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Exotic Fishes and Other Aquatic Organisms Introduced into North America

SMITHSONIAN CONTRIBUTIONS TO ZOOLOGY • 1970 NUMBER 59

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ZOOLOGY

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SMITHSONIAN INSTITUTION PRESS
CITY OF WASHINGTON
1970

ABSTRACT

Lachner, Ernest A., C. Richard Robins, and Walter R. Courtenay, Jr. Exotic Fishes and Other Aquatic Organisms Introduced into North America. *Smithsonian Contributions to Zoology,* 59:1–29. 1970.—The introduction of aquatic animals from foreign lands to the waters of the United States is not a new problem, but it is rapidly accelerating, particularly because of the increase in quantity and in kinds of fishes entering the aquarium trade. The introduction of each fish species that is judged to be established is reviewed with respect to place of origin, mode of transport, area of release, and rationale. Transplants of native fishes from one drainage to another or from one end of the country to the other, though often resulting in harm to local faunas, are only reviewed in a cursory manner.

Twenty-five species of exotic fishes are now established in waters of the United States exclusive of Hawaii. They include one trout (Salmonidae), six minnows (Cyprinidae), one loach (Cobitidae), one catfish (Clariidae), five livebearers (Poeciliidae), two drums (Sciaenidae), seven cichlids (Cichlidae), and two gobies (Gobiidae). Except for the gobies and drums, all are freshwater species. Many other exotic species have been caught in our waters, but their establishment is not yet demonstrated.

The areas affected vary considerably, from local warm springs, in which the exotic species probably could be eliminated, to large and interconnected systems in which no amount of money or effort could remove the introduced animal.

Introductions have been both purposeful and accidental. Though sometimes well intentioned, they have never been preceded by a thorough study of the possible effect of the species in question on the local biota. Where purposeful, introductions have usually involved a single organization which has acted on the basis of its own limited interests.

Particular attention is given to Florida and Hawaii, the states most affected by introductions. They differ markedly in the nature of the problem since in Hawaii freshwater drainages are isolated and small, whereas Florida's fresh waters are extensive and interconnected by canals. Most of the 64 million fishes imported into the United States each year enter through southeastern ports, especially Miami and Tampa. The growth of the aquarium industry in Florida, and careless management of its holding tanks or ponds, has resulted in the introduction and establishment of species that serve no useful purpose and can only offer competition with native fishes.

Brief consideration is given to aquatic plants and invertebrates, both groups of which have created major and expensive control problems.

Although the problems raised by aquatic animals already introduced into our waters are serious, they threaten to become much worse if meaningful control and regulation of imported animals is not quickly forthcoming. The biological pathway involved in the role of introductions is their establishment through reproduction, and their competition with, and, in some cases, extinction of native fauna. Recommendations are made to assist the control of introductions, and the resolutions of a recent conference on this subject are repeated.

Official publication date is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, Smithsonian Year.

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON : 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 45 cents (paper cover)

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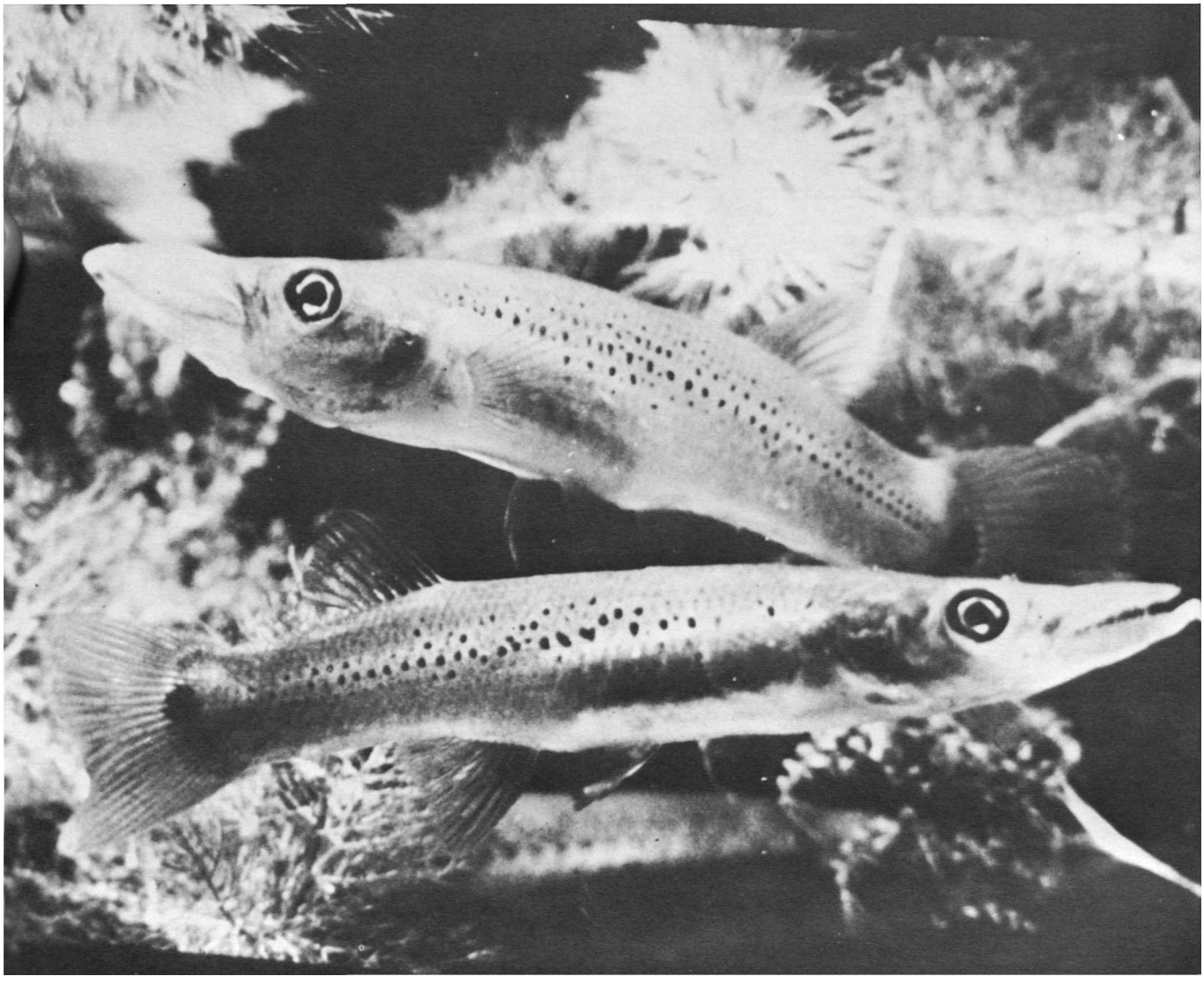

FIGURE 1.—The pike killifish, *Belonesox belizanus,* an import from Yucatan, is well established in waters of south Dade County, Florida. This live bearer, although reaching a length of 8 to 9 inches, is an active, predaceous carnivore on small aquatic life.

Ernest A. Lachner,
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Walter R. Courtenay, Jr.

Exotic Fishes and Other Aquatic Organisms Introduced into North America

Introduction

Many Americans are more conservation minded today than ever before. They are generally aware of the need for water and air pollution control, and even of the developing problems of space pollution. The human needs for water and air are direct and fundamental to sustenance. Other constituents of the environment are more indirectly associated to human uses. In our national directives for environmental control, many areas of our natural heritage remain unguarded. One of these areas, our living, native American biota, is being biologically polluted through the introduction of living exotic (foreign) life. Some of these introductions contaminate the natural environment as severely as a dangerous chemical release in water or air. They also threaten to replace known wildlife resources with species of little or unknown value. The specific subject of this paper is to discuss the extent of introductions of exotic life, especially fishes, into the aquatic environment of North America and to comment, where possible, on the effects of these releases on the environment and man's economy.

Introductions of the starling, English sparrow, and the carp have received such publicity as widespread pests that most North Americans are generally aware that these species were deliberate, man-effected introductions. A vast number of exotic species, especially aquatic animals of which the public is unaware, continue to arrive in North America, and some, through accidental or deliberate releases, become established and are competitively dangerous to native species or ecological communities. Although various federal and state regulations have been enacted in an effort to control aspects of the importation of living organisms, the laws are not comprehensive enough or sufficiently enforced to stop their release. Most agents are unable to judge or verify identifications of aquatic imports listed on invoices. One of the unique natural North American communities, that of tropical Florida, has become a biological cesspool of introduced life.

The kinds of exotic fishes and some of the other aquatic animals and plants released into North American waters are summarized here in respect to: the place of origin, mode of transport, area of release, and use of the species. Many of the species reviewed serve as examples in understanding some problems that develop from exotic introductions. Few Americans realize the diversity and numbers of aquatic plants and animals already released in our waters. Too few Americans realize the biological implications that such releases may have on the native fauna or flora or the entire biological community, or on sport and commercial fishing that the native species support.

Many problems associated with the importation and release of animals in American waters were discussed in an invitational Conference on Exotic Fishes and related Problems initiated by the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, held in Washington, D.C., 18–19 February 1969 (Stroud, 1969a). The principal portion of a paper presented by the first author to this conference

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on the kinds of exotic life introduced into American waters is here included. A statement concerning introductions of aquatic animals into Florida, prepared by the second writer, was read before the conference and most of these comments are also included. The third writer discussed the occurrence and biology of the walking catfish, *Clarias batrachus* (Linnaeus), in Florida before the conference and pertinent aspects of that paper also are embodied herein. The present paper, though stemming from the three reports just mentioned, has been completely reworked.

We follow the conference on the use of the word "exotic," implying that it refers to an introduced organism from a foreign country. The release of organisms from one drainage system to another within our American waters is regarded as a transplant. Most of our data pertain to the freshwater fish fauna of the United States. Other exotic animal and plant introductions, as well as some transplants, into the fresh and marine waters of America, and elsewhere, are discussed for they are pertinent to the problems associated with releases of organisms.

The use of exotic species by man, or the need for transplanting species, has changed considerably in recent years, particularly in North America. Early man utilized the natural resources about him. As a hunter he assisted in the extinction of many animals, such as the woolly mammoths, North American camels, giant sloths, horses, and the giant cave bear. Early community life and an agrarian existence hastened the domestication of animals and the cultivation of plants. Migration and emigration of man necessitated the transport of basic food items. Any organism useful to man's survival became an item in the traffic among early communities. As man advanced socially and technologically he was attracted to natural life for many purposes, not only for its food value but also for his pursuits in recreation and entertainment and for ornamentation, medicinal, and other uses. Through experience, man became selective, and with increased economy, an enormous traffic became possible involving animals and plants on a worldwide scale. Intervention in this traffic in the establishment of controls necessitates consideration of the species involved, where and how they are utilized, and the dangers, known or potential, inherent within each particular species that may become introduced. The task of adequately screening the biological potential of every exotic species considered for release may be enormous, but the results of any improper release may destroy, forever, a natural community or parts thereof, and ruin a commercial or recreational resource.

Many individuals have expressed concern for the dangers inherent in the release of exotic species or transplanting (stocking) within a country. The Department of Lands and Forests, Ottawa, Canada, recently conducted A Symposium on Introductions of Exotic Species (1968, Research Report, number 82, 111 pages). The papers by Crossman (pages 1–20), Christie (pages 73–91), and Regier (pages 92–111) provide background data to some of the problems we discuss. Another recent program reviewed problems associated with the release of birds and mammals.[1] General treatments as *Alien Animals* by Laycock (1966) provide further stimulating light reading of man's supreme meddling with wildlife. The public is generally familiar with adventures as those of Captain Bligh and his quest in establishing breadfruit in the West Indies, but it is often unfamiliar with common, exotic species living about them. In fact, the "Washington Conference" on exotic fishes was prompted by an exchange of correspondence among several professional biologists over the release of various species of cichlids, the walking catfish in Florida, and the possible release of the Asian grass carp in several states.

Many conferees were surprised to learn that at least 25 species of exotic fishes had become established in the United States, and that more species were being released. The conferees were further impressed when given a compilation of "Wildlife Imported into the United States in 1968" by the Branch of Wildlife Permits, United States Department of the Interior.[2] This list includes 64,254,190 live fish imports of which 64,218,294 were tropical fish; 120,000 fish eggs; 170,621 amphibians and eggs; 1,950,106 reptiles and eggs; 494,125 birds of which 478,960 were caged birds; and 140,858 mammals of which 124,440 were primates.

[1] Symposium. Introduction of exotic animals: ecologic and socio-economic considerations. Caesar Kleberg Research Program in Wildlife Ecology, College of Agriculture, Texas Agriculture and Mechanical University, College Station, Texas. 1968: 1–25.

[2] Branch of Wildlife Permits, Division of Management and Enforcement, United States Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, D.C., WL–483, February 1969, 4 pages.

Exotic fishes

Almost all imported live tropical species of fishes are destined for the home aquarist. Nearly all other imported species are used by fish culturists and by federal and state agencies or private parties for food, game, or forage purposes. Fishes imported for fish culture are introduced directly and purposefully into our waters, whereas those intended for aquarium use become established through discard of surplus stock, escape, careless management of rearing and holding ponds or through release by the buyer who no longer wants his fishes and is reluctant to destroy them. The exotic species released in the United States and/or Canada and that are definitely known to have established reproductive populations are listed in table 1. Twenty-five species in eight families are included but the number will certainly increase as more field data become available concerning natural reproduction in our waters. We know of many other exotic species that have been released in recent years, especially in Florida, and these are reviewed below. All species listed in table 1 live in fresh waters except the two estuarine gobies and drums. The cichlid, *Tilapia melanotheron* (Rüppel), thrives in fresh and estuarine waters.

