CURRENT TRENDS IN THE ASIAN TILAPIA INDUSTRY AND THE SIGNIFICANCE OF GENETICALLY IMPROVED TILAPIA BREEDS[1]

Madan Mohan Dey and Ambekar E. Eknath
International Center for Living Aquatic Resources Management
MC P.O. Box 2631
Makati City, 0718 Metro Manila
Philippines

ABSTRACT

Tilapia production is increasing rapidly in Asia, and is one of the most popular aquaculture activities in PR China, Philippines, Indonesia, Taiwan and Thailand. The most popular farmed tilapia species is still the Nile tilapia (*Oreochromis niloticus*) cultured in over 40 countries. Tilapia culture is a profitable enterprise and even small farmers can afford to culture tilapia to augment their income. Tilapia is consumed mainly by poor people, as it is relatively low priced.

The International Center for Living Aquatic Resources Management (ICLARM) and its partners, through the Genetically Improved Farmed Tilapias (GIFT) Project, have made a breakthrough in tilapia genetic research. Within six years, the project has demonstrated enormous gains in economic performance of farmed tilapia that are possible from a systematic selection programme. It has produced, in four generation selections, genetically improved Nile tilapia strains which perform significantly better in terms of both growth and survival, than the stocks currently used by tilapia farms in the Philippines and elsewhere in Asia. It is expected that with the adoption of the improved tilapia breeds, production of Nile tilapia in Asia will be increased substantially in the future. The adoption of improved tilapia breeds will benefit both producers and consumers. It will increase the comparative advantage of tilapia cultivation in Asia, and is expected to increase the share of Asia in the world tilapia market.

There is a growing need for such GIFT-type research for different tilapia producing countries of Asia. Other equally important research on aspects such as formulation of cost-effective feeds, sex-reversal to produce monosex populations, fish health and quarantine, and water quality, are clearly needed. These are being addressed by various groups in the region, although on a scale that may not yet match the pace of expansion in tilapia farming. Most of this research, however, is funded from public sources and development organisations. It is imperative that the private sector initiate appropriate research and development efforts.

INTRODUCTION

Tilapia farming worldwide is now in a dynamic state of expansion to satisfy both the domestic and international markets. FAO statistics report tilapia culture in at least 75 countries. Although several tilapia species are cultured, the most widely preferred (in over 40 countries) is the Nile tilapia, *Oreochromis niloticus*, which contributes about 55% to the global production of about 450,000 mt (Pullin *et al.*, 1994).

Unlike the farming of many species of indigenous fish in the tropics and the subtropics, the tilapias represent a special scenario. The natural tilapia genetic resources are restricted to Africa and the Levant, whereas the main aquaculture industries are at present in Asia, where they contribute about 10% of the total finfish production from aquaculture. The global outlook for tilapia farming has been dealt with extensively by Pullin *et al.*, (1994). Pullin (in press) has described in detail the perceived constraints to future expansion of tilapia culture. These include negative attitudes and policies, inadequate research support, poor breeds, poor non-sustainable farming systems, and possible adverse environmental impacts.

Tilapias also have the rare distinction of being the subject of more research and debate than perhaps any other tropical farmed fish (Pullin *et al.*,1994). In addition to the vast information compiled from various field and laboratory sources, three international symposia on tilapias in aquaculture have been held. The knowledge base, however, still lacks an inter-disciplinary approach to match development efforts and the needs and circumstances of producers and consumers (Pullin and Maclean, 1992).

The focus of this paper is on the results of a multidisciplinary research initiative being carried out by ICLARM and its research partners; from documentation of tilapia genetic resources, their

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systematic characterisation, evaluation, and utilisation in applied national fish breeding programmes, to monitoring of the adoption of genetically improved tilapia breeds with due regard to their impact on equity, environment, and biodiversity. To provide an Asian development context and the relevance of this major research initiative, the discussion begins by a description of the current status of the tilapia industry in Asia including a brief history of tilapia introductions in Asia, tilapia farming systems, tilapia prices, and international trade in tilapia. The analysis of current trends in the Asian tilapia industry was largely based on information compiled from various sources: FAO (1990, 1992, 1993 and 1996); on-going surveys and research under the auspices of a collaborative research project on Dissemination and Evaluation of Genetically Improved Tilapias in Asia (DEGITA); and unpublished country reports of national programmes.

STATUS OF TILAPIA INDUSTRY IN ASIA

A brief history of tilapia introduction

The Mozambique tilapia (*Oreochromis mossambicus*) was the first tilapia species to be introduced in Asia, being reported on the Indonesian island of Java in 1939. During the 1950s and 1960s, many individuals and organisations introduced *O. mossambicus* to various countries in Southeast Asia and South Asia. But the fish were discarded by producers because of the problems of overcrowding in ponds and poor yield, and by consumers because of its dark colour and small size. Interest in tilapia culture was revived in Asia only after the introduction of Nile tilapia (*Oreochromis niloticus*) in the early 1970s. Nile tilapia has faster growth, bigger size, and lighter colour. Another important tilapia species introduced in Asia is *O. aureus*. Major tilapia producing countries in Asia are China, Indonesia, the Philippines, Taiwan and Thailand. Nile tilapia has also been proved to be a suitable cultured fish species in Bangladesh and Vietnam, and its demand for aquaculture development is growing fast in these countries.

O. mossambicus was introduced in China from Thailand in 1956, and was cultured along with Chinese carps in ponds for a long time (Li, 1996). It was soon considered an unsuitable species for culture and is being replaced by *O. niloticus*, introduced in 1978 from Africa via Hongkong (Table 1). *O. aureus* was introduced in 1981 to produce nearly all-male offspring through hybridisation with Nile tilapia. Tilapias are commonly cultured in ponds, running warm water, cages, *etc.* But *Sarotherodon galilaeus* and *Tilapia zillii* which were introduced in 1981 are still kept in experimental hatcheries. Tilapias are unable to overwinter in natural waters in most parts of China (Tan and Tong, 1989).

The occurrence of *O. mossambicus*, the Java tilapia, in Indonesia is still not clear. This species was first caught in the south coast of Java by Mr. Mudjair, whose name was later given to it on a suggestion of the Inland Fisheries Department. Nile tilapia was introduced into Indonesia in 1969 from Taiwan (Eidman, 1989).

Table 1: Introduction of tilapia to China

Species	Year	Origin	Number introduced	Culture status
Oreochromis mossambicus	1956	Thailand		Discarded
	1957	Vietnam		Discarded
O. niloticus	1978	Sudan	22	Cultured in most area of China
		Egypt	?	Mixed with above strain
	1988	Egypt	9	Cultured in few area
	1991	USA		Kept in three stations
	1994	Philippines (GIFT strain)	5000	Under evaluation
		Philippines (Egypt strain)	2000	Under evaluation
O. aureas	1981	Taiwan	250	?
	1983	USA	33	Used in many provinces for producing all male tilapia
Red tilapia	1973	Israel	4100	?
Sarotherodon galilaeus	1981	Africa	?	Kept in experimental hatcheries
Tilapia zillii	1981	Africa	?	Kept in experimental hatcheries

Source : Tan and Tong (1989); Li (1996)

