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FISH INTRODUCTIONS IN CALIFORNIA: HISTORY AND IMPACT ON NATIVE FISHES

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ABSTRACT

Since 1871, at least 50 species of fish have been successfully introduced into California's inland waters, and numerous transfers of native fishes have been made between isolated drainage systems. Introductions were made of sport fish, commercial fish, forage fish, bait fish, fish for weed and insect control, and aquarium fish. Most of the introductions were authorised, reflecting a dissatisfaction with the native fishes, but in recent years unauthorised introductions have become common. The continuing decline of the native fish fauna seems to be largely the result of habitat change but introduced fishes may have contributed to this decline through competition, predation, and hybridisation. The lack of information on the native and introduced fishes of California, and their interactions, demonstrates the critical need for a statewide natural history survey.

INTRODUCTION

The enormous impact of introduced exotic fish species on freshwater ecosystems the world over is just beginning to be appreciated (Miller, 1961; Lachner *et al.*, 1970; Voorhen, 1972; Zaret & Paine, 1973; Courtney *et al.*, 1974). In few places is this impact more evident than in California, where 50 of the 133 fish species known to occur in the state are not native and most of the major waters are dominated by introduced species (Moyle, 1976). The potential detrimental effects of the introduced species on the native freshwater fishes of California is a serious problem because over 30 % of the 83 native fish species are found only (or primarily) in the state. This high degree of endemism is caused by the complex geological history of California, which has resulted in the division of the state into six major drainage basins, each largely isolated from the others. Each major basin in turn is

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divided into a number of isolated sub-basins which also contain endemic fishes (Fig. 1). Because of their limited distributions, the endemic species of California are particularly likely to become rare or endangered as a result of man's activities (Miller, 1972; Leach *et al.*, 1974). The presence of endemic species also means that each basin and sub-basin has its own unique problems with introduced species

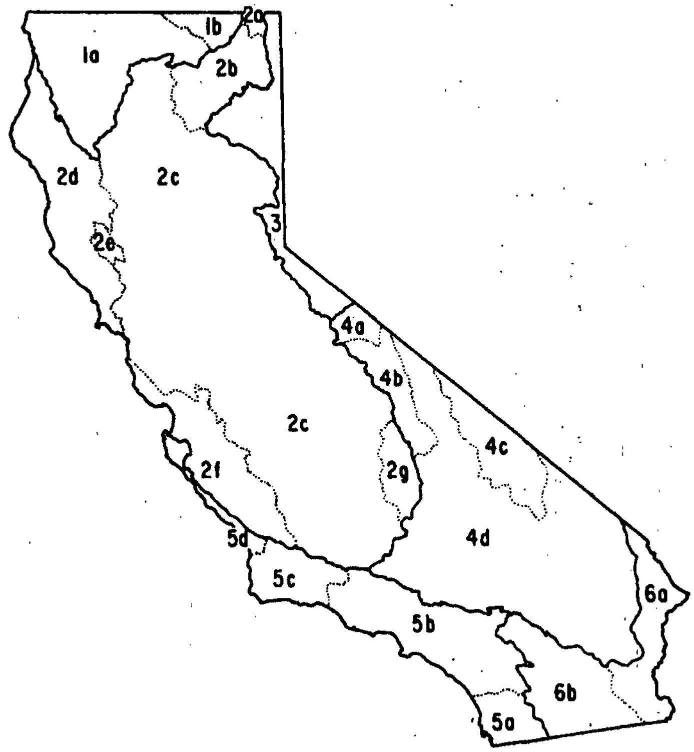

Fig. 1. Major drainage basins and subbasins of California: (1) Klamath system: (a) lower Klamath River, (b) upper Klamath River and Lost River; (2) Sacramento–San Joaquin system: (a) Goose Lake, (b) Pit River, (c) Central Valley, (d) north coast streams, (e) Clear Lake, (f) Pajaro-Salinas system (g) upper Kern River; (3) Lahontan system; (4) Death Valley system: (a) Mono Lake, (b) Owens River, (c) Amargosa River, (d) Mojave River; (5) south coastal drainages: (a) San Diego region, (b) Los Angeles basin, (c) Santa Maria–San Inez drainages, (d) south-central coastal drainages; (6) Colorado system: (a) Colorado River, (b) Salton Sea.

and that the interbasin transfers of native fishes can have potentially as much impact on resident fish populations as can the introduction of exotic fishes. Understanding the impact of the introduced species is becoming increasingly important because the number of successful introductions made into California, as well as into western North America in general, has increased considerably in

