Sri Lanka J. Aquat. Sci. **10** (2005): 1-18

Fisheries, fish culture, tilapias and politics

C.H. FERNANDO*[1] AND J.J.S. GURGEL[2]

[1]Department of Biology, University of Waterloo, Waterloo, Ontario, Canada
[2]Department of Fishery Engineering, Federal University of Ceara, Campus do Pici, Forteleza, 60350-000 Brazil

*Corresponding author (E-mail: chfernan@sciborg.uwaterloo.ca)

Abstract

In the past few years much attention has been focused on dwindling marine fish stocks and the means available to counter the effects of this growing problem. Over fishing has been targeted as the main cause. Many newspaper and magazine articles on the subject of over fishing have been added to the growing scientific journal publications and books. Conservation measures are being implemented but their impacts will very likely not reverse the trend. One option to provide more fish for human consumption is through fish culture which, since traditional techniques began to be modernized in earnest in the 1950's, has been expanding rapidly. With the exception of production in China, efforts with the major carps have not been very productive, especially in tropical countries, and these and several other fishes currently in culture have relatively limited possibilities of substituting the shortfall of marine fish in the future. The tilapias, on the other hand, have shown much greater potential recently, and are increasingly marketed worldwide. In two or three decades, farming tilapias may prove to be the means of supplying a large quantity of fish to fill the increasing gap between demand and supply. Furthermore, tilapias can contribute additional resources through integration with traditional reservoir fisheries and rice-fish culture. This paper explores these growing changes in tilapia culture and inland fisheries especially in the tropics. We do not claim any deep knowledge nor are we predicting the economical and sociological impacts of the winds of change affecting fisheries worldwide.

Introduction

Four decades ago, the 'green revolution' produced high yielding strains of maize, dwarf wheat and rice. These new cereals provided a respite from the spectre of starvation due to an exploding world population that was

occurring predominantly in developing countries. That scenario of mass starvation is now replaced, partially at least, by worldly catastrophes such as the destruction of the ozone layer and global warming, pollution, and threats to biodiversity, not to mention the rapid increase in obesity. However, the cloud which hangs over the issue of food shortages still remains, and particularly the need for some time to come of the availability and accessibility of essential animal proteins to those of lower income.

The problem

Terrestrial animals are expensive to raise for human consumption, but the prices of the once cheap alternative, fish harvested from the oceans, have been increasing rapidly. This is because of the increasing demand for fish which is marketed as a nutritious and healthy food, and the fact that the upper limit of their economic sustainable yield from the oceans, amounting to about 100 million metric tons annually, appears to have been reached. Some stocks, like the Atlantic cod, for example, may be already destined to collapse irreversibly, with consequences to parallel those of the California sardine fishery made famous by John Steinbeck in *Cannery Row*. Pauley and Watson (2003) have provided a popular account of over fishing and its consequences

Parrish (1963) has ably described the dynamics of fish populations and their exploitations by man in his wide-ranging and lucid paper on the history of marine fisheries. He quotes from the inaugural address of Thomas Huxley, the famed British zoologist, at the International Fisheries Exhibition in London in 1883, who summed up the impact of fishing on marine fish stocks as understood at that time in the words, "I believe that it may be affirmed with confidence that, in relation to our present modes of fishing, a number of the most important fisheries such as the cod fishery, the herring fishery and the mackerel fishery are inexhaustible. And, I base this conviction on two grounds: first that the number we catch is relatively insignificant; and secondly that the magnitude of destructive agencies at work upon them is so prodigious, that the destruction effected by the fishermen cannot seriously increase the death rate." While dismissing over-fishing as an unscientific and erroneous fear, Huxley did say "it would meet with its natural check in the diminution of the supply." But his guarded optimistic assessment of the infinite potential of the oceans was proved wrong within a matter of decades. The North Sea herring fishery was the first to show evidence of diminishing, recovering temporarily when World War I closed fishing in most of the area, but continuing its fall again when peace returned.

If hunting was restricted to the use of simple implements, then many populations exploited for food, such as the North American bison, the passenger pigeon, and even the great whales, would have been sustainable.

by the mid-twentieth century, fish stocks began to fall as catch per unit effort increased with steam-driven vessels and more efficient mechanized harvesting equipment, and the trend has never ceased. It is clear that the phenomenon was worldwide. Nations were participating in what was described by Hardin (1968) as the tragedy of the commons, and although the total world catch more or less increased each year for the past fifty years, it was due to unrestricted fishing on new resources with very efficient gear, and not conscientious management.

