The Potential Risks from Farm Escaped Tilapias

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Despite several decades of discussion among ecologists, tilapias that escape from farms and aquaculture research and development establishments remain a concern to suppliers and consumers as well as to environmentalists. This paper summarizes the risks posed by escaped tilapias. We recognize that tilapia farming and related research have resulted in escapes; and also that there is often little that can be done where these escapees have already established resident populations. The "Precautionary Principle" should be adopted while promoting tilapia farming in areas where resident tilapia populations do not already exist; and new introductions of tilapias should be avoided where they can escape and potentially hybridize with native species or native stocks.

General Conclusions

- Scientific studies to address the ecological impact of introduced tilapias have been limited.
- Tilapias have established feral populations in many tropical and subtropical lakes, reservoirs, rivers, and other wetlands, including coastal zones, though some species (for example *O. mossambicus*) have been more successful than others at establishing such populations.
- Feral tilapia populations can have both a positive as well as a negative impact. A positive impact includes increases in species diversity and productivity, though mainly in areas in the Asia-Pacific region where native species with the characteristics of tilapia are limited. A negative genetic impact of tilapia escapees is likely only in areas with native populations of the same or closely-related species.
- Tilapias are not predators so an adverse ecological impact due to tilapia predation on other biota is unlikely.
- Escaped tilapias that become established as feral populations can cause an adverse ecological impact through competition with wild fish for territory, especially feeding and breeding sites, and can alter habitats by grazing vegetation, release of nutrients in excreta and nest building.
- Escaped tilapias can introduce and spread a wide range of pathogens and parasites to wild fish and to other farmed fish including farming tilapias as alien species after ineffective quarantine.

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- New tilapia introductions in areas with no existing tilapias may result in an ecological impact.
- Prediction of the potential impact of tilapia escapees is difficult; furthermore, baseline information on recipient environments and their biological communities prior to escapes, are often lacking.

Recommendations

Recognize that the risks of an adverse impact resulting from the escape of tilapias from aquaculture depends not only upon the characteristics of those tilapias, especially their genetic and behavioral differences from wild fish, but also on potentially accessible environments and their biological communities.

New introductions of tilapias for aquaculture and enhanced fisheries should not be made into areas with high conservation value; or into areas with no existing free-living populations of tilapias.

New introductions of tilapias for aquaculture and enhanced fisheries should be avoided where they can escape and compromise the conservation of wild populations of the same or potentially hybridizing species that constitute important wild tilapia genetic resources for future use in breeding programs and research.

New introductions of tilapias for aquaculture and enhanced fisheries into areas with no captive or free-living tilapias need careful consideration, following the Precautionary Principle and FAO guidelines.

INTRODUCTION

Farmed tilapias have been an important global commodity since the 1990s. The production of farmed tilapias reached approximately 2.3 million tons in 2006, second only to farmed carps (FAO, 2006). Concern about potential ecological harm of escaped tilapias is also growing. Although all tilapia species are native to regions of Africa and the Levant, they have been introduced into more than 100 countries worldwide on every continent except Antarctica. Almost all farmed tilapia are species or hybrids of the cichlid genera, *Oreochromis* and *Sarotherodon*, with Nile tilapia (*Oreochromis niloticus*) and its hybrids accounting for over 90% of production. Eighty-five percent of farmed tilapia production now comes from countries outside their native ranges (Gupta and Acosta, 2004). Their ability to grow on a wide range of diets and to reproduce readily in captivity makes them attractive for culture (El-Sayed, 2006). However, their wide environmental tolerance and adaptability also make them potentially invasive in natural ecosystems (see information listed by species in Fishbase, www.fishbase.org).

The spread of free-living (non-captive) tilapias to areas outside their native ranges have been both positive and negative. Some free-living populations of tilapias that were introduced as alien species for fisheries enhancement or aquaculture provide important sources of food and income, e.g., in Papua New Guinea and Sri Lanka (De Silva et al. 2004). However, concerns have also been raised over the negative impact of escaped and purposefully released alien tilapias on biodiversity (Pullin et al., 1997; Canonico et al., 2005). All tilapias, either being cultured or studied, are potentially invasive (Pullin et al., 1997; Casal, 2006).

