

# **Environmental Impacts of Tilapias <sup>1</sup>**

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Pullin, R.S.V., M.L. Palomares, C.V. Casal, M.M. Day and D. Pauly. 1997. Environmental impacts of tilapias. p. 554-570. In: K. Fitzsimmons (ed.) *Tilapia aquaculture - Proceedings from the fourth international symposium on Tilapia in aquaculture*. Northeast Regional Agricultural Engineering Service Cooperative Extension, Ithaca, New York. Vol 2.

## **Abstract**

Tilapias have been introduced as alien species to about 90 tropical or subtropical countries and territories, purposely for aquaculture or fisheries, or accidentally. In Africa, tilapias have been moved, again mainly for aquaculture and fisheries, beyond their natural ranges. Tilapia introductions are increasing as tilapia becomes an internationally traded commodity, and these introductions include not only alien species and subspecies but also genetically modified fish. Given the scale of past, present and likely future tilapia introductions, little has been published on their environmental impacts. This paper summarizes the information available and discusses how to improve the knowledge base. The invasiveness of tilapias is also discussed, using information from FishBase, a large relational database on the biology of finfish.

## Introduction

Tilapias, especially the Nile tilapia (*Oreochromis niloticus*) and an increasing number of strains, hybrids and other genetically-modified forms developed from this and other *Oreochromis* spp., are major contributors to world aquaculture production. Tilapia farms are being developed in many new areas to supply a global market. Exchange of live tilapias among existing farms and for the start-up of new farms is therefore increasing both among and within tilapia farming countries. Figures 1 and 2, which show this trend, have been compiled from a large relational database on the biology of finfish known as FishBase (Froese and Pauly 1997). Specifically, FishBase's Introductions Table (Agustin et al. 1996; Casal and Bartley 1997), which builds on the work of Welcomme (1988), provides the data. Note the increasing rate of introductions in around the 1960s, and its recent decrease, due to our consideration of first introductions only.

De Moor and Bruton (1988) emphasized that introductions of species to areas beyond their natural ranges include not only species that are 'alien' to a country but also translocations of indigenous species within a country, to waters beyond their natural range. Introductions of tilapias include wildtypes and genetically modified individuals (GMOs). The term GMO is used here in a broad sense, referring to all individuals that differ from wildtypes, whether as a result of domestication selection, selective breeding, hybridization, chromosome manipulation or gene transfer. Definitions of and perspectives on GMOs remain the subjects of wide debate (e.g., DOE 1994; Pullin 1994; USDA 1995; Pullin and Casal 1996).

We review here the literature on tilapia introductions and their environmental impacts and discuss the future implications of this knowledge (and of knowledge gaps). We consider only tropical, subtropical and warm temperate locations, where tilapias can survive in open waters, and not those locations where survival is possible in heated effluents and impoundments.

### Information on Tilapia Introductions and Their Environmental Impacts

The information available on tilapia introductions and their environmental impacts is surprisingly limited, given the long history and wide use of tilapias for aquaculture and other purposes (Table 1). Moreover, almost all of the published information concerns appraisal only *after* an introduction

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<sup>1</sup> ICLARM Contribution No. 1350.

has taken place. Among the rare examples of pre-introduction appraisals are the strict application of the EIFAC/ICES International Codes of Practice (Turner 1988) for introductions to establish fisheries in the Sepik-Ramu floodplain of Papua New Guinea (Coates 1995) and the procedures used by ICLARM, its Philippine and Norwegian partners in the Genetic Improvement of Farmed Tilapia (GIFT) project (Eknath et al. 1993) and by the members of the International Network for Genetics in Aquaculture (INGA). The GIFT project made prior appraisals (Bentsen et al. n.d.) of environmental risks from tilapia introductions to tropical Asia, and the INGA has agreed on voluntary protocols for safe exchange of tilapia and carp germplasm (INGA 1996).

Tables 2-7 illustrate the pros and cons of tilapia introductions. About 90 tropical and subtropical countries and territories have introduced tilapias. The results have varied with species. For example, *O. mossambicus* has been introduced and become widely established in open waters with some adverse impacts, but is little used in aquaculture. Conversely, *O. niloticus* is used to some extent in almost all countries to which it has been introduced and is the subject of fewer reports of adverse impacts. However, when more than one alien species is introduced, weighing up the pros and cons can be difficult. For example in Sri Lanka, *O. mossambicus*, an alien species, accounted for over 70% of the landings from reservoir fisheries in the early 1980s (De Silva 1985). Another alien species, *O. niloticus*, was introduced in 1975; Amarasinghe and De Silva (1996) have presented evidence that the two species have hybridized, with some imbalance in sex ratios of fished stocks. They pointed out that the long-term effects of this are difficult to predict but that early increases in yields, because the hybrids grow faster, might be followed by reduced recruitment and yields because hybrids are less fecund.

*O. niloticus* and *Lates niloticus* in Lake Victoria illustrate a further complexity. Ligtoet et al. (1995) stated that *O. niloticus* revived the Lake Victoria tilapia fishery and is now the only fished species of major importance apart from the Nile perch (*Lates niloticus*) and the pelagic cyprinid *Rastrineobola argentea*. Hence, although having contributed to the disappearance from the Lake Victoria fishery of native tilapias (*O. esculentus* and *O. variabilis*), *O. niloticus* appears to be now the only tilapia there that can thrive in the presence of Nile perch (Ligtoet et al. 1995). *O. niloticus* and *Lates niloticus* co-exist of course in much of their native ranges.

