus*, consistent with Robins et al. (1980), and will use the word tilapia or tilapias to refer to the group as a whole (Trewavas 1982b). However, in reports where authors use the revised generic names *Sarotherodon* or *Oreochromis*, we will do likewise to remain consistent with their nomenclature.

Trewavas (1965) discussed the morphological and meristic characteristics she used to separate *T. aurea* from *T. nilotica*. The following text and table are excerpted from her work and provide one of the more complete taxonomic descriptions of *T. aurea*. The definitive species descriptions from Trewavas (1965) are included here because of some uncertainty concerning the actual identification of suspected *T. aurea* populations in Arizona and as an aid towards positive identification of the fish or hybrids in the future. The description is based on preserved speciments in the British Museum and on preserved and live specimens in the Tel Aviv University collection.

"DISTINCTION BETWEEN *T. nilotica* AND *T. aurea*

"*T. aurea* and *T. nilotica* are distinguished from each other in these localities as follows (see also Fishelson, 1962. The *exul* population is excluded).

"*T. nilotica*. Caudal fin with alternate narrow black and clear vertical stripes; upper margin of dorsal fin black or grey. Dorsal spines XVII or XVIII, rarely XVI, mode XVII; vertebrae 30-32. Lower parts of head and flanks, dorsal and caudal fins of breeding male suffused with red, making the dark markings appear violet. Lappets of dorsal fin always separated by well-marked notches.

"*T. aurea*. Caudal fin unmarked, or with vague, irregular dark markings, or with a more or less complete dark reticulum with white or clear meshes; upper margin of dorsal fin pink (white when preserved). Dorsal spines XV or XVI, rarely XIV or XVII, mode XVI. Vertebrae 28-31. Breeding male with the usual blue-grey colour intensified on the head to a brilliant metallic blue and with the pink edge of the dorsal fin intensified, by the addition of guanophores, to an opaque vermilion. At least in Israel, in the fully ripe male the notches between the dorsal lappets are obliterated and the margin is thickened.

"Proportions as percent of S.L. Depth of body 35-49, usually over 40 (in the types of *T. monodi* up to 52.5); length of head 33.0-37.2 between standard lengths of 50 and 110 mm, 33.0-35.8 between 110 and 225 mm; length of pectoral fin 29-40.5 (the lower measurements probably of fins with damaged tips); length of caudal peduncle 9-14%, usually 11-13.

"Proportions as percent of length of head. Snout 25.5-31 below 100 mm S.L., 28.5-37 above this length; eye 23 to 30 from 50-103 mm S.L., 18.5-23 above this length; depth of preorbital 16-19.5 below 100 mm S.L., 17.5-23 above this length, approximately equal to diameter of eye at about 140 mm S.L. and over, less below this length; interorbital width 28.5-38.5, with little indication of allometry, but values of 36 or over are all at standard length of about 120 mm or more, and values below 31 are very rare; length of lower jaw 30-36.8.

"The depth of the caudal peduncle exceeds its length, the ratio length-to-depth usually being about 0.7, rarely 0.5 (some W. African specimens) 1.0 (one Palestinian).

"Teeth of jaws bicuspid in the outermost series, tricuspid in the others, shaped as in *T. nilotica*, but sometimes with the main cusp a little broader and more curved that is typical for that species, especially in the Jordan Valley (Figure 3); in 3-5 series, 52-76 in outer series of upper jaw.

"Gillrakers (4-7) + 1 + (18-22) in the outer series of the anterior arch in Palestine and Egypt, (5-8) + (21-26) in Niger R. (Daget).

"The width of the pharyngeal bone, 30.5-33.5% of the length of head, is about the same as in *T. nilotica*, but its median length is slightly less, 24-30% of the head and 1.1-1.28 times its own width (cf. respectively 28-33% and 1.00-1.18 in *T. nilotica*). The difference is better seen in the narrower lobes of the dentigerous area in *T. aurea* (Figures 4 and 5; see also Daget, 1954, Figs. 131 and 132). In Palestine the pharyngeal teeth are finer and more crowded in *T. aurea* than in *T. nilotica*, but I do not find this difference in African specimens. (South of the area inhabited by *T. aurea* a population of *T. nilotica*, that of Lake Edward, has a pharyngeal dentition diverging even more from that of typical *T. nilotica* than that of any *T. aurea*).

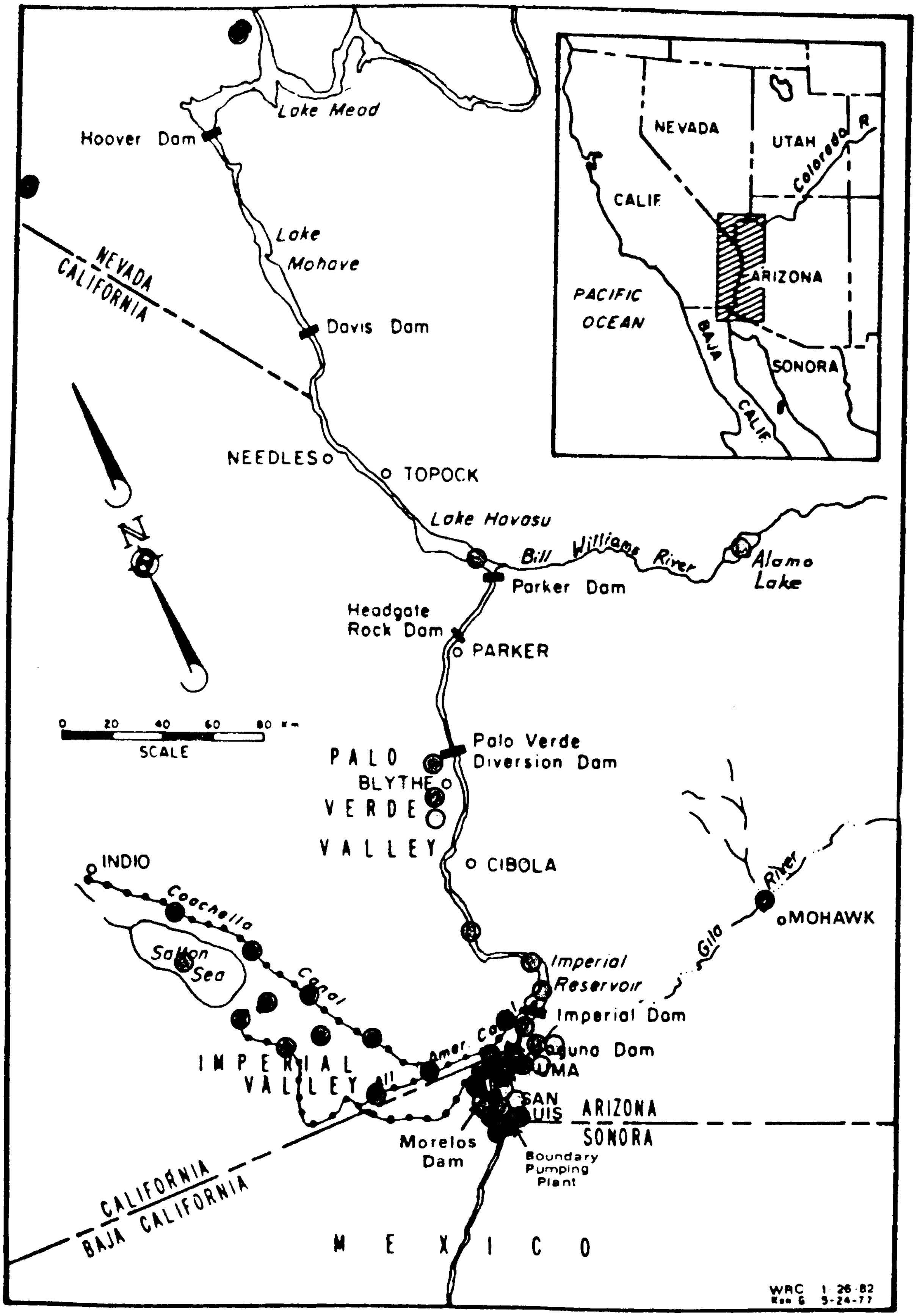

Figure 5. — Distribution of tilapia populations in the lower Colorado River system (from Courtenay 1982, adapted by McCann 1982).

"Scales. Cheek with 2 or 3 horizontal series. Lateral line series 30-33, mode 32; 4-5 between origin of dorsal and lateral line, 5-7 between bases of pectoral and pelvic fins.

"Fins. D XV-XVI 12-15 (XVII recorded once in W. Africa by Daget, found also in one specimen from L. Hula; XIV once in W. Africa); totals and frequencies recorded in Tables I and III. Last spine 13.3-17.4% of S.L.

"A III 9-11; third spine 11-16.4% of S.L., a little shorter than the last dorsal, but stronger.

"Pelvics pale, dusky or dark; not greatly produced.

"Caudal truncate, sometimes with rounded corners, usually scaly only at base and between rays of upper and lower parts of fin.

"Size. Largest examined by me (at Tel Aviv) 255 mm S.L. Dr. Daget reports (in a letter) that in the flood-plains of the Middle Niger it may reach 370 mm.

"Vertebrae 28-31; 14 + 14, 15 + 13, 15 + 14, 15 + 15, 16 + 14 or 15 + 16 (for mode and means see Table 1).

"Colour. General body-colour grey-blue, often darker on the back and top of head; much darker in some environments, probably in L. Tiberias (c.f. Lortet 1883, 138) and in the lagoons and backwaters that yielded the types of *T. lemassoni;* dark bars are emphasized in some emotional states (Fishelson, personal communication). Dorsal fin with dark and light spots alternating on the posterior half, the pearly white spots sometimes conspicuous. A "Tilapia-mark" is either absent or not clearly demarcated at standard lengths of 100 mm and more. Upper margin of dorsal pink (white when preserved). Caudal without markings, or with pearly-white spots alternating with dark, sometimes a dark meshwork with light interstices extending over part or nearly whole of fin, but leaving hind margin pink in life. Anal pale, clouded or with a few spots.

"Breeding colours. The blue of the lower part of the head becomes more intense and metallic, especially in the male; the lower lip may become bluish-white. The pink of the edge of the dorsal is intensified in the male, and at peak breeding condition the edge becomes entire and thickened between the spines and along the dorsal margin of the soft part.

"These colours are recorded from specimens originally from Hula (the site of Lake Hula), living in aquaria in Tel Aviv University. Daget has recorded

"TABLE I
"MERISTIC DIFFERENCES BETWEEN
T. nilotica AND *T. aurea*

		T. nilotica	*T. aurea*
Vertebrae:	range	30-32	28-31
	mode	31	30
mean:	Jordan Valley	—	29.35 (51)
	Palestine, coastal	30.8 (35)	29.9 (15)
	Nile	31.2 (14)	30.2 (9)
	Niger	31.1 (10)	29.9 (11)
Dorsal spines:	range	16-18(14)	15-16(17)
	mode	17	16
Total D rays:	range	29-31	27-30
mode:	Jordan Valley	—	28
	Palestine, coastal	30	29
	Nile	31	29
mean:	Jordan Valley	—	28.27 (48)
	Palestine, coastal	30.24 (29)	29.00 (11)
	Nile	30.59 (42)	29.24 (33)
	Niger	29.92 (51)	28.85 (55)

similar colours in West Africa but adds that throat and belly are greyish or sometimes tinted with yellow, never with red. We (L.F. and E.T.) have never seen the yellow tinge, but we confirm for Israel specimens the absence of red (in contrast to *T. nilotica*). Daget does not record the thickening of the edge of the dorsal fin and the closing of the notches between the lappets, and we have seen it only in fully ripe males. In a mature male from Lake Menzaleh the notches are reduced but not closed.

"Genital papilla. A fully ripe male at Tel Aviv had a papilla with a short bifid flange behind the pore (see Fishelson, 1962, Fig. 3). In the male from Lake Menzaleh the papilla is prominent, but conical, with a subterminal pore."

Payne and Collinson (1983) compared characteristics of *S. aureus* and *S. niloticus* and other tilapia in the lower Nile River obtained from fishermen's catches, to define their use for fish culture in Egypt. They distinguished *S. niloticus* from *S. aureus* by the higher dorsal spine count in *S. niloticus*. In Egypt, 83.3 percent of *S. niloticus* had 17 dorsal spines, while only 10.3 percent of *S. aureus* had 17 dorsal spines. They also indicate that these two species are easily distinguishable by color and other unspecified factors in the field. Electrophoretic analysis of serum and other protein from *T. aurea, T. vulcani, T. nilotica*, and some F_1 hybrids has been used with some success in differentiating these fish species (Avtalion and Wojdani; 1971; Avtalion et al. 1976; Hines et al. 1971; McAndrew and Majumdar 1983) and additional electrophoretic work to elucidate tilapia species identification in the U.S. is planned (McCann pers. comm.).

***Native distribution of* Tilapia aurea.** — Philippart and Ruwet (1982) indicate that the various species of the *Sarotherodon* group (including *S. aureus*) are segregated by geographical and hydrographical barriers and therefore have a more local distribution, except for *S. niloticus, S. galilaeus*, and *S. mossambicus*. The range of *S. aureus* is listed by Payne and Collinson (1983) as the "soudanian" regions of West Africa including the middle Niger and Chad Basin, the lower Nile, and parts of Israel. However, the ranges of *S. aureus, S. niloticus*, and *S. galilaeus* overlap from Senegal to Chad (Philippart and Ruwet 1982). Sympatric occurrence of species of the *Sarotherodon* group would indicate some physical or biological requirements leading to ecological isolation.

The native distributions listed by Philippart and Ruwet (1982) do not include the lower Nile and Israel. McBay (1961), in a description of the biology of *T. nilotica* [in which he indicated that this species had been redescribed as *T. aurea* (Steindachner)], noted the distribution as most of the African continent, including almost every lake and river of Israel. Lee et al. (1980) also includes the lower Nile and Jordan River system in *T. aurea*'s native distribution.

Introduction of* Tilapia aurea *outside their native range including the United States. — In attempting to enhance protein intake of the local population, find a satisfactory biological control for aquatic vegetation, and provide a potential new pond sport fish, several species of tilapia have been introduced into various areas of Africa (Greenwood 1963; Philippart and Ruwet 1982; Trewavas 1982b), Java (Atz 1954, Riedel 1965 in Philippart and Ruwet 1982; Swingle 1960; Trewavas 1966) and other tropical areas of the world (Aravindan 1980; Fryer and Iles 1972; Glucksman et al. 1976; Hickling 1960; Mann 1979). *T. aurea* (at the time confused taxonomically with *T. nilotica*) were first introduced into the United States from Israel in 1957 by Auburn University, Auburn, Alabama (Avault 1970; Shelton et al. 1981; Shafland and Pestrak 1982; Smitherman pers. comm.; Ware 1973; Zale pers. comm.) to evaluate their potential as a pondfish and their ability to control aquatic vegetation (McBay 1961; Ware 1973). These fish were subsequently confirmed as *T. aurea* (Smith-Vaniz 1968). Introductions of *T. aurea* from Auburn University were made into Florida in August 1961, by the Florida Game and Fresh Water Fish Commission (Buntz and Manooch 1969a; Burgess et al. 1977; Courtenay et al. 1974; Crittenden 1962; Harris 1978; Langford et al. 1978; Perry and Avault 1972; Philippart and Ruwet 1982; Shafland and Pestrak 1982; Ware 1973). These fish were placed in pits at the Pleasant Grove Research Station, Hillsborough County. Other species of tilapia as well as *T. aurea* have been introduced into other areas of the United States such as Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Illinois, Iowa, Kansas, Kentucky, Louisiana, Mississippi, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, Texas, and Wisconsin (Becker 1983; Carlander 1978; Dharmamba et al. 1973; Drenner pers. comm.; Guenther 1972; Hoover 1971; Keith pers. comm.; Lee et al. 1980; Martin pers. comm.; Pelren 1969; Pelren and Carlander 1971; Perry and Avault 1972; Taubert and Coble 1977; Van Gorder and Strange 1981; Whiteside 1975), and Canada (Beamish 1970) for legitimate research purposes or by deliberate or accidental fisherman transfer (Lee et al. 1980; McConnell 1965, 1966; Nicola 1979; Philippart and Ruwet 1982; St. Amant 1966; Whiteside 1975). Since *T. aurea* is the principal tilapia species of concern for this literature review and analysis, no attempt is made to detail introductions of other tilapia species into the United States; however, some mention and discussion of other species is necessary and appropriate.

In some cases, the introduction of the various tilapia species into new environments proved successful as determined by reproduction, although introductions were not always deemed desirable. Tilapia are a highly touted fish for use in aquaculture in certain situations and areas, and much research has been conducted to ascertain conditions to optimize growth, methods for producing monosex or predominantly single sex progeny by hybridization or hormone treatment (Shelton et al. 1981) and to minimize reproductive potential. Aquacultural aspects of tilapia will not be discussed in great detail here.

Introductions of* Tilapia *into Arizona and California. Examination of available records indicates that *Tilapia* spp. were first introduced into Arizona from Hawaii by the Game and Fish Department in 1961 (Barrett 1983). These fish were presumably *T. mossambica*. Barrett lists tilapia stocking activities conducted by the Arizona Game and Fish Department from 1961 through 1981. From these initial stockings in the early 1960's, the fish were able to spread throughout canals and backwaters in the lower Colorado River (Minckley 1973). These prolific fish were thought to be the answer to biological control of aquatic vegetation. *T. nilotica* was also in Arizona by 1964 and *T. zilli* was apparently introduced into a canal in Mesa, Maricopa County, and may have overwintered (Minckley 1973).

McConnell (1965, 1966) brought in two strains of tilapia that were used originally to produce the Malacca hybrid. The Java strain was obtained from the Tishomingo (Oklahoma) National Fish Hatchery in 1962, and the Zanzibar strain was obtained from Dr. Gerald Prowse at the Tropical Fish Culture Research Institute at Malacca, Malaysia. The Zanzibar strain was subsequently identified as *T. hornorum* (Barrett 1983; McConnell pers. comm.). McConnell produced all male F_1 progeny from these strains; they exhibited better growth than the parents and, since the progeny were all one sex, they did not overpopulate and become stunted. *T. zilli* were obtained from Israel in 1965 (McConnell pers. comm.).

Table 11 lists tilapia transplanting activities of the Arizona Game and Fish Department from 1961 through 1980, gleaned from an examination of Department stocking records conducted by personnel from the USBR Arizona Projects Office for this literature review. Table 12 lists AGFD tilapia stocking activities compiled by Barrett (1983), and table 13 summarizes tilapia collecting and transplanting activities found in various AGFD publications and job progress reports, principally F-7 reports (Federal Aid in Fisheries Restoration). Examination of tables 11, 12, and 13 indicates that *Tilapia* spp. have been transported and stocked extensively in the central and southwestern counties of Arizona and to a lesser degree in Graham and Apache (or Navajo?) counties to the east.

Table 11. — *Tilapia* spp. stocking activities of the Arizona Game and Fish Department, 1961 through 1980. Compiled from departmental records.

	Receiving water	Species	Dates	Number	Source	Size	Weight
1961	Gila Bend Canal	*Tilapia* sp.	10-16-61	11,504	?	1.5-6	
	Gila Bend Canal	*Tilapia* sp.	10-17-61	15,987	?	1.5-6	
1963	Yuma Canal	*Tilapia* sp.	1-31-63	400	?	1-4	20
1965	Riverside Park-Yuma	*Tilapia* sp.	4-28-65	700	Page Springs	2-4	15
	Greenway Ponds	*Tilapia* sp.	5-13-65	30	Page Springs	4	1
	19th Avenue Ponds	*Tilapia* sp.	5-13-65	295	Page Springs	2-4	4
	Tom's Pond	*Tilapia* sp.	5-18-65	300	Page Springs	4-7	50
	Estrella Park	*Tilapia* sp.	11-19-65	500	Page Springs	5-13	33
1966	Encanto Lagoon	*Tilapia* sp.	5-24-66	783	Page Springs	2.5	13
	Canal-Buckeye	*Tilapia* sp.	5-25-66	250	Page Springs	10	200
	Estrella Park, Goodyear	*Tilapia* sp.	5-25-66	250	Page Springs	10	200
1967	Painted Rock Dam	*Tilapia* sp.	4-10-67	125	Yuma Canal	8	
1968	Painted Rock Lake	*Tilapia* sp.	4-26-68	650	Yuma Canal	4-5	
	Gillespie Canal	*Tilapia* sp.	5-21-68	2,200	Page Springs	2-4	73
	Cholla Lake	*Tilapia* sp.	5-28-68	1,000	Page Springs	2-4	34
	Francis Creek	*Tilapia* sp.	5-28-68	200	Page Springs	3-6	
	Cholla Lake	*Tilapia* sp.	10-09-68	830	Page Springs	Adult	318
	Cholla Lake	*Tilapia* sp.	10-09-68	16,500	Page Springs	1-3	110
	Smith Salt Pond	*Tilapia* sp.	10-18-68	40	Page Springs	1.5	1
	Smith Salt Pond	*Tilapia* sp.	10-18-68	4	Page Springs	4-8	2
	Cholla Lake	*Tilapia zilli*	10-07-68	10,000	Univ. of Ariz.	1.5	20
1969	Smith Pond	*Tilapia* sp.	6-25-69	108	Page Springs	4	6
	Allenville Pond	*Tilapia* sp.	1969	800	Yuma Canal	4	95
	Painted Rock	*Tilapia* sp.	1969	2,000	Yuma Canal	3-4	240

Table 11. — *Tilapia* spp. stocking activities of the Arizona Game and Fish Department, 1961 through 1980. Compiled from departmental records. — Continued

	Receiving water	Species	Dates	Number	Source	Size	Weight
1970	Painted Rock Dam	*Tilapia* sp.	4-01-70	700	?	4	
	Allenville Pond	*Tilapia* sp.	4-02-70	400	?	4	
	Flushing Meadows	*Tilapia* sp.	5-06-70	70	Page Springs	9.5	40
	Picacho Reservoir	*Tilapia* sp.	5-06-70	880	Page Springs	9.5	503
1971	Roper Lake	*Tilapia* sp.	5-20-71	880	Page Springs	2-4	30
1973	No Name (SCS)	*Tilapia* sp.	9-17-73	50	Page Springs	6	
	Tucson Park Hatchery	*Tilapia* sp.	10-16-73	600	Page Springs	6	275
1974	Scottsdale Park	*Tilapia* sp.	5-20-74	250	Bubbling Pond	4-8	100
	NAU Flagstaff	*Tilapia* sp.	5-31-74	6	Bubbling Pond	4-8	100
	NAU Flagstaff	*Tilapia* sp.	6-12-74	12	Bubbling Pond	8	6
	NAU Flagstaff	*Tilapia* sp.	7-02-74	6	Bubbling Pond	8	3
	Randolph Park	*Tilapia* sp.	10-22-74	25,200	Bubbling Pond	1-3	352
	Buckeye Canal	*Tilapia* sp.	10-22-74	4,000	Bubbling Pond	1-3	40
	Salt Canal Park	*Tilapia* sp.	12-13-74	50	Bubbling Pond	3	1
1975	Chaparral	*Tilapia mossambica*	5-20-75	142	Yuma Canal	5-10	
	Chaparral	*Tilapia mossambica*	5-22-75	1,300	Yuma Canal	3-6	
	Randolph Park	*Tilapia aurea*	7-23-75	45	Gila Bend	6-10	
	Salinity Canal	*Tilapia mossambica*	8-01-75	2,646	Sally Ann No. 1	?	279
	Mittry Lake	*Tilapia mossambica*	8-13-75	1,615	Sally Ann No. 1	?	646
	Mittry Lake	*Tilapia mossambica*	8-13-75	5,592	Sally Ann No. 1	?	2796
	UMID Canal A	*Tilapia mossambica*	8-21-75	250	Sally Ann No. 1	1	
	Dankworth Ponds	*Tilapia aurea*	9-25-75	100	Bubbling Pond	?	28
1976	Wellton Pond	*Tilapia mossambica*	5-05-76	500	Yuma Canal	2-6	10
	Chaparral Lake	*Tilapia mossambica*	5-06-76	500	Bubbling Pond	6-10	250
	Yuma City Water Monitor	*Tilapia mossambica*	5-21-76	20	Yuma Canal	2.5	
	A-Canal	*Tilapia mossambica*	5-21-76	2,500	Yuma Canal	4	20

Table 11. — *Tilapia* spp. stocking activities of the Arizona Game and Fish Department, 1961 through 1980. Compiled from departmental records. — Continued

	Receiving water	Species	Dates	Number	Source	Size	Weight
	B-Canal	*Tilapia mossambica*	5-21-76	34	Yuma Canal	3-4	20
	Dankworth	*Tilapia mossambica*	8-25-76	300	Bubbling Pond	8-12	150
1977	Chaparral Park	*Tilapia mossambica*	6-26-77	523	?	?	
	Lakeside Lake	*Tilapia mossambica*	7-29-77	575	?	?	
	Lakeside Lake	*Tilapia mossambica*	9-16-77	1,000	?	?	
	Chaparral Lake	*Tilapia mossambica*	9-16-77	1,000	?	?	
1979	Peck's Lake	*Tilapia zilli*	5-02-79	54	Bubbling Pond	7	28
	Peck's Lake	*Tilapia zilli*	5-03-79	30	Bubbling Pond	14	61
	Phoenix Zoo	*Tilapia zilli*	7-06-79	526	Bubbling Pond	4-6.5	90
1980	Sally Ann No. 1 and 2	*Tilapia zilli*	1-03-80	1,840	Bubbling Pond	1-8	164

Tilapia species have become established in backwaters along the Colorado River. Minckley and McNatt (1974) found *T. mossambica* in Hunter's Hole, Yuma County, and were somewhat surprised at the low number (five) of this generally prolific species that they collected.

Reports indicate that *T. aurea* or some hybrid of *T. aurea* exist in Alamo Lake on the Bill Williams River (Barrett 1983; Jacobson pers. comm.; Thomas 1983; Wanjala pers. comm.). Jacobson (pers. comm.) found 28 *"T. aurea"* in Alamo Lake in 1982, which may have reached Alamo Lake from a plant of *Tilapia* spp. in the confluence of Burro and Francis Creeks in the late 1960's. Departmental records indicate that *Tilapia* spp. were stocked in Francis Creek in May 1968. Jacobson (pers. comm.) indicated that little or no followup of this plant took place, and that high floodwaters in Burro Creek, Francis Creek, Big Sandy River, and Santa Maria River in 1978 may have provided the means for these tilapia or their progeny to move downstream into Alamo Lake (also Thomas 1983). However, one cannot rule out bait bucket transfer by anglers from the Phoenix metropolitan area (Maricopa County), who comprise a large portion of the anglers fishing in Alamo Lake (Arizona Game and Fish Department 1982), or illegal, unauthorized stocking activities by private citizens. Wanjala (pers. comm.) indicated that large numbers of big tilapia (which he tentatively identified as *T. aurea*) exist in Alamo Lake. During high flows out of Alamo Lake, as experienced in 1983, tilapia could possibly move out of Alamo Lake, down into the Bill Williams River, and eventually enter Lake Havasu (Bristow 1983, Loudermilk pers. comm.; Taubert pers. comm.). Jacobson (pers. comm.) stated that it is probably just a matter of time until tilapia from Alamo Lake enter Lake Havasu. Jacobson has not collected tilapia in Lake Havasu, nor has Donahoo (pers. comm.). However, McCann (1982) indicated the presence of *T. aurea* in the lower end of Lake Havasu, but no voucher specimen can be located. If this report of tilapia is correct, then apparently the introduction, from whatever source, was unsuccessful, based on recent surveys by the USBR and USFWS in the Bill Williams Arm (Burke pers. comm.).

About eight tilapia species and hybrids are present or suspected in the lower Colorado River system (Barrett 1983; Guisti pers. comm.; McCann 1982; Ulmer pers. comm.) (fig. 5, table 14).

Table 12. — *Tilapia* spp. transplanting activities, 1961 through 1981 (from Barrett 1983)

Date	Species	Source	Location	Stocking county	Location
10-61	[1]*Tilapia* sp.	[1]Maricopa	Papago Park	Maricopa	Gila Bend Canal
10-61	[1]*Tilapia* sp.	Maricopa	Papago Park	Maricopa	Gila Bend Canal
1-63	[2]*Tilapia* sp.	Maricopa	Unknown	Yuma	Yuma Canal
4-65	*Tilapia* sp.	Yavapai	Page Springs	Yuma	Riverside Park
5-65	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Greenway Ponds
5-65	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	19th Avenue Pond, Phoenix
5-65	*Tilapia* sp.	Yavapai	Page Springs	Unknown	Tom's Pond
11-65	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Estrella Park, Phoenix
5-66	*Tilapia* (hybrid)	Yavapai	Page Springs	Maricopa	Encanto Lagoon, Phoenix
5-66	*Tilapia* (hybrid)	Yavapai	Page Springs	Maricopa	19th Avenue Pond, Phoenix
5-66	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Canal at Buckeye
5-66	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Estrella Park, Phoenix
4-67	*Tilapia* sp.	Yuma	Yuma Canal	Maricopa	Painted Rock Dam
4-68	*Tilapia* sp.	Yuma	Yuma Canal	Maricopa	Painted Rock Dam
5-68	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Gillespie Canal
5-68	*Tilapia* sp.	Yavapai	Page Springs	Apache	Cholla Lake
5-68	*Tilapia* sp.	Yavapai	Page Springs	Yavapai	Francis Creek
10-68	*Tilapia* sp.	Yavapai	Page Springs	Apache	Cholla Lake
10-68	*Tilapia* sp.	Yavapai	Page Springs	Apache	Cholla Lake
10-68	*Tilapia* sp.	Yavapai	Page Springs	Unknown	Smith Salt Pond
10-68	*Tilapia* sp.	Yavapai	Page Springs	Unknown	Smith Salt Pond
11-68	*Tilapia zilli*	Pinal	UA	Apache	Cholla Lake
6-69	*Tilapia* sp.	Yavapai	Page Springs	Unknown	Smith Pond
4-70	*Tilapia* sp.	Unknown	Unknown	Maricopa	Painted Rock Dam
4-70	*Tilapia* sp.	Unknown	Unknown	Maricopa	Allenville Pond
5-70	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Flushing Meadows
5-70	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Picacho Reservoir
5-71	*Tilapia* sp.	Yavapai	Page Springs	Graham	Roper Lake
9-73	*Tilapia* sp.	Yavapai	Page Springs	Yuma	No Name LSCS
10-73	*Tilapia* sp.	Yavapai	Page Springs	Pima	Tucson Park Hatchery
5-74	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Scottsdale Park
5-74	*Tilapia* sp.	Yavapai	Page Springs	Coconino	Northern Arizona University
6-74	*Tilapia* sp.	Yavapai	Page Springs	Coconino	Northern Arizona University
7-74	*Tilapia* sp.	Yavapai	Page Springs	Coconino	Northern Arizona University
10-74	*Tilapia* sp.	Yavapai	Page Springs	Pima	Randolph Park, Tucson
10-74	*Tilapia* sp.	Yavapai	Page Springs	Maricopa	Buckeye Canal
12-74	*Tilapia* sp.	Yavapai	Page Springs	Unknown	Salt Canal Pond
5-75	*Tilapia mossambica*	Yuma	Yuma	Maricopa	Chaparral Lake
5-75	*Tilapia mossambica*	Yuma	Yuma	Maricopa	Chaparral Lake
7-75	*Tilapia aurea*	Maricopa	Gila Bend Canal	Pima	Randolph Park, Tucson
8-75	*Tilapia mossambica*	Yuma	Sally Ann #1 Pond	Yuma	Salinity Canal

Table 12 — *Tilapia* spp. transplanting activities, 1961 through 1981 (from Barrett 1983). — Continued

Date	Species	Source	Location	Stocking county	Location
8-75	*Tilapia mossambica*	Yuma	Sally Ann #1 Pond	Yuma	Mittry Lake
8-75	*Tilapia mossambica*	Yuma	Sally Ann #1 Pond	Yuma	Mittry Lake
8-75	*Tilapia mossambica*	Yuma	Sally Ann #1 Pond	Yuma	UMID, Canal A
9-75	*Tilapia aurea*	Yavapai	Page Springs	Graham	Dankworth Ponds
5-76	*Tilapia mossambica*	Yuma	Yuma Canal	Yuma	Wellton Pond
5-76	*Tilapia mossambica*	Yavapai	Page Springs	Maricopa	Chaparral Lake
5-76	*Tilapia mossambica*	Yuma	Yuma Canal	Yuma	Yuma City Water Monitor
5-76	*Tilapia mossambica*	Yuma	Yuma Canal	Yuma	A-Canal
5-76	*Tilapia mossambica*	Yuma	Yuma Canal	Yuma	B-Canal
8-76	*Tilapia mossambica*	Yavapai	Page Springs	Graham	Dankworth Ponds
5-79	*Tilapia zilli*	Yavapai	Page Springs	Yavapai	Peck's Lake
5-79	*Tilapia zilli*	Yavapai	Page Springs	Yavapai	Peck's Lake
5-79	*Tilapia zilli*	Yavapai	Page Springs	Maricopa	Phoenix Zoo
1-80	*Tilapia zilli*	Yavapai	Page Springs	Yuma	Sally Ann #1 and 2 Ponds
7-81	*Tilapia* sp.	Maricopa	Gila River at Gila Bend	Maricopa	Picacho Lake

[1]Original stock, presumably *T. mossambica*, but not so indicated in original (unpublished) memorandum (AGFD files); obtained from Hawaii.
[2]Identified as *T. mossambica* by Alban Essbach, AGFD, *in* Hoover and St. Amant (1970).

In addition, *T. nilotica* are being reared in fish farms in the Scottsdale, Arizona, area (Barrett 1983). Mr. Alban Essbach (Fisheries Consultant Phoenix, Arizona, pers. comm.) stated that *T. aurea* and *T. zilli* are also being raised in Scottsdale for filamentous algae and macrophyte control. However, Ware (pers. comm.) does not believe that blue tilapia utilize filamentous algae to the extent indicated by some investigations and biologists. He feels that the fish are overrated as a potential biological control for algae. McCann (pers. comm.) suspects that the "*aurea*" in Arizona may actually be hybridized with *nilotica* and that only a few pure *T. aurea* stocks may exist in the United States, possibly at Marion, Alabama, and a site in North Carolina. *T. aurea* stocks at Auburn University may have interbred with others. Smitherman (pers. comm.), on the other hand, thinks that Auburn's *T. aurea* stocks are relatively pure. Zale (pers. comm.) also feels that Florida *T. aurea* may be contaminated with *nilotica* genes. Ongoing and planned morphological, meristic, and electrophoretic studies by the U.S. Fish and Wildlife Service and contractors may help elucidate tilapia systematics in the United States (Courtenay pers. comm.; McCann pers. comm.).

Tilapia have become established in southern California and along the lower Colorado River. A breeding population of *T. mossambica* was discovered in a small pond near the Salton Sea in 1964 (St. Amant 1966). Authorized introductions for aquatic weed and mosquito control, along with unauthorized introductions (possibly bait bucket transfer) and natural movements of the fish, have resulted in *T. mossambica* becoming widely established in southern California (Shapovalov et al. 1981). These fish are found in irrigation systems in the Imperial, Palo Verde, and Bard Valleys (Hoover and St. Amant 1970; Moyle 1976; Nicola 1979). The poor success of *T. mossambica* in controlling aquatic vegetation and the persistence of the aquatic weed problem (Nicola 1979) led to the authorized introduction in the early 1970's of *T. zilli* into ponds, canals, and

Table 13 — *Tilapia* spp. collecting and transplanting activities compiled from an examination of Arizona Game and Fish Department F-7 reports, 1959 through 1981.

