

REVIEW

REVIEWS IN Aquaculture

From Africa to the world—The journey of Nile tilapia

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Abstract

Despite the fact that Nile tilapia (*Oreochromis niloticus*) (Linnaeus, 1758) are African freshwater fish, they have been introduced into many countries inside and outside Africa. The journey of Nile tilapia started during the second half of the 20th Century, especially in Southeast Asia and the Americas, mainly for aquaculture and fisheries enhancement. Most of these introductions became well established in aquaculture. As a result, aquaculture of Nile tilapia has been steadily expanding in many countries. These fish play an important role in the livelihoods of local societies on different continents. This review summarizes the current knowledge on global Nile tilapia introductions and sheds light on their social and economic contributions to the countries into which they have been introduced, as well as their share in the global fish market. The ecological impacts of tilapia introductions have also been addressed. The success stories of the major Nile tilapia producers were highlighted so that the lessons learned from their experiences could be transferred to other countries.

KEYWORDS

Africa, Asia, impacts, introductions, Nile tilapia, The Americas

1 | INTRODUCTION

Tilapia are African freshwater fish belonging to the family Cichlidae. They are distributed all over Africa, except the northern Atlas Mountains and Southwest Africa.¹ About 700 Cichlid species have been reported in the African Nile basin.² Of those, Philippart and Ruwet³ reported 76 tilapia species across Africa. Fishbase⁴ suggested that the family Cichlidae includes 52 tilapia species (32 *Oreochromis*, 13 *Sarotherodon*, and seven *Tilapia* species). More recently, the names of *Tilapia dageti* (Thys van den Audenaerde, 1971), *Tilapia guineensis* (Günther, 1862), *Tilapia zillii* (Gervais, 1848) and *Tilapia mariae* (Boulenger, 1899) have been reclassified as *Coptodon dageti* (Thys van den Audenaerde, 1971), *Coptodon guineensis* (Günther, 1862), *Coptodon zillii* (Gervais, 1848), and *Pelmatolapia mariae* (Boulenger, 1899), respectively. Past publications may refer to the older invalid names, but the updated names are used in this document. This means that

there is still confusion among researchers in the taxonomic classification of tilapia.⁵

Eleven tilapia species are currently farmed in Africa,⁶ compared to only three species in 1980. However, Nile tilapia (*Oreochromis niloticus*) (Linnaeus, 1758) is, by far, the most widely cultured tilapia species,⁷ due to its economic value as one of the most important farmed fish species in the world. The culture of other tilapia species is also practiced, together with “not elsewhere included” or ‘nei’ ‘tilapia’. These species include blue tilapia (*Oreochromis aureus*) (Steindachner, 1864), longfin tilapia (*Oreochromis macrochir*) (Boulenger, 1912), three spotted tilapia (*Oreochromis andersonii*) (Casteinau, 1861), Mozambique tilapia (*Oreochromis mossambicus*) (Peters, 1852), Shire River tilapia (*Oreochromis shiranus*) (Boulenger, 1897), Tanganyikan tilapia (*Oreochromis tanganicae*) (Günther, 1894), mango tilapia (*Sarotherodon galilaeus*) (Linnaeus, 1758), blackchin tilapia (*Sarotherodon melanotheron*) (Rüppell, 1852), redbelly tilapia (*C. zillii*) (Gervais, 1848) and redbreast tilapia (*Coptodon rendalli*) (Boulenger, 1897).

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However, the production of this group is very limited, being only 62,393 metric tons (mt) (4.6%) of total farmed tilapia production in Africa in 2019.⁷

Nile tilapia are naturally distributed in the Nilo-Sudanian region, Ethiopian Rift Valley, the western Rift Lakes (Lake Albert, Lake Edward, Lake George, Lake Kivu and Lake Tanganyika) and Lake Turkana in the eastern Rift Valley. Nile tilapia is also naturally established in Central and

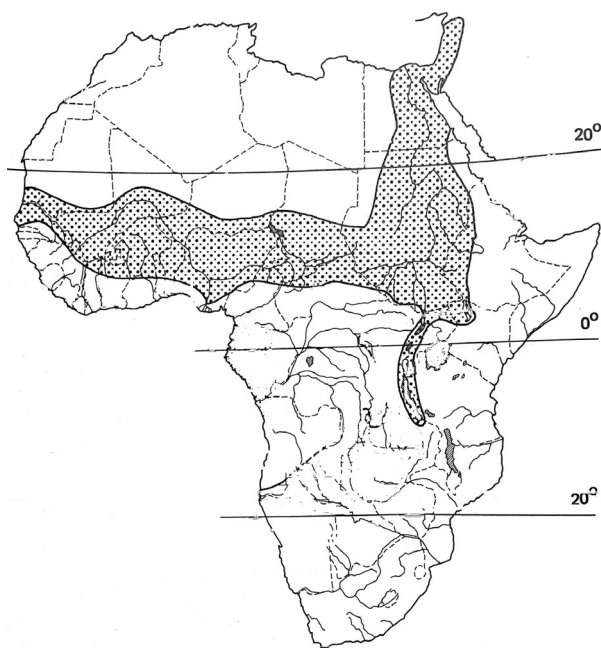


FIGURE 1 Natural distribution of Nile tilapia in Africa. Modified from: Philippart and Ruwet.³

Western Africa (Senegal, Gambia, Volta, Niger, Benue and Chad river basins) (Figure 1).^{1,3} Nile tilapia are highly adapted to tropical, subtropical and temperate environments. They are characterized by their fast growth rates, tolerance to extreme environmental conditions (such as temperature, salinity, pH, and low dissolved oxygen), high resistance to stress and diseases, trophic plasticity and feeding on low trophic levels, and their ability to reproduce in captivity.^{6,8,9} These attributes made them an ideal candidate for aquaculture all over the globe. It is no surprise, therefore, that 114 Nile tilapia introductions have been recorded worldwide (Figure 2), mainly for aquaculture and fisheries enhancement.¹⁰ As a result, tilapia culture has been developing at a high rate since the 1990's. Production of farmed tilapia increased from only 1 million mt in 2000 to over 6 million mt in 2019, with Nile tilapia contributing 74% to this production⁷ (Figure 3).

Nile tilapia, often described as the 'aquatic chicken' can be a low-priced fish compared with other farmed fish, which feed on higher trophic levels.¹¹ Therefore, it is sometimes considered a food for the poor, or the fish for the masses.¹¹ In many locations tilapia has played a significant role in rural development, poverty alleviation, hunger eradication and human health improvement in the developing and least developed countries, thereby directly contributing to the achievement of the United Nations Sustainable Development Goals (e.g., SDGs 1, 2 and 3). (<https://www.undp.org/sustainable-development-goals>). This has been achieved through fish supply for domestic consumption and export, generating more foreign currency, raising producers' income and creating employment opportunities.