Table 2. Introduction of tilapia to the Philippines

Species	Year	Origin	Agency
Oreochromis mossambicus	1950	Thailand	BFAR (*a)
O. hornorum x O. mossambicus	1971	Singapore	Private Sector
O. niloticus (Uganda)	1972	Israel	LLDA (*b)
O. niloticus (Egypt)	1972	Thailand	BFAR
Tilapia zillii	1973 (?)	Taiwan (?)	?
O. aureus	1977	USA	CLSU (*c)
O. niloticus (Ghana)	1977	Israel	CLSU
O. niloticus (Ghana)	1977	Singapore	BFAR
O. aureus (Israel)	1977	Singapore	BFAR
O. aureus (Israel)	1978	Singapore	SEAFDEC (*d)
O. niloticus (Ghana)	1979	Singapore	SEAFDEC
O. niloticus (Ghana)	1979	Israel	SEAFDEC
Red tilapia (hybrid)	1979	Taiwan	SEAFDEC
Red tilapia	1981	Taiwan	Private Sector
O. aureus (Israel)	1982	Israel	Private Sector
O. niloticus (Ghana)	1982	Israel	Private Sector
Red tilapia	1982	Taiwan	Private Sector
O. niloticus	1983-84	Taiwan	Private Sector
O. niloticus (Egypt)	1987	Thailand	BFAR
O. niloticus	1988	Ghana, Africa	ICLARM (*e)/BFAR
O. niloticus	1988	Senegal	ICLARM/BFAR
O. niloticus	1988	Egypt	ICLARM/BFAR
O. niloticus	1989	Egypt	ICLARM/BFAR
O. niloticus	1989	Kenya	ICLARM/BFAR
O. niloticus	1992	Egypt	ICLARM/BFAR

a. Bureau of Fisheries and Aquatic Resources
b. Laguna Lake Development Authority
c. Central Luzon State University
d. Southeast Asian Fisheries Development Center
e. International Center for Living Aquatic Resources Management

Source: Adapted from Aypa (1996)

O. mossambicus was introduced in the Philippines in 1950 from Thailand. Ten out of the one dozen fish survived. The fish spawned successively and fingerlings were then dispersed to backyard farmers. This species is now an established tilapia species in brackishwater farms in the entire country. In 1972, Nile tilapia was introduced from Israel and Thailand by the staff of the Laguna Lake Development Authority (LLDA) and the Bureau of Fisheries and Aquatic Resources (BFAR). The fish were better accepted by farmers and consumers. Since then, the growth of the tilapia industry in the Philippines developed at a fast pace. The private sector has also introduced more strains of tilapia to find a superior strain which would be fast growing and highly acceptable in the market. As well as Nile tilapia, other species and strains introduced were: *O. hornorum*, *O. aureus* and hybrid red tilapia from Singapore, Israel, USA, and Taiwan. A list of tilapia introductions in the Philippines is presented in Table 2. *Tilapia zillii*, a slower growing species, was not intentionally introduced but probably came mixed with other introductions (Aypa, 1996). Under the auspices of a collaborative research project on the Genetic Improvement of Farmed Tilapias (GIFT), ICLARM, in cooperation with BFAR, brought in Nile tilapia strains from Egypt, Ghana, Senegal, and Kenya in Africa during 1988 and 1992.

Records of tilapia introductions in Taiwan is given in Table 3. *O. mossambicus* was originally introduced from Indonesia in 1944, when Taiwan was still under Japanese occupation. However, its culture failed. In 1946, it was brought back into the country from Singapore as a souvenir by two returning soldiers of World War II, named Wu and Kuo. Since then, this species of tilapia has been cultured successfully and has become popular in Taiwan. In memory of its "accidental" introducers, it is called *Wu-Kuo Yu*, *Yu* being the Chinese word for fish. *O. mossambicus* was again introduced in 1981 from the Republic of South Africa (RSA). It was initially crossed with Nile tilapia. The result is a popular hybrid called *Fu So Yu*, *Fu So*

Table 3: Introduction of tilapia to Taiwan

Species	Year	Origin	Number introduced	Purposes	Culture status
Oreochromis mossambicus	1944	Indonesia	-	To increase the supply of animal protein using WWII	Unsuccessful
O. mossambicus	1946	Singapore	13	Brought back out of curiosity by 2 returning soldiers from S.E Asia	Widely spread
Tilapia zillii	1963	South Africa	16	To be used in producing cold-resistant hybrid	Well spread because it is cold resistant; hard to polyculture
O. niloticus	1966	Japan	56	Introduced for culture and hybridisation due to its large size *mossambicus* female	Well accepted especially its large size resulting from a cross with *O.*
O. aureus	1974	Israel	83	Hybridisation	Well accepted especially when crossed with *O. niloticus* female
Oreochromis sp. (Red tilapia)	1979	Philippines	30	Genetic studies and crossbreeding	Maintained at Tungkang Marine Lab; not ready for extension
O. hornorum	1981	Costa Rica	56	To obtain monosex progeny	Not ready for extension
O. mossambicus	1981	Costa Rica	48	To be used in crossbreeding studies	Not ready for extension
O. mossambicus	1981	South Africa	50	To be used in crossbreeding studies	Not ready for extension
T. rendalli	1981	South Africa	25	To add new species	Not ready for extension
O. niloticus	1984	France	690	To maintain new strain	Under hybridisation study
O. aureus	1984	France	170 * 36 **	To maintain new strain	Under hybridisation study
O. mossambicus	1984	France	40	To maintain new strain	Under hybridisation study

Total production of tilapia for 1987 exceeds 100,00 mt.
*Israeli strain.
**Filipino strain.
Source: Adapted from Liao and Liu (1989)

meaning "luck, long life". Sixteen *Tilapia zillii* were also introduced from RSA in 1963 to cross-breed with *O. mossambicus*, but the species never gained popularity (Liao and Liu, 1989).

Nile tilapia was first introduced to Taiwan from Japan in 1966. *O. aureus* or blue tilapia was introduced from Israel in 1974 for the purpose of obtaining all-male offspring through hybridisation with Nile tilapia females. The resulting hybrid is now widely cultured in Taiwan. Thirteen specimens of red tilapia (*Oreochromis* sp.) were introduced in Taiwan from the Philippines, where it is also exotic. This exotic red tilapia, which is different from the local red tilapia strain in Taiwan, was introduced to be used in genetic studies and cross-breeding. *O. hornorum*, also known as wami tilapia, was introduced from Costa Rica in 1981 to obtain monosex progeny by hybridisation with other *Oreochromis* sp. Though all the hybridisation attempts have been successful, these hybrids are smaller in size than *O. niloticus* and *O. aureus* hybrids. *T. rendalli* (red breast tilapia) was introduced from RSA in 1981 for the sole purpose of adding a new species to the local gene pool (Liao and Liu, 1989).

Mozambique tilapia was introduced into Thailand from Malaysia in 1949 and was then spread to Northeastern Thailand. The Thai Nile tilapia strain was introduced in Thailand on 25 March 1965 by His Royal Highness Prince Akihito, the Crown Prince of Japan. This strain is known as the Chitralada strain in Thailand. The fish, called *pla nil* (which means "black fish" in the Thai language), was first distributed to fish farmers in August 1967. In 1980, a further introduction was made of about 1,000 Nile tilapia fingerlings from Israel. In subsequent comparative trials of growth performance between the Chitralada strain and Chitralada strain-Israel strain hybrids, the Chitralada strain was found to be superior, therefore the Israel strain has now been eliminated.

In addition to the widespread uses and commercial importance of the Nile tilapia (Chitralada strain) in Thai aquaculture, the red tilapia strains are important as well. The Thai red tilapia was originally found at the Ubonratchathani Fisheries Development Centre in 1968. Red tilapia strains are hybrids and comprise a gene pool of up to four different species in which *O. niloticus* and *O. mossambicus* are predominant. The original red variant may have been an *O. mossambicus* and this was later hybridised with various pure and mixed strains of *O. niloticus* to improve its culture performance. At Chachoengsao Coastal Aquaculture Development Centre, pure broodstock of about 100 pairs of red tilapia strain have been used to produce offspring with almost pure red colour. In 1984, Her Royal Highness Princess Maha Chakri Sirindhorn named this fish "red tilapia". The Thai red tilapia has been distributed to many fisheries stations, fish farms, and water bodies throughout the country.

Tilapia farming practices

Tilapia is cultured mainly in freshwater ponds in Asia. During 1993-94, about 93% of total production came from inland waters. The Nile tilapia is the species that contributes most to regional production (Table 4).