TABLE 1.—Fishes introduced and established in the United States and Canada. This list includes only those species known to have reproductive populations after release. The Hawaiian Islands are not included.

Common name	*Scientific name*
SALMONIDAE—Trouts, whitefishes, and graylings	
Brown trout	*Salmo trutta* Linnaeus
CYPRINIDAE—Minnows and carps	
Goldfish	*Carassius auratus* (Linnaeus)
Carp	*Cyprinus carpio* Linnaeus
Ide	*Leuciscus idus* (Linnaeus)
Bitterling	*Rhodeus sericeus* (Pallus)
Rudd	*Scardinius erythrophthalmus* (Linnaeus)
Tench	*Tinca tinca* (Linnaeus)
COBITIDAE—Loaches	
Oriental weatherfish	*Misgurnus anguillicaudatus* (Cantor)
CLARIIDAE—Airbreathing catfishes	
Walking catfish	*Clarias batrachus* (Linnaeus)
POECILIIDAE—Livebearers	
Pike killifish	*Belonesox belizanus* Kner
Shortfin molly	*Poecilia mexicana* Steindachner
Guppy	*Poecilia reticulata* Peters
Southern platyfish	*Xiphophorus maculatus* (Günther)
Variable platyfish	*Xiphophorus variatus* (Meek)
SCIAENIDAE—Drums	
Bairdiella	*Bairdiella icistia* (Jordan and Gilbert)
Orangemouth corvina	*Cynoscion xanthulus* Jordan and Gilbert
CICHLIDAE—Cichlids	
Black acara	*Aequidens portalegrensis* (Hensel)
Oscar	*Astronotus ocellatus* (Agassiz)
Convict cichlid	*Cichlasoma nigrofasicatum* (Günther)
Banded cichlid	*Cichlasoma severum* (Heckel)
Jewelfish	*Hemichromis bimaculatus* Gill
Blackchin mouthbrooder	*Tilapia melanotheron* (Rüppel)
Mozambique mouthbrooder	*Tilapia mossambica* (Peters)
GOBIIDAE—Gobies	
Yellowfin goby	*Acanthogobius flavimanus* (Temmineck and Schlegel)
Trident goby	*Tridentiger trigonocephalus* (Gill)

The importation of tropical fish for the aquarist's market has been greatly facilitated in recent years by air transport and in our knowledge of the use of tranquilizers and additives to sustain life during transport. It is estimated that more than 1000 species of tropical fishes are available for public purchase from wholesalers in the United States. We have seen almost 500 species on hand at the establishment of one New York dealer. Illustrated encyclopaedic works on aquarium fishes, in order to serve as a useful guide, must treat more than one thousand species. Many more species will appear on the American market as rapid air travel invites exploration for different species and transport from all countries. The supply of different species (not necessarily quantity) in tropical Asia, Africa, and South America is immense. The numbers of species, estimated by systematists, of such tropical freshwater aquarium inhabitants as the families of characins, minnows, various catfishes, tooth-carps, killifishes or livebearers, and cichlids would exceed 6,000. This does not include the huge tropical marine fish fauna, for which an aquarium market is rapidly developing. The possible release of species from this vast supply of tropical freshwater fishes is a major danger in the southern United States, especially Florida and isolated North American warm springs. Most of these species cannot endure the temperate and cold waters typical of most of the United States and Canada. In recent years, however, we have learned that some species, such as *Tilapia,* can survive colder Floridian winter temperatures than it experienced in its native Africa and that it thrives in both fresh and marine waters even to the point of reproducing in high salinities.

The fish culturists have been primarily concerned with exotic freshwater fishes for pond-food production (cichlids, carp), for their sport value (brown trout), or as possible foragers (grass carp) to eliminate unwanted aquatic vegetation, or for forage. Most of the freshwaters of North America are temperate to cold. Only a small number of exotic species live in such waters over the world, probably not many more than the existing North American native fauna. But the deliberate introduction of one of these temperate species, the carp, has saddled North Americans with a permanent pest. In contrast the tropical waters harbor an immense fauna.

The following review of fish and other aquatic organisms introduced into "new water systems" distinguishes between (foreign) exotics versus (native) transplants, and between introduced (stocked or released including escapes) species versus released and established (known reproductive populations) species. The discovery of an isolated specimen of an exotic species qualifies it for listing as an introduced but not as an established species.

Review of North American Exotic Fish Introductions

Salmonidae—trouts, whitefishes, graylings

Probably the most useful exotic release in North America was the brown trout, *Salmo trutta,* that arrived in the 1880s. The first shipments were eggs from Germany (*Salmo fario:* German trout, European brown trout, Von Behr trout) and England (*Salmo trutta:* Loch Leven trout, Scotch lake trout). At the time, these shipments were believed to represent different species. Within a few years following its arrival in America the brown trout was widely transplanted from local stocks (Smith, 1896:443) and it is today widespread in North American waters (Dymond, 1955:544–546).

The huchen, *Hucho hucho,* a salmonid of the Danube basin, has been introduced into Quebec (Crossman, 1968) but there is no evidence of an established population through natural reproduction (personal communication, W. B. Scott, Royal Ontario Museum, Toronto, Canada).

Esocidae—pikes

North Americans may soon claim all species of this Holarctic family with the contemplated release of young of the Amur pike, *Esox reicherti,* of Asia, in reservoirs of Pennsylvania by the Pennsylvania Fish Commission (Food and Agriculture Organization, 1969 [3]) and Stroud (1969b:7). Of four native North American species of *Esox,* one, *E. lucius,* the northern pike, is also native of Eurasia. The northern pike greatly resembles the Amur pike, especially when young (Nikol'skii, 1954:192). A shipment of 60,000 Amur pike eggs was received by the United States Bureau of Sport Fisheries and Wildlife in exchange for certain American fish stocks. The egg shipment was then transferred to the Pennsylvania Fish Com-

[3] *Food and Agriculture Organization Fish Culture Bulletin,* 1(2):12, January 1969.

mission. Stroud (1969b) reiterates: "This is the sort of independent activity, potentially dangerous as well as possibly beneficial to American fauna and related sport fishing, that gave rise in mid-February, 1969, to a Conference on Exotic Fishes. . . ." Unless the Pennsylvania Fish Commission has a great amount of biological information not available to us, we surmise that the ecological niche suitable for the Amur pike in America can be occupied by one or two native esocids.

Characidae—characins, tetras

Next to the cyprinids, the characins comprise the largest family of freshwater fishes, probably exceeding 1500 species, and are found in South and Central America and Africa. Most of these colorful tropical fishes are excellent aquarium pets for they mature at a small size and many of the species can be bred in small tanks or jars. Some attain enormous sizes, as the tiger fish of Africa, *Hydrocynus goliath,* exceeding 100 pounds in weight. Other species, such as the piranhas, are voracious carnivores and feed on a wide variety of aquatic life and sometimes on terrestrial animals that may enter water, including man. These fishes are not only dangerous to man but to the balance of an aquatic community they invade. Herald (1961:111) lists *Serrasalmus nattereri* as the common and widely distributed species of piranha most often seen in tropical fish stores and public aquaria. Moe (1964:205) lists the pirambeba, *Serrasalmus rhombeus,* as an exotic aquarium import that is in many dealer's stores. Moe (1964) also reviews the high probability of these Amazon tropicals' ability to survive the colder Florida winters and become easily distributed in the Floridian waterways. Herald (1961:111) and Moe (1964:200) review observed reproduction in captivity of the piranha species *Serrasalmus spilopleura, S. nattereri,* and *S. niger.* Accidental release of these fishes in the warm freshwaters of America will surely bring about eventual establishment. No natural reproduction is as yet known for the piranha in Floridian waters. But as Moe (1964:206) cautions, their continued release can occur very easily, irrespective of existing controls, for the small juveniles of the piranha arrive from South America in tranquilized shipments with "harmless" or vegetarian characins, which they may resemble. Only an experienced ichthyologist could identify them. This picture is complicated by the sale in Miami of fishes of the genera *Metynnis* and *Colossoma,* under the name piranha. One member of this family, the Mexican tetra, *Astyanax mexicanus,* of Central America is naturally distributed in the Rio Grande River, Texas, the northernmost North American limit of any characin.

Cyprinidae—minnows, carps

Of the six exotic cyprinids that are established and maintain breeding populations in North America, only one, the carp, *Cyprinus carpio,* is widespread over North America and regarded as a serious pest because of its disturbance of the habitat, its ability to occupy a wide variety of habitats, and its predation on the eggs of other fishes. It was imported from Europe in 1831 by private interests for at that time it was highly regarded in the United States, particularly by immigrants from Germany, as a food fish. Legislation was passed as early as 1850 in the United States, placing a fine on those destroying carp. The carp is a native of Asia, and was introduced and cultivated in Europe for several hundred years before its appearance in America (German carp, and morphological variations, as the leather carp and mirror carp). Because of its long culture in Europe, it received an early and enthusiastic use in America. It was stocked in California waters as early as 1872. Before the turn of the century it was already subject to much criticism (Smith, 1896: 395–403; 1907: 396–398; Crossman, 1968:8). Thriving in temperate rivers and lakes and utilizing these waterways as pathways for dispersal, as well as smaller creeks and irrigation or drainage ditches, the carp continues to invade new river systems. As an example, Dymond (1955: 543–544) reviews a situation in Manitoba, where the carp was unknown until 1938, when it was taken in the Red River, "having presumably spread northward in that river from the United States." The carp subsequently moved farther northward and was taken in Lake Winnipeg and Sturgeon Bay by 1955, an extension of about 200 miles in 15 years. Its entry in the Fraser River system of British Columbia from the state of Washington via the Columbia River is also cited by Dymond (1955). In recent decades some states (e.g., New York) have spent considerable sums to control carps in their waters.

The goldfish, *Carassius auratus,* was imported as an ornamental fish, and numerous releases in private ponds had occurred by 1900. Native to eastern Asia, it

is now widely distributed over the world. It prefers weedy areas of warm ponds, lakes, and low gradient streams. Although locally abundant in many areas of North America it has not proved to be a great pest, compared to its Asian relative, the carp. The goldfish is bred by aquarists for elaborations of the head and fins and brilliant gold-orange colors. These characters do not persist in natural conditions and many of these delicate varieties cannot survive. Thus the free-living stocks that are seen are pale to olivaceous, carplike fishes.

The ide or golden orfe, *Leuciscus idus,* is another Eurasian cyprinid that probably made entry into American waters through private stocks. It is reported from several areas in the United States and it has definitely established itself in a Connecticut pond since 1962 or 1963 (Whitworth, Berrien, and Keller, 1968: 59).

The bitterling, *Rhodeus sericeus,* is native to Eurasian temperate waters and it is of some interest as an aquarium species. This cyprinid was reported as well established in Saw-Mill River, Lower Hudson watershed, New York, by Myers (1925) and Greeley (1937:94). The rudd or pearl roach, *Scardinius erythrophthalmus,* also a native cyprinid of Eurasia, was found established in the Lower Hudson watershed by Greeley (1937). Myers (1925) recorded the rudd in Central Park Lake, New York City. The rudd, superficially resembling the golden shiner, *Notemigonus crysoleucas,* a native North American species, but attaining a larger size, is caught by anglers in New York State. The tench, *Tinca tinca,* another Eurasian cyprinid, was reported as early as 1896 by Smith (1896:403) as "somewhat extensively planted in the United States by the national fish commission." Webster (1941:154) reported it in Winnemaug Lake, Connecticut, and that it spawned in June at the Cornell University Experimental Hatchery, Ithaca, New York. Dymond (1955: 544) records the tench in two lakes in southern British Columbia. These were the results of dumping the tench exhibited at the first World's Fair in Seattle into a goldfish pond. Some apparently were then taken to Lake Union. The tench is predominately a lacustrine fish. It attains a fairly large size, a specimen from Lake Libava, U.S.S.R, measured 46.5 cm and weighed 1,485 g at an age of 10 years (Berg, 1949:616). Smith (1896) said native specimens reach "a maximum weight of 12 pounds" and that the flesh is firm, white, and palatable. Although the tench is commercially marketed in the U.S.S.R., its habits are practically unknown to biologists in America. Perhaps the carp is more aggressive in occupying ecological niches the tench might otherwise seek. For a history of the tench in America, see Baughman (1947).

