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The Introduced Fish Problem and the Aquarium Fish Industry

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Abstract

Of the 46 species of foreign fishes known to be established as reproducing populations in open waters of the contiguous United States, approximately 65% are known or presumed to have originated from the aquarium fish trade. Many escaped or were released from aquarium fish culture facilities and some were introduced by aquarists. More than 50 additional, non-established fishes, mostly aquarium species, have been collected in the wild. These introductions, with established populations, have not been restricted to the so-called Sun Belt states, but have occurred throughout the U.S.

Because many introductions have resulted in serious negative impcts to native fishes, and most have the potential to do so, it is imperative that the aquarium fish industry and trade take measures to curtail such releases. The means of accomplishing this goal are relatively inexpensive. Industry must assist in public education to reduce introductions by aquarists.

The aquarium fish industry is an important factor in the economy of the United States (Axelrod 1971; Boozer 1973; Ramsey 1985) and other nations. Beyond sales of aquaria, air pumps, filters, food, medications, and other supplies, its primary products—aquarium fishes—have brought pleasure to millions of persons. It has taught many the meaning of the words "water quality" and respect for aquatic vertebrates. Moreover, it has led (or lured) a number of people into the specialty areas of ichthyology and fishery science. There have been negative aspects of this industry and the hobby it supports from introductions. This paper addresses those of environmental importance. While the industry and hobby have been a major source of introduced fishes into waters of many nations, they have not been the only source.

The first exotic fish to establish a reproducing population in open waters of North America was an aquarium species, the goldfish, *Carassius auratus* (Linnaeus), introduced three centuries ago (DeKay 1842). Since then, but mostly in the 20th century, an additional 45 species of non-indigenous fishes escaped or were released into waters of the contiguous United States and became established as feral populations. Of these, at least 28, and perhaps as many as 30 species, have been popular in the aquarium trade and hobby. Some are known to have escaped or were purposefully released from aquarium fish culture facilities, and others were introduced by well-meaning but misguided aquarists; at least one introduction appears to have been made maliciously, to disrupt or destroy a reintroduced endangered fish species.

The purpose of this contribution is to summarize those species which are known or believed to have resulted from aquarium fish introductions, to describe the known or potential detrimental impacts of these releases, and to provide recommendations for reducing, and in many cases eliminating, future introductions.

Aquarium Fishes in U.S. Waters

Table 1 lists fishes occurring as established populations in open waters of the

TABLE 1. *Aquarium fishes established in open waters of the contiguous United States.*

Family	Scientific name	Common name	State(s)
Cyprinidae	*Carassius auratus*	goldfish	most states
	Leuciscus idus[a]	ide	Maine
	Rhodeus sericeus	bitterling	New York
	Scardinius erythrophthalmus[a]	rudd	Maine, new York
Cobitidae	*Misgurnus anguillicaudatus*	oriental weatherfish	California, Michigan, Idaho
Clariidae	*Clarias batrachus*	walking catfish	Florida
Loricariidae	*Hypostomus* sp. (#1)	suckermouth catfish	Florida
	Hypostomus sp. (#2)	suckermouth catfish	Nevada
	Hypostomus sp. (#3)	suckermouth catfish	Texas
	Pterygoplichthys multiradiatus	radiated ptero	Florida
Poeciliidae	*Poecilia mexicana*	shortfin molly	California, Colorado(?), Idaho, Montana, Nevada, Texas
	Poecilia reticulata	guppy	Arizona, California(?), Florida(?), Idaho, Nevada, Texas, Wyoming
	Poeciliopsis gracilis	porthole livebearer	California
	Xiphophorus helleri	green swordtail	California(?), Florida, Idaho, Montana, Nevada (as hybrid), Wyoming
	Xiphophorus maculatus	southern platyfish	Florida, Nevada (as hybrid)
	Xiphophorus variatus	variable platyfish	Florida, Montana
Cichlidae	*Astronotus ocellatus*	oscar	Florida
	Cichlasoma bimaculatum	black acara	Florida
	Cichlasoma citrinellum	Midas cichlid	Florida
	Cichlasoma managuense	jaguar guapote	Utah
	Cichlasoma meeki	firemouth	Florida
	Cichlasoma nigrofasciatum	convict cichlid	Idaho, Nevada
	Cichlasoma octofasciatum	Jack Dempsey	Florida
	Cichlasoma urophthalmus	Mayan cichlid	Florida
	Geophagus surinamensis	redstriped eartheater	Florida
	Hemichromis bimaculatus	jewelfish	Florida
	Oreochromis mossambicus	Mozambique tilapia	Arizona,[b] California,[b] Florida, Idaho, Texas[b]
	Sarotherodon melanotheron	blackchin tilapia	Florida
	Tilapia mariae	spotted tilapia	Florida, Nevada
Anabantidae	*Trichopsis vittata*	croaking gourami	Florida

[a] Aquarium trade/hobby origin questionable.

[b] Populations in other states mostly from governmental agency releases.

contiguous United States that are known or believed to have been released from aquarium fish culture facilities or by aquarists. These are treated individually below, in phylogenetic order, according to source of introduction.