In China, tilapias are cultured in ponds, cages, and running warm water. Though both polyculture and monoculture systems are followed in ponds, polyculture of tilapias with Chinese carps (mainly bighead, *Aristichthys nobilis*, grass carp, *Ctenopharyngodon idellus*, and silver carp, *Hypophthalmichthys molitrix*) is the most popular system. Mixed-sex tilapias are cultured together with carps in freshwater ponds supplied with animal manure, vegetation and agricultural by-products. More than 80% of the total farmed tilapia production in China comes from pond polyculture. In cages and running warm water, tilapias are cultured in monoculture system. Almost 100% of national tilapia production is from Nile tilapia (Table 4). At present, the Nile tilapia-1978 is the most widely cultured strain.

In Indonesia, tilapia culture is located almost exclusively on the island of Java. *O. mossambicus* is still the predominant tilapia species, contributing about 75% of total tilapia production (Table 4). Mixed-sex *O. mossambicus* are cultured with animal and human manure and/or fed agricultural by-products. Recently, Nile tilapia and red tilapia have been introduced to Java. Monosex culture of sex-reversed male tilapia or mixed-sex tilapia in cages expanded when pelleted fish feeds became available in Java.

Tilapias in the Philippines are produced in freshwater ponds, pens and cages, and in brackishwater ponds. The contribution of freshwater farmed tilapia to total farmed tilapia production rose from 55% in 1983-84 to 93% in 1993-94 (Table 5). This is mainly because of consumers' and producers' preference for Nile tilapia grown in freshwater areas. The increase in freshwater farmed tilapia production came from freshwater ponds and cages. Tilapia production from freshwater ponds and cages grew yearly at the rate of 15% and 17% respectively, from 1983 to 1994, which contributed about 45% and 35% of total farmed tilapia production in 1994, respectively. Monoculture of mixed-sex tilapia is the predominant farming practice. Sex-reversal technology to produce male tilapia is available but the supply of male fingerlings is limited.

Tilapias are farmed all over Taiwan but the majority of fish are raised in the south because of the warmer climate. Principal farmed tilapia are hybrids of *O. mossambicus and O. niloticus*, *O. niloticus*, *O. aureus*, and red tilapia. Traditional methods of tilapia farming are

Table 4: Farmed tilapia production by species and environment in selected Asian countries and Asia in total, 1993-1994

Country	Environment	Species	Production (mt) 1993	Production (mt) 1994	% of country's regional total (1993/1994)
China	Inland	*O. niloticus*	191,257	235,940	100
Indonesia	Inland	*O. niloticus*	18,495	10,790	25
		O. mossambicus	21,469	22,900	37
	Brackishwater	*O. mossambicus*	21,932	23,300	38
Philippines	Inland	*O. niloticus*	70,614	68,560	73
		Oreochromis spp.	17,781	15,933	18
	Brackishwater	*O. niloticus*	3,972	4,915	5
		Oreochromis spp.	3,972	4,914	5
Thailand	Inland	*O. niloticus*	53,997	59,397	100
		O. mossambicus	2	2	-
	Brackishwater	*O. mossambicus*	115	115	-
Asia	Inland	*O. niloticus*	338,256	379,861	72
		O. mossambicus	25,936	27,469	5
		Oreochromis spp.	86,818	72,726	16
	Brackishwater	*O. niloticus*	3,972	4,915	1
		O. mossambicus	22,047	23,415	4
		*Oreochromis*spp.	6,895	10,806	2

Source: FAO (1996).
Note: *Oreochromis* spp." refers to aggregated data reported as such by FAO, comprising widely distributed species, such as *O. aureus*, *O. niloticus*, *O. mossambicus*, naturally coloured and red hybrids among *Oreochromis* species, and other species of minor importance.

Table 5: Philippines tilapia production (mt) from aquaculture by culture system, 1983-1994

Year	Total	Freshwater ponds	Brackishwater ponds	Freshwater cages	Freshwater pens
1983	30,800	11,300	14,800	4,700	0
1984	32,000	11,600	13,300	7,100	0
1985	43,800	13,900	13,300	7,200	9,400
1986	55,800	14,100	16,500	8,900	16,300
1987	75,800	26,800	17,900	16,800	14,300
1988	75,000	30,100	18,200	17,200	9,500
1989	81,700	30,900	23,100	18,500	9,200
1990	76,100	35,200	18,800	18,200	3,900
1991	76,600	37,400	14,100	21,000	4,100
1992	83,300	40,300	13,000	25,000	5,000
1993	96,500	47,900	8,000	35,600	5,000
1994	94,400	8,900	9,800	31,900	13,800
[1] Growth rate (%)	9.11	14.59	-2.48	16.55	-14.20

Source : Bureau of Agricultural Statistics and BFAR Fisheries Profile
[1] Estimated by fitting semi-logarithmic trend lines on the three yearly moving averages of the time series for the respective culture systems.

Table 6: Production of tilapia by culture system and region, Thailand, 1992

Region	Pond	Paddy fields	Ditch	Total
North	4,827	14	7	4,848
Northeast	3,420	364	1	3,785
Central	5,817	8,665	194	34,676
South	607	-	-	607
Whole Kingdom	14,671	9,043	202	43,916

Source: Basic data from Department of Fisheries, Thailand

monoculture of mixed-sex tilapia integrated with animal husbandry in small, freshwater ponds. Taiwan has modernised its tilapia culture practices in recent years. Intensive monosex culture of sex-reversed tilapia is widely practised. Red tilapias are also cultured in brackishwater pond and sea cages.

In Thailand, nearly 80% of total farmed tilapia production comes from pond culture, the rest is from paddy fields and ditch culture (Table 6). The central region is the main freshwater tilapia producing area due to the availability of good irrigation schemes in the region. Tilapia culture, particularly Nile tilapia, is not very common in the coastal region. Though tilapia is cultured by all types of farmers, large commercial tilapia farms, with an average size of 4 ha per farm, dominate tilapia production in areas surrounding Bangkok. A recent survey of tilapia farmers in the central region revealed that more than 60% of fish farmers used to grow rice before switching to aquaculture for higher income, and more than 50% of sample farmers considered fish farming as their main occupation.

Traditional tilapia culture practice in Vietnam is mainly based on polyculture in semi-intensive culture systems where tilapia is stocked together with Chinese carps (silver carp and grass carp) and Indian carps (rohu and mrigal). This culture system is commonly found in village ponds and sewage areas. In brackishwater, tilapia are stocked in large ponds with other brackishwater species in extensive culture system. Monoculture of tilapia is practised only in integrated fish farms with pig or chicken. At present, *O. niloticus*, *O. mossambicus* and a hybrid between *O. mossambicus* and *O. niloticus* are used as cultured fish species in different aquaculture systems.

Current production and recent trends

Tilapia culture is growing rapidly in Asia. Its production has increased from 154,509 mt in 1984 to 519,192 mt in 1994, with an annual growth rate of 12%. Asia accounted for 87% of the globally farmed tilapia during 1993 and 1994. China, Philippines, Indonesia, Thailand, and Taiwan account for most farmed tilapia production in Asia: 43, 19, 12, 11, and 10%, respectively, during 1993 and 1994 (Table 7).

In China, tilapia production from aquaculture has increased from a marginal 18,100 mt in 1984 to 235,940 mt in 1994, with an average growth rate of 28% per year. The contribution of farmed tilapia to total aquaculture rose from less than 0.5% in 1984 to about 2% in 1994.

Though tilapia production in Indonesia increased rapidly during the 1980s, it has remained stagnant at around 60,000 mt in recent years. Farmed tilapia contributed less than 10% of the total aquaculture production of the country from 1990 to 1994.