Remedies to preserve fish stocks

Recently there has been more emphasis on the co-management of fish stocks where resource users and centralized management units share responsibilities (Pomeroy 1995). Whether this concept can be applied effectively for the sustainability of marine fisheries, still dominated by national interests and individual greed, remains to be seen. But there are other options for conserving stocks and providing them with some respite. An arrangement called Individual Transfer Quotas has been successfully used to reduce over fishing in New Zealand and Iceland with some success. Also some governments, for example, have set aside marine areas as sanctuaries and fishing reserves to protect resources; and fishery scientists, such as Pauly and Watson (2003), have proposed. In addition they proposed the more efficient use of the industrial fisheries for human consumption rather than conversion of part to fishmeal and fish oil. More international cooperation can also be effective to help prevent major depredations in the ocean fish stocks, as demonstrated by the agreement to ban drift net fishing. The signing of the United Nations sponsored Law of the Sea convention in 1982 (Mann 1983), and its ratification by the required number of nations by the end of the century (Hettiarachchi 2004), has given international status to scientific conservation of marine resources. Politics between fishing nations, remains a major problem in fish conservation. Nonetheless, the best scenario, which can be expected is that, more progressive conservation measures for marine fisheries management will eventually slow down and ultimately halt the decline in the strength of many marine stocks before they are irreversibly damaged. Also the ultimate losses in production will perhaps be partly compensated for, by a rapid growth in fish culture on a worldwide scale, particularly in the tropics.

Aquaculture

Aquaculture was touted in the late 1940s and 1950s as a means of providing an abundance of cheap protein for the underprivileged of the world.

Although the global production of freshwater fish and shellfish for human consumption approaches 38 million Mt live weight now (FAO 2003), it contributes less than 0.5% (by weight) of the human food consumed globally. Furthermore, the cost of raising fish is still high, and unless production per hectare is increased (as the areas available for aquaculture are relatively small), and the cost of production is reduced, then aquaculture will not provide the cheap protein to replace the shortfall due to the collapse of marine fisheries but will remain doomed to provide high-priced food products to a small percentage of the population who are not in any need. However, if cheap and good quality fish, like tilapia, can be produced globally as it is currently being done in China and other parts of tropical Asia and South America, then it is possible for cultured fish to provide large quantities of protein for low-income people who are desperately in need of healthy food as fish.

Genesis of fish culture

Fish culture has its origins in the ancient cultures of China and India at least two millennia ago, and was only practised in Europe when the common carp was introduced during Roman times. With the exception of China and India, where the culture of a great variety of carps is quite large, but static or diminishing (Pullin 1986), carp culture in Europe has either been abandoned altogether, or plays a diminishing role in certain land-locked countries, such as Hungary and The Czech Republic (Personal observation by C.H.F. 1999). However, when the rosy pictures of cheap and abundant fish through culture were painted by western-trained fisheries biologists to meet the needs for protein at the end of World War II, the carps were the obvious choice. Consequently, colonial biologists persuaded the governments of tropical countries that carps offered the *only* viable fish for widespread culture in ponds because, with a higher range of water temperatures, fish yields in the tropics would be much higher than yields in temperate climates. Evidence to support these arguments came from Dutch workers in Indonesia, who were raising common carps with some success but at considerable cost (US$ 4-12 per kg), according to Fernando (1980). Tilapias caught in reservoirs were sold at US$ 0.30 per kg at this time.

Unfortunately, one factor not considered by these experts was whether temperate water species were ideally suited to the tropics. The assumption that temperate water fish could maximize growth in warmer waters, and produce high yields in ponds, proved largely a failure. But the effort continued in the belief that the problem was the shortage of fry, and the oft-repeated mantra by many European and Indian biologists was that fish culture would become highly productive when large numbers of cheap fry were available. However, when carp breeding and larval propagation became successful, still no

revolution occurred. Cultured fish, mainly carps, are still available in most parts of the tropical world but only at a high price. Where there is an option of other species, the carps are at best second choice because of their edible qualities (Pullin 1986). The preferred freshwater fishes, such as tilapias, catfishes, gourami, and perch, are being cultured successfully and in increasing quantities. The preferred marine fishes are the oceanic species, such as cod, halibut and diadromous fishes like salmon and eel, and coastal species such as bass, sea bream, and mullets. All of these species will contribute to the availability of cultured fish for human consumption for coming decades, but they are costly to raise and so far their production volume is low and the potential for the future appears somewhat limited. Once production increases to a certain volume by culture, then production costs and prices will begin to fall - like that of Atlantic salmon, which in Canada is now cheaper than imported tilapias. But this too will change when the cost of production of tilapias decreases, and then the market for this farmed fish might well become like that of the chicken over the past half century.