Substantial efforts have been made to document tilapia introductions (e.g., de Moor and Bruton 1988 - see Table 8; Welcomme 1988; Agustin et al. 1996) but there are large knowledge gaps regarding their environmental consequences. The evidence summarized in Tables 2-7 is, to our knowledge, the only published information.

### **Invasive species**

Predicting the ability of a species to invade new aquatic habitats, in addition to reviewing known impacts of the species in habitats that it has colonized, can help to assess the desirability of further introductions. Pimm (1989) suggested the invasiveness of a species can be measured and predicted, based upon the numbers introduced, its intrinsic rate of population increase and its longevity. These can be reexpressed, for fish, in terms of mortality rates, which are strongly related to length (Beverton and Holt 1959; Pauly 1980). Thus, invasiveness may be inferred from the maximum length of fish species.

To test this, establishment success (percentage of introduced species that became established in open waters) and their maximum total lengths (grouped in quantiles), based on 756 introduced species obtained from data in the Introductions Table of FishBase (Agustin et al. 1996, Casal and Bartley 1997), were plotted in a scatter graph (Figure 3). There is a clear trend of decreasing success by bigger species of fish. The negative sign of this relationship differs from what might have been expected from Pimm (1989), a theme not followed upon here.

The most widely introduced tilapias have such a large scatter about the line for all fishes that length is not a good predictor of their invasiveness. What can be seen, however, is that all these tilapia species (except *O. macrochir*, which has not been taken very seriously as a candidate for aquaculture and therefore its introduction has not been followed by sustained production) are moderately to highly invasive, having about a 60-95% chance of becoming established in open waters. It is not possible from this limited dataset to comment on the relative invasiveness of mouthbrooders and substrate spawners (see Noakes and Balon 1982 for a relevant discussion of these different life history strategies).

Pimm (1989) stated that impacts of introduced species could also be inferred from their new environmental conditions and community structures. The impacts of introducing carnivorous species are easily appreciated, and tilapias are not significantly carnivorous. However, severe impacts also may be expected when large herbivores are introduced into habitats lacking large predators or competitors. Similarly, communities with limited trophic options may collapse if herbivorous alien species take over major pathways.

### **A recent attempt to document tilapia impacts in Asia**

From June 1994 to June 1997, the Asian Development Bank supported an ICLARM project to study the impacts of tilapias, parallel to introductions of *O. niloticus* from the GIFT project to five countries: Bangladesh, the People's Republic of China, the Philippines, Thailand and Vietnam. The project was called "Dissemination and Evaluation of Genetically Improved Tilapia Species in Asia (DEGITA)". In order to identify farmers' perceptions of ecological impacts of the introduction of tilapias in the five countries, 521 fish farmers, in different agroecological and socioeconomic conditions, were asked whether introductions of tilapia had caused displacement or reduction of other species harvested from natural waters. Their responses are summarized here.

In Bangladesh, tilapia is not yet a popular fish, tilapia farming is not widespread, and few tilapias have escaped. Open water populations of tilapias are still small. In Kaptai Lake, a large reservoir, a decline in the fishery for Indian carps has been accompanied by an increase in tilapia landings, but the basis for this is not yet clear. Tilapias account for only about 1% of the catch from this lake, and a thorough study, including the effect of the increased use of disruptive gear and of harvesting indigenous carps during their spawning migration, has not yet been undertaken.

In most parts of China, tilapias cannot survive year-round in natural waters. Even where they can overwinter in natural waters, such as those of Hainan island and the southern part of Guangdong Province, there is no report so far that tilapias have become established or contribute to inland capture fisheries.

In Thailand, the fish farmers approached during the DEGITA project reported no displacement of other species in natural waters. However, many of the lakes and reservoirs were not sampled during the project.

In the northern part of Vietnam, tilapias are not found in natural lakes, reservoirs and river systems because of the low winter temperatures. Even in the warmer southern part of Vietnam, the fish farmers interviewed reported no displacement of other species to date.

In the Philippines, 84% of fish farmers claimed that tilapias were not causing displacement of other species in natural waters. However, 16% claimed that some natural species had been displaced by tilapias or that the landings of other species had been reduced substantially after the introduction of tilapia. In the Philippines alone, among the DEGITA-participating countries, millions of tilapia fry (*O. niloticus*) are stocked annually in open waters by government agencies. From this deliberate stocking and from substantial escapes from pond, cage and pen aquaculture, tilapias have come to dominate some open waters. In addition to the survey of farmers, a multi-

disciplinary DEGITA-Philippines project team from the government and NGOs employed a Rapid Rural Appraisal (RRA) technique to gather further data. This team did not find any displacement of indigenous species by tilapias except in some lakes where it was alleged that indigenous species (some of commercial value) are indeed threatened by introduced tilapias. Examples are the goby, *Gobiopterus lacustris* in Laguna de Bay; *Sardinella tawilis* in Taal Lake; *Mistichthys luzonensis* in Lakes Buhi and Bato and small endemic cyprinids in Lake Sebu. However, the literature on impacts of tilapia in the Philippines points out that many factors are involved other than tilapia introductions (Gindelberger 1983; De Silva 1997). For example, although a laboratory study indicated that tilapia feeds on *Mistichthys luzonensis* and, in Lake Buhi, an increase in tilapia landings coincided with a decline in the fishery for this species, other factors have contributed to its near extinction: the damming of the lake's outflow; increased fishing effort; and the introduction of motorized push nets, which have destroyed its breeding grounds, the beds of the aquatic macrophyte *Vallisneria* (Gindelberger 1983).