Species Escaped or Released Primarily from Culture Facilities

Misgurnus angullicaudatus (Cantor) — Oriental weatherfish. This species is established in several flood control channels in Westminster, Orange County, California (St. Amant and Hoover 1969) and in headwaters of the Shiawassee River, Oakland County, Michigan (Schultz 1960). Both populations are known to have escaped from culture facilities rearing the species. Another population, probably released by aquarists, is established in the Boise River System, Ada County, Idaho (Courtenay et al. 1988).

Clarias batrachus (Linnaeus) — walking catfish. Walking catfish escaped from an

aquarium fish farm in northeastern Broward County, Florida, in 1966 or 1967 (Courtenay et al. 1974). Additional, apparently purposeful, releases were made by fish farmers in the Tampa Bay, Hillsborough County, Florida, area in late 1967 or early 1968 after the Florida Game and Fresh Water Fish Commission banned the importation and possession of this species. Range expansion of these initially disjunct populations was dramatic, and walking catfish now occur in most fresh waters of the southern half of peninsular Florida (Courtenay 1978, 1979a). Individual specimens, apparently released by aquarists, have been found in open waters of southern California, Georgia, and Nevada, but this fish is only established in Florida.

The introduction of walking catfish provides an excellent example of how readily a foreign species can adapt to waters new to the species. All initial importations and escapes were of albinos, easily seen by predators. Within two to three years after establishment, albinos were becoming rare and the dark brown to gray color phase was common to dominant. A decade after establishment, this fish was collected from waters throughout the southern half of peninsular Florida. That probably represents a record for range expansion by a newly introduced fish (Courtenay et al. 1984). Ironically, its greatest negative impact has been to the aquarium fish culture industry in Florida. Fish farmers have had to erect protective fences around their ponds to prevent walking catfish from preying on fishes in culture.

Hypostomus spp. — suckermouth catfishes. Three morphologically distinct but as yet unidentified species of *Hypostomus* are established. One occurs in Florida, and is known to have escaped from an aquarium fish farm near Tampa, Hillsborough County (Burgess 1958). It appears to have recently expanded its range into the Hillsborough River where it has become abundant. A second species is established in the San Antonio River, Bexar County, Texas, an escape from the San Antonio Zoological Gardens (Barron 1964; Hubbs et al. 1978; Hubbs 1982). The third occurs in a thermal spring west of Las Vegas, Clark County, Nevada (Minckley 1973; Courtenay and Deacon 1982), apparently released there by aquarists.

Pterygoplichthys multiradiatus (Hancock) — radiated ptero. Individual specimens of the radiated ptero have been collected from waters in southeastern Florida since 1971 (Courtenay et al. 1984). In 1983, biologists from the Florida Game and Fresh Water Fish Commission's Non-Native Fish Research Laboratory confirmed establishment of this species near Miami, Dade County. It is also reproducing in Broward and Palm Beach counties to the north.

Poecilia mexicana Steindachner — shortfin molly. An established population of the shortfin molly has persisted in a canal system near Mecca, Riverside County, California, after escaping from a nearby aquarium fish farm (St. Amant 1966, 1970; St. Amant and Sharp 1971; Mearns 1975; Hubbs et al. 1979; personal observation [WRC] 1980). Other established populations occur in thermal waters in Owyhee County, Idaho (Courtenay et al. 1988), Madison County, Montana (Brown 1971), and Clark and Lincoln counties, Nevada (Deacon et al. 1964; Hubbs and Deacon 1965; Courtenay and Deacon 1982); these appear to have been released by aquarists. A large population, possibly introduced by aquarists, was reported from a thermal spring in Saguache County, Colorado (Hahn 1966); the current status of this population is unknown. Recently two established populations were found near Brownsville and San Benito, Cameron County, Texas (J. S. Balsano, personal communication); the sources are unknown but probably represent aquarium fish releases. In Arizona this species has been collected once from Maricopa County (Minckley and Deacon 1968; Minckley 1973). Fishes belonging to the "species complex" in which *P. mexicana* is included (Schultz and Miller 1971) have been collected from open waters in Dade

County, Florida (Courtenay and Robins 1973; Courtenay et al. 1974), but are not known to be reproducing.

Poeciliopsis gracilis Heckel — porthole livebearer. The porthole livebearer is presumed to have escaped into and become established in a drainage canal system near Mecca, Riverside County, California, from an adjacent aquarium fish farm (Mearns 1975; Moyle 1976; Hubbs et al. 1979).

Astronotus ocellatus (Cuvier) — oscar. This cichlid has been established in Dade County, southeastern Florida, since the late 1950s following a deliberate release from an aquarium fish farm (Courtenay et al. 1974). In the late 1970s and early 1980s, it began to expand its range, and the species is now represented by reproducing populations in Broward, Collier, Dade, Glades, Monroe, and Palm Beach counties. It has been collected but is not established in Massachusetts (Halliwell 1979), Mississippi (Anonymous 1979), Pennsylvania (C. N. Shiffer, personal communication), and Rhode Island (W. H. Krueger, personal communication), all apparently aquarist releases.

