ENVIRONMENTAL IMPACT OF INTRODUCED ALIEN SPECIES

Jerome Lazard
Unite de Recherche Aquaculture, CIRAD-EMVT/GAMET, France

Lionel Dabbadie
Estado da Agricultura e do Abastecimento, CIRAD-EMVT, Brazil

Keywords: aquatic living organism, fish introduction , fish transfer, stocking, native species, exotic, species, strain, hybridization, introgression, predation, competition, fisheries, aquaculture, code of practice

Contents

Summary

Introductions of aquatic organisms are a very old practice, although the phenomenon only became large-scale at the end of the last century. Up to 1992, a total of 291 species

had been transferred to 148 countries for aquaculture purposes, for recreational fishing, for improving wild stocks, for ornamental purpose or for biological control of unwanted organisms (mosquito larvae, vegetation, phytoplankton). For several species, movement was also accidental, mostly through a transport in sea vessel ballast.

Impact of introductions concern mostly fish interactions (competition, predation, and stunting), environment (turbidity, eutrophication), and habitat alterations (disappearance of weedy sites), genetic deterioration (hybridization) of wild and introduced stocks, pathologic agents co-transfer or socioeconomic impact. When appropriately managed, these species transfers can lead to great success, as observed in Lake Kariba fisheries after *Limnothrissa miodon* introduction or in the Philippines aquaculture after tilapia transfer. But they can also produce more questionable or negative effects, like in Lake Victoria after *Lates niloticus* stocking or in many countries after brown and rainbow trout introduction through predation on native fish species.

Considering benefits of fish transfers, prohibition would be unrealistic, but on the other side, potential risks inherent to such practices are not to be underestimated. As a consequence, a code of practice has been elaborated in order to reduce the negative consequences of any desired or unexpected introduction and may lead, if appropriately managed with the active participation of the main users, to responsible fisheries and aquaculture throughout the world.

The trend is currently towards a reducing of the number of transfers, but the improvement of some technologies makes highly probable that movement of genetically modified organisms or hybrids may replace traditional fish species transfers.

1. Introduction

Large-scale introductions of exotic fish species are a relatively recent phenomenon, although in Europe introductions of some species are believed to date from Roman times, when common carps, *Cyprinus carpio*, from Eastern Europe have been cultured in ponds in Italy and in Western and Southern Greece.

However, the majority of fish introductions date from the end of the last century. Two types of fish species movements are classically recognized:

- Introduced species (includes both non-indigenous and exotic species): concern any species or race intentionally or accidentally transported and released by man into an environment outside its natural range
- Transferred or translocated species (includes transplanted species): concern any species or population intentionally or accidentally transported and released by man within its natural range

Introductions and transfers are usually carried out in a limited time frame, sufficient to establish the species in its new environment. As a general principle, an aquatic organism is regarded as introduced once it has crossed a national boundary.

Stocking usually refers to the repeated injection of fish into an ecosystem from an

external one. Stocked species may either be native to the recipient water body or may be exotic but previously introduced.

Naturalization refers to the establishment in the wild of free-living, self-maintaining and self-perpetuating populations of introduced fish without any support from man.

2. Trends in Introduction

Until 1989, a total of 1673 introductions concerning 291 species and 148 countries were reported (see Table 1). For the 1990s, there is no accurate information available but easier access to efficient live fish transportation means (such as liquid oxygen and plastic bags) leads to suppose that the number of introductions or re-introductions of commercial new strains may have increased significantly.

Number of successfully introduced species	ASIA	AFRICA	AMERICA	OCEANIA (Including Australia)		TOTAL
> 15	1	2	2	2		7 (8 %)
11–15	2	3	4	3		12 (13 %)
5–10	6	4	6	1		17 (19 %)
1–5	5	16	17	17		55 (60 %)
Total	14	25	29	23		
Most permissive countries	Philippines (22) India (13) Sri Lanka (13)	Madagascar (21) Zimbabwe (14) Kenya (14)	Colombia (33) Puerto Rico (21) Panama (14)	Hawaiian Islands (42) Australia (27) Papua New Guinea (15) Fiji (14) Mariana Islands (11)		

Table 1. Number of successful introductions by geographic region recorded as of 1992.

The number of species introduced into each country ranges from 79 into the USA to only one in 29 countries. Most introductions (36%) were made for aquaculture purpose, about 12% for recreational fisheries and 11% to improve wild stocks. Twenty-eight percent of introductions were either accidental through escape from aquaculture ponds and aquaria, or for reasons that are unknown.

