

# Invasive Species in Water-Dependent Ecosystems

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## Abstract

Alien invasive species may cause as much havoc in water-dependent ecosystems, such as wetlands, lakes and rivers, as they do in terrestrial systems. In the aquatic medium they are more difficult to detect and eradicate or even to control and there needs to be special effort to avoid such invasions from both alien species and genotypes. This paper describes some of the pathways and impacts of alien and other invasive species in aquatic situations and suggests that the intentional introduction of any species to a new environment should be preceded by a rigorous risk assessment process. The proposed introduction of modified *Oreochromis niloticus* (such as the GIFT strain which is now an alien genotype in Africa) is discussed in this light with examples of the impacts of introductions of this species in other places. It concludes with a plea that risk assessment must be taken extremely seriously for re-introduction in Africa.

## Introduction

Alien species are organisms that have been introduced intentionally or accidentally outside of their natural range. Alien invasive species are regarded as the most detrimental to pristine ecosystems and their dependent biodiversity (Williamson 1996; MacNeely 2001). Native species (see below) may also become invasive within their original areas of distribution if ecosystems or habitats change so that the species are “new to their surroundings”.

Intentional introductions in aquatic systems are usually brought about through attempts to enhance local fisheries or other food production systems or for the biological control of weeds, other pests or vectors of disease. They can also occur when there are deliberate movements of plants and animals from one country to another when people move or attempt to enhance their surroundings with foreign or familiar biota from other places. Unintentional introductions in rivers, lakes and wetlands come from the escapes of animals or plants from water-based production systems, especially aquaculture in its many forms. Alien species can spread unintentionally through transport and trade as well as travel, tourism and even relief and development aid - the so-called “pathways of invasion” (McNeely et al. 2001; Wittenberg and Cock 2001). The natural spread of invasion occurs once an alien has become established

in a new continent, country or ecosystem, especially along river systems and up and down catchments.

Following establishment, there is an unexpected or unnatural expansion of the invading population with harmful effects on the ecosystem that it invades. Invasion may result in domination, competition, exclusion and even extinction of local, natural populations of species, communities, habitats and ecosystems.

The following terms are used in referring to invasions and need some definition:

- (i) A native species is a species, subspecies or lower taxon occurring within its natural range and dispersal potential (i.e., within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans).
- (ii) An alien species or alien genotype (introduced, non-indigenous, exotic) is a species, subspecies or lower taxon occurring as a result of human agency in an area or ecosystem in which it is not native. A domesticated or genetically altered native species may become an alien genotype.
- (iii) An invasive species is a species which colonizes natural or semi-natural ecosystems. It is an agent of change and threatens native

biodiversity (species, populations and/or ecosystems).

- (iv) An alien invasive species combined (ii) and (iii) above often has the most serious or severe effects because it has not evolved in harmony with the ecosystem, for example it may have no natural “enemies”.

The term “water-dependent ecosystems” is used here to refer mainly to streams, rivers, floodplains, wetlands and lakes, but can also include creeks, estuaries and coastal marine systems influenced by freshwater, as well as artificial impoundments (dams, reservoirs, ponds) and constructed wetlands.

## Effects of Invasions

Invasive species can be plants or animals or micro-organisms; sometimes they are called weeds or pests or diseases and they cause some changes to ecosystems if they are able to establish themselves. Many introduced species, however, fail to establish or may take decades or centuries to become invasive, but when they do, they mostly cause changes that are deleterious to biodiversity. The main effects of invasions are:

- Competition by invasive plants for light, nutrients, space and niches within a habitat; competition by invasive animals for food, shelter, nesting and resting sites, hunting sites, breeding sites and places for cover from predators;
- Growth inhibition by invasive plants of other (native) plants through root exudates and other means;
- Physical dominance and cover of plants by invasive herbs, shrubs, trees, creepers and fast-growing climbers;
- Predation of animals by invasive animal species; infection by invading micro-organisms;
- Excessive grazing or browsing of plants by invasive animals;
- Introduction of pests, diseases and pathogens with alien invasive species; and
- Hybridization of aliens with native species and the subsequent reduction or extinction

(or permanent alteration) of the native population.