The grass carp, *Ctenopharyngodon idella,* is a recent cyprinid entry to the American environment. Native to eastern Asia, the grass carp or white Amur is reared and propagated for the high quality of its flesh and because of its rapid rate of growth. Because it is mainly a herbivore, this carp is a valuable pond and reservoir fish in the U.S.S.R., China, Taiwan, and other oriental countries. In its native habitat, it occupies the flat areas of rivers and spawns in the river channels. The pelagic eggs undergo development as they are carried downstream. The incubation is from 32 to 40 hours at water temperatures of 27° to 29° C (Nikol'skii, 1954:214). Spawning occurs during the summer months. The larvae and young stages enter inlets where they feed on aquatic invertebrate organisms. The adults will not reproduce in ponds and reservoirs; they require water flow over river beds and channels. This carp attains a length of over a meter and 32 kg. in weight (Nikol'skii, 1954). The grass carp can be bred in hatcheries. Many Asiatics restock their ponds with young fish at each growing period. The grass carp is recommended by Aliyev and Bessmertnaya (1968) for mosquito control because of its feeding upon the soft aquatic vegetation with which the aquatic stage of some mosquitos is associated. Other summaries on the biology, use, and other literature of the grass carp are given by Avault, Smitherman, and Shell (1968), Fielding (1968), and Nair (1968). It has been imported into the United States in recent years and it is currently being reared in ponds by federal, state, university, and private agencies in many states, such as Arkansas, Alabama, Louisiana, Oklahoma, Arizona, and Oregon (data from a communication read, in part, at the "Washington Conference" by Kermit Sneed, Fish Farming Experimental Station, United States Bureau of Sport Fisheries and Wildlife, Stuttgart, Arkansas, and personal communication). At least one agency, the United States Department of Agriculture Aquatic Weed Laboratory wishes introduction of this species in Florida (*Miami Herald,* Broward Co. edition, 23 September 1969). The grass carp is now known to be released in open waters in Alabama. The real danger inherent with the grass carp is not its life in ponds and reservoirs, but the great possibility of its

release, accidental or otherwise, in the large river systems of America. There are many habitats in our rivers suitable for the growth of juvenile grass carp and many of our rivers have adequate breeding beds, channels and alcoves for spawning and growth of the larvae and young. It would not be presumptuous to predict that the release of this temperate species in a river, as the Mississippi, would almost certainly cause its establishment within the next decade. What are the species with which it will compete for food? Probably, in the early years of growth, reproduction, and population increase, the presence of this large river species may not be detected. But if it finds an adequate refuge for reproduction, its numbers could increase enormously in a few years, for the females deposit many eggs (over 800,000 by a 76 cm [30-inch] female; Berg, 1949: 598). The grass carp could become a serious pest, perhaps more so than its cyprinid relative, the carp. Unlike other peoples of the world, most North Americans do not show any immediate interest in the food value of such soft flesh fishes as the carplike cyprinids. In the absence of any actual harvest these species increase rapidly and frequently destroy the habitat of other species more suited to our present economy.

Cobitidae—loaches

The oriental weather fish, weather loach or dojo, *Misgurnus anguillicaudatus,* is a small eel-like loach of North China and Japan that is established and is reproducing in a restricted area of Oakland County, Michigan, and in the Westminster flood control channel, Orange County, California. The Michigan specimens were collected in 1958 by Schultz (1960) in a private pond on Hy Meadow farm and also over a ten-mile area of the Shiawassee River. An aquarium dealer at Holly, Michigan, had the weather fish in stock as early as 1939, from shipments received from Kobe, Japan. The existing wild stock is surely an accidental or deliberate release from specimens obtained from the Holly supplier. Reeve M. Bailey, Museum of Zoology, University of Michigan, captured more specimens in 1965 from the same locality. This temperate-water species attains a total length of about 20 cm (8 inches). It would not be impossible to eradicate this species from the Hy Meadow farm pond and the Shiawassee River. It is not known, however, to be a pest or a competitor in these waters. The California specimens captured, numbering about 300 and ranging from 16 to 224 mm total length, were taken from April to July 1968 near the Pacific Goldfish Farm, over a three-mile area of a flood channel by St. Amant and Hoover (1969). The size range, from young to adults, is good evidence of reproduction. Captured with the loach were other exotic fishes, three species of exotic snails and the exotic African frog, *Xenopus laevis.*

Clariidae—airbreathing catfishes

This family of airbreathing catfishes has accessory respiratory organs, in addition to gills, enabling the fish to utilize atmospheric air. Representatives of the family are found in the warm waters of Africa and southeast Asia. *Clarias batrachus,* the walking catfish or pla duk dam (a Thai name, meaning dull-colored wriggling fish), has a native distribution from India to the Phillipines (Smith, 1945; 348), where it lives in swamps, ditches, canals, lakes, and rivers. It is an aggressive, omnivorous feeder, thriving on the available food supply and, in turn, is eaten extensively by fishermen and farmers. It may be kept alive in moist baskets or tubs and is sold in this condition in the markets. Albinism is fairly common in this species and the pale pink smaller specimens have been sought by aquarists for years. The accidental release of the walking catfish in southern Florida, from outdoor holding ponds of local aquarium dealers, may be the most harmful introduction to any North American area so far witnessed because of its severe competitive habits. In the past few years it has become abundant from Ft. Lauderdale northward to Lake Okeechobee and West Palm Beach. Occurrences in the Miami area apparently resulted from separate releases. Vernon E. Ogilvie, Florida Game and Fresh Water Fish Commission (and discussant, "Washington Conference") says the species is out of control, and that there is no practical method of eradication. Its invasion of the Everglades, northern Florida, and Georgia, and perhaps the Gulf Coast states westward to Texas is inevitable because of its prolific reproduction, rapid growth, ability to maintain itself in dense populations, and to distribute itself easily by the many interconnecting natural and man-made waterways, or by land. Like some species of *Tilapia,* this catfish is tolerant of high salinities. It has been found commonly in parts of the intracoastal waterway in Palm Beach County. Thus coastal avenues of dispersal are also open. This aggressive species has no natural Floridian competitor. It can

FIGURE 2.—Albino walking catfish, *Clarias batrachus,* an Asian import, surface at edge of pond in Brevard County, Florida.

move considerable distances overland, especially on damp or rainy nights and easily occupy new water systems. In its voracious food habits it competes with, and in time may deplete, the native food and game fishes, particularly the centrarchids, of the warm southeastern freshwaters with which it competes directly for food. Small natural ponds from which the walking catfish has been seined in Florida, produced up to 3000 pounds of this species per acre. There is no current American market for its flesh. Certainly, the food fishes it replaces are far more palatable. This species is a severely harmful competitor, for it apparently reduces the entire freshwater community that it invades to one common denominator, more walking catfishes. Buckow (1969) and Idyll (1969) present illustrated accounts of the invasion of Floridian waters by the walking catfish.

Following the alarm raised by biologists and conservationists over the introduction of this species in Florida, much publicity was accorded to it with the result that demand (and prices) for it rose and the species is now reported from aquarium shops in Alabama, Georgia, North Carolina, Ohio, Connecticut, Louisiana, and Texas. Possible widespread introduc-

tion of this species may have been aided by the publicity given it.

Trichomycteridae—parasitic catfishes

The parasitic catfishes, or pygidiids, are small, slender scaleless inhabitants of tropical South America, most of which occur only in freshwaters though the family includes coastal representatives. They enter North America through the aquarium traffic and, like the piranha, are traded as novelties. While some species are free-living, others are parasitic on fishes, feeding on the blood of the gills. The opercle and preopercle are armed with retrose spines, and when the opercle is extended, the fish becomes hooked to objects it contacts. The dreaded candiru (*Vandellia cirrhosa* and other species) is feared by the South American natives because these diminutive fishes penetrate the urogenital openings of men and women bathers (as well as other mammals in water) causing severe pain, inflammation, and hemorrhaging, often necessitating surgery. This species should be rigidly controlled and prohibited from all aquarium trade. No introduction is as yet positively known for these fishes, but once unknowingly released they could thrive in the warm waters of the southern United States, especially in Florida.

Loricariidae—armored catfishes

Many species of loricariid catfishes, as well as the callichthyid catfishes, native to tropical South America, are favored by tropical fish hobbyists. Rivas (1965:256) reports a mailed catfish, *Hypostomus plecostomus,* from a rock pit pond in West Miami. It is also known from the Snapper Creek Canal system.

Callichthys species, has also been captured in southern Florida waters, in Palm Beach County. There is no information on any observed reproduction in Florida of these fishes. From reports by ichthyologists, several other species of armored catfishes are also involved in introductions in the Miami area.

Poeciliidae—livebearers

This New World family is found from the United States to southern South America. The poeciliids, viviparous topminnows or livebearing toothed-carps, number about 150 species and are most abundant in tropical Central and South America. They are very popular species with fish hobbyists for they thrive and reproduce readily in small enclosures. The pike killifish, *Belonesox belizanus,* an import from Yucatan, is established in the Miami area of Florida (Rivas, 1965:256), where it is now abundant. The pike killifish, although attaining a maximum size of only 20 cm, is equipped with sharp teeth and has a vicious disposition. It is an active, predaceous carnivore on small, aquatic life, including young fishes, and serves only as a detriment to our native fauna. During periods of drought when waters are confined to the canals proper, this species has been observed to eliminate all small fishes from the area. This introduction seriously impairs the natural control on mosquito larvae by the mosquitofish, *Gambusia affinis.*

The shortfin molly, *Poecilia mexicana,* is established in Blue Point Spring, and the Moapa River, Nevada, apparently a release from an aquarium fish-rearing business at Blue Point Spring, Clark County, Nevada (Deacon, Hubbs and Zahuranec, 1964). These authors also list the guppy, *Poecilia reticulata,* and the southern platyfish, *Xiphophorus maculatus,* as introduced into Blue Point Spring about 1957 and present in 1963, and also representing releases from a private aquarium dealer at Blue Point Spring. Deacon, Hubbs, and Zahuranec (1964) and Hubbs and Deacon (1964) review the effects of exotic introductions competing with native, endemic fishes in springs of southern Nevada, involving the three introduced species listed above, an introduced exotic cichlid and the mosquitofish, *Gambusia affinis.* Decline in numbers and extirpation of local, native fishes, such as the killifish, *Crenichthys baileyi,* and the Pahrump killifish, *Empetrichthys latos,* were shown as a result of these recent releases. Other local races of native catostomids and cyprinids are predicted also to be adversely affected and one species, the Pahranagat spinedace, *Lepidomeda altivelis,* probably has become extinct through competition. This spinedace was originally described by Miller and Hubbs (1960:26) based on twenty four specimens collected in 1938 from the outflow of Ash Spring, Pahranagat Valley, Lincoln County, Nevada, and from Upper Pahranagat Lake, Lincoln County, by Carl L. Hubbs and party, and three specimens collected by Charles H. Gilbert in 1891 from Pahranagat Valley, Nevada. Extensive field collecting in 1959 to verify its presence revealed none (Miller and Hubbs, 1960). These authors found "hordes of carp" and "considerable numbers" of the mosquitofish, *Gambusia*

affinis, both introductions, which most plausibly contributed to the nearly certain extermination of the Pahranagat spinedace.

Another poeciliid, the variable platyfish, *Xiphophorus variatus,* an import from Mexico, is reported by Brown (1962) as established in the Missouri drainage of Montana.

Poeciliids, a cichlid, and other species, which were introduced into hot springs near Banff, Alberta (McAllister, 1969:31) were determined to be releases from local aquarists. Apparently the following species are successfully reproducing there: *Poecilia latipinna, Poecilia reticulata, Xiphophorus helleri, Gambusia affinis,* and *Cichlasoma nigrofasciatum.* The success of these releases at such a high latitude demonstrates that reproduction was not affected by the different photoperiodism compared with that of lower latitudes. *Gambusia affinis* was introduced in ponds in the Columbia Basin of eastern Washington by the Washington State Health Department in 1968 as a possible control for the mosquito vectors of encephalitis. This "warm-water" species successfully overwintered in the Pacific northwest during one of that area's most severe winters (*Palm Beach Times,* 3 October 1969).

Sciaenidae—drums

Douglas (1953) and Walker, Whitney, and Barlow (1961:78–79) list many transplants into the Salton Sea, California, over a period of 30 years, including such forms as the striped bass, anchovy, bonefish, pompano, corbina, croaker, mackerel, mullet, mojarra, shad, grunion, silverside, flounder, opaleye, wrasse, bairdiella, longjaw mudsucker, thread herring, orangemouth corvina, and others. Of these, nine species survive, including the native desert pupfish, *Cyprinodon macularius.* Only four of the stocked fishes are known to reproduce: the sargo, *Anisotremus davidsoni* (Pomadasyidae); bairdiella, *Bairdiella icistia* (Sciaenidae); the orangemouth corvina, *Cynoscion xanthulus* (Sciaenidae); and the longjaw mudsucker, *Gillichthys mirabilis* (Gobiidae). The success of these transplants is of special interest because of the nature of the environment, for the Salton Sea today is not only saline, but the relative amounts of the various salts differ from that of marine water and it is subject to considerable temperature fluctuations. There was a gradual extirpation of the freshwater species after the Sea was formed in 1906, such that the most abundant species in 1916 (the carp, *Cyprinus carpio*) had disappeared in 1929 with increased salinity. Today the introduced orangemouth corvina is an important game fish. This species abounds in the Sea, attaining weights of 32 pounds. The Salton Sea is an excellent example of an area where there was good chance to gain and nothing to lose or harm by trial and error introductions.

