WHY TILAPIA IS BECOMING THE MOST IMPORTANT FOOD FISH ON THE PLANET

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ABSTRACT

Tilapia has become the shining star of aquaculture with farms starting and expanding across the globe while consumption races ahead of even the most ambitious farm building plans. 2010 saw farmed tilapia exceed 3.2 million metric tons per annum, surging further ahead of the salmon and catfish industries. We are also seeing an explosion of product forms in the grocery stores that is only matched by the variety of preparations we see in the restaurant trade. The global adoption of tilapia as a substitute for all kinds of wild-caught fish has driven demand higher every year, even through the global recession of recent years. The description of tilapia as an "aquatic chicken" becomes more accurate every day. It's wide acceptance across all cultural, religious, and economic groups is similar to chicken. A variety of breeds and strains have been developed and by most measures, tilapia is now the most highly domesticated of farmed fishes. Unique amongst the major farmed fishes, tilapia maintains a key role in rural aquaculture improving the welfare of the poorest farmers while at the same time, it is reared in the most high tech production systems and is sold into international markets for up-scale markets. Tilapia is still the darling of the environmental community and the industry continues to polish its "green" credentials.

Three or four closely related species of tilapias readily hybridize in captivity and produce fecund F1 progeny. This has provided a huge genetic base for the geneticists to perform basic selective breeding. The domestication of tilapias has been a great driver of productivity during the 1990's and 2000's. There is also a concerted effort to describe the tilapia genome. When these genetic maps are distributed we can expect a second wave of genetic research that should further improve productivity. All of this will have been accomplished without the need of transgenics or genetically modified organisms. The basic biology of the fish along with the skill of traditional breeders has provided all of the progress to this point and much more in the near future.

Tilapia continues its march towards eventually overtaking carp as the most important farmed fish crop. With a much wider distribution of production and consumption and a huge base of value added product forms, it is almost certain that tilapia production will someday eclipse that of carp. As tilapia production and consumption grows globally, it is likely to become the foundation product for all farmed fishes, just as chicken is the base for the poultry industry. So someday soon instead of referring to tilapia as the aquatic chicken we may be referring to chicken as the "terrestrial tilapia".

INTRODUCTION

Tilapia holds a somewhat unique position amongst the major aquaculture fishes as a key product in international trade produced in large vertically integrated farming operations, while at the same still being produced in large amounts as a subsistence crop by some of the world's poorest farmers. The tilapias, with their unique mouth-brooding form of reproduction and extreme hardiness, allow farmers with the most meager resources an opportunity to rear the fish. Some farmers have even been known to rear tilapia in cisterns or 200 liter barrels. To an even greater extent than carps, farmers do not need access to hatcheries, or specialized information to rear tilapia in captivity. And similar to the oft used comparison to chickens, small farmers who spawn their own tilapia, will frequently end up with problems of in-breeding and reduced yields. But for a subsistence farmer, this may be a minor problem compared to keeping a family fed.

At the same time, cooperatives of small-scale fish farmers in Asia and Latin America have collaborated with live haulers and processing plants to produce large amounts of fish for domestic and international markets. Cage culture has proven to be a key technique for people with limited resources

and experience to get into aquaculture and generate significant quantities of fish for household and ex-household consumption. Cages can be constructed of locally available materials with minimal investment and placed in small ponds or in public waters. Many countries will provide access to reservoirs, irrigation systems and public waters to farmers and fishers with limited resources or who partner with government sanctioned processors.

Tilapia aquaculture has also attracted multi-national firms who grow fish in multiple countries vertically integrating feedmills, hatcheries, production, processing, packaging, transportation, and marketing. These firms employ thousands of farmers, feeedmillers, processing plant staff, drivers, office staff and sales forces. In many cases these employees are the prime recipients of the foreign exchange generated by these operations (Fitzsimmons and Watanabe, 2010).

Finally, as mentioned above, much of the global tilapia aquaculture has been integrated into irrigation systems. By rearing fish in reservoirs, canals and farm ponds, the effluents from tilapia farming are contributing to the fertilizer value in the water delivered to irrigated crops. This contributes to tilapias "green" reputation with the environmental community while saving on chemical fertilizer costs for resource poor farmers. So tilapia truly are a key contributor to global food security on several levels.