We review global Nile tilapia introductions, and the economic and social roles they play in the regions and countries into which they have been introduced, and the success stories of the major Nile tilapia producers. It also discusses the adverse ecological impacts which may

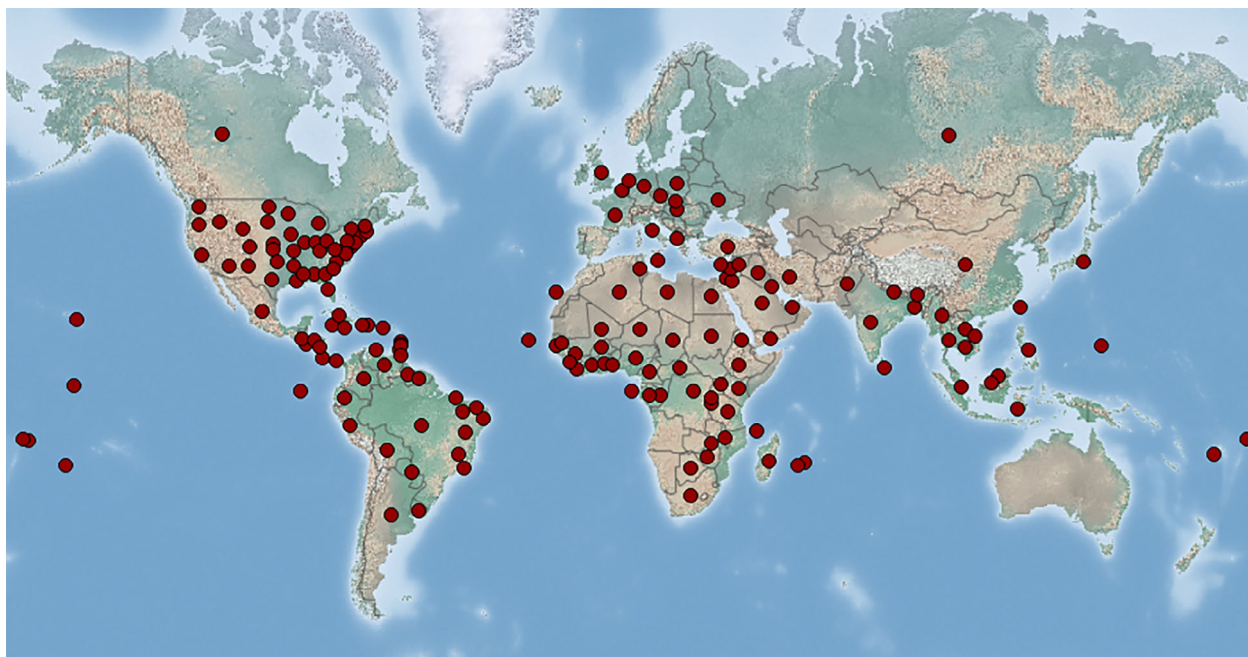


FIGURE 2 Global Nile tilapia introductions. Source: CABI Invasive Species Compendium (<https://www.cabi.org/isc/datasheet/72086>).

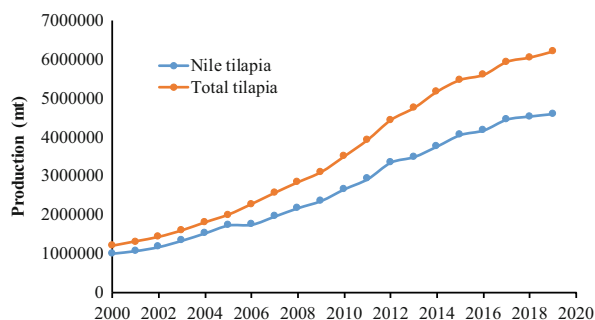


FIGURE 3 Global farmed tilapia production 2000–2019.⁷

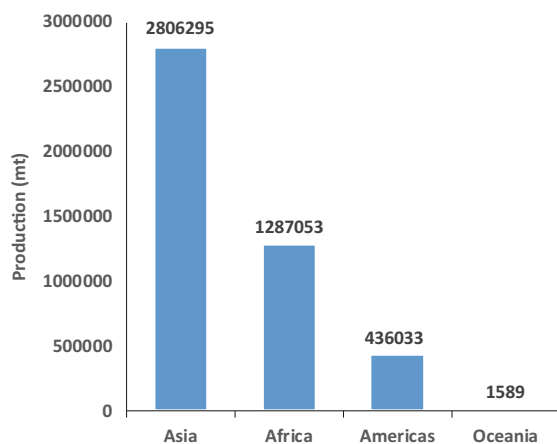


FIGURE 4 Production of farmed Nile tilapia by continent in 2019.⁷

result from tilapia introductions and transfers, so that the necessary precautions can be taken to avoid, or at least minimize, these adverse impacts.

2 | THE JOURNEY OF NILE TILAPIA IN AFRICA

The story of Nile tilapia culture in Africa started about 4000 years ago. As indicated from the biblical references and illustrations from ancient Egyptians tombs, tilapia farming is, arguably, rooted in Egypt, at about 4000 BC, about 1000 years before cyprinid carps culture was practiced and published in the first aquaculture text by Fan Li in China.^{12,13} Although a recent article¹⁴ hypothesizes carps may have been reared as far back as 8000 years ago. In recent history, the first tilapia culture trial dates back to 1924 in Kenya, when water ponds were stocked with different species of tilapias (especially *Oreochromis niger*) (Günther, 1894) followed by African catfish (*Clarias gariepinus*) (Burchell, 1822) and common carp (*Cyprinus carpio*) (Linnaeus, 1758).¹⁵ Ten years later, the first scientific fish farming trials took place in Egypt.¹⁶ Many other tilapia farming trials were conducted during the 1950s and 1960s throughout the continent, where thousands of small ponds were constructed for tilapia farming, mainly for subsistence, using extensive farming techniques.¹⁵

The real journey of Nile tilapia in Africa started in the 1990s, when tilapia was introduced, transferred or translocated in many African countries, mainly for commercial aquaculture and fisheries enhancement.^{17–19} By 2020 Nile tilapia culture was practiced in 30 countries throughout Africa,⁷ and their production increased from only 27,000 mt in 1990 to 1,287,053 mt in 2019, representing 95.4% of farmed tilapia production in Africa, and 68% of African inland water aquaculture outputs,⁷ and contributing 28% of global Nile tilapia output (Figure 4). However, Nile tilapia farming in Africa is dominated by a single country, Egypt, which contributed 84% (1,081,202 mt) to farmed Nile tilapia output in Africa in 2019. Egypt is also ranked third among the top global Nile tilapia producers in the world, after China and Indonesia (Figure 5a). Tilapia culture is also expanding in Uganda, Ghana, Kenya, Mali, Sudan, Tanzania, and Zambia (Figure 5b).

3 | EGYPT'S EXPERIENCE AND LESSONS LEARNED

Tilapia farming in Egypt is practiced mainly by small-scale farmers, using simple farming technologies and outputs. Extensive, semi-intensive (SI), intensive and integrated farming are applied; however, SI remains the most popular system. Over 80% of aquaculture output is produced under SI systems in earthen ponds, with mono-sex Nile tilapia being the primary species.²⁰ Farmed tilapia (and other fish) are fed with high quality extruded feeds (both sinking and floating pellets).^{21,22}

Nile tilapia, despite being freshwater fish, are able to tolerate a wide range of water salinity.²³ They can grow in brackish water (BW), at salinity of up to 15‰. They can also reproduce at water salinity ranging from 13‰ to 29‰.²³ Due to the scarcity of fresh water and abundance of BW in Egypt, Nile tilapia production is practiced mainly in BW environments, especially in the northern delta lakes areas along the Mediterranean coast. In 2019, 89% of farmed Nile tilapia in Egypt were produced from BW, whereas global Nile tilapia production in BW environment represented 21% of total Nile tilapia outputs.⁷

Nile tilapia culture has a major contribution to animal protein supply and food security for millions of Egyptians, especially among the poor and middle-class communities in rural areas.²⁴ Farmed Nile tilapia contributed 66% to national aquaculture production, and 43% to total fish consumption in Egypt in 2019.²⁰ Thus, out of 25.38 kg of fish consumed per capita per year, 11 kg come from farmed Nile tilapia. This confirms the significant contribution of farmed Nile tilapia to food security for the Egyptian population, especially among the poor and middle-class communities.²⁴

Almost all Egyptian tilapia production is directed to the domestic market; only about 10,000 mt are exported (GAFRD, personal communication, 2022),²⁰ mainly to the Gulf Cooperation Council region.²⁴ Farmed tilapia play a significant role in poverty and malnutrition eradication of rural Egyptian households, especially for nutritionally vulnerable groups, through providing good quality animal protein at low prices.^{24,25} In addition, Nile tilapia farming improves the livelihoods of tens of thousands of households, mainly by generating employment opportunities through the whole aquaculture value chain. Taking into account that 14 full-time jobs