Cichlasoma bimaculatum (Linnaeus) — black acara. The black acara was probably the first aquarium fish to have become established in open waters of Florida. It was found to be established in Dade County in the early 1960s (Rivas 1965) and was an important component in the aquarium fish trade until the late 1950s. This species was one of the first aquarium fishes to be cultured in Florida, possibly in the 1930s (R. B. Socolof, personal communication). With the advent of jet cargo aircraft in the 1950s that facilitated importation of more colorful cichlids for sale or culture, it is likely that the market for black acara decreased substantially, resulting in its liberation from one or more aquarium fish farms. There may have been earlier escapes, but on several occasions in Florida there have been deliberate releases to get rid of unwanted (and sometimes illegal) stocks of fishes. This species became a dominant fish in many southeastern Florida canal systems during the early 1970s (Courtenay et al. 1974; Courtenay and Hensley 1979). It recently has increased its range of distribution to encompass Broward, Collier, Dade, Hendry, Glades, possibly Lee, Monroe, possibly Okeechobee, and Palm Beach counties.

Cichlasoma citrinellum (Günther) — Midas cichlid. This species was found to be established in an interconnected canal system in southeastern Dade County by personnel of the Florida Game and Fresh Water Fish Commission in 1981 (Courtenay et al. 1984). Initially it was believed that this was a release by aquarists, but the number of individuals involved and the extension of range into Everglades National Park by 1984 indicate a substantial introduction, probably by escape or purposeful release from an aquarium fish farm.

Cichlasoma meeki (Brind) — firemouth. The firemouth is established in canal systems in Dade County, Florida, near sites of former aquarium fish farms, its presumed source of introduction. It was also known from a pond on a private estate south of Miami, and a large population was eradicated from flooded borrow pits adjacent to a former amusement park south of Fort Lauderdale, Broward County. Minckley (1973) reported one specimen from a canal in Mesa, Maricopa County, Arizona, but there was no evidence of establishment.

Cichlasoma octofasciatum (Regan) — Jack Dempsey. Courtenay et al. (1974) first recorded this cichlid as established in South Miami, Dade County, and in a roadside canal in Ruskin, Hillsborough County, Florida. The canal systems where it was found were adjacent to several aquarium fish farms, the presumed source of the introductions (Courtenay et al. 1974; Hogg 1976a, 1976b). Subsequent releases by aquarists resulted in establishment in Alachua, Brevard, and Levy counties (Courtenay et al. 1984); the Levy County population was intentionally eradicated by the Florida Game and Fresh Water Fish Commission (Levine et al. 1979). It was found in a canal system adjacent to a fish farm near Micco, Brevard County, but

apparently failed to become established (R. G. Gilmore, personal communication).

Geophagus surinamensis Bloch — red-striped eartheater. This species was found to be established in Snapper Creek, Dade County, Florida, in 1982 (Courtenay et al. 1984). It probably escaped from an aquarium fish farm. No individuals were collected during the mid 1980s, and its natural extirpation was assumed. Its continued establishment in the same canal system was reconfirmed during 1989 (P. L. Shafland, personal communication).

Hemichromis bimaculatus Gill — jewelfish. The jewelfish has been established in a canal system and adjacent waters near Miami International Airport, Dade County, Florida, since at least the early 1960s (Rivas 1965; Courtenay and Robins 1973; Courtenay et al. 1974). This species probably escaped in the 1960s from several aquarium fish farms that were along the canal system. It also may have been released from airport facilities (Courtenay et al. 1984). It has been collected in canals in southern Dade County near aquarium fish farms.

Oreochromis mossambicus (Peters) — Mozambique tilapia. Although the Mozambique tilapia has become established in several states (Table 1), its initial introduction into waters of Dade County, Florida, is believed to have originated from aquarium fish farms that cultured the species in the 1960s. It was introduced into the saline Banana River, Brevard County, when it escaped from a pool near the Satellite Beach Civic Center where it had been stocked by aquarists (Courtenay et al. 1974; Dial and Wainright 1983). Releases elsewhere in the U.S. were mostly intentional for aquatic vegetation control purposes (Courtenay et al. 1984, 1986). A red hybrid of this species, possibly with *O. urolepis hornorum,* the Wami tilapia, was found in a thermally heated portion of the Bruneau River, Owyhee County, Idaho, after it escaped from a nearby aquaculture facility (Courtenay et al. 1988).

Sarotherodon melanotheron (Rüppell) — blackchin tilapia. Established populations of the blackchin tilapia occurring in eastern Tampa Bay and adjoining drainages originated as escapees from aquarium fish farms in that area (Springer and Finucane 1963; Finucane and Rinckey 1964; Buntz and Manooch 1969; Lachner et al. 1970; Courtenay et al. 1974; Courtenay and Kohler 1986). It has become a commercial species in Tampa Bay. It was found established in canals and the adjacent saline Banana and Indian rivers in the late 1970s. It presently ranges from near Titusville, Brevard County, southward to near Vero Beach, Indian River County (J. D. Williams, personal communication). It may have been purposefully released into the Banana and Indian River area to create a commercial fishery (Dial and Wainright 1983).