This paper reviews, a) some of the important issues associated with the ecological impact of free-living populations of tilapias, b) provides useful information for producers and buyers to improve existing aquaculture practices, especially to minimize the risk posed by escaped tilapias and c) directs readers to sources of information, advice, and codes of conduct.

BACKGROUND

Description of tilapia species and their physiological tolerance limits

Key species of importance for aquaculture include Nile tilapia (*O. niloticus*), Mozambique tilapia (*Oreochromis mossambicus*), blue tilapia (*O. aureus*) and their hybrids. Nile tilapia (*O. niloticus*) and its hybrids comprise more than 80% of the global tilapia aquaculture production (FAO, 2006). To initially predict whether farmed tilapia species may survive and reproduce in new environments, temperature and salinity limits of three commonly cultured tilapias are summarized below. There is a wealth of information on tilapia biology in databases and literature (see additional sources listed).

Species	Natural habitat	Tolerance limits	
		Salinity	Temperature
Nile tilapia	Tropical and subtropical Africa: in the Nile, Niger, Sénégal and Volta River basins; in Lakes Tanganyika, Albert, Edward and George; and in many smaller basins and lakes in Western and Eastern Africa. Its native range extends up to the Yarkon River, Israel (Trewavas, 1983)	Captivity: Upper limit,18 ppt (Trewavas, 1983; Philippart and Ruwet, 1982)	Captivity: 9 to 42 °C Natural range: 13.5 and 33 °C (FishBase; review by Shelton and Popma, 2006)
Mozambique tilapia	Tropical and subtropical Southeastern Africa from the lower Zambezi and the Limpopo systems	Captivity: Upper limit 120 ppt with gradual acclimatization	Natural temperature range: 17 to35°C Extended temperature range 8-42 °C

	down to South Africa, in fresh and brackish waters (Jubb 1974, Trewavas, 1983)	(El-Sayed, 2006)	(Fishbase; review by Shelton and Popma, 2006)
Blue tilapia	Its range extends from the Sénégal and Niger rivers up to the lower Nile and its deltaic lakes and into Israel (Trewavas, 1983)	Captivity: Upper limit, 45ppt (Trewavas 1983)	Occurs at temperatures ranging from 8°-30°C but can tolerate up to 41 °C. (FishBase)

Hybrids have been produced from various combinations of species within this group. Popular crosses include Nile x Mozambique tilapia, Nile x Blue tilapia and Blue x Mozambique tilapia. Hybridization often aims to produce monosex populations, improve growth, produce red coloration, lower food conversion ratio, and improve disease resistance and saline tolerance. The physiological requirements of these crosses depend greatly on the characteristics of the parental strains (Wohlfarth and Hulata, 1983).

Additional references to tilapia biology include Fishbase, Lim and Webster (2006), Lowe-McConnell (2000), Beveridge and McAndrew (2000) and Pullin and Lowe-MacConell (1982).

The pattern and numbers of escapees

The pattern and number of escapees from an aquaculture facility determine how many individuals and their life history stage (fry, fingerling, adult) enter receiving ecosystems. The pattern of escape can range from frequent escapes of small numbers of escapees (e.g., during production cycles) to less frequent escapes of large numbers of escapees per event (e.g., during a natural disaster such as a flood or storm). Research facilities, breeding programs, commercial hatcheries and grow-out farms may also determine the nature of escapes. For example, researchers – including research groups in commercial aquaculture - often work on a much wider range of species and on genetically altered types (e.g., selectively-bred, hybrids, genetically male tilapia and polyploids) that are in commercial use. The numbers and life history stages of individuals that escape per event and the frequency of escape events facilitate population establishment and geographic spread (Marchetti et al. 2004; Lockwood et al. 2005). This is especially important for impacting an indigenous species. Natural selection will limit the spread of inferior genes that might get into the wild fish through hybridization. If these genes are expressed under normal environmental conditions, they will not have much impact unless the introductions are massive and continuous (see McGinnity et al. 2003).