The balance of evidence seems to suggest that the decline of native species in some Philippine waters and in the Kaptai Lake, Bangladesh, has resulted from a combination of factors, among which the presence of tilapias is but one, and its contribution is hard to determine. It has also been argued that tilapias introduced into Asia have occupied "vacant niches", and consequently are not detrimental to the indigenous fauna (Fernando and Holcik 1982). Tilapias have generalized food habits, tend to adapt these to food availability, and are largely non-predatory (Maitipe and De Silva 1985). However, these views rest largely on assumptions, not on the results of detailed studies. The impacts of introduced tilapias on aquatic biodiversity in general, not just other exploited fishes, are still largely unknown. The DEGITA project experience shows how demanding it is to investigate even specific impacts on other fishes.

## Conclusions

We conclude that decisions taken and statements made about new tilapia introductions are based mostly on guesswork and against a background of polarized attitudes: *laissez faire* lack of caution versus exaggerations of risk. For example, in Southeast Asia, the private sector and some of its consultants are advocating the introduction of saline-tolerant tilapias (*Oreochromis spilurus* and *Sarotherodon melanotheron*) assuming that these species (or hybrids involving them) will thrive in the brackishwater ponds left underutilized by a declining shrimp culture industry. Despite previous bad experiences with the saline-tolerant *O. mossambicus*, such proponents for new introductions of alien tilapias emphasize only their assumed development potential and not their potential risks. On the other hand, those against tilapia introductions sometimes overstate their case, for example:

"In Southeast Asia, local races of fish are dying out from pollution and over-exploitation or are doomed to be replaced by new uniform strains of a hybrid tilapia" (Alvarez 1995).

The former part of this is true, but the latter is not supported by present evidence.

We hope that a more systematic approach to appraisal of the environmental impacts of tilapia introductions will develop, drawing upon and adding to the information available in databases such as FishBase. The recent study of the impacts of salmonid fishes introduced to Australia (Cadwallader 1996) and an action plan for Australian freshwater fishes (Wager and Jackson 1993) provide useful examples.

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Table 1. Reasons for introductions of freshwater fishes (including tilapias), as recorded in the Introductions Table of FishBase 97, with number of documented cases (from Casal and Bartley 1977).

Reason for introduction	Fish groups		Reason for introduction	Fish groups	
	Tilapias	other fishes		Tilapias	other fishes
aquaculture	209	147	research	5	7
unknown	15	112	snail control	-	7
ornamental	5	104	fill ecological niche	3	6
angling/sport	2	74	bait	1	5
accidental	1	43	phytoplankton control	1	5
diffusion from neighboring countries	2	19	off-site preservation	-	3
fisheries	10	17	other	-	3
forage	-	14	weed control	8	3
mosquito control	3	13	Total number of cases	265	581

Table 2. Summary of the history of introductions of *Oreochromis niloticus* to tropical and subtropical/warm temperate countries and territories outside its native range; introduced to 57; farmed on a significant scale in 28; farmed to some extent and used for research in another 28; established in open waters in 32, and probably in another 7; ecological impacts reported in 7. Sources: FAO (1996); Pullin 1988; Welcomme (1984, 1988); personal observations of authors and colleagues.

Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>	Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>
Bangladesh	1974	(+)	+	Laos	?	+	+
Bolivia	1977	+	+	Madagascar <sup>4</sup>	1956	(+)	+
Brazil	1971	(+)	+	Malaysia	1979	(+)	+
Brunei Darus	?	+	?	Malta	?	+	-
Burundi	1951	+	+	Mauritius	1950	(+)	+
Cambodia	?	(+)	?	Mexico	1978	(+)	+
C. Afr. Republic	1957	+	(+)	Nepal	1985	(+)	?
China	1978	+	(+)	Nicaragua	1964	(+)	+
Colombia	1980	+	(+)	Panama	1976	+	+
Comoros	?	-	?	Peru	1979	(+)	+
Congo	?	+	?	Philippines <sup>5</sup>	1970	+	+
Costa Rica	1979	(+)	+	Puerto Rico	1974	+	+
Cuba	1967	(+)	+	Réunion	1957	(+)	?
Cyprus	1976	(+)	(-)	Rwanda	1951	+	+
Dominican Rep.	1979	+	+	Saint Lucia	?	+	?
Ecuador	?	+	+	Saudi Arabia	?	+	-
El Salvador	1979	+	+	South Africa <sup>6</sup>	before 1955	(+)	(+)
Fiji	1968	+	+	Sri Lanka <sup>7</sup>	1956	(+)	+
Gabon	?	+	?	Syria	?	(+)	?
Guatemala	1974	(+)	+	Taiwan	1966	(+)	+
Haiti	1977	(+)	(+)	Tanzania <sup>8</sup>	1950s-1960s	+	+
Honduras	1978	+	+	Thailand <sup>9</sup>	1965	+	+
Hong Kong <sup>3</sup>	1972	(+)	+	Tunisia	1966	(+)	+
India	?	(+)	?	USA	1974	(+)	?
Indonesia	1969	+	+	Viet Nam	?	(+)	?
Israel	1969	+	(+)	Zaire	?	(+)	(+)
Jamaica	?	+	?	Zambia	1983	+	+
Japan	1962	(+)	+	Zimbabwe	1983	(+)	?
Kiribati	?	+	?				

<sup>1</sup> A = used for aquaculture; + = yes, reporting in FAO aquaculture statistics; (+) = information from sources other than FAO aquaculture statistics or indicates limited use in aquaculture or for research only; - = no.

<sup>2</sup> B = established in open waters; + = yes; (+) = probably; - = no; (-) = probably not; ? = no information available; entries in this column may include hybrids with other *Oreochromis* spp.