Tilapia is the most important freshwater cultured species in the Philippines, contributing about 60% of the national freshwater aquaculture production in 1994. Tilapia also ranks second to milkfish in terms of fresh and brackishwater farmed fish production in the country, contributing about 23% of the total aquaculture production. Farmed tilapia production in the Philippines increased at an average growth rate of about 8% per year from 1984 to 1994 (Table 7).

Production of farmed tilapia in Thailand has been increasing since 1984 at an average rate of about 15% per year. At present, Nile tilapia is the most important freshwater cultured species in Thailand, contributing more than 11% of the total aquaculture production.

Taiwan produces about 50,000 mt of farmed tilapia per year. However, the importance of tilapia to the aquaculture industry in Taiwan has decreased over the years. Tilapia production has remained stagnant during the last decade and its share in aquaculture production is declining.

At present, production of tilapia in Vietnam is about 15,000 mt, which accounts for about 5% of the total

Table 7: Production of tilapia (mt) and % of tilapia in aquaculture production of selected Asian countries and Asia in total, 1984-1993.

	China	Indonesia	Philippines	Thailand	Taiwan	Asia
(a) Production						
1984	18,100	29,990	30,908	10,300	53,812	154,509
1985	23,800	42,330	42,640	16,542	51,820	190,617
1986	29,500	24,011	55,819	19,245	49,241	191,245
1987	34,800	35,059	75,769	17,456	51,720	230,154
1988	39,000	44,750	75,046	19,130	49,405	252,070
1989	89,473	38,000	81,675	21,509	47,089	297,754
1990	106,071	53,768	76,142	22,895	53,103	331,766
1991	119,852	54,287	76,570	27,800	51,415	352,295
1992	157,233	59,945	91,173	43,547	47,858	421,830
1993	191,257	61,896	96,339	54,114	57,570	483,924
1994	235,940	56,990	94,322	59,514	48,042	519,192
[1] Growth rate	27.84	8.85	7.84	14.57	0.15	12.15
(b) % share in aquaculture production[2]						
1984	0.45	11.08	8.96	9.20	21.96	1.83
1985	0.54	14.32	13.16	12.18	20.66	2.11
1986	0.61	7.21	17.86	14.99	18.50	1.94
1987	0.63	9.31	21.44	10.00	16.93	2.17
1988	0.60	10.78	20.94	8.73	16.41	2.14
1989	1.25	8.60	21.68	8.27	18.85	2.41
1990	1.45	10.76	19.14	7.85	15.43	2.62
1991	1.43	10.49	17.98	7.87	17.61	2.50
1992	1.52	10.89	22.19	11.74	18.29	2.56
1993	1.51	10.31	23.20	11.83	20.18	2.51
1994	1.60	8.60	23.31	11.46	16.68	2.40

Source: FAO (1996); for Taiwan: Taiwan Fisheries Bureau
[1] Estimated by fitting semi-logarithmic trend lines on three yearly moving average of the time series for the respective countries.
[2] Excluding seaweed production.

fish production from aquaculture. It is estimated that over 10,000 ha of village ponds, 2,000 ha of sewage fed fish ponds and 10,000 ha of brackishwater area are presently being used for tilapia culture. However, tilapia is not found in natural lakes, reservoirs, and river systems.

Profitability of tilapia culture

Profitability of tilapia culture compared to other major aquaculture commodities varies among different Asian countries. These differences can be attributed to variation in soil and water quality, fingerling quality, management practices, input use levels, factor and market prices governed by consumers' preferences. A country by country review of the differences follows.

Nile tilapia and silver barb are the two main species that are cultured in seasonal ponds in Bangladesh. Net profit over variable cost per production cycle of Nile tilapia (US$12.60/100 m^2) was higher than that of silver barb culture (US$5.94/100 m^2). Small farmers prefer Nile tilapia for culturing in their seasonal ponds as it requires no or very limited external inputs, and is resistant to disease like epizootic ulcerative syndrome (EUS). Profitability of tilapia culture was higher than that of extensive shrimp monoculture, but was slightly lower than that of carp polyculture, which is the most common freshwater fish culture system in the country (Table 8).

Tilapia farming is a profitable enterprise in the Philippines. Surveys conducted by ICLARM and the Philippine Bureau of Agricultural Statistics in the main Luzon island during 1994 showed that the net profit of tilapia culture was about US$241.33/100 m^2 in cage

Table 8: Cost and return of selected aquaculture species per 100 m² in Bangladesh, 1991-1992.

Item	Carp polyculture*	Nile tilapia monoculture*	Silver barb monoculture*	Shrimp monoculture** (extensive)
Return				
Production (kg)	81.69	40.50	38.67	-
Value (US $)	21.08	16.41	10.96	10.06
Cash cost (US $)	2.84	1.70	3.68	2.63
Fingerlings	1.61	1.11	2.64	1.29
Lime	0.28	0.34	0.37	-
Inorganic fertiliser	0.34	0.21	0.30	-
Rice bran	0.05	-	0.08	-
Oil cake	0.33	-	0.12	-
Pesticide	0.01	-	0.01	-
Harvesting/labour	0.22	0.04	0.16	1.34
Non-cash cost (US $)	0.90	2.12	1.34	-
Cattle manure	0.46	0.44	0.39	-
Poultry manure	0.02	0.05	0.02	-
Rice bran	0.43	1.63	0.93	-
Total variable cost (US $)	3.74	3.82	5.02	2.63
Net profit over variable cost (US $)	17.34	12.60	5.94	7.43
Cash cost/kg of fish ($/kg)	0.03	0.04	0.10	-
Total variable cost/kg of fish ($/kg)	0.05	0.09	0.13	-

Exchange rate: Taka 38 = US$ 1
Sources: *Ahmed *et al.* (1995); **Rahman *et al.* (1994)

and US$10.25/100 m² in pond (Table 9). While the farm gate price of tilapia was about US$1.75/kg, total cost of production was US$0.75/kg in pond culture and US$0.45 in cage culture. Feed cost was the single major cash cost component of tilapia farming. It amounted to 61% of the total cash cost for tilapia cage culture and 46% for tilapia pond culture. The use of commercial feeds is generally supplemented in ponds by the growing of natural food through fertiliser applications. When compared with other aquaculture activities, tilapia farming was more profitable than milkfish farming and less profitable than shrimp farming. However, shrimp farming's cash requirement was also considerably higher at US$50/100 m² compare to tilapia at US$6/100 m².

In Taiwan, net profit per 100 m² per production cycle of tilapia farming at US$34 was higher than that of milkfish at US$33. And average net income of grass shrimp farming was negative due to the incidence of disease (Table 10). As land is very expensive in Taiwan, tilapia farming is highly capital intensive. The total cost of production of tilapia per 100 m² was US$118 which is the highest in Asia. However, as the production was also very high at 12 mt/ha, tilapia farmers had to spend only US$0.95 as a total cost to produce a kilogram of tilapia. Cost of feed, fertiliser, and medicine was the most important expense for tilapia farming, which amounted to 49% of the total direct cost. The second major cash expense for tilapia farming was the cost of fry or fingerlings. The labor component, including its noncash component, was relatively lower than the cost of fry or fingerlings in the production of tilapia. These results imply that tilapia farming in Taiwan is intensive.

Comparative cost and return figures for tilapia, catfish, and shrimp farming in Thailand are given in Table 11. Though catfish and shrimp culture gave higher net income compared to tilapia culture, rate of return on investment was higher for tilapia culture. Unlike tilapia farming, catfish and shrimp farming in Thailand are highly capital intensive. Tilapia farming's cash requirement was considerably lower at only US$90 compared to catfish at US$105 and shrimp at US$126. Tilapia farmers had to spend US$0.17 as the cash cost and US$0.20 as the total variable cost to produce a kilogram of tilapia. As in the Philippines and Taiwan, feed was the largest expense for tilapia farming in Thailand, amounting to about 38% of the total cash cost. Other major cash expense items for tilapia culture were cost of fingerlings (20%) and hired labour cost (17%).