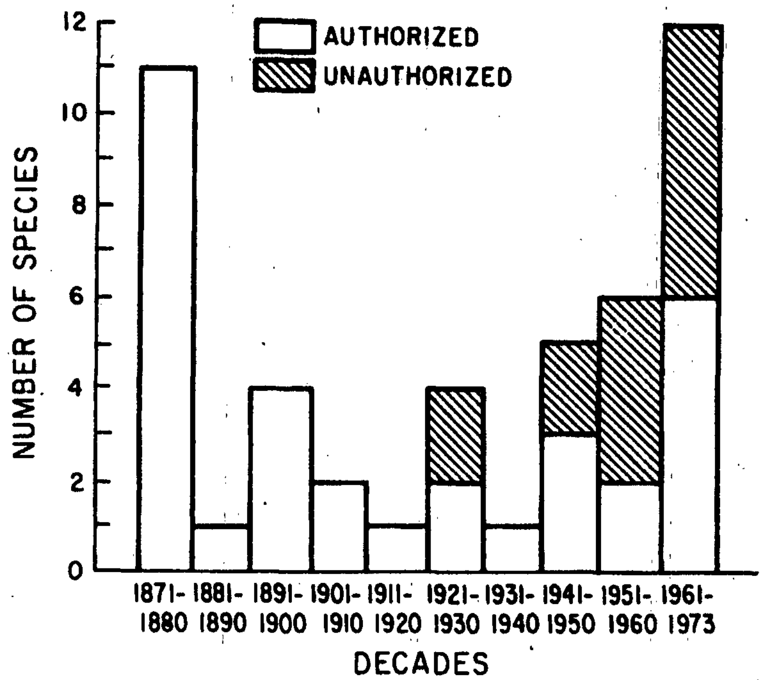

Fig. 2. Numbers of fish species introduced into California by decade, showing the relative numbers of authorised and unauthorised introductions.

recent years (Fig. 2). This paper therefore reviews, (1) the history of exotic fish introductions and interbasin transfers in California, (2) the reasons the introductions were made, and (3) the impact of the introduced species on the native species and ecosystems. The origins and major synonyms of the names of fishes used in this paper are given in Moyle (1976).

HISTORY OF EXOTIC INTRODUCTIONS

California has experienced two major eras of successful fish introductions: 1871–91 and 1960–present (Fig. 2). The first resulted from the completion of the transcontinental railroad in 1869, and from the formation of the California Fish Commission in 1870 and the United States Fish Commission in 1871. The two commissions were enthusiastically dedicated to fish propagation, while the railroad made the transcontinental transport of fish possible. In this period California received many fishes from the eastern United States (Table 1) in return for rainbow trout (*Salmo gairdneri*) and Pacific salmon (*Oncorhynchus* spp.).

TABLE 1

INTRODUCED FISHES OF CALIFORNIA, SHOWING PLACE OF ORIGIN, YEAR OF FIRST SUCCESSFUL INTRODUCTION, REASONS FOR INTRODUCTION, AND CALIFORNIA DRAINAGE SYSTEMS IN WHICH ESTABLISHED. SF = SPORT FISHING; CF = COMMERCIAL FISHING; FO = FORAGE; BA = BAIT; IC = INSECT CONTROL; WC = WEED CONTROL; PR = PET RELEASE; AC = ACCIDENTAL. THE DRAINAGE SYSTEM NUMBERS CORRESPOND TO THOSE IN FIGURE 1.

Species	*Place of origin*	*Year*	*Reasons*	*Drainage systems*[1]	*Reference*
Clupeidae					
American shad, *Alosa sapidissima*	New York	1871	SF, CF	1a, 2c–d	Shelby (1917)
Threadfin shad, *Dorosoma petenense*	Tennessee	1953	FO	2c; f; 5a–d, 6a–b	Kimsey (1954)
Osmeridae					
Wakasagi, *Hypomesus transpacificus nipponensis*	Japan	1959	FO	1a, 2c	Wales (1962)
Salmonidae					
Kokanee, *Oncorhynchus nerka*	Idaho, British Columbia	1941	SF, FO	1a; 2c; 3; 4c	Calhoun (1966)
Brook trout, *Salvelinus fontinalis*	New Hampshire, Wisconsin	1872	SF	1a–c; 2a–d, g 3, 4a–b, d; 5a, c–d	Shelby (1917)
Lake trout, *Salvelinus namaycush*	Lake Superior?	1889	SF	3	Shelby (1917)
Brown trout, *Salmo trutta*	Scotland, Germany	1872	SF	1a–c; 2a–g, 3; 4a–d; 5a–d	Shelby (1917)
Arctic grayling, *Thymallus arcticus*	Montana	1969	SF	1a, 2b	Gerstung (1972)
Cyprinidae					
Carp, *Cyprinus carpio*	Japan, Germany	1872	SF, CF	2b–f; 3; 4b, d; 5a–d; 6a–b	Shelby (1917)
Goldfish, *Carassius auratus*	China	?	PR	2c, e–f; 4c–d; 5a–d; 6a–b	
Tench, *Tinca tinca*	Italy	1922	SF	2f	Shapovalov (1944)
Golden shiner, *Notemigonus chrysoleucas*	E USA	1891	BA, FO	1a–b; 2b–f; 5a–d; 6a–b	Calhoun (1966)
Red shiner *Notropis lutrensis*	Texas	1950–53	BA, FO	6a–b	Hubbs (1954)
Fathead minnow, *Pimephales promelas*	E USA	ca. 1950	BA, FO	1b; 2c, e; 6a–b	Shapovalov *et al.* (1959)
Tiger barb, *Barbus razona*[2]	SE Asia	1973	PR	4b	Naiman & Pister (1974)
Catostomidae					
Bigmouth buffalo, *Ictiobus cyprinellus*	Arizona	ca. 1940	CF	5b	Evans (1950)

