Implications of Transplantations to Aquaculture and Ecosystems

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ABSTRACT–Increasing aquaculture activities occur primarily in areas where support and supply for the developing industry are available, e.g., close to main shipping routes and harbors. Because intensive aquaculture operations often provide ideal conditions for initial establishment of exotic species, the chances for transfer of nonindigenous species increase. Diseases have spread rapidly through multiple transfer of major candidate species for aquaculture. An overview is given of important deleterious side effects accompanying transplantation of aquatic organisms. Well-documented examples on general pathways involved in transplantation of harmful and unwanted species are presented. Problems associated with control measures and regulations are discussed.

Introduction

Since the appearance of life on the earth, organisms have populated new regions, and the advent of man has accelerated the process.

Transplantation of aquatic organisms is a very common activity today. Belief that such introductions are beneficial is the driving force for such activities. This paper reviews some of the well-documented examples of the deleterious side effects accompanying transplantation to demonstrate the need for preventive measures on an international basis.

Implications to Aquaculture and Ecosystems

Transfer by Sea Traffic

Introductions of nonindigenous species via sea traffic (i.e., ship hulls, ballast tanks) are important to aquaculture development in coastal regions for the following reasons: 1) Increasing speed for modern seagoing vessels has not proved a barrier for transfaunation (Allen, 1953); 2) increasing traffic density may provide a continual infusion of foreign species until a critical population size is reached, thus enhancing the chances for successful establishment; 3) intensive aquaculture operations often offer excellent conditions for the initial establishment of potential invaders; and 4) increasing aquaculture activities occur primarily in areas where support and supply for this development branch of industry are already available and where socio-economic needs can be met at least partially by already established industries (Hansen, 1974; Landis, 1971).

There is not much we can do to reduce continuous transfer of organisms on ship hulls and in ballast tanks. Since expansion of the aquaculture industry will most likely take place close to developed transportation systems (e.g., harbors and shipping routes), the opportunity for establishment of exotic organisms is increased. Therein lies the danger.

Although the introduction of the Australian barnacle, *Elminius modestus*, into European waters has not become a serious problem to any aquaculture operation, it is a classical example to demonstrate: 1) the capability of a potential invader to utilize ship hulls as long-distance carriers, and 2) how rapid local spread by other pathways may be ensured.

This barnacle was first recorded at the end of the Second World War from Chichester Harbour, U.K. (Bishop, 1947). It spread rapidly, first to the Netherlands (1947), to The Federal Republic of Germany (1953), and then to Denmark (1961) (Den Hartog, 1953; Barnes and Barnes, 1960; Powell, 1960; Kühl, 1963 a, b). Crisp and Southward (1959) calculated its range extension as 30 km/year. Kühl (1963 b) explained its rapid spread along the German coast as due not only to the high density of sea traffic between harbors, but also to the activity of mussel farmers in transferring seed mussels to different growing areas.

It may be assumed that isolated populations at small fishing harbors along the coast were initiated by fishing boats acting as vectors. Barnes and Barnes (1960) pointed out that this type of dispersal need not involve traffic between harbors; it requires only that boats fish in waters containing abundant larval populations. Wherever *E. modestus* is abundant, it seems to affect adversely the growth of planktonic larvae of other benthic animals that breed in summer, including larvae of the oyster *Ostrea edulis*.

Several species of crabs have been introduced via ballast tanks. The Chinese mitten crab, *Eriocheir sinensis*, was transferred to The Federal Republic of Germany in 1910, to Belgium in 1912, and it reached the coast of Denmark in the twenties. During the

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thirties, this species occurred in the Baltic Sea and was recorded from the Finnish coast in 1933. It also appeared in Dutch and French waters during the thirties (Hoestlandt, 1959; Karppinen and Kairasuo, 1961). In The Federal Republic of Germany, fishing gear and catches were damaged severely and in the Netherlands, damage to dikes was reported.

After more than 60 years of continuous spread that might have made net cage culture in inland waters almost impossible, the Chinese mitten crab stock has diminished. This crab is no longer considered a serious problem, at least in The Federal Republic of Germany and the Netherlands. New population explosions as well as the establishment of this species in other regions cannot, however, be excluded. Nepszy and Leach (1973) reported a first observation in North America. Three specimens were taken in Lake Erie in 1973. Another record of its presence is the collection of a single individual at Windsor, Ontario, in 1965. Presumably this crab was carried to Lake Erie in ballast tanks, as Peters and Panning (1933) considered it may have been carried from Europe.

Ships are probably the principal agent for transferring exotic marine algae. Walford and Wicklund (1973) mention a number of marine algae now found outside their natural range that may have been distributed by ships. For example *Asparagopsis armata*, native to Australia, Tasmania, and New Zealand, has now spread to the British Isles, western Europe, and the Mediterranean. *Fucus inflatus*, a subarctic species, is considered to have been brought by fishing vessels to the Göteborg region in Sweden, where in some places it is the dominant *Fucus* species, and has been found south at least as far as Copenhagen. The green alga *Codium fragile tomentosoides*, presumably native to Japanese waters, has become distributed around the world perhaps in ballast water of ships or perhaps with seed oysters. It threatens many valuable beds of clams and oysters and has already smothered many of them. Not much is known about the ecological implications of such introductions but the effect of *Codium* should be noted. The Japanese seaweed *Sargassum muticum* was accidentally introduced and is now well established along the south coast of England. Eradication of *Sargassum* by hand gathering was attempted initially, but although several hundred tons were removed by this method during 1976, the practice has been largely abandoned as ineffective (Franklin, 1977).

The amphipod *Gammarus tigrinus*, endemic to the east coast of North America (Bousfield, 1958), has been introduced into European waters, possibly in bilge water or ballast tanks (Schmitz, 1960; Bassindale, 1946; Hynes, 1954, 1955; Hynes et al, 1960; Nijssen and Stock, 1966). This species also spread successfully after it had been deliberately introduced in the rivers Weser and Werra in The Federal Republic of Germany. A continuous extension of range of this alien amphipod is reported by Pinkster and Stock (1967) and Smit (1974). Initial mass development caused alarm in the Netherlands and The Federal Republic of Germany where it was reported to cause damage to bownets and fish caught in them. No further negative effects on fisheries due to its introduction have been reported, but this gammarid has now largely replaced the former gammarid fauna of many lake districts in the Netherlands (Chambers, 1973).

There are increasing numbers of reported transfers of fouling organisms via ships to different seas (Walford and Wicklund, 1973). This is of special importance to coastal shellfish and finfish pen culture as fouling organisms may cause serious operational problems. Since its introduction, the barnacle *Balanus improvisus*, first described from North and South America, may have damaged oysters in Lake Hamana and the pearl culture industry along the Japanese coast (Kawahara, 1963).

A number of other translocated fouling organisms may prove to be harmful to aquaculture operations. *Mytilus edulis galloprovincialis* Lamarck, probably transferred on ship hulls from the Mediterranean, caused considerable damage to Japanese oyster culture operations in the vicinity of Ondo near Hiroshima due to competition for space and food. The reduction of the long-term average yield has been estimated to reach approximately 64 percent for the 1973 growing season (Arakawa, 1974). *Balanus eburneus* from the Atlantic coast of North America has been transferred to European and Japanese waters (Bishop, 1951; Utinomi, 1966). *Balanus amphitrite amphitrite*, native to the tropical Pacific, has become common in Japan (Utinomi, 1960). A hydroid, *Hydroides norvegica*, was introduced to New Zealand from Australia. Other fouling organisms introduced into Australasian waters include: *Bugula flahellata*, a bryozoan from the Atlantic and Mediterranean; a British nudibranch, *Thecacera pennigera*; a hydroid, *Bougainvillia ramosu*; and a massive form of the encrusting *Zoovia schizoporella unicornis* (Allen, 1953).