Tilapias as culturable fishes

The tropical African tilapias were probably cultured extensively and perhaps even intensively in Egypt four or five millennia ago, but gradually the practice fell out of favour. Interest was rejuvenated in the twentieth century, when fish culture began to be considered seriously as an alternative source of fish protein to meet the needs of a hungry world. There are about 100 species of tilapine fishes belonging largely to three genera, *Tilapia, Sarotherodon*, and *Oreochromis,* and they reigned supreme in most of the large ancient lakes that are almost exclusive to the African continent. About 25 species of tilapias have been recommended at one time or another for culture, but less than ten remain in culture, of which only three are really successful. China, for example, reports massive production of tilapias, and each year the figure keeps rising, but it is almost all *O. niloticus*.

Unlike many already domesticated animals raised for food, the tilapias filled a newly created niche. They were a spectacular success especially in shallow reservoirs which had been built in their thousands beginning in the nineteenth century. However, their introduction into tropical reservoirs, was opposed, principally by the food nationalists and panglossians (Fernando 1993). They wanted to maintain the *status quo*, with no non-indigenous introductions to the existing fauna, which they believed must have been placed there for the best reasons. And there was also the opposition of sports fishermen, who viewed freshwater fishing like big game hunting, complete with trophies of fish like the heads of tigers and lions.

Threats to indigenous fishes

Arthington (1991), without providing much scientific or factual basis, stated that tilapias were a pest in Australia and, by extension, in many other countries where the species had been introduced. This view was toned down in the paper by Bludhorn and Arthington (1991). But few people in Australia talk about the adverse effects of either brown or rainbow trout on the environment, because they are both popular sport fish. Fishery scientists and sport fishermen made unlikely bedfellows in their opposition to the introduction of tilapias in natural lakes and reservoirs, supposedly to protect the indigenous fauna. These water-bodies however had no equivalent lake-type fish, a fact that Fernando and Holcik (1991) stated, but has largely been consistently ignored despite ample published evidence to support it. Furthermore, Leveque (1998) concluded that the adverse effects on indigenous freshwater fishes came almost entirely from introduced piscivores, whereas tilapias were detritivores or herbivores. This is not to gainsay some negative impacts of tilapia introductions, such as the possibility of hybridisation and the stunting of populations, which can occur with the dominance of r-selected strains, which have faster growth, early maturity, and a short life span.

The canard that the introduction of tilapias is *per se* destructive to indigenous fishes, rather than filling a vacant niche for lacustrine fishes outside Africa, has been gradually eroded by the work and views all over the world of fisheries scientists such as, *inter alia*, Oglesby (1985), Petrere (1996), Ali (1998), Leveque (1998), and Dudgeon (2003). The acceptance that tilapias do not threaten indigenous fishes has also gained ground from the experience and evidence of decades of introductions into water-bodies both inside and outside Africa. de Zylva (1999), for example, who returned to Sri Lanka to study and report on the status of the tilapias which he had been instrumental in introducing some fifty years earlier, stated that they had not had any adverse effects on the indigenous fish fauna. Conversely, exotic tilapias supported a profitable inland fishery accounting for nearly 15-20% of the country's 300,000 metric tons of fish production.

Additional evidence that indigenous or endemic fish species are not threatened by the introduction of tilapias, despite unsubstantiated claims, has been provided by Pullin et al. (1997), following a study in five Asian countries, and by Fernando et al. (2002). Fryer and Iles (1962) state that the very presence of tilapias enhances the productivity of lakes. The mineralization of vegetation consumed by tilapias has been shown likely to increase the trophic status of habitats by Beauchamp (1964), Lowe McConnell (1987) and more recently quantitatively, by Starling et al. (2002). Nixon (1988) in a broad ranging study of energy inputs and the comparative ecology

of lakes and marine ecosystems, notes the unusually high production of tilapias. The more likely threats to indigenous and endemic freshwater fish species, especially in Sri Lanka, appear to be other anthropogenic interventions, such as the damming of rivers, which may change reproductive strategies of some indigenous riverine species, and the general deterioration of habitat as a result of deforestation, siltation, and the improper use of agrochemicals (Fernando et al. 2000). But it is with some irony that one notes that the cheapness of tilapias harvested from reservoirs in Sri Lanka today is putting farmed tilapias (and carps) at a disadvantage (Fernando 2000). Hopefully this will change with time and higher demand.

Evaluation of tilapias

Tilapias raised in farm conditions or harvested from good quality waters are excellent food for human consumption. But they also have other uses. Villagers in developing countries can convert into fishmeal and fertiliser those fishes harvested at a small size in ponds fed by polluted runoff. The risks to human health are minimal, as cultured tilapias being herbivorous do not concentrate toxins from polluted waters anywhere near the extent of the piscivorous fishes.

