Tilapia Culture in Ponds under Controlled Conditions

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Tilapias are valuable pond fish. They are appreciated by consumers in many countries and can produce high yields on relatively low inputs. However, tilapias pose a special management problem. They breed in production ponds when still young and small, greatly increasing the population. This results in competition and stunting due to lack of food. Only by controlling reproduction in production ponds can fish of marketable size and high yields per unit pond area be obtained. Two management methods to overcome this problem are reviewed: (a) rearing a mixed male-female population of young of the year before they attain sexual maturity and (b) rearing an all-male population. Factors affecting the choice of one of these methods are discussed as well as the techniques involved in each method. The effects of chemical fertilization, organic manuring and feeding on the production of tilapia in ponds are also discussed.

Introduction

Tilapias have become increasingly important in fish culture, especially in warm climates. According to FAO (1978), the total world production of tilapias (both *Tilapia* and *Sarotherodon* species, but excluding other cichlids) reached 197,000 t in 1977. Only a part of this production is obtained through aquaculture, but that portion is increasing steadily.

The number of tilapia species cultured in ponds, both experimentally and on a commercial scale, is quite large. Huet (1970) mentions 16 species. Balarin and Hatton (1979) give a list of 23 species which have been cultured at some stage. Of these, however, only two *Tilapia (T. rendalli* and *T. zillii)* and three *Sarotherodon* species *(S. mossambicus, S. niloticus* and *S. aureus)* have seen widespread use. The plant feeder *T. rendalli* is cultured to some extent in the Malagasy Republic and some Latin American countries, e.g., Brazil and Mexico (Balarin and Hatton 1979). *Tilapia zillii* is cultured in

some east African countries. It seems that there is considerable variation in the performance of cultured *T. zillii* since this species can reach a good marketable size in certain east African countries, while in other countries, such as Israel, it is considered a pest due to its small size at maturation. The major production of tilapias in ponds is derived from the three *Sarotherodon* species and most of the references in this paper will deal with these.

Tilapias, though valuable pond fish, pose a special problem when grown in ponds, whether in polyculture or in monoculture. Their early maturation and prolific "wild" spawning produce such large numbers of small fry as to cause stunting of the entire tilapia population and often of other species present in the pond. In some regions it is customary to harvest tilapias a number of times during the growing season. Each harvest removes the larger fish, leaving the smaller ones. When this practice is employed with fish that do not spawn freely in ponds, it usually results in a larger cumulative yield by providing more food for the remaining fish (Van der Lingen 1959a). With tilapia, however, this practice usually lengthens the culture period and results in heavy "wild" spawning. The longer the culture period, the more fry are produced and the population becomes stunted. The number of market-sized fish and the yield at each harvest becomes progressively smaller. In commercial farms, which have to supply relatively large quantities of market-sized fish regularly, such sequential harvesting is not practical and reduces profitability. Silliman (1975) points to another disadvantage of this practice in that the remaining fish which spawn in the pond and from which fry are usually taken for further rearing, are actually selected for slower growth, and this trait may be inherited by their offspring.

There is no doubt that early and prolific breeding under tropical pond conditions is perhaps the greatest disadvantage in the use of indigenous cichlid species for aquaculture in many parts of the world (Okorie 1975; Pillay 1979). It is obvious that Huet (1970) was correct in recommending the culture of tilapia during a definite period, with complete draining of the pond between cycles to control populations. Even then, special measures must be taken to overcome "wild" spawning. The two most common ways to overcome this problem are: culturing a mixed sex population and harvesting before they attain sexual maturity or culturing an all-male population. Two main factors should be taken into account when deciding which method to employ: the size preference of the market and the species used.

If the market accepts small fish (up to 150 to 300 g) and if these can be obtained before they reach sexual maturity, the first method is usually preferred since it saves effort, fingerlings and space. If, however, the market accepts only large fish which reach maturity before marketing, it will be better to use only male fry and thus avoid "wild" spawning and stunted populations.

In some cases the market accepts both sizes but prices are higher for the larger fish. Careful economic calculations should then be made, weighing the higher income for producing larger fish against the extra costs of obtaining male fry and wastage of females. The calculations should also take into account the higher yield expected from an all-male pond as compared to a mixed sex one, since in most tilapia species the males grow faster than the females (Fryer and Iles 1972).

Some species, such as *Tilapia zillii* or *Sarotherodon mossambicus*, breed when they are young and small and cannot reach market-size before maturation. Monosex populations have been obtained, mainly by manual sexing, but this can only be done reliably when the fish have reached a size of 20 to 50 g, so they must first be nursed to at least this size. In many cases these species will breed at an even smaller size. Pruginin and Arad (1977) report that in Malawi, *S. mossambicus* bred and growth stopped due to stunting when the fish reached 30 g. As a consequence the yield after 100 to 150 days culture did not exceed 300 kg/ha. It may be advisable, therefore, to choose species which spawn at an older age, such as *S. niloticus*, *S. aureus* or others. Pruginin (1965) found that while *S. hornorum* in Uganda reached not more than 150 g in about one year, *S. niloticus* usually reached 250 g in 5 to 6 months by the time they reached sexual maturation.

Culture techniques, such as pre-nursing, choice of size at stocking, stocking density, fertilization, feeding, etc., are affected to a large extent by the choice of management approach: mixed sex or all male. However, other factors such as climate and the type of culture system (monoculture or polyculture) have also to be considered.

Young-of-the-Year Culture

For unsexed young-of-the-year populations, the period before they reach sexual maturity is short: about 3 to 6 months. Thus the management method is based on having 2 or 3 cycles/yr, with complete drainage between cycles. In order to ensure rapid growth to the desired market weight during this short period, the stocking density is usually relatively low and depends on the inputs used, e.g., fertilization, manuring and feeding.