Table 9: Cost and return of selected aquaculture species in the Philippines, 1994

Item	Land-Based Culture (per 100 m²)			Cage culture
	Tilapia monoculture*	Milkfish semi-intensive monoculture**	Shrimp semi-intensive monoculture**	Tilapia monoculture* (per 100 m³***)
Return				
Production (kg)	10.50	16.52	15.00	189.40
Value (US $)	18.09	36.22	80.77	333.57
Cash cost (US $)	7.14	26.06	52.80	84.43
Labour	0.71	0.55	4.21	6.33
Fry/fingerlings	2.41	6.92	5.77	24.90
Fertiliser	0.25	1.10	0.73-	
Feed	3.30	15.78	31.15	51.24
Fuel/electricity	0.12	0.58	4.03	0.99
Lime/Miscellaneous	0.35	1.13	6.91	0.98
Non-cash cost (US $)	0.71	1.44	2.60	7.76
Family labour	0.48	1.44	2.60	7.76
Fry/fingerlings	0.23	-	-	-
Total variable cost (US $)	7.85	27.51	55.40	92.19
Net profit over variable cost (US $)	10.25	8.71	25.37	241.38
Cash cost/kg of fish (US $/kg)	0.68	1.58	3.52	0.45
Total variable cost/kg of fish (US $/kg)	0.75	1.66	3.69	0.49

Exchange rate: Pesos 26 = US$ 1

Sources: * Bureau of Agricultural Statistics-ICLARM Field Survey, 1994

** Aquaculture Division, Bureau of Fisheries and Aquatic Resources, 1995

Note: *** Average water depth=4 m: The intention is not to compare the per unit area performance but to show the relative share of various cost components in different aquaculture activities.

Detailed analyses of cost and return of tilapia farming in other Asian countries are not available. Limited information suggests that tilapia farming is a profitable activity in China and Vietnam; with a net income of about US$400 per ha per two years in China and about US$350 per ha per farming season (6-8 months) in Vietnam.

In summary, fish farmers' net profit from tilapia pond culture was higher in Taiwan than in Bangladesh, the Philippines, and Thailand. However, Taiwan's farmers had to pay more to produce a kilogram of tilapia compared with their counterparts in other Asian countries. Apparently, Thailand has a comparative advantage in producing tilapia over Bangladesh, the Philippines, and Taiwan due to its efficient and low-cost production practice.

Tilapia prices

The price of tilapia is relatively low compared to other fish species. Tables 12 and 13 show prices of popular fish species in the Philippines and freshwater fish species in Thailand, respectively, from 1987 to 1992. In the Philippines, tilapia prices were higher than frigate tuna (*Auxis* spp.), roundscad (*Decapterus macrosoma*) and slipmouth (*Leiognathus* spp.), but were lower than milkfish, grouper, cavalla (*Carengoides* spp.), threadfin bream and Indian mackerel. In Thailand, tilapia prices were higher than those for striped catfish (*Pangasius* spp.), but were lower than those for snakehead, silver barb, common carp, and golden price carps. Tilapia prices (in US$) have increased in the Philippines from 1987 to 1992, but have remained more or less constant during the same period in Thailand. The ratio of tilapia price to milkfish price has increased in the Philippines from 0.68 in 1987 to 0.76 in 1992, while the ratio of tilapia price to catfish (*Clarias batrachus*) has remained more or less constant at around 0.37 from 1987 to 1992.

In Taiwan, tilapia prices are lower than those for milkfish, yellowfin tuna, and albacore. Tilapia prices (in US$) and the ratio of tilapia price to milkfish price

Table 10: Cost and return of selected aquaculture species per 100 m² in Taiwan, 1992.

Item	Tilapia	Milkfish	Grass shrimp
Return			
Production (kg)	124.72	70.39	17.42
Value (US $)	152.16	163.31	166.36
Direct costs (US $)			
Own and hired labour	17.63	16.90	28.18
Fry/fingerlings	32.65	19.58	41.10
Feed, fertiliser, medicine	55.49	79.50	70.98
Water and electricity	5.57	11.77	14.56
Maintenance and other expenses	1.44	1.76	12.46
Sub-total	112.77	129.51	167.28
Indirect costs (US $)			
Discount value	0.00	0.00	9.80
Rents and interest expenses	0.00	0.42	21.09
Transportation, packaging, storage	5.24	0.00	0.00
Insurance and business expenses	0.00	0.00	4.06
Sub-total	5.24	0.42	34.95
Total cost (US $)	118.01	129.94	202.23
Net profit (US $)	34.15	33.37	-35.87
Cost/kg of fish	0.95	1.85	11.61

Source : Lo and Hwang (1994)

Table 11: Cost and return of selected aquaculture species cultured in ponds per 100 m² in Thailand, 1992

Item	Tilapia	Catfish	Shrimp
Return			
Production (kg)	55.60	199.50	41.19
Value (US $)	24.99	158.43	230.22
Cash cost (US $)	9.50	105.30	125.69
Fry/fingerlings	2.91	19.54	23.15
Feed	3.64	76.07	68.36
Labour	1.42	3.94	3.44
Drug/lime/other chemicals	0.15	1.03	8.21
Fuel	0.78	3.20	11.48
Maintenance	0.22	0.75	10.74
Others	0.37	0.79	0.31
Non-cash cost (US $)	1.78	5.53	2.80
Fry/fingerlings	0.11	-	-
Feed	0.56	1.64	-
Labour	1.11	3.89	2.80
Total variable cost (US $)	11.28	110.83	128.49
Net profit over variable cost (US $)	13.72	47.60	101.74
Cash cost/kg of fish ($/kg)	0.17	0.53	3.05
Total variable cost/kg of fish ($/kg)	0.20	0.56	3.12

Exchange rate: Baht 25.5 = US$ 1
Source: Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Thailand

Table 12: Wholesale price (US$/kg) of major fish species in the Philippines, 1987-1992

Fishes	1987	1988	1989	1990	1991	1992
Milkfish	1.12	1.14	1.46	1.55	1.67	1.86
Grouper	1.39	1.61	2.09	-	-	2.76
Tilapia	0.77	0.70	-	-	-	1.41
Frigate tuna	0.68	0.67	0.81	-	-	0.98
Roundscad	0.68	0.66	0.83	0.81	0.85	0.86
Cavalla	1.16	1.30	1.55	-	-	2.08
Slipmouth	0.68	0.78	0.98	0.91	0.90	0.77
Threadfin bream	0.92	0.95	1.14	1.15	1.34	1.35
Indian mackerel	0.85	0.88	1.15	1.05	1.18	1.23

Source: Bureau of Agricultural Statistics, Philippines

Table 13: Farm prices (US$/kg) of freshwater fish in Thailand, 1987-1992.

Species	1987	1988	1989	1990	1991	1992
Batrachian walking catfish (*Clarias batrachus*)	0.99	1.18	1.11	1.22	1.16	1.26
Gunther's walking catfish (*Clarias macrocephalus*)	1.64	1.72	1.50	1.48	1.44	1.33
Striped snake-head (*Ophicephalus striatus*)	1.17	1.30	1.24	1.47	1.62	1.80
Tilapia (*Oreochromis niloticus*)	0.36	0.42	0.41	0.47	0.44	0.47
Striped catfish (*Pangasius sutchi*)	0.35	0.31	0.34	0.35	0.35	0.38
Thai silver carp (*Puntius gonionotus*)	0.61	0.64	0.51	0.69	0.72	0.73
Jullien's golden price carp (*Probarus jullieni*)	0.58	0.66	0.88	0.76		
Common carp (*Cyprinus carpio*)	0.98	0.76	0.87	0.63	0.68	0.89

Source: Office of Agricultural Economics, Thailand.

have increased in Taiwan during the last decade (Taiwan Fisheries Bureau, Fisheries Yearbook, various issues).