TABLE 1—*continued*

Species	*Place of origin*	*Year*	*Reasons*	*Drainage systems*[1]	*Reference*
Ictaluridae					
Blue catfish, *Ictalurus furcatus*	E USA	1969	SF	5a–c, 6a	Pelzman (1971)
Channel catfish, *Ictalurus punctatus*	E USA	ca. 1925	SF	2b–c, e; 4b–d; 5a–d; 6a–b	Calhoun (1966)
White catfish, *Ictalurus catus*	New Jersey	1874	SF	2c–f; 3; 5a–d	Shelby (1917)
Yellow bullhead, *Ictalurus natalis*	E USA	1874	SF	1a–b; 2c; 5a–d; 6a–b	Evermann & Clark (1931)
Brown bullhead, *Ictalurus nebulosus*	Vermont, Pennsylvania	1874	SF	1a–b; 2a–f; 4b, d 5a–d; 6b	Shelby (1917)
Black bullhead, *Ictalurus melas*	E USA	1874	SF	1b; 2c, f; 3; 5a–d; 6a–b	Curtis (1949)
Flathead catfish, *Pylodictus olivaris*	S USA	1962	SF	6a–b	Botroff *et al.* (1969)
Cobitidae					
Japanese weatherfish, *Misgurnus anguillicaudatus*	NE Asia	ca. 1930?	PR	5b	St. Amant & Hoover (1969)
Cyprinodontidae					
Rainwater killifish, *Lucania parva*	New Mexico E USA	ca. 1958	AC	2c, 5b	Hubbs & Miller (1965)
Argentine pearlfish, *Cynolebias bellottii*	Argentina	ca. 1970	IC	5b	E. F. Legner (pers. comm.)
Trinidad rivulus, *Rivulus harti*[2]	Venezuela	ca. 1967	PR	6a	St. Amant (1970)
Poeciliidae					
Mosquitofish, *Gambusia affinis*	SE USA	1922	IC	2b–f; 3; 4a–d; 5a–d; 6a–b	Evermann & Clark (1931)
Sailfin molly, *Poecilia latipinna*	SE USA	ca. 1950	PR	6a	Shapovalov *et al.* (1959)
Shortfin molly, *Poecilia mexicana*	Mexico	ca. 1960	PR	6a	St. Amant (1970)
Guppy, *Poecilia reticulatus*[2]	S. America	?	PR	5b	St. Amant & Hoover (1969)
Variable platyfish, *Xiphophorus variatus*[2]	Mexico	ca. 1956	PR	6a	St. Amant & Sharp (1971)
Green swordtail, *Xiphophorus helleri*[2]	Mexico	ca. 1960	PR	5b	St. Amant & Hoover (1969)

TABLE 1—*continued*

Species	*Place of origin*	*Year*	*Reasons*	*Drainage systems*[1]	*Reference*
Atherinidae					
Mississippi silverside, *Menidia audens*	Oklahoma	1967	IC, FO, WC	2c–e	Cook & Mooré (1970)
Percichthyidae					
Striped bass, *Morone saxatilis*	New Jersey	1879	SF, CF	2c–d, f; 6b	Shelby (1917)
White bass, *Morone chrysops*	Nebraska	1965	SF	5d, 6b	Von Geldern (1966)
Centrarchidae					
Black crappie, *Pomoxis nigromaculatus*	Illinois	1908	SF	2b–f; 4b; 5a–d; 6b	Vogelsang (1931)
White crappie, *Pomoxis annularis*	Illinois	1917	SF	1b; 2c, e; 5a–d; 6b	Curtis (1949)
Warmouth, *Lepomis gulosus*	E USA	1891	SF	2c; 6a	Shelby (1917)
Green sunfish, *Lepomis cyanellus*	Illinois	1891	SF	1a–b; 2a–f; 4d; 5a–d; 6a–b	Shelby (1917)
Bluegill, *Lepomis macrochirus*	Illinois	1908	SF	1a–b; 2b–f; 3; 4b, d; 5a–d; 6a–b	Shelby (1917)
Pumpkinseed, *Lepomis gibbosus*	E USA	?	SF	1a–b; 3; 5b	Dill *et al.* (1955)
Redear sunfish, *Lepomis microlophus*	S USA	ca. 1948	SF	2b–c, e; 4b, d; 5a–d; 6b	Calhoun (1966)
Largemouth bass, *Micropterus salmoides*	E USA	1874	SF		Shelby (1917)
Spotted bass, *Micropterus punctulatus*	Ohio	1933	SF	2c; 5b	Curtis (1949)
Smallmouth bass, *Micropterus dolomieui*	Vermont, Michigan	1874	SF	2b–f; 4b; 5a, d; 6b	Shelby (1917)
Redeye bass, *Micropterus coosae*	Tennessee, Georgia	1962–64	SF	5d	Calhoun (1966)