GENETICS

One of the key reasons for tilapia's continued expansion of production in future years is based on the genetic diversity available from which to build. The farmed tilapias are derived from several species in the genus *Oreochromis*. The fact that several of the species easily hybridize and produce large numbers of fecund young has allowed fish breeders to cross several species and develop strains that incorporate various traits from each of the parent species. This further supports the contention that the tilapia have been selectively bred and domesticated to an even greater extent than the edible carps. In fact they may be even more domesticated and differentiated than koi are from wild carps.

Size and body shape – Some of the primary morphological characteristics that breeders wanted to improve were the average size of the tilapia and the body shape, especially reducing the proportion of head to fillet. In both cases the ultimate goal is to have more edible fillet product. Most of the intensive breeding programs have focused on *O. niloticus* (Nile tilapia).

The Nile tilapia strains that have been developed in recent years include:

1. The Genetically Improved Farmed Tilapia (GIFT), originally developed in the Philippines from eight farmed and wild strains collected from around the world. The breeding program continues under the auspices of the WorldFish Centre at Jitra, Malaysia.
2. The Genomar strain was developed by a partnership of biologists from Brazil and Norway. It also included a large hatchery project in China, the Trapia project in Malaysia www.trapia.com.my/ and a hatchery in the Philippines. www.genomar.com
3. The Chitralada strain was developed in Thailand, and actually was started from the stocks of tilapia given to the King of Thailand who kept them in ponds at the Chitralada Palace. Breeders in Thailand continued to work with this strain and eventually developed the line that still bears the Chitralada name. It has also been used as an important line in some of the other breeding programs.
4. The TabTim line was developed in Thailand by the CP Group as their branded tilapia strain. The line is derived from several salt tolerant red tilapia lines, including some from Thailand, the Bahamas and the University of Arizona. Tab Tim has been successfully branded as a premium tilapia which receives an increased price and now is produced and marketed in Indonesia and Malaysia as well as Thailand.
5. The GIFT Excell line is derived from some of the GIFT tilapia that were left behind in the Philippines, when the GIFT program proper was moved to Malaysia. Some of the original GIFT biologists have worked in the original location and have partnered with various hatcheries to improve the strain.
6. The GIFT Bangladesh strain is another derivation from the GIFT tilapia. In this case, Bangladeshi scientists continued a selective breeding program with the GIFT fish sent to Bangladesh. These fish

have been bred to thrive under the climatic and cultural conditions found at the local farms.

YY Supermale – This novel program was envisioned by biologists at University of Wales Swansea and then put into practical operation at the Central Luzon State University in the Philippines (Mair et al, 1997). The commercial entity arising from the project is called FishGen. http://www.fishgen.com The technique of produces all male progeny for stocking on farm by manipulating the reproductive morphology of the grandparent fish. By treating the juvenile grandparent fish with estrogen, breeders can produce fish with a genetically female "father". This results in 25% YY fish in the F1 which can be crossed to normal females to produce virtually all XY (normal) male progeny in the F2 generation. In 2008 and 2009 groups in Egypt and Indonesia, respectively have reported that they have developed their own YY stocks.

Color morphs – There have been several strains of red tilapia developed. These include populations from Florida, Hawaii, Taiwan and Israel. Several have arisen from random mutations in *O. mossambicus* and another one in *O. niloticus*. Diligent breeding managed to "fix" these traits and develop marketable strains. In certain Asian communities the fish fetch a premium as it is the color of "good luck". In other communities, red tilapia resemblance to red snapper or red sea bream gains a premium price.

Salinity resistance – There are several populations of *O. mossambicus* that are recognized for their tolerance for extreme levels of salinity. These populations, especially from Lakes Bardawil and Manzala in Egypt, have been used as broodlines with Red strains and other species crosses to impart the salinity tolerance. This is another major advantage that the tilapias have over several other farmed species including the carps. Salinity tolerance opens up so many more options for farming opportunities in marine and brackish coastal water, inland brackish waters, agricultural and industrial waste water, and even hydroponic solutions used for lettuce and other vegetable production (Watanabe et al. 2006).

Genome project – An international groups of geneticists is rapidly working through the *O. niloticus* genome (Kocher et al., 1998; Lee et al., 2005) The project has benefited from several allied groups sequencing parts of the genetic make-up. Recently large parts have been cataloged and are now being compared to previously described portions from other cichlids and the zebrafish (*Danio rerio)* . A grass carp genome project in 2010 provided the first linkage map, many years behind the work done with tilapia (Xia et al., 2010). Again this further definition and available information will likely benefit the genetic knowledge for the tilapia sooner and to a more full extent that that available for the various carps.

