Marine Resource Economics, Volume 17, pp. 163–173
0738-1360/00 $3.00 + .00

Perspectives

Tilapia: Both Fish and Fowl?

JAMES A. YOUNG
JAMES F. MUIR
University of Stirling

Abstract *Tilapia aquaculture production is now around one million tonnes and is widely tipped to become an even bigger player in the international arena. This paper considers the case for such claims by reviewing the production environment, costs, the key characteristics of the product and its marketing with particular reference to the emergent EU markets and the increasingly established North American market. It is concluded that tilapia has quite distinct comparative advantages, not least being its diverse production scenarios, low cost, and product attributes which are commonly sought by consumers. Coupled with potentially green marketing attributes, it is concluded that this species is likely to appear in a broadening product range including more added value products.*

Key words Added-value, aquaculture, marketing, tilapia.

Introduction

If the Bible is to be believed, tilapia achieved its current-day market predictions some two millennia ago when it was then a mass-marketed species. Whatever may have been the interim history of the tilapia product, this paper is concerned with its current and prospective contributions to global aquaculture. Tilapia has been identified as an emergent major contributor to the international fish market for a wide variety of reasons pertaining to both its supply and demand. In order to assess this prognosis, this paper systematically presents the wider context of the tilapia sector through its supply base, product characteristics, and market potential, and concludes with some discussion of emergent issues that may determine the scale and nature of its future contributions.

The Tilapia Production Environment

Tilapia has a significant supply from capture fisheries which have levelled around 500,000 t over the past decade (Globefish 2001). Egypt accounts for over 20% of this output, which is primarily destined for local markets. Whilst wild-caught supplies are significant, farmed production is now more than double this volume. The global aquaculture production of tilapia has expanded significantly since 1990 and

James A. Young is a professor of Applied Marketing in the Department of Marketing, University of Stirling, Scotland, email: j.a.young@stir.ac.uk. James F. Muir is a professor of Aquaculture Development and Deputy Director at the Institute of Aquaculture, University of Stirling, Scotland, email: j.f.muir@stir.ac.uk.

was estimated to amount to approximately 1 million tonnes in 2000 (IntraFish 2001). This volume puts aquaculture production of tilapia in the same league as farmed Atlantic salmon, whose expansion has achieved a much higher profile. This parallel with Atlantic salmon, which many regard to be at the forefront of aquaculture innovation in terms of penetrating new markets, new product development, and volume growth, raises some interesting questions about the prospects for further growth of tilapia.

Farming of Atlantic salmon is highly concentrated with just four countries (Norway, Chile, the UK, and Canada) accounting for some 90% of volume and the residual being spread amongst around half a dozen others (FAO 2001). This spatial distribution reflects the relatively restricted environmental conditions suitable for commercial production of Atlantic salmon. Although aquaculture production of tilapia, shown in table 1, initially appears to have a similar concentration of production, with over 50% being produced by one country alone, China, and some 77% being grown by the four leading producers, China, Indonesia, Thailand, and the Philippines, the residual contributions constitute a quite different geography. Unlike salmon, there is a much wider production base, with 81 other countries actively farming the balance. Within these countries, significant potential for further expansion has been identified (IFC 2000). The potential for increased production from a much wider range of geographical locations is likely to have significant implications for the industrial structure of tilapia producers and the marketing channels established to service its markets.

Within this wider geographical production base, which reflects the greater tolerance tilapia has to different growing conditions, an industrial structure that is quite different from that of salmon has emerged. In the case of farmed Atlantic salmon, the three leading firms account for some 400 kt, producing a concentration ratio of $CR_3 = 40\%$; however in the case of tilapia, the 30 kt produced by the three leading firms only generates a $CR_3 = 3\%$ (Intrafish 2001). This differential reflects the much more diverse types of aquaculture involved, which span from subsistence artisanal operations to intensive transnational organisations. Of course, given the evolution of industrial concentration which has been witnessed in farmed Atlantic salmon, a similar trend might also unfold within tilapia. Indeed, there is already some portent with the emergence of vertically integrated, large-scale operations. In order to make some assessment of this possibility, a more detailed consideration of the supply base is required.