Tilapia mariae (Boulenger) — spotted tilapia. The introduction of spotted tilapia apparently occurred during the early 1970s, the result of escapes or purposeful releases from several aquarium fish farms in Dade County, Florida (Hogg 1974, 1976a, 1976b). It quickly became established, and is now the dominant freshwater fish in many canal systems of southeastern Florida (Courtenay and Hensley 1979). It has been recorded from Broward, Collier, Dade, Indian River, and most recently, Brevard County. This species is also established in a thermal spring above the Overton Arm of Lake Mead, Clark County, Nevada, after introduction by aquarists (Courtenay and Deacon 1982, 1983).

Trichopsis vittata (Kuhl and Van Hasselt) — croaking gourami. This anabantid apparently escaped from an aquarium fish farm along Lake Worth Drainage District canal L-36 in Delray Beach, Palm Beach County, Florida. It has been established there since at least the late 1970s and persists (P. L. Shafland, personal communication), despite several cold winters.

Species Introduced Primarily by Aquarists

Carassius auratus (Linnaeus) — goldfish. DeKay (1842) recorded the first releases of

goldfish as having occurred in the late 1600s. Although it is possible that the species escaped from ponds, it is more likely, at that time in history, that it was freed by individuals hoping it might become part of the North American fish fauna. While introductions in a few localities over the past century may have originated from aquarists, most releases appear to have been made by fishermen, discarding goldfish used as bait; some occurred from escapes of forage fish being kept at private, state, and federal fish hatcheries. Although this is one of the most widely distributed exotic fishes in North America, much of its established range is restricted to only portions of certain drainage systems. Increases in its established range are probably due to its use as a bait fish.

Rhodeus sericeus (Pallas) — bitterling. Formerly abundant in the Sawmill River at Tarrytown, Westchester County, New York, the bitterling remains established only in the Bronx River at Bronxville, Westchester County (Dence 1925; Myers 1925; Bade 1926; Greeley 1937; Schmidt et al. 1981). Its establishment there appears to be tenuous because industrial pollution has sharply decreased numbers of its spawning host, a freshwater mussel, *Anodonta cataracta* (Schmidt et al. 1981).

Poecilia reticulata Peters —- guppy. Escapes of guppies from aquarium fish farms have been recorded (Courtenay et al. 1974), but none seems to have resulted in other than locally established and usually temporal populations. Every successful introduction can be attributed to releases by aquarists (Courtenay et al. 1984, 1986), typically into waters devoid of predatory fishes, such as thermal springs and their outflows. In some waters of the southwest, such introductions have been particularly damaging to endemic native fishes (Courtenay et al. 1985, 1988).

Xiphophorus helleri Heckel — green swordtail. As with guppies, green swordtails rarely show other than local, temporal establishment after escape from aquarium fish farms (St. Amant and Hoover 1969; Minckley 1973; Courtenay et al. 1984). Most introductions that resulted in establishment were apparently made by aquarists into thermal springs and their outflows (LaRivers 1962; Brown 1971, Moyle, 1976; Minckley 1973; Courtenay and Deacon 1982, 1983; Courtenay et al. 1985, 1988). A hybrid of this species and *X. maculatus* has been established in Indian Spring, west of Las Vegas, Clark County, Nevada (Courtenay and Deacon 1982) since the 1960s. The species was recently found to be established in Idaho and Wyoming (Courtenay et al. 1988).

Xiphophorus maculatus (Günther) — southern platyfish. Escapes of southern platyfish from aquarium fish farms in Hillsborough County, Florida, and Orange County, California, failed to result in permanently established populations. Reproduction has been found in the unstable west Florida populations. Established populations exist in canals near Satellite Beach, Brevard County, Florida, and, as a hybrid with *X. helleri,* in a spring in Clark County, Nevada (Courtenay and Deacon 1982; Dial and Wainwright 1983); these populations are presumed to have been liberated by aquarists.

Xiphophorus variatus (Meek) — variable platyfish. As with other species of *Xiphophorus,* variable platyfish are known to have escaped from aquarium fish farms in Hillsborough County, Florida, and in Orange and Riverside counties, California (St. Amant and Hoover 1969; St. Amant and Sharp 1971; Courtenay et al. 1974). None of these introductions resulted in permanent establishment. The species was established in canals in Tempe, Arizona, but was extirpated by a flood; individuals have been collected periodically from drains near Yuma, Yuma County, Arizona, without evidence of establishment (Minckley 1973). The species is established in Gainesville, Alachua County, Florida (Burgess et al. 1977), probably from introductions by university students (Courtenay et al. 1986). Brown (1971)

reported established populations, released by aquarists, in thermal outflows in Beaverhead, Granite, and Madison counties, Montana; the population in Beaverhead County remains extant (Courtenay et al. 1986).