TABLE 1—*continued*

Species	*Place of origin*	*Year*	*Reasons*	*Drainage systems*[1]	*Reference*
Percidae					
Yellow perch, *Perca flavescens*	E USA	1891	SF	1a–b	Shelby (1917)
Bigscale logperch, *Percina macrolepida*	Texas	1953	AC	2c	Shapovalov *et al.* (1959)
Cichlidae					
Mozambique mouthbrooder, *Tilapia mossambica*	Africa	ca. 1960	WC, SF	6a–b	St. Amant (1966)
Zill's cichlid, *Tilapia zillii*	Africa	1972	WC	6a–b	Hauser (1975)
Gobiidae					
Yellowfin goby, *Acanthogobius flavimanus*	Japan	ca. 1963	AC	2c–d, f	Brittan *et al.* (1970)
Chameleon goby, *Tridentiger trigonocephalus*[2]	Japan	ca. 1970	AC	2c, 5b	Miller & Lea (1972)

[1] Distribution information from Moyle (1976).
[2] Evidence for permanent breeding populations uncertain.

The first successful introduction was American shad (*Alosa sapidissima*). About 10,000 fry were planted in the Sacramento River in 1871, followed by an additional 600,000 or so during the next ten years (Shelby, 1917), and by 1879, a commercial fishery had developed. The next successful introductions, in 1872, were carp (*Cyprinus carpio*) from Japan and Germany and brook trout (*Salvelinus fontinalis*) from the eastern United States (Shelby, 1917). These two species were propagated in hatcheries and spread to suitable waters over much of the state. In 1874, tank cars brought in four species of catfish (*Ictalurus* spp.) and two species of black bass (*Micropterus* spp.). From 1874 to 1891 there was a steady stream of introductions, including at least eight species that never became established (Evermann & Clark, 1931). The most spectacular introduction in this period was the striped bass (*Morone saxatilis*). It quickly became one of the most abundant fish species in the Sacramento–San Joaquin Delta following the planting of a total of 432 fish in 1879 and 1882 (Shelby, 1917).

The rate of introduction was slower for the next 60 years, although brown trout (*Salmo trutta*), six species of centrarchids (*Lepomis, Pomoxis,* and *Micropterus*), threadfin shad (*Dorosoma petenense*), and mosquitofish (*Gambusia affinis*) became established in this period. Since about 1950 the rate of introduction has increased, mostly the result of unauthorised introductions, especially into the warm waters of inland Southern California where the more hardy 'tropical' aquarium fishes can survive. Outside this region, only three recent unauthorised introductions have become well established: Mississippi silverside (*Menidia audens*), bigscale logperch (*Percina macrolepida*), and yellowfin goby (*Acanthogobius flavimanus*) (Brittan *et al.*, 1970; Moyle, Fisher & Li, 1974).

REASONS FOR THE INTRODUCTION OF EXOTICS

The basic reason most exotic fishes were introduced into California was the dissatisfaction of the early settlers with the native fishes. The native salmon, trout, Sacramento perch (*Archoplites interruptus*), cyprinids, and catostomids were heavily utilised prior to 1872, but no one seems to have questioned the statements of the early fisheries workers that the exotic species being introduced were superior to native species (Shelby, 1917; Curtis, 1942). These early workers were not entirely wrong, however, since even before 1900 extensive alterations of California's aquatic habitats were taking place and many of the changed habitats (*e.g.* reservoirs, irrigation ditches) were made more suitable for introduced species. Even today, undisturbed habitats tend to be dominated by native fishes, while disturbed habitats tend to be dominated by introduced species (Moyle & Nichols, 1974). The supposed superiority of introduced species over native species was found in their value as: (1) sport fish, (2) commercial fish, (3) forage fish, (4) bait fish, (5) insect control agents, (6) aquatic weed control agents, and (7) pets. In addition to the fish introduced for these reasons, a number of species were introduced by accident (Table 1).