Information on fish prices collected by ICLARM staff during 1992 from different locations of Bangladesh, China, and Vietnam showed that prices of tilapia were relatively moderate compared to more highly regarded species. In Bangladesh, the average tilapia price was US$1.25/kg, which was one-third of the price of Indian major carps. In China, tilapia prices were lower than those for crucian carp, black carp, and bream, but higher than those for Chinese carps. In Vietnam, prices of small tilapia (with an average size of 100 g) were very low (US$0.45/kg) compared to those for other common species like Indian carps (US$0.75/kg). However, larger tilapia (with an average size of >250 g), which had very limited supply in the country, commanded a high market price (US$1/kg).

International trade

International trade in tilapia in Asia is increasing very rapidly but is not yet well documented. The United States of America is the major importer of tilapia from Asia. In 1995, about 85% of the total tilapia imports to USA came from Asia. European markets, which prefer bigger tilapia are also expanding for Asian tilapia. In Japan, there is a market for *sashimi* grade fish.

Taiwan is the biggest exporter of tilapia in Asia. In 1995, Taiwan exported about 156,000 mt live weight equivalent (LWE, obtained by multiplying the product weight by 1.1 for whole frozen fish and by 3.0 for fillets) of tilapia to the USA, with an average C & F (cost and freight) price of US$ 1.26/kg of LWE fish. These imports accounted for 66% of total tilapia imports to the USA (Table 14). Taiwan exports about 35% of its total domestic production. Other major tilapia exporters in Asia are Thailand and Indonesia. These countries export less than 5% of the domestic production. China is interested in exporting tilapia, and presently, China is the second largest exporter of whole frozen fish to the US. Vietnam has also recently entered into the world tilapia market. In 1995, average C & F prices for tilapia in the USA were highest for fish landed from Indonesia (US$ 1.41/kg LWE) and lowest for fish from Vietnam (US$ 0.67/kg LWE). Unlike other Asian exporters, Indonesia exports almost exclusively in fillet form. Indonesia is a major exporter of frozen tilapia fillets to the USA.

Table 14: Exports of tilapia products from selected Asian countries to USA, by product, 1995

	Products						Total live weight equivalent[1]	
	Whole frozen		Fillets		Fillet frozen			
Country	Quantity (kg)	Price (US$/kg)	Quantity (kg)	Price (US$/kg)	Quantity (kg)	Price (US$/kg)	Quantity (kg)	Price (US$/kg)
China	245,318	1.27	2024	4.26	69,894	3.92	245,318	1.27
Indonesia	-	-	-	-	545,960	4.22	1,637,880	1.41
Taiwan	11,940,634	1.42	-	-	804,468	2.88	15,548,100	1.24
Thailand	39,667	1.00	-	-	423,644	2.86	2,892,045	0.94
Vietnam	10,929	0.74	-	-	-	-	12,022	0.67
Total US import	13,300,340	1.42	1,463,513	2.46	2,167,692	1.88	53,226,696	1.4

Source: American Tilapia Association (1996)
[1]Live Weight Equivalent = whole fish weights are multiplied by a factor of 1.1, and fillet weights are multiplied by 3.0.

The Philippines, the second biggest producer of tilapia in Asia as well as in the world, has so far been unable to compete with other tilapia producing countries in the tilapia export market. Philippine farmers need to pay higher cost to produce a kilogram of tilapia compared to their counterparts in other Asian countries. On the other hand, as tilapia is a preferred species in the Philippines, the local market price (about US$ 2/kg in the wholesale market in 1995) for tilapia is higher than the world market price (C & F price in US in 1995 was US$ 1.4/kg LWE).

GENETIC IMPROVEMENT OF FARMED TILAPIA (GIFT)

The need for genetic improvement

As described earlier, natural tilapia genetic resources are restricted to Africa whereas the main aquaculture industries are at present in Asia. The history of introductions of tilapias (described above) suggests that most farmed tilapias derive from very small founder stocks (as reviewed earlier by Pullin and Capili, 1988; Eknath, 1995). With the notable exceptions of Israel and, to a certain extent, of Taiwan, genetic improvement research destined to benefit the existing and the emergent tilapia industry has scarcely begun. The cost of lost opportunities has been considerable. The stocks in current use by Asian farmers are close to wild undomesticated stocks or perhaps worse (Eknath *et al.*, 1993).

Application of genetics to tilapia farming, on the other hand, can be a complex activity for several reasons: (a) diversity of farming systems; (b) diversity of needs and opportunities in tilapia growing countries; (c) diversity of markets; and (d) the general lack of infrastructure development to successfully disseminate the results of genetic improvement programmes to benefit producers and consumers.

The basic strategy and principles

Before embarking on a research effort in genetics, it should be recognised that the tilapia industry at present is evolving. Aquaculture in general, tilapia culture in particular, represents a new dimension in fish farming not only to the existing farmers but also potentially to many new entrants to aquaculture. At present, as seen in the poultry industry, the 'backyard' type tilapia farming coexists with relatively sophisticated medium and large-scale corporate farms. Therefore, equity and the socioeconomic impacts of research are important considerations. Also, genetic improvement strategies destined to benefit the aquaculture industry should to the extent possible presume relatively minor or gradual structural changes. The lessons learnt from agriculture and livestock research cannot be ignored. While the products of genetic research should assist in enhancing the competitiveness of the private sector, it should at the same time consolidate the pivotal role of small-scale farmers in food production and food security.

To increase and sustain productivity in tropical aquaculture, ICLARM's strategic plan identifies two key research problem areas: genetics and breeding;

and integrated agriculture-aquaculture production systems. These are being approached by interactive research to develop better, sustainable farming systems and better breeders for culture in these systems. Early on, ICLARM recognised that genetic improvement and the various other constituent technical considerations (genotype x environment interactions, approaches and tools to genetic improvement, multiplicity of breeds, *etc.*) are only part of the story. The other crucial aspect is the dissemination of results and products to reach the targeted beneficiaries effectively, including monitoring of the impact and adoption of improved breeds. Management and access to improved breeds are also becoming important issues.

With these guiding principles, ICLARM initiated a major strategic research and training initiative in fish breeding genetics through the UNDP/ADB-funded project known as the "Genetic Improvement of Farmed Tilapias" (GIFT). The primary objective was to develop effective ways of producing improved breeds of Nile tilapia for low external input aquaculture systems, and to provide improved breeds to national and regional testing programmes in cooperation with farmers.

The GIFT project

The project was established in 1988 through collaboration among the Philippine national institutions (Bureau of Fisheries and Aquatic Resources, the Central Luzon State University and the University of the Philippines), the Norwegian Institute of Aquaculture Research (AKVAFORSK), and ICLARM, and funded by UNDP and the ADB.

The process

At the very outset, the GIFT team considered the relative economic importance of each of the diverse tilapia farming systems. A grow-out period of 90 days was chosen as a representative production cycle. Research methods for evaluation of culture performance in these diverse test environments were then refined.

Based on the recommendations and identification of sources of pure tilapia stocks of a 1987 Workshop held in Bangkok, the GIFT team made the first ever collections in 1988, and made direct transfer of Nile tilapia from Africa to tropical Southeast Asia. Breeders (150-160) or fingerlings (200-800) were collected in Egypt, Ghana, Kenya, and Senegal, in collaboration with, among many, the University of Hamburg, Germany; the Musée Royal de l'Afrique Centrale, Tervuren, Belgium; the Institute of Aquatic Biology, Ghana; the Suez Canal University and the Central Laboratory for Aquaculture Research, Egypt; and the Baobab Farms, Mombasa, Kenya. The fish were held in quarantine at the National Freshwater Fisheries Technology Research Centre/Bureau of Fisheries and Aquatic Resources (NFFTRC/BFAR). The team worked with the BFAR Fish Health Unit to develop quarantine protocols: a model for use elsewhere. Experimental stocks of four Philippine commercial Nile tilapia strains were also gathered, giving a total of eight strains for study. All eight strains were described using biochemical and morphometric techniques and held in a newly constructed Tilapia Germplasm Reference Collection Centre at the NFFTRC/BFAR. Spermatozoa from tilapia founder stocks and selected breeders are also cryopreserved, as part of a small tilapia gene bank, for further research.