The number of introductions indicates that the insertion of new species into native fish communities has been viewed as a legitimate management tool in the past and it will probably continue to be regarded so in the future. There is, however, strong international pressure to regulate the movement of species in order to reduce the risks of diseases co-introduction, of damage to the environment, to the native fish stocks and to the genetic composition of resident and introduced fish.

At the species level, a slowing in the number of new introductions has been detected, possibly because most practical introductions have already been made. However, given

the new awareness to local genetic diversity and the current efforts to domestication, to selective breeding and to genetic engineering in favor of obtaining better varieties for aquaculture, it is probable that a future wave of introductions will take place at the level of strains, varieties, hybrids, and GMOs of already existing species.

3. Reasons for Introduction

The purposes for which species have been introduced are various. Moreover, the motives for which exotic fish species have been moved from country to country have changed with time, as shown in Table 2.

Decade	Aquaculture	Sport	Fishery improvement	Ornament	Control	Accident	Unknown
1850	25.0			25.0		25.0	25.0
1860	20.0	50.0	10.0	10.0			10.0
1870	12.5	37.5	25.0	4.2		12.5	8.3
1880	35.7	25.0	10.7			10.7	17.9
1890	36.4	31.8	13.6	6.8		2.3	9.1
1900	29.6	29.6	18.5	7.4	3.7	1.9	9.3
1910	37.0	25.9	11.1		7.4	7.4	11.1
1920	14.5	25.5	10.9	3.6	9.1	21.8	14.5
1930	17.4	24.6	20.3	2.9	8.7	10.1	15.9
1940	25.0	25.0	13.3	1.7	8.3	6.7	20.0
1950	43.6	10.5	19.3	0.6	8.3	2.8	14.9
1960	45.7	8.2	11.4	1.8	10.5	10.0	12.3
1970	59.6	8.8	11.4	0.5	8.3	5.2	6.2
1980	69.4	6.5	8.1	0.0	0.0	4.8	9.7

Table 2. Changes in purpose of introductions expressed as percentage within each decade for each major category of use.

Introductions made for aquaculture purposes have been the most numerous. They have always comprised a significant proportion of the total but have grown in importance in the last decades. Since the beginning of the 1970s, introductions made for this purpose have accounted for well over half of the total.

Sport fishing has provided the second major motive for introduction with a relatively constant number of introductions per decade, although introductions for this purpose have relatively declined in importance since the 1950s.

Introductions made for improvement of capture fisheries in lakes, reservoirs and rivers increased in number from 1950 to 1980, when they overtook sport fishing as the second most important reason.

The use of fish species to control unwanted organisms has a long history but most of the introductions made for this purpose have been concentrated in the decades from 1950 to 1980.

Three categories of introductions are more problematic. Private operators have made most of the introductions of fish species for ornament and some have resulted from escapes into the wild. Dates of introductions are generally unknown and trends are difficult to assess. The dates of introductions due to various types of accidents are also generally unknown and introductions made for motives, which are unknown, declined since the 1940s. The most substantial reduction in this category since 1970 indicates that introductions of exotic species have been more carefully documented in recent years.

3.1 Aquaculture

Exotic species have played an important part in the development of aquaculture. As a result of this trend, only nine species accounted for 78% of the total world freshwater fish-culture in 1996. These major species for fish-culture have been introduced into countries throughout the world.

As of 1988, 98 species of fish have formed the subject of international introductions associated with aquaculture. Early international movements of species, up to 1900, mainly involved freshwater salmonids such as *Oncorhynchus mykiss* and *Salmo trutta trutta* which were introduced into temperate regions for aquaculture associated with the maintenance of sport fisheries, as well as for limited food production. Since the 1970s, salmonids introductions (mainly *Salmo salar* and *Oncorhynchus kisutch*) have involved anadromous forms, which are being used dramatically increasingly for mariculture in cages (Norway, Chile).

Common carp reached its maximum level of introduction and transfer in the decades between 1920 and 1940 and was then successively replaced by tilapias (1950–1980) and Chinese carps (1960–1980) as preferred species. Current trends point to an increasing number of crustacean species, which are being introduced worldwide for the rapidly expending brackish water shrimp culture.

The failure to deploy what are often judged equally desirable local species for aquaculture has often been cited as a criticism for this policy. However, there is a well-known trend for food producers to cut risk by using culture technologies that are already established. This explains the relatively narrow selection of species used in contemporary aquaculture. But there is now a tendency towards exploring the potential of “new” local species, mainly in tropical continents: South America, Africa and South East Asia.

3.2 Management of Inland Waters

The second category of introductions refers to those aiming at the manipulation of wild, or modified stocks in natural water bodies. Stocks of this kind are used for sport or recreational fishing and for a variety of food fisheries ranging from subsistence to fully

commercial.