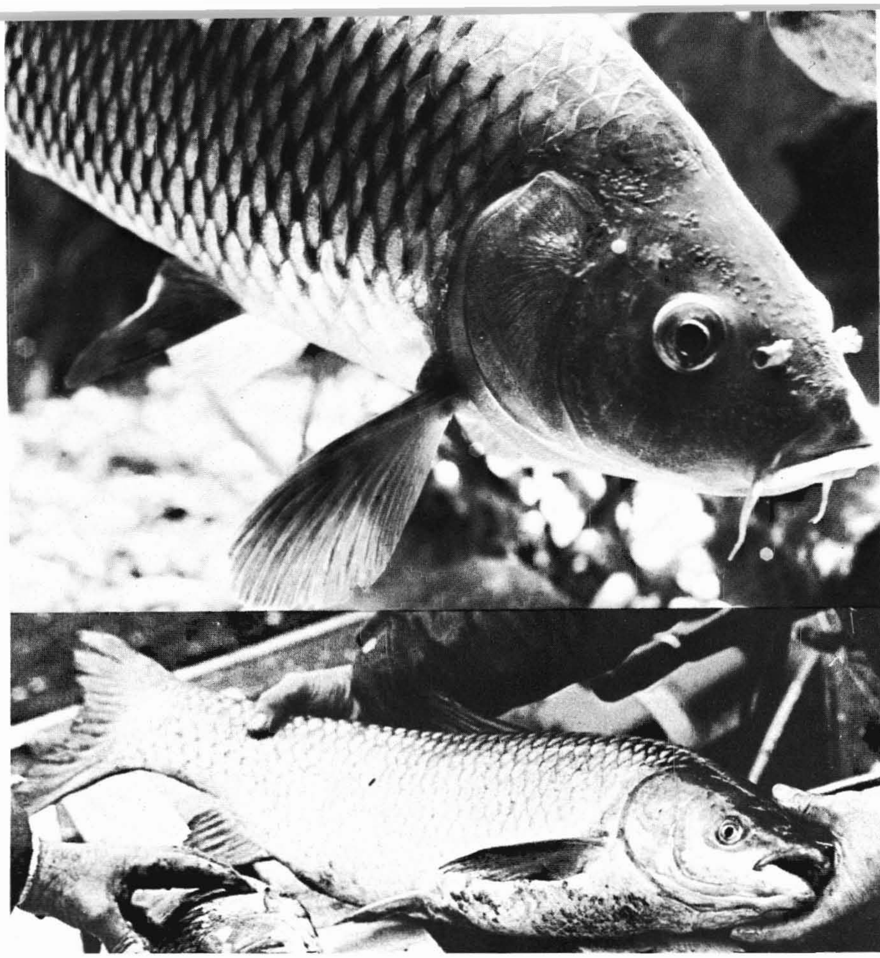
Purposeful Transplantations

Several classical examples of deliberate introductions exist. The history of tilapia, *Tilapia mossambica*, common carp, *Cyprinus carpio*, and grass carp, *Ctenopharyngodon idella*, shows that fish considered successful aquaculture candidates in one region are not necessarily successful in others.

Tilapia

An important stimulus to fish culture development in Southeast Asia, as well as in other areas, was the introduction of the exotic *Tilapia mossambica* and other *Tilapia* species (Bardach et al., 1972). After many successful introductions, it was observed—first in the Philippines—that several species of fish such as *Scatophagus argus*, *Mugil* spp., and *Teuthis* spp., which are often stocked in milkfish, *Chanos chanos*, ponds to provide added income, became stunted in the presence of *Tilapia* and therefore fetched a low price (Pillai, 1972). Rabanal and Hosillos (1957) regarded *Tilapia* as one of the worst pests in ponds in the Philippines, causing injuries to milkfish fingerlings.

Tilapia melanopleura was introduced into Mauritius in 1956 and kept under controlled conditions. Some specimens accidentally escaped into adjacent waters where they have harmed



Classical examples of deliberate introductions include the common carp, *Cyprinus carpio* (top); and grass carp, *Ctenopharyngodon idella* (bottom) Photos courtesy of the U.S. Fish and Wildlife Service and the Missouri Department of Conservation respectively.

indigenous flora and fauna (George, 1975). Introduction of *Tilapia* has had many positive results, but it is obvious in many countries that culture of other species of higher market value is considerably hindered because of difficulties in controlling the population growth of introduced *Tilapia*. Even if the maximum standing crop is very high it will consist largely of great numbers of small "trash" fish. Monosexculture is one way out of the dilemma but unfortunately it cannot be applied everywhere.

Other problems associated with successful transplantations may arise under local conditions. The most serious example reported in the literature is that of pond construction for *Tilapia* culture in Puerto Rico, which has increased the habitat for the fluke responsible for *Schistosomiasis* and its intermediate snail host (Courtenay et al, 1974; Odum, 1974).

Common Carp

The common carp, native to east and Southeast Asia, was introduced into Italy and Greece during Roman times (Thienemann, 1950). It has since been distributed throughout Europe, introduced into Australia (Vooren, 1972) and into North America (Cole, 1905; Dymond, 1955; McCrimmon, 1968). The Federal Government of the United States actively promoted public acceptance of this species near the end of the 19th century. Intentional introductions into Canadian waters progressed during the same period. The less desirable aspects of the carp were not recognized in either country, and early warnings of the likely consequences of its establishment in American waters were overlooked. Both carp and goldfish introduced into New York State in the 1830's later escaped into the Hudson River and multiplied with spectacular rapidity. As early as 1883, an increase of carp in Lake Erie caused a drastic decrease in the wild celery and wild rice beds of the lake. This was typical of the situation which was to develop in literally hundreds of North American waters within a few years (see McCrimmon, 1968; Chambers, 1904; Cole, 1905). In the first annual report of the Fisheries Branch of the Province of Ontario for 1899, it was mentioned that carp feed on the spawn of other fish, although later authors could not show clearly appreciable egg predation in all regions (Ensign, 1960; Harlan and Speaker, 1956). In another later report it was noted ". . . that carp had become so abundant in Burlington Bay at Hamilton that they had driven native catfish and other coarse fish out of the inlets" (McCrimmon, 1968). Since the beginning of this century, carp have been considered nuisances wherever found in North America. Carp are still extending their distribution in Canada and have migrated into the western parts of the country, where they are more destructive, virtually eliminating aquatic vegetation in several areas of Manitoba. Carp have failed to receive public acclaim as a sport fish in North America, but have now become established in 46 states of the United States. Their habits of uprooting vegetation and muddying water have resulted in the expenditure of millions of dollars on control and eradication programs, none of which has been very successful (Laycock, 1966; Courtney and Robins, 1975).

Common carp also have been introduced into Mauritius where they escaped into Lake Mellawaine (Murno, 1967), possibly competing with *Clarias gariepinus* for chironomid larvae, and displacing it (George, 1975).