The geographical concentration of tilapia aquaculture is evident in figure 1, which shows over 80% to be produced within Asia. The majority of current produc-

Table 1
Tilapia Aquaculture Production by Main Producers (tonnes)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998
China	106,100	119,900	157,200	191,300	235,900	314,900	394,300	485,500	525,900
Indonesia	53,800	54,300	59,900	61,900	64,400	71,400	75,500	73,200	70,800
Thailand	22,900	27,800	43,500	54,100	59,500	76,400	91,000	102,400	102,400
Philippines	76,100	76,600	91,200	96,300	90,300	82,000	79,400	91,800	72,000
Taiwan	52,000	50,500	47,200	57,100	47,400	46,500	44,800	42,200	36,100
Malaysia	1,100	3,400	4,600	6,600	8,500	8,900	11,200	8,700	12,600
Egypt	24,900	22,200	21,500	19,900	25,200	22,000	27,900	30,400	52,800
Others	60,700	60,400	76,200	72,900	73,200	89,100	97,000	104,000	100,100
TOTAL	397,600	415,100	501,300	560,100	604,400	711,200	821,100	938,200	972,700

Source: FAO 2001.

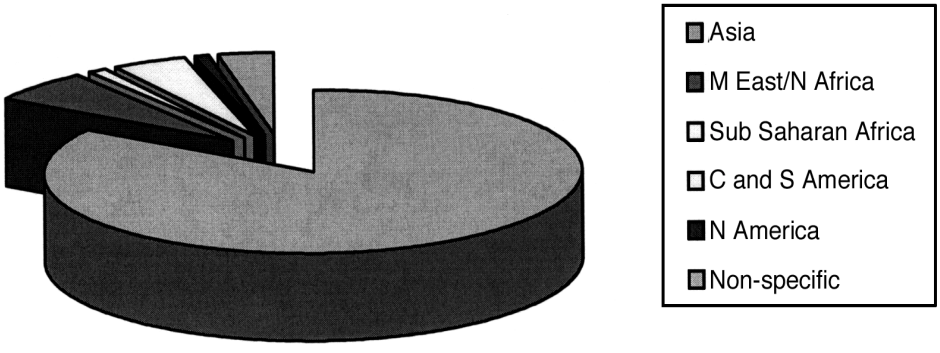

Figure 1. Regional Aquaculture Production of Tilapia (t) 1998
Source: FAO 2001.

tion is in inland environments. Typically these are pond-based, semi-intensive systems using moderate amounts of fertiliser to enhance natural productivity. However, cage culture is also increasing in importance and may be expected to contribute further in the future (Young and Muir 2000). In terms of the species farmed, the freshwater *Oreochromis niloticus* accounts for over 75% of farmed volume and with this dominance, it is not surprising that much of the growth in tilapia production has been associated with inland environments. However, with more saline tolerant species and strains, this may gradually change and widen the production base further.

Although the number of species produced in aquaculture is gradually increasing (FAO 1998), there is evidence of focus around certain groups, due to technical capability, market attributes, and consumer familiarity. These groups include tilapia, freshwater carp, salmon, mussels, and catfish and may become even more concentrated. Reviewing aquaculture development potential in Europe, Young and Muir (1995) noted that of various expansion routes, product development around existing species was one of the more promising. In an earlier assessment of species potential, ICLARM proposed tilapia as the prime candidate for the title "aquatic chicken" because of its desirable product attributes (ICLARM 1984). Tilapia was considered especially favourable because of its simplicity to produce, hardiness, versatility, undemanding feed requirements — with minimal dependence on fish meal and oil resources — firm flesh texture, and neutral flavour. This combination of characteristics, as noted by Haylor *et al.* (1994), augurs well for consumer acceptance in a range of different product formats and market segments. In addition to the market appeal of tilapia, another important consideration is its competitive production costs, which will be considered in more detail later.