Cichlasoma managuense (Günther) — jaguar guapote. The jaguar guapote was found to be established in a thermal spring in St. George, Washington County, Utah, in 1988 (P. C. Marsh, W. L. Minckley, personal communication). This was a release by aquarists.

Cichlasoma nigrofasciatum (Günther) — convict cichlid. Rivas (1965) reported the convict cichlid from a rockpit in northwest Miami, Dade County, Florida, but the species apparently failed to establish there. The source of the Florida introduction was probably escapees from one or more aquarium fish farms in the area. All other introductions, however, are presumed to have been made by aquarists. The species has been established since at least the early 1960s in Clark and Lincoln counties, Nevada (Deacon et al. 1964; Hubbs and Deacon 1965; Deacon 1979; Courtenay and Deacon 1982, 1983). In Lincoln County, it was found in Ash and Crystal Springs in Pahranagat Valley where this species, along with introduced shortfin molly and mosquitofish, was apparently responsible for major declines in three endemic native fishes. Among the native species is the Hiko White River springfish, *Crenichthys baileyi grandis* Williams and Wilde, extirpated from its type locality, Hiko Spring, between February 1966 and June 1967 by introduced fishes (Minckley and Deacon 1968; Deacon 1979; Williams and Wilde 1981). This endangered species was reintroduced into Hiko Spring in early 1984. Convict cichlids, previously unknown from Hiko Spring, were subsequently found in that spring, probably introduced maliciously from stocks in nearby Crystal Springs to disrupt or negate reestablishment of Hiko White River springfish (Courtenay et al. 1985; Baugh et al. 1985).

An established population of convict cichlids was found in a thermal spring in Custer County, Idaho (Courtenay et al. 1988). Minckley (1973) reported two previously established populations from Maricopa County, one which failed to survive the winter of 1970–1971, and another that was destroyed by a flood in 1973.

Cichlasoma urophthalmus (Günther) — Mayan cichlid. The sudden appearance of the Mayan cichlid within the boundaries of the Everglades National Park, Dade County, Florida, appears to have resulted from an introduction by aquarists. The range of the species within the park is disjunct, indicating two sites of release. The species became established at both sites, one of which is highly saline (Loftus 1987, 1989).

Formerly Established Aquarium Fishes

Experience has shown that once an introduced fish has become established and expands its range beyond the initial site of establishment, it is usually physically and fiscally impossible to eradicate it. There have been several instances, all in Florida, where an introduced exotic fish was found to be isolated, and purposeful eradication was successful. There have been other instances in which an introduced fish became established for a few years, but subsequently died out, probably due to lethal temperature conditions (Stauffer et al. 1989). These species are summarized in the following accounts.

Serrasalmus humeralis Valenciennes — pirambeba. The pirambeba, sometimes called white piranha, was established for over a decade at a tourist attraction in southern Dade County, Florida. This was a purposeful aquarium fish release that was eradicated by the Florida Game and Fresh Water Fish Commission (Shafland and Foote 1979).

Hoplias malabaricus (Bloch) — trahira. This species apparently escaped from an aquarium fish farm along the Little Manatee River, Hillsborough County, Florida (Hensley 1976). It failed to survive extremely cold temperatures during January 1977 (Courtenay et al. 1984).

Oryzias latipes (Temminck and Schlegel) — medaka. The medaka was established in Santa Clara County, California, but failed to survive there for unknown reasons (Shapovalov et al. 1981). An established population in Suffolk County, New York, did not survive the cold winter of 1978 (the late D. E. Rosen, personal communication). Both introductions are presumed to have resulted from releases by aquarists.

Aequidens pulcher (Gill) — blue acara. R. B. Socolof (personal communication) reported the blue acara as having been established in Manatee County, Florida, probably as a result of escape from one or more aquarium fish farms. The species was not extant when that area was surveyed in the early 1970s, and may have succumbed to low winter temperatures.

Cichlasoma beani (Jordan) — green guapote. Shapovalov et al. (1981) reported this cichlid as having been established in Solano County, California, probably the result of a release by an aquarist. It become extirpated for unknown reasons.

Cichlasoma salvini (Günther) — yellowbelly cichlid. The yellowbelly cichlid was established throughout a large rockpit system, adjacent to an abandoned tourist attraction, in southern Broward County, Florida. This was probably an intentional aquarium fish release. It was eradicated in 1981 by personnel of the Non-Native Fish Research Laboratory, Florida Game and Fresh Water Fish Commission (Courtenay et al. 1984).

Cichlasoma severum (Heckel) — banded cichlid. Deacon et al. (1964) indicated the banded cichlid as possibly established in Rogers Spring, Clark County, Nevada. The species was apparently eliminated through rotenone treatment in 1963 (Courtenay and Deacon 1982, 1983).

Cichlasoma trimaculatum (Günther) — threespot cichlid. This fish, presumed to have been an aquarium fish release, became established in a pond in Manatee County, Florida. It was subsequently eradicated by personnel of the Florida Game and Fresh Water Fish Commission's Non-Native Fish Research Laboratory in 1975 (Shafland 1976).