Carp have failed to establish themselves as self-sustaining populations where stocked in several natural waters in Egypt and Uganda. George (1975) attributed this to heavy predation of Nile perch, *Lates nilotica*, and other predatory fishes. On the other hand, this species is now well established in Ethiopia, where no adverse effects on indigenous fauna are reported. However, George (1975) citing Jackson

(1960) listed the main reasons why most legislation in Africa now forbids any introduction or transplantation of live carp:

"(a) Carp have a wide ecological tolerance and can thrive when conditions become minimal for other fish, thus hastening the elimination of other species where they live.

(b) They destroy the eggs of other species, destroy the vegetation in their habitats, to the extent often of eliminating all vegetal growth and, by constant rooting in the substrate, muddy the water, and cause salt to accumulate, destroying insect and other benthic life."

This destructive sequence of events may not always be realized in cases where escaped fish from carp farms establish themselves in natural waters, but it is almost impossible to predict which of the above mentioned effects will finally dominate.

Grass Carp

The introduction of grass carp, *Ctenopharyngodon idella*, for biological control of aquatic vegetation has become common in many countries. There is considerable disagreement over the beneficial features of this species. Lachner et al. (1970) reported on early warnings against further introduction into the United States by members of the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, assuming that destruction of aquatic vegetation could cause ecological damage to the native fauna (fishes, invertebrates, and waterfowl). Grass carp have not only been introduced into the Missisippi watershed, but they are said to be in more than 40 states at present, at least in private hands or in confined waters. So far, the consequences are unknown, aside from the fact that grass carp will pull up emergent cattails (*Typha*).

In North America, and in many areas, aquatic weeds are themselves exotic species. At least some of them have spread via aquarium fish importation. In Florida, biological weed control was started by introducing another exotic, the blue tilapia, *Tilapia aurea*. Since its introduction in 1961 it has become so abundant that some streams are devoid of most vegetation and nearly all their native fishes. Nevertheless, not having learned from this lesson, the introduction of grass carp into Florida is probably merely a matter of time.

Courtenay and Robins (1975) discussed the possible ecological implications of experiments with grass carp in Oregon and Florida. Grass carp removed the aquatic plant *Hydrilla* from a pond in 1 year and destroyed spawning areas for native centrarchid fishes.

In the lower Mississippi Valley the grass carp may affect rice production, as pointed out by Courtenay and Robins (1972). Furthermore, statements made by a Chinese committee on freshwater fish raising are cited by Roberts et al. (1973): "*Ctenopharyngodon* are highly destructive of rice plants and must be kept out of paddies," thus implying that this fish may cause an economic disaster in rice-growing areas.

Salmonids

Salmonids have been introduced around the world and in most cases these introductions have proved to be remarkably successful. George (1975) considers the introduction of trout into Africa as not having seriously affected the indigenous fishes because its distribution is restricted to high, cold, upland streams, where economically important indigenous species are seldom resident. However, extermination of local fish such as *Amphylius hargeri* due to trout introduction is known in Rhodesia. Jackson (1960) reported that freshwater mullets, *Trachyistoma euronotus*, and kurpers, *Sandelia capensis*, have disappeared since trout and black basses (*Micropterus*) were introduced into South Africa.

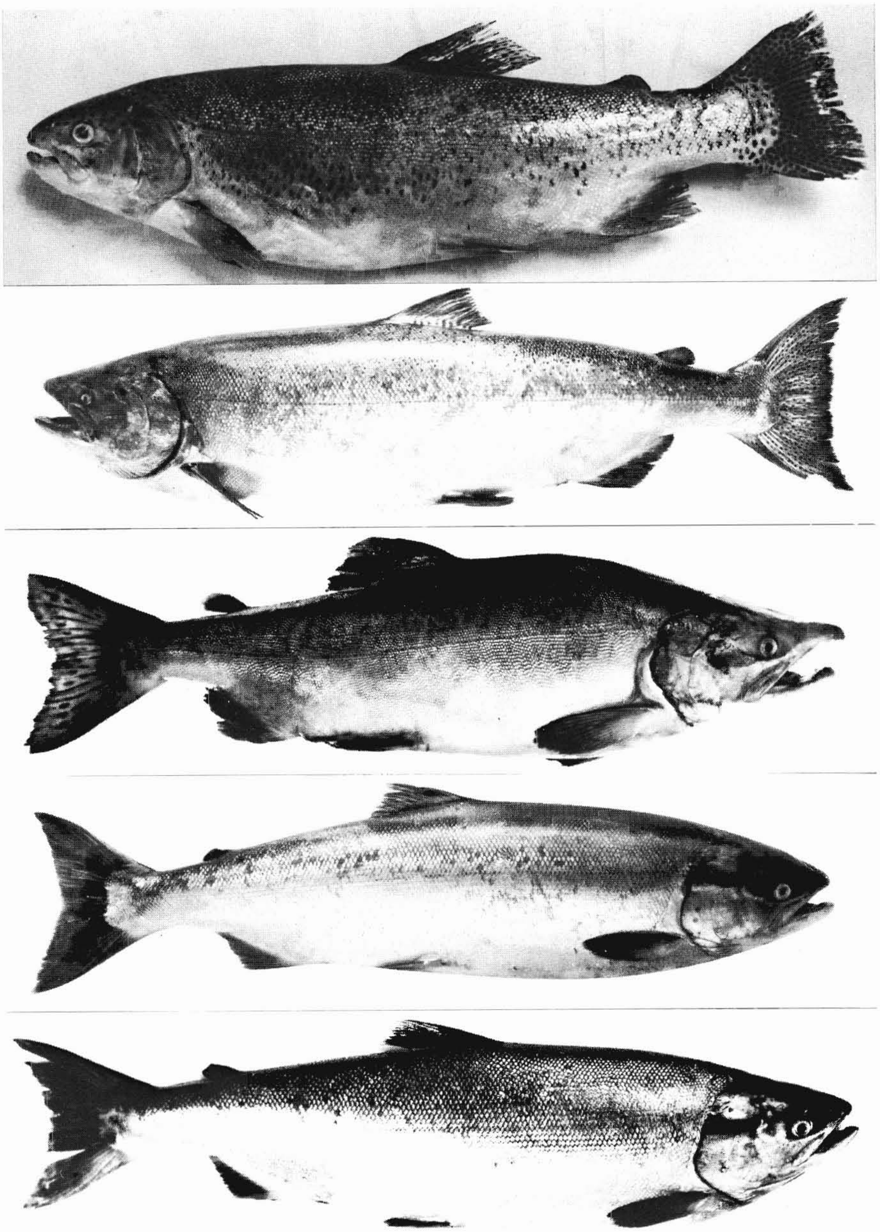
A classical example of deleterious side effects due to the introduction of a highly suitable aquaculture candidate, the rainbow trout, *Salmo gairdneri*, is that of its establishment in Lake Titicaca in South America during the Second World War. From an economic viewpoint this introduction proved to be successful. In the early sixties, between 100 and 410 tons of trout were landed annually. Meanwhile cyprinodont species (*Orestias*) suffered from heavy predation by trout. Because they were no longer abundant, rainbow trout thenceforth took insects as their predominant prey. In the meantime, some *Orestias* species have been eliminated from the native fauna (Villwock, 1963, 1966). *Orestias* also suffered from sporozoan infections, introduced via rainbow trout (Villwock, 1972).