Cichlidae—cichlids

This large family of tropical fishes comprises about 850 to 1000 species found mainly in Central and South America and Africa. One genus occurs in Asia. One species, the Rio Grande perch, *Cichlasoma cyanoguttatum,* is distributed naturally from Mexico to Texas. The cichlids are popular among aquarists because of their brilliant colors and interesting breeding behaviors. They are hardy species that propagate easily and they are used widely for commercial food purposes. Many species adapt both to fresh and estuarine waters and their predaceous habits make them competitive to native North American warm-water bass and sunfish. Many species have been imported and probably more species than we are aware of have been released. The study of the systematics of the family is very incomplete and many species are difficult to identify, particularly the juvenile stages, with the existing literature. Several species have been released, deliberately or through careless pond maintenance, especially in Florida, by state stocking programs, escapes from tropical fish dealers or state experimental ponds, or releases by hobbyists, whose pets outgrow the container. The senseless introductions and the survival possibilities of cichlids is compared with early carp introductions in the United States by Hubbs (1968). The clichlids may be considerably more tolerant and adaptive to environmental hazards than is now suspected (Hubbs, 1968). Populations finding refuge in many of our natural, warmer, southern waters, warm springs, or even in such artificial water sources as areas of thermal pollution, may eventually establish and distribute themselves over most of the southern states.

Eight species, apparently, are established in North America. The black acara, *Aequidens portalegrensis,* and the oscar, *Astronotus ocellatus,* are South American imports established in south Florida canals and waterways (Rivas, 1965:256). The convict cichlid, *Cichlasoma nigrofasciatum,* a central American import,

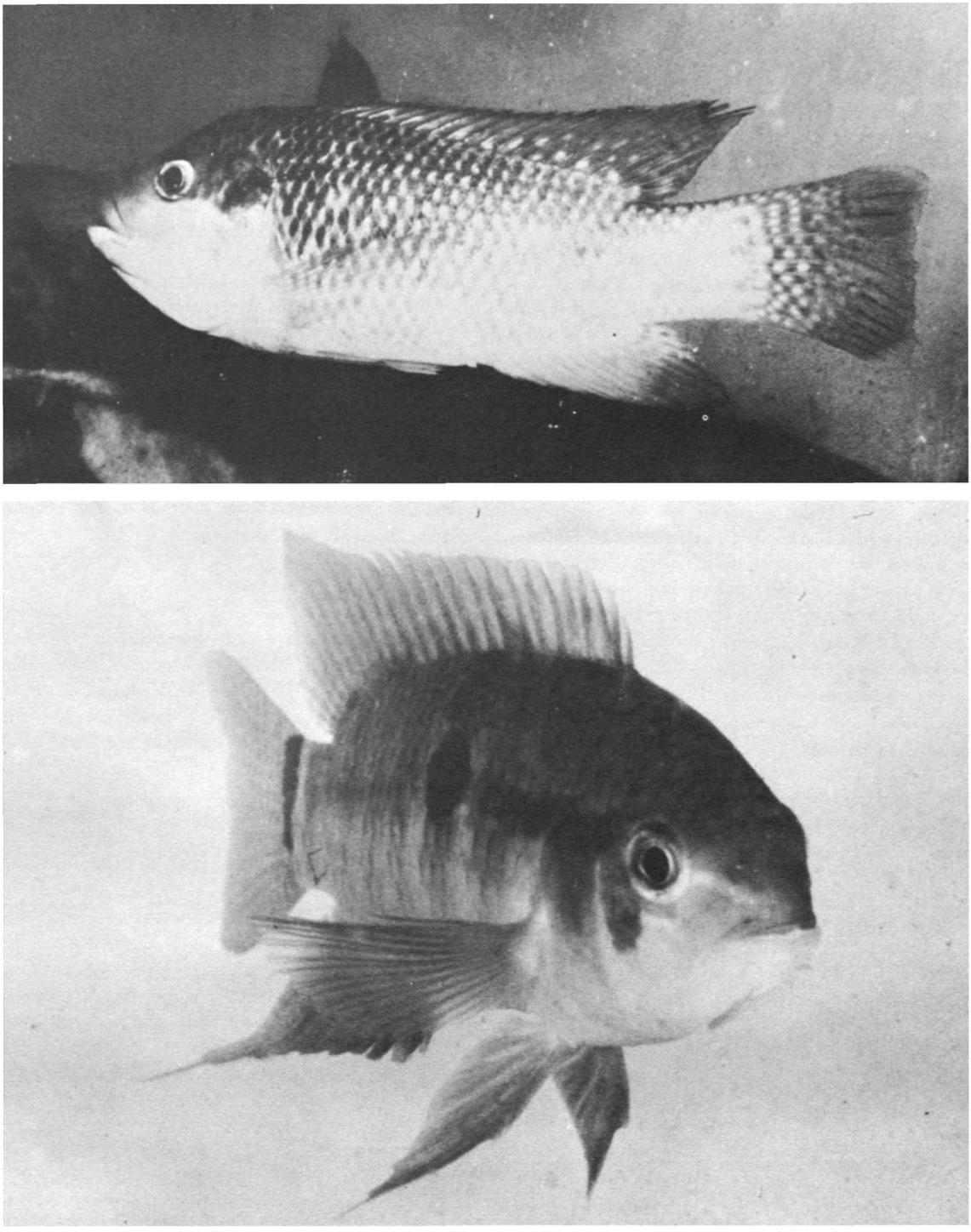

FIGURE 3.—*Upper:* the Mozambique mouthbrooder, *Tilapia mossambica,* native to Africa, has been widely distributed in North America. This specimen was taken from the brackish waters about Hypoluxo Isle, Palm Beach County, Florida.

Lower: the black acara, or port cichlid, *Aequidens portalegrensis,* a South American species, is well established in south Florida canals and waterways. This species appears to thrive in Florida waters occupied by the walking catfish.

is established in ponds about Miami (Rivas, 1965), in Roger Spring and Ash Springs, Nevada (Deacon, Hubbs and Zahuranec, 1964; Hubbs and Deacon, 1964), and in a hot spring at Banff, Alberta (McAllister, 1969). The banded cichlid, *Cichlasoma severum,* a South American species, was released in Roger Spring, Clark County, Nevada (Hubbs and Deacon, 1964). Recently a well-established population of a *Cichlasoma,* the species of which is not yet definitely determined, was discovered in northwestern Miami. The jewelfish, *Hemichromis bimaculatus,* a colorful African species of the fish fancier, is known to be in a Hialeah canal, south Florida (Rivas, 1965:256) and near the Miami airport. The blackchin mouthbrooder, *Tilapia melanotheron,* native of Africa, is well established in the Hillsborough Bay area of west-central Florida (Springer and Finucane, 1963). These authors report that the blackchin mouthbrooder is marketed in Tampa as "African sunfish." They refer to a live commercial catch of 1553 pounds from Bullfrog Creek on 13–17 December 1962 when water temperatures in nearby Old Tampa Bay were 9.6 C (49°F). The Mozambique mouthbrooder, *Tilapia mossambica,* another species native to Africa has been widely distributed (Atz, 1954) and was listed as released in Alabama by Smith-Vaniz (1968), and established in Texas (Hubbs, 1961:12) and in a warm spring pond at Bearmouth, Granite County, Montana, by Brown and Fox (1966).

Other species of cichlids are known to have been released but no data are currently available concerning their reproduction. The tucanare or peacock cichlid, *Cichla ocellaris,* native to South America was released (10,000 juveniles) in the area about Fort Lauderdale, Florida (Moe, 1964: 205; Ogilvie, 1966); the firemouth, *Cichlasoma meeki,* a Central American cichlid was reported from a rock pit pond, Miami, by Rivas (1965); the blue tilapia, *Tilapia aurea,* an African species, is used in pond culture studies in Alabama (Smith-Vaniz, 1968:114) and apparently has been introduced in Florida (*Tallahassee Democrat,* page 6, 20 June 1969); and the Congo tilapia, *Tilapia melanopleura,* was released in Alabama and also used there in experimental pond culture studies (Smith-Vaniz, 1968:114).

Gobiidae—gobies

Two Asian gobies are well established in the Stockton area, California. The yellowfin goby, *Acanthogobius flavimanus,* native to the estuarine waters of Japan, Korea, and eastern China, was first reported in the San Joaquin Delta by Brittan, Albrecht, and Hopkirk

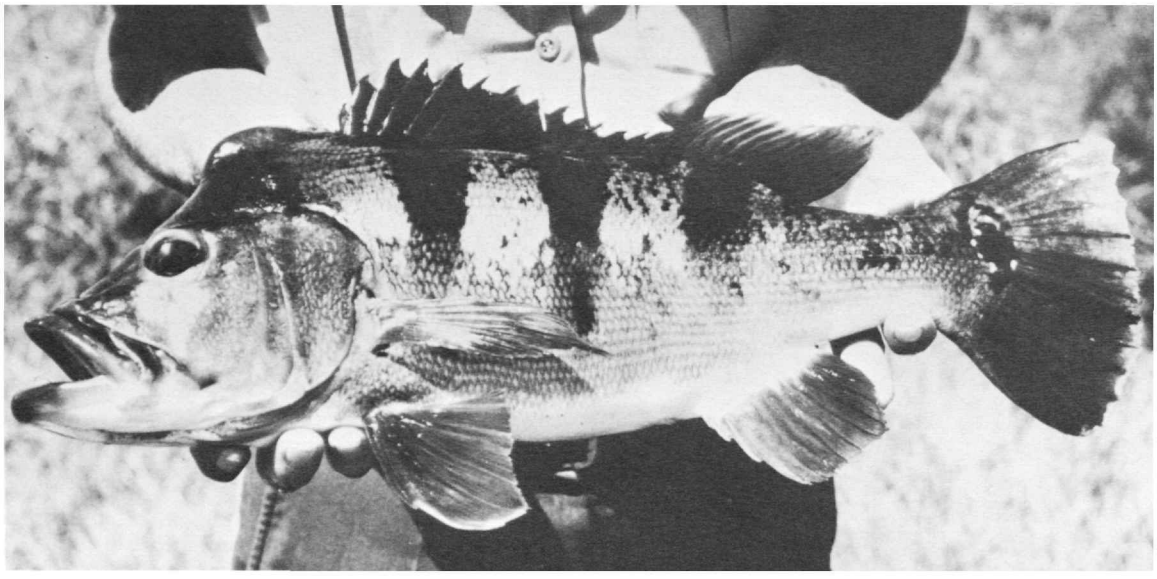

FIGURE 4.—The peacock cichlid, or tucanare, native to South America, attains large sizes. Many juveniles were released in waters of Dade County, Florida in 1964.

(1963). The trident goby, *Tridentiger trigonocephalus,* also from the coastal waters of China from about Hong Kong and the northern Philippines, northward to Japan, Korea, and the Amur River, is known to be established in the Stockton area (Earl S. Herald, Steinhart Aquarium, personal communication; M. R. Brittan, manuscript). Both of these species could be bilge-water transports from Asia.

Marine Fish Introductions

The ease and speed with which delicate, tropical freshwater fishes may be transported applies equally to the transport of marine species, and many colorful, tropical marine forms are appearing in aquarium stores. Although it is not now possible to appraise the extent of marine fish introductions, we can foresee the exchange and introductions of American Atlantic and Pacific faunas. Many marine fishes may not reproduce in the home aquaria, but many beautiful forms can be kept alive for extended periods of time. This is all that is necessary for a prelude to establishment in "new" waters, for releases can be made easily in coastal regions that provide adequate ecological conditions. Exotic marine fishes have already been introduced into the American fauna, either accidentally by bilge-water transport as the two species of Asiatic gobies in California, or by official, deliberate releases.

Some examples of marine fish introductions and the method of transport follow: The milkfish or awa, *Chanos chanos,* family Chanidae, is an Asiatic species established in the marine, inshore waters of Pacific Mexico. Smith (1896:403) reports the release of this species in California waters as early as 1876–1877 by the California Fish Commission. Springer (1963:453) reported on *Omobranchus dasson* (*japonicus*), a marine blenniid fish native to East Africa, Australia, and Japan, from Trinidad. He suspected the Trinidad record to be erroneous but since then the species has been collected by Miami biologists at Trinidad and in Venezuela. In 1969, Robins found this blenny to be the most common species around the docks north of Port of Spain. This species is apparently a bilge-water import. Strasburg (1956; 1966) reported the first Hawaiian record of another blenniid fish, *Omobranchus elongatus,* based on four specimens obtained from a concrete tank located on Coconut Island, Kaneohe Bay, Oahu. A fifth specimen was taken in Pearl Harbor in 1963 from an open reef, 18 miles from Coconut Island, and from this single specimen Strasburg assumed the species to be native of Hawaii. However, the original four tank specimens could have been imports, for in 1951 pieces of coralline rock with *Tridacna* clams and undoubtedly other organisms were removed from the Samoan Islands to the Oahu tank by the staff of the Pacific Oceanic Fishery Investigations, United States Fish and Wildlife Service, Honolulu. The natural distribution of *O. elongatus* includes East Africa, East Indies, and the Central Pacific. Wheeler (1958) demonstrated that the new genus and species described by Fraser-Brunner as *Parviclinus spinosus* from the Conway estuary, England, actually represented a small Caribbean clinid, *Stathmonotus stahli.* Since this species was not a British aquarium form, Wheeler theorized that its transport from its native western Atlantic habitat was either by a floating dock or hold of a dredger, or among the fouling organisms of a ship's hull. The Conway estuary is only 40 miles from the large seaport, Liverpool. A similar example of freshwater introduction, which misled a systematist, was the description by Fowler of a new serranid species, *Pikea sericea,* from Hong Kong, China, which was shown by Robins and Böhlke (1960) to represent the American largemouth bass, *Micropterus salmoides.* Boeseman (1954) recorded two specimens of a neotropical catfish found dead near Biezelinge, Zeeland, The Netherlands, of the genus *Sciadeichthys,* a group known to inhabit the salt and brackish shores and estuaries of northern South America. These specimens were described as a new species, *S. walrechti* Boeseman. Boeseman (1954) remarked that "the present specimens must have been transported by ship."