Anabas testudineus (Bloch) — climbing perch. R. B. Socolof (personal communication) indicated the climbing perch as having been established in Manatee County, Florida, probably the result of escape from one or more aquarium fish farms. It was not found there in surveys conducted in the 1970s and is considered no longer extant. Cold temperatures were the probable factor eliminating this species.

Betta splendens Regan — Siamese fightingfish. A feral population of Siamese fightingfish was found to be established in a canal in Parkland, Broward County, Florida, in the mid 1970s. The source of the introduction is assumed to have been a nearby fish farm from which the walking catfish escaped. The fightingfish population failed to survive exteme cold temperatures in January 1977 (Courtenay et al. 1984).

Ctenopoma nigropannosum (Reichenow) — twospot ctenopoma. This anabantid was found established in a canal adjacent to an aquarium fish farm in Manatee County, Florida, during the early 1970s. Surveys conducted later that decade failed to locate the species in the same or adjacent canals, and it is considered no longer extant, possibly due to cold temperatures (Courtenay et al. 1984).

Macropodus opercularis (Linnaeus) — paradisefish. Myers (1940) listed the paradisefish as established in the "Everglades, Florida." Only a few individuals were collected during extensive sampling during the 1970s. All were found immediately adjacent to aquarium fish farms, but there was no evidence of establishment. Assuming Myers (1940) was correct in his assessment of the species in Florida, it can no longer be considered established.

Other Aquarium Fishes Collected in Open Waters

Table 2 provides a listing of fishes that are or have been popular in the aquarium

TABLE 2. *Non-established aquarium fishes collected from open waters of the contiguous United States.*

Family	Scientific name	Common name	State(s)
Osteoglossidae	*Osteoglossum bicirrhosum*	arawana	California, Nevada
Cyprinidae	*Barbodes schwanefeldi*	tinfoil barb	Florida
	Danio rerio	zebra danio	California, Florida
	Danio malabricus	malabar danio	Florida, Nevada
	Labeo chrysophekadion	black sharkminnow	Florida
	Puntius conchonius	rosy barb	Florida
	Puntius gelius	golden barb	Florida
	Puntius tetrazona	tiger barb	California, Florida
Characidae	*Astyanax mexicanus*[a]	banded tetra	California, Texas
	Colossoma spp.	pacu	Arizona, California, Florida, Missouri, Ohio, Texas, Virginia
	Colosomma bidens	(no common name)	Florida, Georgia
	Colosomma macropomum	tambaqui	Florida
	Gymnocorymbus ternetzi	black tetra	Florida, Colorado
	Hemigrammus ocellifer	(no common name)	Colorado
	Leporinus fasciatus	neon tetra	Colorado
	Metynnis sp.	silver dollar	Florida, Kentucky
	Paracheirodon innesi	neon tetra	Colorado
	unidentified piranhas	piranha	Idaho, Illinois, Kentucky, Missouri, New York, Oklahoma, Pennsylvania, Utah, Washington
	Pygocentrus nattereri	red piranha	Florida, Massachusetts, Michigan, Pennsylvania
Doradidae	*Oxydoras niger*	ripsaw catfish	Florida
	Platydoras costatus	Raphael catfish	Florida
	Pterodoras granulosus	(no common name)	Florida
Pimelodidae	*Phractocephalus hemiliopterus*	redtail catfish	Florida
Callichthyidae	*Callichthys callichthys*	cascarado	Florida, New York
	Corydoras sp.	corydoras	Florida, Colorado
Loricariidae	*Hypostomus* sp.	suckermouth catfish	Colorado, Pennsylvania
	Otocinclus sp.	(no common name)	Colorado
Goodeidae	*Ameca splendens*	butterfly splitfin	Nevada
Poeciliidae	*Poecilia* hybrids		Florida, Nevada
Cichlidae	*Cichlasoma labiatum*	red devil	Florida
	Geophagus brasiliensis	pearl eartheater	Florida
	Labeotropheus sp.	(no common name)	Florida
	Pseudotropheus auratus	gold mbuna	Nevada
	Melanochromis johanni	blue mbuna	Nevada
	Pseudotropheus zebra	zebra mbuna	Nevada
	Pterophyllum scalare	angelfish	Florida, Kentucky
	Tilapia sparmanni	banded tilapia	Florida
Anabantidae	*Colisa fasciata*	banded gourami	Pennsylvania
	Colisa labiosa	thicklip gourami	Florida
	Colisa lalia	dwarf gourami	Florida
	Helostoma temmincki	kissing gourami	Florida
	Macropodus opercularis	paradisefish	Florida
	Trichogaster leeri	pearl gourami	Florida
	Trichogaster trichopterus	threespot gourami	Florida
Channidae	*Channa micropeltes*	giant snakehead	Maine, Rhode Island

[a] Aquarium trade/hobby origin questionable.

fish trade and that have been collected from open waters of the contiguous United States. All were collected as single or a few specimens, without evidence of establishment. The list emphasizes the roles played in releases by aquarium fish culture facilities and particularly by aquarists; aquarium fish farms were cited as the probable source of introduction only when such farms were known to be located near (usually 3 km or less) the site of collection. It also suggests that any exotic freshwater aquarium fish species being cultured or held in aquaria has the potential to be found in open waters at some point in time. While introductions of aquarium fishes are not to condoned, it is emphasized that introductions will not invariably lead to establishment; if the reverse were true, we would have several times the number of established species now present in our waters.