NUTRITION

Omnivores – Herbivores – One of the qualities that continues to make tilapia popular with the "green movement" is the fact that they feed primarily on a very low trophic level. In nature, the tilapias feed upon algae, fresh and decaying plant material and periphyton. In domesticated settings the various tilapias still are fed a formulated diet that consists of grains and agricultural by-products that serve to keep tilapia diets below the average for most other farmed fishes. While many of the carps have similar feeding and nutritional patterns, the fact that tilapia in general are smaller and have smaller teeth and mouths, they tend to be even more efficient at scraping off the finest biofilms and periphyton colonies.

BioFlocs - The ability of tilapia to thrive in biofloc systems is yet another benefit that tilapia have over many of the other common aquaculture species. Avnimelech (2009; and this volume) describes how tilapia are uniquely adapted to thrive under biofloc conditions that would stress most other fish. This relatively low cost system for producing healthy fish and reducing formulated feed costs could be an additional benefit that should keep tilapia prices competitive with other wild and farmed species.

Agricultural plant wastes – Tilapia have proven to be one of the most important fishes used in alternative ingredient studies. The most common goal is to replace fish meal and fish oils. While these tend to be very minor ingredients in tilapia diets, the farmers and researcher still want to further reduce fish

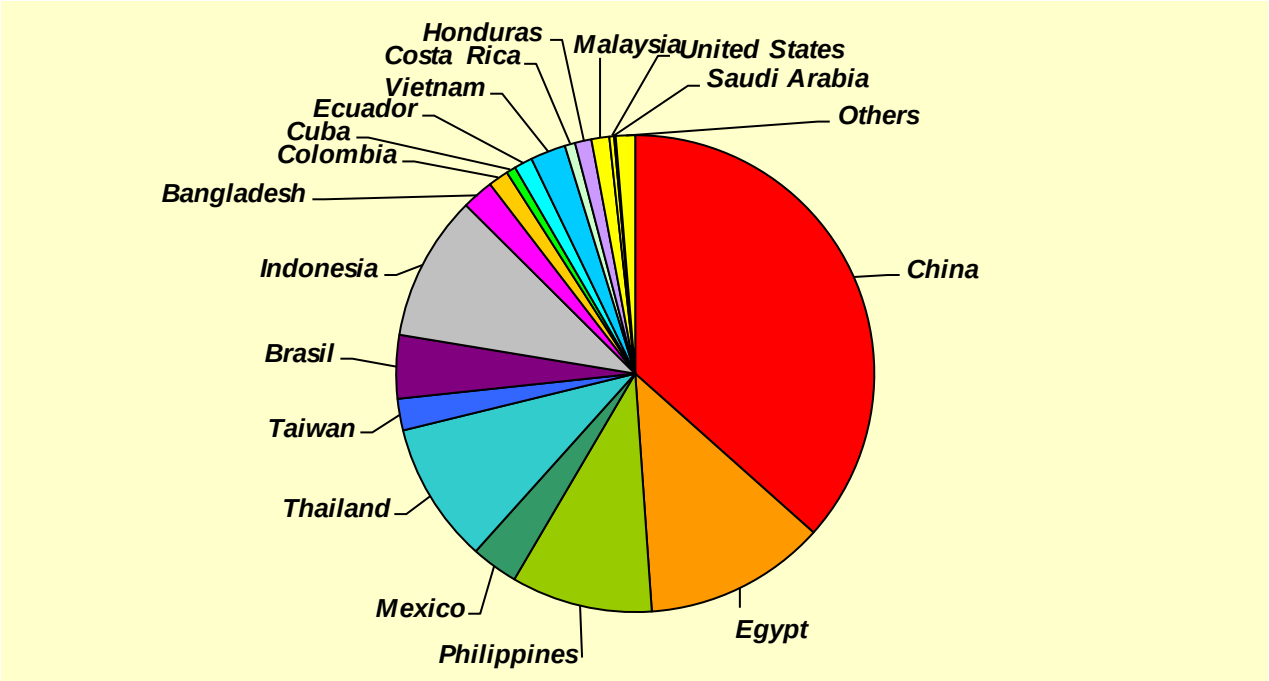
products in the diet and utilize locally available ingredients. There are many studies available, including several more in this volume.