Aquatic Invertebrate Introductions

Many different groups of exotic aquatic invertebrate animals follow the same pathways of arrival to American waters as fishes, and probably they often arrive together. Various species have been imported for their food value, for aquarium uses, for public displays, as items of curiosity, and some have arrived accidentally as ship stowaways by several methods. Only a few salient examples are discussed to illustrate some of the modes of transport, common species released, and dangers involved. Large numbers of an alien crab were found in the Hillsborough River, Hillsborough County, Florida, in 1939 by Marchand (1946). These were saber crabs, *Platychirograpsus typicus* Rathbun, native

to Mexico. The type locality was the Macuspana River, Montecristo, Tabasco, Mexico (Rathbun, 1914:122). Marchand inspected the deck of a ship at Tampa, Florida, in 1940, that had just unloaded its cargo of logs, and several saber crabs and four frogs were found, and he was informed that a snake had been killed on deck before his arrival. This ship was loaded at Frontera, Puerta, Mexico, state of Tabasco. Marchand also learned that the Tampa Box Company, manufacturers of cedar cigar-box lumber, maintained a logging mill on the Hillsborough River. Large cedar logs were first imported from Mexico in 1915, where they were shipped from the Mexican port of Alvaro Obregon, state of Tabasco. The Mexicans floated the logs to the coast; so they were in water for sufficient periods of time to permit organisms to associate with them. Marchand found that the log mill employees were familiar with crabs, snakes, and turtles in the cracks of the logs. Thus, the saber crab made its debut into Floridian waters through lumber mill operations. Newman (1963) reported an edible oriental shrimp, *Palaemon macrodactylus,* in San Francisco Bay, and suggested its transport was through the salt water system of a ship. Kinzie (1968) recorded two species of stomatopod crustaceans, *Gonodactylus falcatus* and *G. hendersoni,* new to the Hawaiian fauna as entries from the Philippines-South China-East Indies area by transport of concrete barges towed to Pearl Harbor following World War II from combat areas in the South and West Pacific. These barges were towed at slow speeds of about three knots, and organisms lodged in fissures and holes in the hull would not become dislodged enroute. Kinzie (1968) discussed the extirpation of the common, native Hawaiian stomatopod, *Pseudosquilla ciliata,* by the two introduced species, particularly in the coral head habitat.

Katkansky, Dahlstrom, and Warner (1969) discuss survival and growth of the European flat oyster, *Ostrea edulis,* in California, a species known to harbor pathogens. They remark (page 72): "The origin of microcells in oysters is of considerable interest, for two reasons. First, if microcells were present in the oysters before importation to California, their introduction and apparent pathogenicity create an extreme danger to existing stocks of oysters and possibly other shell fish . . ." Official transplants of the western Atlantic lobster, oyster, and soft clam to American Pacific coastal waters were commenced nearly a century ago (Smith, 1896). Official oyster introductions in California were attributed to have included two destructive pests, the slipper shell, *Crepidula fornicata,* and the Eastern drill, *Urosalpinx cinereus* (McMillin and Bonnot, 1932). Enemies of the Olympia oyster, *Ostrea lurida,* such as the introduced Japanese oyster drill, *Tritonalia japonica* are discussed by Chapman and Banner (1949). The Japanese oyster drill was introduced into Puget Sound from Japan with the stocking of the Pacific oyster, *Ostrea gigas.* The spawning of the European oyster in the waters of Maine was reported by Loosanoff (1962).

The introduction, dispersal, and reproduction of the Asian clam, *Corbicula fluminea,* is an example of a single organism becoming an expensive permanent pest within the span of a few years. Ingram (1948:90) reported this clam in a number of localities of the Sacramento and San Joaquin River systems of California and from several localities in the Columbia River system, Washington. Widely distributed in its native Asia, it is found in Southeast China, Korea, and in the Ussuri Basin, southeastern U.S.S.R. *Corbicula* clams are marketed and eaten fresh or dried by Asians and they also provide food for domestic ducks and wild ducks. When they were released into the United States waters is not known. Perhaps certain West Coast ethnic groups imported live specimens for local culture, or perhaps they entered through the aquarium trade. Their extraordinary dispersal into most of the main river systems of the United States is reviewed by Ingram (1959), Ingram, Keup, and Henderson (1964) and other authors. From the West Coast this clam has invaded the Colorado, Tennessee, and Ohio River systems and elsewhere in the eastern United States to Florida. Because of its reproductive success and high infestation it has become a serious pest in various irrigation operations, invading in abundance the canals, ditches, pumps, and cooling systems. Near Tracy, California, these clams choked irrigation gates and valve chambers to the point where they were inoperable. Ingram, Keup, and Henderson (1964:122) discuss several possible methods of dispersal of *C. fluminea* in American waters. One is by transport on barges containing river gravel for use in the construction of locks, dams, docks, etc., in building and maintaining navigable waterways. Such gravel is often shipped several hundred miles and it provides sufficient moisture to maintain the clam for long periods of time. Gravel spillage en route could include clams. So many clams were included with gravel used for concrete in

the Tennessee River system that the concrete did not set properly and soon crumbled. Ingram, et al. (1964) also review the idea of clams hitchhiking a ride on water fowl, clamped tightly in resistance to desiccation, or that a clam swallowed by a duck could close itself enough to avoid digestion, pass through the digestive tract alive, and be deposited in another drainage system. More probable methods of dispersal included discard by tourists, by fishermen as bait, or by aquarium hobbyists.

A well-documented molluscan introduction is that of the large ampullariid snail, *Marisa cornuarietis,* into the drainage canal system of south Florida. This is, however, only one of many introductions of this snail outside of its native northern South American habitat. *Marisa* has been much touted as a biological control of the molluscan vector of schistosomiasis, *Biomphalaria glabrata,* in Puerto Rico and Cuba. *Marisa* entered the aquarium trade as the "Colombian ramshorn," but despite its handsome appearance, it has proved to be a destructive pest in aquariums. It is through its release by disenchanted aquarists that *Marisa* became part of the Florida biota (Hunt, 1958). The distribution and biology of *Marisa* in the greater Miami (Dade County) area was studied by Hale (1964) who found that although *Marisa's* poor tolerance of cold would limit its natural dispersal to Florida, *Marisa* was otherwise eminently suited to survive in South Florida. The damage *Marisa* can do in this area, particularly in the Everglades where it will presumably become established, is major since *Marisa* competes with another ampullariid, *Pomacea paludosa,* the food of the Everglade kite and the limpkin. It is not known whether *Marisa* can be substituted in the diet of these birds since *Marisa* is planorbiform and possibly more difficult to extract from its shell than the globose *Pomacea.*

Further introductions of *Marisa* into the United States as a control of aquatic weeds, particularly water hyacinth, are being contemplated and investigated by the United States Department of Agriculture, Aquatic Weed Laboratory, and the Biology Department of the University of Miami. Hale (1964) found that the two most rank weeds in South Florida, the introducted water hyacinth and *Elodea* species, were seldom eaten by *Marisa* because many kinds of other foods were available. Seaman and Porterfield (1961) determined that water hyacinths exposed to densities of *Marisa,* far greater than naturally occurring, were not eradicated, although the snails retarded the plants' growth through root pruning. If *Marisa* is possibly an innocuous introduction (in colder parts of the United States) it is probably also an ineffectual one in its role as an eradicator of aquatic weeds. In Florida it can only be viewed as potentially detrimental to two of our desirable bird species.

Another recent molluscan introduction contrasts the difficulty of eradicating aquatic introductions and the relative speed with which terrestrial exotics can be sometimes controlled. As with *Clarias,* the walking catfish, it also illustrates some peculiar quirks of human psychology.

Achatina fulica is a large snail, up to one foot long, used, if not valued, by the Japanese armed forces and established as food reserves by them throughout the Pacific during World War II. A vegetation-devouring hermaphrodite, it is a scourge in Hawaii. Two years ago a few were smuggled into North Miami by a tourist returning from Hawaii and were subsequently released. By fall of 1969, the restricted population had "boomed" and had become dense enough for the snails to be conspicuous and destructive not only to vegetation but to the stucco walls of houses (*Miami Herald,* 26, 27 September 1969). Fortunately the snail seems still to be confined to an area encompassing roughly 40 city blocks. A $30,000 program of spraying a calcium-baited arsenic poison has been started by the Florida State Agricultural Control. (Presumably, the same bait will be attractive to other snails, notably the native tree snails of the genus *Liguus.*) Due to its terrestrial nature and relatively slow dispersal *Achatina fulica* probably will be eliminated. In contrast, most aquatic and amphibian exotic species, because of their cryptic nature, rapid dispersal, and the still impossible task of selective killing, are with us permanently. Despite repeated requests from county and state officials via all news media, novelty-seekers are apparently removing snails from the area to keep (for how long?) as a curiosity. Thus, there is a distinct and increased threat that this snail will be reestablished in Dade County, conceivably in the multimillion-dollar farming area.

A potentially dangerous introduction is discussed by Abbott (1952) involving a melaniid snail, family Thiaridae, for it serves as an intermediate host of a human trematode. *Thiara (Tarebia) granifera,* an aquatic snail native to the warmer regions of southern Asia, the East Indies, and the larger islands of Oceania,

and an important intermediate host of the oriental lung fluke, *Paragonimus westermani,* was found established in Lithia Spring, Hillsborough County, Florida. This small snail prefers the shallow riffles of fast-flowing freshwater streams. Abbott reports that it exists in Lithia Spring in "extraordinary numbers, sometimes as many as 400 specimens per square foot." He traced its entry into the United States via California and East Coast aquarium dealers. Its release at Lithia Spring could have occurred when a Tampa fish dealer gathered aquatic plants using tubs that were not properly washed free of the snails. *Thiara granifera* serves as an intermediate host of numerous trematodes, three of which are known, in their adult stages, to parasitize man (Abbott:1952:108). A second intermediate host, such as a freshwater crayfish or crab, is a necessary part of the life cycle of the fluke, and there is only a potential menace of human infection, for these crustaceans must be eaten raw if the fluke is to infest man. Abbott (1952:113) lists two other species of thiarid snails that have been raised by aquarists and that may be confused with *T. granifera—Hemisinus cubanianus* from Cuba and *Pachychilus glaphyrus* from Central America. The magnitude of introductions is further realized by Abbott's statement (1952, page 12 and Abbott, 1950) that "In the past hundred years approximately 50 species of exotic species of land and fresh-water mollusks have established themselves in the United States and Canada." Thousands of living European land snails, *Otala lactea* and *Cepaea hortensis,* were reported to have been sold in Ohio as catfish bait (Ingram, 1952). He surmised that these species came from Italy through the port of New York for the New York Italian market and that the fish bait enterprise was a more lucrative subsequent development.

The presence of the blood fluke, *Schistosoma mansoni,* in Puerto Rico and other parts of tropical America, should alert Public Health officials in regard to its potential introduction into North American waters through its intermediate host, *Biomphalaria* (*Australorbis*) (Erdman, 1967).

Many other kinds of animals have been widely distributed through man's activities. The vacationist will often pick up plants and animals along the highway, but tire of them before arriving home, and discard them. Many species of turtles have been introduced into new North American areas in such a manner. Aquatic turtles are common items in the aquarist's trade and these are often discarded into open waters as with aquarian fish. The giant, predaceous fish eater, the eastern alligator snapping turtle, *Macrocheleys temmincki,* was recently reported in Californian inland waters (Murphey, 1969), probably resulting from an aquarist's release.

Aquatic Plant Introductions

Exotic aquatic plants have had a long history of introductions into North American freshwaters. Many species have been introduced by dealers for they are sought by the aquarist and private pond culturists for their beauty and interest value. Different examples of some of the common exotic species now growing wild in the United States and Canada are reviewed below. Among those treated by Hotchkiss (1967) are:

Flowering rush—*Butomus umbellatus:* a European rush found along tidal St. Lawrence River about 1900; known in freshwaters from Michigan to Quebec, Idaho, Illinois, and Vermont.

Eurasian watermilfoil—*Myriophyllum specatum:* known in the United States for about 70 years; inhabits fresh inland waters and fresh-to-brackish coastal waters; found in California, Wisconsin to Vermont, Texas, and Florida.

Parrotfeather—*Myriophyllum brasiliense:* native to South America; a common aquarium plant growing wild in freshwater over most of the United States.

Andean watermilfoil—*Myriophyllum elatinoides:* native of South America; abundant in the Deschutes River, Oregon.

Limnophilas—*Limnophila indica* and *L. sessiliflora:* from southeastern Asia; grown as aquarium plants in North America and they grow wild from Texas to Florida.

Water starwort—*Callitriche stagnalis:* a native of Europe; wild from British Columbia to Oregon, and Wisconsin to Quebec and Maryland.

Naiad—*Najas graminea:* an Old World native; wild in California ricefields.

Naiad—*Najas minor:* Eurasian origin; grows from Illinois to Vermont, Alabama, and Florida; common in tidal Hudson River and in artificial lakes.