Tilapia Production Costs

Typical production costs encountered in producing tilapia reflect the range of alternative systems which are found in different locations. Detailed assessments of individual cases have been undertaken elsewhere, ranging from rural aquaculture in low-input ponds in Africa (Stewart 1995; Dickson and Brooks 1997), in Asia, (Mohan Dey and Eknath 1997), to industrial scale systems with sophisticated technologies and expensive operating inputs (Watanabe *et al.* 1997; Brass *et al.* 1990). Capital and operating costs determine the typical cost ranges, comparative features of production, and the potential for change in cost subject to different installation or

operational variables. Studies have been carried out for a range of tilapia production enterprises and general rules found for tilapia and other production sectors (Muir 1995; STAQ 1996) suggest that capital costs are usually the most important (and sometimes the only) element.

Capital costs include holding facilities, water supplies, feeding and harvesting, transport and handling facilities, feed production and fish processing equipment, buildings, services, and infrastructure. Cages and enclosures are usually the cheapest (typically \$500–1,000 t^{-1} installed capacity), followed by earth ponds (\$800–2,000 t^{-1}), lined ponds (\$1,000–3,000 t^{-1}), tanks and raceways (\$2,000–8,000 t^{-1}); whereas recycle systems are generally the most capital intensive (\$5,000–15,000 t^{-1}). However, some offshore cage culture systems can be comparable (Muir, van Rijn, and Hargreaves 2000). Opportunities for economies of scale exist, related to unit size of holding systems and reduced unit infrastructure costs; however, these are commonly subject to physical site limitations. It should also be noted that small-scale artisanal production systems can be relatively inexpensive, especially when simple materials and local site opportunities are utilised. Hatchery capital costs are generally high compared to capital costs of ongrowing, because of the more complex and smaller scale holding units and operational facilities. This imbalance may favour specialisation and centralisation of hatcheries in some situations. However, in others, low-cost hatcheries based on ponds and hapa (net bags) may be used and in very small-scale systems.

Of the operating costs incurred, feed and fertiliser usually constitute the major components, ranging from 40–75%. Typically, seed is the next most expensive cost, representing 5–25%, while labour accounts for a further 5–15%. In the case of highly intensive systems, capital amortisation and energy costs are obviously significant, but in the case of small-scale artisanal systems with self-supply of fry and uncosted farm inputs, operating costs may be negligible. Production systems based on fertiliser or supplementary feeds are usually less expensive to maintain than those using complete feeds. Lower still are costs associated with systems based on natural productivity (*e.g.*, cages in reservoirs). Case studies, such as Muir (1995) and STAQ (1996), suggest that labour productivity effects may not be too significant, and in small-scale, artisanal production systems they are commonly uncosted or negligible, with profits returning to owner-operator families. In comparison to ongrowing, hatchery production costs are generally several times higher. This results from the higher cost of the facilities, more expensive feeds, and greater skilled labour. However, margins are also generally higher, across a range of production scales, and improvements in efficiency (*e.g.*, through multiple cycles), can be attractive.

Production costs of tilapia can thus be shown to be dependent upon a range of factors, but as noted above, competitive products can be produced in simple artisanal systems just as they can in more sophisticated intensive production systems. Tilapia return comparatively favourable feed conversion ratios (FCRs) and growth rates. Current estimates suggest that tilapia may be produced at costs as low as \$0.50/kg (IntraFish 2001a). Set against current market prices of \$2.3–3.0/kg in the US, this provides an attractive margin and one which is likely to encourage further expansion. In addition to increasing the volume produced, the market is also signalling for more added-value product. At an elementary level, fillet production is expanding and provides scope for additional profits. Fillet yields range from 22–45%, depending upon the type of cut, skin-on or off, *etc*. (Popma and Lovshin 1996). Nonetheless, with current market prices of \$5.0–7.0/kg, significant additional profit can be earned (IntraFish 2001b). These favourable cost structures are important because they indicate a significant cost-price differential and a sizeable margin sufficient to permit further and differentiated versions of the product to be developed, such as smoked fillets, *etc*.