3.2.1 Recreational Fishing

As of 1988, seventy-eight species were recorded as having been introduced for sport purposes. A great number of these are salmonids or larger predators having the fighting qualities sought by sport fishermen. The earlier decades of the century were mainly concerned with salmonids transfers whereas later, centrarchid species (large mouth bass, *Micropterus salmoides* and pikeperch, *Stizostedion lucioperca*) were introduced into a wide number of countries.

Many introductions made originally for sport fisheries have subsequently been adopted for aquaculture or have formed stocks, which are now exploited by subsistence or commercial fishermen.

3.2.2 Improvement of Wild Stocks

The motives for introducing fish species in order to improve wild stocks are numerous: establishment of new food fisheries, filling “vacant niches,” stocking natural waters, providing forage for predators, restoration of fisheries, establishment of a wild stock, control of stunted species... This applies particularly in faunistically impoverished regions such as temperate zones, which suffered glaciation during the Ice Age, islands east of Wallace's line or high elevation mountain waters. For the same reason, introductions have often been made to man-made lakes in which autochthonous species have been unable to establish themselves. In fact all the fish introductions for improving wild stocks refer more or less to the concept of “vacant niche” in the sense that there are resources within a water body which are not being used efficiently due to lack of suitable indigenous species.

The introduction of one species has often resulted in the need to follow it with another. When piscivorous fish species, for example, are introduced into fish communities, which have not evolved in the presence of such predators, the consequential decline or extinction of indigenous species has frequently rendered the introduction of replacement prey fishes essential. Classic examples of this situation are the introductions of *Lepomis* spp. to counterbalance the effects of black bass introductions, or the use of tilapias or *Cichlasoma* spp. as forage for *Cichla ocellaris*. Another example of this type of successive introductions occurs when herbivorous fish such as grass carp or common carp exert a eutrophicating effect on the water by converting primary producers from macrophytic to phytoplanktonic organisms. The resulting algal blooms can reach nuisance proportions and the phytoplanktivorous silver carp *Hypophthalmichthys molitrix* has often been introduced to curb excessive growths of blooms. This kind of fish associations refers to fish farming polyculture practices and can be extended to small water bodies’ management for extensive fish culture.

Several successes have followed the introduction of species as a foundation for capture fisheries, although negative effects may also happen (see: impacts of introduced fishes).

3.3 Example of Africa

Tilapiines, a native African fish Tribe within the family Cichlidae, have proved to be highly successful colonizing species in many countries due mainly to a suite of intrinsic biological attributes, including their rapid growth rates, wide physiological tolerances and habitat preferences, and their ability to feed on different components of the aquatic food chains so that they can exploit unutilized food resources in many systems. They also have a highly efficient reproductive strategy involving the mouth brooding of new recruits for *Oreochromis* and *Sarotherodon* species.

In African natural waters and man-made impoundments, introductions of tilapiines, generally together with fish species from other families, occurred for several reasons:

- Stocking natural lakes where no fish at all was present like Lake Nakuru (Kenya) and where *Oreochromis alcalinus grahami* was introduced, or where no tilapias were present like Lake Naivasha (Kenya) where *Tilapia zillii*, *Oreochromis spilurus niger* and *O. leucostictus* were introduced
- Filling a supposed vacant ecological niche in natural or man-made lakes. In Lake Kyoga (Uganda), the introduction of *Oreochromis niloticus* in the 1950s together with *Lates niloticus* allowed commercial fisheries to develop. Before the introduction of these fish species, the total fish landing was low (4500 t) and the native species constituted the bulk of the catch. In 1977, the commercial catch rose to a peak of 167 000 t where *Oreochromis niloticus* and *Lates niloticus* accounted for 41% and 42% respectively. At the same time, the native tilapiines disappeared from the reported commercial fisheries (which does not mean that they disappeared from the lake). In Lake Victoria, the introduction of the same two species allowed the total landings to reach more than 500 000 t in 1990 from 100 000 t during the 1970s, with a contribution of 300 000 t and 60–70 000 t from *L. niloticus* and *O. niloticus* respectively. In Cote d'Ivoire, it was estimated in 1988 that two introduced species, the tilapiine *Oreochromis niloticus* and the osteoglossid *Heterotis niloticus* accounted both for 50–70% of the total catch from inland fisheries. In the two major man-made lakes of this country, Lake Kossou and Lake Buyo where several tilapias species of genus *Tilapia* and *Sarotherodon* were already present, the introduced *Oreochromis niloticus* allowed the contribution of tilapias to total landings to increase from 50% to 80% in Lake Kossou from 1974 to 1987 and from 21% to 64% in Lake Buyo from 1980 to 1988. In Lake Buyo, *Heterotis niloticus* introduced in 1980 accounted for 16% of total catches eight years later. The aim of these introductions, which was to promote artisanal fisheries can be considered as successful operations