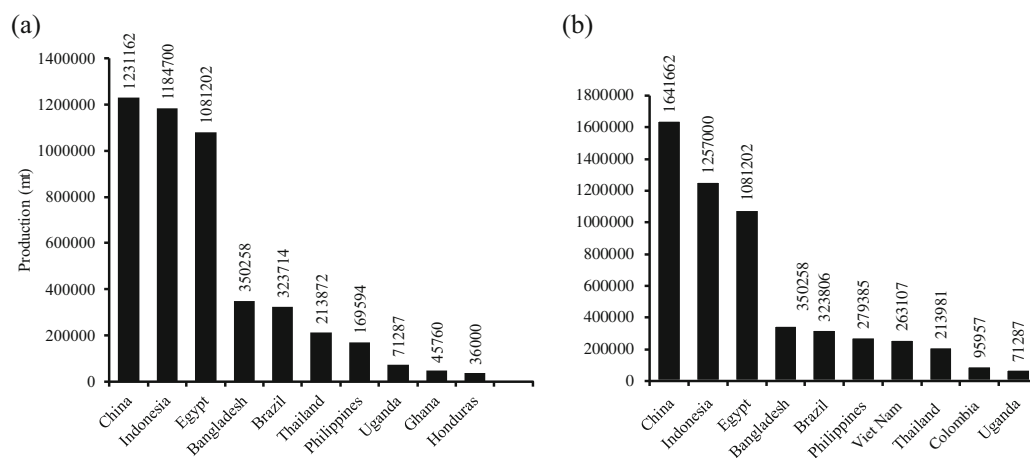


FIGURE 5 (a) Top producers of farmed Nile tilapia in 2019.⁷ (b) Top producers of total farmed tilapia in 2019.⁷

are required to produce 100 mt of fish,²⁶ it has been estimated that full-time employment in the tilapia value chain is currently about 151,000 persons. Many part-time jobs are also created throughout the production cycle (e.g., harvesting, transportation, and pond preparation).

3.1 | Other African countries

Tilapia farming plays a significant role in food security in several other sub-Saharan African regions. Countries such as Benin, Burundi, Cameroon, Congo, Cote d'Ivoire, Mozambique, and Rwanda are expanding Nile tilapia farming.²⁷ Different types of incentives are offered to encourage local and foreign investors to invest in tilapia culture which has been proven profitable. For example, Nile tilapia in Rwanda are farmed as a cash crop, with the cash generated from their sale used for buying necessary commodities.²⁸ In Tanzania, households of small-scale farmers in Mvomero and Mbarali districts consume substantial amounts of Nile tilapia they produce, while the remaining portions were sold mostly fresh to their neighbours.²⁹ In Zambia, tilapia contributes directly to food security and indirectly to income generation through fish retail and job creation. About 40% of fish farming households use all of the harvest for family consumption, while about 57% sell their harvest in local markets.^{30–32} Similarly, farmed Nile tilapia has become a major livelihood source for small-holder households in Ghana,^{33–35} Kenya,³⁶ Nigeria,³⁷ and Uganda,³⁸ through improving rural income, food and nutrition security and poverty alleviation.

4 | TILAPIA FARMING SYSTEMS IN AFRICA

Despite the huge potential of Nile tilapia farming in Africa, it has not kept pace with the changes in aquaculture technologies and lags far behind other producing regions. Tilapia farmers in most African countries, except a few countries (e.g., Uganda, Ghana and Kenya) adopt

non-commercial extensive systems in earthen ponds, mainly for subsistence. Farm ponds are generally very small (<100 m²–1000 m²).^{27,39,40} In Cote d'Ivoire, the Acadja-enclos system is still used in ponds with tree branches or bamboo poles placed in ponds to encourage periphyton to grow where the tilapia can easily graze. The branches and/or poles are then removed to simplify harvest.⁴¹ Family labour is generally used on African farms, while the use of hired labour is very rare because many small-scale farmers do not have the cash to hire external labour. Small fish ponds have been reported to improve food security, poverty reduction and health status and economic standard of rural households in Zambia,^{31,32} Uganda^{38,42} and Tanzania.²⁹

In commercial tilapia culture systems, both monoculture of Nile tilapia (*O. niloticus*) and polyculture of tilapia with North African catfish (*C. gariepinus*) and common carp (*C. carpio*) are commonly practiced, especially in sub-Saharan Africa (SSA).⁴³ The use of mixed-sex tilapia is common, although sex-reversed (all male) tilapia culture is spreading in a number of SSA countries.⁶ This system is primarily based on fertilization using a compost crib built inside the pond, where farmed tilapia depends on the enhanced natural food production. Stocking densities of tilapia fingerlings in this system are generally low, ranging from 1 to 4 fish/m³.²⁶ The more advanced farming systems, namely SI and intensive farming technologies are also practiced, especially in Egypt, Uganda, Ghana and Kenya. SI tilapia farming in earthen ponds is popular; where tilapia monoculture and polyculture systems are commonly used.^{6,39}

Intensive tilapia culture is practiced in a few African countries (Egypt, Ghana, Kenya, Nigeria, Malawi, Zambia, Zimbabwe, Cote d'Ivoire and Uganda), mainly in cages and, to a lesser extent, in tanks, raceways and recirculating systems.^{44,45} The aquaculture of Nile tilapia in floating cages is widely practiced in Egypt, with a production amounting to 119,291 mt in 2019, representing 11% of total farmed tilapia production and 7.3% of total aquaculture output.²⁰ While tilapia cage culture is developing in other African countries, it is still a relatively low contributor to total tilapia production.^{27,45} Small (48 m³) to medium (108 m³) cages, made of locally available materials, are

generally used. Commercial, large-scale cages (800–1200 m³) are also used in Ghana and Zimbabwe.^{39,46} In 2021 and 2022, multi-million dollar international investments have been placed for the cage culture of Nile tilapia in Ghana, Zimbabwe, and Lake Victoria (Uganda and Kenya) (El-Sayed, 2022, personal survey).

Intensive tank tilapia culture in Africa, especially in Egypt, is also growing. Most tank tilapia farmers in Egypt use concrete tanks for raising all-male Nile tilapia, at densities ranging between 25 and 100 fish m⁻³, depending on the initial stocking size. Tank-raised tilapia are generally fed with extruded feeds (sinking or floating pellets-25%–30% crude protein), to grow to about 200–300 g over a 5–7-month period. Tilapia culture in concrete tanks and raceways in the rest of Africa is very limited and is practiced in only a few countries, such as Kenya and Zambia.³⁹ The size and shape of tilapia culture tanks vary depending on the culture objectives. A few other large-scale commercial tilapia enterprises have been established in SSA (e.g., Republic of South Africa and Congo) (A.-F.M. El-Sayed, 2018, personal survey). Fish are fed either farm-made pellets or commercial feeds (mostly imported).

5 | THE JOURNEY OF NILE TILAPIA OUTSIDE AFRICA

During the second half of the 20th Century, Nile tilapia was introduced into many countries outside Africa, especially into Southeast Asia and the Americas, mainly for aquaculture and fisheries enhancement.^{4,47} Most introductions were successful; domesticated broodstocks and self-sustaining Nile tilapia populations are now established in many countries.^{10,48} Consequently, Nile tilapia became an important component of inland fisheries in many tropical and subtropical countries.^{49–51} Tilapia aquaculture was successful in many countries and has played a considerable role in the livelihoods, health and economies of rural societies in these countries.^{11,49} The following sections will briefly describe Nile tilapia culture in Asia and the Americas, with emphasis on major producers.