Different tilapia farming systems, levels of confinement and farm management practices pose different risks of escape. Tilapia farming systems include, in order of their levels of confinement and of isolation from surrounding environments: floating cages, pens, ponds, flow-through raceways, outdoor recirculating systems and self-contained recirculating systems. However, the risk of fish escape from a particular farming system depends also on farm location, the engineering design and construction of a farm (especially filters and other barriers to escapes) and maintenance and farm management by farm operators. The numbers of possible escapees may also depend on the intensity of production, ranging from low intensity (integrated aquaculture, extensive) to high intensity (large commercial monoculture) production systems.

Ecological concerns and documented ecological impacts

The types and extent of the potential adverse impact of free-living tilapias depends on the characteristics of the receiving ecosystem (lake, reservoir, wetland, river or estuary) as well as the characteristics of tilapia, the pattern of escapes, and the farm practices (Weyl, 2008). Tilapias have established resident populations in many bodies of water in tropical and subtropical areas around the world (Pullin et al., 1997; Fuller et al., 1999; De Silva et al., 2004; Morgan et al., 2004), including Australia, North and Central America, Africa, Asia, and the Pacific islands. The FAO Database on Introductions of Aquatic Species (http://www.fao.org/fishery/introsp/search) indicates that aquaculture is the major reason for the introduction of fish species to different countries. The ecological consequences of these introductions appear to be more severe in systems with a high level of endemism (Pullin et al., 1997; Casal, 2006).

Despite a large number of tilapia introductions worldwide, there are few reports on their ecological impact. Furthermore, it is difficult to conclude that an observed impact (such as reduction in biodiversity) is solely due to the spread of a free-living tilapia since most investigations were conducted after the introduction of tilapia. Gozlan (2008) showed that cichlids (including tilapias) had a relatively small likelihood of having an impact (the ratio of a documented negative impact to the number of introductions was <10% for cichlids) compared to many groups of introduced species such as catfish (family Clariidae) or perch (family Percichthyidae). Even though tilapias are considered to be invasive (i.e., rapidly spread into a new environment) in many locations invasiveness does not necessarily reflect their impact on the environment. Examination of a broad range of alien species (invertebrates, vertebrates and plants) did not reveal a strong relationship between invasiveness of a species and its impact (Ricciardi and Cohen, 2007).

A reduction in biodiversity (if any) due to a free-living population of an escaped tilapia would likely be a consequence of ecological interactions such as competition for feeding and breeding sites, spread of pathogens and/or alteration of habitats. In general, specialized carnivorous alien species that prey on native species are more likely to have a larger adverse impact than tilapias, most of which are unspecialized microphagous omnivores and detritivores.

Genetic Impact

Interbreeding between tilapia escapees and wild populations of the same or closely related species results in populations of free-living hybrids. As hybridization alters the characteristics of such populations, it may threaten or eliminate pure wild populations that are important tilapia genetic resources for future breeding programs for aquaculture. Most *Oreochromis* species interbreed freely, in nature and in captivity (Wohlfarth and Hulata, 1983; D'Amato et al., 2007). While introgression may be occurring in Africa between wild and cultured stocks, the risk of a negative impact may not be significant (Brummett, 2008). In addition to hybridizing with closely related species, tilapias also tend to inbreed and thus rapidly create sub-populations that can be distinguished both morphologically and with DNA. Important is the observation that these sub-populations tend to have less genetic variability than the original founder stock. Except for one population in Kenya that is tolerant of high temperatures, there does not seem to be adaptive value of any of this variability (Brummett and Ponzoni, in press). Thus, potentially adverse genetic impact from hybridization remains a major concern in areas with native populations of tilapias (Gupta et al., 2004).

Ecological impacts

An ecological impact may be triggered by the spread of free-living populations. It results from an alteration of the biotic or abiotic characteristics of the receiving ecosystem. The impacts that may be most pertinent to tilapia escapees include competition for food and space for breeding, the spread of pathogens, and changes in the physical or chemical properties of the water bodies. It is difficult to forecast potential impact(s). Therefore, Guidelines developed by international bodies such as the FAO emphasize precaution where relevant data are inadequate.