The most important reason for introducing fish into California has been to improve sport fishing. For this reason American shad, carp, tench (*Tinca tinca*), yellow perch (*Perca flavescens*), exotic salmonids, and all members of the families Ictaluridae, Percichthyidae, and Centrarchidae (except Sacramento perch) were introduced. The successful introductions of five salmonid species, together with the unsuccessful introductions of at least four others, were meant to increase the variety of cold water fishing in a state that already contained 12 species of salmon, trout, and char (Moyle, 1976). The other sport fish introductions were perhaps more understandable, since they were meant to supplement a warmwater fish fauna that contained only one species (the Sacramento perch) widely accepted as a game fish. Some of the sport fish introductions have also been harvested commercially (American shad, striped bass, and carp), although only one species (bigmouth buffalo, *Ictiobus cyprinellus*) was introduced just for that purpose (Evans, 1950).

Only two species have been introduced solely to provide forage for game fishes, threadfin shad, and wakasagi smelt (*Hypomesus transpacificus nipponensis*), but forage potential has been used as an additional reason to introduce kokanee (*Oncorhynchus nerka 'kennerlyi'*), golden shiner (*Notemigonus chrysoleucas*), red shiner (*Notropis lutrensis*), fathead minnow (*Pimephales promelas*), and Mississippi silverside. The threadfin shad is by far the most widespread of these fishes, followed by the golden shiner, although the Mississippi silverside is spreading rapidly (Moyle, Fisher & Li, 1974). The golden shiner, fathead minnow, and red shiner have been released primarily by bait fishermen who often discard minnows they do not consume in fishing.

Prior to about 1960, the only fish introduced into the state for biological control was the mosquitofish, which is now found in most of California's warm waters. With the increased use of biological control techniques, four other species have been introduced for this purpose, Mississippi silverside, Mozambique mouthbrooder (*Tilapia mossambica*), Zill's cichlid (*Tilapia zillii*) and Argentine pearlfish (*Cynolebias bellottii*). The most spectacular of these introductions has been the Mississippi silverside, which was illegally introduced into Clear Lake, Lake County, in 1967 to control the pestiferous gnats and midges and to reduce the nuisance blooms of bluegreen algae (Cook & Moore, 1970). It is now the most abundant species of fish in Clear Lake and is rapidly spreading to other bodies of water. However, its ability to control either gnats or algae has not been clearly demonstrated. The two *Tilapia* species were introduced for aquatic weed control into irrigation drainage ditches in southern California. *T. mossambica* is confined to drainage ditches in extreme southeastern California because of its inability to tolerate low temperatures. *T. zillii*, widely distributed in southern California, may control aquatic weeds if stocked in sufficient numbers (Legner *et al.*, 1973; W. E.

Hauser, pers. comm.). However, since it has apparently overwintered and reproduced in a central California pond, has the potential to disrupt aquatic ecosystems by altering plant communities, and might easily be confused with the generally prohibited and coldwater hardy *T. sparrmanii*, *T. zillii* has been prohibited except in six southern California counties (Pelzman, 1973). The Argentine pearlfish is established only in a few ponds in southern California where it was introduced for mosquito control (E. F. Legner, pers. comm.). This species, and other annual cyprinodont fishes, are being studied for possible use in rice fields, because they deposit eggs that can survive in the soil after the water has evaporated or been drained.

Pet fishes have been introduced as the result of releases by aquarists tired of their charges or by deliberate and accidental releases from tropical fish farms. The waters of northern and central California are too cold to support most such fishes, so successful introductions are largely confined to southern California. The only exception to this is the goldfish (*Carassius auratus*), which is abundant in many localities throughout the state (Moyle, 1976).

Accidental introductions are a comparatively recent phenomenon, the result of modern rapid transport systems. The bigscale logperch came in with an airplane shipment of largemouth bass (*Micropterus salmoides*) from Texas that was planted in some ponds at Beale Air Force Base, Yuba County. During a wet year, the ponds apparently overflowed into the Yuba River and the species is now widespread in the Central Valley (Moyle, Fisher & Li, 1974). The rainwater killifish (*Lucania parva*) was introduced with a shipment of largemouth bass into southern California. The northern California populations of this euryhaline killifish, however, apparently originated from eggs attached to oysters planted in San Francisco Bay (Hubbs & Miller, 1965). The most likely explanation for the sudden appearance of two euryhaline goby species (yellowfin goby and chameleon goby, *Tridentiger trigoncephalus*) is that they were present in bilge pumped from ships coming in from Japan (Brittan *et al.*, 1970).