6 | THE JOURNEY OF NILE TILAPIA TO ASIA

Mozambique tilapia (*O. mossambicus*) was introduced in Indonesia in 1939, and to many other Asian countries during the 1950s and 1960s; but it was not widely accepted by the consumers.⁵² Alternatively, Nile tilapia was introduced from Africa to some Asian countries in the 1960s and early 1970s, for aquaculture and fisheries enhancement.^{3,49,52} During the following years, it was widely distributed throughout the continent. For example, Nile tilapia was introduced to Japan from Egypt in 1962, and was then introduced to Thailand and Taiwan in mid-1960s.⁴⁹ In the 1970s through 1990s, this species was introduced from Thailand to several Asian countries, including Bangladesh, India, Lao PDR, Malaysia, Myanmar, Nepal, Philippines,

and Vietnam.⁴⁹ Several Nile tilapia introductions from unknown origins have also been reported.⁴

As a result, Nile tilapia culture has become a popular, well-established, and profitable activity in Asian countries, such as Bangladesh, China, India, Indonesia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam.⁶ Nile tilapia culture is currently playing an important role in food security of local rural poor, due to the provision of cheap, high-quality food both to farmers' households and local markets and generation of cash incomes.^{11,53}

Nile tilapia has been a subject of continuous genetic improvement for many years in many countries. For example, the World Fish Centre (formerly known as the International Centre for Living Aquatic Resources Management [ICLARM]) initiated a selective breeding research programme in the Philippines, for genetic improvement of Nile tilapia more than 30 years ago, which resulted in the production of the genetically improved farmed tilapia (GIFT) strain.⁵⁴ After nine generations, the GIFT strains showed a 64% cumulative increase in growth over the original base population. As a result, GIFT has been disseminated to other Asian countries, including Bangladesh, Indonesia, Malaysia, and Sri Lanka.¹¹

7 | ROLE OF TILAPIA IN FOOD SECURITY AND RURAL DEVELOPMENT IN ASIA

Despite the fact that tilapia is not native to Asia, their introductions, especially in Southeast Asia, have resulted in significant benefits, including: a) establishment of capture fisheries in certain countries⁵⁵; b) an important aquaculture fish in most countries in the region, appropriate for a wide range of aquaculture operations^{49,56}; c) a source of affordable animal protein in many countries, improving nutritional and economic status of local households⁵¹; and d) providing employment and increasing income, and playing a significant role in rural development and welfare.⁴⁹ For example, introduced Nile tilapia is currently among the most important farmed freshwater fish in Southern China, especially in Guangdong and Hainan Provinces, mainly due to favourable geographic location and weather conditions.^{55,57} However, production is seasonal, and there are distinct periods of low growth. The fact that the commercial supply is stable is a testimony to the success in developing an export-oriented sector, with careful control of inventories.

As a result, Asia is currently the largest producer of farmed tilapia in the world, with a production of 4,141,976 mt in 2019, contributing 69% to global tilapia production.⁷ Nile tilapia is the dominant species, contributing 68% (2,806,295 mt) to total Asian tilapia production and 45% to global tilapia output (Figure 4). Most of this production comes from small-scale, rural farms.^{58,59} These family-owned, often contract farmers, in much of Asia are becoming more competitive to large-scale, commercially-managed tilapia farms.^{58,60} Nile tilapia is cultured mainly in polyculture systems or in integrated systems with other plant/animal species and separate information and statistical data on

tilapia production, value, etc., is generally not available in many countries.⁴³

Most of cultured Nile tilapia in Asia is produced in China, Indonesia, Bangladesh, Philippines, Thailand, and Vietnam, which are among the most heavily populated countries in Asia. These six countries produced over 65% of total farmed tilapia in Asia in 2019.⁷ Tilapia production is directed mostly to domestic consumption; however, significant amounts are exported to foreign countries, in different forms.^{61–63} The following section summarizes the role of tilapia production in general, and Nile tilapia in particular, on the livelihood and rural economies in these countries.

8 | BANGLADESH

Nile tilapia (*O. niloticus*) (Chitralada strain) was introduced into Bangladesh from Thailand in 1974, to replace another introduced species (*O. mossambicus*), which was not accepted by the farmers.⁶⁴ Nile tilapia was quickly accepted by the public, and has become the primary farmed tilapia species, due to their low prices, and low-cost operation with good financial returns.^{11,65} The culture of the GIFT strain has overtaken the Chitralada strain across most of Bangladesh as a means of increasing tilapia production and economic return, due to their better performance. Currently, there are more than 400 fish hatcheries in Bangladesh, using the GIFT strains, with a production of over four billion tilapia fry every year.⁶⁶ As a result, tilapia production in Bangladesh has witnessed a sharp increase in recent years. Until 2008, no official tilapia production from Bangladesh was reported in Food and Agriculture Organization (FAO) records; reported production started in 2009, with only 16,237 mt. Since then, Nile tilapia production has grown to reach 350,258 mt in 2019, over only 11 years.⁷

Nile tilapia culture plays a vital role in rural livelihood in Bangladesh since the fish are produced exclusively in freshwater environments in rural areas, through production, direct consumption,

distribution and marketing.⁵³ Tilapia is now the third most important fish species in Bangladesh, after pangas (*Pangasius* sp.) and rohu (*Labeo rohita*) (Hamilton, 1822).⁶⁵ Tilapia are used mainly for subsistence and can be an economical source of food fish and additional income. Small-scale Nile tilapia culture in rural regions is basic, requiring very low inputs and labour, and can be undertaken by women and even children.^{11,67} Tilapia farmers made significant profit by selling tilapia seeds to other tilapia growers.^{68,69} In addition, landless farmers can benefit from tilapia farming by culturing these fish in common property roadside ditches.⁷⁰ The integration of Nile tilapia farming with existing farming systems has also significantly improved the livelihoods and reduced poverty of households in rural and peri-urban areas in Bangladesh.⁶⁷

9 | CHINA

China is the world's leader in tilapia farming, with a production of 1,641,662 mt in 2019, contributing 20% to total tilapia outputs (Figure 5b).⁷ Also, China contributed 27% (1,231,162 mt) to total global Nile tilapia production. Guangdong, Hainan, Guangxi, Fujian and Yunnan are the major tilapia producing provinces in China; contributing over 95% to national total tilapia production⁶⁰. Small-scale and household-based tilapia farming is widely practiced in these provinces, making an important contribution to sustainable rural development, including food security, employment, income generation, diversifying livelihoods, utilizing family labour, and empowering women.⁶⁰

Tilapia production has been expanding at a steady rate, along with domestic and international markets. Huge governmental support has been provided to tilapia producers, processors, and traders.⁷¹ An example of this support is the development of tilapia culture in Guangdong Province, especially around the city of Maoming. Governmental support comprises services and supervision for all tilapia industry stakeholders, including improving farming technologies, well-trained researchers, strict quality supervision systems, disease

TABLE 1 The contribution of tilapia to total freshwater (FW) fish production in major tilapia producing countries in 2019.⁷

Production system	Africa	Americas		Asia					
	Egypt	Brazil	Mexico	Indonesia	Philippines	Bangladesh	China	Thailand	Vietnam
Tilapia fisheries (mt)	140,702	22,770	91,143	70,450	41,802	NA	NA	19,300	NA
Total FW fisheries output (mt)	229,479	218,932	151,638	480,935	90,421	929,872	1,383,929	129,300	128,120
% tilapia in total FW fisheries output	61.31	10.40	60.11	14.69	46.23	NA	NA	14.92	NA
Aquaculture of Nile tilapia output (mt)	1,081,202	323,714	NA ^a	1,130,000	174,212	350,258	1,231,162	213,872	NA
Total tilapia aquaculture output (mt)	1,081,202	323,806	56,945	1,166,800	279,386	350,258	1,641,662	213,981	263,107
% Nile tilapia in total tilapia output	100	99.97	-	96.84	62.40	100	75.00	99.94	-
Total FW aquaculture output (mt)	1,306,335	527,591	63,017	3,714,500	298,132	2,209,839	25,068,485	383,309	2,950,200
% tilapia in total FW aquaculture output	82.77	61.37	90.36	31.41	93.7	15.85	6.55	55.82	8.92
% tilapia in total FW fish output	70.40	46.42	68.99	29.49	71.9	11.16	6.21	45.51	8.55

^aNot Available.

prevention and treatment, establishing breeding technology, and low interest financing for contract farming, processing plants and marketing support.⁷² As a result, tilapia culture was rapidly developed in the Maoming district, so that it has become China's largest tilapia producer, and also the main centre for tilapia export processing^{11,55} (CICCE, China International Cold Chain Equipment and Fresh Logistics Exhibition) (<http://www.coldchain-china.com/index.php?m=content&c=index&a=show&catid=66&id=68>).