The success of the Lake Tanganyika fishery, based largely on catches of pelagic clupeids (*Limnothrissa miodon* and *Stolothrissa tanganicae*) which feed on the abundant plankton, gave rise to proposals for the introduction of these clupeids into other lakes lacking pelagic fish species. In 1967 and 1968, *Limnothrissa miodon* was introduced into the man-made Lake Kariba where it allowed a sustainable fishery to develop. The colonization of Cabora Bassa reservoir, below Lake Kariba downstream

the Zambezi River was even possible by individuals of *L. miodon* surviving passage through the hydroelectric turbines. In Lake Kariba, the total annual fish production from fisheries was estimated to be 2 600 t in 1970, twelve years after impoundment. First catches of *Limnothrissa miodon* were recorded in 1974 (500 t) and in 1991, total catches from the Lake were estimated at 30 000 t of which 26 000 t were *L. miodon* allowing the development of a sustainable commercial fishery.

The two species of Lake Tanganyika clupeids were also transplanted into Lake Kivu between 1958 and 1960 and an artisanal fishery started to exploit the clupeid stock at the beginning of 1980s. This plankton feeder occupied a vacant niche and the stock gradually developed and increased in size. This introduction has been presented as a biological and economical success and at the beginning of 1990s amounted to nearly two-thirds of the total catch.

-
-
-

Bibliography

Billington N. and Hebert P. D. N. (1991). Proceedings of the International Symposium on: The Ecological and Genetic Implications of Fish Introductions. *Canadian Journal of Fisheries and Aquatic Sciences*, **48**(1), 181. Ottawa, Canada: Canada Communication Group.

Conseil Supérieur de la Pêche (1997). *Les Introductions D'Especes Dans Les Milieux Aquatiques Continentaux En Métropole*, 518 pp. Bulletin Français de la Pêche et de la Pisciculture, 344–345, Paris, France: GIP Hydro systèmes.

Cowx I. G. (1998) *Stocking and Introduction of Fish*, 456 pp. Oxford: Fishing News Books/Blackwell Science.

FAO (1996). *Precautionary Approach To Capture Fisheries And Species Introductions*, 54 pp. *Technical Consultation on the Precautionary Approach To Capture Fisheries* (including: *Species Introductions*), Lysekil, Sweden, 6–13 June 1995, Rome, Italy: *FAO Technical Guidelines For Responsible Fisheries 2*.

Gophen M., Ochumba P. B. O., and Kaufman L. S. (1995). Some aspects of perturbation in the structure and bio-diversity of the ecosystem of Lake Victoria (East Africa). *Aquatic Living Resources* **8**, 27–41.

Lazard J. (1990). Transferts De Poisson Et Développement De La Production Piscicole. Exemple De 3 Pays D'Afrique Sub-Saharienne. *Revue D'Hydrobiologie Tropicale*. **23**(3), 251–265.

Lévêque C. (1994). Role and consequences of fish diversity in the functioning of African freshwater ecosystems: a review. *Aquatic Living Resources*, **8**, 59–78.

Welcomme R. L. (1988). *International Introductions Of Inland Aquatic Species*, 318 pp. FAO Fisheries Technical Paper, 294. Rome: FAO.

Biographical Sketches

Lionel Dabbadie graduated from the Agronomic School of Montpellier (France) with a doctorate from the University of Paris 6, has been working on fish farming in Africa and Brazil for the French

government-owned *Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (CIRAD). He has been awarded the silver medal of the French Academy of Agriculture for his work on the pond dynamics in the framework of African extensive fish farms. He is presently working in the Brazilian Tocantins State on a project of culture of Amazonian native fish species, particularly on the endangered Osteoglossid *Arapaima gigas*, in cooperation with the Tocantins government and private operators.

Jerome Lazard graduated from Montpellier University (Ph.D. Aquatic Ecology) and Paris 12 (HDR). He is currently appointed to the French government-owned *Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (CIRAD) in Montpellier (France) where he is in charge of the Aquaculture Research Unit. He spent 15 years as a scientist in West Africa where he implemented and carried out R. and D. fish culture projects, mainly based on tilapia aquaculture. Once back in France, he did several missions both as a consultant for building research and development strategies in the field of inland fish culture in many tropical countries (Africa, Asia, South America) and for the implementation of scientific collaborative programs in this field. His research topics focus on tropical fish culture production systems. He has been awarded the silver-gilt medal of the French Academy of Agriculture and he is a Life-Member of the Society of Aquaculture Engineers of the Philippines. He is the author of publications on tilapia aquaculture and fish culture projects analysis.