Release of Pacific salmon from hatchery produced stocks into creeks and rivers other than their native ones is a common practice throughout the North Pacific region. In many instances returns within the recipient tributary did not exhibit the expected success. As Ricker (1972) summarized, chinook transfers made over great distances very often resulted in poor returns or at least into such straying from the stream of release. For example, Columbia chinooks of spring stock transplanted to "fall" streams had very poor success in locating their adopted tributaries even after entering the main river in large numbers, and in fact many went right past the tributary of rearing and release and on up the river. Pink salmon transplanted to the Kola peninsula returned in large numbers in 1960, but principally to streams other than those in which they were planted. According to Ricker (1972) there exists some evidence for a hereditary component in the guiding mechanism as well as in time of return. Thus it can not be excluded that extended releases of stocks for aquaculture purposes may have led to some destruction of genetic programs of local wild stocks.

Problems associated with transplantation of salmonids involve numerous diseases, which have caused considerable concern to aquaculturists. This subject is dealt with in a later section.

Other Fishes

Some further examples are worth mentioning. The mosquitofish or top minnow, *Gambusia affinis*, native to the southern Mississippi Basin, has been introduced into many tropical areas, and has become a strong com-



Many salmonids have been introduced throughout the world. From top to bottom are the rainbow trout, *Salmo gairdneri*; chinook salmon, *Oncorhynchus tshawytscha*; pink salmon, *Oncorhynchus gorbuscha*; coho salmon, *Oncorhynchus kisutch*; and sockeye salmon, *Oncorhynchus nerka*.

petitor of common carp in the Transcaucasus and central Asia (Nikolski, 1961; Vooren, 1972). At least the younger stages of carp show retarded growth where they coexist with *Gambusia* in ponds. Courtenay and Robins (1973) noted, in many regions where *Gambusia* have been introduced, that existing native fishes were as effective mosquito destroyers as *Gambusia*, and the documented result of these introductions has been the destruction of many small native fish species. George (1975) stressed that great care should be exercised in the introduction of *Gambusia* into new ecosystems. Introduction of this species for larvicidal purposes has been recorded from various African countries but it could not establish itself in habitats where there are predatory fish such as *Lates niloticus* and *Clarias* sp.

Nikolski (1961) also mentioned that perch (*Perca fluviatilis*) may form dense populations of small stunted fish when introduced into water bodies without native competitors. Additionally, in restricted areas they may displace species belonging to lower trophic levels. This was found to be true in a reservoir in Belgium, where brown trout, *Salmo trutta*, wild carp, and minnows disappeared after introduction of the perch around 1900 (Thienemann, 1950). Vooren (1972) listed five introductions that stand out as cases where obvious detrimental effects on indigenous species have been recorded: the pike (*Esox lucius*) in Ireland; *Perca fluviatilis* in Belgium; largemouth blackbass, *Micropterus salmoides*, and the sunfish, *Lepomis auratus*, in northern Italy; and *Gambusia affinis* in the U.S.S.R. The destructive pressure on indigenous species has been noted with the organisms which constitute their prey. Furthermore, in some local waters in the Netherlands, *Micropterus* and *Lepomis* have already caused a decline in the abundance of some indigenous piscivorous fishes.

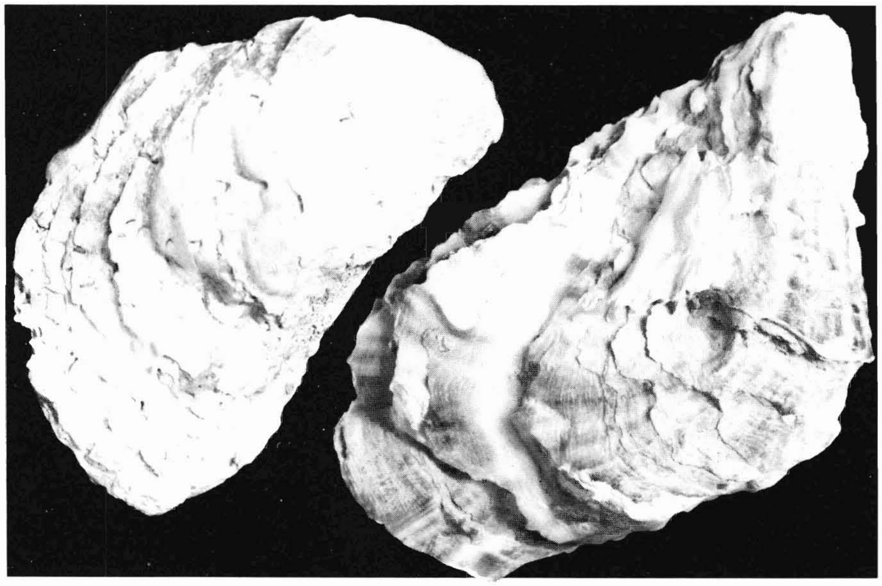
Vooren (1972) concluded that ". . . successful introductions of large high-level predators have often recreational value, but from a commercial fishery point of view their value is usually small or very local. . . . Where there exists a commercial fishery for species that occupy a lower trophic level, the establishment of a foreign piscivorous predator may be detrimental to this fishery. . . ."

In Japan, elvers of the European eel, *Anguilla anguilla*, were imported for several years to meet fish farm requirements for seed. So far success has been limited because of the high mortality and disease susceptibility of European elvers in Japanese waters. Eel farms in Japan can make a profit only when the survival rate is about 70 percent from local species and about 30 percent for imported species.

Crayfish

Recent introductions of nonindigenous crayfish species into many parts of the world are well documented. The red swamp crayfish, *Procambarus clarkii*, was imported to Kenya lakes by well-meaning people around 1967. It was hoped that the crayfish would reduce the population of a snail carrying a stage of bilharzia disease. Unfortunately, the newcomer multiplied rapidly, reducing bottom vegetation to such an extent that young fish became easily available to predation. As a consequence, fish populations declined drastically (Unestam, 1976). During the first half of this century the same species has been transferred from the United States to Japan, probably to serve as forage for other economically important species. As the result, crayfish are now considered a pest to the rice crop. On Hawaii, introduction of *Colocacia esculenta* has become a great threat to the taro crop (Unestam, 1974).

Crayfish, which often feed on diseased fish, are considered as possible vectors in spreading introduced fish diseases, such as infectious pancreatic necrosis. As has been pointed out by Unestam (1974), a certificate from veterinary laboratories stating freedom from dangerous parasites in examined crayfish is of little value since no general methods exist which can detect specialized parasitic bacteria, fungi, and viruses.



The transplanting of oysters has also introduced other exotic species to new areas Above are the American oyster, *Crassostrea virginica* (left), and the Pacific oyster, *Crassostrea gigas*

Accidental Introductions of Other Species

Oysters

One example, representative of many, is the accidental introduction of the slipper limpet, *Crepidula fornicata*. Native to the Atlantic coast of North America, it was carried to northern Europe and to the Pacific. Stocking of the American oyster, *Ostrea virginica*, in English beds at the end of the 19th century led to the establishment of the unwelcome limpet on the Kent and Essex coasts. Korringa (1942) explained how *Crepidula* succeeded in extending its range in coastal waters of western Europe. Dutch oyster farmers regarded the slipper limpet as a pest because it settles on seed collectors, grows fast, and tends to crowd out the tiny oyster spat on cockle shells (used as spat collectors at the time *Crepidula* arrived in Dutch waters). "Scattering [cockle] shells as collectors [for oyster seed] became unprofitable as it simply turned formerly good oyster grounds into vast Crepidula beds", reported Korringa (1951). The oystermen were forced to revert to the old-fashioned tile collectors, expensive but efficient in offering only a rough surface for attachment, one not readily accepted by *Crepidula*.