In addition to supplying the domestic market with tilapia as a source of high quality, low-cost animal protein source, huge amounts of tilapia are exported to international markets.⁶³ The local tilapia fish market is dominated by farmed Nile tilapia, while the contribution of tilapia from captured fisheries is limited (Table 1). China has been the largest tilapia exporter in the world for many years, with a huge competitive advantage over other exporters, due to the low cost of Chinese tilapia. A total amount of 445,844 mt of tilapia (mainly Nile tilapia) was exported in 2018, contributing 87.4% and 79.2% to Asian and global tilapia exports, respectively,⁷ with USA and Africa being the main markets for Chinese tilapia.

China realized the importance of tilapia as an export commodity to foreign markets and took strong measures to promote tilapia exports. The Chinese government established an early warning system on tilapia trade for assessing and monitoring the status and trends of tilapia culture industry.⁷¹ The system provides the necessary strategies that facilitate sustainable tilapia development in China, using economics, management science and information technology to analyse the status of the tilapia industry, identify the major warning signals and, in turn, forecast the future trend of the industry.

However, between 2015 and 2020, the China Aquatic Products Processing and Marketing Association reported that cost of production has been increasing 5%–7% per year as government hatcheries have been replaced by private hatcheries, marketing support has decreased, and labour and regulatory costs have increased.⁷³ Some low-cost loan programs have also been removed. Farmers have had to absorb most of these costs as processors have not offered much higher prices. Many farmers are switching to high-value fish (in marketing terms) or trying to increase production per hectare with intensification and automatic feeders to reduce labour. The COVID-19 crisis also reduced tilapia harvests and domestic and international demand for tilapia products in 2020 compared to 2019.⁷⁴ In 2021, increasing demand and exports were resumed, but still not to the level of 2019.⁷⁴ Early in 2022, opinion seems to be that Chinese production of tilapia will grow only slightly with much of the demand coming from value added forms in domestic markets, with minimal new demand from international markets at the higher prices demanded by farmers and processors and higher transport costs affecting global trade.

10 | INDONESIA

In Indonesia, Nile tilapia gradually overtook carps and Mozambique tilapia to become the dominant freshwater aquaculture species. Indonesia is currently the second largest tilapia producer in the world

(after China). Farmed tilapia output represents 31.4% of total freshwater aquaculture production in 2019; with Nile tilapia contributing 96.8% to total tilapia production.

Tilapia culture is practiced mainly in earthen ponds, by small farmers and households. Raising tilapia in floating cages and rice paddies is also widely practiced.⁷⁵ Commercial-scale cage farming of Nile tilapia in lakes and reservoirs for export has also been growing in Indonesia (e.g., Regal Springs). Therefore, in addition to the role of farmed Nile tilapia in local Indonesian markets, exporting tilapia with value adding to international markets has emerged in recent years. In 2019, Indonesia exported 11,107 mt of tilapia, mainly to the US market, in the form of frozen fillet.⁷ Tilapia seed production and trade has also become a major source of employment and profit in many rural regions in Indonesia.⁷⁶ Tilapia farming is expected to become a major employer by 2030.⁷⁷

11 | PHILIPPINES

Tilapia culture (especially GIFT strain) in the Philippines has witnessed rapid development during the last decades, leading the country to occupy the sixth position among the top tilapia producers in the world.⁷ Nile tilapia is currently one of the most important animal protein sources in the Philippines, especially in rural areas.^{78,79} In fact, tilapia prices are included in the market basket of goods that determine the cost-of-living government statistics.⁷⁹ These fish provide local communities with affordable, high-quality protein, and improve the nutrition and health status of rural households. Nile tilapia farming is also considered a cash crop; generating income and employment opportunities.⁷⁸

The seeds of the GIFT strain of Nile tilapia are currently used throughout the country, leading to a sharp increase in tilapia production from only 13,214 mt in 1980 to 279,386 mt in 2019, representing 94% of freshwater aquaculture production of the country.⁷ The use of improved seeds significantly improved the livelihood and profit margins of hatchery operators and fish farmers, created more employment in rural societies, and empowered women.⁸⁰

In continuation with the development of the GIFT technology, a “Strategy for Sustainable Aquaculture for Poverty Reduction in Philippines” has been adopted and implemented by Philippine Department of Agriculture-Bureau of Fisheries and Aquatic Resources (DA-BFAR), with support of the WorldFish Center.¹¹ The main targets of this strategy were to increase farm incomes through the use of viable tilapia production approaches, promote the investment in post-harvest facilities, and improve the capability of local government units to foster production and marketing partnerships with BFAR and the private sector. The role of the Southeast Asian Fisheries Development Center (SEAFDEC) in tilapia culture development and promotion in the Philippines, and many other Asian countries is outstanding. The centre has carried out a number of research projects on the contribution of small-scale aquaculture to sustainable aquaculture and rural livelihood development. It also provides training and capacity building, extension services and technical supports to stakeholders along the

whole tilapia culture value chain. GET EXCEL tilapia is another new breed developed by the government of the Philippines by combining an improved breed of Nile tilapia using within-family selection and a rotational mating scheme. The Bureau of Fisheries and Aquatic Resources-National Freshwater Fisheries Technology Centre (BFAR-NFFTC) has sustained the development of a fast-growing fish known as GET EXCEL 2002 through the use of genetically improved tilapia.

12 | THAILAND

Thailand is currently the eighth largest world tilapia producer and sixth largest tilapia producer from aquaculture in Asia, after China, Indonesia, Bangladesh, the Philippines, and Vietnam, with a production of 213,981 mt in 2019.⁷ Tilapia production comes mostly from freshwater aquaculture; which represented 56% of total freshwater aquaculture production in 2019,⁷ with Nile tilapia and the hybrid red tilapia representing 99.9% of total farmed tilapia production.^{7,81} The hybrid red tilapia (*O. niloticus* x *O. mossambicus*) strain developed by Charoen Phokpand (locally known as TabTim or Tub-Tim) is a popular variety that is grown in fresh water and brackish water as it has a higher salinity tolerance.^{82,83} In some locations it is grown in polyculture systems with shrimp where it is reported to reduce occurrences and severity of shrimp diseases and provide a firmer texture for the tilapia flesh.^{84,85} Tilapia farming is practiced primarily in private/family-owned, small to moderate-size ponds (1–3 ha).