The Project's first experiment was to investigate the magnitude of genotype x environment interactions (GE). A total of 11,400 individually tagged fingerlings from all eight founder strains were distributed to 11 test environments and communally reared for about 90 days. The GE was very low, indicating no need to develop environment-specific strains for each of the different farming systems used in the test. Some of the African strains grew much faster than the Asian farmed strains (Eknath *et al.*,1993).

This GE experiment was followed by a complete 8 x 8 diallele crossing experiment, producing all 64 possible hybrid crosses among the strains in order to estimate the magnitude of heterosis or 'hybrid vigour'. The estimated gain in growth and survival by crossbreeding was too low to be of significance in an applied breeding programme. A simple purebreeding strategy was then started by selecting best growing individuals from the 25 best performing purebred and crossbred groups (out of the 64 evaluated) to build a genetically mixed base population (synthetic breed). This synthetic breed served as the base for further generations of selection and purebreeding (Eknath, 1995).

Selection means breeding from the 'best' individuals. In one form or another, it accounts for most of the improvements that have been made in domesticated plants and animals. There has been no equivalent effort for fish. The GIFT team adopted a combined family and within family selection strategy. The test fish were ranked based on 'breeding value' - the additive genetic value of an individual - estimated by evaluating the performance of the individual itself and its full- and half-sibs. After only one generation of selection in the synthetic breed, the selected fish grew 26% faster in on-station trials than the previous generation and 75% faster than the most commonly farmed strain in the Philippines. The team has been evaluating in every successive generation, about 20,000 individually tagged fingerlings from 120-200 selected full-sib families (within 100 half-sib families) in a variety of test environments (Eknath, 1995).

The GIFT strain is now in its sixth generation of combined family selection. The average genetic gain per generation across five generations of selection carried out so far has been about 12-17%. The potential for developing late-maturing tilapias and inclusion of this important trait in the on-going selection (for growth performance) programme are being investigated.

Some early impacts

In 1993, the Philippine President, Fidel V. Ramos, launched the national distribution of the GIFT tilapias. The Philippines has since initiated a National Tilapia Breeding Programme. In preparation for the development of national tilapia breeding programmes elsewhere in Asia, the social, economic, and environmental impact of new tilapia breeds are being investigated in a range of aquaculture systems in Bangladesh, China, Indonesia, Thailand and Vietnam.

The early achievements of the GIFT project has already led to the establishment of an International Network on Genetics in Aquaculture (Seshu *et al.* 1994). Thirteen countries are collaborating in research and exchange of genetic materials, initially tilapias and carps: Bangladesh, China, Côte d'Ivoire, Egypt, Fiji, Ghana, India, Indonesia, Malawi, Malaysia, the Philippines, Thailand, and Vietnam. ICLARM is the member-coordinator.

NATURE AND IMPACT OF GIFT TECHNOLOGY

Nature of GIFT technology

The GIFT project has demonstrated clearly the enormous gains in economic performance of farmed tilapia that are possible from a systematic selection programme. The project demonstrates a cost-effective and simple route to genetic improvement which has some advantages over more costly and complex genetic management and biotechnological approaches. Conventional selection programmes are well regarded in public opinion. The structural changes for implementing such programmes are relatively minor and gradual. Selective breeding, however, is not an exclusive approach. Emergent technologies such as ploidy manipulation, transgenics, *etc.*, can be woven into such breeding schemes, after assessing their environmental and social impacts.

The comparative performance of GIFT and existing (mostly 'Israel') tilapia strains was evaluated in 8 provinces of the Philippines, representing different agroecological environments, during 1992 to 1994. These experiments were conducted mostly in pond systems; only four trials were conducted in cage systems. This sub-section discusses the performance of the GIFT strain compared to the existing strain to understand the nature of the GIFT strain. We used the results of pond experiments only in the analysis.

Both the GIFT and existing strains were cultured under similar management regimes; extensive to semi-intensive types of management were practised for all ponds. Resources available on the farms such as chicken manure and other farm wastes (pig, duck, cow, and carabao manure) were used by farmers to fertiliser the ponds. Some farmers applied inorganic fertilisers. The majority of the farmers gave supplemental feeding using feeds such as rice bran and poultry or livestock feeds; some of them formulated their own feeds by mixing rice bran, fish meal, soybean meal and other leaf meals. The fish were harvested after a grow-out period of about 120 days.

The results of the on-farm trials along with their production environments are summarised in Table 15. The GIFT strain had higher final mean weight (58.2 g) than the existing strain (40.8 g). Percent recovery (survival rate) was also higher in the GIFT strain (73%) than in the existing strain (49%).

Yield or production per unit of area of a tilapia farm depends on the stocking density, average weight at harvest (growth rate) and survival rate. Growth and survival rates are again dependent on various factors: input use levels, production environments, and genetic characteristics of the strain used. We estimated regression models for average growth and survival rate based on on-farm trial data. In these equations, four 'primary' independent variables were used: total protein and total nitrogen level as measures of input use level, water depth to represent production environment, and a binary 'GIFT' dummy variable to identify differences in genetic quality of the strains used. As both the equations (average weight and survival rate) have similar sets of independent variables and are parts of a simultaneous system, regression coefficients are estimated by the seemingly unrelated regression (SUR) method (Zellner, 1962). Details of regression results are presented in Table 16. The estimated equations are restricted translog types (Antle and Capalbo, 1988).

Results reveal that the GIFT strain has a significant and positive impact on both average weight and survival rate. The GIFT strain had 37% higher growth rate and about 23% higher survival rate. The reasons for faster growth of the GIFT strain were identified using the statistical decomposition method. The results indicate that 90% of the incremental growth of the GIFT strain is due to the higher efficiency in protein and nitrogen utilisation (Table 17). These findings show a similarity between the GIFT technology and the "green revolution" technology of rice and wheat, although the results are very preliminary.

Yield potential of GIFT strain

The yield potential of a technology may be interpolated from yield of experimental plots (*e.g.* Herdt and Mandac,

Table 15: Relative performance of GIFT technology under on-farm conditions, the Philippines,1992-1994

Input use/Performance	GIFT	Non-GIFT
Input use level		
Total N (kg/ha)	251.0	278.0
Total protein (kg/ha)	270.0	288.0
Water depth (ft)	2.5	2.5
Duration (months)	4.0	4.0
Stocking density (no./m²)	2.0	2.0
Performance		
Average weight at harvest (g/fish)	58.2	40.8
Survival (%)	73.0	49.0
Yield (kg/ha)	904.0	336.0

Table 16: Seemingly unrelated regression (SUR) estimates of growth and survival models

	Dependent variables			
	ln (av. weight)		% Survival	
Independent variable	Parameters	[t]	Parameters	[t]
Constant	-5.484	4.00	45.701	1.16
ln (total protein)	0.002	0.02	-3.841	1.03
ln (total N)	1.008 **	2.04	-0.205	0.01
ln (water depth)	0.824 **	2.13	23.734 *	1.75
GIFT Dummy	0.037	0.05	22.737 ***	4.27
1/2 ln (total protein)* ln (total protein)	-0.066 ***	2.74	0.351	0.41
1/2 ln (total N)* ln (total N)	-0.237 **	2.51	-1.250	0.39
ln (total protein)* GIFT	0.076 *	1.65		
ln (total N) *GIFT	0.009	0.06		
ln (total protein)* ln (total N)	0.024	0.64	1.169	0.90

Note:
*** 1% level of significance
** 5% level of significance
10% level of significance

Table 17: Source of growth due to GIFT technology

Source	% Change in av. wt.	Share
Higher efficiency of protein	0.289	78
Higher efficiency of N	0.044	12
Others	0.37	10
Total	0.370	100

1981) or the most efficient farmers in a sample (*e.g.* Kalirajan and Flinn, 1983). The former was adopted in this study to find out the yield potential of GIFT compared to the existing strains in Asia.