Tilapia Product Attributes

The production economics of tilapia have been shown to be attractive, and the comparative advantage of the species is further enhanced by the inherent product characteristics. Tilapia is widely available throughout the year, which ensures a potentially continuous flow of product to service any capital invested in processing plants, labour, and equipment. The suitability of the raw material for processing and the scope to market a broad product range is also boosted by the ability to produce a range of discrete product specifications within well-defined parameters. Product attributes such as colour, texture, flavour, weight grade, and size can be produced to consistent tolerances, thus minimising losses due to lower yields and unusable product. Off flavours can result from certain feeding conditions, and these clearly have the capacity to endanger product adoption if unchecked through appropriate quality assurance schemes, as has been done with catfish in the USA (Young and Muir 2000). Historically, tilapia has been marketed in both live and round whole fish forms, but over the past decade there has been dynamic growth in the trade of both fresh and frozen fillets. Further extensions of tilapia product ranges have been launched, and more can be expected as processors attempt to add more value to the raw material. Given the highly competitive raw material costs of tilapia, there remains considerable scope to generate even higher margins through the incorporation of other non-fish ingredients in products marketed.

In comparison to most other farmed species, tilapia could also be recognised as having strong green credentials. The production process can be more natural and less intensive than that of other species, whilst its production systems tend to have a lesser dependence upon chemicals. Feeds are commonly simpler, and those consumed generate greater returns through a high FCR and growth rate. These combine to make more efficient use of inputs to the production process (Jauncey 1998). Tilapia are also noted for having good disease resistance, which, again, lessens dependence upon external inputs. Attempts to improve the genetic stock have been undertaken, notably the Genetic Improvement of Farmed Tilapia (GIFT) based in the Philippines (Circa, Eknath, and Taduan 1995; Eknath *et al.* 1995) and Genetically Male Tilapia (GMT) (Penman and McAndrew 2000). Such programmes have attempted to enhance FCR, disease resistance, age at maturation, yield, and similar attributes. Despite the progress that has been achieved in this work, some concerns exist that such developments could result in tilapia becoming enmeshed in wider debates about genetically modified organisms (GMOs) within the market for foods (CEC 1990). Tilapia is not unique amongst fish in this respect—similar publicity has been raised in connection with farmed Atlantic salmon (*Seafood International* 1998). However, it remains to be seen whether such concerns will curtail their incursion into international markets.

Markets and Marketing Tilapia

The scope for tilapia on the international market is especially interesting because of its widespread presence, diverse acceptance, and comparative cost advantages. Some have argued that tilapia has greater potential than most other species (Lister 1998; Muir and Young 1998). Its ubiquity is such that much of the world's population is already familiar with it, albeit in quite different contexts, and responds favourably to it. Because of its widespread production, international trade in tilapia has been comparatively low in relation to aggregate demand, but as markets have expanded and become more diverse, exporting has expanded significantly. In an attempt to schematise the diversity of the international markets served, Little (1998)

has outlined a tripartite division, each with its attendant supplies. Intense industrial production systems, supplying primarily developed country markets with a range of tilapia products spanning live to added-value processed product, can be regarded as the highest profile sector. Secondly, important commercial operations constitute another category which serve the rapidly expanding urban markets in S and SE Asia. The third sector is that comprised of the markets serving the very marginal, poorest communities that depend upon smallholder, highly localised production systems to supplement their meagre food supplies. Whilst the concept of food "choice" may embrace quite different meanings in such markets, the tilapia product's role here is arguably greater in terms of its relative importance to the consumers concerned. Only very few fish species command such a variety of positions in the global market, and these may have implications for future marketing of tilapia (Muir 1995; Paquotte 1998). Currently, and most likely for the immediate future, tilapia's most significant market is North America. It also has significant potential within the EU, whose key market characteristics are outlined below.

EU Tilapia Markets

With a consumer population already over 370 million, and poised to grow further as the EU expands its membership to the east, the composition and contemporary profile of the EU is an attractive target for tilapia producers. Tilapia is affordable to Euro-consumers, and the EU has a growing trade deficit in fish due to declining indigenous supplies from capture fisheries and a healthy demand because fish is perceived to be a healthy foodstuff. Despite the notion of a single European market and the process of internationalisation, entrenched differences remain between and within EU members. In terms of population, four countries currently have more than 55 million inhabitants, whilst six have under 20% of this. The largest importers of fish for consumption are France, Germany, the UK, and Italy, whilst Portugal then Spain have the highest per-capita consumption levels. The expanding volume of EU imports supply a discrete range of market segments covering the more traditional groundfish products, through various ethnic groups, to a more wide-ranging demand for exotic species fuelled by increased foreign travel and the variety-seeking fish connoisseur.