Intensive and SI tilapia culture are commonly practiced in Thailand. Polyculture systems with carps and silver barb are some of most popular.^{58,86} Integrated agriculture-aquaculture systems (IAAS) (fish-chicken/duck-pig, fish-cum-rice) are also very common in Thailand. Integrated tilapia culture currently plays a significant role in rural areas, by providing high-quality, cheap protein source, generating additional income and rehabilitating the soil through better on-farm nutrient recycling.^{58,71,86} In Northeast Thailand, tilapia/carp polyculture is profitable, because pond inputs such as rice bran, crop by-products, broken rice, cattle, and buffalo manure are available, mostly on-farm, at low cost. Cage culture of tilapia in the extensive canal systems across Thailand has grown enormously in recent years, providing economic opportunities for landless farmers.^{81,87} However, cage-based culture in rivers faces several challenges including water quality and disease. More research is needed on farm practices and risks, river and water management, and the complete commodity value chain.⁸⁷

13 | VIETNAM

Nile tilapia culture in Vietnam grew at a high rate during the last decade (2010–2019), to become an important component in the food security of local rural poor.^{88,89} Vietnam was ranked seventh among the top tilapia producers in the world in 2019.⁷ Tilapia is among the most important fish species stocked in integrated systems in the Mekong Delta, second only to carps.⁹⁰ Nile tilapia is also integrated with silver barb and common carp in rice fields.⁹¹ In addition, the

culture of red hybrid (*O. mossambicus* x *O. niloticus*) in floating cages is widely practiced in the Mekong River, often in cages abandoned by *Pangasius* farmers who moved into intensive pond systems.^{92,93}

Most tilapia produced in Vietnam is directed to local consumption. However, Vietnamese tilapia exports have gained significant attention in recent years. The exports increased from 0 mt in 2010 to 11,969 mt in 2019,⁷ mainly in the form of frozen whole fish and frozen fillet. Major importers include the United States, Colombia, the Netherlands, Turkey, Italy, Belgium, Spain, Germany, South Korea and Saudi Arabia.⁶¹

14 | OTHER ASIAN COUNTRIES

In addition to the above-mentioned Asian countries, Nile tilapia (especially GIFT) farming is practiced in 16 other Asian countries at varying intensities. In addition, 14 countries farm other tilapia species, namely, Mozambique tilapia (*O. mossambicus*), blue tilapia (*O. aureus*) Sabaki tilapia (*O. spilurus*) or tilapia hybrids. Large amounts of tilapia are also recorded in the FAO aquaculture statistics under “not elsewhere included (nei)” tilapia’ (*Oreochromis* [= *Tilapia* = *Coptodon*] spp). Significant amounts of Nile tilapia are produced in Taiwan, Cambodia, Myanmar, Sri Lanka, Lao PDR, Saudi Arabia, Malaysia, and Nepal.^{94–96} Semi-intensive tilapia culture in earthen ponds, intensive systems in cages and tanks and integrated aquaculture/agriculture systems are all adopted at varying levels. Nile tilapia culture is gaining increasing attention in some other Asian countries such as India, Pakistan, Iran, and the Arabian Gulf Cooperation Council (GCC) countries. Extensive research is currently underway in these countries to develop sustainable tilapia culture industries.

15 | THE JOURNEY OF NILE TILAPIA TO THE AMERICAS

In the Americas, Mozambique tilapia (*O. mossambicus*) was first introduced from Malaysia into the Caribbean Island of St. Lucia in 1949.⁹⁷ These fish were then introduced from St. Lucia to many American countries during the 1950s and 1960s, mainly for aquaculture, fisheries, mosquito and weed control and fee fishing.^{98,99} However, Mozambique tilapia was poorly accepted by the consumers as a food fish. Nile tilapia (*O. niloticus*) was then introduced, during the 1960s and 1970s, as a major candidate for aquaculture and fisheries. According to Fishbase,⁴ Nile tilapia was introduced from Cote d'Ivoire to Brazil in 1971 and then to many Latin American countries in the 1970s, including Bolivia, Colombia, Panama, and Peru.⁴ In North America and the Caribbean, Nile tilapia was introduced from Africa to Mexico in 1964, and Puerto Rico and the United States in the 1970s.¹⁰⁰ As a result, Nile tilapia has become a major component of freshwater aquaculture industry in some countries in the Americas.

Seventeen countries, especially in Latin America and the Caribbean, now practice Nile tilapia culture, with a production of 436,033 mt in 2019, representing 75% of total farmed tilapia production (584,202 mt), and 42% of total FW aquaculture output (1,031,434

mt).⁷ As shown in the following section, Nile tilapia represents 61% of total freshwater aquaculture in Brazil.⁷ Moreover, Nile tilapia represents 92% of total freshwater aquaculture in Costa Rica, and the only freshwater fish species with data reported to FAO from Honduras.⁷ Red tilapia hybrids are also farmed in Honduras for local consumption and export to the US market,¹⁰¹ but data are not available on the production of this hybrid. This demonstrates the role Nile tilapia plays in food security in these countries. Most tilapia production in the Americas is directed to domestic markets, with significant value-added tilapia exports to the US.^{24,61,100,102}

16 | THE ROLE OF NILE TILAPIA CULTURE IN BRAZIL

Brazil is the most important Nile tilapia producer in the Americas, with a production of 323,714 mt in 2019.⁷ Currently Brazil is ranked 5th among the top Nile tilapia producers in the world. Several additional large-scale vertically integrated tilapia projects have been announced in 2019 and 2021.^{103,104} If these and other project expansions are all realized, the production would exceed 500,000 mt by 2025. Different farming systems are deployed, including SI in earthen ponds, intensive and integrated practices. Cage culture in lakes, reservoirs and just below hydroelectric power dams has also gained more popularity in recent years^{105,106} contributing over 40% of total aquaculture production in Brazil.¹⁰⁶

Nile tilapia culture in floating cages in reservoirs in semi-arid Brazilian regions is supported by state and federal governments as a means of food security and poverty alleviation.^{107,108} Reservoirs that were created by governments, initially for drinking water and irrigation, now support cage culture which has become an important livelihood for resource-poor rural households, which generally live under harsh environmental conditions and low social development.^{107,108} For example, it has been demonstrated that Nile tilapia aquaculture and fisheries activities contribute significantly to local economy in two semi-arid Brazilian reservoirs, Santa Cruz and Umari.¹⁰⁸ These activities provide over 44 mt of tilapia per year, for local consumption, in addition to various goods and services, with aquaculture generating higher revenues than fisheries. It has also been reported that cage culture of Nile tilapia in Santa Cruz reservoir is sustainable.¹⁰⁹ The benefit–cost ratio indicated that total revenue was US\$ 1.34 for each US\$ 1.00 invested (i.e., 34% profit).

17 | OTHER AMERICAN COUNTRIES

As a result of the continuous national and international efforts, small-scale and vertically integrated large-scale production of Nile tilapia in other American countries including Mexico, Colombia, Honduras, Ecuador, Costa Rica, El Salvador and Paraguay have recorded significant increases.^{7,102,110,111} These countries produced 105,355 mt of Nile tilapia in 2019, representing 69% of their total farmed tilapia

production, and contributed 41% to total tilapia production in the Americas, excluding Brazil.⁷

In Mexico, net pens, constructed out of local materials, are commonly used for raising Nile tilapia by low-income groups or individuals¹⁰³. More sophisticated, large-scale production of Nile tilapia in floating cages are also in use, mainly in irrigation reservoirs. Floating or slow-sinking pelleted feeds are commonly used for feeding caged tilapia. In Colombia, Nile tilapia are also produced, mainly in cages, for export, while red tilapia are produced for the domestic market. Cage culture is practiced in large hydroelectric power reservoirs, using all-male Nile tilapia. The caged fish are generally fed with commercial extruded feed (24%–34% cp). Significant amounts of other tilapia species (e.g., *O. aureus*) and hybrids are produced in other American countries such as Peru and the United States. Over 90% of tilapia production in the Americas is directed to domestic consumption.

However, some of these Latin American countries produce high quality tilapia, which is exported to the United States in the form of fresh fillets. While China remains the leading Nile tilapia exporter to the US market, exports from other American countries are increasing. The rising of production costs in China and the change in government policy with regard to product subsidies will make Chinese producers less competitive over time, leaving more room for imports from neighbouring Central and South American countries. As a result, 13 countries from these regions are currently exporting tilapia and tilapia products to the US market; with Honduras, Colombia, Costa Rica, Mexico and Ecuador, respectively, being the largest exporters, contributing 95% of total tilapia export from these regions to US market.⁶¹ The fresh tilapia market in the United States is dependent almost exclusively on these regions, since they contributed over 99.5% of total fresh fillet imported to the US market.⁶¹ A total of 19,141 mt of tilapia fillet were exported from Colombia, Costa Rica, Honduras, Ecuador and Mexico to the US market in 2019.⁷ Domestic production of tilapia in the United States has been fairly stable during the last two decades (2000–2019), with an annual production ranging from 8000 to 10,000 mt.⁷ This production meets only 8% of the increasing demand for tilapia in the US market, leading to significant tilapia imports, as explored in the next section.