<u>Tilapia escapees may compete with native species</u> for food and breeding sites, thereby reducing their abundance, growth and reproductive success. Successful competitors utilize more of the limited resources that are available (i.e., exploitative competition) or exhibit behavior, such as territoriality or biting, that interferes with other species' ability to utilize these resources (i.e., interference competition; Fausch, 1998). Interspecific competition between escapees and resident populations has negative effects when: (a) resources are limiting, either by quantity or by the ability to access the resources; (b) there is a high degree of overlap in resource requirements between the introduced and native species; and (c) species are co-occurring.

The negative impact from food competition is difficult to measure in tilapias. Tilapias consume a wide range of diets (see Fishbase). They feed low in the food chain (e.g., algae, macrophytes, detritus and its microbial flora and fauna, benthic invertebrates and zooplankton). However, baseline information on the feeding ecology of potentially affected native species is often lacking. Moreover, data on dietary overlap between escapees and potentially affected fish alone are not adequate to predict whether competition will occur. For example, pond experiments conducted in Bangladesh and Nepal suggested that, despite food selectivity and dietary overlap between Nile tilapia and some small indigenous species (SIS), the introduction of Nile tilapia did not have a significant impact on the growth or the population structure of the SIS in a 21-month study (Ahmad et al., 2007).

Competition for breeding space may have serious implications in some locations where spawning areas are limited. *Oreochromis* spp. are female mouth brooders. Mouth brooding tilapias build nests in shallow areas in lakes, reservoirs and river margins. The males are highly territorial during reproduction. Tilapias breed year-round in the tropics. In Western Australia, Mozambique tilapia used over 80% of the shallow areas in the Gascoyne River to build nests approximately 60 cm. in diameter (Morgan et al., 2004). In Lake Nicaragua, Nile and Blue tilapia became dominant in some portions of the lake with a decline in the abundance of some native cichlid species (McKaye et al., 1995) presumably due to competition for feed and spawning space.

There are also a handful of cases in Asia and the Pacific where the spread of free-living tilapias might have caused a decline in biodiversity (Pullin et al., 1997; De Silva et al., 2004), but the ecological interactions of tilapias with local species were not thoroughly investigated. For example, Nile tilapia might have contributed to the elimination of endemic cyprinids from Lake Lanao, Philippines (reviewed in Pullin et al., 1997). Mozambique tilapia were considered among the main threats to the endemic sinarapan (*Mistichthys luzonensis*) in Lake Buhi, in the Philippines (reviewed in De Silva et al., 2004). Mozambique tilapia was also suspected to have reduced a valuable population of mullet, *Mugil cephalus*, in Hawaii (reviewed in Pullin et al., 1997). However, other anthropogenic factors such as heavy fishing pressure, habitat alteration and pollution may also have contributed to or even caused such declines.

In Asia where most tilapia is produced, there have been relatively few reports of a negative impact from escaped tilapias (Pullin et al., 1997; De Silva et al., 2004; ADB, 2005). This may be partly due to the limited number of detailed tilapia ecological impact studies in Asia, the species of choice (mainly Nile tilapia), and the types of ecosystems where the tilapia were released, e.g., some were areas with an already low abundance of other local species prior to the introductions (Fernando, 1991). However, a significant factor is likely to be the presence of wild predaceous fish such as snakeheads that are abundant in most inland ecosystems in topical and subtropical East, South and South East Asia; snakeheads and other native carnivorous fish consume tilapias and most likely keep their numbers and potential adverse ecological impact in check in relatively undisturbed environments.

<u>*The spread of pathogens*</u> by introduced species could occur either by bringing new pathogens to the new environment, or by harboring existing pathogens. This is a serious concern for many aquatic species that are transferred between regions/countries (FAO/NACA, 2001). Tilapias are relatively resistant to disease compared to other species, although a number of bacteria and parasites are known to affect their health (Shoemaker et al., 2000). These pathogens may not be specific to tilapias. The only paper that specifically discusses the possibility that free-living tilapias could spread a pathogen is a study of Lake Nicaragua (McCrary et al., 2007). The dominance of tilapias in Lake Nicaragua was associated with an outbreak of trematodes (parasites) that affect several native cichlid species. To effectively prevent the spread of pathogens, the precautionary approach is warranted (e.g., FAO/NACA, 2001).