Van der Lingen (1959a) has found that with increasing levels of management, the maximum standing crop (carrying capacity) which can be sustained in the pond increases. He gives the following carrying capacities for *S. mossambicus*: natural feeding (no fertilization), 840 kg/ha; high level fertilization, 2,466 kg/ha and high level supplementary feeding with fertilization, 6,165 kg/ha. Van der Lingen (1959a) further states that over the same culture period and under the same conditions the yield per unit area at any level of nutrition is dependent upon the initial stocking biomass per unit area and not on the number of fish per unit area. He therefore recommends stocking by weight according to the expected carrying capacity. However, this statement is based on only a few experimental observations. Since the relative growth rate (i.e., relative to unit body weight) of small fish is higher than that of larger fish (Ghosh 1974; Hepher 1978), it is usually found in practice that for a given biomass of fish, the higher the density the higher the yield, provided enough food is available. Moreover, the practice of stocking by weight may lead to stunting of the population if the average weight of the stocked fry is low, since the number of fry per unit of stocked weight will be large and they will reach the carrying capacity while still small. Van der Lingen (1959a, 1959b) stocked fingerlings of 21 to 56 g average weight. His recommended stocking weights and densities relative to the carrying capacities for different inputs are given in Table 1. The number of fish stocked

Table 1. Stocking biomass recommended by Van der Lingen (1959a, b) for tilapia cultured in ponds with different inputs and the calculated fish densities (assuming an average weight of 38 g).

Inputs	Stocking biomass (kg/ha)	Calculated density (fish/ha)
None (natural feeding, no fertilization)	56-112	1,475-2,950
Fertilized ponds	112-224	2,950-5,900
Fertilized ponds with supplementary feeding	560-1,680	14,750-44,200

were calculated, taking into account an average weight of 38 g. If all the fingerlings stocked according to these recommendations survive by the time carrying capacity is attained and no "wild" spawning occurs, the average individual weight at harvest (carrying capacity/density) will be 139 to 417 g, which is a good market weight. However, if fry of 1 to 2 g are stocked, as is common in many countries, the average weight at harvest under the same conditions will be only 7 to 22 g. In Van der Lingen's (1959b) experiments only 15 to 30% of the harvested fish reached a market size of over 224 g. The densities given in Table 1 seem therefore to be too high since they will not permit rapid growth. In Israeli ponds, where protein-rich pellets are fed, tilapia are stocked at densities of 3,000-5,000/ha.

Allison et al. (1979) experimentally cultured unsexed *S. aureus* in concrete tanks (surface area 0.002 ha) at very high densities: 50,000, 100,000, 200,000/ha. "Wild" spawning decreased with increasing density (from 222,900/ha in the lowest to 38,380/ha in the highest density) and yield was high (from 1 t/ha in the lowest to 17.3 t/ha in the highest density). Allison et al. (1979) do not give the rate of growth but calculating from the yield and the density, it seems to be very low. The extrapolation of such data for application in commercial fish ponds is very questionable.

Yashouv (1969) has demonstrated that in a polyculture of *S. aureus*, common carp *(Cyprinus carpio)* and grey mullet *(Mugil cephalus)*, the tilapia (if stocked below 5,000/ha) do not affect the growth of the carp but in many cases even stimulate it. The growth of the tilapia is also not affected by the presence of the common carp or mullet at densities up to 2,500 to 3,000/ha. These synergistic effects may be explained by the increased amounts of detritus through the presence of the common carp and its consumption by the tilapia. The detritus carries dense populations of bacteria and protozoa (Odum 1968) and constitutes a nutritious food for the tilapia. On the other hand, the consumption of the detritus by the tilapia improves the oxygen regime for the benefit of the common carp. The increased yield in the polyculture pond explains why most, if not all, young-of-the-year tilapia culture in Israel is done in polyculture systems.

Polyculture may have an additional advantage. Since common carp and grass carp *(Ctenopharyngodon idella)*, when large enough, can prey to some extent on tilapia fry spawned in the pond (Spataru and Hepher 1977), they can, therefore, help to alleviate the problem of "wild" spawning that may

develop towards the end of the culture period. This problem can, however, be solved much more effectively by including a predator in the polyculture, such as the Nile perch *(Lates niloticus)* in Africa (Pruginin 1965, 1967; Meschkat 1967), the mud fish *(Channa striata)* in the Philippines (E.M. Cruz, pers. comm.) and Thailand (Chimits 1957), *Cichlasoma managuense* in Central and South America (Dunseth and Bayne 1978); and the sea bass *(Dicentrarchus labrax* or *D. punctatus)* in Israel (Chervinski 1974, 1975). The last two species are marine fish which can adapt to freshwater. The predators are in most cases stocked at about 10% of the tilapia population. The use of predators in tilapia ponds, despite its promise, has not received wide application and has been practiced mainly on an experimental scale, partly because of the difficulty in obtaining predator fry. This is true for both the Nile perch and the sea bass. Their inability to breed spontaneously in the pond can be considered an advantage but a source of fry must be found for commercial application.

In the subtropics the winter is usually too cold for growth of tilapia and the growing season is restricted to the summer. Balarin and Hatton (1979) quote Bishai (1965) who gives the range of 17.2 to 19.6°C, below which the growth rate of most tilapias decreases. For spawning to take place, temperatures must also be higher than this. The lowest temperature for spawning is 20 to 23°C (Huet 1970; Uchida and King 1962). This restricts the length of the season for culture of young-of-the-year even more. In Israel spawning starts only in May, and fry of approximately 1 g for stocking growout ponds are not available before June. This limits the season for rearing young-of-the-year from June to October so that only one cycle can be carried out. The fry are transferred from the spawning pond into the growout ponds when they are over 1 g. The culture period is sufficient to bring them to a market size of 200 to 300 g.

Since tilapias grow well above 18°C, the early part of the summer (March to June) can also be utilized for culture but the only fry then available are those hatched the previous year. If a mixed sex population is cultured they will spawn in the ponds when the temperature reaches 20 to 21°C in May. Since this occurs shortly before harvesting, the fry thus produced do not reach a size which can cause much harm in the pond and the stocked tilapia reach market size unaffected. Halevy (1979) reported that unsexed fry hatched in the previous year could be cultured during the first cycle and young-of-the-year during the second. A typical example of one growing season during 1977 is given in Table 2. In this case it can be seen that the cool spring weather is an advantage and high yields of market-sized tilapia can be obtained.