Receiving Water	Species	Dates	Number	Source	Size	Weight
Tom's Pond (Phoenix)	*Tilapia mossambica*	5-18-65	300	?	4.0-7.0	
Tom's Pond (Phoenix)	Hybrid *Tilapia*	5-13-65	295	?	2.0-4.0	
Deer Valley Office Ponds (Phoenix)	Hybrid *Tilapia*	5-13-65	30	?	4.0	
Encanto Lagoon (Phoenix)	Hybrid *Tilapia*	5-24-66	783	?	2.5	
Deer Valley Office Ponds (Phoenix)	Hybrid *Tilapia*	5-24-66	40	?	2.5	
Drainage Canal (Buckeye)	Male *Tilapia mossambica*	5-25-66	250	?	10	
Estrella Park (Goodyear)	Male *Tilapia mossambica*	5-25-66	250	?	10	
Painted Rock Lake	*Tilapia* sp.	4-69	2,000	?	—	
Allenville Pond	*Tilapia* sp.	8-01-69	800	?	—	
Imperial Valley	*Tilapia* sp.	7-14-69	250	Salinity Canal (Yuma)	—	
Private military lake near Corona, Calif.	*Tilapia* sp.	7-15-69	300	Salinity Canal (Yuma)	—	
Gila Bend Canal	*Tilapia* sp.	3-71	—	—	—	
Boy Scout Pond	*Tilapia* sp.	1971	127	Salinity Canal	—	
Imperial Valley	*Tilapia* sp.	2-22-71	3,300	Salinity Canal	Catchable	
Palo Verde Valley	*Tilapia* sp.	2-22-71	326	Salinity Canal	Catchable	
Reservation Main Canal — Bard	*Tilapia* sp	2-23-71	1,200	Salinity Canal	Catchable	
Lake Tamarisk — Riverside, California	*Tilapia* sp.	2-23-71	85	Salinity Canal	Catchable	
Painted Rock Lake	*Tilapia* sp.	3-29-71	500	Salinity Canal	Catchable	
Wellton-Mohawk Canal	*Tilapia* sp.	3-30-71	1,200	Salinity Canal	Catchable	
Upper Salinity Canal	*Tilapia* sp.	3-30-71	600	Salinity Canal	Catchable	
Palo Verde Valley	*Tilapia* sp.	3-30-71	*1,933	Salinity Canal	Catchable	
Boy Scout Pond — YPG	*Tilapia* sp	3-30-71	500	Salinity Canal	Catchable	
Reservation Main Canal — Bard	*Tilapia* sp.	3-30-71	2,400	Salinity Canal	Catchable	
Imperial Valley	*Tilapia* sp.	3-30-71	3,933	Salinity Canal	Catchable	
Painted Rock Lake	*Tilapia* sp.	5-31-72	500	East Main Drain (Yuma Valley)	—	
University of Oregon	*Tilapia* sp.	1972	25	East Main Drain	—	

Table 13 — *Tilapia* spp. collecting and transplanting activities compiled from an examination of Arizona Game and Fish Department F-7 reports, 1959 through 1981. — Continued

Receiving Water	Species	Dates	Number	Source	Size	Weight
Various waters in Arizona and Calif.	*Tilapia* sp.	1973-74	26 tons	Salinity Canal	—	

*Palo Verde Irrigation District borrowed Imperial Irrigation District's equipment early in the morning and took a large percentage of the available *Tilapia* during the Salinity Canal dry-up period and transported them to the Palo Verde Valley. Both Imperial Irrigation District and the Arizona Game and Fish Department took the remainder of the tilapia.

Table 14. — *Tilapia* populations present or suspected in the lower Colorado River system (from McCann 1982)

Tilapia aurea	blue tilapia
Tilapia aurea x *T. nilotica*	blue/Nile tilapia hybrid
Tilapia aurea x T. *mossambica*	blue/Mozambique tilapia hybrid
Tilapia mariae	spotted tilapia
Tilapia mossambica	Mozambique tilapia
Tilapia mossambica x *T.* sp.	Mozambique tilapia/? hybrid
Tilapia rendalli?	redbreast tilapia
Tilapia ? hybrid	unknown tilapia hybrid
Tilapia zilli	redbelly tilapia

drains in southern California and several ponds in central California (Shapovalov et al. 1981). It was felt that the more herbivorous *T. zilli* might control aquatic vegetation better than the more planktivorous *T. mossambica*, but *T. zilli*'s unexpected tolerance to lower water temperatures in central California led to its placement on the prohibited species list for this area of California. *T. zilli* is, however, established and abundant in many areas of southern California, from the Colorado River westward (Lee et al. 1980). Two specimens were reported from the marine environment near Huntington Beach and in Newport Bay, Orange County (Knaggs 1977 in Shapovalov et al. 1981). *T. zilli* seems to be a very aggressive tilapia (McConnell pers. comm.) and may become a more serious competitor with sport fishes than the somewhat docile *T. mossambica* (Nicola 1979).

It is readily apparent from an examination of tables 11, 12, and 13 that various *Tilapia* species, including *T. aurea* have been collected and transported around the State of Arizona. Less easy (or impossible in some cases) to document are informal and/or unauthorized transport of tilapia by fish farmers, ranchers, irrigation districts, sportsmen's groups, or individual anglers. Apparently, introductions of tilapia into stock ponds and golf course ponds for aquatic weed control or sport occur on a routine and poorly documented basis. *T. aurea* has also been considered by certain utilities for control of filamentous algae in canals, and the fish are being raised in Scottsdale to provide fish for this purpose (Essbach pers. comm.).

Table 15 lists by county the locations around the State of Arizona where *Tilapia* spp. have been introduced. These waters are not the only waters where tilapia have been collected in Arizona, but represent areas where State, Federal, university, or private fishery biologists have stocked or held tilapia for various types of investigations.

Figure 6 graphically summarizes information listed in table 15. The black dots represent known, documented introductions of *Tilapia* spp. in Arizona, except Alamo Lake, by State, Federal, university, or private fishery biologists. Tilapia have been collected at other locations around the State, principally along the lower Colorado River. Minckley (1973) reported tilapia from Warm Springs, a tributary of the San Carlos River. This population may no longer exist. In addition, Minckley (pers. comm.) reported that tilapia, possibly *T. mossambica*, have been stocked in the headwaters of the San Pedro River in Mexico, which eventually flows into the Gila River near Winkelman, Arizona.

Bubbling Pond is a warm water source at the AGFD Page Springs Hatchery. The hatchery is located on Oak Creek and hatchery water drains into Oak Creek, a tributary of the Verde River. Both *T. mossambica* and *T. zilli* have been cultured at Page Springs for forage for largemouth bass and for weed control. Largemouth bass apparently consumed the young tilapia readily. *T. zilli* controlled weeds but apparently did not reproduce (Essbach pers. comm.). *T. aurea* have

Table 15. — Summary of locations, by county, of documented introductions of *Tilapia* spp. into the waters of Arizona. Specific locations (latitude/longitude) of waters are listed when these could be determined.

Table 15. — Summary of locations, by county, of documented introductions of *Tilapia* spp. into the waters of Arizona. Specific locations (latitude/longitude) of waters are listed when these could be determined. — Continued

County	Specific location
Coconino	
Northern Arizona University, Flagstaff	
Graham	
Dankworth Ponds*	32°43'15"/109°42'15"
Roper Lake	32°45'15"/109°42'15"
Smith Pond	32°49'15"/109°50'30"
Maricopa	
Encanto Lagoon, Phoenix	15th Ave. and Encanto Blvd.
Deer Valley Office Ponds, Phoenix	
Greenway Ponds, Phoenix	
19th Avenue Ponds, Phoenix	
Papago Park, Phoenix	Galvin Pkwy. and E. Van Buren
Tom's Pond, Phoenix	
Zoo, Phoenix	
Chaparral Lake, Scottsdale	Hayden Rd. and Chaparral Rd.
Scottsdale Park	
Drainage Canal, Buckeye	
Estrella Park, Goodyear	
Painted Rock Reservoir	33°04'15"/113°00'30"
Allenville Pond	
Flushing Meadows	
Gila Bend Canal*	
Gillespie Canal	
Navajo	
Cholla Lake	34°56'30"/110°18'00"
Pima	
Lakeside Park, Tucson	8300 E. Stella Rd.
Randolph Park, Tucson*	
Tucson Park Hatchery*	
Pinal	
Picacho Reservoir	32°52'00"/111°29'15"
Yavapai	
Bubbling Pond	
Page Springs Hatchery	
Peck's Lake	34°46'45"/112°01'45"
Yavapai/Mohave	
Francis Creek	
Yuma	
Boy Scout Pond YPG	32°50'15"/114°26'30"
Mittry Lake	32°49'15"/114°28'15"
No Name LSCS	
Redondo Lake	32°44'30"/114°29'00"
Riverside Park, Yuma	
Sally Ann No. 1	32°42'45"/114°31'30"
Sally Ann No. 2	32°43'15"/114°28'45"
Salinity Canal	
Wellton Pond	32°42'15"/114°06'15"
Yuma Canal	
Yuma City Water Monitor	
Location unknown	
Smith Salt Pond	
Salt Canal Park	

**Tilapia aurea* stocked or held at some time.

also been held at Page Springs Hatchery. Any fish that escaped from the hatchery could enter Oak Creek, and eventually the Verde River. *T. zilli* have been stocked in Peck's Lake, an old oxbow of the Verde River near Clarkdale and Cottonwood, Arizona, that was dammed off but which has a pipe connection to the river. Although the water temperatures in the river are considered to be too cool for tilapia reproduction, any fish that escaped into the Verde River and any from Page Springs Hatchery might have been able to migrate down the Verde River to a thermal refugia at Verde Hot Springs near the Childs Powerplant. It is not known if tilapia have successfully entered the Verde River by this route or survived in thermal refugia.

Water quality requirements.

Temperature. — It is generally understood that the tilapia are thermophilic cold-sensitive fishes and that their distributions are determined principally by temperature, especially low temperature (Chimits 1957; Philippart and Ruwet 1982). Populations would be able to maintain themselves in a particular habitat if the temperature at some time during the year was high enough to allow spawning and growth and prevent exposure to low lethal temperatures.

T. aurea have a mean lower lethal temperature of 6.2 °C; for juveniles the lower lethal temperature

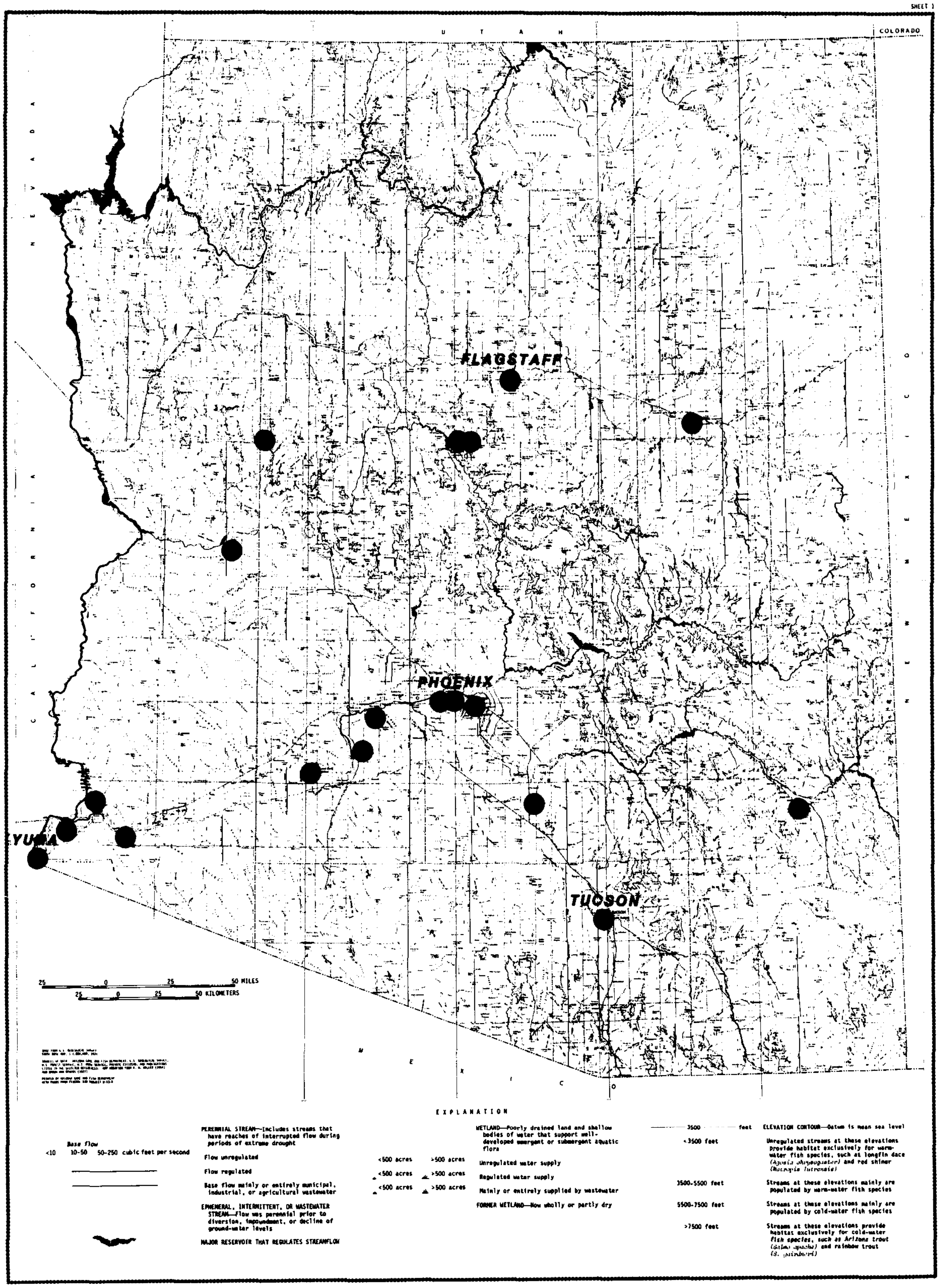

Figure 6. — Locations of known, documented introductions of *Tilapia* spp. in Arizona, except for Alamo Lake, by State, Federal, university, or private fishery biologists. (Map used with permission).

is 6.0 °C while for adults it is 6.5 °C (Shafland and Pestrak 1982). McBay (1961) reported that 8.8 °C was lethal to *T. nilotica* (= *T. aurea*) under some conditions. All sizes of tilapia up to 15.2 cm were affected by temperature in a 0.10-ha pond 1.52 m deep. McBay (1961) did not indicate if mortality was complete or not. However, in other larger ponds, larger fish (229 to 279 mm) survived exposure to colder water better and actually tolerated a temperature of 2.8 °C for a short time. Avault (1970), in comparative physiological studies with *T. aurea*, *T. mossambica*, and hybrids, found *T. aurea* to be the hardier fish; *T. aurea* began dying at 7.2 °C, while *T. mossambica* began dying at 12.8 °C. Lee (1979) reported that *T. aurea* had greater cold tolerance than *T. hornorum* and *T. nilotica*, and cold tolerance seemed to be transmitted to hybrids via some kind of maternal inheritance. Zale (pers. comm.) reported a lower lethal temperature for *T. aurea* of about 6.0 °C in freshwater and about 5.0 °C in water having a salinity of about 5 000 to 11 600 mg/L. However, as salinity increased to about 33 000 to 35 000 mg/L, the lower lethal temperature increased. In experiments in which the temperature was decreased stepwise by 1 °C per day to a constant 8 °C all *T. aurea* died within 4 to 9 days; if the test temperature was reduced to only 10 °C, *T. aurea* died within 11 to 30 days; if the test temperature was reduced to and held at 12 °C, *T. aurea* survived for 2 months at which time the experiment was terminated. Therefore, fish held at about 8 °C will succumb in about a week. Courtenay (pers. comm.) also indicated that *T. aurea* is the most cold tolerant of the tilapia found in the United States and that cold tolerance increases as salinity increases up to some level. Shafland (pers. comm.) has reported a lower lethal temperature for *T. aurea* of 5 to 6 °C, when the fish were subjected to a 1 °C decrease per day. St. Amant (pers. comm.) indicated that *T. aurea* is hardier than *T. mossambica* and winterkills at around 8 to 11 °C. Beamish (1970) found that temperature preferenda for a given acclimation temperature was lower at intermediate salinities than at salinity extremes. When test salinities were nearly isosmotic with the fish, energy for osmoregulation was reduced, which could allow the use of the saved energy for other metabolic functions.

Sarig (1969 in Philippart and Ruwet 1982) reported that *S. aureus* died at 8 to 9 °C while Philippart and Ruwet (1982) indicate that *S. aureus, S. niloticus*, and *S. galilaeus* are slightly less tolerant to low temperatures than *T. zilli*. These authors showed a normal range of temperatures for *S. aureus* as about 12.8 to 32.3 °C, with an extreme low temperature of 7.0 °C tolerated in some habitats; however, the upper lethal temperature for this fish may be as high as 38 °C (Chervinski and Stickney 1981). *S. niloticus* has a similar low temperature tolerance but an upper lethal temperature of about 42.0 °C. Crittenden (1962) reported that *T. nilotica* (= *T. aurea*?) in Florida could tolerate short-term exposure to 2.8 °C.

Pelren and Carlander (1971) stated that tilapia will not survive in water less than 13°C and thus there is no danger of their becoming established in north-central United States and competing with native fish. This temperature is high compared to other reported lower lethal temperatures. Hoover (1971) felt that temperature was the environmental factor that would limit the use of tilapia in California, and stated that almost total mortality of tilapia occurred when water temperatures dropped below 13.9 °C for an extended period of time. In areas subjected to annual water temperature fluctuation, tilapia would likely not survive winters, although they could survive in thermal refugia.

Tilapia are very adept at locating and utilizing thermal refugia, no matter how limited they might be (McCann pers. comm.). Apparently, thermal springs in Florida serve as refugia for thermophilic exotic fish species and allow them to survive north Florida winters (Burgess et al. 1977). Generally, however, tilapia do not grow below 15 °C (Yashouv and Halevy 1973). In Trinidad Lake, Germany and Noble (1977) reported winter mortality of *T. aurea* when the water temperature reached 10 °C. Massive mortality occurred from 6 to 9 °C.

Dissolved oxygen. — Tilapia seem to be very resistant to low dissolved oxygen levels (Rakocy and Allison 1981) and utilize several physiological means to tolerate low oxygen levels (Philippart and Ruwet 1982). Tilapia generally required 1.0 mg/L dissolved oxygen. At lower levels, they may gulp air to use atmospheric oxygen or bathe the gills in oxygen-rich surface water. *S. mossambicus* and *S. niloticus* can tolerate short-term exposure to dissolved oxygen levels close to 0.1 mg/L. Ware (1973) indicated that tilapia can achieve their greatest abundance in eutrophic waters, with rich, hypereutrophic conditions also providing excellent conditions for population growth. In these types of situations, diurnal oxygen levels may fluctuate widely and result in severe daily reductions in dissolved oxygen (Wetzel 1975). Langford et al. (1978) reported that dense populations of tilapia thrive in hypereutrophic lakes in Florida. Payne (1979), however, stated that low oxygen levels may cause a reduction of feeding or food conversion efficiency and thus may reduce production. The ability of tilapia generally to tolerate levels of dissolved oxygen from around 1.0 mg/L and short-term exposure to even lower levels allows them to inhabit areas where nearly deoxygenated conditions occur occasionally that would kill some other fish species. But tilapia are not entirely unaffected by low oxygen levels. Mass mortality of tilapia due to deoxygenated conditions has been documented (Philippart and Ruwet 1982), especially when deoxygenation occurs rapidly as during violent storms.

Salinity tolerance. —Tilapia generally are able to survive, reproduce, and grow in a wide range of salinity concentrations (Chervinski and Zorn 1974). *T. aurea* can survive direct transfer to 60 percent seawater and can withstand concentrations of 150 percent seawater if the salt concentration is increased gradually. They can be maintained indefinitely at 35 000 mg/L NaCl (McConnell 1966), although Payne and Collinson (1983) estimated 10 000 to 15 000 mg/L salinity for unimpeded growth of *T. aurea.*

Preferred habitat. — Tilapia have colonized a wide range of habitats, including fast- and slow-moving waters, lakes, freshwater, highly saline lakes and coastal lagoons and estuaries, and swampy aquatic environments (Philippart and Ruwet 1982) Colonization of diverse habitats reflects the tilapia tolerance for a wide range of conditions present in the tropical and subtropical aquatic environment. Not all tilapia are tolerant of a wide range of conditions. Some, for instance, prefer slow-moving or still waters over fast-moving water; others prefer shallow water to deep water.

T. aurea has become abundant in the lower Colorado River (Minckley 1982b) and in parts of the Gila River where it has replaced *T. mossambica* by its adaptable, agressive nature.

In Florida, *T. aurea* preferred eutrophic waters with muck bottoms, especially in the winter (Buntz and Manooch 1969a). Large numbers of tilapia were found over muck deposits from 10.2 to over 183 cm in depth. Very few tilapia were found over sand substrate. *T. aurea* also seemed to congregate around areas containing decaying organic detritus, such as those that develop in areas used by cattle as watering sites. Five of the six Florida lakes in which Buntz and Manooch (1969a) collected *T. aurea* were eutrophic. The sixth lake had a population of waterfowl which received supplementary food daily, which might have been used by *T. aurea* as well. Productive eutrophic waters generally satisfy the planktonic food requirements of the tilapia; these waters are less desirable for sport fish but seemingly more suitable for rough fish.

For spawning, *T. aurea* move to sand-bottom, shallow, shoreline areas where the male builds a nest. In Lake Parker, Florida, bluegill and redear sunfish also utilized these areas for spawning (Buntz and Manooch 1969), so competition for the nest sites can result. In Silver Glen Springs, Florida, *T. aurea* entered shallow areas for spawning (Zale pers. comm.).

Food and feeding habits. — Many species of tilapia exhibit a diversified feeding regime utilizing predominantly plant material with animal material contributing less to the overall diet (Philippart and Ruwet 1982). *T. aurea* is primarily a planktivore (McBay 1961) but can act as an omnivorous opportunist and generalist which consumes its food according to availability (Lowe-McConnel 1959; Spataru and Zorn 1976, 1978; Rifai 1980). Tilapia of the same species may utilize one food source in lakes but shift to different food items in ponds; they will utilize eggs and fry of the fish species when these are available (Manooch 1971).

In Lake Kineret, Israel, Spataru and Zorn (1976) found also that food differs from one fish to another depending on the relative abundance of the food items in the water occupied by fish at any one time, and that *T. aurea* has not adapted itself to any particular trophic niche, thereby propagating its random food habits. Spataru and Zorn (1978) later concluded that zooplankton was the main food of *T. aurea* in Lake Kinneret, with vegetable detritus serving as an additional and alternative food. These dietary preferences may not necessarily apply to tilapia in other ecosystems. Manooch (1971) cultured the contents of the digestive tracts of three size categories of *T. aurea* from Lake Parker, Florida, in February. He found 21 taxa of algae in the culture vessels, with green algae predominating. Only one blue-green was identified. A few fragments of vascular plants were found, as were insignificant numbers of invertebrates. There was no major differentiation in diet correlated with the size of *T. aurea*, although the smallest specimen examined was 140 mm total length. In most planktivorous species of tilapia, the adults and young both feed on tiny algae and plankton, thus not providing the adults with any competitive edge over the young in relation to production (Hickling 1963; Lowe-McConnel 1959). McBay (1961) said that small (25 mm) fish utilized small crustaceans to a greater extent than larger fish, although all size classes were plankton feeders. Payne (1974) also described phytoplanktonic and benthic opportunism of tilapia, depending on availability of food resources.

Hendricks and Noble (1979) compared food habits of *T. aurea*, gizzard shad, and threadfin shad in Trinidad Lake, Texas. They found that food habits were generally similar, with organic detritus an important component of the diet. Diatoms and filamentous algae were prominent in the tilapia diet, with other planktonic components less important but utilized by all three species. Tilapia seemed to select zooplankton to a greater extent than the two shad species. Diets changed seasonally, concomitant with the change in the composition of the plankton community. If food resources are in short supply, interspecific competition can result because of the generally overlapping food habits of the three species.

Winfree and Stickney (1981) investigated the optimum dietary protein level, the energy level, and the protein to energy ratio for blue tilapia fry. They found that protein levels in the diet in excess of 40 percent with high (95-123) protein to energy ratios produced better growth than diets with lower protein levels or protein to energy ratios. As the fish grew, the protein requirement decreased and reflected the natural diet of tilapia fry. Early in development, tilapia fry consume zooplankton, high in both protein and fat. As the fish grow, they consume more phytoplankton and filamentous algae, with a concomitant decrease in the intake of protein and energy-rich fat. Davis and Stickney (1978) found that juvenile *T. aurea* had the highest growth rates on a diet containing 36 percent protein.

Reproduction. — African cichlid fishes belonging to tilapiini exhibit two relatively distinct modes of protecting developing eggs and larvae. One group guards the eggs and larvae in a nest (substrate brooders) while the second group protects the developing eggs and larvae in the mouth of one of the parents (mouthbrooders) (Lowe-McConnel 1959; Payne 1974). Trewavas (1982a) prefers to assign the mouthbrooders to the genus *Sarotherodon*, while retaining *Tilapia* for the substrate brooders. Maternal mouthbrooding is the rule among the *Sarotherodon* (Trewavas 1982a) and is generally considered most successful among lacustrine species (Fryer and Iles 1972; Lowe-McConnell 1959), although paternal mouthbrooding is exhibited by the reproductively atypical type species of *Sarotherodon, S. melanotheron. S. galilaeus* differs from others by being biparental mouthbrooders (Fryer and Iles 1972).

Prespawning and postspawning behavior in this species is, thus, different from the true maternal mouthbrooders. *S. aureus* (= *T. aurea*) is a maternal mouthbrooder (Boulenger 1908 in McBay 1961; Curtis 1983; Pagan-Font 1975; Pelren and Carlander 1971; Trewavas 1982a, 1982b; and Ware 1973); however, Valenti (1975) reported that the male *S. aureus* picks up the fertilized eggs and incubates them. Shafland (pers. comm.) thinks this is an error, since all other authorities regard *S. aureus* as a maternal mouthbrooder.

Sexual dimorphism exists in *T. aurea* (Chervinski 1971) and may be important in courtship rituals. In addition, males are sometimes brightly or conspicuously colored and grow larger than females (Chervinski and Zorn 1974).

In true maternal mouthbrooders, the male prepares or constructs some sort of nest. *S. aureus* nests are generally saucer-shaped depressions about 40 cm in diameter in shallow, weedy areas (Fryer and Iles 1972; Payne and Collinson 1983; Philippart and Ruwet 1982). Maternal mouthbrooders are not monogamous and usually do not form long-lasting pair bonds. The female, after picking up the eggs, will retreat to a quiet area to brood the eggs. Courtship and spawning rituals are usually of very short duration (Fryer and Iles 1972; Philippart and Ruwet 1982).

Although mouthbrooders generally require a substrate in which to construct a nest, Shafland (pers. comm.) feels that tilapia could reproduce in concrete-lined canals, but not too successfully. *T. aurea* have been observed to spawn in bare metal tanks without "substrate" (Zale pers. comm.). Tilapia in a canal could probably locate some quiet water areas and spawn. Arizona Game and Fish Department (1971) felt that tilapia would not live or reproduce in cement-lined canals having a swift current and essentially no protection.

Mouthbrooding, usually associated with low fecundities (Dadzie and Wangila 1980), confers advantages to tilapia since the fewer eggs produced have a greater chance of survival and less maternal energy is required for gamete production (Fryer and Iles 1972). Female *T. aurea* had a mean fecundity of 719 eggs with a range of 325 to 4,392 (Dadzie 1970a), and is closely related to the square of the length (Payne and Collinson 1983). In addition, mouthbrooders are better able to adapt to rapid changes in water levels due in part to their pelagic nature (Lowe-McConnell 1959; Philippart and Ruwet 1982). Payne and Collinson (1983) suggest that at least in Egypt *S. aureus* have a protracted spawning season with two more or less distinct spawning peaks from May to September. In certain other areas with annual low temperatures, inhibition of year-long spawning may also occur (Philippart and Ruwet

1982). Normal spawning activity for *S. aureus* begins at about 22 °C (Fishelson 1966 in Payne and Collinson 1983; Katz and Eckstein 1974; Terhatin-Shimony and Yaron 1978) and most tilapia need water of at least 20 °C; however, *T. sparrmanii* can reproduce at 16 °C (Chimits 1957). Generally, reproductive activity ceases below 18 °C. *T. aurea* held at 21 °C had delayed gonadal differentiation compared to fish held at 30 °C (Dutta 1979 in Shelton et al. 1981). McBay (1961) observed first spawning in *T. nilotica* (= *T. aurea*) held at a constant aquarium temperature of 23.3 °C, and in outdoor ponds when diurnal temperatures ranged from 21.1 to 28.8 °C. Factors other than temperature, such as photoperiodicity, light intensity, water level, and proximity to suitable spawning and nursery areas may also influence spawning behavior (Philippart and Ruwet 1982). Because of its mouthbrooding characteristics which confer protection to the young, *S. aureus* can be a very prolific fish (Dr. Ray Drenner, Department of Biology, Texas Christian University, Fort Worth, Texas, pers. comm.). Stunted populations can occur in which fish as small as 20 g (Perry and Avault 1972) to 31 g (Pelren and Carlander 1971) are mature and can reproduce.

Induced spawning of *T. aurea* has been successful. Dadzie (1970a, 1970b) found that HCG (human chorionic gonadotrophin) was consistent and effective in inducing spawning. Other hormones were investigated but were less successful.

Competition. —Tilapia introduced into an aquatic system may interact with resident fish in several ways. Introduced tilapia may compete with gizzard and threadfin shad for food (Crittenden 1962; Harris 1978; Hendricks and Noble 1977; Payne 1974) and with bass (principally largemouth) and panfish for spawning habitat (Harris 1978; Hendricks and Noble 1977; Nicola 1979; Noble et al. 1975; Perry and Avault 1972); they allegedly also feed on game fish larvae (Harris 1978; Junor 1969). *T. aurea* is particularly adaptable to eutrophic situations (Buntz and Manooch 1969a) and if they flourish, their numbers could increase to the point that they might not be controlled by native predators (Ware 1973). In mesotrophic situations, however, with good water quality and diverse habitats, where game fish flourish and are abundant and where algal blooms are rare, blue tilapia exist as only a minor component of the fish community (Ware 1973). Pelren (1969) reported that largemouth bass in some Iowa ponds preyed on *T. aurea* and prevented the tilapia from becoming abundant enough to control vegetation. Besides predation by largemouth bass, YOY tilapia were also possibly preyed upon by aquatic invertebrates (Belostomatidae, and hydrophyllid and dytiscid beetles) and tiger salamanders. Black bullhead stomachs from one pond contained young tilapia, and in another pond recruitment of tilapia was probably reduced by abundant green sunfish and goldfish. Largemouth bass preferred *T. aurea* as prey compared to bluegill of the same size under experimental conditions (Zale pers. comm.). A good predator will probably keep tilapia numbers in check (Smitherman pers. comm.). Tilapia populations kept in check by largemouth bass grew faster and exhibited better condition than those where predation was absent and the forage fish became overpopulated (Crittenden 1962). If tilapia populations can be controlled by a predator such as the largemouth bass or by some other means to allow adequate bass reproduction, especially in mesotrophic situations, it should be possible to maintain both a selfsustaining bass population and a harvestable size tilapia population (Noble et al. 1975). Habel (1975) reported that *Tilapia* spp. were stocked into 21.5 ha Crenshaw County Public Lake in Alabama almost yearly from 1962 to 1971; in 1971, 26,500, 51 to 127 mm *T. aurea* were stocked. The lake also contained largemouth bass, bluegill, redear sunfish, black crappie, and channel catfish. The tilapia were stocked to control filamentous algae and provide an additional game fish. *T. aurea* overwintered in the lake, and in 1972 to 1973, about 592 kg/ha of tilapia were harvested; the tilapia had no adverse effects on the game fish population of the lake as indicated from catch records.

Legner and Medved (1973) reported male dominance among 1 year old *T. mossambica* in the lower Colorado River. They felt that the territorial behavior exhibited by these fish, as well as significant predation by bass would serve to reduce the number of fry in the summer, help keep unmanaged tilapia populations at low levels, and help reduce the threat of adverse outbreaks in the aquatic habitats of the American Southwest.

On the negative side, the presence of large populations of tilapia may reduce or eliminate spawning success of game fish, especially centrarchids such as largemouth bass, bluegill, and redear sunfish (Buntz and Manooch 1969; Harris 1978; Noble et al. 1975). Adult game fish may survive and exhibit good growth, but lack of successful spawning results in negligible game fish recruitment (Noble et al. 1975). Reduction or cessation of spawning by game fish in ponds or small water systems in the presence of high numbers of forage fish may be due to buildup on an undefined repressive factor secreted by the forage species. In 303-ha eutrophic Trinidad Lake in Henderson

County, Texas, an accidental introduction of *T. aurea* in the late 1960's lead to the production of up to 2640 kg/ha (Germany and Noble 1977); at this high level of tilapia, recruitment of largemouth bass apparently ceased. Even fast growing Florida largemouth bass failed to recruit successfully (Noble et al. 1975). In Florida, 2245 kg/ha of tilapia had an impact on largemouth bass spawning (McCall pers. comm.). Although a piscivorous fish like a largemouth bass can and does utilize tilapia for forage (Noble et al. 1975; Zale pers. comm.) the predatory fish population is usually unable to remove sufficient quantities of the young tilapia to maintain the desirable balance of predator to prey fish in the population (Pagan-Font 1975) and the tilapia may grow out of the forage range for bass (Shafland pers. comm.; Ware pers comm.). Tilapia may also prey directly on young, recently hatched game fish, or may compete with the young game fish for food and, thus, reduce game fish recruitment (Buntz and Manooch 1969; Junor 1969; Perry and Avault 1972). Zale (pers. comm.), however, feels that competition with channel catfish is uncertain but, because of dietary differences, competition would be low, except perhaps among young fish. Allen and Carter (1976) reported that channel catfish ate blue tilapia that escaped into a divided raceway compartment containing channel catfish. Flathead catfish also prey on tilapia (Mr. Don Wingfield, Arizona Game and Fish Department, Yuma, pers. comm.) as do common carp and silver carp, if the size of the tilapia fry and the carp are suitable (Spataru and Hepher 1977). Competition for available plankton and other food resourcs may explain the decrease in the catch of *S. galilaeus* after the introduction and continued stocking of *S. aureus* into Lake Kinneret, Israel (Gophen et al. 1983a). These two species apparently have a high degree of niche overlap in food and spawning requirements.

The results of introductions of tilapia into suitable waters are mixed and range from low or moderate effects (Habel 1975; Ware 1973; Zale pers. comm.) to severe effects (Burgess et al. 1977; Courtenay and Robins 1973; Crittenden 1962; Curtis 1983; Harris 1978; Mann 1979; Manooch 1971; Noble et al. 1975; Payne 1974; Perry and Avault 1972; Shafland 1976, 1979; Spataru and Zorn 1976; Ware 1973). In Florida where sportfishing success for *T. nilotica* was low, and where they survived winter water temperatures, the species was not considered desirable (Barkuloo 1964). Nonnative organisms introduced into a new and different environment will seek a certain trophic level, which may not necessarily be the same as the one occupied by the fish in its native habitat (Courtenay and Robins 1973); open water areas are probably more easily exploited by the planktivorous mouthbrooding *Sarotherodon* spp. than by substrate brooding *Tilapia* spp. (Payne 1974). In areas with a depauperate ichthyofauna, the introduction of exotic or nonnative fishes may result in the extermination of endemic species (Courtenay and Deacon 1983; Hubbs and Deacon 1964). "The introduction of an exotic organism is an irreversible step with unpredictable consequences" (Mann 1979). When exotic or nonnative fish species are planned for introduction, sufficient ecological data about the new species must be reviewed and evaluated, as well as ecological conditions in the receiving waters. Potential areas of interspecific competition must be identified to ascertain that the new introduced species do not consume the food of the already existing and possibly desirable species (Courtenay and Robins 1973; Spataru and Zorn 1976) or compete for spawning area. In Lake Kinneret, Israel, the catch of *S. galilaeus* declined following the stocking of *S. aureus* and two other exotic fish species (Gophen et al. 1983b). Gophen et al. (1983b) challenged Ben-Tuvia's (1981) assertion that the stocking of exotic fish species into Israeli waters was economically advantageous and that stocking of Lake Kinneret with exotic fish species, including *S. aureus*, added several hundred tons to the annual catch without any observable negative effect on other fish stocks. Minckley (1983) stated that interactions between native and nonnative animals could result in the elimination of one species or the other. Likewise, interactions between established nonnative and exotic or recently introduced nonnative fishes could lead to elimination of one or the other. Minckley feels that predation by introduced fish species may be a primary cause in the decrease or even extirpation of the established fish species. Predation, rather than direct competition for resources, may be the major force in bringing about faunal change.