The alteration of habitats resulting from the spread of free-living tilapias has been documented in Nicaragua and Brazil. The types of alteration included the removal of underwater vegetation, *Chara* sp. (McCrary et al., 2007); and increased nutrient loading from tilapia excretion, leading to eutrophication and algal blooms (Starling et al., 2002). Tilapia (Blue, Mozambique and Nile tilapia) have been dominant species in some watersheds within Nicaragua since the 1980s. In two lakes, *Chara* sp. beds rapidly disappeared soon after the spread of free-living tilapia (McCrary et al. (2007) ; *Chara* beds provided important feeding and breeding habitats for other native species and their removal may have contributed to the sharp decline in some native cichlids. In Lago Paranoá, a shallow reservoir in Brazil, Starling et al. (2002) measured the nutrient loading after removing some tilapia from some parts of the reservoir and concluded that high densities of Nile tilapia and Redbreast tilapia (*Tilapia rendalli*) might have contributed to eutrophication.

RISK ASSESSMENT

The documented negative impacts of the spread of free-living tilapias are few relative to their geographical distribution outside and within their native ranges; and to the scales on which the same species are farmed. The types and magnitude of such impacts are highly variable because of variations in the characteristics of the receiving ecosystems and of other factors, especially human interventions such as fishing pressure, water abstraction, siltation and pollution that affect both native and feral fish. This makes risk assessment even more challenging. The outcome of a risk assessment is risk characterization, illustrated as a matrix between the probability of an ecological event occurring and the severity of the impact (Miller et al., 2004).

The risk of a genetic impact is low for farming in areas outside tilapias' native ranges, unless an established feral population has become an important resource in its own right. However, the risks here of tilapia escapees becoming established as new feral populations in new ecosystems can be high. Most subtropical and tropical lakes and shallow reservoirs are prone to new colonization by tilapias that can tolerate, mature and reproduce in those environments. Mozambique tilapia, saline-tolerant strains of *Oreochromis* species, and hybrids can colonize brackish waters and some can survive and grow well in full strength seawater, though they cannot breed there. Factors that could suppress the proliferation of feral tilapias include fishing pressure, natural predators, and unsuitable habitats for feeding and breeding. Farms located in subtropical, and particularly in seasonally cold or saline areas, will tend to have a lower risk for the establishment of feral populations. However, global warming will likely expand the natural and farmable geographical ranges for some tilapias and the survivability of escapees.

The risk for genetic impact could be high from tilapia farming in areas where there is the possibility of escapees entering ecosystems with native populations of tilapias. The magnitude of a genetic impact from escapees will depend on the numbers of escapees into the wild compared to their wild counterparts, genetic differences between escapees and wild fish, the outcome of competition for feeding and breeding sites, reproductive success and the fitness of hybrid offspring.

It is important to be sure of the identification and breeding history of tilapias brought to farms because various tilapia species/strains have different physiological limits and different potential for being invasive in a particular location. Tilapia species may be identified by morphology or by the more recent technique of electrophoresis of biochemical and mitochondrial DNA markers (e.g., Penman and McAndrew, 2000; Costa-Pierce, 2003).

RISK REDUCTION MEASURES

In areas with heightened conservation concerns, risk reduction and mitigation measures may include the following:

1. restrict the expansion of tilapia farm areas;
2. prevent or reduce the number of escapes through physical, geographical and/or biological confinement;
3. promote strains that would be expected to have low to zero survival in nature;
4. eradicate or remove escapees from natural waters using mechanical (e.g., seining), biological or chemical methods; and
5. evaluate risk reduction measures by monitoring the presence of tilapias in the new environments

Restricting the expansion of tilapia farm areas

Zoning appropriate areas for farming tilapias and for conservation may help to prevent an undesirable ecological impact. Considerations for zoning may include geographic distance between the two zones and the connectedness of water bodies. The FAO Code of Conduct of Responsible Fisheries and the FAO technical guidelines for responsible fisheries (aquaculture development) provide general guidelines for designing aquaculture operations that would minimize impacts on the surrounding ecosystems (FAO, 1995; 1997). In addition, a newly proposed concept of 'twinning' development/oversight of aquaculture may provide guidelines for co-planning and management of aquaculture and biodiversity conservation (Bartley et al. 2008; FAO, in press).