Invasions in water-dependent ecosystems may also have some of the following effects on the water of an ecosystem:

- ◆ Alteration (often impediment) of flow and changes in natural cycles of flow;
- ◆ Alteration (mostly reduction) of quantity and sometimes also in timing (seasonality);
- ◆ Alteration (usually lowering of acceptable standards) of quality in its broadest sense (including eutrophication, de-oxygenation, fouling, poisoning, and reduction of nutrients);
- ◆ Reduction or loss of hydrological benefits of wetland function; and
- ◆ Alteration of wetland functions downstream of invasions and across national and international borders.

While these are not necessarily the primary effects of the introduction of (say) alien fish, they may become the secondary impacts of such introductions if the fish concerned becomes invasive.

**Note:** Although the subject of this workshop consultation is the possible introduction of a fish, the effects of invasions relating to plants are just as relevant as there is a significant probability that an invasive herbivore may (directly or indirectly) alter the habitat such that plants become invasive as a result.

## Invasions in Water-Dependent Ecosystems

Invasions in lakes, rivers, floodplains, and wetlands are especially problematic because they are difficult to manage. This is because they are hard to detect (especially the submerged species). One reason is because the water they invade is often part of other ecosystems of value. Another reason is because the affected ecosystem or habitat is linked to others through the water sources or drainage systems - both upstream and downstream (Howard 2001; Kasulo 2001).

There are sometimes significant benefits from invasions such as increased fisheries yields from some invasive fish and crustaceans, and the by-products of invasive water-weeds like water hyacinth. Thus it is not possible to provide a prescription for wetland invasive management;

rather it is useful to consider why we want to prevent or control invasions and what is the desired state of an ecosystem after management has succeeded.

Note that in this approach, the impacts of aquatic invasive species are seen primarily as impacts on the invaded ecosystem as well as the possible long-term influences on people's uses of that ecosystem. Water-dependent ecosystems are frequently linked via watersheds, streams, and rivers to downstream systems so it is especially important to consider invasions in the upper catchments of a river basin or lake since these are likely to have the furthest-reaching impact in the long run.

## Management of Invasions

The best form of management for invasive species is prevention. This requires that potential pathways for invasions are known and that the identity of potential invasive species can be determined. Both are possible in many cases since the necessary information is becoming widely available through local and global databases of invasive species (for example <http://www.issg.org/database>) and because experiences are exchanged and lessons learnt are shared around the world. While this is necessary to protect ecosystems from unintentional introductions, there is a more defined process for intentional introductions. It is possible to ascertain if a species proposed for introduction has been shown to be invasive in other situations or at other times and to then make an assessment of the risk that introduction will lead to invasion. This is the process of risk assessment in relation to the proposed introduction of alien species that has its own well-defined logic and procedure (Groves et al. 2001; Wittenberg and Cock 2001). If the assessment shows that the risk is too great, a sensible decision is often to prevent the introduction or to ensure that it does not lead to invasion, if that is possible and feasible. Prevention of introduction of potentially invasive species is widely seen as the best and most effective way to avoid the consequences of invasions by alien and non-alien species. This principle of preventing the introduction of potentially invasive species is fundamental to the strategies for management of invasions as outlined in the Convention on Biodiversity in the Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species, by IUCN in the

Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species and by GISP in the Global Strategy on Invasive Alien Species (McNeely et al. 2001). Codes of practice specific to aquatic species have been developed by the International Council for the Exploration of the Sea (ICES 1995) and have been adopted by the FAO Code of Conduct for Responsible Fisheries (FAO 1995).

If the intentional introduction of a species is proposed but the information for an effective risk assessment is not available, the precautionary approach (Bartley and Minchin 1997; FAO 1996) should be invoked. Thus if there is no certainty that the available information can show that an introduction is not likely to lead to an invasion, the introduction should not go ahead, at least until the information becomes available to make that risk assessment.

Prevention of unintentional introductions is often not possible, so some form of management is required once an invasion has occurred. Ideally the best form of management is eradication - but this is often impossible to achieve - thus we usually refer to control as the process for reducing an invasion to tolerable levels.

Control of invasive in water-dependent ecosystems follows the normal methods for other ecosystems, but does have a special relationship with water due to the associated problems of access, visibility and connection to other ecosystems through the watery environment (Howard 2000):

- \* Mechanical: Control by removal, destruction, trapping or catching;
- \* Chemical: Control by pesticides, herbicides and poisons - few of which are specific;
- \* Biological: Control of exotics and usually with exotic biocontrol agents;
- \* Ecosystem manipulation: management, such as watershed management, water management, pollution control, competition with crops or local species; and
- \* Integrated management: strategies using some or all of the above.