It is obvious that fish size, the time of stocking and especially the time of harvesting may be crucial to the success of culturing the previous year's fry in spring. The later the stocking and the smaller the fry, the smaller the fish at harvest time and the later the harvesting, and the more troublesome is the "wild" spawning. This is a considerable drawback in large farms where, due to market demand, the stocking and harvesting times are usually phased so that some ponds are stocked in late spring and harvested in mid-summer. These cannot, therefore, be used for early spring stocking and growout.

Table 2. Polyculture of tilapia *(Sarotherodon aureus)* with common, silver and grass carp in a 1.4-ha pond at Dor, Israel (after Halevy 1979).

	First culture period: February 6 to May 30						
	Stocked		Harvested		Gain		
Species	Density (fish/ha)	Average weight (g)	Density (fish/ha)	Average weight (g)	Average daily weight gain/fish (g)	Average daily yield (kg/ha)	Total yield (kg/ha)
Tilapia *(Sarotherodon aureus)*	5,000	6	2,140	200	1.3	2.8	398
Common carp *(Cyprinus carpio)*	3,000	5	2,960	642	4.4	13.0	1,885
Silver carp *(Hypophthalmichthys molitrix)*	930	378	890	2,000	11.3	10.2	1,428

	Second culture period: July 3 to November 22							
	Stocked		Harvested		Gain			
Species	Density (fish/ha)	Average weight (g)	Density (fish/ha)	Average weight (g)	Average daily weight gain/fish (g)	Average daily yield (g)	Total yield (kg/ha)	Annual total yield (kg/ha)
Tilapia *(Sarotherodon aureus)*	5,000	0.5	4,560	224	1.6	7.3	1,018	1,416
Common carp *(Cyprinus carpio)*	7,170	125	4,450	533	2.9	12.9	1,776	3,661
Silver carp *(Hypophthalmichthys molitrix)*	1,070	750	1,070	2,220	10.3	11.0	1,572	3,000
Grass carp *(Ctenopharyngodon idella)*	1,430	10	1,290	150	1.0	1.3	180	180
						Grand total annual yield		7,957

There is another serious drawback to mixed sex spring culture which is economic in nature. The cost of overwintering tilapia fingerlings is high and the rate of growth of unsexed fingerlings in spring is lower than that of all-male fingerlings. This is because males grow faster and because large fish grow better than small ones in culture ponds. At much the same cost, therefore, one can raise overwintered all-male fingerlings which have been nursed to a larger average weight. This is the reason why most tilapia culture in Israel uses all-male populations.

When rearing young-of-the-year in warmer tropical climates, it should be remembered that their age is a most important factor affecting sexual maturity. Stunted fry cannot be cultured because they will breed early in the ponds. It is important therefore to use recently hatched fry. It is also important to completely drain the rearing pond between cycles and eliminate all the remaining fish, if necessary by poisoning. The intrusion of fish from outside the pond should be prevented by screening the water inlets.

All-Male Culture

A monosex male population can be obtained in three ways: manual sexing; crossing two species of *Sarotherodon* to produce all-male or a high percentage (90% and over) of male hybrids and sex-reversal at an early age by incorporating hormones in the feed.

While much experimental work is being carried out on hybridization and sex-reversal and these methods appear promising for the production of all-male populations, it is only very recently that commercial use has been made of monosex hybrids and no commercial application has yet been made of sex-reversal. The main method used today to achieve an all-male population is still manual sexing. This is a relatively simple procedure. In many tilapia species the sexes can be distinguished by the genital papilla which has one orifice in the male as compared to two orifices in the female. The female often also has a smaller genital papilla.

It is important to sex the fish carefully. The less errors in the sexing, the less "wild" spawning occurs. The earlier the sexing is done the better since the females are then discarded. Early sexing thus saves space which can be used for rearing of the males and minimizes feed wastage on unwanted females. There is, however, a certain minimum size of fish for sexing with an acceptable degree of confidence. In field conditions the optimum size for sexing in most tilapia species is 50 to 70 g. This means that the fry have to be nursed to at least this size before growout. The hybrid crosses that produce high percentages of males are advantageous even if they do not produce 100% all-male population. Using such hybrids, fewer females are discarded, space is saved and sexing can be done on large fingerlings with a greater degree of confidence.

Here again, climate is an important consideration. Where a cold winter exists, nursing is done in the summer and growout is usually postponed to the following year. The final weight of the nursed fingerlings will depend to a large extent on the length of the nursing period. Those which hatched early and were stocked in the nursing ponds early in the season (end of

May-beginning of June) can reach a final weight of 100 g and over by autumn. However, those hatched later and stocked in the nursing ponds in July-August will only reach a weight of 40 to 60 g. The minimum weight for overwintering fingerlings is about 20 g. With smaller fingerlings the survival rate during winter is very low. The stocking density preceding overwintering is adjusted according to these expected final weights. When fingerlings are expected to reach a final weight of 100 g, the stocking density is about 50,000/ha. In order to better utilize the natural productivity of the pond, fry are often stocked at a density of 100,000/ha for the first part of the nursing period until they become 50 g fingerlings. They are then thinned out to 50,000/ha. Fry of later spawning, which can reach a final weight of 50 g before overwintering are stocked at a density of 100,000/ha.

One of the most important considerations in determining the desirable final weight of the nursed fingerlings in regions with cold winters is the available overwintering capacity. If special facilities and large investments are required for retaining a higher than ambient water temperature in the overwintering ponds (e.g., covering of the pond and/or warming the water), then this usually means a restricted overwintering pond area and, therefore, a limitation of the standing crop of fish that can be held over the winter. A certain number of fingerlings are required for stocking the culture ponds in spring and the maximum average weight of these can be obtained by dividing the standing crop which can be overwintered by the required number of fingerlings. Smaller fingerlings can be obtained by increasing the fry stocking density in nursing ponds relative to the desired final fingerling weight. These fingerlings can be nursed again in spring if necessary.