Tilapia, because of their planktivorous nature, may compete with gizzard and threadfin shad and, in fact, might be a desirable method of controlling shad populations by reducing available plankton (Crittenden 1962).

Age and growth. — *Tilapia aurea* survive and grow in various concentrations of seawater (Chervinski and Zorn 1974) as well as in freshwater. Survival in seawater for about a 5 month period was 56 percent; the fish gained an average of 311.9 g or 1.97 g/day.

In 303 ha Trinidad Lake in Texas, Gleastine (1974 in Germany and Noble 1977) found that male tilapia were 242, 318, and 346 mm at ages 1, 2, and 3, respectively, and females were 223 and 307 mm at ages 1 and 2. Payne and Collinson (1983), on the other hand, reported that *T. aurea* females were larger than males for the first 2 years of life, after which the males grow larger. Growth rate slowed down in the second year, probably because *T. aurea* spent a large amount of energy on reproduction, since once the fish matured, they could spawn repeatedly if environmental conditions are suitable.

Excerpts and summaries from Arizona Game and Fish Department Federal Aid to Fish Restoration reports relative to Central Arizona Project waters. — The following section is a chronological summary of narrative statements regarding introduction, status, and effects of tilapia in Arizona gleaned from an examination of various Arizona Game and Fish Department progress and completion reports for the period 1959 to 1982. The particular report from which the information was obtained is indicated, and any material quoted is so indicated.

(1.) F-7-R-5, November 1961 through October 1962, work plan 5, by W. G. Gaylor. — *Tilapia mossambica* were stocked in pond 7, presumably one of the Papago Ponds. Twenty-one 142-mm tilapia were stocked on April 11, 1961. On March 27, 1962, 16,071 tilapia weighing 552.3 kg were harvested, for production of 270 pounds per surface acre. These 16,071 fish were stocked in Encanto Park, Tom's Pond Buckeye Canal, Buckeye Lake, Maytag Zoo, and Deer Valley. No mortality due to cold water was observed in any receiving waters.

(2.) F-7-R-7, November 1963 through December 31, 1964, work plan 5, job No. S-1, p. 91. — The tilapia introduction program in the Phoenix area canals and small ponds has been discontinued for the present. Plants have produced few returns and apparently there was no reproduction or carryover through the winter. Hatchery research is being done at Page Springs Hatchery, and there is a possibility of developing a fishery by stocking fingerlings in the spring. This would provide a fishery from August to September until occurrence of fatal low temperatures in December. (Tilapia species not indicated).

(3.) F-7-R-8, January through December 1965. — Electrofished for tilapia in Yuma drainage canals. Most tilapia stomachs were empty. Those with food had minnows, or minnow fragments, and plant debris. (Tilapia species not indicated).

(4.) F-7-R-10, January through December 1967, work plan 4, job No. S-1. — A tilapia fishery of significant proportions was developed in Painted Rock Lake through early spring stocking of adult fish with primary harvest of young occurring in late summer and fall. (Tilapia species not indicated).

(5.) FS-4, January through December 1968, work plan 4, job No. S-1. — Two tilapia collected by electrofishing in 1968 in Gadsden Lake (now Hunter's Hole), 172- and 185-mm long, weighing 109 and 136 g respectively.

(6.) FS-5, January through December 1969, work plan 4, job No. S-2. — Tilapia were collected in Salinity Canal and transported to various parts of Arizona and California.

- 2,000 tilapia were transplanted into Painted Rock Lake about mid-April 1969.
- 800 tilapia were transplanted into Allenville Pond, August 1, 1969.
- 550 tilapia were collected from Salinity Canal in Yuma, July 14 and 15, 1969.
- 250 released in Imperial Valley for aquatic plant control in Imperial Irrigation District.
- 300 transported to private military lake near Corona, California.

Recommendation No. 6: "Redondo Lake be renovated and restocked with various warm water game fish which would include a yearly stocking of tilapia."

Recommendation No. 8: "Tilapia transplanting to various areas in Arizona and California be continued."

1969 electrofishing — Gadsden Lake, eight tilapia collected.

(7.) FS-7, January through December 1971, work plan 4, job No. S-1, by Allen F. Guenther. — "Cement lining of the Salinity Canal should reduce the tilapia fisheries and side ponds are being asked to mitigate losses."

"Tilapia populations experienced their normal winter die-off." (Location not clearly indicated).

Imperial Reservoir — no tilapia were taken in the spring electrofishing survey.

Salinity Canal. — "Bureau of Reclamation is proposing to cement line the last 13.1 km of the Salinity Canal. This will destroy the excellent tilapia fishing in this section and below to Morelos Dam on the Colorado

River. The Arizona *Tilapia mossambica* record of 1.09 kg was recently taken from this area as was the preceding record tilapia.

"Tilapia will not live or reproduce in cement-lined canals with swift current and no protection. Region IV personnel checked for tilapia reproduction in the upper area of the Salinity Canal on November 17, 1971. A net was placed in the canal at Avenue 43E and County Third Street near Roll. A gallon of rotenone was poured into the canal about three-fourths of a mile above the net. Only four mollies were collected in this area.

"Mitigation for losses to the fishery value currently consists of three ponds to be constructed along the canal. These proposed ponds are to be about 91.4 or 122 m long and 11.6 m wide at the top. In addition to the pond, a 61 m silled area is proposed in the canal. These ponded areas are still under study."

Tilapia spp. were transplanted into Gila Bend Canal in March 1971.

15,900+ tilapia were collected in the Salinity Canal during 1971 and transplanted in waters of Arizona and California.

127 to Boy Scout Pond at Yuma Proving Ground, 16,468 to other waters in Region IV

Thousands of fish in a drainage ditch near Somerton were killed. Most were tilapia. (No date given for fish kill).

September 6, 1971 — 18 tilapia killed from anhydrous ammonia spill in B37W lateral.

Tilapia had annual winter die-off in Painted Rock Lake, Colorado River, and some Yuma canals. Unconfirmed reports of tilapia die-off in Boy Scout Pond during summer.

(8.) FS-4, January through December 1972, work plan 4, job No. S-1, by Allen Guenther. — Five hundred tilapia were electrofished in East Main Drain in Yuma Valley and transplanted into Painted Rock Lake on May 31, 1972. Tilapia had normal die-offs in Painted Rock Lake, Colorado River, and other marginal canals in the Yuma area where water temperatures drop below 12.8 °C.

Twenty-five tilapia were sent to Dr. George Streisinger of University of Oregon for temperature tolerance and reproduction research.

Bureau of Reclamation awaiting okay to line 13.1 km of Salinity Canal. AGFD should assist Bureau of Reclamation with fish salvage there. Unlined portion getting much fishing pressure. State tilapia record broken three times recently in this unlined section.

(9.) F-7-R-16, July 1973 through June 1974, by Tom Robinson. — Drawdown of 13.6 km of Salinity Canal for lining eliminated a significant tilapia fishery.

Three small ponds received as a mitigation measure. Twenty-six tons of tilapia seined and restocked in Arizona and California. Estimated 200 tons of tilapia lost.

Tilapia apparently affected very little by TDS.

(10.) F-7-R-19, July 1976 through June 1977, by Tom Robinson. — Speculates that as the deeper pools in the lower 33.6 km of Colorado River just above the international boundary dry up, tilapia and other species will disappear.

Weekly temperatures were taken in Bill Williams River 1.6 km upstream from Lake Havasu and two other sites to determine if temperatures were low enough to be detrimental to survival of *Tilapia* spp. (10 °C = 50 °F). Daily minimums 10 °C or less from January 10 through February 8, 1977, but daily maximum during this period was about 17.0 °C.

(11.) F-7-R-21, July 1978 through June 1979, by Brad Jacobson. — Two tilapia collected electrofishing the Ehrenberg Strip.

(12.) F-7-R-22, July 1979 through June 1980, by Brad Jacobson. — Fish kill in Painted Rock Reservoir on January 31, 1980. About 50 percent of estimated 1 million fish killed were tilapia. Suffocation from anaerobic water suspected. [However, surface limnological data for Painted Rock Lake (upper) indicated a temperature of 17 °C with 2.0 mg/L D.O. in February 1980, and for Painted Rock Lake (lower) a surface temperature of 19 °C and 7.5 mg/L D.O. in February 1980. It is not clear where the fish kill occurred or what the limnological conditions were immediately prior to the fish kill.]

Ten tilapia were collected electrofishing the Ehrenburg Strip of the Colorado River in 1979-80.

Eight tilapia were collected in the Yuma Division and one tilapia was collected in Mittry Lake.

In Painted Rock Lake, 72 tilapia were taken and were the third most common fish in the creel (11.5 percent).

In the Imperial-Cibola Division of the Colorado River, nine tilapia contributed 1.1 percent to the creel.

(13.) F-7-R-22, July 1979 through June 1980, by Ken Hanks. — Fish kill in Painted Rock Reservoir, January or February 1980, killed about 3 million fish (carp, threadfin shad, tilapia, and bluegill). Anaerobic conditions suspected.

(14.) F-7-R-23, July 1980 through June 1981, by Brad Jacobson. — Imperial Division — A few tilapia were collected by electrofishing 1980 to 1981. Eight percent of the creel was tilapia, although the average length decreased from 1979 to 1980.

Yuma Division. — In 1980 to 1981, sharp increase in tilapia (22.6 percent) collected by electrofishing compared to 1979-80 (1.57 fish/minute versus 0.20 fish/minute). Average length of the 1980 to 1981 tilapia was 16.5 cm and average weight was 98 g. Tilapia, however, contributed only about 6.1 percent to the creel.

Existing Fisheries of CAP Source and Receiving Waters.

Relevant features of the fisheries of Lake Havasu, Lake Pleasant, Alamo Lake, and the Salt and Verde Rivers will be discussed. Information on the fisheries of these systems from 1961 to the present (spring 1983) was compiled from an examination of Arizona Game and Fish Department Federal Aid to Fish Restoration Reports (F-7), open literature articles, and personal communication with State, Federal, university, and private fishery biologists.

Fishery aspects of Lake Havasu. — For purposes of this literature review and analysis, a discussion of fishery aspects of Lake Havasu will be limited to the areas in and around the mouth of the Bill Williams River, the CAP intake channel, and other appropriate or relevant locations. Lake Havasu itself supports a substantial sport fishery. A detailed account of distribution and abundance of fishes in the Lower Colorado River (including Lake Havasu) was prepared by Minckley (1979) and the U.S. Fish and Wildlife Service (1980). Seventy-nine species are included in the USFWS report; however, *Tilapia aurea* is not listed, although *T. mossambica* and *T. zilli* are listed. Minckley (pers. comm.) has collected *T. aurea* from the lower Colorado River, however. In the stocking records section of the U.S. Fish and Wildlife Service (1980) report, which covers the period 1880 through 1978, no tilapia are listed. However, introductrions of striped bass and white bass are listed and are discussed elsewhere.

Minckley (1979) conducted an extensive and exhaustive aquatic study of the lower Colorado River from 1974 to 1976. Here we consider only the fishery aspects of that report.

The Havasu Division was sampled in summer (June) 1974 and winter (December to January) 1975 to 1976. Several methods were used to collect fish in the lower Colorado River; seines, gillnets, hoop nets, fyke nets, and trammel nets. Hoop nets were generally not productive in Lake Havasu and other methods were employed for most sampling.

Minckley (1979) listed 19 fish species from the Havasu Division of the lower Colorado River; 3 native species (bonytail chub, Colorado squawfish, and razorback sucker), 15 introduced species, and 1 hypothetical species (white sturgeon). Largemouth bass, channel catfish, striped bass, and black crappie were the important sport fish. Other species caught or observed in Lake Havasu by Minckley included: threadfin shad, red shiner, yellow bullhead, mosquitofish, green sunfish, redear sunfish, bluegill, and carp. Numerous threadfin shad were collected by seines, followed by juvenile bluegill, red shiner, mosquitofish, young largemouth bass, and juvenile black crappie. Gillnets yielded principally carp, followed by channel catfish, largemouth bass, and threadfin shad. Vertical gill nets, intended to obtain data on depth distribution of fishes, caught only threadfin shad in midwater habitat. The use of vertical gillnets was discontinued. Trammel nets caught largemouth bass, followed by carp, channel catfish, striped bass, yellow bullhead, and small numbers of the abundant threadfin shad, due to net selectivity. Generally, carp contributed more biomass than all other fish species combined, although less than 50 percent of total number of fish collected.

During the 1974 to 1976 sampling period, only the mouthbrooder (*T. mossambica*) and redbelly tilapia (*T. zilli*) were collected, and these were from the Laguna, Yuma and Limitrophe, and Palo Verde and Limitrophe Divisions, respectively. No *T. aurea* were reported collected or observed, and no tilapia of any sort were reported from Lake Havasu. Ulmer (pers. comm.) and Guisti (pers. comm.) also indicate that in the Colorado River, tilapia are restricted to below the Palo Verde Diversion Dam.

Personnel of the Bureau of Reclamation and Fish and Wildlife Service conducted limited electrofishing at three sites and gillnetting at two sites in and near the Havasu intake channel from April 26 through 28, 1982, to determine (1) if the manmade dike and intake channel provide suitable habitat for fish, and (2) to compare the use of the dike to nearly comparable natural areas in terms of species, age class, biomass, and number of individuals. The three sites were as follows:

Site A. — The shoreline of the manmade dike on the inlet side of the intake channel
Site B. — The shoreline of the manmade dike facing the Bill Williams arm side of the lake
Site C. — A segment of the natural shoreline south of the dike which formed part of the shoreline of the intake channel

Each site was electrofished once, and night gillnetting was conducted at sites A and C. The species of fish collected and lengths and weights are shown in table 16.

Results of gillnetting sites A and C are shown in table 17. The study concluded that the manmade dike was used by several species and age groups of fish, and the use exceeded that of a comparable shoreline segment in the same general area. Apparently, some spawning by sunfish was indicated at site A.

The Bill Williams unit of the Havasu NWR (National Wildlife Refuge) has been sampled for several years by Mr. Mike Donahoo of the U.S. Fish and Wildlife Service, Parker, Arizona. A variety of collecting methods was employed, including experimental-mesh gillnets, 1.8 by 38.1 m, and hook and line. In December 1979, striped bass, largemouth bass, and razorback suckers were collected at the confluence of Bill Williams River and Lake Havasu. In October 1980, near the CAP intake cove, five largemouth bass and one green sunfish were captured. In November 1980, at the mouth of Bill Williams River, using three experimental-mesh gillnets, 18 striped bass were captured as well as 5 channel catfish, 2 black crappie, 2 largemouth bass, 2 threadfin shad, and 7 carp. The striped bass were reportedly in poor condition.

Table 16. — Species of fish collected electrofishing at three sites in and near the Havasu intake channel, April 26 through 28, 1982

Species	Site A			Site B			Site C		
	N	Length (mm)	Weight (g)	N	Length (mm)	Weight (g)	N	Length (mm)	Weight (g)
Largemouth bass	9	85-335	12-577	6	108-260	10-215	4	140-300	150-310
Bluegill	15	46-98	[1]70	8	42-168	2-105	13	80-191	?-130
Green sunfish	39	48-130	?-48	4	78-100	15-20	6	74-110	10-20
Channel catfish	3	78-575	5-2000	4	76-272	2-130	1	460	670
Carp	10	425-480	1100-1350	3	421-460	900-1150	4	432-521	820-1350
Threadfin shad	5	78-102	5-10	1	77	5	1	95	2
Black crappie				1	205	110	1	200	105

[1]Combined individual weights.

Table 17. — Fish collected with gill nets at sites A and C of the Havasu intake channel April 26 through 28, 1982

Species	Site A			Site C		
	N	Length (mm)	Weight (g)	N	Length (mm)	Weight (g)
Striped bass	1	491	1082			
Threadfin shad	14	100-158	—	1	145	22
Channel catfish	1	100	4			

In March 1981, largemouth bass and many carp were observed in a beaver pond in the Bill Williams River area of Havasu NWR, but it is not clear whether the pond was on the Bill Williams River or on a tributary. Red shiners were also observed spawning below the beaver dam. The report suggested that the refuge portion of the river be sampled in more detail to obtain baseline data of resource information for the refuge. In July and August 1981, several sites were gillnetted: the Bill Williams Arm of Lake Havasu, a site midway down the CAP dike, one in a cove east of the CAP worksite, one to the west of the U.S. Highway No. 95 bridge, and one on the north shore across from the CAP site. One hundred twenty-two fish were captured, including five YOY striped bass taken in the net set on the CAP dike. Also collected were 39 largemouth bass, 37 channel catfish, 1 flathead catfish, 2 black crappie, 1 bluegill, 14 carp, and 1 goldfish. No threadfin shad were collected. In December 1982, experimental-mesh gill nets were set in the Bill Williams arm of Lake Havasu near the confluence, another in the delta area west of the U.S. Highway No. 95 bridge, and the last on the north side of the CAP inlet dike. Seventy-nine fish were collected: 55 striped bass, 11 largemouth bass, 7 channel catfish, 2 carp, and 1 each yellow bullhead, black crappie, bluegill, and threadfin shad. No tilapia were collected at any time in the Bill Williams River or nearby areas of Lake Havasu.

The following additional information regarding the fishery aspects of Lake Havasu was obtained from Arizona Game and Fish Department Federal Aid in Fish Restoration reports.

In 1959, it was felt that as time, personnel, and funds were available, surveys should be made in the area of Lake Havasu to Yuma to determine the present trends and problems of the fisheries. Increased utilization of the fisheries in this area dictated the need for a sound management program.

Six thousand trout were planted below Davis Dam, April 1961 to October 1961.

Two hundred and seven largemouth bass from 14.0 to 48.5 cm in length were taken from Lake Havasu during the 1962 shocker barge operations. The 1-year-old size group dominated the sample while older size groups were not as well represented. This indicated a successful 1961 spawn with a lack of spawning success or high mortality among the 2-year-old group.

One hundred forty-three largemouth bass were sampled from Lake Havasu during the 1963 shocker operation. "Yearling" bass in the 17.8-cm class dominated the catch. A similar situation occurred on Lake Mead. This indicated that Lake Mead and Lake Havasu had a successful 1962 bass hatch. However, fishing success on Lake Havasu was far below that on Lake Mead. There were 84,400 trout planted below Davis Dam during the year. Plantings were made starting below Davis Dam and ending about 19.2 km downriver at Fort Mohave. There were also some plants made in the Needles, California area.

In the later part of 1963 and most of 1964, 51 man-days were spent contacting 1,005 anglers. These anglers fished 2,658 hours and caught 636 fish, for an average of 0.22-fish-per-hour compared to 0.34-fish-per-hour in 1963. The average fishing day was 2.6 hours long. The composition of fish in the creel was as follows:

Species	Number	Average length (cm)	Percent of total
Largemouth bass	401	32.8	63.3
Bluegill sunfish	36	19.1	5.7
Green sunfish	1		0.1
Crappie	51	35.1	8.0
Channel catfish	131	33.5	20.7
Carp	4	41.9	0.6
Rainbow trout	10	32.5	1.6
Total	634		100.6

In the Topock Marsh, 43 man-days were spent gathering creel information. Four hundred and forty-two fishermen were contacted. They had caught 407 fish in 1,552.5 hours for an average of 0.26-fish-per-hour. The average fishing day was 3.5 hours long. The composition of fish in the creel was as follows:

Species	Number	Average length (cm)	Percent of total
Largemouth bass	176	34.8	43.2
Bluegill sunfish	2	19.1	0.4
Crappie	61	25.9	14.9
Channel catfish	128	44.7	31.4
Carp	4		1.3
Rainbow trout	16	31.2	3.9
Others	20	23.1	4.9
Total	407		100.0

In 1965, largemouth bass of Lake Havasu in the 27.9 to 38.1-cm group were much more numerous than in 1963. Cove renovation in Lake Havasu yielded similar results to those of 1964. In addition to largemouth bass, other species of fish obtained in the Lake Havasu cove renovation were bluegill, green sunfish, brown bullhead, and black crappie.

The large increase in the numbers of bass in the 12.7 to 22.9-cm size group indicated good spawning success the previous summer. Also captured in the 1965 sampling were three black crappie, (average length 32.8 cm; average weight 0.57 kg), six green sunfish (average length 12.7 cm), and two rainbow trout (average length 33.3 cm; average weight 0.51 kg). Records were unclear as to exact location and sampling method used to obtain the data.

Two plankton nets were fished for 3 consecutive days, May 11 through May 13, in order to sample the Colorado River in the Topock Gorge area immediately above Lake Havasu for larval striped bass and eggs. None were found.

> "No major changes occurred during the past project year in the physical, chemical, and biological conditions of the waters of the lower Colorado River and Lake Havasu. Largemouth bass from Lake Havasu in the 10.2-22.9 cm group greatly exceeded the number of this size group taken in 1965."

Cove renovations were conducted in Lake Havasu in 1966, and results differed from results of the previous year. Cove "one" produced 30 largemouth bass in 1966 and 111 in 1965, while cove "two" produced 56 bass in 1966 and 47 in 1965.

The cove renovation work consisted of applying rotenone in 0.08-ha and 0.05-ha coves. Aquatic vegetation was described as being very dense to relatively heavy in the 0.31 to 0.97-m deep shore margins. Water was about 30°C.

It was felt, from information obtained in the cove renovation work, that reasonably adequate recruitment of largemouth bass had occurred in Lake Havasu.

Other sunfishes, principally bluegill, occur in very high density levels in the size ranges up to 12.5 cm and could be exerting adverse competitive and/or predatory pressure on the largemouth bass population. This situation should be closely studied and appropriate remedial action taken through stocking or other population control methods if deemed necessary.

In 1967, an electrofishing survey yielded 19 black crappie averaging 16.8 cm in length, 12 carp averaging 44.2 cm in length, and 4 green sunfish averaging 17.3 cm in length.

> "A cove renovation was done on Lake Havasu in 1967. No major changes occurred during the past project year in the physical, chemical, and biological conditions of the waters of Imperial Reservoir and Lake Havasu."

In Lake Havasu, in 1968, 695 fish were collected with electrofishing gear in the spring and 795 fish were collected in the fall. In the fall, 683 largemouth bass were collected, along with 69 bluegill, 14 carp, 12 crappie, 11 green sunfish, and 6 bullheads.

Largemouth bass made up 63.8 percent of the total spring catch and 86.0 percent of the fall catch. In the spring, bass in the 15-cm class were predominant in the catch, and in the fall, bass less than 15 cm were predominant. This high number of the 15-cm and smaller largemouth bass taken in both the spring and fall indicated successful survival of the 1967 and 1968 hatches.

An electrofishing survey at several sites in Lake Havasu conducted from December 5 through 9, 1969, yielded 718 fish; 604 largemouth bass, 66 bluegill, 34 carp, and 14 crappie.

The Willow Beach National Fish Hatchery planted 208,170 trout between Davis Dam and Needles, California in 1971.

In 1978, one razorback sucker (*Xyrauchen texanus*) was caught by a fisherman in Mesquite Cove in Lake Havasu. A shoreline examination of Mesquite Cove turned up the skeleton of another razorback sucker. Electrofishing was curtailed due to equipment failure. Table 18 shows the creel summary for 634 fish harvested in 1977 to 1978 in Lake Havasu.

Results in the table were based on 69 creel census days from November 1977 to April 1978; catch per man-hour over 3,445 hours was 0.18 fish.

From July 1978 through June 1979, 158 anglers were checked during 6 man-days of creel census on Lake Havasu (table 19). In 462 hours of fishing, 128 fish were taken for a catch rate of 0.28 fish per hour. This was an increase of 0.10 fish per hour when compared to 1977-1978. Largemouth bass made up 57.8 percent of the creel for the year (table 20). In 1977-1978, largemouth bass only constituted 29 percent of the harvest.

Average length of largemouth bass in 1978-1979 (312 mm) decreased slightly from 1977-1978 (337 mm).

Channel catfish were the second most prevalent fish in the creel for 1978-1979 (26.8 percent). Channel catfish only contributed 15 percent to the creel in 1977-1978. The average length dropped from 355 mm in 1977-1978 to 335 mm in 1978-1979.

Creel census efforts on Lake Havasu were limited to the months of September, March, and April. These months were generally accepted as being the best largemouth bass fishing months.

From July 1979 through June 1980, 47 anglers were checked during 6 man-days of creel census on lower Lake Havasu (table 21). Seventy-six fish were taken in 179 hours of fishing for a catch rate of 0.42 fish per hour.

Black crappie accounted for 50.8 percent of the fish harvested during the year. They averaged 283 mm in length, a 39-mm increase over black crappie taken the previous year.

Table 18. — Creel summary of Lake Havasu, FY 1977-1978

Fish species	% of total	Mod. lgth. (mm)	Max. lgth. (mm)
Largemouth bass (185)	29	325	337
Black crappie (119)	19	312	264
Channel catfish (95)	15	301	355
Sunfish (76)	12	152	166
Striped bass (35)	6	ND	634
Carp (3)	1	ND	ND
Unclassified (121)	19		

Largemouth bass were the second most abundant fish in the creel at 26.2 percent of the catch. Average length increased from 312 mm in 1978-1979 to 378 mm in 1979-1980.

Table 19. — Creel census summary of Lake Havasu 1978-1979

Months checked	Days checked	Total anglers	Total hours checked	Total fish	Fish/ hour	Fish/ angler	Successful anglers	Percent success
Sept.	3	67	188	58	0.31	0.87	22	32.8
March	1	28	79.5	18	0.23	0.64	9	32.1
April	2	63	194.5	52	0.21	0.83	26	41.3
Total	6	158	462.0	128			57	

Table 20. — Percent composition and average size of species in the creel — Lake Havasu, (1978-1979)

	July-Sept.			Oct.-Dec.			Jan.-March			April-June			Yearly total		
Species	No.	% total	Avg. lgth. mm	No.	% total	Avg. lgth. mm	No.	% total	Avg. lgth. mm	No.	% total	Avg. lgth. mm	No.	% total	Avg. lgth. mm
Largemouth bass	28	48.0	284	0	0	0	14	78.0	332	32	62.0	325	74	57.8	321
Channel catfish	19	33	361	0	0	0	1	5.0	356	14	27.0	352	34	26.6	335
Sunfish	11	19	163	0	0	0	0	0	0	0	0	0	11	8.6	162
Black crappie	0	0	0	0	0	0	3	17.0	305	5	9	208	8	6.3	244
Black crappie	0	0	0	0	0	0	0	0	0	1	2	229	1	0.7	229
Total	58	100.0	-	-	-	-	18	100.0	-	52	100.0	-	128	100.0	-

Table 21. — Creel census summary of Lake Havasu, 1979-1980

	July-Sept.	Oct.-Dec.	Jan.-Mar.	Apr.-June	Total
Days checked	-	-	2	4	6
Total anglers	-	-	37	10	47
Arizona	-	-	37	3	40
California	-	-	0	7	7
Other	-	-	0	0	0
Total hours fished	-	-	153	26	179
Total fish	-	-	74	2	76
Fish/hour	-	-	0.48	0.08	0.42
Fish/angler	-	-	2.00	0.20	1.62
Successful anglers	-	-	23	2	25
Percent successful	-	-	62.2	20.0	53.2

Three hundred eighty-one fish were collected on Lake Havasu during fishery surveys. Sunfish comprised 43.0 percent of the fish collected, at a rate of 1.06 fish per minute of shocking time. Largemouth bass followed at 34.1 percent and 0.86 fish per minute, carp at 15.0 percent and 0.16 fish per minute, channel catfish at 4.7 percent and 0.11 fish per minute, and black crappie at 3.2 percent and 0.06 fish per minute.

Carp were the largest fish taken, averaging 453 mm in length, followed by channel catfish (365 mm) and largemouth bass 238 mm (table 22).

Largemouth bass, in the 200- to 250-mm size class represented 37.7 percent of the bass taken, followed by 21.5 percent in the 250- to 300-mm size class. Fish less than 150 mm in length made up 10 percent of the sample and fish over 400 mm long amounted to 3.1 percent.

Table 22. — Length and weight data for fishtaken from Lake Havasu electrofishing surveys, 1979-1980

	Length (mm)			Weight (gms)		
Species	Min.	Max.	x̄	Min.	Max.	x̄
Sunfish	42	192	94	10	160	48
Largemouth bass	63	534	238	43	1970	277
Carp	287	775	453	380	n/a	1160
Channel catfish	180	557	365	50	1559	504
Crappie	68	323	202	28	580	271

From July 1980 through June 1981, 573 fish were collected during survey operations on Lake Havasu. Sunfish predominated at 44.3 percent, followed by largemouth bass (35.1 percent), and carp (16.2 percent). Channel catfish, striped bass, goldfish, and black crappie accounted for the remaining 4.4 percent of the fish collected. Catch per unit of effort was constant with electrofishing gear. In 1979-1980, sunfish were collected at a rate of 1.06 fish per minute and in 1980-1981, the rate was 1.05 fish per minute. Largemouth bass followed with 0.86 fish per minute in 1979-1980, and 0.83 fish per minute in 1980-1981. Carp was the only species which increased from 0.16 fish per minute to 0.38 fish per minute.

Sunfish ranged in size from 3.9 cm to 19.4 cm in length with a mean of 10 cm (table 23). This was comparable to a mean of 9.4 cm in 1979-1980. Largemouth bass decreased from a mean length of 23.8 cm in 1979-1980 to 21 cm for 1980-1981.

Channel catfish had a mean length of 35.3 cm. Striped bass and carp averaged 25.9 cm and 46.9 cm in length, respectively.

Condition factors for the various species declined slightly from 1979-1980, except for channel catfish which remained the same at 0.79. Largemouth bass decreased from 1.33 to 1.20 and bluegill decreased from 1.81 to 1.50.

There were no fish kills reported for Lake Havasu during the fiscal year 1980-1981. A total of 99 anglers were interviewed during 26 man-days of creel census on Lake Havasu (table 24). Anglers caught 68 fish in 228.5 hours of angling for a catch rate of 0.30 fish per hour. Annual success for 1980-1981 averaged 27.3 percent.

Table 23. — Length and weight data for fish collected from Lake Havasu electrofishing surveys during 1980-1981

Species	Length (mm) Min.	Max.	$\bar{x}$	Weight (gms) Min.	Max.	$\bar{x}$
Sunfish[1]	3.9	19.4	10.0	<5	135	33
Largemouth bass[2]	5.1	54.0	21.0	<5	2060	192
Carp[3]	37.8	66.9	46.9	520	3860	1299
Channel catfish	25.4	46.2	35.3	110	940	381
Striped bass	19.3	32.5	25.9	80	335	208
Goldfish	-	-	40.0	-	-	1240
Black crappie[4]	-	-	7.5	-	-	-

[1]$\bar{x}$ weights based on 150 fish.
[2]$\bar{x}$ weights based on 190 fish.
[3]$\bar{x}$ weights based on 92 fish.
[4]No weight taken.

Table 24. — Creel census summary of Lake Havasu, 1980-1981

	July-Sept.	Oct.-Dec.	Jan.-Mar.	Apr.-June	Total
Days checked	4	9	10	* 3	26
Total anglers	19	*36	*13	*13	*99
Arizona	10	18	10	8	46
California	9	13	18	4	44
Other	0	4	2	0	6
Total hours fished	69.5	112	29	18	228.5
Total fish	26	34	4	4	68
Fish/hour	0.37	0.30	0.14	0.22	0.30
Fish/angler	1.37	0.94	0.13	0.31	0.69
Successful anglers	10	13	2	2	27
Percent success	52.6	36.1	6.5	15.4	27.3

*Origin of one unknown

Fishery aspects of Lake Pleasant. — At a water surface elevation of 518 m above sea level, upper Lake Pleasant has 1451 surface ha, and lower Lake Pleasant has 31.9 surface ha. Construction of New Waddell Dam would increase the area of the lake to between 6882.6 and 7287.4 surface ha. In 1961, several fish species were reported from Lake Pleasant. A creel census conducted January through October 1961 indicated that anglers harvested 6,877 largemouth bass, 1,872 black crappie, and 1,933 channel catfish. In 1962, angler hours at the lake increased over 1961; anglers harvested 4,028 bass. However, crappie fishing success declined, while channel catfish harvest increased to 5,026 fish. 1962 to 1963 electrofishing activities at Lake Pleasant revealed 552 largemouth bass, 20 crappie, 129 bluegill, 21 green sunfish, 89 carp, but no channel catfish or bullheads.

In 1963, the fish population in Lake Pleasant was in danger of being lost due to early year low water levels, but runoff from summer rains caused a rise in water level, with no resultant fish mortality. In 1964, electrofishing and cove renovation operations were conducted. Four hundred sixty-eight fish were collected during shocker operations in March, including 234 largemouth bass, 98 bluegill, 47 carp, 45 yellow bass, 18 green sunfish, 16 shad, 8 channel catfish, and 2 crappie. Low water levels apparently resulted in poor spawning conditions for largemouth bass. No largemouth bass were among the 350 fish collected during cove renovation operations. One hundred and fifty green sunfish, 115 threadfin shad, 67 bluegill, 12 carp, 4 channel catfish, and 2 bullhead were collected. Limited trapnetting in the lake in 1964 yielded 8 crappie and 2 largemouth bass. Sampling of three coves with rotenone in 1965 in Lake Pleasant produced a total of 259 largemouth bass, 43 bluegills, 21 threadfin shad, 12 green sunfish, 5 plains red shiner, and hundreds of mosquitofish. On July 14, 1965, 25,000 black crappie fingerlings were stocked in Pleasant. Thousands of crappie fingerlings were also stocked in Bartlett Lake on the Verde River and Saguaro Lake on the Salt River, in an attempt to determine if previous decreases in crappie population resulted from competition from threadfin shad. The source of crappie fingerlings was Willow Lake near Prescott.

Good water conditions in Lake Pleasant in 1964 through 1965 provided for a good largemouth bass spawn, with twenty-five 20.3- to 22.9-cm fish being collected by the shocker in January 1966. In addition, electrofishing yielded 47 carp, 53 bluegills, 17 white bass, 8 goldfish, 2 green sunfish, and 1 channel catfish. Cove rotenone sampling apparently yielded only a few fish, and none of these were reported in the annual report. The estimated angler harvest in Lake Pleasant from February to October 1966 included 16,012 largemouth bass, 7,293 bluegill, 3,689 white bass, 2,683 green sunfish, 503 channel catfish, and 419 carp.

In 1966-1967, winter electrofishing operations yielded 497 largemouth bass, 46 white bass, at least 64 bluegills, at least 56 carp, 21 goldfish, and at least 7 green sunfish. Results indicated lack of a successful largemouth bass spawn in 1966, since very few of the bass were less than 27.9 cm in length. White bass spawn was also poor in 1966 and was speculated to be poor again in 1967. No cove rotenone sampling was conducted in 1966-1967.

Winter 1967 through 1968 electrofishing produced 811 largemouth bass, 529 bluegill, 399 carp, 20 green sunfish, 18 white bass, 12 goldfish, 1 crappie, and 1 channel catfish. In the period February through October 1968, anglers harvested an estimated 9,746 largemouth bass, 5,122 green sunfish, 3,130 bluegill, 640 white bass, 498 carp, 427 channel catfish, and 71 bullhead from Lake Pleasant.