Although there were a few voices pointing out the potential benefits of tilapias to developing countries in the post-World War II years, the majority of fishery biologists subsequently ignored them and even became downright hostile to any introductions anywhere. Labelled as pests, the debates about the fish became quite intense. In shades of the Inquisition, one scientist even threatened an editor of a house magazine for an international fisheries organization in the Philippines with a libel suit if he published articles on tilapia introductions - a threat which the editor dutifully ignored (Maclean 1988); and a well-known Canadian granting agency chided one of the authors, who was in fact studying the very issue, for *not* condemning the practice as the agency was "concerned" about fish introductions. Perhaps, as one of us (C.H.F.) told them, the Pope was also concerned about Galileo's heliocentric theory.

The fear of tilapias became quite widespread among some people, especially in India where many fishery biologists were apprehensive that the Indian carps, their favourite farmed species, would be superseded by tilapias. Much money and propaganda were lavished on raising brood-stocks of carps and inducing spawning, as this approach was considered the route to lowering the cost and opening the door to potentially unlimited fish production. Indian, European, and Chinese experts all pushed their own varieties of the fish to culture. Sen (1975), an Indian agriculturist, noted that Indian scientists were quick to support carp culture even when the evidence for its economic success

was non-existent. Fortunately that protective attitude has faded (Sugunan 1997), and the unfavourable edible qualities of the carps have taken their toll in the market-place as the standards of living in most developing countries have begun to rise.

The growth of tilapia culture

By the late 1970s and early 1980s, the culture of some tilapias was recognised to be much more profitable than carp culture. Research organizations within the tropics, such as the Southeast Asian Fisheries Development Centre and the International Centre for Living Aquatic Resources Management: in the sub-tropics, such as the University of Auburn in the southern United States; and even in temperate climate, such as Stirling University in Scotland, all were conducting research programs on tilapia culture. Since then, the number of national centres pursuing research into tilapia culture has grown rapidly. In the past 50 years tilapias have been studied more intensively than any other freshwater fish in the world. From 1980 to 2004, six international conferences have been held on tilapia culture on four continents. While only one such international conference on carp culture has been held in the same period and in France.

The technology for production of tilapias has also changed, and the traditional practices of pond culture in Asia have been surpassed by production in floating cages and prefabricated concrete or fibreglass tanks on shore. Similar developments of an industry throughout many North, Central, and South American countries can be found in Fitzsimmons (1997) and Fitzsimmons and Filho (2000). Integrated fish farming involving tilapias in irrigation systems has been suggested by Fernando and Halwart (2000), shown in Figure 1. With some exceptions these technologies have not been transferred to most countries in Africa, where poor infrastructure and inadequate investment, not to mention political instability, have all worked against development of farming practices beyond the traditional subsistence scale; the exceptions are South Africa and Zimbabwe in the south, together with Egypt and other coastal Mediterranean countries in the north, where more commercial development has taken place.

The largest producer of freshwater fishes in culture in the world is China (57% 0f the world total), where tilapias are raised throughout both the country's tropical and sub-tropical regions. Despite being the epicentre of carp culture, producing over 12 million Mt among 8 species in 2001 (FAO 2003), China has rapidly increased its production of tilapias in its warmer regions. The most recent figure for 2001 (FAO 2003) approaches 680,000 Mt. Although the authenticity of fisheries data from China has been questioned by Pauly and Watson (2003), the current imports of tilapia into the United States

are very real, increasing 570% in five years to almost 90,000 Mt (live weight), most of which comes from China (Harvey 2003). According to Roderick and Gillespie (2003) tilapias are being cultured from Iceland and Belgium and some other European countries in industrially heated or geothermal waters to Brazil, South Africa, Mexico, much of tropical Asia and North America. The tilapias, in a variety of product forms, have become an important commodity traded internationally, but the same cannot be said for carps.