Nursing can also be done in polyculture ponds while rearing other fish (sometimes including large male tilapia) to market weight. In such cases the density is sometimes lower than for nursing ponds. Table 3 gives an example of such nursing on an Israeli farm where tilapia were introduced in late summer (August 9).

The culture of an all-male population removes the restrictions on final age and thus on weight at harvest associated with mixed sex culture. The fish can therefore be cultured to a much larger final weight, usually 400 to 600 g, even though this takes longer. Growout can be done either in polyculture or in monoculture systems. The advantages of polyculture have already been discussed above. The stocking density used in polyculture is not much different to that for young-of-the-year culture, but since males grow better and the growing period is longer, they usually attain a much larger final weight.

Here again, the density depends on the levels of inputs (fertilization, manuring and feeding). Pruginin (1967) stocked all-male hybrids *(S. niloticus* x *S. hornorum)* of 50 g average weight at densities of 1,000 to 1,500/ha. The daily weight gain was 1.5 to 3.0 g/fish, and the average weight at harvest was 200 to 450 g after a culture period of only 100 to 150 days. No information was given on fertilization or feeding rates. Shell (1968) conducted an experiment to study the stocking of male *S. niloticus* using supplementary feeding (pelleted Auburn No. 2 fish feed, rich in protein). The growth rate was independent of fish density up to 5,000 fish/ha at 2.1 to 2.3 g/fish/d. Rearing at this density gave the highest yield of 1.6 t/ha/163 d. The feed conversion

Table 3. Nursing tilapia fingerlings in a 5.7-ha polyculture pond with other species grown to market weight at Hama'apil, Israel.

Species	Stocking date	Harvesting date	Culture period (days)*	Average stocking weight (g)	Density at harvest (fish/ha)	Average weight at harvest (g)	Yield (kg/ha)
Common carp *(Cyprinus carpio)*	Mar. 12	Dec. 29	245	29	4,540	1,106	4,889
Mullet *(Mugil cephalus)*	Mar. 17	Dec. 29	244	156	1,750	500	563
Silver carp *(Hypophthalmichthys molitrix)*	Mar. 7	Dec. 29	245	195	1,400	2,268	2,980
Tilapia *(Sarotherodon aureus)*	Aug. 9	Dec. 29	98	13	9,120	100	835
					Annual yield (245 days)		9,267

*Taken as within the period March 15 to November 15, when the temperature is suitable for fish growth.

Table 4. Culture of all-male tilapia hybrids *(Sarotherodon niloticus* x *S. aureus)* in a 4.2-ha polyculture pond at Gan-Shmuel, Israel, over two culture periods.

Species	Stocking date	Harvesting date	Culture period (days)*	Average stocking weight (g)	Density at harvest (fish/ha)	Average weight at harvest (g)	Yield (kg/ha)
Common carp *(Cyprinus carpio)* I	Feb. 24	Aug. 6	143	50	3,000	942	2,670
Common carp *(Cyprinus carpio)* II	Apr. 6	Aug. 6	122	15	3,444	230	730
Tilapia	Apr. 5	Aug. 6	123	148	2,020	487	680
Silver carp *(Hypophthalmichthys molitrix)*	Feb. 24	Aug. 6	143	200	1,720	1,311	1,910
		Totals for first culture period			10,184		5,990
Common carp *(Cyprinus carpio)* I	Aug. 8	Dec. 12	99	387	3,230	1,018	2,040
Common carp *(Cyprinus carpio)* II	Aug. 11	Dec. 12	96	10	3,120	235	700
Tilapia	Aug. 8	Dec. 12	99	48	2,850	288	680
Mullet *(Mugil cephalus)*	Aug. 22	Dec. 12	85	160	1,180	430	320
Silver carp *(Hypophthalmichthys molitrix)*	Aug. 22	Dec. 12	85	416	1,600	1,000	930
		Totals for second culture period			11,980		4,670
		Total annual yield (242 days)					10,660

*Taken as within the period March 15 to November 15, when the temperature is suitable for fish growth.

ratio (FCR) was 2.31.

In Israel the stocking densities for all-male tilapias in polyculture systems are usually 3,000 to 5,000/ha, when the fish are fed supplementary feed (25% protein pellets). Table 4 presents results obtained from a well-managed polyculture pond in Israel which included sexed all-male tilapia hybrids *(S. niloticus* x *S. aureus).* The tilapia stocked in spring were nursed the previous year and then overwintered. Those stocked in the second cycle in August were young-of-the-year, which were nursed to 48 g and then sexed. The total annual yield of tilapia was 1.36 t/ha: over 10% of the total pond yield.

The most economic stocking density is not necessarily that which results in the highest average growth rate, but rather that which results in the highest yield per unit area. Up to a certain density, an increase in stocking density does not depress growth rates proportionally and the yield per unit area increases. This effect is quite pronounced with tilapia. At densities of 3,000 to 4,000/ha, when fed protein-rich pellets, each fish can gain 3 to 5 g/day. The daily weight gain drops when the stocking density is increased, but at 20,000/ha it is still 1.5 to 2 g/day, which results in a high yield. The standing crop of such densely stocked ponds can reach 25 t/ha. This is only possible, however, when no restrictions are imposed on the length of the culture period and the fish can be given longer period to reach market weight: as in all-male culture.

Lovshin et al. (1977) cultured all-male *S. niloticus* and all-male hybrids of *S. niloticus* x *S. hornorum* at densities of 10,000/ha. The tilapia were stocked at 60 to 63 g and harvested at an average weight of about 240 g. The yields after a 180-day culture period were 2.8 and 3.2 t/ha for the *S. niloticus* and hybrids, respectively.

Sanchez (1974, cited by Lovshin and Da Silva 1975) stocked male *S. aureus* at 40,000/ha with an average weight of 113 g. After 60 days he harvested the fish at an average weight of 143 g. Though the yield was high (2.1 t /ha), the growth was very low (0.5 g/fish/day). This may have been due to the feed which contained 30% coffee pulp.

Sarig and Marek (1974) stocked male *S. aureus* at even higher densities: up to 60,000/ha. The fish were fed a pelleted diet containing 25% protein and in spite of the high density gained 2.39 g/day. The mean feed conversion ratio (FCR) was somewhat high (3.4) but the total yield during the 67-day culture period was 15.6 t/ha.