Korringa (1951) also provides other arguments which indicate the nuisance of this invader. If present in great numbers on an oyster bed, *Crepidula* deposits so much silt and soft mud that the beds are rendered unsuitable for oyster planting. Further, it ingests oyster larvae during their pelagic lives, thus impairing production of cyster spat.

In later years, Dutch oyster farmers used thin, brittle mussel shells as oyster spat collectors. Young *Crepidula* may settle on mussel shells as do young oysters. Thin mussel shells soon break away leaving the young oyster free, but *Crepidula* dies off soon after it loses its foothold. This type of control measure requires thorough supervision and care, not allowing *Crepidula* to develop harmful chains of individuals. *Crepidula fornicata*, originating from the Atlantic coast, has also been introduced into Puget Sound on the U.S. west coast.

Petricola pholadiformis, introduced into the United Kingdom in the late 19th century with *Crassostrea virginica* from the United States, has colonized several north European countries by means of its pelagic larvae (International Council for the Exploration of the Sea, 1972). The oyster drill, *Ocenebra japonica*, reported as being extremely destructive to oyster beds, was introduced with oyster shipments from Japan to the United States. *Ostrea edulis*, transplanted to South Africa, was responsible for the introduction there of the European gastropod *Ocenebra erinacea* (Hancock, 1960). *Mytilicola orientalis*, also introduced with oyster seed from Japan to the U.S. Pacific coast (Chew et al., 1964), has been shown to cause pathological changes in the gut of the Pacific oyster, *Crassostrea gigas*.

How *Mytilicola intestinalis* spread to

northern Europe from its original home in the Mediterranean is not known. In some areas this may have been entirely accidental and in others the result of some deliberate introductions (International Council for the Exploration of the Sea, 1972). In Great Britain, the species was first recorded in 1947 from the Northumberland coast (Hepper, 1955). *Mytilicola intestinalis* was also introduced into west Scotland, possibly with oysters from France in the late sixties, where it is now affecting mussels (International Council for the Exploration of the Sea, 1972).

Plantings of Japanese oysters along the west coast of North America are responsible for the introduction of another oyster drill, *Purpura clovigera* (Quayle, 1964 a, b) as well as for the establishment of the oyster *Crassostrea rivularis* (Walford and Wicklund, 1973) and the bay mussels *Modiolus demissus* and *M. senhousei* (Hanna, 1966). Some further invaders of British Columbia waters associated with Japanese oyster plantings are listed by Quayle (1969). In addition to a coelenterate (*Dradumene*), there is a worm (*Pseudostylochus estreophagus*), a mollusk (*Batillaria zonalis*), and a seaweed (*Sargassum muticum*), to mention only a few examples. The distribution of *Battilaria cumingi*, a Japanese snail, in British Columbia waters is directly related to plantings of Japanese oysters.

Van Engel et al. (1966) found a high percentage of the crab, *Eurypanopeus depressus*, from the Virginia coast parasitized with the sacculinid *Loxothylacus panopaei*. This species is known from Xanthids from the Caribbean and the Gulf of Mexico as well as from the Pacific coast of North America, but has not been reported from the Atlantic coast. The authors considered this as a clear example of an introduced species: ''Since 1960 when oyster stocks in lower Chesapeake Bay were reduced by a disease called 'MSX', a substantial quantity of live oysters has been imported from the Gulf of Mexico each year in refrigerated trucks. This practice is new and is a highly probable source of sacculinid-infected mud crabs.''

At least one exotic estuarine fish, a goby (*Acanthogobius flavimanus*), has been established on the Pacific coast of North America. Brittan et al. (1963) believed that the explosive spread of this fish in the San Francisco Bay region, was a result of the introduction of a few specimens accompanying the transport of culture organisms from Japan.

Diseases

At present eight major communicable fish diseases are potentially dangerous to freshwater finfish culture in Europe; Thompson et al. (1973) showed the following distribution of their reported incidence in 22 European countries in 1972.

Disease	*Countries*
Whirling disease	16
Furunculosis	15
Viral haemorrhagic septicemia (VHS)	14
Infectious dropsy of cyprinids (IDC)	13
Ulcerative dermal necrosis (UDN)	7
Infectious pancreatic necrosis (IPN)	7
Swim bladder inflammation of cyprinids (SBI)	6
Infectious haematopoietic necrosis (IHN)	0

Furunculosis in trout, first reported from Bavaria in 1894, is known to occur in most of Europe and North America, but was probably native to western North America, because it was in epizootiological balance with rainbow trout, *Salmo gairdneri*. In Europe, furunculosis became a serious problem in brown trout, *Salmo trutta*, after rainbow trout had been introduced. The first outbreak of this disease in Sweden in 1951 might also be attributed to an import of infected fish eggs (Nybelin, 1951).

Furunculosis is now present almost everywhere salmonids are cultured, except in Australia and New Zealand (Snieszko, 1973). The disease is caused by a bacterium *Aeromonas salmonicida*. Some authors believe that this pathogen is closely associated with its host, but others claim that it reproduces freely in nature. Christensen (1972) mentioned transmission of this disease by infected eggs and by fish with latent infections, which act as reservoirs.

Infectious pancreatic necrosis (IPN), which affects several salmonids, was first recorded in the United States and later in France, Denmark, Sweden, Italy, Scotland, and Japan. It is caused by a virus and prophylaxis is its only effective control. The results of Moewus-Kobb (1965) indicate that marine fish cell lines will support the multiplication of IPN-virus in vitro, and that the virus survives in several species in vivo, but without proof of multiplication. This is an important observation with regard to rainbow trout culture in coastal waters. Where viruses are concerned, fish culture in most cases is restricted to measures for avoidance, and propagation of specific-pathogen-free stocks.

In the case of IPN, Wolf (1972: 316) stated: ''It should not be assumed that virus will always result in high mortality among exposed populations. There are considerable observational data which suggest that host and pathogen reach some biological balance in a restricted system such as a hatchery which propagates a particular lineage of carrier trout. The danger of such a situation is that it fosters complacency in management. Because the virus may not be considered serious, infected stock could be distributed to places where virus may not be present and this could certainly result in further spread of the virus.''

Only the young fry and the juvenile fish suffer from the clinical form of IPN, whereas larger fish are rarely killed off but become virus carriers (Scherrer, 1973). This might be one reason why IPN is now distributed to almost all countries involved in salmonid farming. Sano (1973) demonstrated experimentally that IPN could easily be transferred to two species of Pacific salmon (*Oncorhynchus* spp.) when virus-contaminated trout are released from culture ponds to natural water bodies.

Infectious dropsy of cyprinids (IDC)

occurred in Czechoslovakia in 1929 and 1930 when common carp, *Cyprinus carpio*, fry were imported from Yugoslavia. A further rapid spread occurred during the Second World War, when stock carp were transported from one European country to another, without proper health control (Havelka, 1973). As a consequence, carp culture in Europe was affected severely for more than a decade and the disease spread not only to most pond farms but also to some natural waters.

Liebmann (1973) reported rapid spread of swim bladder inflammation of cyprinids (SBI) since the early fifties; in former years this disease was only sporadically recorded. He stated that the disease, which apparently originated in the U.S.S.R., spread westward to Austria, Czechoslovakia, The Federal Republic of Germany, Hungary, and Poland. Fish without symptoms can act as carriers.

Another virus disease, infectious haematopoietic necrosis (IHN), is believed to have occurred in sockeye salmon, *Oncorhynchus nerka*, on the west coast of North America since 1952. It also affects *O. tshawytscha* and rainbow trout. It recently has spread into the states of Minnesota, Washington, Montana, South Dakota, Idaho, and Oregon, where it affects rainbow trout. Transplantation of diseased fish or eggs from infected brood stocks is considered as the continuous supply (Amend et al., 1973).