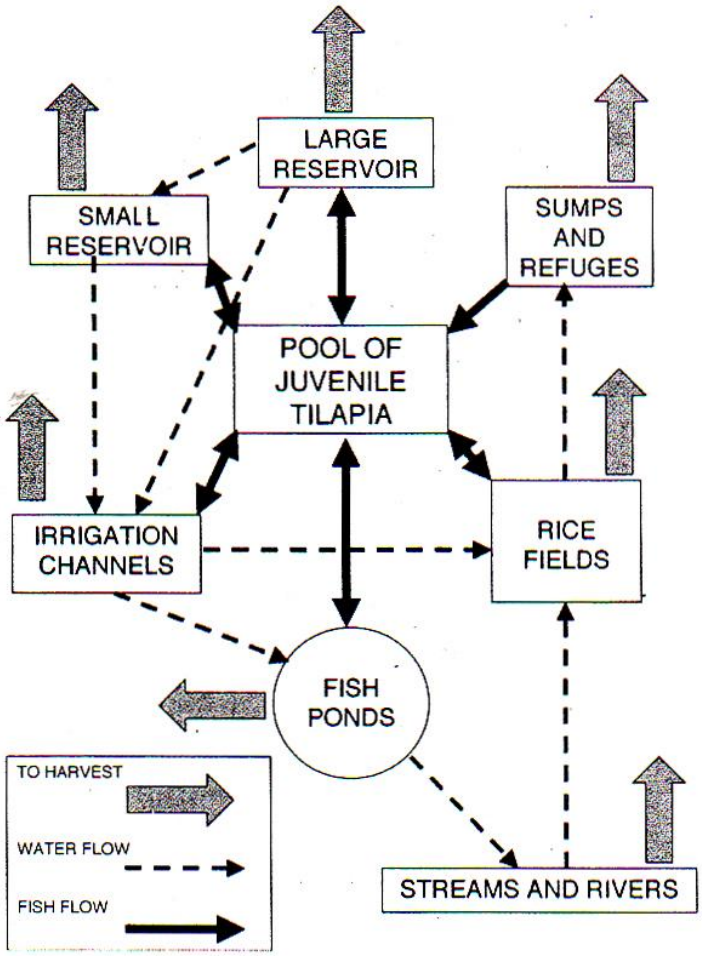

Figure 1. Diagrammatic scheme for integrated fish culture (after Fernando 2002). Reprinted with permission from World Aquaculture.

Indonesia, where carp culture was established and flourished under Dutch colonial rule, is now another major supplier of tilapias to global markets producing 100,000 Mt annually. It is said that old habits die hard, but tilapia farming has spread and replaced carp farming as the economic realities became clearer. Once the only choice for farmers to produce, the common carp is also being replaced by the giant gourami, which is popular among Asians as a gourmet fish, as are pangasid catfish. This apparent anomaly is like comparing raising potatoes (the tilapias), which are abundant and cheap, with raising artichokes (the gourami), which are rare and expensive. However, in the market-place it is only tilapias harvested naturally which are cheap. Farmed fish are more expensive. But this is not to say that the price of farmed tilapias will not drop in the future as production costs are decreased, just like the price of chicken started to fall in the 1970s.

Nonetheless, the rapidly increasing production of tilapias worldwide will not eliminate the shortages of animal protein in tropical countries, nor will it provide vast quantities of cheap fish in the future to low income groups. However, its success has opened a window of hope for fish culturists to fulfil the dreams once held for non-tropical carps. The figures being touted for tilapia production seem almost gargantuan. A relatively recent estimate (Maclean 1984a) is 600-700 Mt/ha equivalent as a possible annual yield. Yields of 60-70 Mt/ha equivalent are being achieved routinely in Malaysia (Pers. Obs. by C.H.F. 1999).

Tilapia the aquatic chicken

The tilapia has long since been thought of as the equivalent of an 'aquatic chicken.' But, unlike chicken farming, tilapia culture does not depend on expensive feed ingredients, such as grain and fish meal. Perhaps the analogy that tilapias, like chickens, can be produced in any quantity, only limited by demand, may be already coming to pass rather rapidly.

The most important impact of tilapia production is that it has finally made fish-pond culture in the tropics a success. Just like the distribution of the common potato from Peru, which had an enormous positive impact during the industrial revolution in Europe's rapidly rising population by providing a high quality and cheap carbohydrate, the tilapias are beginning to make a meaningful impact with their readily-utilisable protein. Although tilapias are still costly to raise, there is the very good possibility that they too will be produced abundantly and cheaply in the near future, just like the potato, with still further advances in production technology. For example, it may be possible to integrate production of crude *Spirulina*, now cultured commercially as a food supplement, with tilapia production as the fish are unique in their ability to digest blue-green algae. An inquiry by one of us

(C.H.F.) on tilapia culture, an official in Illinois in the fish culture arm of ADM (one of the largest producers and processors of food) stated that they were raising tilapias on corn waste. The possibilities for raising tilapias on cheap food are immense but largely untapped at present.

Palatability of tilapias

There is clear and independent evidence that tilapias are acceptable to a wide variety of tastes. They are becoming increasingly available in western supermarkets, and can be found on the menus of restaurants from Port Moresby to Pretoria, and Toronto to Tel Aviv. The most common species available is *O. niloticus*, followed by *O. mossambicus*. Both are harvested at between 300 - 500 g in weight. In the wild, of course, and where fishing is not intense, these fish can weigh between 2 - 5 kg. The fish process well and can be shipped as whole fish or fillets, both fresh and frozen. The meat is firm, and their nutritional value is high. The American Tilapia Association quotes that a typical 113 g fillet will contain about 21 g of protein, and about 90 mg of omega-3 fatty acids. The tilapias, in fact, are credited with reducing starvation in Indonesia during the Japanese occupation in the 1940s, and are still one of the main sources of animal protein to the poorest sections of populations in Asia, Africa and the Caribbean, where even the smallest fish are used to make soups and relishes. In Haiti, one of us (C.H.F. in 1988) found dried tilapias of a very small size and wet weight of about 30 g being used as food.