When the stocking rate is so high, the existing natural food resources of the pond are divided between a great number of fish, and the role of natural food and productivity in the overall nutrition of the fish decreases. The advantages of polyculture are then very limited and the extra work involved in sorting the different species of fish at harvest becomes a burden. Monoculture is therefore more rational at high stocking densities. This can, however, be modified by environmental factors. In Israel filamentous algae develop early in the growing season and become a nuisance when the fish are harvested. In order to control this a number of common carp are introduced into the ponds (stocked at up to 20% of the tilapia density). By burrowing in the mud, the common carp prevent the development of the filamentous algae. The monoculture thus becomes a duoculture, with the tilapia as the dominant member.

Table 5. Yields of all-male tilapia hybrids *(Sarotherodon niloticus* x *S. aureus)* cultured alone and with common carp *(Cyprinus carpio)* in two Israeli fish farms.

1. Monoculture at the Ginossar technological experiments station (U. Rappaport, pers. comm.)
Pond area: 0.02 ha

Species	Stocking date	Harvesting date	Rearing period (d)	Density at harvest (fish/ha)	Average stocking weight (g)	Average weight at harvest (g)	Yield (kg/ha)	Daily weight gain (kg/ha)
Tilapia hybrid	Aug. 20	Nov. 11	76	30,000	217	380	4,890	64.3

2. Duoculture at a farm at Nir David.

Species	Stocking date	Harvesting date	Rearing period (d)	Density at harvest (fish/ha)	Average stocking weight (g)	Average weight at harvest (g)	Yield (kg/ha)	Daily weight gain (kg/ha)
Tilapia hybrid	July 1	Sept. 1	62	18,400	250	450	3,680	
Common carp	July 1	Sept. 1	62	1,000	250	600	350	
							4.030	65.0

Lovshin et al. (1977) experimented with a duoculture of 8,960/ha all-male hybrid tilapia *(S. niloticus* x *S. hornorum)* and 1,785/ha common carp. They found that the total yield was somewhat lower than that for tilapia hybrid monoculture. However, the feed added to the duoculture pond was much lower than that added to the tilapia monoculture pond.

In ponds with very high stocking densities, oxygen usually becomes a limiting factor. Aeration is therefore mandatory, at least during the night. Other drawbacks of the system are the accumulation of metabolites in the water and organic matter in the bottom mud. The latter causes a reduction in the redox potential and the appearance of H_2S which is toxic to fish and fish food organisms. These two factors curtail the growing season to about 100 days, after which the water has to be changed.

In densely-stocked ponds, fish are fed protein-rich pellets which seem to be sufficient to sustain their growth at 1.5 to 2 g/d. In spite of the high density, the FCR usually remains relatively low. Table 5 presents the yield in two ponds under such a culture system.

Inorganic Fertilization and Manuring

The tilapia species dealt with here are all microphagous: feeding either on plankton or detritus. When reared at low densities they can obtain a major part of their nutritional requirements from natural sources. Increasing the production of this natural food by inorganic fertilization and/or manuring, when coupled with increased stocking density, usually results in a considerable increase in yield. Van der Lingen (1959a) found that the yield of *S. mossambicus* could be increased 2.5 times over that from natural production alone by means of inorganic fertilization. George (1975) conducted an experiment on the effect of fertilizers on the yield of *S. niloticus* in ponds of 0.02 and 0.15 ha. Although no replications were carried out for treatments, the effect of both inorganic fertilizers (triple superphosphate) and organic manures (cow and chicken) were clearly demonstrated. Superphosphate increased production 3.4-fold, cow manure 1.7-fold and poultry manure 3.3-fold over natural production. The highest yield was obtained using a combination of superphosphate and cow manure, which increased the yield 5-fold.

Organic manures stimulate food production in a different way to inorganic fertilizers. They add detritus which stimulates the heterotrophic food chains, producing more bacteria and zooplankton (Schroeder 1978). The microphagous tilapias are very responsive to such treatment and yields can be increased considerably. Chimits (1955) describes a method of rearing of *S. mossambicus* in Thailand where considerable amounts of manure (pig, cow and chicken) were added to ponds. The annual yield reported from these ponds was about 4 t/ha. Moav et al. (1977) experimented with the effect of liquid cow manure on fish in polycultures which included tilapia. They found that high yields of tilapia could be obtained by manuring, even at high stocking densities, thus replacing supplementary feed to a large extent. Feeding tilapia under these conditions did not have much additional effect on their growth rate. Table 6 gives the relevant results.

Table 6. Yields of tilapia *(Sarotherodon aureus)* from ponds receiving cow manure with and without supplementary feeding with grains (after Moav et al. 1977).

	Stocking density (fish/ha)	Average initial weight (g)	Average final weight (g)	Daily weight gain (g/fish)	Survival (%)	Daily yield (kg/ha)
Ponds receiving only cow manure						
Tilapia 1	3,320	97*	430	2.6	91.5	8.9
Tilapia 2	1,680	21	221	1.6		
Ponds receiving cow manure + supplementary feed						
Tilapia 1	3,320	97*	416	2.5	88.5	8.5
Tilapia 2	1,680	21	220	1.6		

*Hand-sexed, all-male

Lovshin and Da Silva (1975) report that ponds stocked with all-male hybrid tilapia at a density of 8,000/ha (average weight 25 g), when manured with 500 kg/ha/wk chicken manure gave an average yield of 1.35 t/ha after 189 days and an average weight at harvest of 186 g.

Fresh manure disintegrates in water into colloidal particles which are attacked by bacteria and readily incorporated in the food web. Integrated farming systems where animals are kept over fish ponds and their wastes fall directly into the pond usually result in high fish yields. Here again, tilapias are very responsive. Van der Lingen (1959c) cultured ducks (1 duck/8.3m^2) on a pond stocked with tilapias *(S. mossambicus, S. macrochir* and *T. rendalli).* He obtained a yield of 3.48 t/ha, of which more than 40% were over 225 g. Culture experiments carried out in Israel also showed increased yields of *S. aureus* in a polyculture (H. Barash pers. comm.).