INTERBASIN TRANSFERS

The transfer of fish from one isolated drainage basin to another in California has been done for five main reasons: (1) for sport fishing, (2) for use as bait, (3) for forage, (4) for species preservation, and (5) for experimental purposes. In addition, interbasin transfers of fish are probably occurring during the massive interbasin transfers of water that are now taking place in California, although the only record of this seems to be the transfer of the Owens sucker (*Catostomus fumeiventris*) to the Los Angeles Basin via the Los Angeles Aqueduct (Hubbs *et al.*, 1943).

The earliest and most extensive interbasin transfers were those of sport fishes, especially trout. In the latter half of the 19th century, rainbow trout, golden trout

(*Salmo aguabonita*), and cutthroat trout (*S. clarki*), along with exotic brown trout (*S. trutta*) and brook trout (*Salvelinus fontinalis*), were enthusiastically planted by anglers and fisheries workers throughout the usually fishless high mountain areas of California, with little regard for the fish and invertebrate species already present. Many of these transfers were unofficial and unrecorded, confusing the already naturally complex zoogeography and taxonomy of California salmonids. Even the original description of the golden trout was based on an introduced population (Schreck & Behnke, 1971). The royal silver trout (*Salmo regalis*) described from Lake Tahoe was an introduced population of rainbow trout showing phenotypic adaptations to the lake environment (Moyle, 1976), while the San Gorgiono trout (*S. evermanni*) was an introduced population of Lahontan cutthroat trout temporarily established in the mountains of southern California (Benson & Behnke, 1961). By far the most common of these interbasin transfers was that of rainbow trout, which exist today in suitable waters throughout the state, with many populations still maintained by stocking hatchery fish. Even the Sacramento perch, California's only native warmwater gamefish, has been transplanted to alkaline reservoirs in other basins, especially in recent years. Today they are more abundant outside their native Sacramento–San Joaquin drainage system than they are within it (Moyle, 1976).

Bait-bucket introductions by fishermen seem to be the best explanation for the anomalous distribution patterns of at least seven species of native nongame fishes (Table 2), despite the fact that records of the transfers are lacking. Some of the bait-bucket introductions may also have been made to provide forage for game fishes. This is the most likely explanation for the presence of threespine stickleback (*Gasterosteus aculeatus*) in the interior basins of southern California, although their spread into these basins may also have occurred by accident. Sticklebacks are sometimes present in trout hatchery water supplies and may be transferred to new waters along with trout (J. St. Amant, pers. comm.).

In recent years, one of the most common reasons for interbasin transfers has been to preserve fish species whose existence is threatened in their native basins. So far all such transfers have been between basins in southern California, usually from a small desert spring or stream containing fish to another such spring or stream without fish (Leach *et al.*, 1974). Transfers of fish between southern California basins has also been made for experimental purposes. Between 1939 and 1955, R. R. Miller made 23 inter- and intrabasin transfers in order to test the effects of a changed environment on the morphology and meristics of the fishes (Miller, 1968). Four of these transfers resulted in reproducing populations.

IMPACT OF INTRODUCTIONS

The impact of introduced exotic fishes and interbasin transfers falls into two main

TABLE 2

KNOWN SUCCESSFUL INTERBASIN TRANSFERS OF NATIVE CALIFORNIA FISHES. SF = SPORT FISHING; FO = FORAGE; BA = BAIT; EX = EXPERIMENTAL; SP = SPECIES PRESERVATION; AC = ACCIDENTAL. THE BASIN NUMBERS CORRESPOND TO THOSE IN FIGURE 1

Species	*Basin of origin*	*Basins of introduction*	*Year*	*Reason*	*Reference*
Golden trout, *Salmo aguabonita*	2g	2c, 3, 4a–b	pre 1900	SF	Calhoun (1966)
Rainbow trout, *Salmo gairdneri*	2c[1]	All	1872	SF	Wales (1939)
Lahontan cutthroat trout, *Salmo clarki henshawi*	3	4a	?	SF	E. P. Pister (pers. comm.)
Piute cutthroat trout, *Salmo clarki seleneris*	3	4d	1946	SF, SP	Vestal (1947)
Lahontan tui chub *Gila bicolor obesa*	3	2b–c; 4b	?	BA	Miller (1973)
Mojave tui chub, *Gila bicolor mohavensis*	4d	5b	1970	SP	St. Amant & Sasaki (1971)
Arroyo chub, *Gila orcutti*	5b	5c; 4d	pre 1940	BA	Hubbs & Miller (1943)
Speckled dace, *Rhinichthys osculus*	5b	4a	1940	EX	Miller (1968)
Lahontan redside, *Richardsonius egregius*	3	2c	pre 1950	BA	Kimsey (1950)
California roach, *Hesperoleucus symmetricus*	2f	5c	pre 1970	BA	Greenfield & Greenfield (1972)
Tahoe sucker, *Catostomus tahoensis*	3	2c	pre 1950	BA	Kimsey (1950)
Mountain sucker, *Catostomus platyrhynchus*	3	2c	?	BA	Smith (1966)
Owens sucker, *Catostomus fumeiventris*	4b	4a, 5b	pre 1940	BA, FO, AC	Hubbs *et al.* (1943)
Desert pupfish, *Cyprinodon macularius*	6b	6a, 4d	1907	AC, SP	Moyle (1976)
Amargosa pupfish, *Cyprinodon nevadensis*	4c	4a	1940	EX	Miller (1968)
Salt Creek pupfish, *Cyprinodon salinus*	4c	4d	1939	EX	Miller (1968)
Threespine stickleback *Gasterosteus aculeatus*	5b?	4a, d	?	FO, AC	Moyle (1976)
Sacramento perch, *Archoplites interruptus*	2c	1b, 4b, 3	1877–1966	SP, SF	Moyle (1976)