Survival of "Egtved virus" the causative agent of viral haemorrhagic septicemia (VHS), for a prolonged period in frozen trout has been reported. So far, transfer of this virus due to importation of frozen trout and introduction of live salmonid eggs from Europe to North America has not occurred (Ghittino, 1973).

Whirling disease is found in 14 salmonid species and the grayling (*Thymallus*). It is caused by the sporozoan, *Myxosoma cerebralis*, first described in southern Germany in 1903 (Christensen, 1972), and is now present in almost all areas where salmonids are cultured, including the U.S.S.R., continental Europe, British Isles, Republic of Korea, South Africa, and North America (Bogdanova, 1973). It also occurs in seven species in natural waters. The very pronounced species difference in susceptibility of salmonids to *M. cerebralis* is well documented. "The hypothesis has been put forward that the invasion is indigenous in the European brown trout and therefore balanced, while the American rainbow trout and brook trout not coming from the same biotope are more susceptible" (Christensen, 1973). Thus, infected fish, or fish transported in contaminated water must have been transferred to North America. Viable spores can also be transferred in frozen trout.

Two cases of whirling disease causing substantial economic losses in the United States may be mentioned as typical examples. One trout grower was completely out of production for almost 3 years due to whirling disease transfer from his supplier. Another trout hatchery supplemented its well water supply with water from a nearby river system. Unfortunately the river had been stocked previously with trout carriers of whirling disease, which led to a total loss of the hatchery stock. Thompson et al. (1973) stated that the direct cost to the agency administering the publicly-owned hatchery was between US$250,000 and $300,000, and the loss to the angling fishery the hatchery would have supported is no less than four times the direct loss.

Disease organisms pathogenic to man may also be transferred in the water accompanying imported aquatic species. More than 100 million fish were imported into the United States in 1972, together with a minimum of about 11.3 million liters of water. There exists a great danger of introducing *Schistosomiasis* (bilharzia) in regions with suitable conditions. This has already happened in some areas of the Caribbean (Odum, 1974). Regarding the import of live aquatic animals from tropical regions, rapid air transport increases the survival chances of waterborne stages of flukes and other pathogens such as *Salmonella* and *Vibrio cholera* (Courtenay and Robins, 1975).

Janssen (1970) has pointed out that most bacterial pathogens of fish belong to the genera *Aeromonas, Pseudomonas,* and *Vibrio*, which include species also pathogenic to man. Chronic granulomatous lesions of the extremities are caused by *Mycobacterium ballnei*, sometimes found in swimming pools, aquariums, or tropical fish tanks. According to Oppenheimer (1962), Middlebrook (1965), and Janssen (1970), this organism is identical to *Mycobacterium marinus*, a pathogen of fresh and saltwater fish. *Mycobacterium tuberculosis* innoculated into carp multiply and maintain their virulence for years (Griffith, 1930). *Vibrio parahemolyticus* is one of the few fish-borne human pathogens which has been found to be identical to a pathogen occurring in oysters (*Crassostrea virginica*) and blue crab, *Callinectes sapidus* (Krantz et al., 1969). This suggests the organism is widespread in its marine distribution, and that the practice of cooking seafood may be the chief factor in limiting this fish-borne human disease among western nations (Janssen, 1970). Janssen and Meyers (1968) reported that fish may be actively infected in nature by a variety of human pathogens associated with contaminated water. Therefore, transfer of human pathogens with the fish trade remains a danger.

Fish Parasites

Transfer of fishes is much more effective in successful transplantation of parasites than would be expected from the literature. Usually only a few cases are reported due to a lack of experts available for immediate and reliable identification. Hoffman (1970) listed several intercontinental disseminations of fish parasites: "At least 48 species (5 protozoa, 31 monogenea, 5 digenea, 3 nematodes, 1 acanthocephalan, 3 copepods) of freshwater fish parasites have become established on other continents through the transfer of infected live and frozen fish." Five of these monogenetic trematodes reported from Israel were carried by *Tilapia* imported from Africa. One might expect an equal number of cases reported from other areas where *Tilapia* has been introduced, sometimes even more intensively. Few parasitologists have looked into this problem. It is impossible therefore to evaluate the ecological implications of massive transfer of diseased organisms. Merely because there are as yet no records does not mean that disruptions of existing ecosystems have not occurred.

Recently, new cases of disease transfer have been noted in the literature. Several authors cite grass carp, *Ctenopharyngodon idella*, as a notorious carrier of parasites and diseases (Cross, 1969; Courtenay and Robins, 1975). *Hemiophrys*, an exotic ciliate protozoan, is believed to have been introduced into Missouri with grass carp, its host (Courtenay et al., 1974). Bardach et al (1972) reported that the tapeworm, *Bothriocephalus gowkongensis*, introduced into U.S.S.R. with grass carp imported from China, has become a serious problem in European cyprinids. Kezić et al. (1975) detected this parasite for the first time in Croatia, Yugoslavia, during 1972, about 8 years after the transfer of grass carp to that country. Also in The Federal Republic of Germany *Bothriocephalus* has spread to many carp farms, causing some mortality in heavily infested specimens.

Argulus pillucides, first recorded in Egypt on mirror carp, *Cyprinus carpio*, in 1952, seems to have been transmitted with introduced specimens from France (George, 1975).

Highly migratory species may be considered as subsequent invaders of regions other than those where introduced, and straying individuals may also be regarded as potential disease carriers. The sturgeons, *Acipenser güldenstädti* and *A. baeri*, which were transplanted into the Gulf of Riga by the U.S.S.R., have been caught along the Swedish coast. Pacific salmon (*Oncorhynchus*) introduced by the U.S.S.R. into the river systems draining into the Barents Sea have been caught repeatedly in Norway, Iceland, and Scotland.

Shulman (1954) reported that introduced species constitute a focus of infestation for the local fauna, as happened when the sturgeon *Acipenser stellatus* was transplanted to the Aral Sea. A monogenetic trematode of the gills (*Nitzschia sturionis*), transmitted from it to the local *Acipenser nudiventris*, caused massive mortality among the local species of the Aral Sea.

Infestation of acipenserid fishes by parasites of cyprinids and salmonids has been observed in a number of cases. This raises the important question of the nature of specificity in fish parasites. It is well known that under laboratory conditions the strict specificity of many parasites is lost. This indication that changed environmental conditions may change host specificity can be demonstrated by many examples. The first intermediate host of the liver fluke in Europe is *Limnea truncatula*. This parasite will not develop in other representatives of the genus *Limnea* even when experimentally inoculated, but in other areas (North America, Australia), to which the liver fluke has been introduced, other species of *Limnea* and even another genus of snails will serve as intermediate hosts for this parasite.

Soviet scientists studying whitefish transplanted from one lake system to another provided a clear example of the breakdown of host specificity. Shulman (1954) reported that larval *Unionicola*, normally parasitic in the mollusks *Unio* and *Anodonta*, had infested the introduced whitefish. He considered two circumstances worthy of attention: 1) the larvae of *Unionicola* had not established themselves on a native whitefish but on an introduced one, and 2) this larva resembled *Unionicola crassipes*, which is not a normal parasite of this genus of host, i.e., a form which has less stable specificity. The relaxation of specificity here is connected with the action of the external environment on one link or the other (or on both together) of the "parasite-host" system.