PRODUCTION SYSTEMS and LOCATIONS

Variety of production modes – Tilapia are unique in the array systems used to rear them in captivity. Commercial operations include: ponds, cages, raceways, tanks, net pens, lake ranching, seawater, brackish water, freshwater, aquaponics, plastic drums and computer controlled intensive recirculation systems.

Geographic distribution – FAO reports tilapia production from over 100 nations. This vast base of production and interest in the fish vastly exceeds any other farmed fish. The consumer demand is equally widespread. There are not any reports of cultural or religious restrictions on consuming tilapia. The major producing countries produced just over 3,200,000 metric tons of tilapia in 2010 (Fig. 1).

Figure 1. World Tilapia Production of 3,200,000 mt in 2010



Low cost production costs - Tilapia with their grain and vegetable based diets and ability to gather significant nutrition from grazing on algae and biofilms, have some of the lowest feed costs of any farmed fishes. With the high densities achieved on many farms, the infrastructure costs are therefore spread across a larger volume of fish. Finally, hatchery technology is relatively simple, allowing for fewer hatchery workers.

Hatchery technology – The high level of parental care provided by the female mouth brooders, simplify the activities of the tilapia hatchery manager. If the fry are left with the mother, the primary activity is to collect fry as they leave the female and start foraging. If the eggs are flushed from the mother's mouth and reared in a hatchery settling, the technology is only slightly more sophisticated; requiring hatching jars (or recycled plastic bottles) or open trays. With the hatching jars, the sick and dead eggs flow out, while trays do require maintenance to remove infected or unfertile eggs.

POLYCULTURE

An additional area in which tilapia production is rapidly increasing is polyculture. Many carp farmers in China, Vietnam and Indonesia have now incorporated tilapia into their traditional carp ponds and cages. In many cases this is for the better market price that tilapia sometimes gets and in others they appreciate the different niches (feeding and physical) that the tilapia occupy compared to their carps. Integration of tilapia and shrimp has been found to be beneficial for shrimp health and for economic return (Yuan et al 2010; Cruz et al. 2008). Across most shrimp farming regions, tilapia are increasing being produced in cages or hapas inside shrimp ponds, or are produced in supply channels or head ponds. The increasing interest in integrated multi-trophic aquaculture systems for tropical production is certain to further contribute to overall tilapia production as most systems consider tilapia to be a key component to the systems.

Strong domestic markets – In many of the biggest producing countries, domestic demand is so strong, there are virtually no exports from countries including the Philippines, Mexico, Brazil, and Bangladesh. Even China, with the world's biggest production, consumes more than half of all its production. In fact, Ecuador, Costa Rica and Honduras are probably the only countries which export a majority of the tilapia produced. This is a testament to the strong demand across all socio-economic groups for tilapia products.

Stronger international markets – The United States continues to be the single largest market for tilapia products. Increasing demand for all forms of tilapia products and more market share in restaurants, food-service, club stores, hypermarkets and groceries is encouraging live and on-ice tilapia sales from US farms and a flood of imports from Asia and Latin America.

Table 1. US imports of tilapia products in 2009 and 2010 (values in US$)

Product	Country	2009 Kilos	2009 Value	2010 Kilos	2010 Value
TILAPIA FILLET FRESH	BELIZE	9,304	76,620	0	0
TILAPIA FILLET FRESH	BRAZIL	264,232	1,892,361	332,471	2,445,064
TILAPIA FILLET FRESH	CHILE	643	3,589	3,218	29,250
TILAPIA FILLET FRESH	CHINA	20,769	109,200	0	0
TILAPIA FILLET FRESH	CHINA - TAIPEI	207,949	1,348,949	220,166	1,250,038
TILAPIA FILLET FRESH	COLOMBIA	1,627,884	12,655,428	1,796,060	13,549,639
TILAPIA FILLET FRESH	COSTA RICA	5,720,984	41,979,201	5,825,430	39,803,789
TILAPIA FILLET FRESH	ECUADOR	9,059,973	57,594,646	7,852,974	49,715,847
TILAPIA FILLET FRESH	EL SALVADOR	480,827	3,720,300	332,289	2,447,784
TILAPIA FILLET FRESH	FAROE IS.	0	0	3,283	25,384
TILAPIA FILLET FRESH	GUATEMALA	0	0	1,361	9,000
TILAPIA FILLET FRESH	HONDURAS	6,511,715	51,607,530	7,245,304	56,201,338
TILAPIA FILLET FRESH	NICARAGUA	430,635	3,424,958	46,428	342,391
TILAPIA FILLET FRESH	PANAMA	1,362	10,117	3,808	28,268
TILAPIA FILLET FRESH	PERU	4,009	31,199	55,044	431,899
TILAPIA FILLET FRESH	THAILAND	17,654	84,472	0	0
Subtotal		**24,357,940**	**174,538,570**	**23,717,836**	**166,279,691**