[1] Rainbow trout are native to most coastal drainage systems as well as the Sacramento–San Joaquin system. However, most planted populations are probably derived from the McCloud River (a tributary to the Sacramento River) population although strains from other localities, including British Columbia, have also been propagated.

areas: reduction or elimination of native fish populations and ecosystem alteration. It should be emphasised, however, that evidence showing the direct impact of introductions on native fishes and habitats is very limited because in most situations in California the impact is masked by severe man-caused habitat alteration.

The reduction or elimination of native fishes by introduced fishes can be caused by: (1) competition, (2) predation, and (3) hybridisation. Competition for scarce resources is often given as a reason for faunal change but it is very difficult to demonstrate. In California, the only change that seems best attributed completely to competition is the virtual elimination of Sacramento perch from its native habitats. This species is ecologically very similar to bluegill (*Lepomis macrochirus*) but is much less aggressive (Moyle, Mathews & Bonderson, 1974), and can be driven from cover, food supplies, and breeding sites. It exists today in a wide variety of waters where it has been introduced (Moyle, 1976), all of which lack large populations of bluegill and other similar centrarchids. Native populations of trout, especially cutthroat and golden trout, are often reduced following the introduction of exotic trout. This may be attributed in part to competition, although the greater vulnerability to angling of the native trout complicates the picture. Competition, or perhaps predation, by lake trout (*Salvelinus namaycush*) may have been the final blow which drove the cutthroat trout populations in Lake Tahoe to extinction following their extreme reduction by commercial fishing (La Rivers, 1962). Competition from mosquitofish may also have contributed to the decline of a number of the pupfishes (*Cyprinodon* spp.) of southern California (Pister, 1974).

Like competition, predation is very hard to demonstrate as a cause of species elimination, but it undoubtedly has contributed to at least local reductions in the populations of a number of native forms. The presence of largemouth bass in the habitat of the Owens pupfish (*Cyprinodon radiosus*) was probably a major cause of its near extinction (Miller & Pister, 1971). The negative correlation between the abundance of the rare Modoc sucker (*Catostomus microps*) and the abundance of large brown trout is most likely related to brown trout predation on the sucker (Moyle & Marciochi, 1975). California roach (*Hesperoleucus symmetricus*) are almost completely gone from the upper San Joaquin, Fresno, and Chowchilla river systems in central California, apparently because of predation from green sunfish (*Lepomis cyanellus*). The sunfish invade small intermittent streams favoured by both species, where they can easily eliminate the roach when the two become trapped together in isolated pools during the summer (Moyle & Nichols, 1973, 1974). Some of these streams are now completely barren of fish in the summer, presumably because the green sunfish are less capable of surviving the severe late summer conditions (high temperatures, low oxygen) than the roach they eliminated.

Hybridisation is a major problem with interbasin transfers, since closely related species likely to hybridise usually exist in adjacent basins and one species can eliminate another through genetic swamping. The widely introduced rainbow trout has hybridised so extensively with Lahontan cutthroat trout, golden trout, and redband trout (*Salmo* sp.), that they are all included in the threatened trout management programme of the California Department of Fish and Game (S. J. Nicola, pers. comm.). In these cases, the rainbow trout phenotype usually becomes dominant or the hybridisation at least increases the phenotypic variability. The redband trout has not yet been formally described as a species or subspecies largely because hybridisation with rainbow trout has left only a few small isolated populations remaining, of uncertain purity (Hoopaugh, 1974).