Biological control (and associated integrated management) is the most enduring method of management of invasive as it brings original "enemies" (parasites, predators, pathogens, grazers, and browsers) of the invader to reduce its numbers to acceptable levels - just as it was in its native home. Once introduced with the

necessary precautions, biological control usually needs little extra inputs and, if properly screened in advance, should have no negative effects on other organisms.

### **Introduction of Nile tilapia (*Oreochromis niloticus*)**

*O. niloticus* is a freshwater fish native to the Lower Nile River Basin, some lakes of the Albertine Rift Valley, the Lake Chad Basin and some other river systems in West Africa and the Middle East. It has been intentionally introduced into many wild lakes, rivers and wetlands in Eastern and Western Africa to augment local fisheries and has been spread around the tropical and sub-tropical world as a species (or species complex) for aquaculture in Africa, Asia, the Americas and the Pacific. It is a favored and effective species for intensive, extensive, and low intensity production of fish for domestic and market consumption and, as with many other species in pond and cage culture, has a history of escape from the production systems and entry into wild waters wherever it has been cultured. It has become invasive in many situations around the tropics. A few examples are mentioned below.

*O. niloticus* (in its broadest sense including a range of subspecies, and varieties,) has become invasive in many water and wetland systems as a result of intentional introductions or escapes from aquaculture. Pullin et al. (1997) examined evidence of the impact of introductions of tilapias (especially *O. niloticus*) in Asia and were not convinced of excessive damage done. The invasive nature of *O. niloticus* in Lake Victoria, East Africa, however, is well known and its impacts there have been described as including competition with, and consequent elimination of, other *Oreochromis* species, other Cichlidae and possibly other types of fish as well (Pitcher and Hart 1995). Its introduction may have been the final blow that brought about the extinction of *O. esculentus* and *O. variabilis* in much of the lake (Twongo 1995), and it is now recorded as expanding its diet to include invertebrates and other fish as well as zooplankton, algae and plant material. Nevertheless, *O. niloticus* is now a very valuable component of the three-species fishery in Lake Victoria and is a favored food item for local and export consumption.

*O. niloticus* was introduced to fish farms in Zambia in 1982 from where it escaped to enter the Kafue River, a major tributary of the Zambezi.

It was also introduced for aquaculture in the Lake Kariba catchment and has now established in both the middle and lower Zambezi Basins. According to van der Waal (2002), it was distributed further south by anglers and fish farmers and eventually entered the Limpopo River Basin where it has now established and is regarded as a threat, through hybridization, to the indigenous *O. mossambicus*. Hybridization between *O. niloticus* and *O. mossambicus* is known to be possible and has been used to improve fish stocks in aquaculture in many countries. So the threat to the native tilapia of the Limpopo is very real.

*O. niloticus* and other tilapias are invasive alien species whose introduction in Meso-America is well known. This has happened principally through escapes from aquaculture projects followed by widespread expansion into many waterways, lakes, and even estuaries in several countries including Belize, Costa Rica, Cuba, El Salvador, Honduras, Mexico, and Nicaragua. Notable is the situation in Nicaragua where tilapias have now spread to all of the largest watersheds in the country (McCrory et al. in prep). Several impacts on natural aquatic ecosystems have been documented there. The biomass of native cichlids, once dominant in large sections of Lake Nicaragua, has been reduced by 80 per cent as a result of the establishment of tilapias (McKaye et al. 1995; McKaye et al. 1998). In Lake Apoyo, *O. niloticus* eradicated underwater vegetation (*Chara* sp.) and has occupied or destroyed feeding and breeding niches, and has promoted outbreaks of parasites among native species (McCrory et al. 2001), including species endemic to this lake, thereby presenting special threats of species extinction (McKaye et al. 2002).

These are but a few examples of the invasive potential of *O. niloticus* when it is introduced or escapes into waters where it is not native. Thus the introduction of this species, modified, hybridized, cross-bred or in its original form must be considered as a potential risk in any country. Its introduction in Africa must be preceded by a serious risk assessment, including consideration of the possible risk of invasion and subsequent short and long-term damage to ecosystems upon which many millions of people and diverse biodiversity depend. Short-term gains from enhanced fish species must be balanced with long-term impacts that could threaten or remove sources of survival for people and biodiversity. Introduction to Africa in general should be

considered a significant risk and introduction to Eastern Africa, especially where the species is already both native and invasive, an even greater risk from hybridization, expanded invasion and impacts on water-dependent ecosystems and their biodiversity.