TILAPIA FILLET FROZEN	CHINA	100,691,098	363,266,149	135,522,960	517,771,039
TILAPIA FILLET FROZEN	CHINA - HONG KONG	0	0	73,935	228,090
TILAPIA FILLET FROZEN	CHINA - TAIPEI	2,332,494	12,483,161	2,248,666	10,093,980
TILAPIA FILLET FROZEN	COLOMBIA	0	0	3,832	12,128
TILAPIA FILLET FROZEN	COSTA RICA	95,838	662,839	152,776	936,587
TILAPIA FILLET FROZEN	ECUADOR	1,118,103	7,391,980	638,368	4,181,009
TILAPIA FILLET FROZEN	FIJI	0	0	16,393	63,880
TILAPIA FILLET FROZEN	HONDURAS	604,502	4,345,036	108,289	673,853
TILAPIA FILLET FROZEN	INDONESIA	8,757,932	56,464,317	10,201,574	68,590,604
TILAPIA FILLET FROZEN	MALAYSIA	0	0	319,912	1,434,481
TILAPIA FILLET FROZEN	NEW ZEALAND	51,710	579,039	0	0
TILAPIA FILLET FROZEN	NORWAY	726	4,247	0	0
TILAPIA FILLET FROZEN	PANAMA	273,499	1,250,091	193,789	871,642
TILAPIA FILLET FROZEN	PHILIPPINES	1,701	10,500	9,232	21,887
TILAPIA FILLET FROZEN	THAILAND	678,831	3,792,956	1,055,543	5,488,994
TILAPIA FILLET FROZEN	VIET NAM	156,028	555,401	224,847	705,939
Subtotal		**114,762,462**	**450,805,716**	**150,770,116**	**611,074,113**
TILAPIA FROZEN	BANGLADESH	490	2,537	1,207	2,230
TILAPIA FROZEN	CAMEROON	19,958	24,080	0	0
TILAPIA FROZEN	CANADA	2,268	10,000	0	0
TILAPIA FROZEN	CHINA	29,671,564	44,185,702	22,938,041	37,337,832
TILAPIA FROZEN	CHINA - TAIPEI	13,179,606	23,915,366	16,296,367	25,434,922
TILAPIA FROZEN	COLOMBIA	97,202	277,719	44,712	132,462
TILAPIA FROZEN	ECUADOR	5	5,162	2,000	4,551
TILAPIA FROZEN	INDIA	0	0	2,790	2,715
TILAPIA FROZEN	INDONESIA	11,026	14,431	22,401	44,939
TILAPIA FROZEN	MALAYSIA	18,144	27,550	0	0
TILAPIA FROZEN	NICARAGUA	6,037	16,395	5,527	14,520
TILAPIA FROZEN	PANAMA	65,136	121,933	158,159	242,112
TILAPIA FROZEN	PERU	42,203	78,650	0	0
TILAPIA FROZEN	PHILIPPINES	23,871	55,079	114,430	212,596
TILAPIA FROZEN	THAILAND	904,663	1,676,321	1,185,152	1,782,752
TILAPIA FROZEN	UNITED ARAB EMIRATES	0	0	7,000	11,700
TILAPIA FROZEN	VIET NAM	132,266	330,770	112,068	288,871
Subtotal		**44,174,439**	**70,741,695**	**40,889,854**	**65,512,202**
Grand Total		**183,294,841**	**696,085,981**	**215,377,806**	**842,866,006**

PROCESSING and VALUE ADDING

One of the primary constraints on the tilapia industry has been the problem off-flavor. Most often the off-flavor is caused by cyanobacteria (blue-green algae) blooming in production ponds. The industry has

made a concerted effort to train farmers, custom harvesters and processing plant operators to recognize the presence of both the algae and the off-flavor odors coming from the geosmin and methyl-isoborneol imparted to the fish by the cyanobacteria. Many farms and processors have developed depuration systems and procedures to ensure that any off-flavor fish are treated before processing. More sophisticated testing and testing labs are also available to assist farmers and processors to ensure that off-flavor products do not reach consumers (Fitzsimmons 2006). It should be noted that sometimes these fish are processed and sold as lower grade product to lower price markets, especially in Russia and sub-Saharan Africa.