Data on world trade for tilapia is incomplete, as it is not separately identified under the International Standard Statistical Classification for Fishery Commodities, and no official figures for the EU exist (Globefish 2001). However, trade estimates suggest that the EU market for tilapia remains comparatively small although growing, and apart from some 350 tonnes produced internally (FEAP 2001), all fish are imported. Imports were estimated to be 1,000 t in 1990, doubling this by the mid-1990s (FEAP 1998), and as much again by the turn of the century (Blow 2001). The traditional EU market for tilapia has been within the ethnic African communities in the main cities of France, the UK, the Netherlands, and low countries along with Chinese and other Asian ethnic groups. The overriding preference is for fresh round fish, so that traditional quality indicators such as gills, eyes, and firm belly can be observed. Extension from the ethnic market origins has been encouraged by some supermarket chains keen to promote a more diverse product range, using both whole fish and fillets. At the premium end of the market, chilled product has been imported, whilst elsewhere frozen fish have been used. The EU market typically requires tilapia grown to a minimum weight of 350 g, which can be reached within one season, but a clear preference exists for 450–700 g fish, which adds the cost of a second growing season. Beyond this, there is a market for fish up to 2 kg, although it is limited in size. Fillets for the EU typically range from 100–250 g, are skinned, and contain no pin bones (Blow 2001a).

As elsewhere, tilapia is accepted because of its basic product attributes: white flesh, firm texture and rather neutral taste. These attributes are consistent with the traditional preferences of the European consumer, especially those in the northern EU countries. For the foreseeable future at least, the lack of familiarity with tilapia compared to other species ensures some differentiating appeal of novelty and willingness to try. Sales of whole product add to the theatre of retail displays and help differentiate it; however, the more standard preference for fish to be filleted or portioned has created added-value opportunities and wider acceptance. Smoked fillets have met with favourable consumer response, but the lower yield does have cost penalties. Nonetheless, tilapia has low production costs, which can absorb lower product yields more readily than some other species.

Processing tilapia at the source in order to take advantage of lower labour and resultant transport costs provides further comparative advantage and generates income and multiplier effects for the exporting country. Recent examples of such developments include plants in Zimbabwe and Jamaica (Hempel 2001). However, for processing operations to meet EU health and hygiene legislation, including HACCP demands, significant investment is required (Gutting 1998). When coupled with the need for channel management, product traceability, and associated logistics support, entry barriers favour the larger-scale industrial producers. Although tilapia can be marketed in a diverse range of product forms, it is very unlikely to be positioned within the EU consumer's perceived top tier of fish products. Even within the live niches, tilapia might rank more within the middle market positions. Market exposure has been varied within the EU; *e.g.*, some UK supermarkets have carried it since the early 1990s, whereas there has been no presence in some other markets. Acceptance may be improved with generic promotion, but doubts have been expressed as to the viability of funding (Hempel 2001). Nonetheless, it remains the case that the market has considerable potential across a range of product types with sufficient pull to follow a path already more firmly established across the Atlantic.

Tilapia Markets in North America

Over the past 10–20 years, the North American consumer (primarily US citizens) has become increasingly accustomed to aquaculture products, notably catfish, salmon, trout, shrimp, and tilapia. Imported supplies of tilapia have increased due to constraints on domestic production and their comparative price competitiveness, and unlike Europe, tilapia-specific official trade data is published by the US Bureau of the Census, Foreign Trade Division. Despite growth in the market for fish, per-capita consumption is still low compared to that of meat and poultry, and some have concluded that significant potential for further expansion remains, particularly in the case of tilapia (Engle 1997). Tilapia was the third most important species from aquaculture after shrimp and Atlantic salmon in the late 1990s (Lister 1998). Since then, the market has undergone dynamic growth. International trade has expanded to satisfy this demand. Since 1992, US imports of tilapia have expanded almost twelve-fold (FAO 2001). For example, in the first quarter of 2001 the volume of tilapia fillets was 90% higher than in the corresponding period of the previous year, with a corresponding average price some 23% higher (SFIA 2001). The vast majority of US imports come from two main regions according to product type. SE Asian exporters dominate in the frozen market with Taiwan, China, Indonesia, and Thailand being the main players; whereas in the case of fresh fillets, Costa Rica, Ecuador, Columbia, Jamaica, and Honduras are the main suppliers because of their geographical proximity. It seems likely that other Central and Latin American countries will also enter the US market. Domestic production, around 20% of the market in

the latter half of the 1990s, is unable to be competitive regarding price, so it focused on colour and quality in the fresh market (Picchietti 1996). In addition, approximately 50% of the live market is also supplied by domestic producers.