From February to October 1969, anglers harvested an estimated 11,303 largemouth bass, 2,862 bluegill, 858 white bass, 572 channel catfish, 143 crappie, and 72 carp from Lake Pleasant.

During electrofishing operations in the winter of 1968 to 1969, 521 largemouth bass were collected, as were 288 carp, 73 bluegill, 61 goldfish, 22 white bass, 19 crappie, 4 green sunfish, and 2 channel catfish.

No information was found in State F-7 reports regarding electrofishing or netting surveys, or creel census of Lake Pleasant from 1969 to 1973 to 1974. In 1973-1974, in electrofishing surveys, 120 largemouth bass, 117 bluegill, 69 carp, 7 white bass, and 5 green sunfish were collected.

In 1974-1975 electrofishing surveys in Lake Pleasant, 125 largemouth bass, 62 bluegill, 13 carp, 9 green sunfish, and 1 each goldfish, golden shiner, and "hybrid" were collected. Creel census data for 1973-1974, and 1974-1975 were deemed of questionable value in the annual reports.

In the 1975-1976 electrofishing survey of Lake Pleasant, 131 largemouth bass, 24 carp, 20 bluegill, 4 green sunfish, and 4 goldfish were collected, while actual documented angler harvest (not overall estimated harvest) was 117 bluegill, 113 white bass, 108 largemouth bass, 37 channel catfish, 25 green sunfish, 5 bullheads, 4 carp, and 2 white crappies.

An electrofishing survey of Lake Pleasant in January 1977 produced 36 largemouth bass, 10 bluegills, and 1 green sunfish. No creel census data were available for this period on Lake Pleasant. Apparently, cover for small fish is considered scarce in Pleasant and will be considered in future study plans.

In 1979-1980, 41 sunfish, 43 largemouth bass, 8 carp, 7 white bass, and 1 black crappie were collected during electrofishing surveys of Lake Pleasant.

The present sport fishery in Lake Pleasant consists of largemouth bass, channel catfish, white crappie, black crappie, bluegill, and white bass. Other species present as either nonsport or forage fish are carp, threadfin shad, golden shiner, mosquitofish, and plains red shiner (Jim Warneke pers. comm.). Threadfin shad are the primary forage fish of the white bass and make up a large portion of the other predators' diet as well. Largemouth bass are the fish preferred most by fishermen, followed by sunfish and black crappie. White bass are caught year-round, but principally during the spring spawning run and contributed about 9.4 percent to the creel in the July 1982 through April 1983 period in Lake Pleasant. The majority of the white bass captured in this creel census period were taken in February of 1983. At this time of year, the white bass are in spawning concentrations, and since they are in shallow water, are more accessible to the angler. White bass start entering the sport fishery when they are 15.2- to 20.3-cm long in Lake Pleasant (Jim Warneke pers. comm.).

The white bass fishery in Lake Pleasant has fluctuated over the years due to high and low water years. From the initial white bass stocking in March 1959 to the present (1983), AGFD fishery data have indicated that the population has generally followed or been influenced by water level fluctuations. The stockings of white bass in 1959 through 1961 met with little observed success. Attempts to locate spawning brood stock were not successful for the first few years following introduction.

Water levels in the lake were very low in 1963 and 1964. In 1965, the water level in Lake Pleasant increased due to high runoff. At least some reproduction occurred since white bass began to appear in the creel. In 1966, the white bass made a marked contribution to the fishermen's creel with an average larger fish than in 1965. In 1968, water levels were high in Lake Pleasant and although little spawning was observed, the angler success in 1969 indicated that a good population of white bass existed in the lake (F-7 reports). Warneke (pers. comm.) stated that white bass populations increase 1 or 2 years after a high winter and early spring runoff. The most recent observations by Arizona Game and Fish Department personnel from winter of 1982 through 1983 indicate that the white bass spawned March through April. In January 1983, the white bass were still fairly well dispersed in the lake with males oozing milt and females with nearly mature egg sacs (Sizer 1983). Females outnumbered males 3 to 1. Almost all white bass captured were in the same size class of about

40.6 cm. In a May 1983 electrofishing survey of lower Lake Pleasant, about 10 percent of the total sample was white bass, and these fish were all in the 40.6-cm size class.

Warneke (pers. comm.) thinks there is a probable loss of white bass from Lake Pleasant during high spring flows when water spills over the top of the lower dam and flows down the Agua Fria River into the Gila River. There have been no recorded observations of white bass in the Gila, but Warneke thinks the possibility is high. Essbach (pers. comm.) on the other hand, does not believe that there has been any successful emigration of white bass from Lake Pleasant, since there are no documented reports of white bass in Painted Rock Reservoir.

Currently, the Arizona Game and Fish Department considers Lake Pleasant to be a selfsustaining warmwater fishery with largemouth bass as the principal sportfish. Lake Pleasant has a very good catch per unit effort of over 0.25 fish per hour. Mr. Jim Burton (Arizona Game and Fish Department, Mesa, Arizona, pers. comm.) reported that a SCUBA study of cover in Lake Pleasant revealed that 16 percent of underwater habitat is suitable fish cover. The cover consists mainly of rock interspace, cut bank, and a small amount of macrophyte vegetation. Cover is considered the limiting factor for fish production here.

In 1964, a catch of 45 yellow bass during an electrofishing survey on Lake Pleasant was reported. No reports regarding the stocking of yellow bass in the lake were found in an examination of State fishery reports. No subsequent reference to either fishermen harvest or fishery survey collections of yellow bass were found; one could speculate that the fish were misidentified white bass or that yellow bass were indeed in the lake for a short time, failed to reproduce successfully, and were never collected again.

Threadfin shad are an important forage fish in Lake Pleasant and constitute the major item in the diet of the white bass. Apparently, threadfin shad are abundant in the lake now and are responsible for the current excellent condition of the white bass. A full range of age classes were among the 1,700 shad collected in a 4.6- by 1.2-m seine haul across 18.3 m of bottom in August 1982. This indicates that a relatively constant supply of forage will be available for the white bass in the near future. Although shad seem to be abundant, no estimate of their numbers in Lake Pleasant was available.

Success of crappie fishing at Lake Pleasant this year (1983) is open to speculation. A "fantastic" fishery for 27.9-cm crappie occurred in 1981, but there is uncertainty about the spawning success of crappies in 1981, the progeny of which would probably enter the fishery this year (Sizer 1983).

Richard Stephenson (Arizona Game and Fish Department, pers. comm.) indicated that the annual economic value of the Lake Pleasant fishery to the State of Arizona is about 8.3 million dollars. This figure represents a minimum value of the fishery, and was derived using numbers of fishermen, days at the lake, number of licensed anglers per household, an economic multiplier, and other assumptions. Park attendance figures indicate 1.1 million recreational visitor days there.

There are no future management changes being considered for Lake Pleasant in the event that CAP does not operate as planned other than possibly some habitat enhancement and construction to increase the reported 16 percent fish cover. The 0.25-fish-per-hour figure is the lowest Arizona Game and Fish Department will accept without investigating factors inhibiting the fishery. Lake Pleasant white bass have strong age classes every 2 to 3 years with no stunting problem so the current management strategy would continue in the absence of CAP (Burton pers. comm.).

Fishery management plans for an operating CAP delivering water would include requesting stable water levels during periods of largemouth bass spawning. An additional mitigation item would be to request a largemouth bass hatchery somewhere in the 6.4 km reversible canal connecting the Granite Reef Aqueduct with Lake Pleasant. Currently, the TDS levels are 450 to 500 mg/L and, with the introduction of CAP water, are expected to rise to about 710 mg/L. This high TDS results in reduced habitat suitability and could stress largemouth bass (Burton pers. comm.). If tilapia and striped bass would enter Lake Pleasant and have an adverse impact on the fishery, then a change in fishery management strategy will be undertaken, but no details about a potential change in management strategy with operation of CAP have been formulated.

Past management plans have included the practice of introducing an additional predator into a water system to boost the creel, when the desired catch per unit effort declined, rather than identifying the problem and managing the entire system to reverse the downward trend in the fishery. Recently, management practices have changed to include studying the ecology of the system before management plans are formulated and put into practice. Currently, a warmwater management plan for the entire State is being formulated and will be followed in the future.

Fishery aspects of Alamo Lake. — Construction of Alamo Dam, an 86.3-m-high earthfill structure on the Bill Williams River about 62.4 km upstream of its confluence with the Colorado River at Lake Havasu began in 1965 and was completed by the U.S. Army Corps of Engineers in 1968. The primary purposes for the dam were for flood protection, conservation storage for irrigation, and public recreational facilities. In June 1966, a fisheries management plan for Alamo Lake was formulated. It was felt that since the design pool for Alamo Lake would be 202.4 ha and contain about 5,000 acre-feet of water, fish species composition for introduction should include a few compatible species not prone to the possibilities of overpopulating and possible stunting. Therefore, it was felt that bluegill should not be introduced into the reservoir. Arizona Game and Fish Department (1967) conducted a fishery survey on Trout Creek, Burro Creek, Big Sandy River, Conger Creek, and Santa Maria River in the Bill Williams River drainage and found the following fish species: Gila sucker, coarsescale sucker, bonytail (roundtail), plains red shiner, longfin dace, and dusky dace. The coarsescale sucker and dusky dace are probably misidentifications. Carp and either bluegill or green sunfish were observed but not collected. Bullheads were also reported to be present. An eradication program with rotenone was suggested to eliminate undesirable fish that could enter and populate the reservoir after filling. Some water quality information was collected and analyzed, and it was concluded that although some parameters such as alkalinity were high, they should not adversely affect fish production as the reservoir filled and dilution occurred. Fish recommended for stocking in Alamo Lake included largemouth bass, channel catfish, and a forage minnow such as the plains red shiner (probably *Notropis lutrensis*). Based on the success of these initial introductions, further introductions of shad (species unspecified) or crappie would be made if warranted (Essbach 1966).

The major ichthyofauna of Alamo Lake was introduced to establish a warmwater fishery; some other fish species present were probably the result of bait bucket transfer or invasion of the upper basin prior to impoundment (Kepner 1980a).

In the spring of 1968, 150 largemouth bass and 15,000 plains red shiners were planted in a borrow pit excavated during construction of the dam. The largemouth bass were collected in Bartlett Lake. In 1969, 15,000 plains red shiners, 200 channel catfish, 400 flathead catfish, 3,075 redear sunfish, and 21,000 bullfrog tadpoles were stocked in Alamo Lake. Shellcrackers (*Lepomis microlophus* x *Chaenobryttus cyanellus*) were also stocked (Kepner 1979).

In 1971, an electrofishing survey of Alamo Lake produced 28 (55 percent) largemouth bass, 14 bluegill, 5 flannelmouth suckers, 2 goldfish, 1 green sunfish, and 1 bonytail (probably roundtail chub). Yellow bullheads, channel catfish, and carp were known to be present but were not collected. The reported flannelmouth suckers may be a misidentification, since this species does poorly in impoundments and generally inhabits larger rivers. Electrofishing on Alamo Lake in 1972 produced 66 (or 82.5 percent) largemouth bass, 11 bluegills, 2 carp, and 1 bluegill-redear hybrid. The bluegill had apparently spawned prior to being collected.

By 1973, there seemed to be a problem in Alamo Lake with a jammed size class on bass at about 25.4 cm. It was thought that a different forage fish, such as shad, might help increase the size of the bass, but since bluegill and redear were of exceptional size and significant in the catch, it was noted that the introduction of any new forage fish should be done cautiously to ensure that bluegill and redear populations are not affected. No mention was made of the plains red shiner.

In 1974, a creel census was conducted on Alamo Lake. One thousand four hundred and seventy-one anglers fished 4,473 hours and caught 2,460 fish consisting of 1,457 (59 percent) largemouth bass, 785 (31.9 percent) bluegill, 84 channel catfish, and 140 bullhead. A creel census of Alamo Lake conducted for 48 days in 1976 through 1977 revealed that 1,360 (40 percent) largemouth bass, 1,191 (35 percent) sunfish (primarily bluegill but some hybrids), 64 redear, 42 channel catfish, 14 yellow bullhead, 1 gold shiner, and 697 unclassified fish were caught. Catch per man-hour had increased to 0.72 fish per hour. During the period July 1, 1977 to June 30, 1978, a creel census was conducted for 36 days on Alamo Lake. Fishermen caught 1,286 (62 percent) sunfish, 548 (26 percent) largemouth bass, 17 channel catfish, 16 yellow bullhead, 4 carp, and 197 unclassified fish. About 2.4 times as many sunfish (redear, bluegill) were caught as largemouth bass, and it was stated that while a good bass fishery exists, Alamo Lake should never be managed to the detriment of the sunfish. This seems contrary to the statement in the June 1966 fisheries management plan for the lake, that bluegill sunfish should not be introduced into Alamo

Lake, apparently due to their tendency to overpopulate and produce stunted individuals. Some sunfish caught in Alamo did have good size, which provided recreation for both young and adult anglers. About 94 percent of the anglers utilizing Alamo Lake came from Maricopa County.

During the period July 1, 1978, to June 30, 1979, a creel census was conducted for 28 days on Alamo Lake. Sunfish again comprised 63.9 percent (2,300) of the catch. One thousand two hundred sixty-four (35.1 percent) largemouth bass, 23 (0.6 percent) channel catfish, 1 bullhead, 9 golden shiners, and 3 black crappie were also caught. Records do not indicate how, when, or by whose intervention golden shiners and black crappies entered Alamo Lake, although bait bucket introduction is a possibility.

From December 1978 to February 1979, Kepner (1979) sampled 64 stations in the Santa Maria River, Burro Creek, and Big Sandy River watersheds, including Alamo Lake. In the reservoir, Kepner either collected or found records for 16 fish species, including the following: goldfish, carp, golden shiner, red shiner, mosquitofish, green sunfish, bluegill, redear sunfish, shellcracker, largemouth bass, Mozambique mouthbrooder, black bullhead, yellow bullhead, channel catfish, flathead catfish, and threadfin shad.

Carp accounted for 48.5 percent of the total catch. Bluegill apparently supplanted redear sunfish and have become the main forage fish for the largemouth bass. Fish were generally in good condition; there was, however, a low frequency (N = 4) of infestation with *Lernaea elegans*, which did not pose a threat to the fishery. Alamo Lake was judged to be an excellent warmwater fishery, with the bluegill fishery being about the best in Arizona, and with a good largemouth bass fishery. The relative abundance of the Mozambique mouthbrooder, *T. mossambica*, was not listed and no statement about its effects on other game fish was made.

In winter and spring of 1980, Kepner (1980b) again surveyed 68 stations in the Bill Williams and Hassayampa River drainages. In Alamo Lake, Kepner reported the same 16 fish species listed above.

Kepner (1983) reported that a 71.8 cm northern pike (*Esox lucius*) was caught in Alamo Lake in December 1979. The origin of this fish is uncertain, and the northern pike is not considered established.

During the period July 1, 1980 to June 30, 1981, the ACFRU (Arizona Cooperative Fishery Research Unit) collected some fishery data on Alamo Lake. They reported length (average 30.9 cm) and weight (average 514 g) on largemouth bass.

A fish kill occurred in Alamo Lake beginning about July 4, 1980, and lasted for several days. About 10,000 channel catfish from 5- to 50-cm long and about 100,000 threadfin shad from 5- to 12-cm long were killed. Apparently, no other species were affected. No mention was made of tilapia. The kill was recorded as a natural phenomenon probably caused by strong winds mixing bottom anaerobic water with surface water and reducing the overall oxygen content of the lake. Threadfin shad had been recently introduced into the lake (Kepner 1980).

Recently, tilapia have been reported from Alamo Lake (Barrett 1983; Taubert pers. comm.; Thomas 1983; Wanjala pers. comm.).

Tilapia have apparently become numerous enough in Alamo Lake to reduce the quality of the largemouth bass and sunfish sport fishery. In addition, it is suspected that in years of high flows out of Alamo, tilapia could enter the Bill Williams River and eventually migrate downstream to Lake Havasu. Limited fisheries work has been conducted on Alamo in the past few years. The Arizona Cooperative Fishery Research Unit has done some work there, but those activities are being terminated (Ziebell pers. comm.). Wanjala (pers. comm.) reported largemouth bass predation on tilapia in Alamo; he felt that these fish were *T. aurea*. Jacobson (pers. comm.) stated that although tilapia are not easy fish to capture, he collected 28 tilapia in Alamo Lake in 1982, ranging in length from 86 to 374 mm, and that until further information is available, these tilapia should be considered *T. aurea*. Barrett (1983) expressed the opinion that tilapia in Alamo Lake may be a hybrid with close affinity to *T. aurea*. On May 28, 1968, two-hundred 76- to 152-mm *Tilapia* sp. from the Arizona Game and Fish Department, Page Springs hatchery, were stocked at the confluence of Burro and Francis Creeks (Kepner 1980). These may have included some *T. zilli*, *T. aurea*, or hybrids of *T. aurea*. They have not been found there since, and might not have survived the winter of 1968 to 1969. In March 1978, a huge muddy recharge from the Santa Maria River and Burro Creek entered Alamo Lake and increased its size to about 2344.1 ha. It was during this period that tilapia, if they survived and persisted upstream in low numbers, could have moved downstream and entered Alamo Lake (Jacobson pers. comm.).

Another possible source of tilapia in Alamo Lake is bait bucket transfer by fishermen from the

Phoenix metropolitan area (Thomas 1983). Apparently, bait fishermen commonly collect fish, including tilapia, from Phoenix area waters and use them as bait for game fish in several widely separated locations. And, *T. aurea* is documented from the Phoenix area (Barrett 1983; Essbach pers. comm.; Marsh and Minckley 1982). Other fish present in the creel from Alamo Lake are probably the result of bait transfer and release (Kepner 1980).

Fishery aspects of Salt and Verde Rivers and the Phoenix metropolitan area. — A discussion of the fisheries of the Salt and Verde Rivers will be limited generally to that 20.8-km reach of the Salt River below Stewart Mountain Dam downstream to the Granite Reef Diversion Dam and to that 36.8-km reach of the Verde River below Bartlett Dam to its confluence with the Salt River. The distance from the confluence to Granite Reef Diversion Dam is 5.6 km. Although extensive fish stocking and diverse fishery management practices have been followed on upstream reservoirs, we will not consider aspects of those fisheries for the purpose of this report, unless some unique aspect of these systems warrants discussion. Fisheries data from about 1960 to the present were gleaned from Arizona Game and Fish Department fishery reports and personal communications; in 1975, a complete fishery survey of the Salt and Verde Rivers from below Stewart Mountain and Bartlett Dams was conducted for the Orme Reservoir Environmental Study on Fish and Wildlife (U.S. Fish and Wildlife Service 1976) and will be discussed later.

Prior to 1960, there was apparently some discussion regarding the establishment of a trout fishery below the chain of lakes on the Salt River, specifically the area below Stewart Mountain Dam (Saguaro Lake) with possible extension down to the Granite Reef Diversion Dam. Based on the fact that flows from Saguaro Lake could stop for up to 1 month at a time, the establishment of a trout fishery with 76- to 102-mm fish was deemed infeasible in the F-7-R-3 report of the Arizona Game and Fish Department (1960). By 1966, however, management strategies apparently changed, because 10,000 64-mm trout fingerlings were planted in the Salt River below Stewart Mountain Dam.

By late summer, fish averaged 259 mm and by early fall about 4,420 of the fish had been harvested by anglers. It was reported that if this growth rate could be maintained in the future, this reach of the Salt River could prove to be a worthwhile central Arizona fishery. It was felt that the good trout growth was the result of the almost complete removal of all fish from the river during a January flood. Plans were formulated to plant trout of about the same size in the Salt River in 1967 to evaluate growth rates with other fish species present. In October 1966, largemouth bass and other unspecified warmwater fish entered the Salt River by escapement from Saguaro Lake. Because of the fluctuating nature of the water level in the Salt River below Stewart Mountain Dam, with the prospect of poor winter habitat for trout, it was stated that early spring rotenoning might be necessary to remove resident fish in this reach of river before spring stocking of trout occurred.

On March 21, 1967, 10,000 89- to 102-mm rainbow trout fingerlings were stocked in the Salt River below Stewart Mountain Dam. These grew rapidly to about 254 mm and began to enter the creel by late June and July. About 6,170 were harvested. In addition to these trout, 6,491 bluegills, 707 carp, 643 largemouth bass, 514 yellow bass, 386 suckers, 257 channel catfish, and 161 green sunfish were harvested from June to October.

The excellent growth and return to the creel of the introduced rainbow trout prompted the recommendation that the stocking rate for 1968 be increased to 50,000 fish. Actually, 20,000 rainbow fingerlings were planted in April and 5,000 catchables were planted in September. Some fish from the early plant grew to 381 mm. For the period June to October 1968, an estimated 6,418 rainbow trout, 515 suckers, 398 carp, 187 bluegill, 211 largemouth bass, 164 each walleye and channel catfish, and 47 bullhead were harvested. It was recommended to increase the rainbow trout stocking to 50,000 fish in 1969, with a staggered planting schedule.

In 1969, 48,000 rainbow trout fingerlings were stocked, with an estimated angler harvest of 7,155. Apparently, the sucker, roundtail chub, and carp populations were increasing to a point where they were beginning to compete with the stocked rainbows based on a decline in the average size of the trout in the creel, and control by fish toxicant was suggested. Fifty thousand rainbows were recommended for stocking in 1970. Trout stocking of the Salt River was apparently discontinued in the early 1970's but stocking was initiated again in 1973 and 1974, when in May and June, a total of 9,000 tagged, catchable rainbows were stocked.

Additional plants were planned for the summer. No estimated harvest was reported. For 1974 and 1975, 15,000 catchable trout were stocked. Four hundred eighty-two trout were documented in the creel, along with 20 green sunfish, 17 bullheads, 8 bluegills, 6 carp, 4 each largemouth bass and yellow bass, 3 channel catfish, 2 brown trout, and 1 unspecified fish. It was assumed that 41 percent of the stocked trout were returned to the creel.

In spring and early summer 1977, 51,000 fingerling to catchable size trout were stocked in the Salt River; 9,400 catchables were stocked in Saguaro Lake in June 1977. The possible introduction of flathead catfish in Saguaro Lake was mentioned without details. Apparently, the largemouth bass population had declined. Beyond 1977, there was no mention of rainbow trout stocking in the Salt river. However, Essbach (pers. comm.) stated that the trout stocking program on the Salt River was discontinued due to potential disease problems on trout associated with the widely fluctuating annual flow in the river.

Tables 25 through 29, taken from the Orme Reservoir Environmental Study on Fish and Wildlife, indicated fish species composition and abundance from the mainstream of the Salt and the Verde Rivers, and for selected back water areas. Fifteen species of fish were represented in the Salt River mainstream collections with six of these species represented in backwater collections. Three thousand two hundred and ninety-six fish were collected from the Salt River. In the Verde River, 16 fish species were collected in the mainstream, with 8 of these species represented in backwater collections. Six thousand seven hundred and seventy-six fish were collected from the Verde River. No tilapia, striped bass, or white bass were found in these collections. Only 3 of the 15 fish species in the Salt River and 3 of the 16 fish species collected in the Verde River are native species; the remaining fish species present were introduced for various reasons some time in the past. Marsh and Minckley (1982) list 44 native and introduced fish species in the Phoenix Metropolitan area. Their list was used to verify native and introduced species in the Salt and Verde Rivers.

One unusual fish found in both the Salt and Verde Rivers is the sailfin molly, *Poecilia latipinna* (U.S. Fish and Wildlife Service 1976). This fish generally is associated with the aquarium trade and has little or no value as a sport fish, but possibly some minor value as a forage fish if it is available to predators. The sailfin molly occupies a niche similar to the mosquitofish and is in the same family. They were introduced into the lower Salt and Verde Rivers in the early 1950's (Minckley 1973), and have been found in the Phoenix area canals (Marsh and Minckley 1982).

Table 25. — Salt River Mainstream Fish Summary Data — Totals For All Fish Taken During Entire Study Period[1] (from USFWS 1976)

Species	Total Numbers	Total Weight	% of Total Number	% of Total Weight	Mean Weight	Station Occurrence[2]
Threadfin shad, *Dorosoma petenense*	2	0.12	0.43	0.01	0.01	1
Rainbow trout, *Salmo gairdneri*	5	3.35	0.18	0.24	0.67	2
Longfin dace, *Agosia chrysogaster*	35	0.42	1.25	0.03	0.01	2
Carp, *Cyprinus carpio*	218	564.37	7.79	39.96	2.54	12
Red shiner, *Notropis lutrensis*	236	2.83	8.43	0.20	0.01	8
Desert sucker, *Catostomus clarki*	570	296.74	20.36	21.02	0.52	14
Sonora sucker, *Catostomus insignis*	383	330.13	13.68	23.39	0.86	17
Yellow bullhead, *Ictalurus natalis*	134	30.04	4.79	2.13	0.22	16
Channel catfish, *Ictalurus punctatus*	6	4.58	0.21	0.32	0.76	4
Mosquitofish, *Gambusia affinis*	378	0.38	13.51	0.03	<0.01	4
Sailfish molly, *Poecilia latipinna*	237	1.19	8.47	0.10	<0.01	4
Yellow bass, *Morone mississippiensis*	12	14.97	0.43	1.06	1.25	2
Green sunfish, *Lepomis cyanellus*	294	34.04	10.50	2.41	0.12	12
Bluegill, *Lepomis macrochirus*	70	10.89	2.50	0.77	0.16	9
Largemouth bass, *Micropterus salmoides*	209	117.62	7.47	8.33	0.56	17
Total	2,799	1,411.67				

[1]Does not include fish from backwater sample stations.
[2]A total of 20 stations on the mainstream of the river were sampled.

Table 26. — Salt River Backwaters Fish Summary Data[1] (from USFWS 1976)

Species	Total Numbers	Total Weight	% of Total Number	% of Total Weight	Mean Weight	Station Occurrence[2]
Carp, *Cyprinus carpio*	11	13.87	2.21	63.45	1.26	1
Mosquitofish, *Gambusia affinis*	310	1.55	62.37	7.09	<0.01	3
Sailfish molly, *Poecilia latipinna*	150	1.50	30.18	6.86	0.01	3
Green sunfish, *Lepomis cyanellus*	8	0.97	1.61	4.44	0.12	2
Bluegill, *Lepomis macrochirus*	13	1.38	2.62	6.31	0.11	3
Largemouth bass, *Micropterus salmoides*	5	2.59	1.01	11.85	0.52	2
Total	497	21.86				

[1]Backwaters were sampled only during the summer.
[2]A total of 5 stations were sampled.

Table 27. — Verde River Mainstream Fish Summary Data — Totals For All Fish Taken During Entire Study Period[1] (from USFWS 1976)

Species	Total Numbers	Total Weight	% of Total Number	% of Total Weight	Mean Weight	Station Occurrence[2]
Threadfin shad, *Dorosoma petenense*	1	0.01	0.02	<0.01	.01	1
Rainbow trout, *Salmo gairdneri*	10	6.33	0.16	0.27	0.63	7
Longfin dace, *Agosia chrysogaster*	30	0.35	0.47	0.02	0.01	12
Carp, *Cyprinus carpio*	690	1,143.38	10.89	48.64	1.66	27
Roundtail chub, *Gila robusta*	28	10.83	0.44	0.46	0.39	11
Red shiner, *Notropis lutrensis*	2,812	31.12	44.40	1.33	0.01	27
Desert sucker, *Catostomus clarki*	1,196	580.56	18.89	24.72	0.49	26
Sonora sucker, *Catostomus insignis*	247	268.50	3.90	11.43	1.09	27
Flathead catfish, *Pilodictis olivaris*	1	1.62	0.02	0.07	1.62	1
Yellow bullhead, *Ictalurus natalis*	397	66.54	6.27	2.83	0.17	25
Channel catfish, *Ictalurus punctatus*	264	131.67	4.17	5.61	0.50	19
Mosquitofish, *Gambusia affinis*	363	2.90	5.73	0.12	<0.01	21
Sailfish molly, *Poecilia latipinna*	1	0.01	0.01	<0.01	0.01	1
Green sunfish, *Lepomis cyanellus*	100	13.64	1.58	0.58	0.14	10
Bluegill, *Lepomis macrochirus*	14	2.77	0.22	0.12	0.20	4
Largemouth bass, *Micropterus salmoides*	179	88.73	2.83	3.78	0.50	25
Total	6,333	2,348.96				

[1]Does not include fish from backwater sample stations.
[2]A total of 27 stations on the mainstream of the river were sampled.

Marsh and Minckley (1982) noted the presence of *T. aurea*, *T. mossambica*, and *T. zilli* in the Phoenix area canals, although their study area was generally limited to the area below Granite Reef Diversion Dam. They stated however, that some fish species in Phoenix area canals are apparently annual immigrants from the Salt and Verde Rivers or their impoundments, and escapement from these upstream systems may explain the presence of some species, such as threadfin shad.

Barrett (1983), in a discussion of the statewide distribution of *T. aurea*, indicated that they range from east of Phoenix to the lower Colorado River, but the specific location east of Phoenix was unclear. Minckley (pers. comm.) indicated that tilapia collected in the Phoenix area waters are

Table 28. — Verde River Backwaters Fish Summary Data[1] (from USFWS 1976)

Species	Total Numbers	Total Weight	% of Total Number	% of Total Weight	Mean Weight	Station Occurrence[2]
Threadfin shad, *Dorosoma petenense*	22	1.06	4.97	1.78	0.05	1
Carp, *Cyprinus carpio*	59	48.05	13.32	80.88	0.82	3
Red shiner, *Notropis lutrensis*	7	0.08	1.58	0.02	<0.01	1
Yellow bullhead, *Ictalurus natalis*	6	1.14	1.35	1.92	0.19	1
Mosquitofish, *Gambusia affinis*	308	0.38	69.53	0.64	<0.01	3
Green sunfish, *Lepomis cyanellus*	6	0.10	1.35	0.17	0.02	2
Bluegill, *Lepomis macrochirus*	7	0.28	1.58	0.47	0.04	2
Largemouth bass, *Micropterus salmoides*	28	8.39	6.32	14.12	0.30	4
Total	443	59.48				

[1]Backwaters were sampled only during the summer.
[2]A total of 5 stations were sampled.

Table 29. – Orme Site Complete Lists Of All Fish Collected From the Orme Site in 1975 (from USFWS 1976)

Species	Total Numbers	Total Weight	% of Total Number	% of Total Weight	Mean Weight	Station Occurrence[1]
Threadfin shad, *Dorosoma petenense*	35	1.19	0.35	0.03	0.03	3
Rainbow trout, *Salmo gairdneri*	15	9.69	0.15	0.25	0.64	9
Longfin dace, *Agosia chrysogaster*	65	0.77	0.65	0.02	0.01	14
Carp, *Cyprinus carpio*	978	1,769.67	9.71	46.06	1.81	43
Roundtail chub, *Gila robusta*	28	10.83	0.28	0.28	0.39	11
Red shiner, *Notropis lutrensis*	3,055	33.95	30.33	0.88	0.01	37
Desert sucker, *Catostomus clarki*	1,766	877.30	17.53	22.84	0.50	40
Sonora sucker, *Catostomus insignis*	630	598.63	6.26	15.58	0.95	44
Flathead catfish, *Pilodictis olivaris*	1	1.62	<0.01	0.04	1.62	1
Yellow bullhead, *Ictalurus natalis*	537	97.72	5.33	2.54	0.18	42
Channel catfish, *Ictalurus punctatus*	270	136.25	2.68	3.55	0.51	23
Mosquitofish, *Gambusia affinis*	1,359	5.21	13.49	0.14	<0.01	35
Sailfin molly, *Poecilia latipinna*	388	2.70	3.85	0.07	<0.01	8
Yellow bass, *Morone mississippiensis*	12	14.97	0.12	0.39	1.25	2
Green sunfish, *Lepomis cyanellus*	408	48.75	4.05	1.27	0.12	26
Bluegill, *Lepomis macrochirus*	104	15.32	1.03	0.40	0.15	18
Largemouth bass, *Micropterus salmoides*	421	217.33	4.18	5.66	0.52	48
TOTAL	10,072	3,841.90				

[1]A total of 57 stations were sampled.

used by anglers as bait in Salt River reservoirs. Careless or unsuspecting anglers could release baitfish into the river system at the end of their fishing trip. Any or all of the three tilapia species documented from Phoenix area waters could be collected by anglers for use as bait, since they are generally abundant and many anglers would not be concerned with or knowledgeable about positive species identification. Rinne (1973) described fish distribution in the Salt River reservoirs above Stewart Mountain Dam; his results are available but will not be discussed here.

Water Quality Aspects of CAP Source and Receiving Waters

Information regarding water quality on Lake Havasu, Lake Pleasant, Alamo Lake, and the Salt and Verde Rivers was compiled from several sources (Arizona Game and Fish Department 1982; Baker and Paulson 1983; Broadway and Herrgesell 1978; Ponder 1971; Bureau of Reclamation 1982: U.S. Geological Survey 1980; and SRP). The Arizona Lakes Classification Study (Arizona Game and Fish Department 1982) compiled and analyzed available data on State lakes, to assist various State decisionmakers regarding management strategies for these lakes in the future.

Lake Havasu. — Ponder (1971) studied temperature and dissolved oxygen levels in Lake Havasu for the period June 24, 1969, to June 11, 1970, to assess the lakes suitability as a rainbow trout fishery. His station 1 was just upstream of Parker Dam. Since this station is closest to the Havasu Pumping Plant, temperature and dissolved oxygen data from this station are relevant to this report and are summarized here. With some exceptions, stations were generally sampled every 2 weeks. At station 1, on January 7, 1970, the minimum temperature was about 8.9 °C, and the maximum was about 9.4 °C. These were the lowest temperatures recorded at station 1 during the study period. On August 19, 1969, the minimum temperature was about 22.2 °C and the maximum water temperature was about 29.4 °C.

At this station, recorded biweekly maximum dissolved oxygen levels were between about 6.8 and 9.6 mg/L. The minimum level however, dropped to about 1.0 mg/L about August 24, 1969; the next lowest minimum dissolved oxygen level was about 3.8 mg/L on August 7, 1969. During the study period, all other dissolved oxygen minimums were greater than about 4.3 mg/L. Ponder (1971) concluded that temperature and dissolved oxygen would be suitable for the survival of rainbow trout and recommended that 50,000 rainbow trout be planted in Lake Havasu.

Ince (1976) provided almost a full year of chemical, physical, and biological information about the lower part of Lake Havasu, lower Bill Williams River near its confluence with Lake Havasu, and the Havasu Intake Channel. For the period April 1974 to January 1975, water temperatures varied from a low of 9.0 °C to a high of about 30.0 °C in the main reservoir, and a degree or two warmer in the Bill Williams River. The highest recorded surface water temperature was 32.5 °C on September 6, in the Bill Williams River. The shallower water in the Bill Williams delta area tended to get a degree or so warmer than the station in the main reservoir. In January 1975, at a midreservoir station, the water column was isothermal at 9.0 °C, while the CAP intake channel was isothermal for 8 m at 10.1 °C. As the weak stratification of the lake broke down from about October, near isothermal conditions existed from about November to January. No water quality data were collected after January, so it was not known how long isothermal conditions persist into the spring. However, the reservoir reportedly stratifies weakly with gradual warming during the spring and early summer. In most cases, dissolved oxygen levels were above 5 mg/L, but in and near the Bill Williams River, dissolved oxygen levels did decrease to as low as 0.40 mg/L when water temperatures were around 30.0 °C.

Broadway and Herrgesell (1978) sampled 19 stations along the lower Colorado River from above Needles near the California-Nevada State line to Morales Dam. Stations were sampled quarterly. Various physical-chemical parameters were measured, as well as phytoplankton primary productivity and standing crop estimates. Their station 4 was the Bill Williams Arm of Lake Havasu. They considered this station lentic or relatively still or quiet water compared to some other stations that were lotic or flowing water. Here, we consider station 4 in detail since it is the closest station to the Havasu Pumping Plant. In general, annual water temperatures in the lower Colorado River system ranged from 9 to 30 °C; dissolved oxygen from 5.8 to 12.0 mg/L; pH from 7.2 to 8.4; and TDS (total dissolved solids) from 380 to 1300 mg/L.