A second constraint is the relatively low percent recovery for tilapia fillets compared to other fishes with a more beneficial body form. This has become even more of an issue as processors implement additional trims and deeper skinning at the request of some customers. Breeders are attempting to overcome this constraint by selecting fish with a better body conformation to increase fillet yield. A second aspect is the development of co-products from the processing industry. One of the co-products has been the increase in a variety of leather goods derived from tilapia skins. This technique first appeared in Brazil, which still has the most diverse selection of products. But we are seeing additional products including tilapia skin swimwear from Thailand.

Figure 2. Tilapia skin leather goods.

Sophisticated equipment and low labor costs – processing companies are continuing to utilize a mix of high technology and low skill labor to prepare the variety of tilapia goods in the market. High capital investment equipment including freezers, scalers, packaging, and computer aided weight checkers is mixed with hand fillet lines and manual packing of boxes. The low cost labor countries with tropical growing conditions will continue to be the industry leaders.

Explosion of product forms – More than any other factor, the plethora of tilapia products hitting the market is encouraging demand and will be the ultimate reason that tilapia will eventually surpass carps to become the most popular farm raised food fish. Breaded fillets, tilapia loins, stuffed fillet, ready to bake or microwave tilapia with sauces and side-dishes are flooding the markets in the US, Europe and the East Asia countries. As young women in Asia continue to join the work force, the idea of purchasing a whole fish (especially carp) and preparing it for smaller families is declining. Women shopping after a work day in the office want the convenience of a packaged fillet product that will be easy to prepare with minimal waste for disposal. Smoked and sashimi forms are also becoming more popular.

The consumption of tilapia in the US market continues to increase and Europe and East Asia are likely to follow the trend of more value added tilapia forms making up an increasing share of the market demand. Tilapia may become the fourth most popular seafood in the US by 2012.

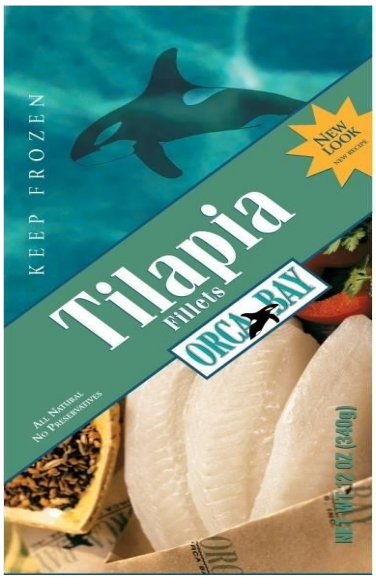
Table 2. United States per capita consumption of seafood products in pounds per person.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Tuna 3.5	Shrimp 3.4	Shrimp 3.7	Shrimp 4.0	Shrimp 4.2	Shrimp 4.1	Shrimp 4.4	Shrimp 4.1	Shrimp 4.1	**Shrimp 4.1**
Shrimp 3.2	Tuna 2.9	Tuna 3.1	Tuna 3.4	Tuna 3.4	Tuna 3.1	Tuna 2.9	Tuna 2.7	Tuna 2.8	**Tuna 2.5**
Pollock 16	Salmon 2.0	Salmon 2.0	Salmon 2.2	Salmon 2.2	Salmon 2.4	Salmon 2.0	Salmon 2.4	Salmon 1.8	**Salmon 2.0**
Salmon 15	Pollock 12	Pollock 11	Pollock 17	Pollock 17	Pollock 15	Pollock 16	Pollock 17	Pollock 1.34	**Pollock 1.45**
Catfish 11	Catfish 11	Catfish 11	Catfish 11	Catfish 11	Catfish 10	**Tilapia 1.0**	**Tilapia 1.14**	**Tilapia 1.19**	**Tilapia 1.21**
Cod 0.8	Cod 0.6	Cod 0.7	Cod 0.6	Tilapia 0.7	Tilapia 0.8	Catfish 0.97	Catfish 0.90	Catfish 0.92	**Catfish 0.85**
Clams 0.5	Clams 0.5	Crabs 0.6	Crabs 0.6	Cod 0.6	Crabs 0.6	Crabs 0.7	Crabs 0.68	Crabs 0.61	**Crabs 0.59**
Crabs 0.4	Crabs 0.4	Clams 0.5	Tilapia 0.5	Crabs 0.6	Cod 0.6	Cod 0.5	Cod 0.47	Cod 0.44	**Cod 0.42**
Flatfish 0.4	Flatfish 0.4	Tilapia 0.4	Clams 0.5	Clams 0.5	Clams 0.4	Clams 0.4	Clams 0.45	Flatfish 0.43	**Clams 0.41**
Scallops 0.3	Tilapia 0.4	Flatfish 0.3	Scallops 0.3	Scallops 0.3	Scallops 0.3	Scallops 0.3	Flatfish 0.32	Clams 0.42	**Pangasius 0.35**
Tilapia 0.3									