South American Elodea—*Elodea densa:* a common aquarium plant; widespread over the United States, in fresh waters and sometimes coastal waters.

Curly pondweed—*Potamogeton crispus:* native to Old World; known in North America for at least 150 years; ranges from Alberta to Quebec, California, and Florida; inhabits fresh inland waters and fresh to somewhat brackish coastal waters.

Salvinia—*Salvinia rotundifolia:* native to tropical America; abundant in freshwaters of Georgia and Florida.

Ottelia—*Ottelia alismoides:* introduced from southeast Asia or Australia; wild and abundant in southwestern Louisiana.

European frogbit—*Hydrocharis morsus-ranae:* escaped from cultivation at Ottawa, Ontario; since 1932 it has spread several miles down the Ottawa River and is near Montreal, Quebec.

Yellow floatingheart—*Nymphoides peltatum:* a European import; abundant locally, in Washington, New York, New Jersey, Missouri, Oklahoma, and Arkansas; inhabits freshwater and, rarely, coastal areas.

Ivyleaf buttercup—*Ranunculus hederaceus:* native of Europe; established locally from Newfoundland to South Carolina.

Waterchestnut—*Trapa natans:* native of Eurasia; a great pest since about 1930 in fresh and some coastal waters from Massachusetts to Virginia; abundant growth crowds recreational areas and replaces valuable duck-food plants.

Duckweed—*Spirodela oligorhiza:* native to southeast Asia and Australia; known wild since 1930 in California, and from Missouri to Maryland, Louisiana, and Florida.

Water hyacinth—*Eichornia crassipes:* an emergent aquatic, native to South and Central America; abundant in Florida for many years; found wild from Missouri to Virginia, Texas, Florida, and California.

Alligatorweed—*Alternanthera philoxeroides:* an emergent tropical plant, sometimes forming floating mats over extensive areas and crowding out more desirable species; found in fresh tidal marshes in southeast United States and locally in the Tennessee Valley.

The Florida Travesty

Nowhere in North America have people been more neglectful than in tropical Florida in regard to releases in natural waters. Only Hawaii exceeds Florida in numbers of introduced exotic animals. King (1968: 103) listed fifty-seven species of exotic vertebrates introduced into the Floridian fauna. The introduced reptiles lead the list of vertebrates, numbering seventeen species. One of these is the well-known South American caiman, *Caiman crocodilus.* There are 15 species of mammals, including the nutria, *Myocastor coypus,* an aquatic rodent; twelve species of birds; and three introduced amphibians (including the giant toad, *Bufo marinus,* from Central and South America). At least ten species of fishes are recognized as successful releases; of these the cichlids exceed all others in numbers of species, and collectively they may rank with the walking catfish and carp as the most harmful and undesirable introductions into the American fauna.

The distressing fact concerning the walking catfish and the cichlid fishes is that both are relatively recent introductions. This lack of respect for the natural environment is indicative that the existing laws and regulations are either inadequate or insufficiently enforced, or both, or that there is disregard of the inherent dangers arising from introductions. Another important factor concerning the Floridian introductions is their potential spread northward into the warm waters of the southern United States. Although the Hawaiian aquatic fauna has had many more introductions than Florida, these may not prove as harmful, and also, may be controlled or contained, because of the insular geography of the state. The exotic invertebrate introductions into the Floridian fauna, including insects, crustacea, mollusks, and other forms, exceed the introduced vertebrates.

Florida's mild climate is so much appreciated by man that we should not be surprised when animals that escape captivity or are otherwise introduced into the fauna, should not only survive, but, in a discouraging and increasing number of instances, succeed in establishing a breeding population. Florida's climate, topography, and drainage systems combine to make the problem of animal releases especially serious, notably with regard to aquatic resources. First, there is no longer any real division of stream systems in the state. The many canals that were first dug for drainage (for flood and mosquito control) and then for irrigation, and the recent and essential development of back pumping systems for water conservation, have resulted in connected water systems that permit access of any introduced freshwater animal to most of the drainages in the state. Secondly, the abundance of springs and

seeps is sufficient to provide many havens for introduced species with essentially stable water temperatures on a year-round basis. The availability of such refuges permits survival of tropical species during abnormally cold winters when most other waters cool to temperatures below the supposed tolerance limits of some of the released species. Thirdly, because of the warm climate and in recognition of the abilities of tropical fishes to live in Florida, a large number of aquarium fish importers and suppliers are located in south Florida. It is estimated that about 70–75 percent of the imports of tropical fishes to the United States arrive at Miami and Tampa. Importers and suppliers of other tropical animals, including birds, mammals, reptiles, and amphibians, similarly find south Florida to be an ideal site for their commercial activities. Florida thus has three essential factors for establishment of exotic animals: (1) A large and steady source of exotic animals is maintained in the state on a year-round basis. (2) Suitable environment is prevalent for their survival. (3) Easy dispersal routes are present.

Although many biologists have been concerned about introductions, programs aimed to study the spread and impact of exotic species already established, as in Florida have not been forthcoming. There is no monitoring of the water systems to detect newly introduced species. Programs to investigate the importation, release, survival, behavior, competition, and dispersal of introduced aquatic animals should be commenced on a broad basis in cooperative studies involving the universities of the State of Florida, and state and federal organizations. Some of these now bear responsibility for introducing animals that survive in the state's waters.

Introduced species are no respectors of political boundaries. The chachalaca, *Ortalis vetula,* a gallinaceous bird from Central America was introduced into coastal islands of Georgia, and apparently is established. It could spread southward through lowland xeric regions to the Florida Keys. The red-whiskered bulbul, *Pycnonotus jocosus,* a tropical oriental bird whose flocks may be seen in southern Miami, could spread as far north as Virginia. Although game and fish releases are managed by the states, it is our view that exotic introductions as well as transplants into interstate water systems should be recognized as a federal problem and covered by federal statute. Many of the Floridian exotic introductions have been accidental, but a number of releases have been planned and deliberate. Such official introductions were made without serious consideration and study of the real benefits to be derived and without any understanding of the possible detrimental effects of these releases. In some instances the specific identity of the stocks is uncertain. The coho salmon, recently introduced into the Great Lakes, is the type of release where there was much to gain and little to lose. A large niche in the lake ecosystem was unoccupied, and the coho salmon filled this vacuum and occupied a food chain without much competition to alternate species. None of the animals introduced into Florida nor any of those contemplated for introduction, as certain cichlids, is similar to the coho example.

The walking catfish is of little value as a sport or food fish in America, certainly less than the native food and game fishes with which it will compete. The oscar, well-established in Dade County, having weathered our coldest and driest weather on record, similarly, does not compare well with the native bass or sunfish. Efforts have been made to popularize this introduction with anglers, but the oscar can only provide competition for the more desirable native species. The pike killifish, also abundant in Dade County, is of no benefit and is a serious and capable predator on small fishes. In some canals, when periods of drought confine the waters to the dredged portions, this fish has eliminated such abundant species as the mosquitofish, *Gambusia affinis,* as well as other young fishes. The pike killifish may present a problem to the natural control of mosquitos.

Various species of *Tilapia* have been introduced deliberately in several southern states. This speciose genus is not fully understood—not only in regard to the identification of species but also in regard to its ecological requirements and life histories. New species are still being described in this group. Some of the species show considerable tolerance toward saline waters and can disperse through coastal marine waters of near normal salinity, as well as through freshwaters. Obeservations of *Tilapia* occupying typical inshore marine habitats have been observed by a number of workers. At least eight species of *Tilapia* are already involved in the Floridian fauna. These were reviewed above in the discusion of the family Cichlidae. The blackchin mouthbrooder, *T. melanotheron,* has already survived temperatures in Florida much lower than 20 C that was supposedly its lower limit of resistance. Vaas and Hofstede (1952) showed that *T. mossambica*

reproduces equally well in fresh and brackish water up to 30 ppt salinity, and that it survives in 40 ppt. Zaneveld (1959) was able to get this species to reproduce in waters of 36.2 ppt.

Fishes introduced in rivers and ponds in Alabama and Georgia could easily become a major Florida headache as well as disperse farther westward. The grass carp, *Ctenopharyngodon idella,* is an example of a species now introduced in Alabama that could spread to Florida. The *Tilapia* problem may be one of the worst fish cultural blunders in the United States since the introduction of the carp. Neither the economy of Florida nor the excellent warm water native sport fishes already present justify introduction of such soft-fleshed species and highly capable competitors. The peacock bass was released into restricted ponds by the Florida Fresh Water Fish and Game Commission on the basis that it is a superior sport and food fish. Ichthyologists, who have seen this fish in South America, view it as a serious competitor to the largemouth bass in Florida, as well as a poor fighting fish for the angler. Efforts were attempted to stop release of the peacock bass in Florida. The state program was conducted without regard to the unresolved biological problems concerning the peacock bass and other species from South America.

Hawaiian Introductions

Continental Americans generally associate Hawaii with Pacific marine waters and do not realize that the six major islands of that state contain a relative abundance of fresh water streams, particularly on the windward slopes, as well as numerous reservoirs and irrigation canals. Prior to introductions, Hawaiian fresh waters contained only a few native gobies, several prawns, and fewer euryhaline forms.

Although Hawaii may lead in the number of introduced species, the freshwater forms are contained by insular geographic location. Many, if not most of these introductions involve continental sport fishes, and these have been generally beneficial since they provide a new resource without major danger to native forms.

Brock (1952) presents a history of the introduction of aquatic animals in Hawaii. He lists 28 species as established, including the giant clam, *Tridacna* (new evidence indicates this species no longer exists in Hawaii, personal communication, John B. Shoup, University of Miami); the Samoan crab, *Scylla serrata;* rainbow trout; carp; goldfish; oriental weatherfish; sailfin molly, *Poecilia latipinna;* largemouth bass; bluegill; and the snakehead, *Ophiocephalus striatus.* About half of the total number of introduced species have no economic value, but some of these may be of interest as aquarium forms.

Morita (1965) provides a more recent treatment of freshwater fish introductions implemented by the Hawaii Division of Fish and Game. Two salmonid introductions, including brown and brook trout failed. Those that survived and are presently established include rainbow trout (spawning in restricted areas; supplemented by stocking with eggs from the mainland) largemouth and smallmouth bass; bluegill; and four nominal species of *Tilapia.* Most recent are the channel catfish, the oscar, and the tucunare or peacock bass. These last two species are protected. *Tilapia,* carp, the snakehead, Chinese catfish (cited as *Clarias fuscus*), and the native freshwater gobies are listed as nongame species. A recent Job Completion Report, Research Projects Segment of the State of Hawaii for 1 January to 31 December 1968, lists the release of 2000 fingerling grass carp, *Ctenopharyngodon idella,* that were imported from Taiwan and stocked in the Waiakea Public Fishing Area for weed control evaluation. Other Job Completion Reports for the same period record restockings of two nominal species of *Tilapia,* oscar, channel catfish, Chinese catfish, and a large freshwater shrimp, *Macrobrachium lar.* Brock (personal communication) reports successful establishment of the tucunare in irrigation reservoirs where it has become a favored sport fish, and that another recently introduced freshwater shrimp, *Macrobrachium rosenbergi,* is now established.

Brock (personal communication) also cites several marine introductions. He points out that the Hawaiian islands have, essentially, a partial western Pacific marine fauna and flora and that beneficial marine introductions can be made from this western Pacific source. He and John E. Randall are responsible for the successful introduction of two species of snappers, *Lutjanus vaigiensis* and *L. kasmira,* and one grouper species, *Cephalopholis argus,* all from Moorea, Society Islands.

While Hawaii stands to gain new sport fishing and commercial resources from some of these introductions and hopes to obtain solutions to specific internal problems, as in the case of the grass carp introduction, the geographic location and unique freshwater situ-

ations of that state can tolerate this variety of management and experimentation. The fresh waters of continental North America, however, cannot afford such environmental manipulation, primarily because the ecosystems are vastly different. The results of Hawaiian introductions, therefore, must not be interpreted as unquestionably positive data for continental application; these results, in fact, apply specifically and exclusively to Hawaii.