<sup>3</sup> Produced stunted populations and interbred with other tilapias such as *O. mossambicus* (Welcomme 1988).

<sup>4</sup> Hybridized with introduced *O. macrochir*, the basis of a former fishery in Lake Itasy and caused its disappearance (Welcomme 1984; 1988).

<sup>5</sup> Implicated in the elimination of endemic cyprinids from Lake Lanao, although other introduced species and environmental degradation were probably the main culprits (Bleher 1994).

<sup>6</sup> May hybridize and compete for spawning grounds with the indigenous *O. mossambicus* (de Moor and Bruton 1988).

<sup>7</sup> Has hybridized with introduced *O. mossambicus*, resulting in some imbalanced sex ratios (male dominance) and a decline in fecundity (Amarasinghe and de Silva 1996).

<sup>8</sup> Its establishment in Lake Victoria contributed to the disappearance of *O. esculentus* and *O. variabilis* (Welcomme 1988; Ogutu-Ohwayo 1991).

<sup>9</sup> Replaced some native species; reported as a pest in open waters (Welcomme 1988; de longh and van Zon 1993).

Table 3. Summary of the history of introductions of *Oreochromis mossambicus* to tropical and subtropical/warm temperate countries and territories outside its native range; introduced to 64; farmed on a significant scale in 10; farmed to some extent or used for research in another 8; established in open waters in 55; ecological impacts reported in 11. Sources: Eldredge 1994; FAO (1996); Welcomme (1984, 1988); personal observations of authors and colleagues.

Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>	Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>
Algeria	1961	(+)	+	Malaysia	1943	+	+
Amer Samoa	1957	-	+	Malta	?	-	(-)
Australia <sup>3</sup>	?	-	+	Martinique	1950	-	+
Bangladesh	1954	(+)	-	México	1964	-	+
Bolivia	1983	-	+	Micronesia	1970s	-	+
Brazil	1960s	(+)	+	N. Marianas	1955	-	+
Cambodia	?	+	?	Nauru <sup>8</sup>	1960s	-	+
China	1957	+	+	Nepal	1985	(+)	(-)
Colombia	1960	-	+	New Caledonia	1955	-	+
Cook Islands	1955	-	+	Nicaragua	1959	-	+
Costa Rica	1960+	-	+	Niue	?	-	+
Côte d'Ivoire	?	-	?	Pakistan	1951	(+)	+
Cuba	1968	-	+	Panama	1950	-	+
Dominica	1950	-	+	Papua New Guinea	1954	-	+
Dominican Rp	1953	+	+	Peru	1981	-	+
Egypt	1954	-	+	Philippines <sup>9</sup>	1950	+	+
El Salvador	1958	-	+	Puerto Rico	1958	-	+
Fiji	1954	(+)	+	Saint Lucia	1949	?	+
Grenada	1949	-	+	W. Samoa	1955	-	+
Guam	1954	+	+	Singapore <sup>10</sup>	1943	-	+
Guatemala	1955	-	+	Solomon Is <sup>11</sup>	1957	-	+
Guyana	1951	+	+	Sri Lanka <sup>12</sup>	1952	-	+
Haiti	1951	-	+	Tahiti, Fr. Polynesia	1950s	-	+
Hawaii <sup>4</sup>	1951	-	+	Taiwan	1944	(+)	+
Honduras	1956	-	+	Thailand <sup>13</sup>	1949	+	+
Hong Kong	1940	-	+	Tonga	1955	-	+
India <sup>5</sup>	1952	(+)	-	Trinidad and Tobago	1949	-	+
Indonesia <sup>6</sup>	1939	+	+	Tunisia	1966	-	+
Israel	1966	-	-	Tuvalu	?	-	+
Jamaica	1950	-	+	Uganda	1962	-	+
Japan	1954	-	(-)	USA <sup>14</sup>	1955	-	+
Kiribati <sup>7</sup>	1958	-	+	Vanuatu	1956	-	+
Korea Rep.	1953	+	-	Venezuela	1958	-	+
Laos	1955	-	+	Viet Nam	1955	-	+
Madagascar	1956	-	+	Wallis Fut. Is.	1966	-	+

<sup>1</sup> A = used for aquaculture; + = yes, reporting in FAO aquaculture statistics; (+) = information from sources other than FAO aquaculture statistics or indicates limited use in aquaculture or for research only; - = no.

<sup>2</sup> B = established in open waters; + = yes; (+) = probably; - = no; (-) = probably not; ? = no information available; entries on this column may include hybrids with other *Oreochromis* spp.

<sup>3</sup> Hybridized with *O. urolepis hornorum* and possibly other tilapias as well, little is known about the mixed strain which is recognized as a pest, with heavy penalties for farming or for distributing it (Arthington 1989); its diet overlaps those of some Australian fishes (Bludhorn et al. 1990).

<sup>4</sup> Suspected of reducing a valuable population of mullet, *Mugil cephalus*, by competing aggressively for the same food source of soft algae and detritus (Randall, 1987).

<sup>5</sup> Caused considerable damage to fisheries; widespread but not appreciated because of its poor taste and stunted growth; competes with more popular local fishes (Welcomme 1988; Shetty et al. 1989).

<sup>6</sup> Caused extinction of endemic molluscs as well as the endemic fish *Xenopoeilus sarasinorum* in Lake Lindu, Sulawesi (Welcomme 1988; Kottelat and Whitten 1996).

<sup>7</sup> Interfered with milkfish (*Chanos chanos*) culture (Lobel 1980) and caused a decrease in the mullet, bonefish and milkfish populations in the Fanning Atoll (Eldredge 1994).