Fishes

Borisova (1972) listed ten species of fish (*Opsonichtys uncirostris amurensis, Pseudorasboa parva, Pseudogobio rivularis, Hemibarbus maenlatus, Hemiculter lencisculus, H. eigenmanni, Rhodeus sericeus, Perceottus glehni, Hypselaotris swinhonis,* and *Rhinogobius similus*) accidentally introduced with grass and silver carp into fish farms near Tashkent (Uzbekistan) since 1961. All of these small nonexploited species originated from the Yangtse River. Nevertheless, the natural range of these species includes the northern and southern districts of China, as well as Korea, Japan, and the Amur Basin. These fishes first became established in a fish farm, but about 3 years later most of them penetrated through canals into adjacent rivers, where they partially displaced indigenous species and formed new biocoenotic structures. They showed a more rapid growth rate and a higher fecundity under their new conditions than populations of the Far East. These changes were connected with alterations in feeding habits; they not only utilized a wide range of planktonic and benthic food organisms but also made maximum use of artificial feeds at the fish farm. Because of their small size, it is almost impossible to eliminate these fish from ponds by gill nets.

San Feliu (1973) reported the accidental introduction of *Micropterus salmoides* into a Spanish lagoon of the Mediterranean coast around 1956. The fish has become acclimatized and is now rather abundant. It is not known whether native species are affected.

Other Introductions

Live Transport and Storage

Another source of unintentional introduction of a species is the live transport and storage of aquatic animals prior to sale—a common business in many countries. Lobsters and crayfish are usually sold alive. For many years the Netherlands has stored lobsters obtained from Norway, Scotland, and Ireland in ponds in Zeeland. In Great Britain, many thousands of American lobsters, *Homarus americanus*, have been imported from North America since 1968. Mussels from Ireland are held in Wales, and prior to sale to consumers the same species is quite commonly held in coastal "basins" in France after importation from Spain.

Hoffman (1970) provided a table showing the species of marine animals imported live for consumption from six continental European countries, the

British Isles and Canada to 10 European countries and the U.S.S.R. Ten species of molluscs, four species of crustacea, and two species of eel (*Anguilla anguilla* and *A. rostrata*) are involved. This listing covers a very restricted area, but as such activities occur throughout the world, the high potential for transfer of nonindigenous species parallel to such activities is obvious.

Ornamental Fish Trade

The pet fish industry provides another example of the high risk involved in escape of exotic species kept and raised in fish farms. The most spectacular recent experience is with the walking catfish, *Clarias batrachus*, from Asia, which escaped from a fish farm in Florida and became established. Since the mid-sixties, it has distributed itself over more than 8,750 km² in 10 counties of Florida. The range of this exotic may extend into other states within the next few years. The threat to native fishes is thought to be serious (Courtenay and Miley, 1975).

Courtenay et al. (1974) and Courtenay and Robins (1975) have reviewed the introductions of exotic fishes into Florida. Forty-two exotic species and several hybrids were found in waters of Florida during the early seventies. Of these, 24 species and 5 hybrids are considered to be established permanently. Most of these introductions involved escapes from pet fish farms. Waterways in the vicinity of pet fish farms often contain more species of exotic fishes than native forms, and existing ecosystems have been altered considerably. Besides ecological disruption in isolated areas, so far only four species have expanded their range to create considerable concern: *Clarias batrachus, Cichlasoma bimaculatum, Tilapia aurea,* and *Belonesox belizanus*.

Of about 65 fish species introduced into Arizona (some confined to reservoirs), only 29 are food and game fishes in the United States.

In Papua, New Guinea, where an estimated 12,000 aquarium fish are imported annually, two aquarium fish species have become established (West, 1973), although six species account for about 50 percent of ornamental fish imports. The guppy, *Lebistes reticulatus* (Peters), was first observed in 1967 in the Port Moresby region from where it spread to nearby swamp areas of the Laloki River system. The species has spread further since—as could be expected from experience gained in Indonesia, where it competes for food with more valuable native fish (Schuster, 1950). The second species found recently in shallow back waters is the threespot gourami, *Trichogaster trichopterus trichopterus* (Pallas), where it dominates in numbers both native fish species and the deliberately introduced *Tilapia mossambica*.

The American eel, *Anguilla rostrata*, is one of many species often transported live around the world. Photo by Lloyd Poissenot, Louisiana Department of Wildlife and Fisheries.

With the exception of a few species, the supply of saltwater aquarium fish will not be derived by egg-to-egg culture but will be obtained by transfer of collected specimens from natural sources for many years to come. For the same reasons, regulations are needed not only for import-export of live species but also for local transfer of specimens within the natural distributional range of a species.

With respect to the export of ornamental fishes, Conroy (1975) described the situation of disease control in prophylactic measures for South America as follows: "The present situation . . . is that the ornamental fish shippers place a blind faith in the use of substances such as acriflavine and methylene blue, or on imported commercial products, usually without any understanding of the nature of the disease(s) or of the correct method of using such products."

Bacterial diseases as well as endo- and ectoparasitic infections are extremely common among ornamental fishes in many countries. Establishment of harmful parasites due to continuous and indiscriminate transfer of their hosts in other areas cannot be excluded. The worldwide transfer of live ornamental fish has reached astonishing proportions; the trade still has to be considered as an expanding industry. For example, in 1974, Colombia alone exported over 12 million ornamental fish (124 species) to about 17 countries in Europe, Asia, and the Americas. Peru, in 1971, exported about 13 million ornamental fish (72 species) to about all countries in these regions.

Conroy (1975) described the danger of introduction of diseases by common export practice for ornamental fish as follows: " . . . many exporters ship their fish in water taken from ponds, streams and rivers of questionable biological and bacteriological quality. The principal danger lies in the practice, common in the trade, for the water in which incoming fish have been received to be disposed of in an untreated state through channels or conduits in the floor. Although in urban areas this effluent usually enters the public sewage system, in rural areas it is common for the effluent to enter directly into the open ditches or streams. In the event that organisms, potentially pathogenic to fish or aquatic plants, should be present in the incoming water, these organisms could thereby gain access to open waters in the country of destination. . . While it holds true that several of the more common fish parasites are also known to occur naturally in regions other than those to which the imported fish are native (e.g., *Saprolegnia* spp., *Ichthyophthirius multifiliis, Argulus* spp.), the danger is the possibility of 'exotic' strains of these parasites being introduced and, in this way, causing epizootics among members of the native fish fauna of the waters into which they were accidentally introduced.''

From the ornamental fish trade in the United States it is reported that about 60 percent of all imported tropical fishes die within 30 days, and that most of the fishes have ichthyophthiriasis or fungus infections. Thompson et al. (1973) mentioned two arguments supporting the opinion that transferred diseased fish may also lead to the establishment of pathogens in new environments: 1) Host specificity is uncertain in new environments, and 2) new and more virulent strains of pathogenic bacteria may develop or be imported into the new environment.

Fish Disease Control Problems

Thompson et al. (1973) in reviewing national and international measures for the control of the major communicable fish diseases of Europe and North America, listed five major reasons for delayed or incomplete control of fish diseases: 1) Lack of veterinary skills, 2) fear of adverse economic effects, 3) lack of a central registry and reporting service, 4) lack of research, diagnostic techniques, and quarantine methods, and 5) administrative and enforcement shortcomings and difficulties, including lack of interest by governmental organizations, lack of trained customs inspectors, and inadequate legal authority. These reasons may be applied almost equally to the entire problem of control of introductions and transplantations of aquatic organisms by widening the sense of their statements, e.g., ''and lack of ecological skills'' might be added to the first reason.