The integration of tilapia culture and pig fattening has also given good results. Lovshin and Da Silva (1975) constructed pigsties on the borders of 0.01 ha ponds to give manure loadings of 70 pigs/ha of pond. The pig manure was washed daily into the ponds. The ponds were stocked with 8,000/ha tilapia (all-male hybrids of 25 g) and were harvested after 189 days at an average weight of 205 g. The fish yield was 1.5 t/ha. The only supplementary feed was that supplied to the pigs.

Feeding

Tilapias larger than 4 to 5 cm take supplementary feed readily (Le Roux 1956; Bishai 1962; Huet 1970). Meschkat (1967) lists many feedstuffs used in tilapia culture such as plants, copra wastes, cotton seeds, etc. No information is given, however, on the effectiveness of these feedstuffs. It seems that some feeds are less effective than others. Experience in Israel has shown that whole sorghum grain does not affect the growth of *S. aureus* much, either because they are not eaten or have a low nutritional value. A

possible explanation is that the tilapia cannot crush the hard grain of sorghum as well as can the common carp. The latter have molar-like pharyngeal teeth suitable for such a task.

Stickney and Simmons (1977) incorporated dried poultry waste into pelleted trout feed and fed this to *S. aureus*. At levels of incorporation of 20 and 30%, a considerable negative effect on the growth rate of the fish was noticed. Supplementary feeding with a proper diet can however increase yields very considerably. Huet (1970) suggests that yields of tilapias with supplementary feeding can be increased 2- to 10-fold over yields from non-fed ponds. The effect of supplementary feed is emphasized at higher stocking densities. Lovshin et al. (1977) conducted a feeding experiment at two stocking densities (5,600 and 8,960/ha) with all-male hybrid tilapia *(S. niloticus* x *S. hornorum)*. They fed a mixture of 50% wheat chaff and 50% castor bean meal. The diet contained 25% protein and was fed at 3% of body weight. Taking the net yield in the control ponds as 100% (= 288 kg/ha at 5,600 fish/ha and 179 kg/ha at 8,960 fish/ha) the following increased yields were found: at 5,600/ha with organic fertilizer, 265% and with supplementary feeding, 326%; at 8,960/ha with organic fertilizer, 518% and with supplementary feeding, 938%.

The FCR can serve, to a certain extent, as an indicator of the nutritional value of a feed, although feed conversion is also affected by other factors such as the physiological state of the fish, environmental conditions, the amount of available natural food and the amount of feed consumed. Balarin and Hatton (1979) give a feed conversion table for various supplementary feedstuffs. The following FCR values for *S. niloticus* will illustrate their wide variability with different feeds: groundnut cake, 3.6; cottonseed cake, 4.8; pelleted chicken feed + 10% fresh fish equivalent, 1.8 to 6.5; brewery waste, 12.6; cottonseed crush, 18.9.

Natural food in ponds contains about 55% protein on a dry weight basis and can therefore be supplemented, to a certain extent, by carbohydrate-rich feeds such as rice bran. Tilapias seem to utilize such carbohydrates well. E.M. Cruz (pers. comm.) conducted experiments in the Philippines to determine the effect of feeding rice bran and copra meal on the production of *S. niloticus* and common carp. The addition of these feedstuffs increased the yield of the tilapia by about 50% over that of fertilized ponds with no supplementary feeding.

With increased standing crops, the quality and quantity of dietary protein become more important. Inclusion of protein in diet of *S. niloticus* reduced feed conversion considerably (de Kimpe 1971). In Israel it has been observed that feeding pellets of 25% protein, which include 10 to 15% fishmeal, has a pronounced effect on the growth of tilapia hybrids *(S. niloticus* x *S. aureus)*, especially at high densities (Piperno 1970a, 1970b; Marek 1970).

Not many systematic studies have been done on rates of feeding. Since natural food constitutes an important part of the nutrition of tilapias, the amount of supplementary feed given is usually lower than that for common carp. Shell (1967) shows that the best FCR for protein-rich pellets (Auburn No. 2) by *S. mossambicus* was when fed at a rate of about 2% of its body weight per day. For *S. niloticus* the best was obtained at 4% of body weight per day. Marek (1975) developed a feeding chart for tilapias in Israel

Table 7. A feeding chart for the culture of tilapias in Israel (after Marek 1975). The daily feeding rates are expressed in g/fish and % body weight.

Fish weight (g)	Daily feeding rates For polyculture with carp (g)	(%)	For monoculture (g)	(%)	Fish weight (g)	Daily feeding rates For polyculture with carp (g)	(%)	For monoculture (g)	(%)
5-10	0.4	5.3	0.5	6.7	100-150	2.2	1.8	2.7	2.2
10-20	0.6	4.0	0.8	5.3	150-200	2.5	1.4	3.0	1.7
20-50	1.3	3.7	1.6	4.6	200-300	3.0	1.2	3.7	1.5
50-70	1.6	2.7	2.0	3.3	300-400	3.6	1.0	4.5	1.3
70-100	1.9	2.2	2.4	2.8	400-500	4.2	0.9	5.2	1.2
					500-600	4.8	0.9	6.0	1.1

(Table 7). He considers that tilapia in polyculture gain some natural food from association with common carp and other fish species and therefore the amounts of supplementary food he recommends are somewhat lower than for monoculture. In both cases higher rations are given when the tilapia are small and the ration decreases with increase in body weight. Differences in response of tilapia to supplementary food in polyculture and monoculture were also found by Lovshin et al. (1977). In a polyculture pond the FCR for tilapia and carp combined was lower than that for tilapia alone in a monoculture. It was concluded that less feed was required to raise a given biomass of hybrid tilapia and common carp than was needed to raise the same biomass of hybrids cultured alone.

Conclusion

From this review it can be seen that very high yields of tilapia can be obtained with relatively low inputs. This, however, requires complete control of reproduction and the choice of proper methods according to existing conditions. It is doubtful whether this can be done in small homestead ponds, but with sufficient know-how it can be achieved in small or large commercial ponds.