<sup>8</sup> Destroyed traditional milkfish farming, a former source of food used for special occasions and ceremonies. Milkfish had to be imported from Guam or Kiribati (Eldredge 1994).

<sup>9</sup> Competed with milkfish for food in brackishwater farms (Juliano et al. 1989); led to the extinction of an endemic fish, *Mistichthys luzonensis*, in Lake Bui (De Silva 1989; Kottelat and Whitten 1996).

<sup>10</sup> Proliferated in reservoirs and man-made lakes; not well received as a food fish; feral populations inhabit freshwater and low-salinity habitats (Chou and Lam 1989).

<sup>11</sup> Probably led to the extinction of two duck species *Anas superciliosa* and *A. gibberifrons* (Nelson and Eldredge 1991; Eldredge 1994).

<sup>12</sup> Threatened a native species, *Schismatogobius deranigalae*, by competing with and preying on it in the Kelani basin (Pethiyagoda 1994).

<sup>13</sup> Considered a nuisance species and a bottom competitor to a brackishwater shrimp, *Penaeus merguensis*, in culture ponds (Piyakarnchana 1989).

<sup>14</sup> Generally regarded as a pest (Welcomme 1988).

Table 4. Summary of the history of introductions of *Oreochromis aureus* to tropical and subtropical/warm temperate countries and territories outside its native range; introduced to 24; farmed on a significant scale in 6; farmed to some extent or used for research in another 11; established in open waters in 12; ecological impacts reported in 2. Sources: FAO (1996); Pullin (1988); Welcomme (1984, 1988); personal observations of authors and colleagues.

Country/ Territories	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>	Country/ Territories	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>
Brazil	1965	(+)	+	Panama	1987	+	+
China	1981	(+)	+	Peru	1983	-	+
Costa Rica	1965	(+)	+	Philippines	1977	(+)	(-)
Côte d'Ivoire	1981	(+)	?	Puerto Rico	1971	-	?
Cuba	1968	+	+	Singapore	?	-	?
Cyprus	1976	?	(-)	South Africa <sup>3</sup>	1910	(+)	+
Dominica	?	+	?	Taiwan	1974	+	?
El Salvador	1963	(+)	+	Thailand	1970	-	?
Guatemala	1974	(+)	+	Untd. Arab Em.	?	+	?
Japan	1980	(+)	(-)	USA <sup>4</sup>	1954	(+)	+
Mexico	1964	-	+	Zambia	1980s	-	?
Nicaragua	1978	+	+	Zimbabwe	1983	(+)	?

<sup>1</sup> A = used for aquaculture; + = yes, reporting in FAO aquaculture statistics; (+) = information from sources other than FAO aquaculture statistics or indicates limited use or for research only; - = no.

<sup>2</sup> B = established in open waters; + = yes; (+) = probably; - = no; (-) probably not; ? = no information available; entries on this column may include hybrids with other *Oreochromis* spp.

<sup>3</sup> May have hybridized with *O. mossambicus* (de Moor and Bruton 1988).

<sup>4</sup> Competed with *Micropterus salmoides salmoides* for spawning space, thereby affecting its population size (Hale et al., 1995).

Table 5. Summary of the history of introductions of *Oreochromis urolepis homorum* to tropical and subtropical/warm temperate countries and territories outside its native range; introduced to 22; farmed in none on a significant scale; farmed to some extent or used for research purposes in 3; established in open waters in 4 with information lacking in others; ecological impacts reported in 1. Sources: FAO (1996); Pullin (1988); Welcomme (1984, 1988).

Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>	Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>
Brazil	1971	(+)	?	USA	1960s	(+)	+
Colombia	Unknown	-	?	Japan	1981	-	?
Costa Rica	1960s	-	+	Malaysia	1958	-	?
Côte d'Ivoire	1967	-	?	Mexico	1978	-	?
Cuba	1976	-	?	Nicaragua	1974	-	+
Dominican Rep.	1980	-	?	Panama <sup>3</sup>	1976	-	+
El Salvador	1979	-	?	Peru	1978	-	?
Fiji	1985	-	(-)	Puerto Rico	1963	-	?
Guatemala	1974	-	?	Singapore	?	-	?
Honduras	1979	-	?	Sri Lanka	1969	-	?
Israel	1977	-	-	Taiwan	1981	(+)	?

<sup>1</sup> A = used for aquaculture; (+) = information from sources other than FAO aquaculture statistics or indicates limited use or for research only; - = no.

<sup>2</sup> B = established in open waters; + = yes; (+) = probably; - = no; (-) probably not; ? = no information available; entries in this column may include hybrids with other *Oreochromis* spp.

<sup>3</sup> Considered undesirable in natural waters (Welcomme 1988).

Table 6. Summary of the history of introductions of *Tilapia rendalli* to tropical and subtropical/warm temperate countries and territories outside its native range; introduced to 18; farmed on a significant scale in 2; farmed to some extent in another 1; established in open waters in 13; ecological impacts reported in 3. Main sources: FAO (1996); Welcomme (1984, 1988).

Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>	Country/ Territory	Year	+/- A <sup>1</sup>	+/- B <sup>2</sup>
Antigua Barb.	?	-	?	Mauritius	1956	-	+
Brazil	1953	-	+	Papua New Guinea	1991	(+)	+
Burundi	1956	-	+	Peru	1966	-	+
Colombia	1960+	+	?	Puerto Rico <sup>5</sup>	1963	-	+
Cuba	1968	-	+	Rwanda	1956	-	+
Dominican Rep.	1979	+	?	Sri Lanka	1955	-	+
El Salvador	1960	-	+	Thailand	1955	-	?
Kenya <sup>3</sup>	1955	-	+	Uganda	1953	-	+
Madagascar <sup>4</sup>	1951	-	+	Wallis Fut. Is.	?	-	?