Like Europe, ethnic markets for tilapia are important in many of the main US urban centres. Asians dominate as the fastest-growing market, particularly on the West Coast and into Canada (Kohler 1994). Clearly, these markets may also be attractive to imported product, although premium niches and live trade are likely to be more difficult. The standard size sought by the market is 1–1.5 lbs. (450–680 g), but demand extends to larger fish weighing about 3 lbs. (1.4 kg). Tilapia may be sold live, fresh, or frozen as whole, gutted, gutted and scaled, H&G, and as fillets: skinless and boneless but also as skin-on. Fillet size is generally quite small between 2–5 oz. (60–140 g). Product-yields for skin-on boneless fillets are unlikely to top 40%, and will be even less with other strains of species and boneless product forms. In general, frozen fillets sell at around 11–14% less than fresh product, and competition within this sector is fierce, as SE Asian producers attempt to secure a greater share of the US market.

Three broad grades of tilapia can be identified in the US market (Sipe 1992). Category A covers product cultured and harvested in the best quality environment, then purged and processed within a chilled, or cold, chain. Category A product is aimed at the premium market segments where it competes with grouper, snapper, swordfish, and the like. Lower production costs and increasing volumes should also enable a greater focus upon the more mainstream traditional quality whitefish products. Category B fish are cultured with lesser emphasis on quality, so inconsistencies in flavour, texture, and other attributes are found. These command a lower price. Category B product targets the price-sensitive consumer, but there is a risk that such inferior product might create confusion. Category C product consists of wild fish, which even if properly handled, may vary in taste due to the irregular environmental conditions of their habitat. These are primarily marketed to US Asian communities which prefer live or freshly frozen whole tilapia, but would tend to purchase Category A product when available. This suggests that the market for Category C product, and indeed category B, may diminish in the future as consumer standards rise. Future market penetration is critically dependent upon further reductions in production costs, but whilst maintaining stringent and consistent quality control throughout the marketing chain. As A-quality product prices fall to the levels of chicken and turkey, tilapia will become much more competitive. Elsewhere within the market, niche sectors will retain some appeal, including the higher prices for live product and emergent ethnic catering sectors such as Thai, Indonesian, and sushi bars will provide other opportunities.

Conclusions

Tilapia would seem to have a number of significant points of comparative advantage when competing against substitute products. The low cost of production from a variety of different production environments is likely to favour its further expansion, and such moves are likely to be encouraged through technical progress in husbandry techniques. Growth in output, especially of lower unit cost, will also encourage extension of the product range and will stimulate processing of added-value products for different target markets. Perhaps of greatest importance is the fact that these advantages can be realised in many different countries and with varied levels of investment. While developments may need to be made in some of the key producer countries to shift from domestic production to export, and to adopt the procedures and standards of importing nations, there is ample potential in many areas to do pre-

cisely this, and an increasing record of successful export achievement to boot. The supply chain for tilapia could take on a number of different guises and thus generate widespread benefits.

However, the heterogeneity of marketing channels also poses some potential threats in terms of the perceived standard of tilapia. Whilst prized for the neutrality of its taste, tilapia can take on off flavours through its natural feeding habits. This could undermine the acceptability of the product, especially where the product is new to the consumer. Quality assurance schemes routinely counter deviations from intended specifications, but the more diverse range of production systems used to produce tilapia does make this task more difficult. Agreeing to apposite quality standards and ensuring their effective and efficient enforcement is clearly going to be more difficult as the number and location of producers increases, especially with each attempting to lower production costs. Unlike the salmon and catfish sectors, where producer concentration and market-oriented approaches have encouraged the development of brands, well-defined quality standards, and stronger consumer recognition, the tilapia sector is still relatively fragmented. Some may regard the green attributes of tilapia positively within the future food marketing environment. However, it is difficult to predict just how significant facts such as use of non-fish feeds, tolerance of poorer water conditions, *etc.*, might be; clearly, such communications might also be perceived negatively. This may also be the case in respect to genetic modifications mentioned earlier, particularly within EU markets.