At station 4, water temperature ranged from 11.5 to 29.5 °C with a mean of 21.30 °C. Dissolved oxygen ranged from 6.7 to 10.0 mg/L and averaged 8.6 mg/L. TDS ranged from 380 to 431 mg/L and averaged 417.75 mg/L. Turbidity varied seasonally and ranged from 9 to 18 JTU (Jackson Turbidity Unit), with an average of 12 JTU. Turbidity generally increased downstream from station 1 to station 11 (Taylor Lake), then decreased further downstream. Station 4 at 12 JTU had the highest average turbidity of the four stations upstream of Parker Dam.

Other water quality parameters were reported by Broadway and Herrgesell (1978). Generally, their findings were close to those of Ince (1976). Broadway and Herrgesell (1978) concluded that most of the lower Colorado River system is oligotrophic, based on their evaluation of the trophic conditions in the system. Station 4, however, was highest in primary productivity among the nine lentic stations, fourth lowest in chlorophyll a, lowest in TDS, fifth in Secchi disc transparency, and fourth lowest in TSI (trophic state index). The TSI is an attempt to provide a simple index which incorporates the advantages of multiparameter indices while avoiding the necessity for monitoring several parameters. Chlorophyll a is used to calculate TSI from the equation:

$$TSI\ (chl\ a) = 10\left(6 - \frac{2.04 - 0.68 \ln chl\ a}{\ln 2}\right)$$

with chl a in mg/m^3

Although station 4 (the Bill Williams Arm of Lake Havasu) has the highest production, due probably to high nutrient input and seasonal optimal lentic conditions, its overall TSI is around 40, which is considered mesotrophic. Although the Bill Williams River seasonally could provide nutrients to Lake Havasu in flood waters, its flow into Lake Havasu is considerably diluted as is its potential downstream impact on water quality.

The Arizona Game and Fish Department (1982) in the Arizona Lakes Classification Study listed Lake Havasu as having an average surface water temperature of 19.5 °C with a range of 10.0 to 29.3 °C and an average dissolved oxygen level of 9.6 mg/L with a range of 7.7 to 11.5 mg/L. The number of observations used to calculate these and other reported limnological parameters was not indicated, nor were the location(s) where the data were collected. These values may be valid for some location, but as seen above, the range of values actually reported by other workers exceeds those in the Lakes Classification Study.

Baker and Paulson (1983) updated some earlier limnological work (Ince 1976) on Lake Havasu. They sampled four sites in the lake, including one site in the Bill Williams Arm (H-1) and another at the mouth of the Havasu Intake Channel (H-4). Surface water temperature at station H-4 was slightly higher than at station H-1 with averages of 21.1 °C and 20.9 °C, respectively, with ranges of 10.9 to 30.1 °C and 10.8 to 30.1 °C, respectively. Dissolved oxygen levels at both stations were almost identical with averages of 8.64 and 8.63 mg/L; at station H-4, dissolved oxygen levels ranged from 5.83 to 12.20 mg/L, and at H-1, ranged from 6.75 to 11.20 mg/L. Data for these two sites are shown in table 30. No temperature or oxygen data was reported for January 1983. It is not possible to say, then, if the surface water temperature during this period was higher or lower than the 10.8 to 10.9 °C recorded in February. Previous studies have indicated that the lowest observed water temperatures at stations in the lower part of Lake Havasu occurred in January. Depth of the water at the stations varied somewhat during the study period to reflect water storage and later release for downstream use. Generally the water temperature difference from surface to bottom was small. Based on available water temperature and dissolved oxygen data, it would appear that tilapia could survive in the lower end of Lake Havasu in the area around the intake channel, although for some time during midwinter, they will be thermally stressed. During some winters with lower water temperatures, an unknown number of fish would succumb to winterkill. Ponder (1971) described seasonal minimum and maximum water temperature conditions in the lake and at his station 1, there is generally some daily warming. The lowest temperature he reported at his station was about 8.8 °C, above the temperature at which

Table 30. — Surface water temperature and dissolved oxygen levels for two sites in Lake Havasu, March 1982 through February 1983 (Baker and Paulson 1983)

Date	Temperature (°C, surface)	Dissolved oxygen (mg/L)
Station H-4 — Mouth of Havasu Intake Channel (midchannel)		
03-30-82	16.8	9.40
04-27-82	19.8	8.15
05-29-82	24.4	9.08
06-30-82	26.6	9.04
07-27-82	30.1	12.20
08-25-82	28.9	7.75
09-29-82	25.0	5.83
10-27-82	19.7	7.17
11-23-82	15.9	7.70
12-21-82	13.6	9.65
01-11-83	—	—
02-03-83	10.9	9.07
Station H-1 — Bill Williams Arm at buoy line (midchannel)		
03-30-82	16.5	9.60
04-27-82	19.5	8.15
05-29-82	24.2	8.62
06-30-82	26.5	9.15
07-27-82	30.1	11.20
08-25-82	28.8	7.86
09-29-82	24.6	6.75
10-27-82	19.7	8.10
11-23-82	15.9	7.40
12-21-82	13.4	9.05
01-11-83	—	—
02-13-83	10.8	9.05

blue tilapia survived for short exposure periods. Tilapia may also experience temperatures above 22 °C for a sufficiently long period of time to breed successfully. Tilapia would likely establish populations in lower Lake Havasu; predation by resident predator fish species and competition would have a minor influence in regulating the population.

Alamo Lake. — Alamo Dam, located 62.4 km upstream from Lake Havasu on the Bill Williams River, was completed in 1968. The physical features of the lake are discussed elsewhere in the report. Sometime in the early 1970's, limited limnological studies were begun on Alamo Lake. In 1974, the average yearly surface water temperature was 23.3 °C, dissolved oxygen was 6 mg/L, and TDS was 725 mg/L. No ranges were reported for these parameters. However, in another section of the same report (Arizona Game and Fish Department F-7-R-16, July 1, 1973 to June 30, 1974), with one observation, a water temperature of 22.7 °C, dissolved oxygen of 5.0 mg/L, TDS of 511 mg/L, and pH of 9.0 was reported.

For the period July 1, 1976 to June 30, 1977, three locations in Alamo Lake were sampled. A summary of these data is found in table 31. Table 32 shows similar data for July 1977 to June 1978. It appears that water temperatures as reported for Alamo Lake would allow the survival and reproduction of tilapia. This has apparently occurred.

Water quality in Alamo Lake is apparently suitable to support a population of tilapia that is "near *aurea*" (Minckley pers. comm.). Surface water temperature in Alamo averages 25.4 °C, with a range of 22.8 to 28.0 ° C (Arizona Game

Table 31. — Selected limnological parameters for three locations in Alamo Lake, June 1976 to June 1977 (Arizona Game and Fish Department, F-7-R-19, 1977)

	Dam			Midlake			Upper		
Date	Temp °C	D.O mg/L	pH	Temp °C	D.O. mg/L	pH	Temp °C	D.O. mg/L	pH
9-16-76	28	7.0	8.5	28	7.0	8.5	28	8.0	8.5
10-14-76	25	8.0	8.5	25	8.0	8.5	25	7.0	8.5
11-18-76	18	4.0	8.5	18	4.0	8.5	18	5.0	8.5
12-17-76	14	9.0	8.0	13	9.0	8.5	13	8.0	8.0
1-05-77	11	9.0	8.5	11	3.0	8.5	11	9.0	8.5
2-08-77	13	13.0	8.5	11	12.0	8.5	14	13.0	8.5
3-29-77	15	10.0	8.5	15	10.0	8.5	17	10.0	8.5
5-05-77	22	7.0	8.5	22	8.0	8.5	22	8.0	8.5
6-26-77							32	2.6	

Table 32. — Selected limnological parameters for three locations in Alamo Lake, July 1977 to June 1978 (Arizona Game and Fish Department, F-7-R-20, 1978)

	Dam			Midlake			Upper		
Date	Temp °C	D.O mg/L	pH	Temp °C	D.O. mg/L	pH	Temp °C	D.O. mg/L	pH
7-28-77	31	8.0	8.5	32	8.0	8.5	33	9.0	8.5
8-18-77	30	7.0	8.5	30	7.0	8.5	30	7.0	8.5
10-13-77	25	8.0	8.5	25	7.0	8.5	25	7.0	8.5
11-18-77	18	5.0	8.5	18	6.0	8.0	18	7.0	8.0
1-08-78	13	9.0	8.5	13	9.0	8.5	14	8.0	8.5
2- -78									
3- -78									
4-11-78	18	9.0	8.5	20	9.0	8.5	22	9.0	8.5
5-28-78	26	9.0	8.5	27	10.0	8.5	28	10.0	8.5
6-06-78	28	9.0	8.5	27	8.0	8.5	28	8.0	8.5

and Fish Department 1982). These reported temperatures are sufficiently high to prevent substantial winter die-offs of tilapia and allow successful reproduction. In fact, tilapia have increased to nuisance proportions in Alamo Lake (Thomas 1983) from what is suspected to be bait bucket transfer or downstream migration into the lake from an original stocking of tilapia at the confluence of Burro and Francis Creeks in 1968. It is felt that in years of high springtime precipitation and runoff, tilapia from Alamo Lake will be washed out of there into the Bill Williams River and enter Lake Havasu, where they would probably survive and reproduce.

Bill Williams River. — Maximum and minimum water temperature data were collected on the Bill Williams River from November 1976 to June 1977, to determine if temperatures dropped below 10 °C and for how long, to assess the period during which tilapia might be exposed to lower lethal temperatures (Arizona Game and Fish Department F-7 1977). These water temperature data are shown in table 33. Recent thermal tolerance data indicate, however, that tilapia will survive short term exposure to temperatures well below 10 °C (Shafland pers. comm.; Zale pers. comm.). The minimum water temperatures reported for the Bill Williams River would probably not stress tilapia sufficiently to cause significant winterkill, and tilapia, once established, will probably persist in the Bill Williams River, with the potential for downstream migration into Lake Havasu.

Surface water temperature, dissolved oxygen, and pH for an unspecified location in the Bill Williams River for August 1978 to February 1979 are shown in table 34.

Lake Pleasant. — Water quality data for Lake Pleasant have been collected and reported by different State and Federal agencies over about the last 30 years, but there seems to be no standardization of parameters monitored and no concensus on report format. The available data are scattered and often incomplete for a year. In some cases only a few parameters were measured, or parameters were only measured once a year, the sampling date was not reported or the sampling station was not made clear. Limited STORET data are available for some recent years. Arizona Game and Fish Department has conducted some limited limnological work on Lake Pleasant, but even this work has not provided sufficient data to describe Lake Pleasant completely, and significant gaps still exist in these data. Most of the available water quality data for Lake Pleasant are found in appendix 1. Examination of STORET data for 1982 reveal the following data for September 8.

water temperature	27.5 °C
dissolved oxygen	5.8 mg/L
pH	8.6
specific conductance	541.0 μS/cm
TDS	325 mg/L

Table 33. — Maximum-minimum temperatures (°C) on the Bill Williams River 1 mile above Lake Havasu (Arizona Game and Fish Department, F-7-R-19, 1977)

Date	Maximum	Minimum
11-24-76	20.0	14.5
12-01-76	21.1	13.3
12-08-76	21.1	13.3
12-16-76	20.0	12.2
12-21-76	20.0	11.1
1-10-77	17.2	7.2
1-18-77	17.2	6.1
1-31-77	17.8	8.9
2-08-77	16.6	10.0
2-21-77	20.0	11.1
3-08-77	15.5	13.3
3-29-77	16.6	13.3
4-12-77	13.3	11.1
4-18-77	16.7	11.1
4-27-77	22.2	14.4
5-04-77	23.2	14.4
5-17-77	22.2	20.0
5-25-77	23.2	18.8
5-31-77	23.2	20.0
6-08-77	24.4	21.1
6-14-77	25.5	21.1
6-23-77	24.4	22.2
6-29-77	24.4	21.1

Table 34. — Surface water temperature, dissolved oxygen, and pH for one unspecified location in the Bill Williams River, July 1978 to June 1979

Month	Temperature °C	Dissolved oxygen (mg/L)	pH
August	21	10	9.0
September	23	10	9.0
October	20	9	9.0
December	10	11	9.0
January	10	11	9.0
February	13	10	9.0

Data available for the Agua Fria River below Lake Pleasant were not considered in the analysis.

Although data are not available from year-round sampling or at least not identified as such, the water quality of Lake Pleasant seems to be of sufficiently good quality to support an extensive sport fishery (Sizer 1983). Limited water quality information compiled by the Arizona Game and Fish Department (1982) listed an average water temperature of 21.1 °C and a range of 12.0 to 30.3 °C with dissolved oxygen averaging 8.7 mg/L with a range of 4.9 to 10.7 mg/L. Although data from various sources were used to complete the Arizona Lakes Classification Study, no information is presented listing the number of observations used to calculate average parameter values, or the time period from which the observations were obtained, other than a general introductory statement concerning the use of values for 10-year increments.

If data were not available for some seasons of the year, the calculated average values would not reflect accurately the real conditions in the lake. However, based on available water temperature information for Lake Pleasant, it appears that the minimum reported water temperatures would be suitable for winter survival of tilapia, and that temperatures suitable for successful spawning would exist during warmer months of the year.

Lake Pleasant has been classified as mesotrophic by Roline and Miyahara (1983), based on an algal growth potential test that was conducted on Agua Fria water, the present source water for Lake Pleasant. Ince (1976) classified Lake Havasu as oligotrophic. An algal assay was conducted on combined Lake Havasu and Lake Pleasant waters (Roline and Miyahara 1983, unpublished). The study showed that Lake Havasu waters did not enhance phytoplankton production when mixed with Lake Pleasant water. Introduction of CAP water into Lake Pleasant is a concern because if the potential for increased eutrophication exists, the waters could be unfavorable for striped bass, which generally do not prefer eutrophic waters. Considering only temperature and dissolved oxygen levels, Lake Pleasant seems suitable for striped bass at certain times of the year. Adult striped bass prefer temperatures from 16 to 20 °C, while juveniles perfer 24 to 25 °C. Spawning generally occurs in 15 to 18 °C water. Since summertime temperatures sometimes exceed 30 °C in Lake Pleasant, striped bass may be stressed thermally if there are no cool water refugia available. Existing water quality data indicate some thermal stratification of Lake Pleasant, but at least in June 1979, there was an accompanying decrease in dissolved oxygen with depth. With the limited limnological data available about Lake Pleasant, it is difficult to describe temperature and dissolved oxygen profiles adequately for an extended period of time. Therefore, striped bass could be subjected to the temperature-dissolved oxygen "squeeze" described elsewhere in this report.

Salt and Verde Rivers. — Water quality data collected at two U.S. Geological Survey stream gage stations were examined for the Salt River about 5.6 km downstream from Stewart Mountain Dam, 9.6 km upstream from the confluence with the Verde River, and the Verde River about 3.4 km downstream from Bartlett Dam. Additional water quality data for the Salt and Verde Rivers were provided by the U.S. Forest Service and for the Granite Reef Forebay by the Salt River Project. Water diverted from the Salt River at Granite Reef Diversion Dam is used principally for municipal, industrial, and irrigation water in the Phoenix metropolitan area. The water is generally suitable for the prescribed uses. The rivers support a variety of fish life, (U.S. Fish and Wildlife Service 1975; Marsh and Minckley 1982; Essbach pers. comm.), with occasional supplemental fish stocking and management by the Arizona Game and Fish Department to enhance recreational use along the river. Several years worth of water temperatures for the outflow of Granite Reef Diversion Dam into the Arizona and South Canals were provided by SRP. Table 35 shows these water temperatures. These temperatures probably reflect actual water temperatures in the forebay since during most of the year all water in the forebay is diverted into these two canals to supply the metropolitan area, resulting in a very short residence time for water in the forebay. Thus, the shallow forebay acts essentially like a flume. As a result of the constant inflow and outflow, water temperature throughout the water column is probably uniform.

The Salt and Verde Rivers are both highly regulated, and flows may range from no or insignificant flows in late winter or during construction work on the dam, to excessive floodflows in spring. Discharge (m^3/s) and air and water temperatures for the Salt River from September 1967 to May 1982 and the Verde River from April 1966 to April 1982 are shown in table 36 and 37. Table 38 shows some recent water quality data from the Salt and Verde Rivers obtained from the U.S. Forest Service.

Examination of STORET retrieved water quality data for the Salt River below Stewart Mountain Dam, revealed a mean water temperature of 16.74 °C with a minimum of 9.0 °C and a maximum of 25.0 °C for 72 observations. For the Verde River below Bartlett Dam, the mean temperature

Table 35. — Temperatures (°C) at outflow of Granite Reef Forebay. First number is day of month, second number is reported temperature. Data obtained from Salt River Project.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1983	4-12.8 11-11.7 17-13.9 24-11.1											
1982		1-12.2 8-11.7 16-16.1 23-17.2	2-17.2 9-12.8 16-12.8 23-17.2	6-13.3 13-13.9 18-15.0 29-15.6	3-17.8 11-17.8 18-18.9 25-20.0	1-21.1 8-21.7 15-22.8 22-22.2 29-21.7	6-18.9 12-18.9 19-18.9 27-19.4	2-25.0 9-20.0 16-19.4 27-20.0	3-19.4 10-19.4 17-18.3 20-18.9	1-17.2 7-18.3 14-17.2 20-17.8 27-17.2	1-16.7 9-18.3 17-16.1 22-16.1 29-15.6	8-12.8 15- 7.8 23-14.4 28-12.2
1981					12-17.5	10-22.2 29-22.0		3-25.0 13-23.3 17-23.0 25-25.0	1-24.0 8-24.5 15-23.0 22-23.0 29-24.0			7-12.8 18-12.8 22-12.8 28- 9.4
1980	10-14.5		13-13.5 27-13.0	10-16.7		5-18.9	17-23.9		11-22.8		11-17.5	
1979	23-10.0	20-10.0	6-10.0 20-12.0	24-13.0	8-14.0 22-17.0	19-16.5	3-20.0	21-19.5	4-21.5	9-18.0		13-11.6
1978	10-11.0		7-12.0 21-13.5	11-15.0 25-15.0		27-20.0	25-22.0	8-22.0 22-22.0			9-11.0 21-15.5	

was 14.89 °C with a minimum of 7.5 °C and a maximum of 27.0 °C for 103 observations.

Tilapia aurea die in about 1 week when exposed to constant 8 °C, in about 2 weeks at 10 °C, and apparently survive indefinitely at 12 °C (Zale pers. comm.). *T. aurea* also are thought to be the most cold tolerant of the tilapias in the United States (Shafland pers. comm.). Reported wintertime water temperatures in the Salt and Verde Rivers infrequently drop below 10 °C, and the period of time these temperatures persist is not long. However, the available records contain large gaps. Wintertime water temperatures will probably not be a major factor limiting the survival of tilapia populations in these rivers. An undetermined percentage of the population will winterkill, but sufficient tilapia would survive to reproduce the following year and reestablish the population.

Tilapia generally spawn at temperatures above 22 °C. If we choose 20 °C as a reference temperature for the initiation of maturation prior to spawning activity, consistent with the alleged biological adaptability and apparent increasing hardiness of the species, we see that water temperatures above 20 °C occurred in the Salt River from June 17 through September 10, 1968; September 17, 1969; June 1 and July 31 through August 18, 1970; September 16 through November 2, 1971; July 18 through August 16, 1972; November 1, 1973; July 3 through October 2, 1974; April 21, June 19, and September 2 through October 17, 1975; April 19 through August 19, 1976; April 14 and June 15 through November 14, 1977; October 1980; and June and August 1978; August 1979; June 1 through October 21, 1981

In the Verde River below Bartlett Dam, reported water temperature was at or above 20 °C in July and August 1966; August through October 1967; July and October 1968; June through October 1969; May through June 1970; September 1971; early April and August 1972; August, September, and October 1973; mid-April, mid-May, and July through October 1974; June, July, and September through November 1975; July through October 1976; June through November 1977; June, August, and October 1978; April, June, August, September, and October 1979 (but not continuously); August through November 1980; August through October 1981. These are minimum periods during which the reported water temperatures of the Salt and Verde Rivers were at or above 20 °C. Annual fluctuations of water temperatures in the Granite Reef forebay generally reflect those found upriver, with temperatures

Table 36. — Salt River — Below Stewart Mountain Dam, Arizona

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
09-28-67	1240.00	35	19
10-04-67	718.00	24	—
10-12-67	768.00	—	—
10-24-67	386.00	27	17
11-01-67	7.68	28	18
11-13-67	4.44	29	18
12-05-67	5.00	—	—
12-18-67	13.80	—	—
01-03-68	13.40	6	10
01-15-68	6.53	17	12
02-01-68	7.13	26	—
02-12-68	104.00	17	11
02-14-68	4590.00	12	9
02-23-68	1530.00	—	—
02-28-68	5020.00	27	10
03-01-68	2400.00	—	10
03-15-68	1720.00	23	14
04-01-68	2060.00	—	—
04-15-68	3210.00	—	—
05-01-68	2110.00	38	17
05-14-68	1040.00	24	18
05-24-68	1070.00	30	19
06-03-68	1290.00	—	19
06-17-68	964.00	20	32
07-01-68	886.000	38	20
07-19-68	1480.00	—	—
08-01-68	1280.00	38	20
08-14-68	1190.00	35	20
09-10-68	1770.00	39	22
09-19-68	2210.00	32	19
10-01-68	1660.00	29	18
12-03-68	315.00	16	15
12-13-68	962.00	24	10
12-31-68	525.00	20	12
01-16-69	96.80	17	12
02-03-69	22.30	16	11
03-03-69	831.00	21	12
03-18-69	569.00	—	16
05-01-69	2630.00	33.3	7.2
06-16-69	2340.00	33	13
07-15-69	1400.00	44	—
09-17-69	1010.00	32	22
11-17-69	7.13	19	15
12-18-69	1000.00	21.5	13
01-02-70	237.00	14	11
02-02-70	337.00	13.5	11
02-17-70	752.00	28	8
02-27-70	1180.00	22.5	10
03-03-70	566.00	21.5	10
04-11-70	1200.00	21	—

Table 36. — Salt River — Below Stewart Mountain Dam, Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
06-01-70	1460.00	33.5	20
06-12-70	2110.00	27	9
07-01-70	2360.00	35.5	20
07-17-70	1850.00	35	19
07-31-70	1800.00	39	20
08-18-70	1120.00	37	22
01-18-71	4.10	24	13
02-01-71	62.20	26	13
02-05-71	225.00	27	13
03-19-71	1640.00	25	12
04-02-71	1310.00	27	13.5
05-03-71	1250.00	30	15
07-01-71	1270.00	33	17
09-01-71	850.00	41	17
09-16-71	505.00	35	26
10-01-71	299.00	22	24
11-02-71	7.99	24	21
11-16-71	6.65	11	15
01-17-72	5.21	20	14
02-15-72	5.20	20	17
03-03-72	5.20	21	14
05-01-72	1310.00	23	16
07-10-72	1540.00	41	19
07-18-72	1230.00	32	20
08-16-72	900.00	32	27
11-01-73	1190.00	28	20
11-16-73	12.70	12	11
12-03-73	15.30	14	9
01-03-74	3.00	1	—
05-01-74	1430.00	32	17
05-17-74	1490.00	26	15
07-03-74	1970.00	38	21
08-02-74	1620.00	32	—
09-18-74	1350.00	29	—
10-02-74	537.00	29	22
01-07-75	2.40	20	10
03-18-75	6.20	7	12
04-21-75	1.37	26	20
05-08-75	1520.00	28	16
06-03-75	1690.00	40	19
06-19-75	1750.00	38	20
07-01-75	1700.00	38	19
07-17-75	1690.00	35	—
08-14-75	1810.00	35	19
09-02-75	1730.00	34	20
09-16-75	1520.00	35	20
10-02-75	1240.00	33	20
10-17-75	2.63	28	24

Table 36. — Salt River — Below Stewart Mountain Dam, Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
11-05-75	1.47	28	18
11-18-75	0.88	22	15
12-02-75	1.52	20	11
12-23-75	1.32	17	13
01-06-76	0.68	14	11
01-27-76	665.00	14	13
01-27-76	668.00	17	13
02-04-76	538.00	14	13
02-04-76	464.00	16	14
02-18-76	2.06	19	17
03-04-76	4.81	14	14
03-17-76	6.09	18	13
04-02-76	929.00	30	16
04-19-76	5.79	24	25
05-17-76	917.00	37	21
06-03-76	1310.00	33	—
07-01-76	1150.00	39	22
08-03-76	1770.00	—	22
08-19-76	1880.00	30	25
10-04-76	506.00	24	—
11-01-76	8.11	*64	7
11-18-76	3.96	23	17
12-01-76	4.00	10	—
04-05-77	674.00	24	13
04-14-77	1370.00	26	22
05-02-77	1260.00	35	—
06-01-77	1710.00	42	17
06-15-77	1900.00	41	21
07-05-77	1780.00	35	—
07-14-77	2270.00	37	20
08-02-77	2040.00	35	—
08-16-77	1590.00	31	21
09-02-77	1670.00	37	—
09-16-77	1090.00	34	24
10-03-77	517.00	29	23
10-18-77	518.00	29	—
11-02-77	6.68	21	20
11-14-77	0.96	26	20
12-02-77	0.85	10	—
10-05-78	1240.00	28	—
11-16-78	2.43	24	15
04-18-79	1010.00	24	—
05-02-79	3940.00	32	—
07-05-79	1860.00	43	—
09-14-79	2300.00	43	—
11-01-79	26.00	25	19
10-03-80	2390.00	36.2	21.6
10-07-80	129.00	37	21.5

Table 36. — Salt River — Below Stewart Mountain Dam, Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
01-13-81	466.00	20.5	14.5
02-02-81	691.00	19.5	13.0
03-05-81	1040.00	17.0	14
04-13-81	1370.00	33	15.5
05-04-81	1430.00	31	18.5
06-01-81	411.00	34.5	23.0
06-12-81	1770.00	35.5	22
08-13-81	1760.00	30	22.5
09-02-81	1820.00	31.5	24
09-14-81	1350.00	37	24
10-05-81	318.00	29	23
10-21-81	387.00	25	20.5
01-05-82	4.07	13	12
01-27-82	2.20	21	15.6
02-19-82	2.80	24	17.9
05-18-82	721.00	29	17.5

*A temperature of 64 Celsius was reported; this is probably an error and should be degrees Fahrenheit.

above 20 °C in recent years occurring from June through September. Temperatures below 10 °C have occurred from December to March. Water temperatures in these rivers are influenced in part by releases from Stewart Mountain Dam and Bartlett Dam. During some years, waterflow in the river fluctuates wildly with low flows generally, but not always, occurring in the fall and winter. The period of time that water temperatures exceed 20 °C in some years will be sufficient for a mouthbrooder such as *Tilapia aurea* to reproduce successfully.

White bass need spawning temperatures from 10 to 18 °C to ensure survival of the species (Vincent 1968). Twelve degrees Celsius is the average thermal cue needed to induce white bass spawning. Temperatures appear to be within the required range in the Salt and Verde Rivers, although other environmental conditions also influence successful reproduction.

Yellayi and Kilambi (1969) set a lower lethal temperature for white bass larvae (100 percent mortality) of 12.8 °C. Adult white bass can tolerate cold water of 3.0 °C for an unknown period of time (Reutter and Herdendorf 1976). Cvancara et al. (1976) reported that YOY white bass could survive temperatures of 30 °C over a prolonged period of time providing other conditions were

Table 37. — Verde River — Below Bartlett Dam Arizona

Date	Discharge (ft³/s)	Temperature °C air	water
04-18-66	281.00	12	21
07-13-66	1550.00	36	21
05-31-67	678.00	22	13
06-16-67	635.00	27	15
07-18-67	796.00	34	—
08-02-67	448.00	37	24
08-22-67	536.00	37	24
09-01-67	506.00	30	25
09-19-67	323.00	26	24
10-03-67	18.90	31	24
10-21-67	87.60	32	21
11-01-67	592.00	28	19
11-14-67	362.00	29	18
12-04-67	118.00	18	16
01-03-68	775.00	10	7
01-16-68	228.00	20	9
02-15-68	120.00	19	10
03-01-68	85.20	26	8
03-15-68	89.50	20	12
05-01-68	762.00	33	—
06-18-68	1790.00	44	—
07-17-68	1610.00	32	23
08-20-68	961.00	33	—
09-03-68	887.00	27	—
10-11-68	133.00	32	23
12-03-68	36.60	15	12
12-13-68	33.10	17	8
12-30-68	37.80	12	11
01-16-69	62.60	20	10
02-03-69	137.00	20	14.5
04-16-69	385.00	22	14
06-17-69	414.00	32	22
07-16-69	1330.00	34	—
09-12-69	54.50	33.5	27
10-02-69	43.40	28	24
11-13-69	182.00	21.5	18
12-02-69	27.20	16.5	14
12-16-69	35.50	23	12
12-31-69	32.70	14	10.5
01-14-70	21.50	22	12
02-12-70	20.00	24	14.5
03-05-70	52.40	18	12
03-12-70	35.00	24	13
03-30-70	343.00	14.5	12
05-01-70	51.50	26.5	14
05-14-70	32.20	34	24
06-01-70	32.30	38	21
06-17-70	31.80	35	23

Table 37. — Salt River — Below Bartlett Dam, Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	water
07-01-70	73.80	34	18
07-08-70	738.00	40	13
08-03-70	498.00	41	10
09-03-70	172.00	32	19
10-02-70	595.00	33.5	18.5
11-20-70	370.00	27.5	11
12-02-70	274.00	13	15
12-14-70	450.00	16	13
01-05-71	554.00	6	9
01-19-71	60.50	14	9
02-02-71	27.70	18	10
02-17-71	535.00	17	9
03-18-71	12.00	23	8
05-18-71	35.50	22	16
06-03-71	47.80	26	16
07-01-71	757.00	32	13
09-15-71	1440.00	36.5	24
11-02-71	545.00	21	19
11-16-71	339.00	16	16
12-01-71	244.00	13	7
12-16-71	470.00	15	11
01-03-72	535.00	13	11
01-17-72	129.00	24	—
02-01-72	237.00	12	8
02-14-72	691.00	14	7
03-01-72	1390.00	18	8
03-17-72	520.00	28	10
04-04-72	161.00	29	26
04-18-72	58.80	20	17
05-01-72	39.30	34	14
05-16-72	43.00	35	18
06-01-72	51.60	34	17
07-03-72	282.00	41	19
08-01-72	386.00	36	24
12-01-72	448.00	30	14
02-15-73	1340.00	16	—
06-01-73	398.00	32	—
08-01-73	903.00	35	20
08-15-73	1140.00	37	19
09-04-73	524.00	37	21
10-15-73	41.60	32	21
12-04-73	370.00	13.5	14.5
12-17-73	982.00	18	13
01-02-74	447.00	12	10
02-01-74	841.00	17	10
03-15-74	66.70	26	14
04-03-74	13.70	24	19
04-15-74	30.40	27	20

Table 37. — Verde River — Below Bartlett Dam Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
05-02-74	39.20	24	15
05-15-74	103.00	30	23
06-03-74	111.00	25	15
06-11-74	101.00	38	17
07-02-74	585.00	38	20
08-01-74	587.00	30	22
09-05-74	174.00	25	23
09-18-74	53.00	30	21
10-01-74	188.00	30	22
10-16-74	761.00	33	24
12-03-74	270.00	16	15
12-13-74	620.00	18	12
01-06-75	323.00	12	9
01-17-75	575.00	14	9
02-03-75	125.00	22	13
02-19-75	133.00	18	12
03-04-75	751.00	26	15
04-02-75	51.20	18	11
05-07-75	58.80	30	18
06-04-75	55.90	33	20
07-07-75	153.00	40	20
07-08-75	438.00	36	18
07-18-75	286.00	36	18
08-02-75	576.00	35	18
08-22-75	300.00	38	—
09-01-75	416.00	36	23
09-15-75	29.10	38	26
10-16-75	334.00	32	33
11-04-75	399.00	37	21
11-17-75	527.00	27	18
12-01-75	281.00	19	15
12-16-75	578.00	19	13
01-05-76	447.00	14	10
01-22-76	18.10	24	16
02-03-76	14.10	23	13
02-13-76	526.00	19	12
03-10-76	713.00	21	11
03-18-76	1280.00	18	11
04-15-76	251.00	16	14
05-05-76	0.80	26	18
05-18-76	760.00	34	16
06-14-76	246.00	33	18
06-24-76	945.00	36	16
07-06-76	937.00	35	18
07-15-76	673.00	37	20
08-04-76	446.00	—	21
08-17-76	359.00	34	23
09-02-76	579.00	29	25
10-05-76	97.30	30	—
10-19-76	522.00	28	23
11-03-76	330.00	29	19

Table 37. — Salt River — Below Bartlett Dam, Arizona — Continued

Date	Discharge (ft³/s)	Temperature °C air	Temperature °C water
11-17-76	660.00	22	16
12-01-76	238.00	20	15
12-07-76	0.62	16	9
12-07-76	6.42	16	9
12-20-76	747.00	17	11
01-03-77	288.00	16	—
01-18-77	265.00	26	10
02-01-77	378.00	18	10
02-16-77	807.00	25	10
03-01-77	875.00	16	10
03-15-77	648.00	25	12
04-04-77	19.60	21	—
04-28-77	10.90	29	—
06-08-77	43.80	41	—
06-10-77	49.00	35	—
06-16-77	175.00	40	29
07-01-77	50.80	38	—
07-13-77	60.70	39	33
07-19-77	32.00	36	30
08-01-77	21.90	35	—
08-15-77	25.00	35	27
08-18-77	31.40	38	36
09-02-77	22.30	41	—
09-15-77	22.70	35	27
10-27-77	491.00	—	21
11-01-77	247.00	27	20
11-15-77	595.00	26	18
12-02-77	250.00	24	—
12-15-77	272.00	25	16
01-04-78	169.00	18	13
01-19-78	139.00	15	11
02-01-78	91.00	21	—
02-17-78	119.00	19	11
05-02-78	839.00	16	10
05-18-78	458.00	32	11
06-02-78	767.00	35	13
06-14-78	129.00	31	12
07-03-78	568.00	38	13
08-02-78	843.00	35	—
09-06-78	508.00	35	—
10-02-78	3.71	—	22
10-17-78	126.00	32	19
11-02-78	33.10	27	—
12-01-78	312.00	17	—
01-02-79	999.00	12	—
02-05-79	302.00	12	9
04-03-79	3280.00	25	—
07-03-79	1350.00	41	—
09-13-79	561.00	32	28
10-01-79	78.50	36	24

Table 37. — Salt River — Below Bartlett Dam, Arizona — Continued

Date	Discharge (ft^3/s)	Temperature °C air	Temperature °C water
12-04-79	512.00	26	14
12-14-79	490.00	20	—
01-14-80	222.00	21	13
02-11-80	8.56	22	13
05-06-80	157.00	33	14
08-21-80	1080.00	41	24
10-17-80	498.00	23	22
11-03-80	649.00	26	—
11-11-80	1180.00	31	25
12-02-80	484.00	25	16
12-16-80	960.00	26	14
01-06-81	602.00	23	13
06-02-81	202.00	38	17
08-04-81	352.00	36	25
09-01-81	348.00	34	28
09-15-81	67.20	33	28
10-01-81	69.40	28	24
10-14-81	83.30	24	20
11-12-81	479.00	32	19
12-02-81	128.00	21	15
12-15-81	250.00	23	15
01-05-82	225.00	14	12
02-01-82	237.00	17	12
02-17-82	177.00	22	15
03-15-82	7040.00	17	12
04-02-82	1760.00	21	12
04-07-82	1290.00	24	13

favorable, but that no YOY white bass survived water temperatures of 35 °C. These water temperature requirements are met in the Salt and Verde Rivers.