Track record

The tilapias have been the mainstay of inland fisheries in African lakes for centuries, and provide considerable quantities of cheap and much appreciated fish to rural areas and cities. In Asia, where they have been introduced into shallow lakes and reservoirs, they produce some very high yields, which of course make them cheaper to buy than many of the indigenous fishes, including carps, and the quality is higher. Reservoir fisheries have since been created only lately, thanks to tilapias in the tropical countries of Central and South America, where millions of these small water bodies have been constructed (Fernando and Gurgel 2000). This has given rise to the debate about which production practice can do the most good, developing tilapia fisheries or developing tilapia farming. There is no question that, because of the millions of permanent and temporary water bodies in the tropics, tilapia fisheries provide an invaluable resource at a very modest cost, as they can be caught by almost anyone with cheap gear. However, the total harvest of these fisheries will always be much less that what can be produced,

with significantly more effort and cost, through culture.

The success of this latest movement to spread tilapias through the tropics one of us (C.H.F.) has labelled the "Dark Brown" fish revolution somewhat optimistically in comparison to the well-known "green" revolution of the 1960s. The choice is apt, as the fish and flesh of tilapias is somewhat darker than that of the carp, their predecessor, which is white, and the species are endemic to Africa, the continent predominantly populated by black people. Perhaps the revolution might have occurred sooner if the tilapias had come from another continent. Africa is not known for its contributions to domesticated plants and animals according to Diamond (1997), and much of Africa is poor in technology development and economic clout. But through the tilapias, Africa has provided an item of human food whose contribution to narrowing the animal protein gap is already considerable. Furthermore, it is just the apex of the mountain. Given time, the tilapias alone could well broaden and fill part of the protein gap brought on by the collapse of marine fish stocks. Two prominent fish culturists, according to Maclean (1984b), have predicted that tilapias will be the most important fish in the twenty-first century, and they may well be just that. When and whether they will alleviate the protein shortage, and put high quality nutrition within the reach of the underprivileged is yet to be seen.

No fish in the history of fish culture has been cultured successfully on all six continents on such a wide scale as tilapias. The growth of tilapia culture appears to be accelerating according to very recent reports (Roderick and Gillespie 2003).

In the closing years of the twentieth century, tilapias have come into their own in a big way. Finally, they are being accepted as fish, which do not in fact impact, with a few exceptions, on the native fish faunas as much as was assumed. The old chauvinistic view, which has been held for years even by one of the authors (Fernando 1956), that indigenous fish are good and introduced fish are bad, has been thoughtfully questioned by Dudgeon (2003), and at an appropriate and opportune time. With the rapid decline of many valuable marine fish stocks around the world it is necessary to leave no stone unturned in the search for something to fill the growing protein gap. The promise is in fish farming, according to The Economist (Anon. 2003), and the tilapias seem to have the best potential for making a major contribution to world fish production.

Perhaps we should end this paper with a quotation from a biologist who can be considered the Charles Darwin of ecology, namely the British pioneer Charles Elton. In his book (Elton 1959) on the dispersal of plants and animals, the ecology of invasions by animals and plants he says" I believe that conservation should mean the keeping or putting in the landscape of the greatest possible ecological variety- in the world, in every continent or island

and as so far as practicable in every district. And provided the native species have their place, we have no reason why the reconstitution of communities to make them rich and interesting and stable should not include a careful selection of exotic forms, especially as many of these are in any case going to arrive in due course and occupy some niche" The tilapias have been viewed with suspicion for a variety of reasons, not all of them objective or scientific. In tilapias we have an added bonus that this introduced fish will probably change our food habits and provide us with much additional food globally.

Epilogue

Young and Muir (2000) have estimated a possible global production of tilapias in 2030 of about 90 million Mt annually. This estimate may be high, but by no means impossible to achieve, particularly if there prove to be added increases of production after genetic manipulation. Also for example, with the selection of strains of tilapias more tolerant of colder waters, the fish could be raised seasonally in natural water bodies at higher latitudes and then harvested at the end of summer. This is not as fanciful as it sounds, as research in this area is already taking place in South Africa according to Roderick and Gillesspie (2003). Then there is the possibility of producing a very domestic variety of tilapia, suitable for raising in small family ponds close to the house, just as one grows vegetables or raises chickens. Another variety would be useful for production in rice fields, a practice that was always thought to have potential but never quite realised without it being integrated with other types of fish culture and reservoir fisheries. A distinct advantage of rice field fisheries in rural areas is that no additional land is lost for agricultural use, and the presence of fish makes a positive impact on the yields of rice (Fernando 2002). A scheme for achieving integrated fish culture in different types of habitats using tilapias has already been referred to. Renewable resources, which are in great demand are always destined to be threatened by human intervention and national greed. Domestication, through selection and careful introductions, is a practical option to help sustain it. But it is not achieved without opposition. For example, Fernando (1993) cited two major food resources, the potato, and the tilapias, both of which were resisted for decades by environmentalists, politicians, nationalists, religious groups, and even biologists. The coconut another major food resource was introduced by prehistoric humans. But hopefully those hard and fast attitudes are disappearing. Perhaps the domestication of fish is finally to happen, and the 'aquatic chicken' is about to emerge in the supermarket. Modern people are no longer dependent on hunting of birds and other land animals for food, so why not fish? The tilapias provide the opportunity, and their immense potential is only limited by the demand and the cost of production.