Notwithstanding these potential pitfalls, it remains the case that tilapia products have demonstrated the capacity to span across the most marginal consumer markets within developing country situations to premium segments of international trade, in both live and added-value formats. When combined with the aforementioned evolving production and processing options, an interesting matrix of product and market opportunities emerges, with significant benefits for the adjacent economies. Indeed, with such variety, it may well become nearly impossible, and certainly more difficult, to determine whether fish or (aquatic) fowl.

References

Blow, P. 2001. Personal communication. April.

___. 2001a. *Tilapia from Africa Bound for Europe.* Presentation to Tilapia 2001, Kuala Lumpur, Malaysia, May.

Brass, J.L.. M.B. Rust, L. Olla, and R.I. Wicklund. 1990. Preliminary Investigations into the Socioeconomic Feasibility of Saltwater Cage Culture of Florida Red Tilapia in Haiti. *Journal of the World Aquaculture Society* 21(3):192–200.

Circa, A.V., A.E. Eknath, and A.G. Taduan. 1995. Genetic Improvement of Farmed Tilapias: The Growth Performance of the GIFT Strain of Nile tilapia (*Oreochromis nilotica*) in Fish-rice Environments. *Aquaculture* 137:329–30.

Commission of the European Communities (CEC). 1990. Council Directive 90/220/EC on the Deliberate Release into the Environment of Genetically Modified Organisms. *Official Journal* No. L117 (8/5/90):15–27.

Dickson, M.C., and A.C. Brooks. 1997. *Fish Farming in Malawi: A Case Study of the Central and Northern Regions Fish Farming Project.* Govt. of Malawi and European Commission 70 p.

Eknath, A.E., R.A. Reyes, H.L. Bolivar, M.S. Palada-de Vera, J.B. Danting, E.E. Dionisio, and F.M. Longalong. 1995. Genetic Improvement of Farmed Tilapias: Estimations of Genetic Variation and Heritability for Age and Size at First Spawning in Nile Tilapia (*Oreochromis niloticus*). *Aquaculture* 137:279–80.

Engle, C.R. 1997. Marketing Tilapias: *Tilapia Aquaculture in the Americas* Vol. 1,

B.A. Costa-Pierce and J.E. Rakocy, eds., pp. 244–58. Louisiana, USA: World Aquaculture Society.

FAO. 1998. Aquaculture Production Statistics. *FAO Circular No. 185*. Rev. 10. Rome, Italy.

___. 2001. www.fao.org/waicent/faoinfo/fishery/fishery.htm

Federation of European Aquaculture Producers (FEAP). 1998. www.feap.org Species production totals 1993–97.

___. 2001. www.feap.org/minprod.html

Globefish. 2001. *Commodity Update - Freshwater Fish* FAO Eastfish. February. Copenhagen.

Gutting, R. 1998. The HACCP Era. *Seafood Business* 17(2):8–10.

Haylor, G.S., J.A. Young, J.F. Muir, and D.C.B. Scott. 1994. *Commercial Aquaculture in Africa - An opportunity study.* London, England: Commonwealth Development Corporation (CDC), 150 p.

Hempel, E. 2001. The Market for Tilapia in Europe. *Seafood International* 16(8):16–7.

ICLARM. 1984. Introducing the Tilapias. *ICLARM Newsletter* 7(1):3.

International Finance Corporation (IFC). 2000. *Investment Strategy for Aquaculture in Developing Countries.* Unpublished report. Washington, DC, USA: World Bank Group.

IntraFish. 2001. First to the winning post. Intrafsh Comment. www.intrafish.com/article.php?articleID=10842. 13 March.