<sup>1</sup> A = used for aquaculture; + = yes, reporting in FAO aquaculture statistics; (+) = information from sources other than FAO aquaculture statistics or indicates limited use or for research only; - = no.

<sup>2</sup> B = established in open waters; + = yes; (+) = probably; - = no; (-) probably not; ? = no information available.

<sup>3</sup> Reported from the Tana River and Lake Victoria where it has possibly hybridized with *T. zillii* (Welcomme 1988).

<sup>4</sup> Although reported useful for weed control, it devastated nearly 3000 ha. of *Ceratophyllum* and *Nymphaea* beds which resulted in the almost total disappearance of a valuable indigenous fish *Paretroplus petiti* (de Moor and Bruton 1988).

<sup>5</sup> An efficient snail predator (Erdman 1984).

Table 7. Summary of the history of introductions of some tilapias (*Oreochromis*, *Sarotherodon* and *Tilapia* spp.) that are not yet widely used in aquaculture, to tropical and subtropical/warm temperate countries and territories outside their native ranges. Main sources: FAO (1996); Pullin (1988); Welcomme (1984, 1988).

Species	No. of Countries/ Territories to which introduced (names or regions)	Year(s) of first introduction(s)	No. of countries where any significant aquaculture of the species ensued	No. of countries (names/region) in which the species became established in open waters <sup>1</sup>
<i>Oreochromis andersonii</i>	3 (Congo, South Africa, Tanzania)	1960s-1970s	0	2 (S. Africa, Tanzania), ?
<i>Oreochromis esculentus</i>	1 (Rwanda)	1950s	0	1 (Rwanda)
<i>Oreochromis leucostictus</i>	2 (Kenya, Tanzania)	1954	0	2 (Kenya, Tanzania)
<i>Oreochromis macrochir</i>	14 (African continent and Indo-Pacific Islands)	1950s-?	0	3 (Mauritius, Madagascar, Hawaii), ?
<i>Oreochromis mortimeri</i>	1 (Zaire)	1958	0	1 (Zaire)
<i>Oreochromis shiranus</i>	1 (Madagascar)	1969	0	0
<i>Oreochromis spilurus</i> spp. <sup>2</sup>	7 (Africa, Mediterranean, Middle East)	?	2 (Malta, Saudi Arabia)	?
<i>Sarotherodon galilaeus</i> spp.	2 (China, South Africa)	1981, 1959	0	0
<i>Sarotherodon melanotheron</i> spp.	2 (Japan, USA)	1960s	0	1 (USA)
<i>Tilapia zillii</i>	16 (Africa, Caribbean, Japan, Mexico, Indo-Pacific Islands, South and Southeast Asia, USA)	1940s-1960s	0	10 (Antigua Barb, Guam, Japan, Kenya, Madagascar, Mauritius, Mexico, New Caledonia, Tanzania, USA), ?

<sup>1</sup> ? = status unknown in countries other than those mentioned here.

<sup>2</sup> *O. spilurus spilurus* and *O. spilurus niger*.

Table 8. Introductions of alien tilapia species and translocations of indigenous tilapia species, for aquaculture and inland fisheries in parts of southern Africa (Botswana, Namibia and South Africa): summarized from de Moor and Bruton (1988).

Species	Location(s) <sup>1</sup>	Impact <sup>2</sup> on natural communities or (degree)	Established not <sup>3</sup>	Source	Comments <sup>4</sup>
<b>1. Alien Species</b>					
a. <i>Oreochromis aureus</i>	n, S. Africa (western Cape, Natal)	- (p)	?	Israel	Range limited by cold; prevent contact with natural populations of indigenous tilapias.
b. <i>O. niloticus</i>	f, S. Africa (Natal, Stellenbosch)	- (?)	?	Israel	As 1a.
c. <i>O. niloticus</i> x <i>O. mossambicus</i> and other hybrids and red tilapias	c, S. Africa	? (?)	-		As 1a.
d. <i>O. spilurus niger</i>	c, S. Africa	? (?)	-		As 1a.
e. <i>Sarotherodon galilaeus</i>	f, S. Africa (Stellenbosch)	- (p)	-	Israel	As 1a.
f. <i>Tilapia zillii</i>	f, S. Africa (Jonkershoek valley)	- (m)	-	Israel	As1a; potentially very detrimental <sup>5</sup>
<b>2. Translocated Indigenous Species</b>					
a. <i>O. andersonii</i>	d, Botswana, northern Namibia (Shashi dam, Hardap dam)	- (?)	+	Okavango System	Prevent contact with natural populations of other indigenous tilapias outside its native range.
b. <i>O. macrochir</i>	d, Botswana, northern Namibia (Shashi dam, Hardap dam)	- (p)	+	Okavango System	As 2a.
c. <i>O. mossambicus</i>	d, f, n, Namibia, S. Africa (widely distributed)	± (m)	+	Limpopo and Zambezi Systems	As 2a.
d. <i>T. guinasana</i>	n, Namibia (Lake Otjikoto)	? (?)	+	Lake Guinas, Namibia	An endangered species.
e. <i>T. rendalli swierstrae</i>	d, f, S. Africa (Natal, Transvaal)	± (m)	+	Phongolo pans	As 2a; a nuisance species in some waters <sup>6</sup> ; selectively removes macrophytes.
f. <i>T. sparrmanii</i>	d, f, n, Namibia, S. Africa (Swakop and Kuiset Systems, widely distributed in the eastern and Southern Cape)	- (m)	+	Cunene river, southern Orange river	As 2a; potentially invasive.