Striped bass have been reported to spawn between 10.0 to 25.0 °C, with peak spawning activity occurring between 15.0 to 18.0 °C. Additional conditions required for successful spawning generally include a long stretch of water (60 to 74 km) with a water velocity greater than 0.3 m/s to keep the semibuoyant eggs suspended. The Salt and Verde Rivers would have the water temperatures required for spawning in the spring, but not a sufficiently long stretch of river. On the average, a unit volume of water from below Stewart Mountain Dam would reach the Granite Reef Diversion Dam in 3.5 to 4.0 hours, while a unit volume of water from below Bartlett Dam would require only about 9.0 hours to reach the dam (Bauman pers. comm.).

Physical Features of Pumping Plants and Potential Effects on Fish

Havasu and Granite Reef Aqueduct Pumping Plants. — The initial 244-m lift of water out of Lake Havasu and into the Granite Reef Aqueduct will be accomplished by Havasu Pumping Plant, and smaller pumping lifts on the aqueduct will be done at Bouse Hills, Little Harquahala, and Hassayampa Pumping Plants. A reversible pump/generation plant will be installed at Lake Pleasant, but specifications for this portion of the project were not available for this report.

Havasu Pumping Plant will have six pump units, each with a maximum discharge capacity of 14.2m^3/s with the maximum discharge for this system of 85.0 m^3/s (Bureau of Reclamation 1974). Bouse Hills, Little Harquahala, and Hassayampa Pumping Plants each have 10 pumps of 3 different sizes.

Figure 7 shows a typical section through a suction tube and pump.

The pumps for Havasu, Bouse Hills, Little Harquahala, and Hassayampa Pumping Plants are vertical shaft, single-stage, centrifugal type. Tables 39 and 40 show pump pressure, clearance, and dimensions for all four pumping plants.

Each unit has a rated capacity as tabulated in column a of table 39 and is driven by a motor with a horse-power rating as listed in column b.

The impeller inlet diameter is listed in column c, and the seal clearance between the impeller and pump casing is shown in column d of table 39. The impeller rotational speed is as specified in column e. The minimum clearance of the water passages through the impeller is listed in column f. The minimum clearance is the term used to describe the maximum diameter of a sphere that will pass through the pump impellers.

The velocity of the outlet edge of the impeller at rated speed is tabulated in column a of table 40, and the approximate interval volume between impeller blades within a pump is shown in column b. Water passing through the upstream trackracks, before entering a pump, has the velocity given in column c and increases to the velocity shown in column d as it enters the impellers. Within the pump, the water is accelerated to an average velocity given in column e of table 40.

The velocity in the discharge line varies from tabulation (1) in column f with one pump running to tabulation (2) in column f with the number of pumps running shown in column g.

Table 38. — Summary of relevant water quality data for the Salt River above the confluence with the Verde River, and the Verde River above its confluence with the Salt River

Date	Site	Temp. (°C)	D.O. (mg/L)	pH	Conductivity (μS/cm)	Alkalinity (mg/L)
05-78	Salt	17	10.1	8.3	1180	122
	Verde	18	9.8	8.3	205	98
06-78	Salt	23	11.0	8.4	1190	119
	Verde	22	10.2	8.7	185	105
08-78	Salt	19	7.6	7.6	800	105
	Verde	25	8.8	8.5	400	140
10-78	Salt	12	7.7	8.1	600	125
	Verde	17	5.2	7.2	700	288
12-78	Salt	13	5.9	8.4	1000	195
	Verde	14	9.4	7.9	345	198
04-79	Salt	15	9.5	7.0	392	90
	Verde	21	6.6	7.8	375	145
06-79	Salt	17	7.2	7.8	449	120
	Verde	20	7.5	8.3	230	114
08-79	Salt	20	7.5	7.2	465	86
	Verde	24	8.5	7.5	305	90
	Salt $\bar{x}$	17.00	8.31	7.96	759.50	120.25
	s	3.67	1.71	0.42	330.64	33.67
	Verde $\bar{x}$	20.13	8.25	8.03	343.13	147.25
	s	3.68	1.71	0.52	164.73	66.59

Table 38. — Summary of relevant water quality data for the Salt River above the confluence with the Verde River, and the Verde River above its confluence with the Salt River. — Continued

		Anions, mg/L				Nutrients, mg/L			
Date	Site	CO_3	HCO_3	SO_4	C1	PO_4-P	T-P	NO_2+NO_3	NH_3-N
05-78	Salt			56.0	313.0	0.52	0.51	0.095	1.40
	Verde			20.0	9.0	0.51	0.62	0.400	0.19
06-78	Salt			58.0	295.0	0.14	—	0.130	0.18
	Verde			16.0	7.0	0.40	—	0.210	0.18
08-78	Salt			47.0	360.0	0.18	0.23	0.146	0.32
	Verde			20.0	21.0	0.13	0.52	0.090	0.16
10-78	Salt			80.0	317.0	0.16	0.19	0.160	0.11
	Verde			133.0	112.0	0.15	0.15	0.150	0.09
12-78	Salt			72.0	343.0	0.12	0.26	0.130	0.07
	Verde			54.0	25.0	0.12	0.08	0.110	0.07
04-79	Salt			64.0	79.0	0.05	0.17	0.070	0.10
	Verde			46.0	21.0	0.14	0.18	0.480	0.17
06-79	Salt			64.5	100.0	0.11	0.14	0.055	0.16
	Verde			21.0	10.0	0.17	0.25	0.050	0.30
08-79	Salt			63.0	83.0	0.12	0.14	0.040	0.05
	Verde			25.5	10.0	0.11	0.18	0.050	0.05
	Salt $\bar{x}$			63.06	236.25	0.175	0.234	0.103	0.299
	s			10.02	124.99	0.145	0.129	0.045	0.453
	Verde $\bar{x}$			41.94	26.88	0.216	0.283	0.192	0.151
	s			39.28	35.06	0.151	0.205	0.163	0.081

Table 38. — Summary of relevant water quality data for the Salt River above the confluence with the Verde River, and the Verde River above its confluence with the Salt River. — Continued

Date	Site	Cations, mg/L				Heavy metals, µg/L				
		Ca	Mg	Na	K	Cu	Fe	Mn	Pb	Zn
05-78	Salt	46.7	15.4	184.0	5.7	5.2	186.7	42.8	2.00	4.7
	Verde	25.0	11.5	10.2	2.1	20.1	766.7	25.8	3.10	10.5
06-78	Salt	43.8	15.6	173.0	5.3	9.5	90.0	49.0	3.70	18.2
	Verde	23.3	8.9	6.8	1.9	6.2	410.0	16.2	2.90	6.0
08-78	Salt	33.0	11.0	102.0	4.1	8.0	42.0	70.0	3.30	11.0
	Verde	37.0	15.0	24.0	2.4	15.6	60.0	27.9	2.10	19.1
10-78	Salt	41.0	12.0	106.0	4.1	5.0	4.0	9.3	1.90	15.8
	Verde	66.0	40.0	52.0	3.7	1.9	7.0	14.3	1.70	4.9
12-78	Salt	54.0	15.0	210.0	5.2	4.3	290.0	595.0	1.70	2.7
	Verde	46.0	24.0	35.0	3.5	1.4	80.0	13.9	1.50	3.4
04-79	Salt	37.0	12.0	52.0	4.2	6.8	230.0	20.9	1.50	8.0
	Verde	38.0	21.0	22.0	3.5	5.2	37.4	5.0	0.70	20.0
06-79	Salt	33.0	10.9	39.1	2.9	10.0	290.0	33.2	1.00	8.4
	Verde	23.0	13.0	9.6	1.6	7.6	520.0	31.7	2.40	48.2
08-79	Salt	37.0	10.0	50.0	3.1	8.4	320.0	61.1	2.92	264.0
	Verde	30.0	15.0	16.0	2.3	10.8	250.0	21.1	4.39	7.9
	Salt $\bar{x}$	40.69	12.74	114.51	4.33	7.15	181.59	110.16	2.25	41.60
	s	7.26	2.25	66.93	1.02	2.16	122.15	196.92	0.95	90.01
	Verde $\bar{x}$	36.04	18.55	21.95	2.63	8.60	266.39	19.49	2.35	15.00
	s	14.60	9.96	15.27	0.82	6.56	275.83	8.79	1.13	14.80

Water enters the first stage of the pump at the depth below the surface of the forebay shown in column h. At this depth, the hydrostatic pressure is as tabulated in column i of table 40. As the water enters a pump, the pressure instantaneously increases to the value shown in column j of table 40. Pressure changes exerted on the fish during passage through the pumps vary from the pressure in column j of table 40 to zero at the end of the discharge line. The elapsed time for water to flow from a pump and out the discharge line ranges from slightly more than tabulation 1 in column k with one pump running to approximately tabulation 2 in column k with the given number of pumps running in column g of table 40.

Havasu Pumping Plant has two manifolds joining three pumps, as shown in column g, table 40. The two manifolds joining the two sets of three pumps come together in the lift conduit up to the Buckskin Mountains Tunnel.

The same is true in column g for two manifolds joining two sets of five pumps at the other three Granite Reef Pumping Plants. The three Granite Reef Pumping Plants (Bouse Hills, Little Harquahala, and Hassayampa) each have four pumps capable of 3.7 m^3/s discharge, two pumps capable of 7.4 m^3/s, and four pumps capable of 14.4 m^3/s discharge. These pumps will be computer controlled when the aqueduct is put into operation.

Since there are no turnouts in the aqueduct, there is an enlarged pooling area between the Havasu pump and Bouse Hills pump that will be used as a buffer area so that mismatching of pumped water between Havasu and Bouse Hills can occur. The previous information on the Havasu, Bouse Hills, Little Harquahala, and Hassayampa pumps was supplied from manufacturers' drawings and specifications and was scaled and calculated by Mr. Leroy Heigel, M.E., at the E&R Center, Denver, Colorado.

Mr. Bob Sund (Division of Design, E&R Center, pers. comm.) reported that there are six trashracks in the Havasu Pumping Plant, one per pump. They are 5.8 m wide and 6.40 m high. The trashrack has 15.2 cm openings between 15.9 mm bars with 25.4-mm cross bars spaced 40.5 cm apart going up the trashracks (fig. 8).

The A.D. Edmonston Pumping Plant and fish passage. —The A.D. Edmonston Pumping Plant, in the southern San Joaquin Valley, south of Bakersfield, California (one of the seven pumping plants

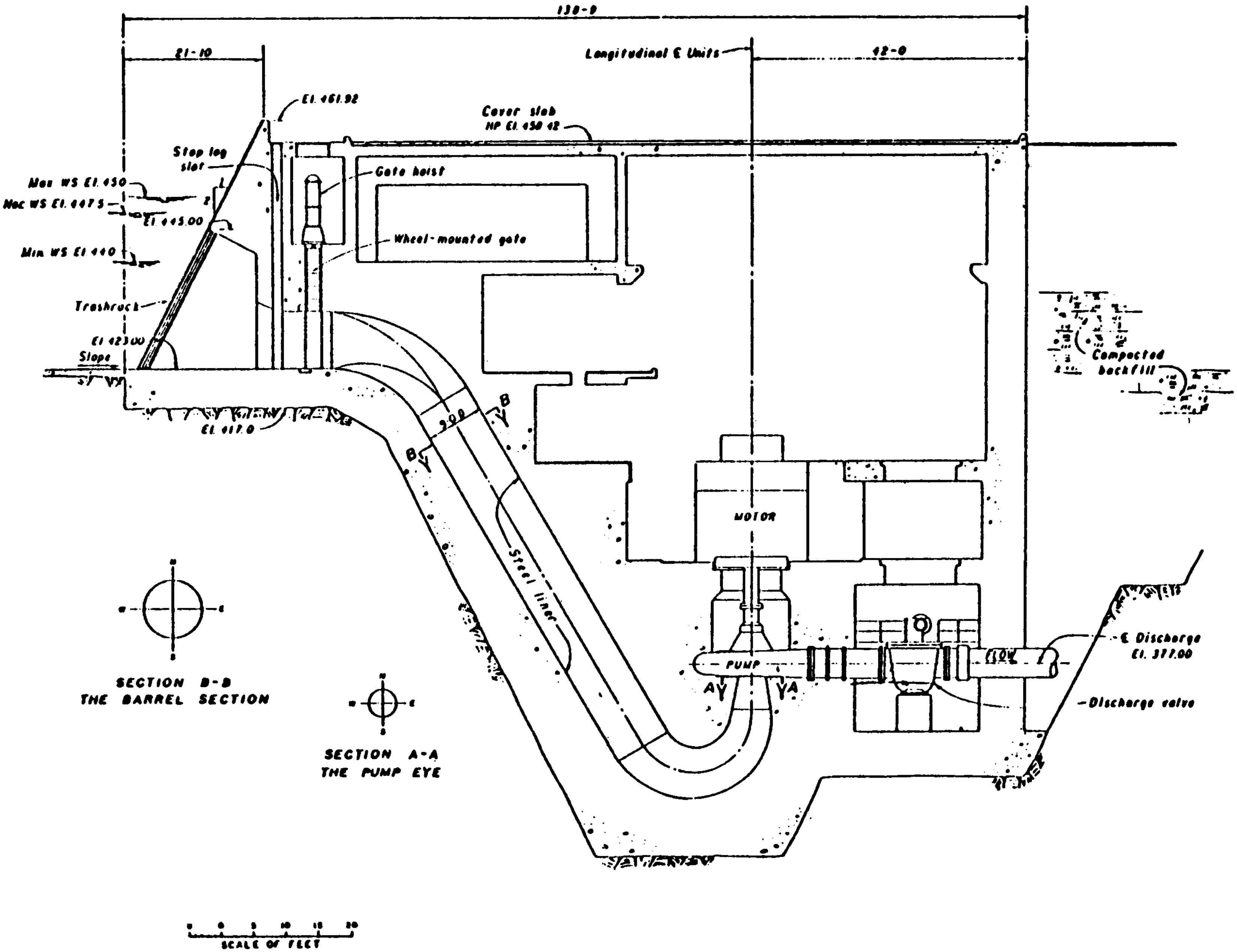

Figure 7. — Typical section of suction tube and pump.

Table 39. — CAP pump discharges, dimensions, and minimum clearance (explanation in text)

Pumping plant	a (ft³/s)	b (hp)	c (in)	d (in)	e (r/min)	f (in)
Havasu	500	60,000	52	0.06	514	6.3
Bouse Hills	130	2,250	36	0.04	450	4.1
	260	4,500	50	0.06	327	5.7
	510	9,000	71	0.06	225	8.1
	130	2,250	36	0.04	450	4.1
Little Harquahala	260	4,500	50	0.06	327	5.7
	510	8,000	71	0.06	225	8.1
Hassayampa	130	3,500	32	0.04	600	3.5
	260	7,000	46	0.06	400	5.1
	510	14,000	63	0.06	300	7.0

Table 40. — CAP pump capacities, pressures, and times for water passage (explanation in text)

Pumping plant	(ft³/s)	a (ft/s)	b (ft³)	c (ft/s)	d (ft/s)	e (ft/s)	f (ft/s) (1)	f (ft/s) (2)	g No. pumps	h (ft)	i (lb/in²)	j (lb/in²)	k (hours) (1)	k (hours) (2)
Havasu	500	219.5	5.9	1.1	33.9	200	4.42	13.26	3	65	28.0	380.6	0.16	0.06
Bouse Hills	130	100.7	1.8	0.69	17.4	90	1.15	13.62	5	21	9.2	57.9	0.08	0.01
	260	101.6	4.7	1.09	18.3									
	510	100.3	15.8	2.1	17.7									
Little	130	100.7	1.8	0.69	17.4	90	1.15	13.62	5	28	12.1	61.8	0.11	0.01
Harquahala	260	101.6	4.6	1.09	18.3									
	510	100.3	13.7	2.1	17.7									
Hassayampa	130	126.6	1.9	0.38	28.3	110	1.15	13.62	5	24	10.4	93.6	0.17	0.02
	260	123.8	7.8	0.59	25.2									
	510	126.1	12.6	1.2	27.8									

in the California Aqueduct system), lifts water 587 m over the Tehachapi Mountains. This pumping plant contains two sets of seven pumps. Each of these pumps has a rated capacity of 8.9 m³/s and is operated by an 80,000 hp motor. Aasen et al. (1982) studied the system for 2 years after startup to determine species and abundance of fish transported. Live fish and mutilated fish were pumped. During the 2 years of sampling, nine species including threadfin shad, hardhead, white catfish, prickly sculpin, starry flounder, channel catfish, striped bass, bluegill, and green sunfish were caught by a midwater trawl set 900 m downstream of the outlet. The most numerous fish were striped bass (86.2 percent), prickly sculpin (2.9 percent), and threadfin shad (1.6 percent). The net was set so that surviving fish were collected. Each year the greatest number of fish were collected between June and the end of August, with the peak occurring around the third week of June. The fish ranged in size from 32-cm channel catfish, to striped bass that were less than 2 cm. The average size of 1,463 surviving fish collected was 4 cm.

Aasen also set a trawl net upstream from the pumping plant to determine the size of fish in the canal before water entered the pumps. Large numbers of striped bass, ranging in length from 25 to 41 cm (mean length of 34 cm) were caught upstream. Many large bluegill ranging in size from 5 to 20 cm were taken (mean length of 14 cm). The upstream sampling did not produce any fish similar in size to the fish captured downstream of the pumps (mean length of 4 cm). Occasionally, a large dead fish or pieces of fish were observed near the downstream sampling site. Large fish apparently were able to avoid the intake flows or their remains settled out before reaching the net.

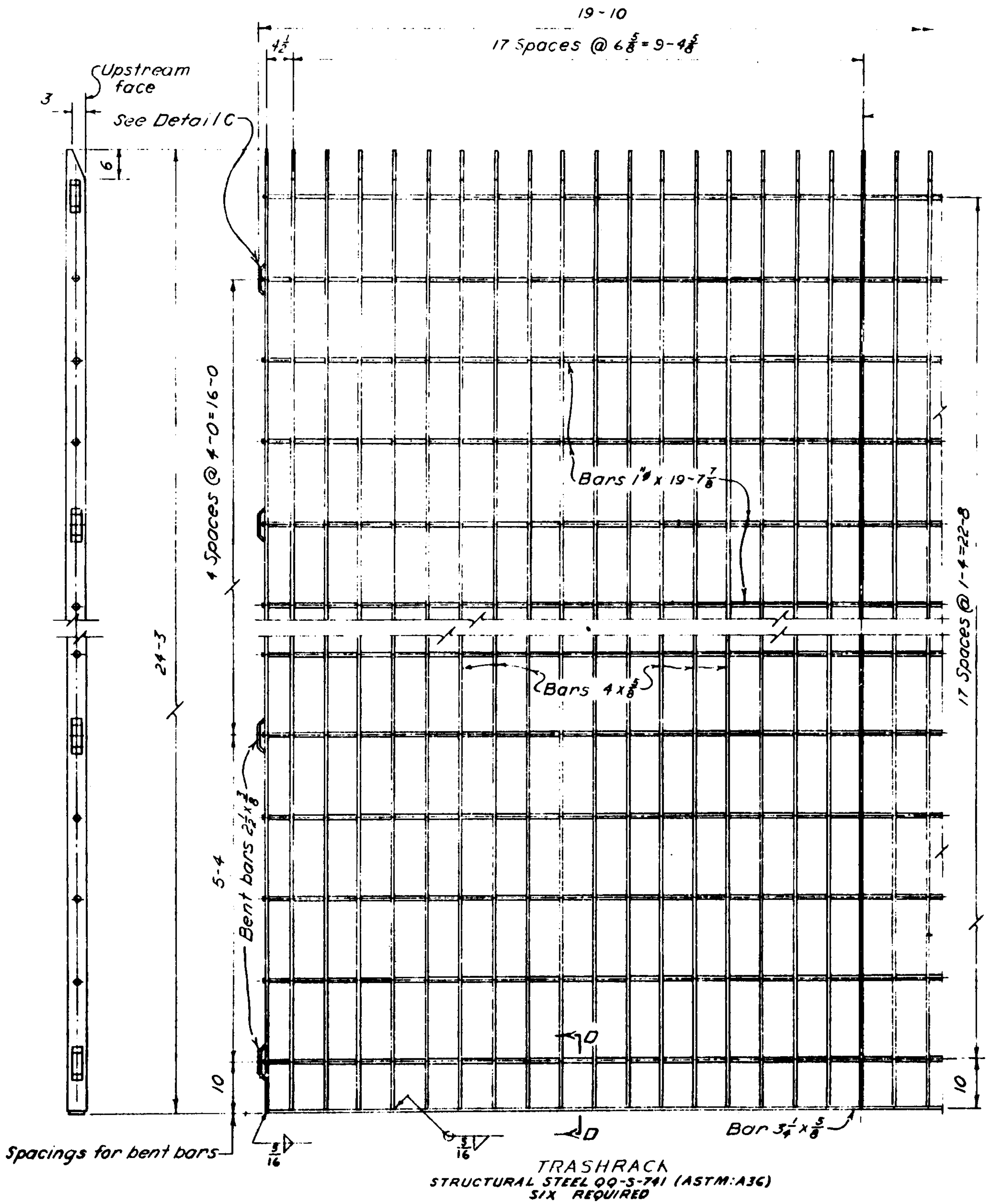

Figure 8. — Typical trashrack for Havasu Pumping Plant.

In this study, it was confirmed that fish are able to withstand the sudden and extreme pressure changes they experienced when passing through the A.D. Edmonston Pumping Plant. This study also indicated that survival is inversely related to size, with only the small fish surviving (Aasen et al. 1982).

Aasen (pers. comm.) reported that striped bass have survived passage through as many as seven or eight pump stations to move through the California Aqueduct and enter Silverwood Lake. The entire 640 km California Aqueduct is open to walk-in and bike-in fishermen and has a striped bass fishery along with white crappie, black crappie, white catfish, channel catfish, and bullhead. There are a few other centrarchids (bluegill, largemouth bass), but they are usually found in slower flowing waters near turnouts and pumps.

Mr. George Reiner (fish biologist, California Department of Water Resources, pers. comm.) observed threadfin shad, bluegill, and crappie in great numbers in the California Aqueduct upstream from the A.D. Edmonston Pumping Plant. He has not observed many fish pumped through the plant, either dead or alive.

Whitsett Intake Pumping Plant and fish passage — The Whitsett Intake Pumping Plant, on the California side of Lake Havasu, pumps water from the Colorado River for the Metropolitan Water District of southern California. The water is lifted 89 m to Genes Wash Reservoir then up 89 m to Copper Basin and then through the mountains, west to southern California. This pumping plant has nine pumps (table 41) each rated at 5.66 m^3/s. This plant was put on line in 1940. At that time, environmental concerns such as pumping of fish were not considered, and information about fish populations in the intake area is sparse. It is known that striped bass and largemouth bass as well as other fish species have been pumped in sufficient numbers to sustain populations in Genes Wash (Mr. Ray Hurd, Metropolitan Water District of Southern California, pers. comm.). A large striped bass weighing 5.4 kg that had a deformity scar on its tail, probably from pump damage, was captured in 1982 by hook and line in Genes Wash. It is not known how long this striped bass lived in Genes Wash before capture. The Whitsett Pumping Plant is capable of pumping almost 53.8 m^3/s when all pumps are on line, but the number of pumps being used varies with the demand for water and the availability of electricity to power the 90,000-hp pumpmotors. A trashrack with about 10.1-cm-wide openings surrounds the pump intakes (Hurd pers. comm.).

Mr. Al Whitsett, Chief Mechanical Engineer of the Metropolitan Water District of Southern California, provided the majority of the specifications for the Whitsett Pumping Plant. The lift out of Genes Wash Reservoir into Copper Basin is the identical distance, 89 m, and has the same nine pump arrangement as the lift pump from Lake Havasu. He says striped bass have survived passage through both sets of pumps and inhabit the system. Table 41 shows a comparison of selected specifications of the Havasu, A.D. Edmonston, and Whitsett Pumping Plants.

Aasen et al. (1982) found that at the A.D. Edmonston Pumping Plant, the largest fish captured alive in the pump exit was 32 cm long. The volume between impeller blades of about 0.05 m^3 for each stage of the four stage A.D. Edmonston pumps is less than the 0.167 m^3 volume between the impeller blades of the single stage Havasu pumps. Fish should have an even better chance of passing through the single stage Havasu pumps than through the A.D. Edmonston pumps. The Whitsett pumps have a minimum clearance (defined as the maximum size of a sphere that could pass) of about 12.7-cm diameter, so larger fish should also have a better chance of surviving

Table 41. — Comparison of selected specifications of the Havasu, A.D. Edmonston, and Whitsett Pumping Plants.

	Rated capacity (ft^3/s)	Horse-power	Hydrostatic pressure at inlet end of pump (lb/in^2)	Instant pressure increase within pump (lb/in^2)	Impeller seal clearance with case (in)	Velocity as water enters pump (ft/s)	Within the pump acceleration velocity (ft/s)	Minimum clearance of the water passage (in dia. sphere)	Water lift (ft.)	No. of pumps
Havasu Pumps	500	60,000	28	380.6	0.06	33.9	200	6.3	800	6
A.D. Edmonston Pumps	315	80,000	31	853	0.12	14	188	N/A	1,926	14
Whitsett Intake Pumps	200	90,000	4	127	0.002-004	23	133	5	292	9

passage through the Havasu pumps which have a minimum clearance of 16.0 cm. As the water moves down the Granite Reef Aqueduct, it is pumped through three other pumping plants, having a total of 30 pumps with minimum clearances ranging from 8.9- to 20.6-cm-diameter, depending upon which pumps are operating.

Effects of shear force on fish. — Velocity may affect striped bass and blue tilapia eggs and larvae. Variation of velocity with position gives rise to shear fields which, with respect to time, can produce accelerative or deaccelerative stress (Morgan et al. 1976).

Eggs and larvae can both be damaged by differing velocities across the surface causing them to tear apart; eggs can also be damaged by the centrifugal effects of rapid spinning (Morgan et al. 1976).

In tests on effects of shear on eggs and larvae of striped bass, Morgan et al. (1976) showed that the longer the eggs and larvae experience shear forces, the greater the chance of damage. Exposure of striped bass eggs to a shear level of 350 dynes/cm^2 kills 36 percent of the eggs in 1 minute and 69 percent in 2 minutes. Exposure of larvae to 350 dynes/cm^2 kills 9.3 percent in 1 minute and 30.0 percent in 2 minutes. Shear force of Havasu Pump and conduits was calculated (P. Johnson pers. comm.) and were lower than those reported by Morgan et al. (1976). However, these figures were calculated using the scale model information from the E&R Center Hydraulics Laboratory, and velocity measurements near the inside edge of the pipe were difficult to obtain because of the size of measuring equipment with relationship to the scale of the model. Johnson (pers. comm.) stated that within the pumps there are many areas where shear forces are found, but calculation of them would be extremely difficult. Accurate figures of shear forces are also difficult to obtain when there are bends in the conduit or obstructions such as valves, trashracks, and smooth/coarse walled conduit that could cause turbulance. Shear forces increase with velocity and inversely with conduit diameter. The volume of water in a conduit, wherein shear is potentially damaging, is a small fraction of the total volume. In a 2.74-m intake conduit for example, the shear forces will be in about a 7.60-cm layer around the inside of the conduit. The physical bombardment of fish eggs and larvae on impeller blades, seals, and cases is small because fish eggs and larvae are about as dense as water and would be suspended in the flow. In addition, pumps are designed to force water tangently so waterflows against the blades are at an angle.

Pressure and shear forces will damage fish eggs and larvae to some degree. These pressures and shear forces along with pounding against objects will affect larger fish. Damage to striped bass eggs reported in Morgan et al. (1976) included breakup of the yolk or a separation of the developing embryo from the yolk sac. There did not seem to be any particular developmental stage that was more vulnerable to the shear force than another.

Bell (1973) stated that beginning at approximately 12.2 m/s, shearing action may cause injury or death to fish. The first evidence of damage to fish (juvenile to adult) is descaling.

Effects of pressure on fish. — Pump pressures within the CAP water transport system will be greatest in the Havasu pumps. Fish (eggs, larvae, and adults) passing through these pumps will be subjected to instantaneous pressure change of from 193.1 to 2624.2 kPa (kilopascal) for a period of between 9.6 to 3.6 minutes. Loudermilk (pers. comm.) stated that the pumps at Havasu were a Francis type and that pressures generated would not be great enough to kill fish.

Swim bladders of fish could be damaged by severe pressure changes, which could affect survival. Beck et al. (1975 in Setzler et al. 1980) exposed striped bass eggs and larvae to a pressure of 13.8 kPa for 2 seconds, followed by a 10-second return to atmospheric pressure and then a sudden increase in pressure to 3316 kPa. A return to atmospheric pressure followed about 12 minutes later. The following results were obtained:

Age of eggs and larvae tested	Results
45-hour eggs —	20 percent reduction in survival compared to controls, 48 and 72 hours postexposure
81-hour eggs —	54 percent reduction in survival after 24 hours
15-18 day — larvae	70 to 80 percent reduction in immediate survival, 56-64 percent reduction after 24 hours

Thirteen- to 17-day-old larvae exposed to 310 kPa for 3 days suffered 36 to 64 percent reduction in immediate survival and 38 to 58 percent reduction after 24 hours. These results indicate that larvae are more sensitive to pressure than eggs. Fish eggs, larvae, and juveniles will be exposed to these great pressures for fractions of an hour. These rapid pressure increases followed by a gradual reduction to near zero pressure will occur for a period of between 9.6 and 3.6 minutes. These are times required for pumped water to travel from the pump and out the discharge line at Buckskin Mountains Tunnel. These times vary with the number of pumps on line. These pressures could affect the fish, but to what extent is difficult to say. Mr. Milo Bell (Consulting Engineer, Mukilteo, Washington, pers. comm.) stated that in general, literature describes few effects of pressure on small organisms. Bell was retained as a consultant for the proposed Stormking Pumped Storage Powerplant on the Hudson River and concluded that there would be little effect of pressure on pumped striped bass. Bell also consulted on the A.D. Edmonston Pumping Plant, and recalled that he did not feel pressure would be a big factor in killing fish. He participated in tests on salmon pressurized to a depth of 228.5m (2302 kPa), and found gravid salmon to have a few erratic movements at that pressure, but no mortality. Salmon can adjust to fairly rapid pressure decreases, however. As long as pressures are on the positive side, there is little problem; it is the releasing of pressure that causes problems. When fish experience higher pressures, air in the body is compressed. There is a possibility of nerve blockage, but this is rare. Depressurization, if very rapid, can cause a range of effects on the fish ranging from gas embolism to literally exploding. A gradual depressurization, such as will occur in the Havasu Plant, should reduce the negative effects of pressure on the pumped fish. How this gradual depressurization affects survival is unknown at present.

Reiner (pers. comm.) discussed mortality of fish due to pressure in the A.D. Edmonston Pumping Plant. He noted that there is a lack of published data on pressure influences on individual species and life stages of fish. In the California Aqueduct system, the water users in the San Joaquin/Sacramento Delta area mitigate water withdrawal by decreasing pumping during spawning periods of striped bass and salmon. Other mitigation measures include louvered plate screens and possibly the establishment of a striped bass hatchery near the Delta. Pyramid Lake and Silverwood Lake, several hundred miles away along the California Aqueduct, have very good striped bass fisheries. Striped bass in those reservoirs came through the California Aqueduct from the San Joaquin/Sacramento River Delta. Reiner (pers. comm.), does not think that there is successful reproduction taking place in the aqueduct system or reservoirs. He attributes this to the fact that there are times during the day when there is no flow in the aqueduct system. If striped bass eggs were in the system and experienced intermittent or irregular flows, the semibouyant eggs would drop to the bottom and become smothered.

Reiner suggested that one way to reduce fish introduction through pump systems was to use a pump that effectively kills fish during its operation. There are generators that destroy eggs that bombard the blades, but to his knowledge, no pump will significantly destroy organisms. Reiner mentioned a reservoir below Pyramid Lake, California, linked to Pyramid Lake by a pumped-storage powerplant. Pyramid Lake has a good fishery for striped bass, but the reservoir below has no striped bass in it that he knows of. He feels that since there is no successful recruitment into the reservoir system, the stripers are all too large at this end of the system to pass the pumped storage trashrack and they are also large enough to escape flows through the pump/generation cycles.

Effects of aqueduct temperatures on fish. — Water temperatures in the 304 km Granite Reef Aqueduct can be expected to vary with the seasonal ambient air temperatures as the water passes through pumps, canals, and siphons to the junction with the Salt River behind Granite Reef Diversion Dam. Biological organisms within the water will be subjected to these changes in temperature. The temperature of CAP water arriving in the Granite Reef Diversion Dam area (proposed Orme damsite) was projected in 1975. Equilibrium temperature and heat exchange coefficients were computed from climatological data available for Las Vegas, Nevada, and Phoenix, Arizona. Expected temperatures of water arriving at the proposed Orme damsite from the Granite Reef Aqueduct would be within the range of 8.3 °C in the winter, and 27.7 °C in the summer. These temperature projections were based on 85 m^3/s flows. Changes in demand and releases could influence these temperatures when CAP is on line. Mr. Jim Wagner (USBR, Phoenix, Arizona, pers. comm.) stated that a general formula for calculating average daily water temperature in a canal the size of Granite Reef Aqueduct is to use the average daily air temperature, which will be within a few degrees of the water temperature.

Mr. Randy Chandler (Arizona Projects Office, pers. comm.) noted that flows down the Granite Reef Aqueduct will not fluctuate much from the design capacity of 85 m^3/s for the first few years. When the enlarged Lake Pleasant is able to store water, summer flows through the Granite Reef Aqueduct could stabilize at a lower flow. These flows would probably reach higher summer temperatures because of the smaller volume of water at the lower flows. If flows are low for a sufficiently long period of time, water temperatures could conceivably reach 32.2 °C. July is generally the warmest month in the year. Average July air temperatures from 1897 to 1957 at Parker, Arizona, Phoenix, Arizona, and outside Mesa, Arizona (closer to Granite Reef Dam) are as follows:

Parker	— 33.4 °C
Phoenix	— 32.5 °C
outside Mesa	— 31.1 °C

Water temperatures exert an important influence on determining rate of development and survival of eggs, larvae, and postlarval striped bass and *Tilapia*. Egg incubation time decreases with an increase in temperature up to a certain limit. For striped bass, egg hatching percentage decreases as water temperatures exceed 21 °C. No striped bass eggs survived 25.5 °C water (Shannon 1969). The following information from Shannon (1969) presents recommended critical time/temperature on striped bass egg incubation. He indicated that mortality after hatch was greater after exposure to the time periods at these temperatures:

Time (hr)	Incubation temperature (°C)
72	18.3
60	21.1
45	23.9
28	26.7
0	29.5

This indicates that if eggs are exposed to temperatures for these periods of time, survival will be low. Shannon (1969) also stated that early development of the freshly fertilized egg is impeded at temperatures of 26.7 °C, but a more advanced stage of development at a lower temperature increases egg tolerance to higher temperatures. In another section of this report, it is noted that the longer the time the egg is exposed to 18.3 °C, the more tolerant the eggs become to shock exposure to higher temperatures. Coutant and Kedl (1975 in Setzler et al. 1980), reported that approximately 2-week-old, 4- to 6-mm striped bass larvae could tolerate a temperature of 29°C for 30 minutes without mortalities; however, temperatures of 31° and 33°C resulted in 50 percent mortalities within a 5- or 6-minute period. Juvenile striped bass, in a series of temperature gradient experiments, seemed unable to discern lethal temperature and did not avoid heated waters that proved to be fatal to some. Dorfman (1974 in Setzler et al. 1980, and Meldrim et al. 1971 in Setzler et al. 1980) demonstrated that there was a significant seasonal difference in fish responses at a given temperature. A direct relationship between ambient acclimation temperatures and upper avoidance temperatures for juvenile striped bass was reported by Meldrin and Gift (1971 in Setzler et al. 1980). Fish acclimated to 27 °C waters in late August avoided 34 °C water. The intakes at Havasu could possibly pull in 18.3 °C water with striped bass eggs and larvae; when the water is then pumped into the aqueduct, the air temperatures, along with increased surface area of water exposed to ambient temperatures, could increase the canal temperature to a point where a high percentage of striped bass eggs and fry would not survive. Tilapia initiate spawning at about a temperature of 22 °C. These eggs and larvae could survive temperatures up to about the 29.4 °C that the canal water may reach.