Acknowledgements

Recent articles in scientific journals and semi-popular magazines on the destruction of marine fisheries stimulated this paper, together with the opportunity to advance the theories by the authors of lacustrine and riverine fishes which can offer explanations of the extremely high productivity of tilapias and provide solutions to fish farming in the tropics that had hitherto languished. We have been greatly helped by comments from David Dudgeon, Department of Ecology and Biodiversity, University of Hong Kong, Juraj Holcik, Bratislava, Slovakia, Upali Amarasinghe, University of Kelaniya, Sri Lanka, Ron Jones, Ottawa, Canada, R. Victor, Oman, Ray de Zylva, Taradale, New Zealand, H.B.N. Hynes Waterloo, Canada , David Coates, Montreal, Canada, Rudolf Hermes, formerly working in The Philippines and now in Germany and Rafael Guerrero, Los Banos, Philippines. Mike Dickman, Welland, Canada answered some relevant questions about productivity of inland waters. Charles Heckman, Olympia, Washington was very critical of any fish introductions at first but modified his comments to a more positive stance about these introductions after the ideas in the paper were explained in detail. This paper has been read and commented upon in draft form by scientists on six continents. We thank World Aquaculture for permitting us the use of Figure 1.

References

Ali, A.B. 1998.
Impact of fish introductions on indigenous fish populations and fisheries in Malaysia. In: Stocking and introduction of fish (I.G. Cowx ed.), pp. 274-286. Fishing News Books, Blackwell, Oxford.

Anon. 2003.
The blue revolution: the promise of fish farming. The Economist August 9-15th.

Arthington, A.H. 1991.
Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. Canadian Journal of Fisheries and Aquatic Sciences 48 (Supplement 1): 33-43.

Beauchamp, R.S.A. 1964.
The rift valley lakes of Africa. An introduction to tropical limnology. Internationale Verenigung für Theoritische and Angenwandte Limnologie 11: 91-99.

Bludhorn, D.E. & A.H. Arthington 1991.
Tilapia in Australia and small Pacific Islands: Unwanted pest and unappreciated resource. In: Indo - Pacific Fisheries Commission

Country Reports presented at the Fifth Session of the Indo-Pacific Fisheries Commission, Bogor, Indonesia (E.A. Baluyut ed.), pp. 120-128. FAO Fisheries Report No. 458, Suppl. FAO, Rome.

Borgese, E. M. 1983.
The law of the sea. Scientific American 248 (3): 42-49.

de Zylva, E.R.A. 1999.
The introduction of exotic fish in Sri Lanka, with special reference to tilapia. Naga 22 (3): 4-8.

Diamond, J. 1997.
Guns, germs, and steel: the fates of human societies. Norton, New York.

Dudgeon, D. 2003.
Review: Sri Lanka freshwater fauna and fisheries. C.H. Fernando and S.R. Weerawardhena (editors), Sri Lanka freshwater fauna and fisheries, A third millennium book. Kitchener, Ontario. The Raffles Bulletin of Zoology 51: 173-174.

Elton, C. 1958.
The ecology of invasions by animals and plants. Methuen, London

FAO 2003.
Aquaculture production and value. Fishstat plus: statistical database. Food and Agriculture Organization, Rome.

Fernando, C.H. 1956.
On the food of four common freshwater fishes of Ceylon. Ceylon Journal of Science (C) 7: 210-217.

Fernando, C.H. 1980.
Tropical reservoir fisheries: A preliminary synthesis. In: Tropical Ecology and Development (J.I. Furtado ed.), pp. 883-892. International Institute for Tropical Ecology, Kuala Lumpur, Malaysia.

Fernando, C.H. 1993.
Coconuts, potatoes and tilapias, the wonderfish. Biologue (Waterloo, Canada) 11: 9-12.

Fernando, C.H. 2000.
A view of the inland fisheries of Sri Lanka: past present and future. Sri Lanka Journal of Aquatic Sciences 5: 1-26.