International Exchanges

Introductions of exotic species and transplants of native species into new drainages have occurred for many years on a broad basis over the world. Myers (1947) cautions against the indiscriminate use of North American species in foreign countries. He pointed out the dangers of the carp ponds in Brazil (the carp is now established in Brazilian natural waters) as well as the exportation of fishes from American waters, labeled for example, bluegills, where actually several species of sunfishes were involved. Myers (1955) discusses the freshwater fish fauna of Central America in reference to the pond culture of *Tilapia mossambica*. He points out, as others have, that *T. mossambica* is extremely aggressive and that in Mexican waters it could become widely dispersed into new water systems in a short period of time. De Buen (1959) lists a number of exotic fish species in the waters of Chile, such as: carp, *Cyprinus carpio;* goldfish, *Carassius auratus;* tench, *Tinca tinca;* black bullhead, *Ictalurus melas;* mosquitofish, *Gambusia affinis;* rainbow trout, *Salmo gairdneri;* brook trout, *Salvelinus fontinalis;* and others. Gines, Marcuzzi, and Martin (1952) discusss the ecological conditions surrounding the introduction of the rainbow trout and the brook trout in Venezuelan waters. Thompson (1940) discusses ten species of exotic fishes introduced into the Argentine Andes, from about 1904 to 1931 and includes four species of trout, four species of North American salmon, the lake whitefish, *Coregonus clupeaformis,* and the Atlantic cod, *Gadus morhua*. Of this number, four became established, the brook trout, *Salvelinus fontinalis,* rainbow trout, *Salmo gairdneri,* brown trout, and Atlantic salmon, *Salmo salar*. Jones and Saronjini (1952) discuss the introductions of exotic fishes into Indian waters and a history of transplantations. Four general groups of fishes are involved: game fishes; food fishes; larvicidal fishes; and ornamental fishes. Exotic fishes introduced into Indian waters include: the gourami, *Osphronemus goramy,* native of Indonesia and introduced in India in the early half of the 1800s; the tench, imported from England about 1870 with the golden carp or crucian carp, *Carassius carassius,* both native of Europe; and the common carp, *Cyprinus carpio,* originally native to China, and first introduced into Ceylonese waters at about 1914. Exotic introduced game fishes include the rainbow trout and brown trout. The exotic larvicidal Indian introductions for antimalarial work include the poecilids, the mosquitofish, *Gambusia affinis,* from North America and the guppy, *Poecilia reticulata,* from South America. Many ornamental fishes have arrived in India through centuries of contact with Southeast Asia. Examples from Southern Asia and other countries include the goldfish from China, the angelfish, *Pterophyllum,* and tetras from South America, the fighting fish from Thailand, the jewel fish from Africa, the paradise fish from China, swordtails and platys from Mexico, and several barbs from southern Asia. A survey of the introductions and transplantation of fishes in the Indo-Pacific region is given by Schuster (1952). Planned transplantations of fishes between different areas of the region include 18 species. Krumholz (1948) lists fifty-nine different countries in which the mosquitofish has been released. Arnoult (1952) gives several exotic introductions for Madagascar, the earliest one being a gourami, an anabantid fish from Indo-Malaysia, introduced as early as 1857. The American cyprinodont fish, *Jordanella floridae,* was reported in Borneo by Myers (1940). Maitland and Price (1969) cite a North American monogenetic trematode new to the British Isles that probably entered Britain with the largemouth bass, *Micropterus salmoides*. A review of the American crawfishes introduced into foreign lands is given by Penn (1954), and Thompson (1952) discusses the acclimatization of the American Pacific oyster in Australian waters. Dementiev (1960) reviews the introduction and transplantation of fishes in the U.S.S.R. relevant to a discussion of the protection of the fauna. In recent FAO Fish Culture Bulletins (volume 1, number 1, 1968 and volume 1, number 2, 1969) introductions and transplantations are given for various countries of the world in which species, such as the grass carp, various *Tilapia,* and salmonid fishes are being widely used for experimental culture and breeding purposes. Erdman (1967) lists nineteen species of fishes introduced into Puerto Rico, most of which were from North America.

North American Fish Transplantations

The problems related to exotic introductions into the American aquatic environment are often similar to those involved in transplanting native forms into new drainage systems. The inherent results may be the same. We know considerably more about the biology of our native freshwater fish fauna than any foreign one. Nevertheless, we have stocked or caused the release of fishes in some of our river systems or ecological areas to the point of no return, with the result that we can never completely realize the nature of our original fauna. Intensive and widespread stocking has created competition leading to or hastening extirpation of many of our indigenous species.

Elton (1958) reviewed the destruction caused in land and water habitats through the introductions of plants and animals in his "ecology of invasions." The Welland Canal, constructed in 1829 as a bypass from the St. Lawrence River into Lake Erie and opening the Great Lakes seaways for midwest grain shipments, also opened the waterways for the sea lamprey, *Petromyzon marinus,* for dispersal and population of the lakes and subsequent damage to the fisheries in a time span of about 100 years.

Many states followed the United States Fish Commission, organized in 1872, in its early practice of wide-scale stocking programs, with little or no apprehension of the ensuing results. Only a professional ichthyologist may recognize all of the introduced species in parts of backyard America. The State of Connecticut has 29 native species of freshwater fishes and 24 stocked species (Whitworth, Berrien, and Keller, 1968:120). Of 87 fish species listed for Colorado by Beckman (1952), 33 were introduced or transplanted. Shapovalov, Dill, and Cordone (1959) list 67 freshwater fish species for California, of which 32 were introduced. Miller (1961) points out that there are more introduced fishes in Arizona than "natives," and his discussion of the changing fish fauna of the American southwest gives the following numbers of native versus introduced forms for several southwestern states based on his field data and other published accounts: New Mexico, 61 native, 22 introduced; Arizona, 28 native, 37 introduced; Utah, 26 native, 24 introduced; and Nevada, 41 versus 21. Miller (1961) links the period of intensive introductions, between 1930 and 1950, with the construction of major dams and water diversions and marked increase in human population. Most of the 36 alien species in the southwestern states came from eastern United States in "large part as intentional plants of game fishes." Only eight introduced species were known as established in the area before 1930.

Miller (1961) further comments that "many of the established aliens have affected the native species either directly—through predation, competition, and hybridization—or indirectly by altering the habitat (as carps have done)." The Mohave chub, *Gila mohavensis,* is endangered because it has been reduced in numbers by hybridization and competition with an introduced minnow, *G. orcutti.* The Little Colorado spinedace, *Lepidomeda vittata,* faces extinction because of competition from introductions and by environmental modifications. Most countries are weak in protecting, by law, their rare and vanishing fishes (Myers, 1953). Many of our indigenous western trout were extirpated, or otherwise lost their identity forever through endless transplantation of new stocks, interbreeding in hatcheries or in nature, introduction of competitive species, and through environmental modification (Miller, 1950; Myers, 1953). At least 33 nominal species of trouts were described (Miller, 1950) mostly from only one or a few specimens, and the biology and ecology of many remain unknown. Among those forced to extinction were the emerald trout of Pyramid Lake, Nevada, *Salmo smaragdus,* and the royal silver trout, *Salmo regalis,* of the deep waters of Lake Tahoe, California and Nevada. Many subspecies and headwater races are today trout genomes resulting from frequent introductions of other native stocks into natural populations where extensive intraspecific interbreeding has occurred.

There is little documentation of North American marine fish transplantations. The alarm expressed by many biologists over the dangers of continued intermixing of natural populations of animal and plant life, however, is based on an enormous amount of data. That many individuals complacently refuse to recognize the destruction, as well as the benefits, resulting from introductions is even more alarming. Briggs (1969) and others have reviewed the biological effects related to the completion of a sea-level canal in Central America. It is not possible to estimate today what effect a sea-level canal will have on the marine biota of both oceans for we know very little about the biology of almost all of the marine inhabitants of the area. Because these areas repeatedly have been connected through natural portals as recently as a few million years ago scientists disagree on the faunal effects of opening a sea-level

canal. Based on the history of introductions elsewhere, it is not presumptuous to predict that considerable faunistic changes will occur. Because drifting and swimming organisms tolerant to both fresh and salt water, and those clinging to the hulls of ships or in ballast tanks, can make their way through the existing canal is little reason to assume that there is unnecessary alarm over a sea-level canal (Sheffey, 1969). Unless some barrier (thermal, electrical, freshwater, chemical, etc.) is included in the plans of the new canal, many different kinds of organisms with many different capabilities will utilize the open passageway. Again there is disagreement concerning the numbers that will successfully establish populations on the opposite side. The present Panama Canal with its fresh-water barrier and the Suez Canal with a high salinity barrier only permitted passage of certain types of animals, and in relatively limited numbers. It took 100 years for the Mediterranean to acquire 26 known species (Ben-Tuvia, 1966, and manuscripts of B. B. Collette, and A. Ben-Tuvia and A. Lourie) of fishes from the rich Red Sea fauna, and none is known to have made the reverse route. The relatively depauperate Mediterranean fauna may have unoccupied ecological niches available today for the Red Sea migrants. Ben-Tuvia (1966) reported that the Red Sea species constitute 9 percent of Israel's Mediterranean coastal fish fauna and "their ecological importance is fairly great since 18 species are among the more common in this area, and nine are commercially exploited." Each canal (Welland, Suez, and Panama) is in areas where the faunas differ qualitatively and quantitatively, and where the ecological associations were also quite different opposite the canal sites. It is unfortunate that we still lack basic, detailed studies on what organisms may be moving through the current Panama Canal. Certainly all biologists agree that extensive studies of the marine faunas of both coasts of tropical America are long overdue.

Discussion and Recommendations

In our review of North America introductions several facts are apparent that are useful in drafting recommendations that will curb the release of exotic organisms into our waters and, hopefully, permit the development of an overall program useful in preventing many other aquatic releases. Most introduced species of fishes have occurred through the importation and sale of tropical pond and aquarium fishes. Many of the fish releases are caused by American citizens, who carelessly dispose of their live fish in water systems near their homes. Other tropical fish are accidentally and carelessly released by importers, dealers, and culturists who do not maintain escape-proof ponds or otherwise do not isolate their culture and maintenance activities. Other releases, including some which may result in great ecological damage, have been through official activities of the federal and state governments in their quests for food, game, or forage species. The biology and identification of many of the exotic fishes imported into North America that are used for commercial and sport fishing purposes, or for the aquarium hobbyist, are not properly understood. Most official releases while satisfying certain political wishes have not served effective biological purposes. The release of exotic fishes by fish culturists has in all cases been made without regard to the existing natural ecosystem. Stocking has been carried out independently by state officials without regard to the open waters in which the fishes are placed and their free passage to many other states. Very little attention has been given to the disease and public health problems associated with the importation and release of exotic organisms. Dangerous fishes such as the piranhas and the *Vandellia*-like catfishes are released by individuals with complete ignorance of the hazards involved. Official releases have been made of species, such as those of *Tilapia,* with complete disregard of their competitive ability and aggressiveness.

The competitive ability of many introduced exotic terrestrial vertebrates is well known and publicized. Many exotic terrestrial releases have caused extinction of large numbers of native forms. The extinction of about 100 species of birds in which exotic introductions played an important role, particularly in insular areas, is treated by Greenway (1958) and Ziswiler (1967). Our endemic fish fauna, particularly in southwestern United States, is in many ways restricted to a confined habitat, much like insular endemic species. Many of these endemics could easily become extinct through exotic introductions, or continued transplants of more aggressive native species, as has been done in the past. We reiterate Miller's (1964) statement that "the deterioration of the native fish faunas can also be plausibly attributed to the construction of dams, water diversions, pollution, mining operations, use of toxic chemicals, depletion of ground water, and the introduction of alien species."

The dangers to our native flora and fauna can arise from many direct and indirect sources. Most of our

popular editorial articles such as the discussion in *Life* by Jackson (1969) on "Threatened America" are insufficient to cover details of our threatened native species. Man's encroachment directly on large natural habitats, such as the Pine Barrens of New Jersey, may lead to its destruction. In a similar manner the introduction of a few (or even one) aggressive exotic aquatic organisms may alter the entire ecosystem.

The administration of the "Lacey Act of May 25, 1900," has proved inadequate in controlling the hazards resulting from the importation and use of live, exotic aquatic life. The release of organisms is not treated in this Act. Current national activities, such as studies on environmental quality, or those concerned in "The Wilderness Act," may be effective in maintaining some semblance of the natural environment, but the problems of the release of organisms into the very lands and waters preserved by official action are unsolved.

The Bureau of Land Management, the United States Department of the Interior, reviewed the advisability of introducing exotic big game species on public lands and drafted guidelines in 1966 to be followed in considering such proposed releases. These guidelines, presented by Craighead and Dasmann (1966), and approved by the Secretary of the Interior as public land policy, are presented here because of their applicability to the control of releases in the aquatic environment: (1) It should be objectively determined that there is a real need for a proposed introduction, and it should appear likely that the introduction will have desirable ecological, recreational, and economic impacts. (2) The introduction should fill a definite vacant ecologic niche, one not filled or suitable for a native species. The probable existence of such a niche should be reasonably well documented. (3) An introduction should not be considered if there is any danger, even apprehension, over the action leading to drastic reduction or regional displacement of indigenous populations. Pending future study, the introduction of exotic big game species on federal lands should be governed by the necessity for protecting the native biota and for preventing conflict with other existing or proposed land uses. (4) Studies of the ecology of the animal considered for release should precede and guide introductions. Studies should, likewise, be made to determine the suitability of the proposed release area. (5) Every effort should be made to study disease interrelationships and to take steps for assuring effective quarantine resulting in disease-free game. (6) Precautions against hybridization should be taken by selecting animals that do not have close relatives in this country and rejecting those that do. (7) Small trial introductions in suitable areas using adequate numbers of stock should first be conducted on an experimental basis under controlled conditions such as in a fenced area (or for fishes, escape-proof, and storm-proof ponds, etc.). The results should be carefully studied using the latest and best research methods. An evaluation of this introduction should serve as a basis for further action. (8) Before an exotic is introduced, positive assurance should be obtained that adequate control methods can be instigated to prevent overpopulation or spreading. Further recommendations were that all exotics from national parks, wilderness areas, wildlife preserves, etc., be excluded and that individuals or organizations be held liable for damages caused by releases that become pests.

The resolutions and recommendations of the Washington Conference published in the *Sport Fishing Institute Bulletin* (Stroud, 1969a:3–4) are repeated below (with brief additions) in order that these guidelines may be reviewed with greater perspective because of the data presented in this paper on the kinds of exotic aquatic introductions, and their source, release. behavior, and establishment.