Effects of velocity on fish. — The intake approach velocity of water at the Havasu Pumping Plant is 33.5 cm/s. This is lower than what Bibke et al. (1974 in Bowles et al. 1976) stated:

> "... intake velocities present at most power plants (15.2 to 30.5 cm/sec) should not impinge fish such as young striped bass, which apparently escape water velocities greater than 61 to 79.2 cm/sec if they chose. Clearly, other parameters such as water temperature and a variety of additional factors... may modify a fish's normal swimming behavior with respect to water velocity."

Area and distance traveled by 80 mm striped bass increased with increasing temperature up to 20 °C, then declined at higher temperatures. Entrainable larval striped bass demonstrated poor swimming ability, exhibited frequent drift behavior, and remained stationary for minutes (Bowles et al. 1976).

As water velocity increased from 0 to 30 cm/s, distance traveled by juvenile striped bass 10 to 80 mm long decreased. However, as water velocity increased from 0 to 3 cm/s, distance covered by larval striped bass increased. The presence of food increased the activity of larval striped bass but decreased the activity of juveniles. Area covered by striped bass at test velocities ranging from 0 to 30 cm/s increased in proportion to body length. Juvenile striped bass tested at acclimation temperatures from 20 down to 5°C experienced a 30 percent reduction of activity. Activity was also reduced as acclimation temperature increased from 20 to 30°C (Bowles et al. 1976).

Striped bass larger than 50.8 mm in length can effectively escape from 30.5 cm/s intake velocity (Jensen 1970).

Bell (1973) also reported that 25 mm striped bass fingerlings have a swimming speed of 30.5 cm/s. This is close to the 33.5-cm/s intake approach velocity so striped bass 25 mm and less would be entrained if they enter the intake flows. Burst speed was not mentioned. The other three pumps in the Granite Reef Aqueduct also have pumps with intake approach velocities at the trashrack of over 30.5 cm/s (36.6 and 64.0 cm/s). Fish of 25 mm would have little choice to avoid the flow. Fingerlings 12.7 cm long can swim at 83.8 cm/s and they could thus avoid all approach velocities at the trashracks and avoid entrainment.

Predicting fish passage through the CAP pumping plants. — Eggs and young fish that would be withdrawn from Lake Havasu would probably be a small percentage of the total number of each of the life stages of the striped bass present in the lake unless there was an attractant influence in the intake area (abundance of preferred prey, suitable temperature, or desired spawning habitat). Those fish species that spend most of their lives along beaches rather than in protected backwaters or offshore should be particularly vulnerable to entrainment at shoreline intakes (Cole 1978). White bass were in the group of fish considered less vulnerable to entrainment in the Monroe Powerplant on southwestern Lake Erie because they were concentrated along distant beaches or in remote backwaters of tributaries. Some of the other species such as gizzard shad appeared to be vulnerable to entrainment because they were more concentrated inshore than offshore (Cole 1978). No generally accepted method has yet been established for predicting the zone of influence on aquatic organisms around powerplant or pump intakes (Boreman 1977). Simplistic mathematical models do not consider hydrodynamic phenomena necessary to predict flow conditions at intake areas, and field verifications with dye and drogue studies do not reflect the reaction of aquatic organisms to intake velocities. Eggs and early larval stages of aquatic organisms are particularly vulnerable to entrainment. Fish may also hold a position immediately in front of the intake structure and become susceptible to entrainment upon exhaustion (Boreman 1977).

A relatively simple mathematical model by Goodyear (1977) is used to estimate percentage loss of populations of aquatic organisms that are entrained by intakes on lakes and streams. In order for this and other mathematical models to be used, parameters such as average concentration of organisms in the intake water and main body of water and the average period organisms are vulnerable to entrainment are necessary. At present, there is limited information of this type available for Lake Havasu.

To determine percent mortality of fish passing through the Havasu pumps, previous studies that investigated percent mortality of fish in similar pumping situations were reviewed. The few reports found presented only limited data. Taft et al. (1981) found that striped bass larvae had a 4.7 percent average mortality (3.7 to 6.1 percent) in tests of larvae passage through a jet pump. Yellow perch prolarvae 6 mm in length had 32 percent mortality through the jet pump. In tests of yellow perch prolarvae through a screw-impeller (hydrostal) pump, 6.1-mm-long prolarvae had a mean mortality of 8.3 percent, but as the larvae grew to 19.4 mm, mortality declined to zero. There will probably be differential mortalities among eggs, larvae, juveniles, and adults of any fish species pumped through CAP pumps, with larvae appearing most vulnerable. Loar (1982) reported 15 percent mortality of fish passing through turbines in a dam.

An estimate of the abundance and distribution of striped bass and blue tilapia in Lake Havasu is needed to determine how many of what size fish would be pumped. In an April 1982 fisheries inventory on Lake Havasu in the vicinity of the intake channel (Jakle 1982), one striped bass was captured in a gillnet on the inlet side of the manmade dike at the intake channel for Havasu Pumping Plant. Systematic sampling and monitoring programs must be conducted in the area of the intake channel before any conclusions can be reached concerning how many and what kind of fish would be pumped during operation of the CAP.

Selected Life History Aspects of the Southern Bald Eagle as Related to CAP

General considerations. — Several active nesting sites of the southern bald eagle (*Haliaeetus leucocephalus*) have been documented along the Salt and Verde Rivers. Here we summarize apsects of the eagles' food habits and focus particularly on the percentage and species of fish in their diet as determined by prey remains beneath nests. The principal concern relates to the possible disruption in the availability of prey fish used by the bald eagles and competition between these fish and three nonnative fish species, striped bass, white bass, and blue tilapia. The central Arizona population of bald eagles is of special interest because they represent almost exclusively the entire bald eagle population known to breed in southwestern deserts [CAWCS (Central Arizona Water Control Study 1982)]. The resident bald eagles of particular concern to operation of the CAP nest along the Salt and Verde Rivers upstream of the Salt and Verde confluence and below Stewart Mountain Dam and Bartlett Dam.

Bald eagles forage for prey and, in central Arizona, foraging usually takes place in the backwater pools and riffles of rivers (Hildebrandt and Ohmart 1978 in Ohmart and Sell 1980). Three methods of foraging have been observed in central Arizona: (1) foraging from a perch, where the eagles typically stoop toward the water; (2) foraging from the air, where the eagles stoop at prey from a low flapping flight over water; and (3) foraging from the air, where the eagles stoop from high altitudes.

The resident bald eagles in Arizona are opportunistic feeders, generally feeding on fish at or near the surface in flowing or quiet waters. The breeding bald eagles feed especially on carp and catfish and, to a lesser extent, on suckers throughout the river system, but also utilize crappie, largemouth bass, yellow bass, waterfowl, songbirds, reptiles, small mammals, and carrion (Haywood and Ohmart 1982). Eagles in other parts of the country, also utilize a variety of food. In parts of Utah, bald eagles prey mainly on jackrabbits (Endangered Species Office, Helena, Montana, pers. comm.), while in northeast Wyoming, bald eagles prey on prairie dogs, jackrabbits, and dead deer, antelope, and sheep (USFWS, Cheyenne, Wyoming, pers. comm.). In Glacier National Park, Montana, bald eagles feed on kokanee salmon during the salmon's spawning runs and on carp and suckers when salmon are not abundant.

Winter activity periods for northern migrant bald eagles in Arizona include arrival in October to November, departure in March to April, with peak populations from December to February (Grubb 1978; Todd 1978 in Ohmart and Sell 1980). Winter migrant bald eagles in Arizona are confined to the higher elevations, generally north of the Mogollon Rim. There is thought to be no overlap between wintering migrant birds and resident populations (Mr. Terry Grubb, Raptor Biologist, Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture, Tempe, Arizona, pers. comm.). Some of the wintering bald eagles in Arizona are known to migrate from their breeding grounds in Canada and the northern United States (Ohmart and Sell 1980).

Wintering bald eagles (postbreeding) in Arizona are opportunistic in their feeding habits. Waterfowl, American coots, and fish (trout) are the primary prey items, with rabbits, carrion of game mammals, and livestock utilized to a lesser extent (Grubb 1978 in Ohmart and Sell 1980).

Resident eagles nesting along the Salt and Verde Rivers in central Arizona breed during winter and spring. Adults behave differently from immature birds in that the adults may remain at some sites in Arizona year-round (Ohmart and Sell 1980).

Location of nests. — Recent breeding activity has been concentrated along the Salt and Verde Rivers, with 10 recently active nest sites (Ohmart and Sell 1980). During 1981 and 1982, 14 young were produced. Thirteen young fledged from seven nests in 1983 (Anonymous 1983a). There are an estimated 30 to 35 eagles in the Salt-Verde population. Nest productivity increases downstream toward the Salt and Verde confluence. The Blue Point/Stewart Mountain nest has the highest production rate of the entire central Arizona eagle population (CAWCS 1982).

The nesting sites are almost always within 0.4 km of the river. The distance between nests averages 20.9 km, which may also delineate the foraging range for the bald eagles (Grubb pers. comm.).

Because of the endangered status of the bald eagle, only the general locations of the three nests of concern will be provided. These active sites are the Bartlett and Fort McDowell nests on the Verde River and the Blue Point/Stewart Mountain nest on the Salt River.

Bartlett area (Verde River). This area lies below Bartlett Dam and has been occupied since the early 1940's. There are cliff and tree nest sites. Adult eagles were observed preying on fish from Bartlett Reservoir during the autumn of 1978. At the Bartlett nest site, 26 observations were made of prey captures (Haywood and Ohmart 1982). There were 25 fish captures and one mammal capture. The fish remains (1979-1981) consisted of channel catfish, Sonora and desert sucker, carp and flathead catfish (table 42).

Fort McDowell area (Verde River). — All known nests have been constructed in trees and have been very productive since 1974. The primary foraging area is south of the nest site, possibly as far south as the Salt and Verde confluence, and

Table 42. — Percentage of prey remains found beneath three bald eagle nest sites, 1979-1981.

Species	Bartlett	Ft. McDowell	Blue Point/ Stewart Mtn.
Channel catfish	34.5	11.2	10.7
Sonora sucker	23.0	22.3	28.6
Carp	3.6	33.3	3.6
Desert sucker	3.6	11.2	10.7
Flathead catfish	5.4		
Bullhead catfish		5.5	17.8
Bass spp.			7.1
Yellow bass			3.6
American Coot	7.3	5.5	7.1
Great Blue Heron	3.6		
Unidentified bird	1.9		3.6
Gila Woodpecker	1.9		
Great Egret			
Common Flicker			
Yellow-bellied Sapsucker			
Northern Oriole		5.5	
Unidentified duck	1.9		
Black-tailed jackrabbit	3.6	5.5	3.6
Unidentified mammal	1.6		3.6
Cottontail rabbit	3.6		
Neotoma spp.			
Peromyscus spp.			
Yuma antelope ground squirrel			
Rock squirrel			
Perognathus spp.			
Unidentified snake	2.6		

may include areas along the Salt River, both above and below the confluence. The primary prey remains by the nest site included carp, sucker, and catfish (table 42).

Blue Point/Stewart Mountain (Salt River). —A nest was located in a cottonwood tree in 1972. The nest fell in 1975, and an attempt to build a new nest has not occurred. The present nest site (since 1981) is on a cliff face below Stewart Mountain Dam. Three young were fledged in 1982. This nest site is considered the most productive. The majority of the prey remains were Sonora sucker, bullhead catfish, channel catfish, and the desert sucker (table 42) (Haywood and Ohmart 1982).

Food habits. — Table 43 (Haywood and Ohmart 1982) summarizes composite prey remains for all nest sites by the number of individuals from 1979 to 1981 and the percentage and rank for each prey. Channel catfish, Sonora sucker, carp, and desert sucker comprised 67.5 percent of all prey remains. Other fish, birds, and mammals made up the remainder of the observed prey remains. Another study found that fish comprised about 80 percent of the diet of the eagles, and mammals comprised the remainder (CAWCS 1982). Four species of fish comprised 95 percent of the 197 fish prey remains examined: channel catfish, carp, desert sucker (*Catostomus clarki*) and Gila sucker (*C. insignis*). Seventy-five percent of the prey remains were catfish and carp. Fish abundance and distribution may possibly be correlated with bald eagle reproductive success. The most productive nests are in areas where either carp, channel catfish, or Gila suckers occur (CAWCS 1982). Arneson and Bors-Koefoed (in CAWCS 1982) reported that fish spawning might also have a direct effect on eagle predation habits. They observed that carp and catfish deliveries to the nest sites occurred most frequently at a time coinciding with their spawning. More carp were taken earlier in the season than were catfish,

Table 43. — Composite Prey Remains, 1979 to 1981.

Species	Number of individuals 1979	1980	1981	Total number	Percent total	Rank order
Channel catfish	14	5	70	89	36.18	1
Sonora sucker	6	2	27	35	14.23	2
Carp	7	4	21	32	13.00	3
Desert sucker		2	8	10	4.07	5
Flathead catfish	1	1	5	7	2.84	7
Bullhead catfish			6	6	2.44	8
Bass spp.			2	2	0.81	10
Yellow bass			1	1	0.41	12
American Coot	1	3	11	15	6.10	4
Great Blue Heron		2	2	4	1.62	9
Unidentified bird	1		3	4	1.62	9
Gila Woodpecker			1	1	0.41	12
Great Egret	1			1	0.41	12
Common Flicker	1		1	2	0.81	11
Yellow-bellied Sapsucker	1			1	0.41	12
Northern Oriole	1			1	0.41	12
Unidentified duck			1	1	0.41	12
Black-tailed jackrabbit	2	1	6	9	3.66	6
Unidentified mammal	1	5	1	7	2.84	7
Cottontail rabbit	1	2	4	7	2.84	7
Neotoma spp.		1	2	3	1.22	10
Peromyscus spp.			3	3	1.22	10
Yuma antelope ground squirrel	1			1	0.41	12
Rock squirrel			1	1	0.41	12
Perognathus spp.			1	1	0.41	12
Unidentified snake			2	2	0.81	11
TOTAL	39	28	79	246		

while more catfish were taken later during the eagle's breeding season.

The size of the suckers, carp, and catfish ranged primarily from 203 to 356 mm and weighed from 0.05 to 0.54 kg. Eagles have also taken 127- to 152-mm yellow bass (Grubb pers. comm.).

A fishery survey was conducted on the Salt and Verde Rivers mainstream and backwaters from June 1974 to December 1975 (USFWS 1976). Table 27 summarized fishery data on the Verde River mainstream below Bartlett Dam. Over 90 percent of fish biomass is contributed by four species; the carp (48.64 percent), desert sucker (*C. clarki*) (24.72 percent), Sonora sucker (*C. insignis*) (11.43 percent), and channel catfish (5.61 percent). The remaining 12 species accounted for less than 10 percent of the fish biomass. Some confusion exists regarding the names of suckers in central Arizona. To avoid confusion, the scientific name of the native suckers follows the common name, unless the common name is unquestionably only one species. Table 44 lists some of the common names used to designate *Catostomus insignis* and *Catostomus (Pantosteus) clarki*.

Composite prey remains at the Ft. McDowell nest (table 42) consisted of 33.3 percent carp, 22.3 percent Sonora sucker, and 11.2 percent for both channel catfish and the desert sucker and generally reflect the relative abundance based on biomass reported by USFWS (1976). About 78 percent of the prey remains found beneath bald eagle nests consisted of the four fish species that contributed to over 90 percent of the fish biomass in the Verde River. Carp also contributed to over 80 percent of the fish biomass in Verde River backwater areas.

Prey remains data for the Bartlett nest suggest that the eagles may be somewhat selective in their diet. Composite prey remains at the Bartlett nest site consisted of 34.5 percent channel catfish, 23.6 percent Sonora sucker, 5.4 percent

Table 44. — Common names used for *Catostomus insignis* and *Catostomus* (*Pantosteus*) *clarki*

Catostomus insignis	*Catostomus* (*Pantosteus*) *clarki*	Author
Gila sucker	Gila mountain-sucker (*Pantosteus*)	Minckley 1973
Gila sucker	Desert sucker	CAWCS 1982
Sonora sucker	Desert mountain-sucker	Marsh and Minckley 1982
Sonora sucker	Desert sucker	USFWS 1976
Gila sucker	Gila mountain-sucker	Kepner 1979
Sonora sucker	Desert (also Gila)	Robins et al. 1980
Sonora	Desert	Eddy and Underhill 1978
Gila	Gila mountain-sucker (*Pantosteus*)	Koster 1957
Sonora	Desert	Lee et al. 1980
Gila	Mountain	Haywood and Ohmart 1981

flathead catfish, and 3.6 percent each carp and desert sucker. Channel catfish and Sonora sucker make up about 58 percent of the prey remains beneath the Bartlett bald eagle nest but constitute only about 17 percent of the fish biomass in the river. These eagles use carp and desert suckers for only about 7.2 percent of their diet, while these 2 fish species make up 73.36 percent of the fish biomass in the Verde River.

A discrepancy exists between the prey remains found below a nest and the fish biomass in the river. This discrepancy could be due to actual prey preference and selection by the eagles, field sampling error, foraging by the bald eagles in Bartlett Reservoir or that the distribution and abundance of carp and suckers reported for the river did not coincide with foraging areas used by the eagles.

Prey remains were identified for each nest site, but fish biomass was a composite. Another reason for the discrepancy could be actual localized changes in fish abundance and distribution that could have occurred during the several year time period between the fishery study of the rivers and the analysis of the nest prey remains. The present species composition, abundance, and distribution in these rivers may deviate somewhat from that reported earlier (USFWS 1976).

Table 25 summarized fishery data on the Salt River mainstream below Stewart Mountain Dam. Three fish species accounted for about 84 percent of the fish biomass; carp (39.96 percent), Sonora sucker (23.39 percent), and the desert sucker (21.02 percent). The remaining 12 species contributed to about 16 percent of the fish biomass. The prey remains beneath the Stewart Mountain bald eagle nest consisted of about 28.6 percent Sonora sucker, 17.8 percent bullhead catfish, 10.7 percent each channel catfish and desert sucker, 7.1 percent bass spp., and 3.6 percent carp, whereas, the percent biomass of these fish species in the Salt River was 23.39, 2.13, 0.32, 21.02, 8.33, and 39.9, respectively. The apparent abundance of prey near the Stewart Mountain nest may explain the relatively high productivity of this nest in 1982. During early June and mid-October 1981, reaches of the Salt and Verde Rivers were sampled to determine eagle prey distribution relative to known foraging areas (CAWCS 1982). The CAWCS report stated that the desert (*C. clarki*) and Gila (*C. insignis*) suckers were quite abundant (no data were reported and "quite abundant" was not defined) in the regulated reach (not defined) of the Salt and Verde system, while carp and channel catfish were widely distributed in the system and not abundant at any one location.

Since fish comprise most of the bald eagle diet, the impact of introducing additional nonnative fish species into the Salt and Verde Rivers is a valid concern. Fish contributed about 82.1, 83.5, and 70.7 percent of the food items (based on prey remains) to the diet of the Stewart Mountain, Ft. McDowell, and Bartlett eagle nests, respectively. If striped bass, white bass, and tilapia entered the Salt and Verde Rivers during operation of the CAP, and if they were available as prey, they would probably be consumed by the eagles. If no reproduction occurred, the impact of recruitment by introduction could possibly be to broaden the food base for the bald eagles (Grubb pers. comm.). This is indicated by the fact that bald eagles prey on yellow bass from the Salt River and Saguaro Lake. Stewart Mountain eagles also consumed both yellow bass and bass spp. Grubb (pers. comm.) observed an eagle taking a 150-mm yellow bass from Saguaro Lake back to the nest.

Yellow bass are similar to the white bass in ecology, behavior, and sporting qualities (Minckley 1973). Because of this similarity, bald eagles will likely utilize white bass as prey. Striped bass are larger than white bass and generally pelagic in nature. Free-roaming adult or large subadult striped bass would not likely be as available to bald eagles unless they were in shallow water. Eagles usually feed on slower, less agile fish at or slightly below the water surface. In some African lakes, birds of prey feed heavily on tilapia (Chimits 1957). Gwahaba (1973) reported that eagles and other predatory birds preyed on *T. nilotica* in Lake George, Africa. Arizona bald eagles may be able to utilize tilapia also.

It is the opinion of some raptor biologists that the worst effect the three nonnative fish species could have on the Salt and Verde River system would be displacement of catfish, carp, and suckers, thereby reducing the eagles' prey base. If the currently abundant food base was reduced in availability, and the striped bass, white bass, and tilapia could not replace this prey as suitable forage, then the eagles might not be able to obtain sufficient food (Grubb pers. comm.; Dr. Robert Ohmart, Professor of Zoology, Tempe, Arizona, pers. comm.; Mr. Richard Bauman, raptor biologist, U.S. Bureau of Reclamation, Phoenix, Arizona, pers. comm.; Mr. Steve Hoffman, endangered species biologist, U.S. Fish and Wildlife Service, Albuquerque, New Mexico, pers. comm.). Such an occurrence would affect the breeding capabilities of the adult eagles and the fledging of young in the area.

Ohmart (pers. comm.) explained that if the catfish and carp were to become a limited food source, the eagles would not breed successfully and would fledge no young. Bauman (pers. comm.) stated that the bald eagles on the Salt and Verde Rivers probably could not raise young on terrestrial forage alone or shift their food base successfully. Hoffman (pers. comm.) felt that if the tilapia population were to proliferate, exhibit interspecific competition in the river system, and eventually become stunted, the fish species would not represent an adequately sized food for the eagle. Grubb (pers. comm.) reiterated the concern about carp, catfish, and suckers, but felt that the "opportunistic" bald eagle would feed on other abundant and available prey.

Bald eagle food habits have been based principally on prey remains found beneath individual nest sites along the Salt and Verde Rivers. Studies on the prey actually taken from the rivers, surrounding lakes and reservoirs, as well as foraging patterns and food preferences, have been limited. Prey remains analyses may not accurately represent the types of food items utilized by the eagles because some remains are larger, stronger, and more persistent in the environment than others, and more easily identified. Vandalism of the prey remains site by scavenging animals, field sampling errors, or infrequent sampling could also bias these results.

Elaboration of life history phenomena of the bald eagle is required. Many questions regarding life history phenomena of the bald eagle along the Salt and Verde Rivers remain unanswered. Some of these questions include: where do immature birds go; do the eagles select prey on the basis of availability, size, movement, or some other factor; what is the actual composition of the diet; what percentage of the diet consists of fish and what percent consists of nonfish items; what is the foraging range; do the eagles utilize stressed or diseased fish that may be near the surface. The historical food habits of the bald eagle prior to man's intervention and the introduction and establishment of nonnative fish species would allow an analysis of the rate and degree to which the eagles were able to alter their diet to reflect successful reproduction and establishment of the introduced fish species.

ANALYSIS

Future Without CAP Operations

Without the operation of the CAP, water and the subsequent introduction of fish species from the Colorado River into Lake Pleasant and the Salt and Verde Rivers would not occur. No impact attributable to operation of CAP would occur on existing fishery resources in these designated receiving waters and little change in the fish forage base of the southern bald eagles nesting along these rivers would be expected. The fishery resources in the CAP receiving waters would probably remain relatively stable, influenced principally by annual precipitation, runoff, and downstream demand for water, including water level fluctuations in reservoirs with their sometimes negative effects on fish spawning success, abundance of forage fish available for sport fish, inter- and intraspecific interactions for food, mates, and suitable spawning habitat, and management and fish stocking policies and practices of the AGFD. Accidental or intentional importation into the State and/or transportation around the State of any fish species by well-intentioned but misguided or careless anglers has been a problem in other states as well as Arizona and will likely continue to be a problem. For example, sailfin mollies were intentionally introduced into the Salt and Verde Rivers about 1952 to produce fish for the aquarium trade (Minckley 1973). They reproduced prolifically in that habitat and are now found in the lower Gila River and in the lower Colorado River. Populations of sailfin mollies existed in the Salt and Verde Rivers (USFWS 1976) and in Phoenix metropolitan area canals (Marsh and Minckley 1982) and are probably present today.

Parker Canyon Lake, south of Tucson, on the other hand, is an example of illicit fish introduction. It was originally built with D-J (Dingell-Johnson) funds in the early 1960's to support a year-round trout fishery. It was thought that the 1524 meter elevation of the lake would allow trout survival year round. However, summertime water temperatures in excess of 26.7 °C were lethal for trout (Mr. Will Hayes, Fisheries Specialist, Arizona Game and Fish Department, Tucson, Arizona, pers. comm.). Recently, largemouth bass, bluegill, green sunfish, and channel catfish have been found in the lake. "Bait bucket Charlie" was suspected of making these introductions (Hayes 1983). In Alamo Lake, several game fish and forage fish species were stocked after completion of the dam. Recently, Kepner (1979) has documented additional fish species that were not stocked under authority of the Game and Fish Department and attributed these introductions to bait transfer and release.

In addition, sportsmen's groups could also have an impact on existing fishery resources by exerting pressure on resource management agencies to introduce additional or alternate fish species. Whether desirable or not, fish transfers do occur; the angling public, farmers, and ranchers can and will redistribute fish around the State, despite State fishery management plans or regulations. Even without human intervention, given the dynamic nature of ecological systems, including aquatic communities, some changes would likely continue to occur over time as they have in the past.

The increasing population in the Phoenix metropolitan area will undoubtedly increase the demand on water resources for both domestic and industrial use as well as for recreational use. In the 10-year period from 1970 to 1980, Arizona's population increased 53 percent to 2,718,425. By 1990, the State's population is projected to increase to 3,609,000, with a projected 2,033,200 of those in Maricopa County, and by 2000, the State's population could reach 4,626,000, with 2,634,700 in Maricopa County (Valley National Bank of Arizona 1982). The principal angling and nonangling water-based recreational areas in central Arizona include Lake Pleasant, Alamo Lake, and the Salt and Verde Rivers with their reservoirs. Even without CAP water transfers, but with an increased urban population, there will be increased angler and recreational pressure on these resources with the possibility of increased transport and introduction of fishes, either accidentally or intentionally. State fishery biologists would need to establish some rigorous guidelines to prevent movement of fish by individuals. It is unrealistic to expect that any system of safeguards would not be circumvented somehow or sometime.

Future with CAP Operations — Possible Effects of the Introduction of Three Nonnative Fish into CAP Receiving Waters

Striped bass. — Based on characteristics and physical parameters of the CAP pumping plants, and on the results of limited fishery studies at other pumping plants already in operation, there is an almost certain likelihood that young striped bass, as well as other fish species, will be lifted out of Lake Havasu and transferred into the Granite Reef Aqueduct, contingent upon the presence of striped bass and other fish species in the Havasu Intake Channel. The fish species pumped and the number of each species transferred cannot be predicted accurately, since only limited fish species composition and abundance data are available for the intake channel and the lower part of Lake Havasu. Small fish that cannot avoid the intake approach velocity, or those fish that become exhausted by attempting to maintain position within the intake channel will be entrained. Fish larger than 2.5 cm could probably avoid being pumped since they could avoid the intake approach velocity of 33 cm/s, as measured at the trashrack. Fish approximately 2.5 cm in length that have a swimming speed of less than 30 cm/s would probably be entrained.

Some fish will be killed during passage through the pumps, but an undetermined number will survive. Once in the Granite Reef Aqueduct, striped bass, as well as other species, would be subjected to intermittent high velocities and occasional rising temperatures, but some fish will survive and move down the canal and enter Lake Pleasant. Cumulative mortality of fish pumped through the Havasu Pumping Plant and the three inline pumping plants could be substantial. Those fish surviving passage through the pumps would be stunned and possibly battered, and vulnerable to predation by canal resident fish and gulls, herons, and cormorants, and susceptible to disease in the sometimes warmer canal water. A portion of the fish will pass through the pumps unharmed. If we assume an arbitrary 15 percent mortality for fish passing through each pumping plant, as determined for fish passage at some damsites (Loar 1982), out of 100 units of fish at the Havasu intake channel we would have:

	Survival %	Mortality %
Intake channel	100	0
Havasu Pumping Plant	85	15
Bouse Hills Pumping Plant	72.25	27.75
Little Harquahala Pumping Plant	61.4	38.58
Hassayampa Pumping Plant	52.21	47.79

We calculate that an approximately 30.5-cm striped bass could be pumped and transported down the canal in a viable condition, based on the minimum clearance of water passage through impellers, and on results of A.D. Edmonston Pumping Plant fish recovery studies. These fish would be about 1 to 2 years old and would mature in about 2 to 3 years. If striped bass do survive to maturity in Lake Pleasant, reproductive success would likely be low compared to other reservoirs where they exist, since striped bass generally require a particular combination of length of river and water velocity to spawn successfully.

Some fish species may become established in the canal. The degree to which establishment will occur, and the fish species composition and abundance, cannot be known until after the CAP is in operation. If striped bass or other species of concern established reproducing populations in the Granite Reef Aqueduct, they could alter the immigration rate into CAP receiving waters from that expected based solely on the abundance of fish in the area of the Havasu Pumping Plant. Predation by resident fish may reduce the number of recently pumped small fish, although the degree to which this would occur, if it would occur at all, is unknown.

Fish that enter Lake Pleasant will initially be subjected to predatory and environmental pressures that may reduce the chances for survival, although some fish will likely survive these pressures. Under current plans, CAP water will be diverted into Lake Pleasant for storage only from October to March, then withdrawn from April to September; therefore fish should only be able to enter the lake during the October to March period. Since striped bass spawn at temperatures of from 14.5 to 18.4 °C, (table 45), and since the temperature of lower Lake Havasu is about 16.5 °C by the end of March, there is the likelihood that striped bass fry from early spawning fish could be pumped into the Granite Reef Aqueduct if the fry were in the immediate area of the intake channel. However, it is not known for certain where, when, and to what extent striped bass spawning occurs in Lake Havasu. If spawning occurs far enough upreservoir of the CAP intake, then possibly by the time any fry reached the area of the intake channel, they would be of sufficient size to avoid the intake approach velocity. Spawning sites, nursery areas, and movement of striped bass adults, fry and YOY in Lake Havasu must be determined before an estimate of the extent of entrainment at the Havasu Pumping Plant and eventual transport can be made. Striped bass are known to survive passage through the Metropolitan Water District Pumping Plant on the California side of Lake Havasu, because mature striped bass are occasionally caught in Gene's Wash Reservoir, a storage reservoir for the system. Recruitment of striped bass in Lake Pleasant will be by introduction by way of the Granite Reef Aqueduct.

During some months in the summer, the surface temperature of Lake Pleasant exceeds 30 °C. The requirements for many environmental parameters for different life history stages of striped bass are shown in table 45. Although Lake Pleasant is a deep lake, the degree to which it stratifies thermally over an entire season is not known; dissolved oxygen levels at depth for part of the summer are reduced to about 1 mg/L or less. These summertime conditions of high surface water temperature and low dissolved oxygen levels at depth will subject the striped bass to the temperature-dissolved oxygen "squeeze" in which the striped bass seek deeper, cooler water but also where dissolved oxygen levels are low. The striped bass will seek the most suitable combination available between desired temperature and adequate dissolved oxygen levels and will probably occupy restricted strata in the lake. Water level fluctuations in Lake Pleasant may exacerbate the situation for the striped bass.

Preferred food for striped bass (clupeid fishes, also used by the resident white bass) would probably be less available to the striped bass inhabiting the cooler water, since shad prefer warmer water temperatures.

Striped bass generally require flowing water in which to spawn and, if the introduced striped bass survive to maturity, they may attempt upstream migration in the Agua Fria River. Precipitation and runoff can vary greatly from year to year and with it, water temperature and the suitability of the Agua Fria River as spawning habitat. In-lake spawning of striped bass has been documented in some Colorado River reservoirs with

Table 45. — Tolerance and optimum ranges of environmental parameters for various life history stages of striped bass, and generally required spawning conditions (compiled from numerous sources.)

Life history stage	Environmental parameter	Tolerance range / optimum range
Eggs	Temperature (°C)	10-27 / 15-20
	Dissolved oxygen (mg/L)	1.5-? / 3-7
	pH	?
	Salinity (mg/L)	0-10 000 / 1000-3000
	Substrate	Generally require flowing water to remain suspended
Larvae (up to 20 mm in length)	Temperature (°C)	12-26.7 / 16-19
	Dissolved oxygen (mg/L)	2-? / 5-8
	pH	6-9 / 7-8
	Salinity (mg/L)	?-15 000 / 5000-10 000
	Flow (m/s)	0-5 / 0.3-1
	Food	Zooplankton
	Substrate	Sand or gravel
Juveniles (20-50mm)	Temperature (°C)	7.2-35 / 24-25
	Dissolved oxygen (mg/L)	0.8-? / 6-12
	pH	5.3-10 / 7-9
	Salinity (mg/L)	?-20 000 / 10 000-15 000
	Flow (m/s)	0-5 / 0-1

Table 45. — Tolerance and optimum ranges of environmental parameters for various life history stages of striped bass, and generally required spawning conditions (compiled from numerous sources.) — Continued

Life history stage	Environmental parameter	Tolerance range / optimum range
Juveniles — Continued	Food	Crustaceans, insect larvae, copepods, aquatic insects, fish larvae.
	Substrate	Sand and gravelly bottoms.
Subadults (50-100 mm)	Temperature (°C)	?-30 / 20-24
	Dissolved oxygen (mg/L)	3-? / 6-12
	pH	6-10 / 7-9
	Salinity (mg/L)	0-35 000 / 10 000-20 000
	Flow (m/s)	0-5 / 0-1
	Food	Fish fingerlings, crustaceans.
	Substrate	Sand and gravelly bottoms.
Adults	Temperature (°C)	10.5-26 / 16-20
	Dissolved oxygen (mg/L)	1-? / >5
	pH	?
	Salinity (mg/L)	Can tolerate estuarine, brackish, and marine environments (off the coast or along the coast).
	Flow (m/s)	?
	Food	Prefer clupeids, but will prey on other fish species.
	Substrate	Generally pelagic in nature.

Table 45. — Tolerance and optimum ranges of environmental parameters for various life history stages of striped bass, and generally required spawning conditions (compiled numerous sources.) — Continued

Life history stage	Environmental parameter	Tolerance range / optimum range
Spawning requirements	Temperature (°C)	10-25 / 15-18.4
	Dissolved oxygen (mg/L)	>3
	pH	?
	Salinity (mg/L)	≤3000 / ?
	Flow (m/s)	0.30-0.84
	Food	May not feed during spawning.
	Substrate	Generally prefer flowing water with velocity >0.3 m/s.

the fish apparently keying on structure rather than current. The degree to which successful spawning would occur in Lake Pleasant would depend on environmental and meteorological conditions which would be required to keep eggs suspended or well-oxygenated on a rocky substrate. In many reservoirs of less than 11 000 ha, striped bass reproduction is only marginally successful, if successful at all, and annual stocking is required to maintain the population.