To investigate the performance of the GIFT strain under the diverse environments of tilapia producing countries of Asia, the GIFT fish are being tested in 5 countries outside the Philippines: Bangladesh, China,

Table 18: On-station experimental sites and strains evaluated in those sites

Country	Station	Agroecological zones	Strains evaluated
Bangladesh	Mymensingh	Warm humid tropics	GIFT, Thailand
China	Shanghai, Huzhu, Guangdong	Warm cool humid subtropics	GIFT '1978' introduced '1988' introduced Egypt
	Qingduo	Warm arid and semi arid subtropics	GIFT '1978' introduced Red Tianjin Egypt
Indonesia	Java, Sumatra	Warm humid tropics	GIFT Thai Local (Indonesia)
Thailand	Kamphangphet, Nakornpanom	Warm subhumidtropics	GIFT Chitralada Chitralada I
Vietnam	Hanoi, Ho Chi Minh	Warm humid tropics	GIFT Egypt Thailand Vietnam (Local)

Indonesia, Thailand, and Vietnam. Descriptions of trial sites and the strains used in these sites are given in Table 18. In Bangladesh, where Nile tilapia has a short history with very limited broodstock management, the GIFT strain appears to be 50% superior, in terms of growth, to local strains. In China, Indonesia, Thailand, and Vietnam, where there are longer histories of tilapia farming, greater climatic variation, and therefore the possibility of both natural and artificial selection of local strains to their environments, the GIFT strain appears to be about 10-15% superior to local strains in terms of growth. The on-station data did not show any definite pattern in terms of survival.

We fitted a stochastic frontier model of average weight at harvest based on the on-station experimental data from Bangladesh, China, Thailand, and Vietnam using the maximum likelihood estimation technique. The estimated frontier model shows the maximum body weight that can be obtained from a specific level of inputs. Yield potential of the GIFT strain and the best existing strain under different feeding regimes are given in Table 19. The yield potential of the GIFT strain is about 11% higher than that of the best existing strain. It is worthwhile to note here that the GIFT strain is performing well in all the locations and the existing strains are location specific; a particular local strain may be better in one location but not in another.

The use of sex-reversal technology with the GIFT fish can raise the yield potential of Nile tilapia further. Results of experiments conducted at the Asian Institute of Technology (AIT), Thailand indicate that the net yield of sex-reversed GIFT fish was 28% higher than the yield of sex-reversed Chitralada strain and a 24% higher yield was observed for nonsex-reversed GIFT fish over Chitralada strain (Table 20). The net yield of sex-reversed GIFT fish was about 5% higher than that of nonsex-reversed GIFT fish.

Product market effect of GIFT technology

The gain from research in any commodity and its distribution among various strata of the society depends on, among other factors, price elasticities of demand for and supply of the commodities, proportion of output consumed at home, and the level of international trade.

As the GIFT technology will enable the farmers to produce more using the same level of inputs, the cost per kg of fish produced should decline. In countries like Taiwan, where the international trade affects the tilapia price, the adoption of yield increasing GIFT technology may not cause major price reduction and most of the benefit due to the adoption of technology will accrue to producers in

Table 19: Yield potential of GIFT and non-GIFT tilapia under different feeding regimes

Feeding regimes (kg/fish/180 days)	Av. weight (g/fish) [1]		Yield (kg/ha) [1,2]	
	GIFT	Non-GIFT	GIFT	Non-GIFT
0.5	110	100	1,780	1,590
1.0	170	150	2,750	2,450
1.5	230	210	3,370	3,330

Note:[1] Growing period was assumed at 180 days.
[2] Average survival rate was assumed at 80%.

Table 20: The growth and yield of sex-reversed and non sex-reversed tilapia, AIT, Thailand (duration of experiment was 90 days)

Parameters	Non sex-reversed fish		Sex-reversed fish	
	Chitlada	GIFT	Chitlada	GIFT
Initial weight (g/fish)	11.11	10.70	10.57	11.12
Final weight (g/fish)	103.30	118.01	110.96	129.32
Survival rate (%)	81.0	87.0	75.0	85.0
Net yield (kg/200 m^2 pond)	45.25	56.18	45.84	58.79

Source: Unpublished results from the AIT/ICLARM Project.

direct proportion to their sales.

In the Philippines and Thailand, where about 80-90% of the tilapia production is marketed, consumers will generally benefit from technological progress (the GIFT technology). As tilapia is consumed mainly by poor people because of its relatively low price and as the price elasticity of demand for fish is higher for poor people than for the rich, the major portion of the consumers' benefit will go to poor consumers.

In countries like Bangladesh, where tilapia fish farmers consume about 70% of their produce, the major portion of economic gain that is due to the adoption of GIFT technology will be internalised by producers, especially the small subsistence ones. In subsistence farming, the reduction in market price due to higher production has relatively little influence on producers' income.

FUTURE OUTLOOK

Pullin (1991) forcasted a doubling of world tilapia production from 1991 to 2001, provided that research considers more explicitly the farmers' needs. Based on sustainability considerations, and to avoid adverse environmental impacts, Pullin (1991) strongly recommended integration of tilapia farming with other agricultural development initiatives. The current trends in tilapia production suggest that doubling of tilapia production by the turn of the century is possible (Pullin *et al.*, 1994). From a global perspective, however, it is important to recognise the fact that Africa, the home of tilapias, has high potential for tilapia farming but is currently the region that benefits the least (Pullin, 1994). The global wealth of tilapia genetic resources for potential benefit to aquaculture worldwide is at present in Africa. These resources are, in many circumstances, under severe threat of irreversible loss due to environmental threat, fish transfers and introductions (Pullin, 1988; Eknath, 1995).

In Asia, the future for tilapia farming remains optimistic. Interest in and development of tilapia farming is increasing at a rapid pace. Against this optimism and quantum jump in interest in tilapia farming, one has to seriously consider the possible directions the tilapia industry is likely to take in the next few years; specifically, the role of the large-scale corporate farming sector versus that of small-scale farmers. Agricultural research during the past few decades has clearly shown that the research results and products are not always scale-neutral. It is also important to recognise that the establishment of a research base necessary for rapid development of sustainable tilapia farming systems has just begun. Experience from other aquaculture enterprises has clearly demonstrated that establishing a strong research base with built-in anticipatory components (*i.e.*, provisions to cope with sudden shifts in technology, markets, biotechnical problems encountered, *etc.*) are vital to the long-term success of an enterprise and to avoid the boom-bust trap.

The research initiative on the genetic improvement of Nile tilapia described in this paper (the GIFT project) is a major example of a multidisciplinary and participatory research initiative in the region. It has successfully linked a number of activities along the continuum from the documentation of tilapia genetic resources through their systematic evaluation and utilisation in national breeding programmes. The GIFT project is unique in its approach. It has explicitly *ex-ante* considered the potential benefits to a spectrum of aquaculture enterprises, ranging from extensive small-scale to semi-intensive medium-scale farms. Preliminary analysis of the GIFT strain of Nile tilapia indicates that the technology may be virtually scale-neutral, *i.e.* small scale as well as large scale operators can benefit.

There is a growing need for such GIFT-type research for other widely-farmed aquatic fish species. Other equally important research on aspects such as formulation of cost-effective feeds, sex-reversal to produce monosex populations, fish health and quarantine, and water quality are clearly needed. These are being addressed by various groups in the region, although on a scale that may not yet match the pace of expansion in tilapia farming. Most of these research, however, is funded from public sources and development organisations. It is imperative that the private sector too initiate appropriate research and development efforts.

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