## References

- Bartley, D.M. and D. Minchin. 1997. Precautionary approach to species introductions. Sweden/FAO Fisheries Technical Paper No. 350/2:159-189.
- FAO. 1995. Code of Conduct for Responsible Fisheries. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAO. 1996. Precautionary approach to capture fisheries and species introductions. Sweden/FAO Fisheries Technical Paper No. 350/1.
- Groves, R.H., F.D. Panetta, and J.G. Virtue (eds.) 2001. Weed risk assessment. CSIRO Publishing, Collingwood, Australia, 244 p.
- Howard, G.W. 2000. Control options, p. 227-232. *In* Preston, G., G. Brown, and E. van Wyk (eds.) Best management practices for preventing and controlling invasive alien species. The Working for Water Programme, Cape Town, South Africa, 316 p.
- ICES. 1995. ICES Code of Practice on the Introductions and Transfers of Marine Organisms. International Council for the Exploration of the Sea, Copenhagen, Denmark. 5 p.
- Kasulo, V. 2000. The impact of invasive species in African lakes, p. 183-207. *In* C. Perrings, M. Williamson, and S. Dalmazzone (eds.) The Economics of biological invasions. Edward Elgar Publications, U.K., 249 p.
- McCrary, J.K., E.P. van den Berghe, K.R. McKaye, and L.J. López Pérez. 2001. Tilapia cultivation: a threat to native fish species in Nicaragua. *Encuentro* 58:9-19.
- McCrary, J.K., B. Murphy, and Stauffer J.R. Jr. Distribution and status of tilapia (*Oreochromis spp.*) in Nicaragua, in preparation.
- McKaye, K.R., J.R. Ryan, J.R. Stauffer, L.J. López Pérez, G.I. Vega, and E.P. van den Berghe. 1995. African tilapia in Lake Nicaragua: ecosystem in transition. *BioScience* 45:406-411.
- McKaye, K.R., J.R. Ryan, J.R. Stauffer, L.J. López Pérez, G.I. Vega, E.P. van den Berghe and J.K. McCrary. 1998. Tilapia africana en el Lago de Nicaragua: ecosistema en transición. *Encuentro* 46:46-55.
- McKaye, K.R., J.R. Stauffer, Jr., E.P. van den Berghe, R. Vivas, L.J. Lopez, J.K. McCrary, R. Waid, A. Konings, W.J. Lee, and T.D. Kocher. 2002. Behavioral, morphological and genetic evidence of divergence of the Midas Cichlid species complex in two Nicaraguan crater lakes. *Cuadernos de Investigación de la UCA*, 12:19-47.
- McNeely, J.A. (eds.) 2001. The great reshuffling. Human dimensions of invasive alien species. IUCN - The World Conservation Union, Gland, Switzerland and Cambridge, UK, 242 p.
- McNeely, J.A., H.A. Mooney, L.E. Neville, P. Schei, and J.K. Waage, Editors. 2001. A Global strategy on invasive alien species. IUCN, Gland, Switzerland and Cambridge, U.K., 50 p.
- Pitcher, T.J. and P.J.B. Hart (eds.) 1995. The impact of species changes in African lakes. Chapman and Hall, Fish and Fisheries Series 18, 601 p.
- Pullin, R.S.V., M.L. Palomares, C.V. Casal, M.M. Dey, 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, Volume 2. Northeast Regional Agricultural Engineering Service (NRAES) Cooperative Extension, Ithaca, New York, 808 p.
- Twongo, T. 1995. Impact of fish species introductions on the tilapias of Lakes Victoria and Kyoga, p. 45-57. *In* T.J. Pitcher, and P.J.B. Hart (eds.) The impact of species changes in African lakes. Chapman and Hall, Fish and Fisheries Series, 18, 601 p.
- Van der Waal, B.C.W. 2000. Another fish on its way to extinction? *Science in Africa*.  
<http://www.scienceinAfrica.co.za/2002/january/tilapia2.htm>
- Williamson, M. 1996. Biological invasions. Chapman and Hall, 244 p.
- Wittenberg, R. and M.J.W. Cock (eds.) 2001. Invasive alien species: a toolkit of best prevention and management practices. CAB International, Wallingford, Oxford, U.K., 228 p.