Discussion

HENDERSON: Can you give us some idea of the relative price structure for fish sold from these pond culture systems? What percentage of the profit of the farm comes from farming tilapias and what percentage from the other species?

HEPHER: I am afraid I cannot. Maybe Mr. Mires can help?

MIRES: On a national basis, we produce per year about 7,000 to 8,000 t of common carp, about 1,000 t of silver carp and about 3,000 t of tilapias. The prices are: common carp, about $2/kg; tilapias also about $2/kg and silver carp about $1.50/kg. We also produce about 700 to 800 t of mullet which fetches about $4/kg and miscellaneous species—grass

carp, big headed carp, etc. totalling about 200 t. There is a price differential between small and large tilapia. A 200 g fish costs about $1.20 and the bigger ones about $2.

NASH: Dr. Hepher, can I ask if you tried the same stocking formula for polyculture in different sized ponds, and do you get the same results operating at say, 1 ha and ½ an acre.

HEPHER: Yes, we do. Once you have prevented wild spawning or uncontrolled reproduction, the results are the same irrespective of pond size.

LOVSHIN: I would like to suggest another method which I think is valid for raising tilapias. Dr. Hepher has been talking largely about the Israeli situation, but elsewhere, a predator to control unwanted recruitment can be very useful if a good native species is available. In Israel, they do not have a predator but there are many places in the tropics where native predators are available and can be reared easily. This is a good system.

HEPHER: I agree. The only problem is that most information on the use of such predators is from experimental work not commercial culture. I think the main reason is the great difficulty in obtaining the fry of some of these predators. Take for instance the Nile perch which when grown in combination with tilapias will prey on the small tilapia. You cannot get large quantities of Nile perch fry very easily. It will not spawn readily in ponds. I think though that you have used predators successfully.

LOVSHIN: We have used *Cichla ocellaris*, but mostly for experimental work. The mass rearing of this species is no problem. I do know also of small scale commercial use of a *Cichlasoma* sp. in El Salvador.

MIRES: What is its native name?

LOVSHIN: It is a cichlid. *Cichlasoma managuense.*

HEPHER: Although it has not been used commercially, I can give you another example of a good predator—the seabass species, *Dicentrarchus labrax*, or *D. punctatus.* Again, you face the same problem. They are wonderful fish, but you cannot get the fry.

LOVSHIN: In Taiwan, I know that the snakehead *Channa striata* is used commercially. They reproduce it and they put it in the tilapia ponds, and it works well as a controlling predator. What I am saying is that there are some commercial examples; not as much as the use of monosex culture, but still enough to indicate a valid system. I think as tilapia culture expands, we are going to see more and more use made of predators.

HEPHER: I agree.

PULLIN: In the Philippines, the ICLARM and Central Luzon State University cooperative project on integrated animal-fish culture uses snakehead as a controlling predator for tilapia culture in manured ponds. We have found, however, that simple predator:prey ratios are not adequate as management guidelines for different lengths of culture period. You have to adjust to the different recruitment loads.

LOWE-MCCONNELL- Dr. Hepher, is sexing done by eye, because I know that some tilapias are much more difficult to sex than *Sarotherodon mossambicus*?

HEPHER: We do not sex *Sarotherodon mossambicus*, but we do sex *S. aureus* and hybrids. It is quite easy. At Dor, all we have is about a 3 to 4% error. It should be done when the fish are over 50 g because then the differences are more marked.

GUERRERO: In the Philippines, we are experimenting with polyculture of tilapias with invertebrates, with freshwater shrimps and prawns. We think there is commercial potential for these systems, particularly in developing countries.

COCHE: In relation to the two previous questions, the prey-predator relationship and sexing, at the pilot commercial fish farm in the Ivory Coast sexing of *S. niloticus* is done by hand on 25 g fish with about 10% error. Then to control this error, a small predator *(Hemichromis fasciatus)* is used in the ponds without any calculation of prey:predator ratio. One kilogram of predators is used per 1,000 m^2 pond. They remain very small and can be reused several times. When the pond is drained, the predators are taken out and transferred to another pond. When some tilapia recruitment is needed, the predators can be removed and tilapias can be bred in the ponds. This combination of predators and early hand sexing seems to work well.

HEPHER: May I comment on the response of tilapias to pond fertilization? Fertilization may be organic or inorganic. Tilapias are much more responsive than other fish to organic fertilization. This may be because of their feeding habits, for example, consumption of detritus. A wide variety of different manures are readily divided into small colloidal particles, for instance, liquid cattle or chicken manure, and even the sludge remaining after processing manure for bio-gas. Tilapias are very responsive to all of these. We manure ponds every day, in some cases in very big quantities, up to 150 to 180 kg dry matter/ha/day. With respect to feeding, we have found that the feeding rate of tilapias is almost half that of carps. Using feeding charts, we can feed half the amount of supplemental feed for the same standing crop of tilapias as for carps.

MORIARTY: You are using *S. aureus* and a *niloticus* x *aureus* hybrid. Presumably, *S. aureus* feeds on phytoplankton in nature. Are you encouraging blooms of algae in the ponds?

HEPHER: No, more detrital feeding.

MORIARTY: Are they really feeding on detritus? Has anyone actually looked at the contents of the stomach?

HEPHER: Yes, Spataru has analyzed the stomach contents of *S. aureus* and *S. galilaeus* from Lake Kinneret. The majority of the contents is detritus. This is probably why they are so responsive to manures.

MORIARTY: The manures will also encourage the algal blooms as well.

HEPHER: Yes.

MIRES: Our carp ponds always suffered very much from blue-green algae blooms in the past. Then, with the production of tilapias and with a combination of tilapia and silver carp, this problem has been totally eliminated. Although what is found today in the stomach of tilapias may not suggest that they consume much blue-green algae, we have had the impression in the past that they can clear these algae from the pond.