Reduce the numbers of escapes through better physical, geographical and biological confinement

The aim of confinement is to prevent farmed fish from entering, or to reduce the number of escapees in the receiving ecosystem. Physical confinement includes structures that prevent escape such as screens, catchment basins, recirculating systems and pond dikes. Geographic confinement includes selecting farm locations in environments in which escapees cannot survive, such as extreme temperature and salinity conditions. Biological confinement aims to reduce the ability of escapees to propagate in the wild; this approach usually entails impairing reproduction of farmed animals, such as inducing polyploids or producing monosex populations. Because different types of confinement have different strengths and weaknesses, a combination of confinement types will maximize their efficiency. Mair et al. (2007), NRC (2004) and ABRAC (1995) provide strategies for confining genetically modified organisms. Similar principles can apply to managing escapes from farms.

Farm tilapia strains with low to zero probability of survival in nature

Some domesticated strains of tilapias are more prone to predation and less adaptable to new environments (e.g., red tilapia). Unfortunately, documentation on low to zero probability of survival in nature of domesticated tilapia strains is lacking.

Remove escapees and their recruits from natural waters using mechanical, biological or chemical methods

Conventional approaches in fisheries management to remove individuals from ecosystems include mechanical, biological or chemical methods (Wiley and Wydoski, 1993). Mechanical methods entail using seines or traps. To help improve water quality following the explosion of a tilapia population in a reservoir in Brazil, tilapia fishing was proposed as a strategy to remove tilapia from the reservoir (Starling et al., 2002). Biological methods include introducing specific predators, pathogens or manipulating relationships among plants and animal species in an ecosystem. Chemical methods include the use of rotenone. Important factors to consider when using chemicals include the doses specific to species, area of application and potential impact on other desirable species. These mechanical, biological and chemical controls need careful evaluation as they could lead to other problems.

Relevant resources to evaluating and managing risks posed by farm escaped tilapia:

Topics	Resources	Citations/URL
Tilapia biology	• Fishbase • Reviews, monographs and books on tilapia biology	www.fishbase.org Lim and Webster (2006), Lowe-McConnell (2000), Beveridge and McAndrew (2000) and Pullin and Lowe-Macconnell (1982).
Management of risks posed by alien aquatic species	Overall ecosystem • FAO Technical Guidelines for Responsible Fisheries 5: Aquaculture Development. • International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Health issues • Manual of Procedures for the Implementation of	 FAO (1995) FAO (1997) FAO/NACA (2001)

	the Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals • Aquaculture development. 2. Health management for responsible movement of live aquatic animals. <u>Genetic issues</u> • Towards Policies for the Conservation and Sustainable Use of Aquatic Genetic Resources. • Use of genetically improved and alien species for aquaculture and conservation of aquatic biodiversity in Africa. • Workshop on Status and Trends in Aquatic Genetic Resources <u>Confinement</u> • Book chapters and reports	FAO (2007) Pullin et al. (1999) Gupta et al. (2004) Bartley et al. (2007) Mair et al. (2007), NRC (2004) and ABRAC (1994)
Additional relevant web-based information sources	Asia Regional Tech Guidelines & Beijing Consensus ftp://ftp.fao.org/docrep/fao/005/x8485e/x8485e00.pdf Australian Guidelines. http://www.deh.gov.au/biodiversity/trade-use/invitecomment/index.html Canada Department of Fisheries & Oceans. 2003. National code on introduction and transfer of aquatic organisms http://www.dfo-mpo.gc.ca/science/aquaculture/national_code_e.htm Code of Conduct for Responsible Fisheries. http://www.fao.org/fi/agreem/codecond/codecon.asp FAO Technical Guidelines for Responsible Fisheries – Precautionary Approach to Capture Fisheries and Species Introductions. http://www.fao.org/DOCREP/003/W3592E/W3592E00.HTM ICES Code of Practice on Introductions & Transfers of Marine Organisms http://www.ices.dk/reports/general/2004/ICESCOP2004.pdf	

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