In February 1980, the high average inflow to Lake Pleasant was 145.4 m^3/s, but by March, average inflow had decreased to 14.2 m^3/s (U.S. Geological Survey 1982). Sixteen km upstream on the Agua Fria River near Rock Springs, average flow in February 1980 was 94 m^3/s decreasing to 9.3 m^3/s and 3.6 m^3/s in March and April, respectively. About 29 km further upstream at the Mayer gaging station (19 km southeast of Mayer, Arizona), average flow in February was 33.4 m^3/s with a decline to 2.3 and 0.9 m^3/s in March and April, respectively. In all cases, water velocity exceeded 0.5 m/s. However, 1980 was an exceptionally high water year on the Agua Fria River and was one of only 6 years that Lake Pleasant spilled since 1927, when the lake first began to fill, so these flows were atypically high. At the Mayer gaging station, 45 km upstream from Lake Pleasant, the higher flows recorded from February to May 1976 to 1983, have generally been accompanied by water temperatures ranging from 10-15 °C, and with the depth of water ranging from 0.15 to 0.61 m. During the remainder of the year, water depths at Mayer average about 0.09 m. Water velocities may reach 2.5 m/s, but decrease to and hold relatively steady around 0.6 m/s in late spring. At a flow of 0.6 m/s, a unit volume of water would travel the 45 km from the Mayer gaging station to Lake Pleasant in about 21 hours. At higher flows and velocities, travel time would decrease. Flows and velocities begin to decrease at about the time water temperatures begin to rise to the preferred spawning temperature of striped bass. As water temperatures increase, mature striped bass in Lake Pleasant could attempt upstream migration. If the bass did spawn successfully around the Mayer gaging station, eggs would be moved downstream into Lake Pleasant in less time than required to hatch; however, in the shallower water associated with the reduced flows, some eggs might settle out or be injured in riffles. If the eggs settled on suitable substrate and remained viable, they could hatch there. Other eggs would continue to Lake Pleasant. Once in Lake Pleasant, the eggs would settle out.

Some of these eggs might hatch if they settled onto suitable substrate. The required combination of velocities and water temperature may exist in the Agua Fria River during years of high precipitation and runoff to provide conditions for limited striped bass spawning.

Striped bass could be introduced into the Salt and Verde Rivers during operation of the CAP through the proposed SRP interconnection. In these rivers, striped bass would be subjected to summertime water temperatures that would approach the upper lethal temperature of about 30 °C for subadults and about 26 °C for adults. There is no deep water refuge for striped bass in the Salt River. Even if striped bass did mature in the Salt and Verde Rivers, spawning would not be successful because the high floodflows in spring would transport eggs to the Granite Reef Diversion Dam in about 9 hours, even from as far up the Verde River as Bartlett Dam. This is far less time than is required for hatching. The eggs would be lost to the system by either diversion into the Arizona or South Canals or release of water into the normally dry Salt River, or settle out in the river. In any case, reproductive success would be low because the eggs would be flushed out of the system before they had a chance to develop and hatch, substantially reducing the chance for recruitment by reproduction. However, recruitment by introduction during operation of CAP will likely occur.

Blue tilapia. — Blue tilapia are suspected of entering Lake Havasu from Alamo Lake via the Bill Williams River. To date, however, no voucher specimen has been confirmed for Lake Havasu. Conditions in Lake Havasu around the area of the intake channel would generally be favorable for tilapia survival (table 30) and reproduction; reproduction occurs at temperatures above 22 °C. However, recorded wintertime water temperatures in the intake channel area of lake Havasu have dropped to 10 °C. Exposure to this temperature thermally stresses tilapia. Although the lower lethal temperature of blue tilapia is about 6.0 °C in the laboratory, exposure to 8 °C kills tilapia in 4 to 9 days, and exposure to 10 ° kills tilapia in 11 to 30 days. Some winterkill could be expected. Rate of water temperature change, age or size, state of health of the fish, and the period of exposure to low water temperatures are some factors that affect the ability of a fish to survive exposure to low water temperatures, and thus, determine to some degree, the percentage of the population that would experience winterkill. Oxygen levels are generally adequate throughout the year in lower Lake Havasu. Sufficient food would probably be present for the opportunistic blue tilapia. In evaluating whether or not tilapia would survive and become established in CAP receiving waters, their environmental requirements during different life history stages were compared with recorded environmental conditions in CAP receiving waters (table 46).

Blue tilapia are a hardy fish (Shafland pers. comm.) and if they occur in Lake Havasu, would probably survive passage through the pumping plants (Smitherman pers. comm.). If tilapia were pumped into the Granite Reef Aqueduct, they would eventually enter Lake Pleasant. Any fish species introduced into Lake Pleasant during CAP operation will initially be disoriented after recent passage through the pumping plant in the 6.4 km reversible canal and will be subject to predation by resident predators. The lacustrine environment of Lake Pleasant would be suitable for survival of tilapia, although predation by game fish would have an undetermined effect on their numbers. The food supply should be adequate because the meso-eutrophic conditions in Lake Pleasant support another planktivorous fish, the threadfin shad.

Blue tilapia would reproduce successfully in Lake Pleasant, but the degree to which the population would expand cannot be predicted. During spawning, the male blue tilapia excavates a nest in which a female deposits eggs; the quality and quantity of spawning substrate (even in the mouthbrooder) may limit or affect reproductive success. Tilapia have proliferated in Alamo Lake, but Lake Pleasant has an additional predatory species, the white bass, not reported from Alamo Lake.

The largemouth bass fishery is an important component of the overall Lake Pleasant fishery. Largemouth bass and other predators will utilize the blue tilapia to an unknown extent. Zale (pers. comm.) reported that in laboratory investigations, largemouth bass prefer the blue tilapia to bluegill. Because of the importance and desirability of largemouth bass to the Lake Pleasant fishery, their numbers could be supplemented by stocking.

Tilapia should not compete directly with largemouth bass for spawning habitat since largemouth bass begin spawning at a temperature as much as 7 °C lower than the temperature required for tilapia spawning. Therefore, largemouth bass spawning should be completed before tilapia begin to spawn. Tilapia could, however, interfere with largemouth bass reproduction by harassing the adult bass guarding the eggs or fry, resulting in lowered bass reproductive success. The largemouth bass that do survive would prey on the younger and smaller tilapia fry when the bass change to a fish diet from an invertebrate diet.

If blue tilapia entered the Granite Reef Aqueduct from Lake Havasu or from Lake Pleasant, they

Table 46. — Ranges of environmental parameters for various life history stages of blue tilapia, and generally required spawning conditions (compiled from numerous sources)

Life history stages	Environmental parameter	Range	Receiving waters: Lake Pleasant	Receiving waters: Salt River	Receiving waters: Verde River
Adults	Temperature (°C)	6.0-38	12.0-30.3 (AGFD) (avg. 21.1)	9.0-25 (STORET) 7.2-32 (USGS)	7.5-27.0 (STORET) 7.0-36.0 (USGS)
	Dissolved oxygen (mg/L)	<1.0-?	4.9-10.7 (AG&F) (avg. 8.7)	1.6-13.7 (EIS) (6.61 avg.)	8.6-17.8 (EIS) (11.6 avg.)
	Salinity (mg/L)	Freshwater to >35 000	TDS 220-460 (AG&F) (avg. 325)	TDS 316-1300 (avg. 635)	TDS 109-550 (avg. 314)
	Substrate	Muck and decaying organic bottom preferred	This substrate is available but the percentage of total bottom is unknown.	This substrate is present in pools and low flow areas but the percentage of total bottom is unknown.	
	Trophic level	Tilapia thrive in eutrophic waters	Classified mesotrophic	Potential for moderate production.	
	Depth	10.2->183 cm	0-13.7 m	Pools of 3.6-4.6 m are present at low flow.	Pools of 3.0-3.7 m are present at low flow.
	Food	Primarily planktivorous (algae, diatoms) but can act as an omnivorous opportunist.	Plankton present (supports threadfin shad population)	Plankton present (support an unknown number of threadfin shad)	
	Flow (m/s)	0-?	Lacustrine	0-2.16 (1976-1982) (USGS)	0-3.11 (1976-1982) (USGS)
Juveniles	Temperature (°C)	6.0-?	12.0-30.3 (AGFD) (avg. 21.1)	9.0-25 (STORET) 7.2-32 (USGS)	7.5-27.0 (STORET) 7.0-36.0 (USGS)
	Food	Primarily Zooplankton	Present	Present	Present
Spawning requirements	Substrate	Male builds nest in sand or weedy bottom; may not need to build nest to reproduce successfully	Substrate present but percent of total substrate is unknown	Substrate present but percent of total substrate is unknown.	
	Depth	Shallow (as a maternal mouth brooder, rapid changes in water levels have little affect on hatch)	Depths sufficient	Periodically fluctuating depths.	
	Temperature (°C)	>22	12.0-30.3 (AGFD)	9.0-25 (STORET) 7.2-32 (USGS)	7.5-27.0 (STORET) 7.0-36.0 (USGS)
	Flow (m/s)	0-?	Lacustrine	0-2.16 from 1976-1982 (USGS)	0-3.11 from 1976-1982 (USGS)
	pH	?	7.2-8.6 (AGFD and STORET)	4.5-9.1 (avg. 7.74)	6.8-8.8 (avg. 8.01)
	Alkalinity (mg/L)	?	120-190 (AGFD and STORET)	15-189 mg/L (EIS) (avg. 130)	28.0-350 mg/L (EIS) (avg. 185)

would eventually be introduced into the Granite Reef Forebay through the SRP interconnection. Those tilapia that survive the introduction may move up the system and find generally suitable habitat such as in backwater areas. However, various piscivorous species present in the river system would exert some predatory pressure on the introduced tilapia. Water temperatures in the Salt and Verde Rivers fluctuate from about 7.0 to 36.0 °C. Low wintertime temperatures of 7.0 °C would stress the fish with some winterkill expected as explained previously. Some tilapia may find refugia and survive the winter, but at this time, refugia cannot be identified. Summertime water temperatures generally exceed 22 °C for a sufficiently long period of time for successful reproduction to occur. Backwater areas in the rivers and in the Granite Reef Forebay might provide suitable spawning habitat. Food resources in the Salt and Verde Rivers may dictate a change in the diet of the tilapia from that in Lake Pleasant. The tilapia may also compete with native suckers, carp, and some other fish species for food resources.

In addition to the introduction of tilapia into Lake Pleasant and the Salt and Verde Rivers by operation of the CAP, and the tilapias' probable survival and establishment to some unknown level, tilapia may also be introduced into these aquatic habitats by area anglers who sometimes collect these fish from Phoenix area waters to use for bait. Increased angler use of these central Arizona water resources may increase the likelihood of fish introductions, especially tilapia, regardless of operation of the CAP. A thorough fishery survey of the Salt and Verde Rivers is required to determine if tilapia are already present, and if so their distribution and abundance.

White bass. — White bass could enter the Salt and Verde Rivers from Lake Pleasant via the Granite Reef Aqueduct and SRP interconnection. However, the number of fish leaving Lake Pleasant would depend on their distribution around the submerged outlet works (currently designed to withdraw water at 463.3 m elevation; the design spillway elevation is 518.8 m) and fish survival through the pumping-generator plant, aqueduct and SRP interconnection. Current plans call for water to be withdrawn from Lake Pleasant from April to September. White bass spawn in Lake Pleasant in early spring. Contingent upon favorable water temperatures and other environmental condtions, spawning of the bass in shallow water will probably peak before April. After spawning, adult white bass apparently move to deeper water where they are less vulnerable to fishermen. Young white bass remain in shallow nursery areas over rocky substrate, and gradually move off shore into deeper water as they grow and mature. By fall, the juvenile white bass have entered deeper water. By this time, withdrawal of water from Lake Pleasant for CAP will probably have ceased for the season, so age 0+ fish will not likely be withdrawn through the submerged outlet. However, during their second year, white bass, which are generally sexually mature at that time, could be withdrawn from the lake through the outlet works, if they inhabit that area of the lake. Depth distribution and abundance of white bass in Lake Pleasant are not known to the extent necessary to determine how many or what proportion of the population of the lake would likely be withdrawn.

In evaluating whether or not white bass would survive and become established in CAP receiving waters, their environmental requirements during different life history stages were compared to recorded environmental conditions in CAP receiving waters (table 47).

White bass introduced into the Salt and Verde Rivers would likely survive, but they would likely find a reduced number of the preferred shad for food, based on limited survey data of the rivers which indicated that clupeid fishes constitute only a small percentage of the ichthyofauna. The low number of clupeid fishes, suggested by surveys, may in fact be due to sampling error. If clupeids are not abundant, the white bass would have to utilize other, generally less preferred, forage fish. Rapid water temperature changes and water level fluctuations seem to limit the success of clupeid fishes in these rivers (Burns 1966 in USFWS 1976). Minckley (1973) reported that shad are unable to establish substantial populations in other desert streams as well, but shad survival and reproduction is apparently sufficient, at least at certain times of the year, to allow fish to immigrate from the rivers into the Arizona and South Canals.

Striped bass and white bass will sometimes utilize other fish species for food, but to what extent this will occur in the Salt and Verde Rivers is unknown. Striped bass were reported to feed on blue tilapia in a Florida reservoir and may prey on tilapia in the Salt and Verde Rivers as well as in Lake Pleasant and Lake Havasu. In a river system with fluctuating water levels, more pronounced predator-prey relationships may prevail at times of low flow. At these times of the year, it is possible that both predators and prey may be forced out of the cover they normally inhabit at higher flows and be forced together into a more limited environment. This could intensify predator-prey interactions.

Table 47. — Ranges of environmental parameters for various life history stages of white bass, and generally required spawning conditions. (compiled from numerous sources)

Life history stage	Environmental parameter	Range	Receiving waters	
			Salt River	Verde River
Eggs	Temperature (°C)	14-26	(Feb.-April 1976-1982) 12 to 25 (USGS)	(Feb.-April 1976-1982) 9 to 15 (USGS)
	Dissolved oxygen (mg/L)	Lower limit 20% saturation at 19°C (1.6-2.0)	1.6-13.7 (EIS) (avg. 6.6)	8.6-17.8 (EIS) (avg. 11.6)
Larvae (sac-fry)	Dissolved oxygen (mg/L)	Lower limit 20% (1.6-2.0 mg/L)	Unknown during larval growth period	
	Temperature (°C)	14-26	(Feb.-April 1976-1982) 12-25 (USGS)	(Feb. -April 1976-1982) 9-15 (USGS)
YOY	Temperature (°C)	35 is upper lethal limit	9.0-25 (STORET) 7.2-32 (USGS)	7.5-27.0 (STORET) 7.0-36.0 (USGS)
	Substrate	Prefer rock substrate	Rock substrate available but usable percentage is unknown	
	Food	Prefer clupeid fish	Threadfin shad are in these rivers, but their percentage of total forage population is unknown	
Adults	Temperature (°C)	0.5-31	9.0-25 (STORET) 7.2-32 (USGS)	7.5-27.0 (STORET) 7.0-36.0 (USGS)
	Food	Prefer clupeid fish	Threadfin shad are in these rivers, but their percentage of total forage population is unknown	
	Alkalinity (mg/L)	30 to ?	15-189 (EIS) (avg. 130)	28.00-350 (EIS) (avg. 185)
	Dissolved Oxygen (mg/L)	?	1.6-13.7 (EIS) (avg. 6.6)	8.6-17.8 (EIS) (avg. 11.6)
	Depth	>10 ft (3.05 m)	3.7-4.6 m at low flow	3.0-3.7 m at low flow
	Clarity	Relatively clear	1-10 JTU (EIS) (avg. 2.9)	1-2800 JTU (EIS) (avg. 83.3)
	pH	?	4.5-9.1 (avg. 7.74)	6.8-8.8 (avg. 8.01)
	TDS (mg/L)	? to 6000 (chlorides)	316-1300 (avg. 365.0)	109-550 (avg. 314)
	Flow (m/s)	Thrive in lacustrine environment with good inflowing river	0-2.16 from 1976-1982 (USGS)	0-3.11 from 1976-1982 (USGS)
Spawning	Dissolved oxygen (mg/L)	?	1.6-13.7 (EIS) (avg. 6.6)	8.6-17.8 (EIS) (avg. 11.6)
	Temperature (°C)	10-23	(Feb.-April 1976-1982) 12-25 (USGS)	(Feb.-April 1976-1982) avg. 9-15 (USGS)
	Substrate	Firm substrate, gravel, rock	Spawning substrate at proper depths is present, but upstream water releases may alter amounts of substrate available.	
	Depth	1-3 m		
	Flow (m/s)	No flow (lacustrine) to ?	(Feb.-April 1976-1982) 0-1.89 (USGS)	(Feb.-April 1976-1982) 0.12-3.11 (USGS)

The white bass is a schooling species and generally large numbers of fish take part in spawning activities. Although white bass can spawn in calm or flowing water, they do not reproduce successfully to any great extent in a river that does not have access to a lake or reservoir. In the southeast United States, white bass seem to have better reproductive success in reservoir systems having a good, steady inflow. Flow in the Salt and Verde Rivers fluctuates greatly during the year; water temperatures also fluctuate. These two factors will affect survival of eggs, larvae, and adults. Although the eggs of white bass are demersal, high floodflows in the rivers may flush some of the eggs out the system as described above or reduce egg survival. Limited nursery areas would also affect survival of young fish. The white bass would also lack deep water refugia when summertime water temperatures increase. White bass were introduced intentionally in the lower Colorado River, a much larger system, with no apparent success, as determined by reproduction.

Adult white bass may be vulnerable to limited predation by bald eagles. Eagles nesting along the Salt River have been documented to feed on bass spp. (undefined) and yellow bass, a species related to both the striped bass and the white bass.

Bald Eagles. — Many biologists have expressed the concern that the introduction, establishment and proliferation of three additional nonnative fish species in the Salt and Verde Rivers will upset the ecological balance exhibited by the existing ichthyofauna and lead to adverse impacts on the bald eagles. The resident bald eagle nests of concern are the Bartlett and Fort McDowell nests on the Verde River and the Blue Point/-Stewart Mountain nest on the Salt River. The primary prey of these bald eagles, as determined from prey remains found beneath nests, consists of catfish, carp, and suckers captured at or near the surface of lakes and rivers. These fish species comprised 70.7 to 83.5 percent of the diet of the bald eagles from 1979 to 1981 (table 42). The bald eagles feed to a lesser extent on other fish species, waterfowl, reptiles, and mammals. Raptor biologists have suggested a correlation between productive nest sites, in terms of young fledged, with abundance of forage.

Striped bass, white bass, and blue tilapia will almost certainly enter the Salt and Verde Rivers through the SRP interconnection during operation of the CAP. In addition, blue tilapia could enter the rivers by bait bucket transfer. At least some of the introduced fish will survive and mature. Spawning and thus reproductive success will differ among the three fish species. The striped bass will be least likely to reproduce successfully, based on requirements for a long stretch of flowing water to keep the eggs suspended during incubation. If large numbers of introduced striped bass survive to maturity and migrate upstream to spawn, they could compete for space with suckers and other fish spawning below Bartlett and Stewart Mountain Dams, with a possible reduction in spawning success of these fish. White bass would probably spawn successfully but both bass species would lack suitable deep water refugia to escape summertime water temperatures. Blue tilapia would be most likely to survive and reproduce successfully. Tilapia have proliferated in the lower Gila River, but the extent to which they would proliferate in the Salt and Verde Rivers is open to speculation. Therefore, the impact of tilapia on the fish food base of the eagles cannot be quantified or determined accurately without collecting additional data. Some competition will exist between the three nonnative fish species of concern and established resident fish for food resources, but unless the introduced fish displaced but did not replace the existing carp, native suckers, and catfish, the supply of prey for the eagles would not be drastically altered and nest productivity would be related to other environmental factors. Eagles have taken yellow bass, a species related to both the striped bass and white bass, and may take these two species as well when the fish enter shallow water. If the three nonnative fish species of concern proliferated but did not replace the preferred displaced fish species, eagle nest productivity would probably decline, since eagles are reportedly less productive on a nonfish diet.

In addition to possible reproduction by the three nonnative fish species, there would be regular recruitment by introduction of these fish species into CAP receiving waters, contingent upon fish abundance in the vicinity of the pumping plants, the size and age of the fish, and the ability of the fish to avoid the pumping plant intake approach velocity.

SUMMARY

The Central Arizona Project will pump water from Lake Havasu on the Colorado River to provide irrigation, municipal, and industrial water for central Arizona. There is concern among biologists that three fish species, the striped bass, white bass, and blue tilapia, will be transported in the Granite Reef Aqueduct and introduced into CAP receiving waters. Once in these waters, the fish could

become established, with undesirable consequences, leading to the upset of the existing ecological balance in these waters. Of special concern is the impact the establishment these three fish species would have on the fish forage base of the breeding population of bald eagles nesting along the Salt River below Stewart Mountain Dam and the Verde River below Bartlett Dam.

Four pumping plants will lift water from the Colorado River and transport it through the Granite Reef Aqueduct into central Arizona. Fish in the intake channel of the Havasu Pumping Plant that cannot avoid the intake approach velocity will be pumped into the Granite Reef Aqueduct. Some fish in the aqueduct will have little chance to avoid entrainment into inline pumping plants. Some mortality will occur during passage through the pumping plants. Some mortality will occur during passage through the pumping plants, but some fish will survive and eventually be transported to Lake Pleasant and the Salt and Verde Rivers. Sections of this literature review and analysis where detailed discussions of each objective in the Scope of Work are found are listed in table 48.

Striped bass that enter Lake Pleasant would compete with resident white bass for shad; however, the number of striped bass that would actually enter Lake Pleasant cannot be accurately predicted, although the number would probably be small, based on the limited fishery survey data from the area around the Havasu Intake Channel. However, annual pumping of water into Lake Pleasant will allow annual recruitment by introduction. These fish would not mature sexually for several years after entering the lake. During this period, they would be subjected to environmental conditions such as high temperatures and reduced oxygen levels that will cause physiological stress. Reproductive success of striped bass would be limited, since striped bass require specific conditions of temperature and flow for successful reproduction. Many intentional introductions of striped bass in larger reservoirs, such as in 6680 ha Elephant Butte Reservoir in New Mexico, have reportedly failed to establish reproducing populations, and introductions must be made periodically to maintain the population. Striped bass do not seem to coexist with white bass in reservoirs of less than about 11 000 ha. Even the enlarged Lake Pleasant would be less than 7000 ha in surface area. Striped bass reproduction as a source of recruitment should not be significant, but survival of regularly introduced fish may allow a population to become established. Surviving striped bass may contribute to the sport fishery of Lake Pleasant, but angler acceptance or rejection of this species in a central Arizona reservoir cannot be determined at this time.

Striped bass would also enter the Salt and Verde Rivers through the proposed 22.6 m^3/s SRP interconnection. There is an undetermined but probably low amount of preferred forage for striped bass in these rivers, and no deep coolwater refugia in which to avoid high summertime water temperatures, so fish would be stressed. Conditions for successful reproduction are generally unfavorable. Even if conditions of flow and water temperature were suitable, the majority of eggs would be

Table 48. Sections of this literature review and analysis where specific information relative to each objective is discussed.

Objectives listed in the Scope of Work	Sections where objectives are discussed in detail.
1. Limnological and water quality aspects	p. 74-84
2. Existing fisheries of the water systems in question	p. 59-73
3. Passage of biota through pumping plants	p. 84-94
4. Biological requirements of three fish species	p. 5-59
5. Assess probable establishment of three fish species in CAP receiving waters	p. 99-110
6. Determine impacts on bald eagles	p. 94-99

flushed out of the system before they hatched. In addition, bald eagles may prey on suitably sized striped bass when they are near the surface, since eagles prey on yellow bass, a related species, and bass spp. Although reproductive success of striped bass in the Salt and Verde Rivers will probably be limited and although some of the introduced fish will succumb to predation, fishing mortality, and adverse environmental conditions, some striped bass will likely survive. The percentage of recruits from each year's introduction that survive will contribute to a resident population of undetermined size, and therefore, with an undetermined impact on the system.

Tilapia, if and when they occur in Lake Havasu in the vicinity of the Havasu Pumping Plant, will survive and be pumped into the Granite Reef Aqueduct and enter Lake Pleasant. Some mortality could be expected in the concrete-lined canal and inline pumping plants. These fish would find conditions in Lake Pleasant generally favorable for survival and reproduction. They would, however, be subjected to some predation by predatory fish present in the lake. The planktivorous tilapia would compete to some degree with shad for food. Tilapia that enter the Salt and Verde Rivers through the SRP interconnection would experience less favorable environmental conditions than those tilapia that enter Lake Pleasant. Spawning substrate would be limited. Water temperature fluctuations will be more extreme in the Salt and Verde Rivers than in Lake Pleasant, which will affect spawning success and growth. During most years, the water temperature will be high enough for successful reproduction to occur. During wintertime, water temperature may approach the tilapia's lower lethal temperature. Prolonged exposure to low temperatures will result in some winterkill. Tilapia will also be subjected to predation by catfish, largemouth bass, other animals, and perhaps the bald eagle. The extent to which tilapia population would proliferate in the Salt and Verde Rivers cannot be determined with the existing data base; however, the blue tilapia is a hardy and adaptable fish species and some tilapia will almost certainly survive to reproduce each year in these rivers. Tilapia have become established in the lower Gila River, the lower Colorado River, and the St. Johns River in Florida. Tilapia may already be present in the Salt and Verde River system since anglers from the Phoenix area reportedly collect tilapia in Phoenix area waters for use as bait.

White bass from Lake Pleasant would enter the Salt and Verde Rivers through the SRP interconnection, and would experience environmental conditions different from those in Lake Pleasant. The bass may find only limited numbers of their preferred forage and would have to utilize alternative prey. They would not have access to a large reservoir with deep water refugia as found in other situations where the white bass have become established and have reproduced successfully. High summertime temperatures during some years may approach the fish's upper lethal temperature. Some reproduction will likely occur, but it will not be as successful as in Lake Pleasant. Reproduction in Lake Pleasant, where conditions are apparently favorable, is successful (as indicated by year class strength), only a few years out of 10 and was only documented about 5 years after two intentional introductions of several hundred fish. The white bass may also be subject to limited predation by bald eagles nesting along these rivers since the bald eagles already prey on the related yellow bass. Although some white bass will likely survive the conditions in the Salt and Verde Rivers, they will face competition from currently established fish species. The extent to which white bass will establish populations cannot be predicted with the present data base. Concern exists relative to the impacts the introduction of three nonnative fish species will have on three pairs of bald eagles nesting along the lower Salt and Verde Rivers. The primary prey of the eagles consists of fish at or near the water surface, such as carp, suckers, and catfish, especially during the spawning season for these fish species. Nest productivity, as measured by number of young fledged, seems to be correlated with prey abundance. Bald eagles have utilized the yellow bass, a fish species closely related to the striped and white bass, and the eagles would probably utilize these fish to some extent when the fish are near the surface and vulnerable to predation. Because of the general opportunistic feeding habits of the bald eagle, they will probably utilize whatever fish are available and easy to capture. If introduced fish species would outcompete and displace established fish species, but not replace them in the sense of being available as prey, then the fish food base of the eagle would be reduced, with possible reduction in eagle productivity. Since the extent of proliferation of the three fish species in CAP receiving waters can only be estimated based on existing data, the impact of their introduction on the three bald eagle nests cannot be determined.

Some fish introduced into the Salt and Verde Rivers will likely survive, and some reproduction will occur. Striped bass reproduction will probably be least successful of the three fish species of concern, since the eggs would likely be flushed out of the rivers before they hatched. Annual recruitment by introduction is expected to occur. White bass will likely survive introduction into the Salt and Verde Rivers, and some reproduction is expected to occur, since white bass can spawn in both calm and flowing waters. Success of spawning will probably be greater than that for striped bass, and will depend on annual environmental conditions. Tilapia, if they are not already in the Salt and Verde Rivers, will survive introduction through operation of the CAP. Environmental conditions such as water temperature, flow, and predation, will limit tilapia populations to some degree. Tilapia will spawn successfully, but winterkill will occur in some years and reduce the population. The three fish species of concern introduced into CAP receiving waters will face competition for food, spawning habitat, and other requirements, from the already established resident fish species. The rate and extent of establishment of these fish species of concern in CAP receiving waters cannot be determined, although tilapia will likely have a better chance for survival and establishment of populations than either the striped bass or the white bass.

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PERSONAL COMMUNICATIONS

Aasen, Kenneth. 1983. Fishery Biologist, California Fish and Game Department, California (June 21, 1983).

Arant, Douglas. 1983. Fishery Biologist, Army Corps of Engineers, Portland, Oregon (April 7, 1983).

Avault, James Jr. 1983. Professor, Louisiana State University, Baton Rouge, Louisiana (May 19, 1983).

Bauman, Richard. 1983. Raptor Biologist, Bureau of Reclamation, Phoenix, Arizona.

Beaudry, Richard. 1983. Fisheries Biologist, Arizona Game and Fish Department, Havasu City, Arizona. August 9, 1983.

Bell, Milo. 1983. Fishery Consultant, Mukilteo, Washington (June 22, 1983).

Bennett, Charles. 1983. Fishery Biologist, Colorado Division of Wildlife, Lamar, Colorado (May 20, 1983).

Burke, Thomas. 1983. Aquatic Biologist, Bureau of Reclamation, Boulder City, Nevada (March 7, 1983).

Burton, Jim. 1983. Fisheries Biologist, Arizona Game and Fish Department, Phoenix, Arizona (June 16, 1983).

Chandler, Randy. 1983. Engineer, Arizona Project Office, Bureau of Reclamation, Phoenix, Arizona (June 21, 1983).

Courtenay, Dr. Walter. 1983. Professor and Chairman, Department of Biological Sciences, Florida Atlantic University, Boca Raton, Florida.

Davis, William. 1983. Senior Environmental Analyst, Salt River Project, Phoenix, Arizona (March 16, 1983).

Donahoo, Mike. 1983. Fishery Biologist, U.S. Fish and Wildlife Service, Parker, Arizona (March 17, 1983).

Drenner, Dr. R. W. 1983. Associate Professor of Biology, Texas Christian University, Fort Worth, Texas.

Endangered Species Office. 1983. U.S. Fish and Wildlife Service, Helena, Montana.

Essbach, Alban. 1983. Fisheries Consultant, Phoenix, Arizona (May 25, 1983).

Finnell, Larry. 1983. Fishery Biologist, Colorado Division of Wildlife, Fort Collins, Colorado (March 23, 1983).

Foye, Robert. 1983. Fisheries Research, Augusta, Maine (June 20, 1983).

Grubb, Terry. 1983. Raptor Biologist, U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.

Gustaveson, Wayne. 1983. Fisheries Biologist, Utah Wildlife Resources, Page, Arizona (June 14, 1983).

Guisti, Mike. 1983. Fisheries Biologist, California Fish and Game Department, Blythe, California (May 19, 1983).

Hansen, William. 1983. Hydrologist, U.S. Forest Service, Phoenix, Arizona (March 16, 1983).

Harris, Glenn. 1983. Biologist, Salt River Project, Phoenix, Arizona (March 16, 1983).

Hayes, Will. 1983. Fisheries Specialist, Arizona Game and Fish Department, Tucson, Arizona.

Heigel, Leroy. 1983. Mechanical Engineer, Bureau of Reclamation, Denver, Colorado (April 5, 1983, May 25, 1983).

Hoffman, Steve. 1983. Endangered Species Biologist, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Hurd, Ray. 1983. Metropolitan Water District, California (March 4, 1983).

Jacobson, Brad. 1983. Regional Fisheries Assistant, Arizona Game and Fish Department, Yuma, Arizona (April 1, 1983).

Jenkins, Al. 1983. Wildlife Biologist, U.S. Fish and Wildlife Service, Denver, Colorado.

Johnson, Perry. 1983. Hydraulic Engineer, Bureau of Reclamation, Denver, Colorado (June 16, 1983, June 17, 1983).

Keith, William. 1983. Chief of Fisheries, State of Arkansas (May 19, 1983).

Klauda, Ronald. 1983. Research Fishery Biologist, John Hopkins University, Shady Side, Maryland (June 22, 23, 1983).

Leishman, Monte. 1983. Fishery Biologist, New Mexico Game and Fish Department, Artesia, New Mexico (March 22, 1983, March 29, 1983).

Little, Ralph. 1983. New Mexico Department of Game and Fish, Las Cruces, New Mexico (May 19, 1983).

Loudermilk, William. 1983. Fisheries Biologist, California Fish and Game Department, Fresno, California (March 22, 1983).

Madsen, Monte. 1983. Supervisor, Fisheries Division, Nebraska Game and Parks Commission, North Platte, Nebraska.

Marsh, Paul. 1983. Assistant Professor, Research. Arizona State University, Tempe, Arizona.

Martin, Mayo. 1983. Extension Biologist, U.S. Fish and Wildlife Service, Stuttgart, Arkansas (May 19, 1983).

Martin, R. 1983. Hydrologist, Forest Service, Phoenix, Arizona (March 16, 1983).

McCann, James. 1983. Director, Leetown, West Virginia, National Fishery Research Center, Leetown, West Virginia (May 11, 1983).

McCleskey, Richard. 1983. Fisheries Director, New Mexico Game and Fish Department, Santa Fe, New Mexico (May 10, 1983).

McConnell, William. 1983. Former Leader, Colorado Cooperative Fishery Research Unit, Fort Collins, Colorado (May 25, 1983).

Meyer, Fred. 1983. Director, National Fisheries Research Laboratory, LaCrosse, Wisconsin (May 19, 1983).

Minckley, W. L. 1983. Professor of Zoology, Arizona State University, Tempe, Arizona (February 9, 1983).

Ohmart, Robert. 1983. Professor of Zoology, Arizona State University, Tempe, Arizona (March 18, 1983).

Otis, Pete. 1983. Massachusetts Division of Fish and Wildlife, Westboro, Massachusetts (May 5, 1983).

Padilla, Cornelio. 1983. Fisheries Biologist, Nevada Department of Wildlife, Las Vegas, Nevada (June 14, 1983).

Pridgeon, Bryan. 1983. Bureau of Reclamation, El Paso, Texas (April 18, 1983).

Raney, Edward C. 1983. Ichthyological Associates, Ithaca, New York (April 2, 1983).

Reiner, George. 1983. Engineer, California Department of Water Resources, Sacramento, California (June 21, 1983, June 27, 1983).

St. Amant, James. 1983. Fishery Biologist, California Fish and Game Department, Long Beach, California (March 21, 1983).

Shafland, Paul. 1983. Project Leader of Nonnative Fish Research, Florida Game and Fresh Water Fish Commission, Boca Raton, Florida (April 8, 1983).

Smitherman, R. O. 1983. Professor, Auburn University, Fisheries Laboratory, Auburn, Alabama (May 26, 1983).

Stafford, Jay. 1983. Fishery Biologist, Colorado Division of Wildlife, Sterling, Colorado (March 23, 1983, May 19, 1983).

Stephenson, Richard. 1983. Arizona Game and Fish Department, Phoenix, Arizona.

Stickney, Robert. 1983. Professor, Texas A&M University, College Station, Texas (May 19, 1983).

Sund, Robert, 1983. Engineer, Division of Design, Bureau of Reclamation, Denver, Colorado (June 23, 1983).

Taubert, Bruce. 1983. Chief of Fisheries, Arizona Game and Fish Department, Phoenix, Arizona

Turner, Paul. 1983. Professor of Fishery Biology, New Mexico State University, Las Cruces, New Mexico (March 24, 1983).

Ulmer, Linda. 1983. Fishery Biologist, California Fish and Game Department, Blythe, California (March 11, 1983).

Wagner, Jim. 1983. Arizona Projects Office, Bureau of Reclamation, Phoenix, Arizona (June 16, 1983).

Wanjala, Benny. 1983. Graduate student, University of Arizona, Tucson, Arizona (March 21. 1983).

Ware, Forrest. 1983. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Warneke, James. 1983. Fishery Biologist, Arizona Game and Fish Department, Phoenix, Arizona (June 16, 1983, June 21, 1983).

Whitsett, Al. 1983. Engineer, Metropolitan Water District of Southern California, Los Angeles, California (June 15, 1983).

Wingfield, Don. 1983. Arizona Game and Fish Department, Yuma, Arizona

Zale, Alexander. 1983. Research Assistant, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, Florida (May 10, 1983).

Ziebell, Charles. 1983. Assistant Leader, Arizona Cooperative Fishery Research Unit, Tucson, Arizona (February 23, 1983).

GPO 846 – 727

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.