Tilapia culture development programs are implemented by local and international organizations in some countries in Latin America and the Caribbean, leading to significant economic and social development in rural societies. For example, a rural development program has been implemented by FAO in El Salvador to promote polyculture of tilapia and white-leg shrimp (*Penaeus vannamei*) (Boone, 1931) as a means of income generation and food security.¹¹² This practice increased the average farmers' income by up to 28%. A similar program has been carried out in Guatemala, also with FAO assistance, for making efficient use of water in Thismuntique village.¹¹² Nile tilapia farming resulted in a significant improvement in the livelihoods of many households. Rural households consumed 39.5% of fish production, while the remaining 60.5% were distributed among the local schools, leading to improving nutrition among Guatemalan school children. A benefit/cost analysis showed that profit margin for producers was 26%.

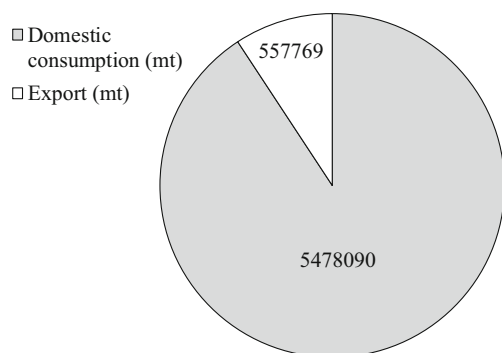


FIGURE 6 Global consumption and export of farmed tilapia in 2018.⁶²

18 | CONTRIBUTION OF INTRODUCED NILE TILAPIA TO FRESHWATER FISHERIES ENHANCEMENT

In addition to the socioeconomic benefits of farmed Nile tilapia, tilapia has made a significant contribution to the wild fisheries in countries to which these fish have been introduced and established. For example, Nile tilapia have been introduced in many rivers in south China and become the most dominant exotic fish species in Guangdong, Hainan, Guangxi, Fujian and Yunnan provinces.^{57,113,114} Also, when Nile tilapia were introduced into East African Lakes (such as lakes Victoria, Kyoga, and Nabugabo), they became the most important commercial Tilapiine fish in many of these water bodies.¹⁷ Similarly, Nile tilapia was introduced into Lake Kutubu, Papua New Guinea¹¹⁵ and in just a few years became the most dominant component of the lake fishery, representing over 50% of total fish yield.^{116,117} These fish have also become an important source of animal protein and cash crop for local communities; exceeding the benefits provided by native fish.¹¹⁷ In Mexico, many new reservoirs have been stocked with Nile tilapia fingerlings from government hatcheries to provide a new fishery resource for those fish displaced by the filling of the reservoir.¹¹¹ Virtually all the wild fisheries catch of tilapia in Mexico come from these reservoirs and at times have been included in Mexico's aquaculture statistics.

19 | NILE TILAPIA- A FISH FOR THE POOR, AND THE RICH

It is clear from the above review that farmed Nile tilapia is a fish for both the poor and the rich in Asia, Africa, and Latin America. These fish can help feed the world, due to their simple farming techniques, good quality and affordable prices. The demand for Nile tilapia is increasing worldwide, especially in developing countries.^{61,118} Consequently, most tilapia are consumed domestically (91% of total tilapia production in 2018)⁷ (Figure 6). It should be emphasized, however, that tilapia trade data and statistics did not separate tilapia imports and exports into species; but reported them as 'total tilapia'. Since

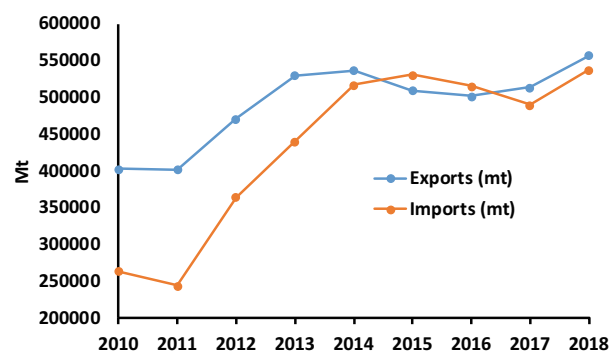


FIGURE 7 Global tilapia imports and exports (mt) during 2010–2018.⁶²

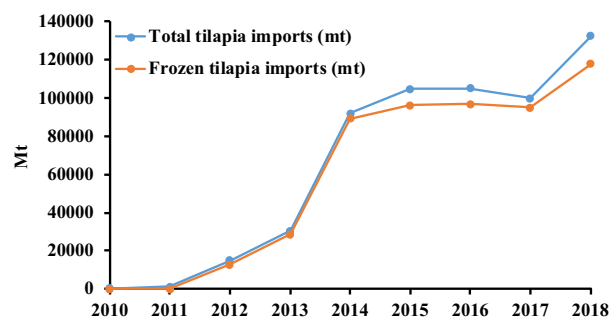


FIGURE 8 Tilapia imports to sub-Saharan Africa during 2010–2018.⁶²

Nile tilapia represents about 75% of total farmed tilapia production, it is fair to suggest that Nile tilapia represent a major source of locally consumed and traded tilapia. Tilapia is also in high demand among the middle-income and high-income communities in many countries.¹¹⁸ Therefore, the global trade of tilapia products has flourished in the last two decades and is expected to continue.⁶²

The demand for tilapia is also growing in traditionally non-tilapia producing countries, especially those countries which rely on white-fish species (e.g., Atlantic cod [*Gadus morhua* Linnaeus, 1758], whiting [*Merluccius bilinearis* Mitchell, 1814], haddock [*Melanogrammus aeglefinus* Linnaeus, 1758], hake [*Urophycis* sp.], Asian catfish [Basa] [*Pangasius* sp.] and pollock [*Pollachius* sp.]),^{119,120} primarily Europe and the United States. Tilapia is currently imported by over 135 countries worldwide. As a result, total tilapia imports doubled during the last 10 years to reach 537,914 mt in 2018 (Figure 7).⁶² The USA is the largest tilapia importer in the world, with imports of 189,565 mt in 2018, representing 35% of total tilapia imports, while China is the largest tilapia exporter; contributing 444,851 mt (80%) to global tilapia exports.⁶²

In other markets, especially Europe, Africa and the Middle East, the demand for tilapia is high. For example, over 35 sub-Saharan African (SSA) countries import tilapia, mostly frozen fish, mainly from China.⁶¹ Tilapia imports in SSA increased dramatically from a couple 100 mt in 2010 to 132,475 mt, representing 25% of global tilapia imports in 2018⁶³ in just 9 years (2010–2018) (Figure 8).

TABLE 2 Major tilapia importers in Europe, and amounts imported (mt) in 2010 and 2015–2019.⁶²

	2010	2015	2016	2017	2018	2019
Belgium	1758	3965	3556	2633	3180	3896
France	769	4649	3839	4418	3555	4800
Germany	2638	3191	2695	2822	2702	2809
Italy	688	2646	2261	2065	2303	2565
Netherlands	2219	6469	5475	5910	6271	7314
Poland	6853	3836	3162	4706	3674	4274
Russian Federation	-	8127	6630	9944	8996	6702
Spain	3424	5498	4933	4856	3919	4408
United Kingdom	477	3622	3488	3693	2791	3852
Other countries	1703	4938	4976	5054	5177	4837
Total	18,826	42,003	36,039	41,047	37,391	40,620
Total Europe	20,529	46,941	41,015	46,101	42,568	45,457

Tilapia imports to 36 European countries, from different global exporters, have also increased during the last decade from 20,520 mt in 2010 to 45,457 mt in 2019.⁶² This increase may appear limited on the global scale; however, in a continent where tilapia had no market until a few decades ago, consuming over 45,000 mt a year is impressive. This suggests European tilapia demand will expand further. The largest importers of tilapia in Europe are Belgium, France, Germany, Italy, the Netherlands, Poland, Russian Federation, Spain, and the United Kingdom (Table 2). They accounted for about 90% of the total tilapia imports during 2015–2019.