Resolutions:

1. Open water release of exotic fishes.

Whereas, there is a possibility that benefits may result from well-planned introductions, there is, however, continuing possibility of intentional releases of undesirable exotic fish species in North American waters, resulting from indiscriminate importations and related ill-informed actions because of insufficient taxonomic and ecologic evaluations, and the consequences of such releases to the fishery resources of North America may well prove disastrous;

Be it herewith resolved, that the Conferees on Exotic Fishes and Related Problems, meeting this 19th day of February, 1969, in Washington, D.C., and representing the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, as well as a broad spectrum of user and governmental interests, do strongly recommend that each state, province, or federal agency, or academic, scientific, commercial groups, and individuals, should voluntarily submit to a Joint Committee on Introduction of Exotic Fishes and Other Aquatic Organisms, all proposals to in-

troduce into open waters any exotic species for prior evaluation and recommendation before consummating such introductions;

Be it further resolved, that the said Joint Committee shall, with their concurrence, be advisory to the International Association of Game, Fish and Conservation Commissioners and shall include membership representation from the United States, Canada, and Mexico, the Chairman of the Names of Fishes Committee of both the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, and, in addition, include broad representation of the various concerned disciplines, government agencies, user interests, etc., such as are reflected in the present conference, as shall be jointly appointed by the two societies sponsoring this conference;

Be it further resolved, that said Committee shall, as first order of business, compile and cause to be publicized, a list of exotic species of fishes and other aquatic organisms considered to be undesirable for import into North America other than for scientific and educational purposes. (The American Fisheries Society, May-June Newsletter, 1969, vol. 13, no. 61 carried the report from President Elwood A. Seaman announcing Dr. James E. Deacon, University of Nevada, Las Vegas, as the Chairman of the Exotic Fishes Committee.)

2. Delayed release of grass carp.

Whereas grass carp are now present in several hatcheries, fish farms, and experimental facilities in the United States, and there is considerable doubt as to the desirability of releasing this species into the waters of North America;

Be it resolved, that the Conference on Exotic Fishes and Related Problems meeting this 19th day of February, 1969, in Washington, D.C., and representing the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, as well as a broad spectrum of users and governmental interests, do recommend that no further releases of grass carp be made into the open waters of North America until the proposed Joint Committee on Introduction of Exotic Fishes and Other Aquatic Organisms has an opportunity to study the matter;

Be it further resolved, that the conferees recommend that all agencies do not release grass carp in the interim.

3. Effect in country of origin.

Whereas, in excess of 64 million fishes were imported into North America in 1968;

Be it resolved, that the conferees express their concern over the possible impact of the removal of these organisms on the biota of the countries of their origin, which was brought most forcibly to attention with particular regard to Latin American countries.

Recommendations:

1. The conferees recognized widespread concern about the effects on natural ecosystems of the rather widespread practice, past and present, of transplanting species native to North America. In some situations such transplants may have effects comparable to those resulting from the introduction of exotic species.

The conferees urged that all agencies treat such transplants as matters for serious study, for careful planning and, where adjacent jurisdictions are involved, as matters for consultation with those agencies. In cases of transplants where exotic species are involved, the conferees further urge consultation with the proposed Joint Committee on Introduction of Exotic Fishes and Other Aquatic Organisms.

2. The conferees recommend that no living fishes or other aquatic organisms be imported except under a Federal license or permit to the importer and that a suitable license or permit be issued by the appropriate government agency to each importer. The specific purpose is to establish his responsibility for the protection of the native fauna of the recipient country. It is recommended that irresponsible activities, as determined by the government agency, shall result in the suspension or revocation of said license or permit. The conferees further recommend that each State or Province consider the development, continuation, and/or enforcement of similar regulations.

3. The conferees recommend that, after consultation with the proposed Joint Committee on Introduction of Exotic Fishes and Other Aquatic Organisms, the appropriate federal governments limit the number of approved Ports of Entry in order to help control the introduction of exotic species in North America. (There were 279 Ports of Entry in 1968.)

4. The conferees strongly recommend that the appropriate government agencies augment their current inspection and enforcement service with a competent identification service in order to accurately determine the composition of the importations of exotic species of fishes and other aquatic organisms and thereby assist

the aquarium and bait fish importers to comply with State, Provincial, and Federal regulations.

5. The conferees recommend that agencies and individuals maintaining fishes and other aquatic organisms initiate and maintain adequate safeguards against accidental release of nonindigenous organisms.

6. The conferees recommend that the government agencies and professional organizations work with the importers of exotic fishes and fish farmers in developing literature to point out and publicize the dangers inherent in unauthorized releases of exotic fishes and other aquatic organisms, and that this industry assist in the dissemination of this information to their customers.

Recommendations are of little value if they receive no intelligent and timely implementation. The "Joint Committee on Introduction . . . " should be cognizant of the various recommendations in forming guidelines useful to the respective governmental agencies in enacting and enforcing reasonable and effective measures that will assist in curbing the senseless tide of North American animal and plant invasions. There is a great task before the official agencies responsible for control of traffic involving the importation of living organisms. There may be no fool-proof set of regulations that will prevent release and establishment of alien species. But we can try to curb the flow of traffic in a manner agreeable to all involved individuals. The recent prohibiting of entry of the catfish family Clariidae (*Federal Register,* volume 34, number 158, 19 August 1969) other than by permit is a useful regulation, and if it had been enacted a few years earlier, it might have prevented the establishment of the destructive walking catfish in Florida. Entry of other undesirable aliens may not be dealt with so easily. If we did "blacklist" several of the harmful characins and cichlids from importation by law, identification must be planned at several hundred possible ports of entry. The problems of control are immense, and it may require extensive, educational programs similar to those related to land and water conservation. The public should be thoroughly informed of the dangers and damages that release of their home aquarium animals may cause. They should be informed of the damage already done to the world environment through introductions. Ziswiler (1967) showed a remarkable positive correlation when he compared extinctions with increase in the world human population. The only real safeguard toward the prevention of unnecessary releases may be a well-informed public respectful of its environment and natural heritage, accomplished through effective, diverse educational activities. The fact that outcries against the walking catfish in Florida have hastened its establishment and popularity elsewhere and that current efforts to eliminate the destructive African land snail, *Achatina,* in Miami may be frustrated by curiosity seekers, emphasizes the importance of education. Cooperative national and state study teams might be useful in pinpointing developing hazards associated with the importation of living organisms and they could signal attention to harmful imports, and possible dangerous releases and transplants. Study and evaluaion of proposed introductions probably should not rest with any one agency, for some of them already bear responsibility for our current problems.

Acknowledgments

We generously acknowledge the participants of the Washington Conference—for we have freely borrowed information discussed before the conferees—and the encouragement received from many conferees to complete this manuscript. We are especially grateful to: Catherine H. Robins, University of Miami, for reading the manuscript and for providing the section on *Marisa* and *Achatina;* Neil Hotchkiss, Patuxent Wildlife Research Center, for providing a list of non-native water plants now growing wild in North America; E. J. Crossman, Royal Ontario Musuem, for information concerning Canadian fish introductions; to Martin L. Wiley, Chesapeake Biological Laboratory, for helpful suggestions in reading the manuscript; and to the following for providing various information: James E. Böhlke, Academy of Natural Sciences, Philadelphia; Earl S. Herald, Steinhart Aquarium; Joseph P. E. Morrison, National Museum of Natural History; and Kermit E. Sneed, Fish Farming Experimental Station, Stuttgart, Arkansas.

Reeve M. Bailey, Chairman, Committee on Names of Fishes, American Fisheries Society and the American Society of Ichthyologists and Herpetologists, provided a provisional list of fishes introduced and established in the United States and Canada.

This paper represents Contribution No. 1207, by C. Richard Robins, from the Institute of Marine and Atmospheric Sciences, University of Miami.

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U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 379-386

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In *synonymy,* use the short form (taxon, author, date, page) with a full reference at the end of the paper under "Literature Cited." Begin each taxon at the left margin with subsequent lines indented about three spaces. Within a taxon, use a period-dash (.—) to separate each reference. Enclose with square brackets any annotation in or at the end of the taxon. For *references within the text,* use the author-date system: "(Jones, 1910)" or "Jones (1910)." If the reference is expanded, abbreviate the data: "Jones (1910, p. 122, pl. 20: fig. 1)."

Simple *tabulations* in the text (e.g., columns of data) may carry headings or not, but they should not contain rules. Formal *tables* must be submitted as pages separate from the text, and each table, no matter how large, should be pasted up as a single sheet of copy.

Illustrations (line drawings, maps, photographs, shaded drawings) can be intermixed throughout the printed text. They will be termed *Figures* and should be numbered consecutively; however, if a group of figures is treated as a single figure, the individual components should be indicated by lowercase italic letters on the illustration, in the legend, and in text references: "Figure 9*b*." If illustrations (usually tone photographs) are printed separately from the text as full pages on a different stock of paper, they will be termed *Plates,* and individual components should be lettered (Plate 9*b*) but may be numbered (Plate 9: figure 2). Never combine the numbering system of text illustrations with that of plate illustrations. Submit all legends on pages separate from the text and not attached to the artwork.

In the *bibliography* (usually called "Literature Cited"), spell out book, journal, and article titles, using initial caps with all words except minor terms such as "and, of, the." (For capitalization of titles in foreign languages, follow the national practice of each language.) Underscore (for italics) book and journal titles. Use the colon-parentheses system for volume, number, and page citations: "10(2):5–9." Spell out such words as "figures" and "plates" (or "pages" when used alone).

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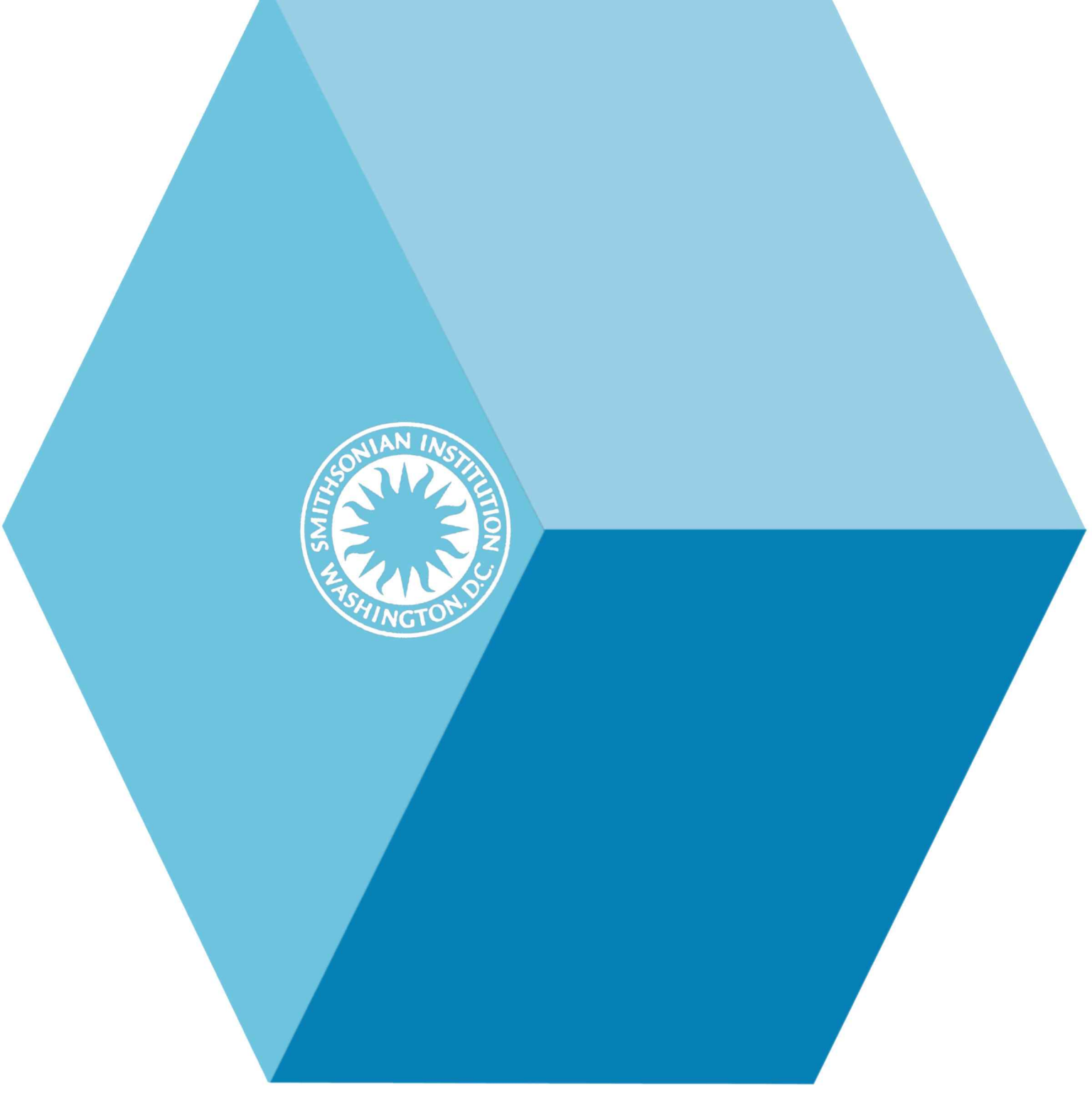
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