___. 2001a. Gold Rush for Tilapia. www.intrafish.com/article.php?articleID=10413. 21 February.

___. 2001b. Lucrative Springboard to the US Market. www.intrafish.com/article.php?articleID=11617. 11 April

Jauncey, K. 1998. *Tilapia Feeds and Feeding.* Bridge of Allan, Scotland: Pisces Press Ltd.

Kohler, S.T. 1994. Using Census Data and Geographical Information Systems to Identify Target Markets for Aquaculture Products in the USA. *World Aquaculture* 27(4):23–35.

Lister, P. 1998. Tilapia Takes Off. *Seafood Business* 17(1):12–6.

Little, D. 1998. Options in the Development of the Aquatic Chicken. *Fish Farmer* July/August:35–7.

Mohan Dey, M., and A.E. Eknath. 1997. Current Trends in the Asian Tilapia Industry and the Significance of Genetically Improved Breeds. *Sustainable Aquaculture* Proceedings of the Infofish-Aquatech '96 Conference, K.P.P. Nambiar, and T. Singh, eds., pp. 59–78. Kuala Lumpur, Malaysia: 25-27 September 1996.

Muir, J.F. 1995. *Perspectives on Aquaculture: Aquaculture and Food Security*. 224 pp. Mimeo. Study Commissioned for FAO. Rome, Italy.

Muir, J.F., and J.A. Young. 1998. Tilapia: Can the Aquatic Chicken Fly?: *Proceedings of the 9th Biennial Conference of International Institute of Fisheries Economics and Trade*, B. Aarst, and T. Vaasdal, eds., pp. 88–98. Tromso, Norway, July.

Muir, J.F., J. van Rijn, and J. Hargreaves. 2000. Production in Intensive and Recycle Systems. *Tilapias: Biology and Exploitation*, M. Beveridge, and B. McAndrew, eds., pp. 405–46. London, England: Kluwer Academic Press.

Paquotte, P. 1998. New Species in Mediterranean Aquaculture: Is it an Answer to the Market Demand for Differentiated Products? *International Symposium on New Species for Mediterranean aquaculture.* FAO, Alghero, Italy, 22-24 April.

Penman, D.J., and B.J. McAndrew. 2000. Genetics for the Management and Improvement of Cultured Tilapias. *Tilapias and Exploitation*, M.C.M. Beveridge, and B.J. McAndrew, eds., pp. 227–66. London, England: Kluwer Academic Press.

Picchietti, M. 1996. Tilapia Marketing Maturity. *Aquaculture Magazine* 22(5):19–26.

Popma, T.J., and L.L. Lovshin. 1996. *Worldwide Prospects for Production of Commercial Aquaculture*. R&D Series No. 44. Auburn University, 23 p.

Seafood International. 1998. Transgenic Salmon Fail to Gain Consumer Confidence 13(2):8.

SFIA. 2001. *European Supplies Bulletin* 21(2) SFIA. Edinburgh, Scotland.

Sipe, M. 1992. Tilapia Marketing in the USA. *Infofish* 92(3):23–5.

Stewart, A.J.A. 1995. *Assessing Sustainability of Aquaculture Development.* Unpublished PhD Thesis. Scotland: University of Stirling.

Stirling Aquaculture (STAQ). 1996. *The European Aquaculture Industry: Key Trends in Science and Technology.* Report to the Science and Technology Office of Assessment, European Parliament.

Watanabe, W.O., B.L. Olla, R.I. Wicklund, and W.D. Head. 1997. Saltwater Culture of the Florida Red Tilapia and Other Saline Tolerant Tilapias: A Review. *Tilapia Culture in the Americas* Vol. 1, B.A. Costa-Pierce, and J.E. Rakocy, eds., pp. 55–141. Louisiana, USA: World Aquaculture Society.

Young, J.A., and J.F. Muir. 1995. Diversity in Adversity? The Case of the UK Aquaculture Sector. *International Co-operation for Fisheries and Aquatic Development 7th Biennial Conference of the International Institute of Fisheries Economics and Trade*, pp. 82–95. Taipei, Taiwan ROC, July 1994.

___. 2000. Marketing and Economics of Tilapia. *Tilapias: Biology and Exploitation,* M. Beveridge, and B. McAndrew, eds., pp. 447–87. London, England: Kluwer Academic Press.