Fernando, C.H. 2002.
Bitter harvest- rice fields and fish culture. World Aquaculture 33 (2): 23-24 and 64.

Fernando, C.H. & J.J.S. Gurgel. 2000.
Extensive culture of tilapias in small reservoirs in the tropics and subtropics. In: Panorama da aquicultura (K. Fitzsimmons & J.C. Filho eds). Rio de Janeiro, Brazil.

Fernando, C.H. & M. Halwart 2000.
Possibilities of integration of fish farming in irrigation systems. Fisheries Management and Ecology 7: 45-54.

Fernando, C.H. & J. Holcik 1991.
Fish in reservoirs. International Revue Gesamten der Hydrobiolgie 76: 149-167.

Fernando, C.H., R.R.A.R. Shirantha, M.J.S. Wijeyaratne & P.R.T. Cumaranatunge 2000.
Tilapias and indigenous fish biodiversity in Sri Lanka. Sri Lanka Journal of Aquatic Sciences 7: 1-22.

Fitzsimmons, K. (editor) 1997.
Tilapia aquaculture. Proceedings of the Fourth International Symposium on Tilapias in Aquaculture, November 9-12, Florida. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Fitzsimmons, K. & J.C. Filho (eds) 2000.
Tilapia aquaculture. 5th ISTA conference, Rio de Janeiro, Brazil. Panorama de Acuicultura, Rio de Janeiro.

Fryer, G. & T.D. Iles 1972.
The cichlid fishes of the Great Lakes of Africa: Their evolution and biology. Oliver and Boyd, Edinburgh.

Hardin, G. 1968.
The tragedy of the commons. Science 162: 1243-1248.

Harvey, D.J. 2003.
Aquaculture outlook. Economic Research Service, US Department of Agriculture, LDP-AQS-18.

Hettiarachchi, A. 2004.
Instruments for global fishery management - A review. Sri Lanka Journal of Aquatic Sciences 9: 1-12.

Leveque, C. 1998.
Fish species introductions in African fresh waters. In: Stocking and Introduction of Fish (I.G. Cowx ed.), pp. 234-257. Fishing News Books, Blackwell, Oxford.

Lowe-McConnell, R.H. 1987.
Ecological studies in tropical fish communities. Cambridge University Press, London.

Maclean, J.L. 1984a.
Tilapia: The aquatic chicken. ICLARM Newsletter (Manila) 7(1): 17.

Maclean, J.L. 1984b.
Editorial . ICLARM Newsletter (Manila) 7: 1.

Maclean, J.L. 1988.
Fish introductiors: Editorial. Naga (Manila) 11(4): 2.

Nixon, S.W. 1988.
Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnology and Oceanography 33: 1005-1025.

Oglesby, R.T. 1985.
Management of lacustrine fishes in the tropics. Fisheries 10(2): 16-19.

Parrish, B.B. 1963.
Obtaining the maximum yield from traditional methods of harvesting. In: The better use of the world's fauna for food.. Symposium of the Institute of Biology, No. 11, London.

Petrere, M. 1996.
Fisheries in large tropical reservoirs in South America. Lakes and Reservoirs: Their Biology and Management 2: 2111-133.

Pauly, D., & R.Watson 2003.
Counting the last fish. Scientific American 289(1): 43-47.

Pomeroy, R.S. 1995.
Community based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. Ocean and Coastal Management 27(3): 143-162.

Pullin, R.S.V. 1986.
The worldwide status of carp culture. In: Aquaculture of cyprinids (R. Billard & J. Marcel eds). INRA, Paris

Pullin, R.S.V., M.L. Palomares, C.V. Casal, M.M. Dey, & D. Pauly 1997.
Environmental impacts of tilapias. In: Tilapia aquaculture (K. Fitzsimmons ed.). Proceedings of the Fourth International Symposium on Tilapias in Aquaculture, November 9-12, Florida. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Roderick, E. & D. Gillespie 2003.
Tilapia goes global. Seafood International. October 2003 pp. 26-32.

Sen, S. 1975.
In reaping the green revolution: food and jobs for all. Orbis Books, Maryknoll, NY.

Starling, F., X. Lazzaro, C. Cavalcanti & R. Moreira 2002.
Contribution of omnivorous tilapias to eutrophication of a shallow tropical reservoir: Evidence from a fish kill. Freshwater Biology 49: 2443-2452.

Sugunan V.V. 1997.
Fisheries management of small water bodies in seven countries in Africa, Asia and Latin America. FAO Fisheries Circular No. 933 FIRI/ C993 Rome.

Young, J.A. & J.F Muir 2000.
Economics and marketing. In: Tilapias: Biology and Exploitation (M.C.M. Beveridge & B.J. McAndrew eds), pp. 447-487. Kluwer Academic Publishers, The Netherlands.