Concern About Aquarium Fish Releases

The introduction of species from foreign lands has been a part of man's history. In prehistoric times, exotic species, usually birds, were used as pets and traded by nomadic tribes with neighboring groups of people. Records of this were left in "rock art" of Indian tribes in the southwestern United States (Shaafsma 1980), and skeletal remains of exotic birds have been found with other artifacts from these cultures.

When humans began to move fishes beyond their native ranges remains unknown, but there is strong evidence indicating that common carp, *Cyprinus carpio,* may have been introduced to Europe for aquaculture purposes during the Roman Empire (Welcomme 1981, 1984, 1988). Since then, at least 237 species of fishes have been introduced worldwide, the majority during the present century (Welcomme 1988); a substantial number of these are commonly found in the world aquarium fish trade.

Why should the introduction of exotic species be of concern? Much of the agricultural production of the world, particularly in so-called "developed nations," is based on crops and many farm animals that were imported. Most of these crops and some of our farm animals, however, are so domesticated by hybridization that they are far removed from the wild, original stocks from which they were developed; they typically require cultivation and care by humans, and rarely create environmental problems when permitted to become feral. In addition to agricultural importations, there have been numerous introductions of trees for various purposes — some to create forest resources where few existed previously (such as the introduction of European evergreens and Australian eucalypts into southern Africa); some to stabilize soils (kudzu vine, *Pueria kobata* (Willdenow) Ohwi, to the American southeast, and Port Jackson acacia, *Acacia saligna* (Labillardiere) Wendland, from Australia to South Africa); some to dry wetlands and reduce mosquito populations (Australian melaleuca, *Melaleuca quinquinervia* (Cavanilles) Blake, in southern Florida); and others strictly as ornamentals. Many of these well-intentioned introductions have become serious pests, frequently spreading and dominating non-target areas, to the detriment of native flora and fauna, and often requiring massive, but largely ineffective, expensive control programs (Courtenay 1979b). Moreover, the agriculture and silviculture literature is replete with numerous examples of introduced diseases and plant pests, often as a result of plant introductions. Nutria (*Mycocastor coypus* [Molina]), being reared for the fur trade, escaped and others were released when the market for nutria pelts failed to materialize; they have become serious pests in several southern states (Courtenay 1979b) and they occur as far north as Maryland. Feral rabbits and cats have created serious environmental damage in several parts of the world. Damage to habitat of pronghorn antelope, deer and other large mammals has occurred from feral populations of goats and donkeys in the American West.

Exotic fishes have been added to the North

American fauna for a variety of reasons. A few were introduced to provide new food resources, new sport species, or to act as biological controls on one or more pest species, themselves often introduced species. In a majority of such intentional introductions, the introduced fish has been ineffective or only partly effective in its intended task; in several, the introduced species has itself become a pest through habitat modification, predation on native species, or displacement of native fish populations through massive population increases or behavioral interactions (Taylor et al. 1984). Many fishermen and fishery biologists regard the brown trout, *Salmo trutta* Linnaeus, as a most successful introduction, but it has had some undesirable impacts on native trouts (Courtenay et al. 1984; Taylor et al. 1984). Introducing a series of sport species to the Salton Sea in southern California was successful in terms of providing new resources without adverse impacts on native biota (Courtenay and Robins 1989). Fish species are sometimes introduced into waters new to them to prevent extinction in their native habitats. Usually these waters are isolated (often thermal springs) where escape into other waters is impossible or extremely remote; moreover, such translocations are intended to be temporary until the species can be reintroduced into its rehabilitated native range of distribution, a wise use for introductions.

The escape or release of aquarium fishes into open waters has never resulted in a beneficial introduction. Some might argue that introductions of blackchin tilapia and perhaps Mozambique tilapia were beneficial in that they formed the basis for new commercial fisheries. Release of the oscar into southeastern Florida in the late 1950s continues to receive favor from a relatively small contingent of sport fishermen; most of its support comes from its first booster, a former newspaper fishing column writer, now an editor of a Florida fishing magazine. These introductions failed to benefit anything from a biological standpoint.

In many such instances, there have been negative impacts on native fishes and habitats. Most impacts, to date, have been in areas where habitat modification has already stressed fish populations, such as the American southwest (Minckley and Deacon 1968; Deacon 1979; Courtenay et al. 1985; Welcomme 1988; Courtenay and Robins 1989). That similar situations might not arise in the future in geographical areas where native fish faunas presently consist of a greater diversity of species in larger numbers is impossible to predict but plausible to project. Because the introduction of several exotic species, particularly plants, did not erupt into major disruption and displacement, sometimes replacement, of native plants until 30 to 50 years after initial introduction is cause for concern; in many ecosystems, one cannot expect to find or determine impacts, positive or negative, within a comparatively short time period.