VERTICAL INTEGRATION

Another huge reason for the rapid expansion of tilapia products and consumption has been the vertical integration in the industry that has been especially beneficial for production in developing countries and market expansion in the US and European Union. RainForest, Regal Springs, Tropical Tilapia and HQ Sustainable Maritime are multi-national firms. Some source from multiple farms in several countries and each sells to multiple countries. The application of technology across borders and multi-national, multi-lingual employees have provided these companies the ability to rapidly adjust techniques and feed formulations, genetics, processing and marketing. Brand recognition and specialized packaging have further improved the tilapia markets.

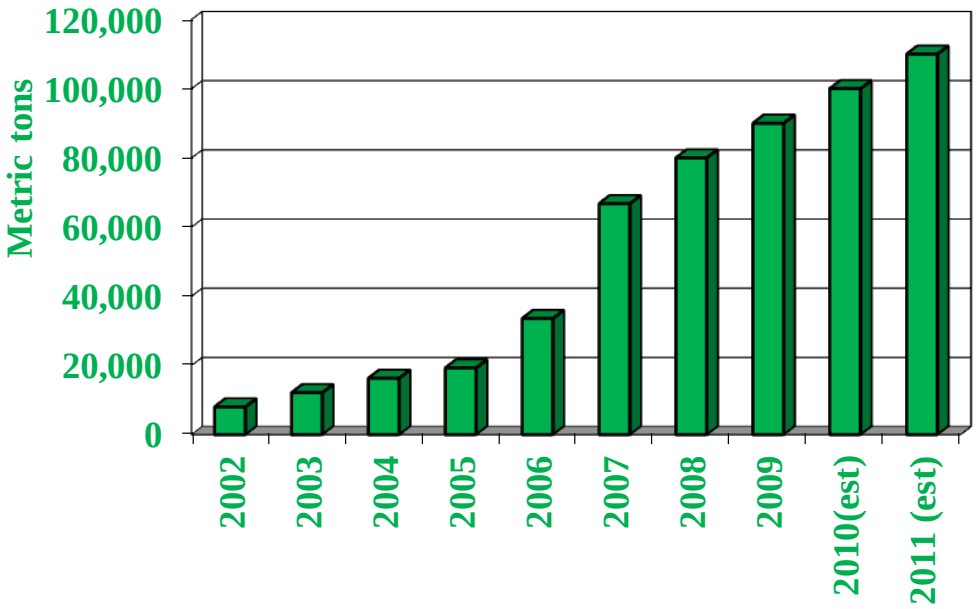
Figure 3. Packaging and brand development



CONCLUSIONS

Global farmed tilapia production has already surpassed that of the salmon and the various catfishes. New producing countries continue to enter the markets producing and consuming large volumes of tilapia. For example, Bangladesh has increased tilapia production from virtually zero in 2000 to 100,000 mt tons in 2010.

Figure 4. Production of tilapia in Bangladesh (2002 – 2011 est.)



On a global basis, while tilapia production is still far behind the carps, the convergence of stronger potential for increased production and the much wider base of consumption leads to the logical conclusion that tilapia will continue to increase production until it surpasses the carps as the most important farmed fish on the planet.

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