<sup>1</sup> c = in captivity; d = in dams; f = in farm dams; n = in natural waters

<sup>2</sup> - = detrimental; ± = equivocal, ? = not known; (m) = major potential impact; (p) = potential impact; (?) = not known.

<sup>3</sup> - = not established; + = established; ? = not known, assume not established or with restricted range.

<sup>4</sup> for further details see de Moor and Bruton (1988).

<sup>5</sup> implicated in the elimination of *O. variabilis* from Lake Victoria.

<sup>6</sup> nuisance, defined as negative impacts generally outweighing any benefits.

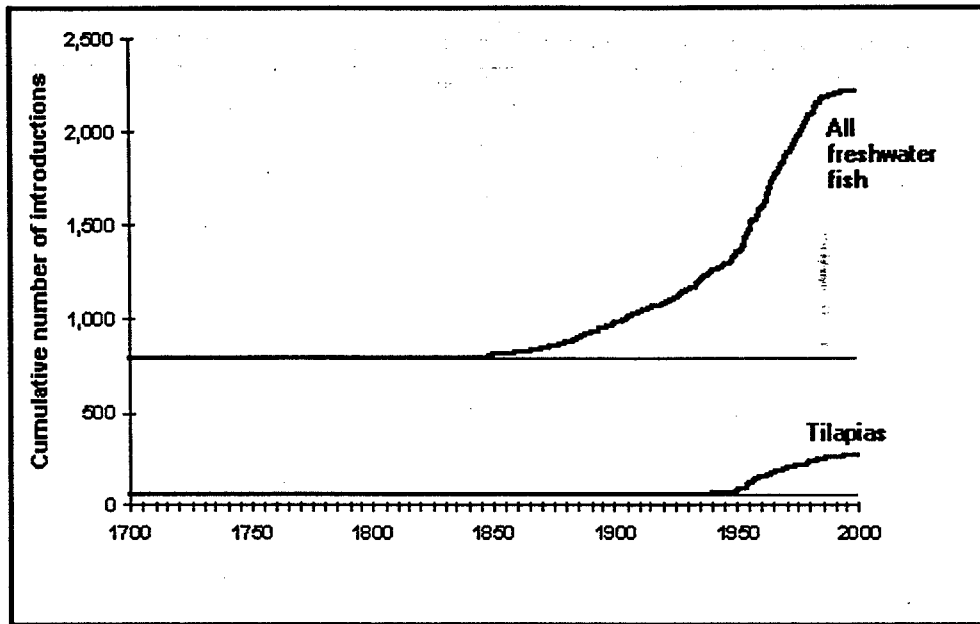


Figure 1. Cumulative number of first introductions of all freshwater fish and tilapias (*Oreochromis*, *Sarotherodon* and *Tilapia* spp.). The baselines represent introductions for which no dates are known. Source: FishBase 97 graph, based on data in Casal and Bartley (1997).