One of the problems involved in a consistent inspection of the international fish trade is demonstrated by the availability of piranhas, which are still displayed by dealers as aquarium fishes in Florida. Concern among biologists about the establishment of these dangerous species in southern Florida's fresh waters, where environmental conditions have permitted the establishment of other exotic tropical species, has led to the prohibition of the importation of piranhas into the United States. Nevertheless, they are still available on the tropical fish market under a variety of Spanish, Portuguese, and native names. Moe (1964) explained the difficulty of controlling importation: ''Most of the piranhas that are imported are young juveniles that find their way into the shipments of other characins. Young piranhas are so similar in shape and color to many of their vegetarian relatives that only an experienced ichthyologist can distinguish them. They often are not recognized until they reach the tanks or outdoor ponds of the wholesaler''. How easy it is for them to slip in when the certificates are dealing with species of a ''clean list'' only.

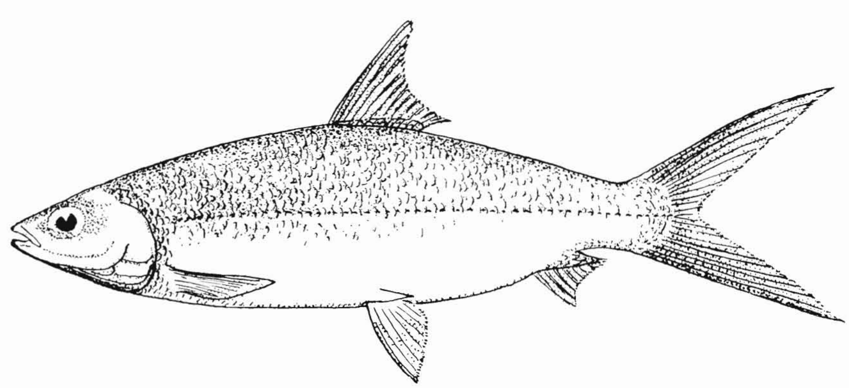
Another problem is that of seed export and import of some of the important aquaculture candidates: Mullet (*Mugil*) and milkfish (*Chanos chanos*) fry and elvers. It is almost impossible to completely eliminate fry or postlarvae of unwanted species (predators, competitors) from shipments.

Considering the world trade in ornamental fish, Axelrod (1973) described how the risk of transferring major communicable fish diseases and parasites can be reduced considerably by improved storing, transporting, and receiving of shipments.

Other gaps still remain. An important one with respect to fish disease is demonstrated by an example of common handling procedure, when transporting fish by truck over long distances in central Europe. Under present transport conditions, water will be exchanged each 24 hours or at least after 1,500 km of travel. Often tank water is discharged into creeks, lakes, or rivers, without disinfection, increasing the opportunity for disease transmittal. As another example, German imports of live trout for consumption are often maintained in farm ponds for several days. After processing, the resulting waste parts are usually fed to fish in adjacent ponds, thus increasing the risk of disease transfer not only for the cultivated stock but also to the native fauna.

International regulations for the control of transplantations of nonindigenous species are also required. Many species, once introduced into an area, may extend their range far across the borders of the country where initially released. Considerable effort on an international basis is necessary if we are to cope with the rapid increase in worldwide transplantation of exotics.

For more than 25 years, the United States Fish and Wildlife Service has sponsored the U.S. Foreign Game Introduction Program. In its early years, Bump (1951) viewed the general problem of the introduction of exotics: ''Nor



Milkfish, *Chanos chanos*.

has any method been so blindly applied and consistently mishandled. Although it is one of the earliest techniques to be applied, few who have used it have bothered to learn by experience, and no one has as yet formulated a set of guiding principles and practices."

Regier (1968) discussed the introduction of exotics under these different concepts: 1) Vacant niche, 2) trophic level, and 3) competition. We may cite Regier directly: "I think what is often meant by vacant niche is that certain possible trophic levels in the community haven't enough organisms in them for the good of the system as a whole. The good of the system of course is almost invariably seen in terms of its potential production of what man sees to be an immediate benefit. *We choose exotics on the basis of what they can do for us and not primarily on what they can do for the nonhuman system*."

With regard to utilization of trophic levels, we may encounter much more complex systems with fish than with other organisms of lower systematic categories. Courtenay and Robins (1973) proposed some minimal methods for considering introductions into U.S. waters in order to stop disastrous imports. These recommendations are summarized here:

1) Reasons for seeking an introduction should be clearly stated and demonstrated.

2) Within the qualifications set under 1), a search for possible contenders should be made, and a list prepared of those fishes that appear most likely to succeed, with the favorable and unfavorable aspects of each species noted.

3) Preliminary assessment should be made of possible impact on aquatic ecology generally, the effects on game and food fishes, on waterfowl and on aquatic plants, the catchability and edibility of the species, and the implication to public health.

4) Assessment should involve appropriate personnel from a variety of agencies or organizations, and not be restricted only to personnel of the agency proposing the introduction.

5) A research program should be developed to test the import in confined waters from which escape is prevented.

6) Evaluation of the results should be made by a panel of representatives from all involved agencies.

7) With favorable reviews the release should be effected.

As emphasized by Courtenay and Robins (1973), "No importation of a species for release purpose is so urgent that its biological implications should not be severely reviewed by a broad panel of experts from representative government and public agencies." Most importantly, we should "seek to hold the line as regards man's unnecessary destruction in those areas where a native community is still flourishing" (Regier, 1968).

But even aside from this biological/esthetical viewpoint, a major concern regarding the present exponential increase of worldwide transplantation activities, is that elimination of introduced pests is extremely costly and frequently impossible. It is true that many transplantations in the past, even without previous assessment of possible side effects, have proved to be extremely successful. The one-sided negative view of this paper is, therefore, intended to stimulate an in-depth discussion of the problems involved.

Under any circumstances it certainly appears that the transplantations of exotic aquatic organisms, at least as far as those made directly by man are concerned, need a much higher degree of control than now exists. The reasons have been outlined and illustrated with well-documented examples. It now remains for more concrete action to be taken.

A forward step was taken, with respect to one aspect of this aim, when the Food and Agriculture Organization of the United Nations convened the Government Consultation on an International Convention for the Control of the Spread of Major Communicable Fish Diseases, at Aviemore, Scotland, in 1974 (Food and Agriculture Organization, 1974). Action toward this proposed convention covering the spread of fish diseases through international traffic in live fish and fish eggs, now awaiting further action by governments, can be regarded as encouraging. Others should follow soon and Druehl's statement made in 1972 still holds: "Action is required now if we are to curb further disruption of the marine biosphere."

Summary and Conclusions

Transfer of aquatic species usually occurs along one of four pathways: 1) Translocation of a species beyond its natural range by sea traffic; 2) Purposeful transplantation of organisms; the target, introduction into new areas; 3) Accidental introduction in connection with transfer of other species; or 4) Escape of organisms transferred for purposes other than actual introduction.

Detrimental effects of the introduction of exotic species include: 1) Reduced growth and development of the introduced forms because of less favorable environmental conditions than those found in their indigenous areas; 2) Population explosion of the introduced species, leading to competition with and eventual elimination of native species; 3) Concomitant introduction of new pests, diseases, and parasites harmful to resident species; and 4) Destructive activities of the introduced species affecting other fields of economic interest.

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