One cannot inject a non-native species, plant or animal, into an ecosystem without altering that ecosystem (Courtenay 1979b; Stauffer 1984; Taylor et al. 1984). In all too many instances, release of wild stocks of plants and animals has had long term, negative impacts that have resulted in losses of native natural resources and costs to society (Elton 1958; Laycock 1966; Courtenay 1979b; Courtenay and Stauffer 1984). Negative impacts have included direct predation, habitat alteration or modification, competition for resources, changes in food resources, and overcrowding after overly successful reproduction and recruitment by the introduced species (Taylor et al. 1984), impacts which in many instances are ecologically predictable (Stauffer 1984).

Fishes and other aquatic organisms cannot be cultured in most currently used culture facilities without the eventuality, perhaps certainty, of escape or release (Shelton and Smitherman 1984). Considering that aquarium fishes are not imported or cultured to be released into open waters, these factors underline the necessity for the aquarium fish industry to undertake some

initiatives to assist in protecting integrity of native natural resources.

The Aquarium Fish Industry and Environmental Responsibility

In nearly all states, it is illegal to introduce any non-native species without authorization from the appropriate state conservation agency (King and Schrock 1985). Therefore, escapes or releases, even if accidental, or the freeing of unwanted aquarium stock by hobbyists are violations of law. Most hobbyists are unaware that such prohibitions exist, and some culturists have openly violated these regulations (Courtenay, in press). In many states, fish culture facilities and retailers must be licensed with one or more appropriate state or local agencies. A few states, such as Florida, mandate that culture facilities provide physical safeguards against escape of culture stocks. Although the aquarium fish industry may dislike these regulations, they were not established by whim but rather as minimal efforts in environmental protection. There are many in the scientific community of ecologists, ichthyologists and fishery biologists who would prefer strengthening of these laws, but such actions may not be necessary if the aquarium fish industry will cooperate by adopting an attitude of environmental responsibility.

Courtenay and Robins (1973) suggested a few alterations to aquarium fish culture facilities that could substantially reduce the risk of escape. These suggestions, along with others, were adopted in 1972 as part of the policy of the American Fisheries Society regarding introductions of exotic species. Because many such facilities, at least in Florida, are constructed on land subject to periodic flooding, they recommended that containment dikes be constructed around the perimeter of the facility to prevent escape of stock with flooding. Several Florida fish farms have done this. Two ideal models for such facilities exist at the Florida Game and Fresh Water Fish Commission's Non-Native Fish Research Laboratory in Boca Raton and the U.S. Fish aand Wildlife Service's National Fisheries Research Center in Gainesville. Courtenay and Robins (1973) also recommended that effluent waters from aquarium fish culture facilities be passed through a simple sand and gravel filter system prior to discharge into receiving waters. This would prevent release of eggs and fry, as well as adult fishes. This recommendation has been followed by some facilities, but not by most. The Florida Wildlife Code requires all aquarium fish culture facilities to be escape-proof, apparently leaving the mechanism for doing so to the owner, but these facilities are inspected periodically for compliance. It is recommended that all states emulate Florida in requiring that fish culture facilities utilizing non-native species be made as escape-proof as possible, and that inspection programs for compliance be implemented. The aquarium fish industry should police itself on this issue, but history has shown that it will not. One of these modifications, diking, is admittedly expensive, but the costs of trying to reclaim or manage aquatic resources after an unwanted introduction are far greater.

Secondly, Courtenay and Robins (1973) recommended that the aquarium fish industry, perhaps together with natural resource agencies as is being done now in other nations, educate the aquarium fish buyer or enthusiast against releasing pets in general and fishes in particular. A simple technique, relatively inexpensive, is to use warning posters in retailer's stores that inform the public of environmental and legal dangers. Reinforcement of this message could be summarized in print on the plastic bags in which buyers receive their fishes. Despite initial enthusiasm over these suggestions by the aquarium fish industry in the early to mid 1970s, nothing was done, and releases by aquarists continue unabated. Moreover, only one state, Florida, published a poster in an effort to educate the public against releasing pets, and there was no mandate that licensed retailers be required to display the poster; it was distrib-

uted to most, if not all, licensed stores, but actually displayed in few. In other nations, such as Australia and South Africa, similar public education programs are underway and appear to be effective. Environmental rationale and legal restrictions against releasing exotic species should be incorporated into natural science curricula in schools as a part of this public education effort in all nations.

Finally, reaction to these recommendations has been disappointing. Nevertheless, one introduction "mistake," from a culture facility or by an aquarist's release, that creates a serious environmental problem can be predicted to result in legal action and/or a public outcry for strong regulation of the aquarium fish industry, a situation to be avoided. The industry recognizes this, and its cooperation is requested through participation in environmental responsibility by preventing escapes or releases.

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