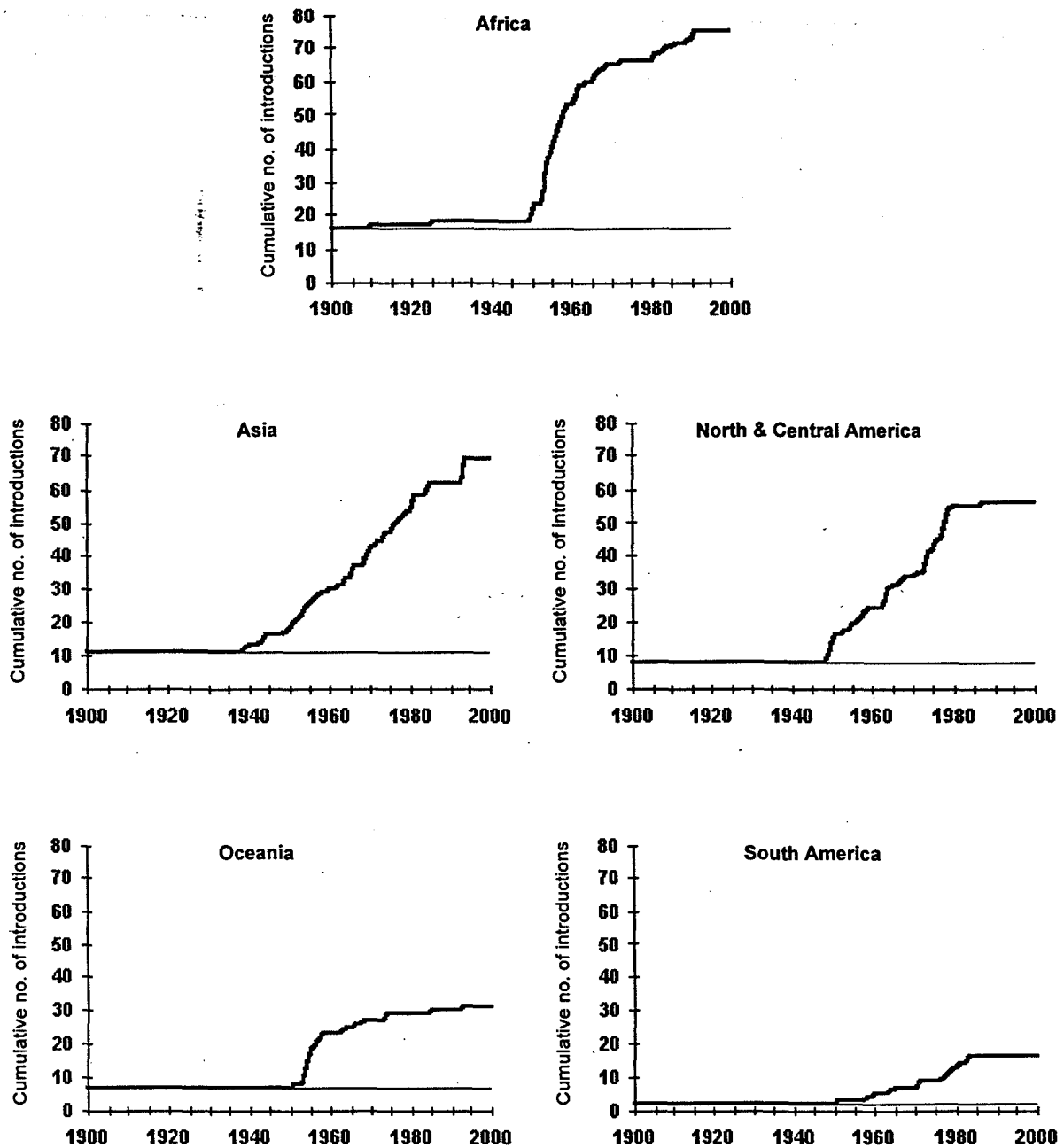


Figure 2. Cumulative number of first introductions of tilapias (*Oreochromis*, *Sarotherodon* and *Tilapia* spp.) by continent. The baselines represent introductions for which no dates are known. Source: FishBase 97 graph, based on data in Casal and Bartley (1997).



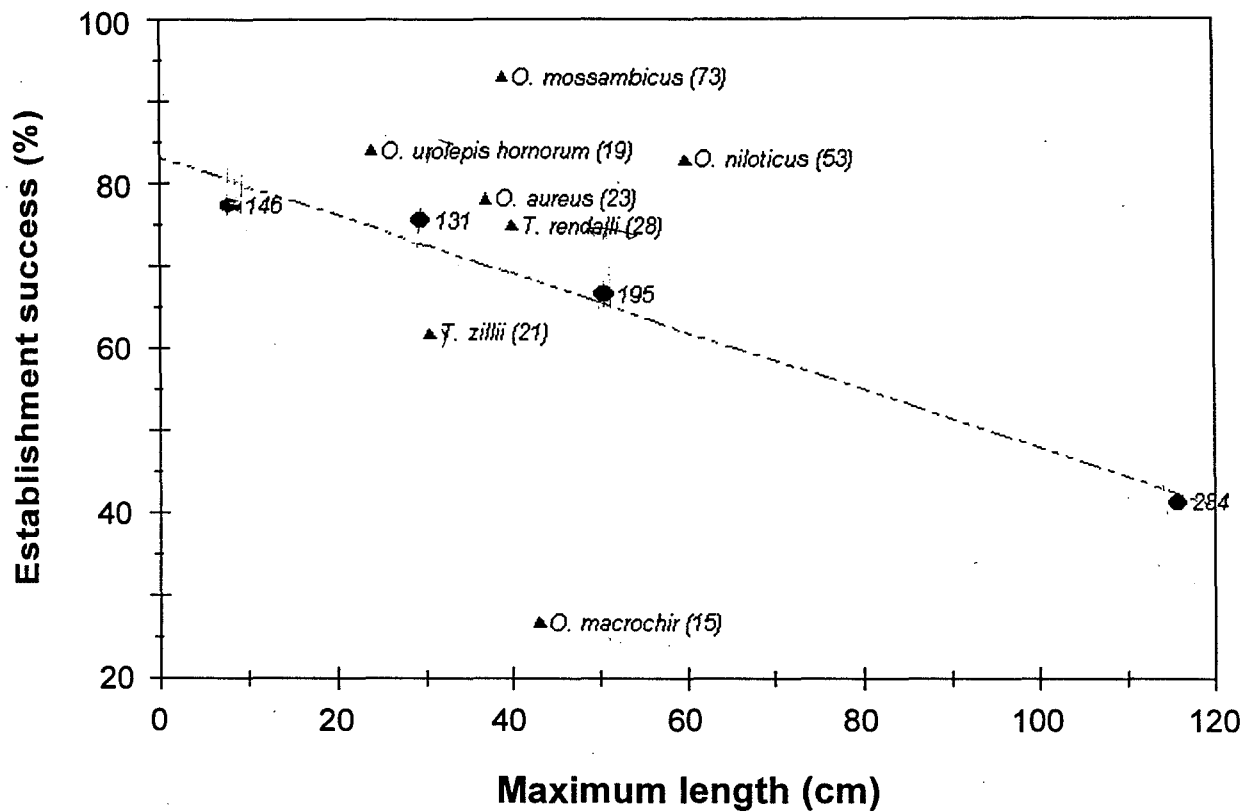


Figure 3. Establishment success (%) of alien fish species in open waters (without the need for subsequent restocking) vs. maximum recorded total length of the species considered. (Dots: all fish, N = 756;  $r = -0.977$ , d.f. = 2; triangles: tilapias, by species; N = 232). The numerical data given for the four points and for the tilapias (*Oreochromis*, *Sarotherodon* and *Tilapia* spp.) are the numbers of cases considered: each case represents 1 species x 1 country; altogether 171 species and 114 countries were considered. Source: records documented in Casal and Bartley (1997), grouped in 25% quantiles.