Genetic swamping has also endangered three subspecies of nongame fish in California. The Mojave tui chub (*Gila bicolor mohavensis*) was nearly eliminated through hybridisation with the arroyo chub (*Gila orcutti*) after the arroyo chub was transferred to the Mojave River from the nearby Los Angeles Basin (Hubbs & Miller, 1943). Hybridisation has created similar problems between the Lahontan tui chub (*G. bicolor obesa*) and the endangered Owens tui chub (*G. bicolor snyderi*), and between armoured threespine sticklebacks (*Gasterosteus aculeatus microcephalus*) and the endangered unarmoured form (*G. aculeatus williamsoni*) (Leach *et al.*, 1974). Both the Lahontan tui chub and the armoured threespine stickleback were introduced from nearby basins.

Ecosystem alteration by introduced species is even more difficult to demonstrate in California than is direct interaction between introduced and native fishes. However, even the introduction of a single species of fish can drastically alter an ecosystem (Hurlbert *et al.*, 1972; Zaret & Paine, 1973), so such effects have to be considered, especially in light of frequent proposals to introduce *Tilapia* species and grass carp (*Ctenopharyngodon idella*) into central California. Carp are most often accused of ecosystem alteration in California, although clear-cut cases are hard to find. The supposed reduction in clarity of Clear Lake, Lake County, may be partially the result of carp stirring up the bottom while feeding. Alteration of zooplankton communities by threadfin shad in California reservoirs often reduces the growth and survival of the young of introduced game fishes which require zooplankton as food (von Geldern & Mitchill, 1975). Similarly, in Clear Lake, changes in zooplankton caused by the recently introduced Mississippi silverside (R. Elston, pers. comm.) may possibly have adverse effects on the native cyprinids which also depend on zooplankton.

CONCLUSIONS

Given the limited perspective most citizens of the United States have as to what constitutes edible, useful, or ornamental fish, the widescale introduction of exotic fish species into California has been inevitable and will undoubtedly continue. The introduced species have undoubtedly contributed to the decline of the native fish fauna but the major cause of the decline has been habital alteration by man. The introduced species primarily occupy disturbed or artificial habitats. The continuous change and degradation of aquatic habitats in California may even make further introductions necessary. For example, after an initial rejection, white bass (*Morone chrysops*) were approved for introduction into California when it became apparent that a pelagic predator was needed to feed on the overabundant threadfin shad present in many reservoirs. The shad were actually depressing the populations of other game fishes, including largemouth bass (von Geldern & Mitchill, 1975). Fortunately, the California Department of Fish and Game now has a policy of carefully evaluating every proposed introduction and in fact has been rejecting most of them (*e.g.* Pelzman, 1972, 1973).

While the official screening policy is effective for controlling formal introductions, many introductions in recent years have been unauthorised. Most common of the unauthorised introductions have been accidental releases, the release of aquarium fishes, and the release of bait fish by fishermen. Accidental releases are the most difficult to prevent since only the careful inspection of all shipments of aquatic organisms into the state and enforcement of a ban on bilge pumping from ships are likely to be effective. The release of aquarium fishes is best prevented by extending the present ban on the sale of obviously harmful species like the pirhanas (*Serrasalmus* spp.), to all potentially harmful species, especially those that have the potential for surviving in the Central Valley. The biggest potential problem with bait minnows is the further spread of red shiner and fathead minnow. Both are legal bait minnows and ecologically similar to California roach. The red shiner is established only in the Colorado River drainage but the fathead minnow is found in scattered localities throughout the state (Moyle, 1976). In the Central Valley, the few streams that are now dominated by fathead minnows were probably originally dominated by California roach. While the impact of these bait minnows on roach and other native minnows is in fact not known, a ban on their sale would seem the safest course of action until more is known. This would leave the already widely established golden shiner as the main bait species.

While the actions suggested above are likely to be beneficial, they will only be stopgap measures unless much more comprehensive steps are taken to protect the aquatic life of California, particularly in the face of the massive water transfers that are part of the California Water Plan and other major alterations of the aquatic environments of the state. Each basin, subbasin and stream system needs a management plan that is part of a statewide plan of resource use, conservation, and management. Before such a plan can be drawn up, however, the contents of each system need to be investigated. One of the sad realities of California is the poor state of the knowledge of the taxonomy, distribution, and ecology of the native flora and fauna, especially those with no immediate monetary value. For example, the California roach was originally described as 6 species (Snyder, 1912) but today is generally considered to be only one species despite the lack of a comprehensive analysis of its systematics (Hopkirk, 1973). Nevertheless, there are a number of distinct forms of roach of uncertain taxonomic status that deserve study and preservation, if not formal recognition, before they disappear and are replaced by exotic species. The same can be said about a number of other wide-ranging forms, such as Sacramento sucker, tui chub and speckled dace. There is thus a need for a comprehensive natural history survey of the state. Only when the results of such a survey start coming in will the full impact of man and his introduced species on the aquatic environment of California be appreciated.

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