20 | ADVERSE IMPACTS OF NILE TILAPIA INTRODUCTIONS

Despite the above-mentioned benefits of Nile tilapia introductions, tilapia may pose adverse ecological and socioeconomic impacts in ecosystems into which they are introduced.^{48,98,121,122} These impacts include: habitat degradation and loss, disruption of native biota, reduction or eradication of native species, reduction in capture fisheries yield, competition for food and breeding sites with native species, hybridization with native species of tilapia, and spread of aquatic diseases. For example, the introduction of Nile tilapia to the Pearl River in China led to a significant reduction in the relative densities and the body sizes of the native fish; thereby impacting the overall ecosystem function.¹²² These changes suggest that Nile tilapia compete with native species for food resources and space,^{48,98} and can seriously alter the trophic position and food web of native species.^{123,124} Similarly, when Nile tilapia were introduced into Tangxi Reservoir (South China), they became dominant over time, leading to a reduction in the catch of other introduced fish, especially bighead carp.¹²⁵ The introduction of Nile tilapia in the Halali Reservoir (India) has also significantly reduced the catch per unit effort (CPUE) of native fish species.¹²⁶ Introduced Nile tilapia into Igarapé Fortaleza hydrographic basin (Amazonas River) have also caused significant impacts on native cichlids,⁹⁹ presumably

due to the competition for food, preying on the eggs and larvae of native cichlids, and occupation of most spawning sites, leaving little room for the spawning of native species.^{98,127} Introduced Nile tilapia also have the potential to transmit diseases into recipient aquatic environments, as demonstrated by McCrary, Murphy, Stauffer and Hendrix¹²⁸ in Lake Nicaragua (Central America). These authors reported that several native cichlid species were affected by an outbreak of trematodes, which was linked to the dominance of both Nile tilapia and Mozambique tilapia in the lake system.

The capability of introduced tilapia to interbreed with natural populations of their closely related native species is extremely high, which may cause genetic impacts and reduce the population size of these native populations.⁴⁸ The introgression between Nile tilapia and native *Oreochromis* spp. in Lakes Victoria and Kyoga resulted in morphological changes and disappearance of native species.¹²⁹ Similar effects have been recorded in Limpopo River (South Africa),⁴⁸ and the Mindu Reservoir and Kidatu Rufiji river system (central Tanzania),^{130,131} where introduced Nile tilapia led to genetic and environmental impacts, including extinction risk of the indigenous species through hybridization, competition exclusion and loss of genetic integrity.

The introduction of tilapia into new freshwater ecosystems may also adversely affect the income of the resource users and other local communities.¹⁰ For example, the increase in Nile tilapia abundance in rivers of Guangdong Province (China) reduced the incomes of local fishers^{55,57,113}; as the contribution of tilapia increased, the CPUE of native species decreased.¹¹² The market prices of tilapia are also lower than that of native species, which are sold at much higher prices, because of their preferences by local consumers.^{57,113} Consequently, fishers' income decreased with increasing the proportion of Nile tilapia in the catch.¹¹³ The spread of tilapia can also adversely affect the value of other species, as they compete for food, which in turn leads to growth retardation and low production; thereby contributing to further decreases in fishers' income.^{55,57}

Similar impacts have also been reported in Brazil,^{98,99} South Africa,¹⁸ and Zambia,¹³² where the spread of Nile tilapia seriously impacted the value of other species, due to the competition for food and reduction in growth rates of other fish. Hybridization between introduced Nile tilapia and native tilapias (three spot tilapia *O. andersonii* and green head tilapia *O. macrochir*) in Kafue River (Zambia) resulted in a significant increase in the CPUE of Nile tilapia, whereas the CPUE of native tilapias showed a continuous decrease.¹³² This situation poses potential threats to native fish production, which provides local communities with self-sufficiency in food, employment generation, and economic profitability.

Although the potential for deleterious effects caused by tilapia introductions must be recognized, tilapia are hardy and able to thrive in some disturbed and polluted environments in which native fish are ill adapted. Many reports of tilapia invasions fail to describe the alterations in water quality, climate change, and placement of dams changing water temperatures and flow rates, or co-introduction of more predatory non-native species that accompanied the introduction of tilapia into a particular watershed.^{10,103,104,133,134} There are also reports that in relatively pristine ecosystems, Nile tilapia introductions did not lead to deleterious effects and that the fish did not even hybridize with indigenous cichlids.¹³⁴

21 | MISMANAGEMENT OF TILAPIA INTRODUCTIONS

Tilapia introductions for insect and weed control, aquaculture and fisheries have occurred in many countries. It is almost impossible to guarantee safe confinement of these fish; their escape from irrigation and aquaculture facilities to natural aquatic ecosystems is inevitable. Therefore, appropriate management measures should be adopted to control tilapia introductions and mitigate any adverse ecological and socioeconomic impacts. In this regard, management strategies vary from one country to another depending on the objectives of tilapia introductions. Some countries adopt protective measures to control tilapia introductions to protect and sustain their native aquatic habitats.¹⁰⁷ For example, the United States has legalized unlimited catch of non-native fish species, as a means of controlling their spread and reducing their stocks.¹³⁵ Obligatory best management practices in aquaculture were implemented in some states (e.g., Florida) to control the stocks of these non-native species through preventing their escape.^{136,137}

On the contrary, some other countries encourage tilapia introductions for aquaculture and natural fisheries enhancement, regardless of the negative effects they may cause.^{107,138} They believe that feeding the public and maintaining better livelihoods of local communities are more important than the conservation of aquatic biodiversity. Current Brazilian federal legislation, for instance, encourages naturalization of non-native fish species, including tilapia, and allows the aquaculture, transportation and trade of these non-native species.^{139,140} Aquaculture in China also depends increasingly on introduced species, including tilapia. Although such introductions can be considered assaults on

already damaged and compromised aquatic ecosystems, government policy supports such introductions, and substantial domestic market and export fish market sectors have been built around these introduced species.^{71,72}

22 | CONCLUSION

This review indicated that while Nile tilapia are endemic to Africa, they have been introduced into many countries worldwide, mainly for aquaculture and fisheries purposes. As a result, aquaculture of Nile tilapia is currently practiced in more than 80 countries and is now ranked third among the top farmed fish species, behind grass carp and silver carp. They make a significant contribution to the livelihoods and economies of rural societies in these countries. In some Asian countries, such as China, India, Bangladesh, Vietnam, and Myanmar, introduced Mozambique tilapia (*O. mossambicus*) has generally not been accepted by consumers. In contrast, the interest in Nile tilapia culture (especially monosex Nile tilapia and the GIFT strain) in those countries is increasing. Nile tilapia are also commercially important in Central and South American countries, especially Mexico, Costa Rica, Honduras, Guatemala, Ecuador, Brazil, and Colombia. The Nile tilapia journey will likely continue to further destinations. The adaptability of Nile tilapia to a wide range of environmental conditions, and their suitability for different farming systems will likely accelerate their spread and distribution worldwide.

Global tilapia markets and trade are expanding, and are expected to continue much further. It is hoped that the success stories of the major Nile tilapia producers will motivate Nile tilapia culture in other countries that intend to introduce this fish for aquaculture purposes. However, countries which introduced, or intend to introduce, Nile tilapia should adopt the necessary policies that support the conservation of native ecosystems and local biodiversity and at the same time, promote tilapia culture and improve the livelihoods of aquatic resource users.

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AUTHOR CONTRIBUTIONS

Abdel-Fattah M. El-Sayed: Conceptualization, data collection and curation, data tabulation and analysis, writing original draft, validation, review and editing, and corresponding author. **Kevin M. Fitzsimmons:** Contributions to original draft and review and editing.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

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