CHERVINSKI: We experimented at Texas A&M University growing *Macrobrachium rosenbergii* by itself or in combination with *S. aureus*. They don't suffer from blooms of blue-green algae in the tilapia pond, but they do suffer from these when cultured alone. We also tried culturing *S. galilaeus* in dirt ponds, but they did not perform well because they are almost exclusively plankton feeders whereas *S. aureus, S. niloticus* and hybrids will bottom-feed as well.

BOWEN: There appear to be two feeding categories amongst the tilapias and sarotherodons. Those adapted to feeding on coarse material, like macrophytes, and the microphagous group. The comments made here emphasize the fact that the microphagous group is highly flexible in its feeding mode. They can feed from suspension or they can feed from substrates, depending entirely on food availability. Certainly, there are some species which tend to feed either always from suspension or always from the bottom in the natural environment, but even in the natural environment, some species are flexible.

There is a good example from Lake George where one species *(S. leucostictus)* is a filter feeder in the open water, but feeds on the bottom near shore. From my own experiments, I know that *S. mossambicus*, which almost always feeds from a substrate in the natural environment, when confined in an aquarium and excluded from any substrate will filter feed on plankton and suspended detritus. So, they are highly flexible and I do not think an absolute distinction between filter feeders versus substrate feeders is valid, especially when we are talking about aquarium or aquaculture situations.

Cage Culture of Tilapias

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This study presents a world-review of tilapia cage culture which is today practiced in an increasing number of countries, mostly in tropical freshwaters. Most culture systems are on an experimental scale, and use *Sarotherodon niloticus*, *S. mossambicus* or *S. aureus*. Among the technological aspects of tilapia cage culture, construction and design of cages, site selection criteria, and management of tilapia stocks are discussed briefly before presenting the various technologies used for the production of either juveniles or food-fish in cages. On the basis of feeding practices, adult tilapia may be raised in extensive, semi-intensive or intensive cultural systems. Extensive systems based on natural feeding are described from eutrophic lakes and fertilized water bodies. Semi-intensive systems (where low-cost and low-protein diets are fed) have been successfully developed on an experimental scale either combining phytophagous tilapia and a vegetable diet or utilizing agricultural byproducts in the presence of algal blooms. As feed quality improves, the cultural system gradually intensifies and feeding aspects become more important from the economic viewpoint. These aspects are therefore discussed thoroughly before reviewing the available data pertinent to intensive tilapia cage culture. Finally, the advantages, constraints, research needs and prospects of this particular technology are discussed. It is concluded that some tilapias present good production potentials, particularly in cultural systems with low energy inputs.

Introduction

Fish cage culture has been defined as the rearing of fish stocks, generally from juvenile to market size, in a totally enclosed water volume through which a free water circulation is maintained.

General reviews of fish cage culture as practiced in inland waters have been published earlier (Coche 1978, 1979). The objective of the present review is to present a synthesis of the information available on the application of this culture technique to the production of tilapias.

Tilapia cage culture has a relatively short history. The first scientific experimentation started around 1970 at Auburn University, Alabama with the rearing of *Sarotherodon aureus* in cages placed in fish ponds (Armbrester

Table 1. Geographical distribution of cage culture of tilapias (*Sarotherodon* and *Tilapia*): in fresh waters, either experimental (EF) or commercial (CF) and in brackish waters similarly (EB or CB).

Country	*S. mossambicus*	*S. niloticus*	*S. aureus*	*S. esculentus*	*S. galilaeus*	*S. melanotheron (T. heudeloti)*	*S. niloticus* x *S. mossambicus**	*T. rendalli*	*T. guineensis*	*T. zilli*	Reference
Europe											
Belgium		EF							EF		Philippart et al. 1979
North America											
Alabama		(EF)	EF								Armbrester 1972; Pagán 1973, 1975; Suwanasart 1972; Anon. 1979c
Africa											
General		EF									Coche 1979; ADCP 1980
Central Africa		EF									N'Zimasse 1979
Ivory Coast		EF									Coche 1977; Campbell 1978a, 1978b
———		EB									De Kimpe 1978
———		CB				CB					Campbell (pers. comm.)
Nigeria		EF			EF					EF	Ita 1976
Tanzania				EF						EF	Ibrahim et al. 1975
Asia											
China	(EF)						EF				dela Cruz 1979; Song (pers. comm.)
Indonesia	EF	EF					(EF)				Rifai 1979, 1980; Pedini (pers. comm.)
Japan	EF										
Philippines	EF	EF	EF				EF			EF	FAO 1977a; Guerrero 1975, 1979a, 1980a, 1980b; Pantastico and Baldia 1979
———	CF										Garcia 1979; Guerrero 1979a; Radan 1979
Sri Lanka	EF										Sollows (pers. comm.)
Thailand	EF										Sollows (pers. comm.)
Latin America											
General	EF	EF	EF					EF			ADCP 1978
Brazil								EF			ADCP 1978
Colombia	EF							EF			Corredor 1978; McLarney 1978
Costa Rica		EB	EB								Nanne 1979
Cuba	EF	EF									Rodriquez 1976
El Salvador			EF								Godinez and Jose 1976a
———			EF								Godinez and Jose 1976b; Hughes 1977; Street 1978
Guatemala	EF										Bardach et al. 1972
Puerto Rico			EF								Jordan and Pagán 1973
———			EB								Miller and Pagán 1973; Miller and Balantine 1974

*hybrid

1972; Suwanasart 1972). Since then, the technique has spread progressively to several other regions of the world (Table 1).

Because of some of its inherent advantages, such as the possibility of using existing tropical water bodies to produce a fast growing and well accepted food fish, tilapia cage culture is raising more and more interest, particularly in tropical, developing countries. It is hoped that this review will contribute not only to the justification of such interest but also to an improved technology and its wise application.

The Present Status of Tilapia Cage Culture

Although a relatively new development, tilapia cage culture is now found in several tropical countries of Africa, Asia and Latin America (Table 1). In North America it remains confined to the state of Alabama, where it has been studied for about 10 years. In Europe, tilapia cage culture is practiced only in Belgium in the thermal effluent of a nuclear power station (Philippart et al. 1979).

Most tilapia cage culture is done on an experimental scale and in fresh waters. The few exceptions are as follows: experimental/brackishwater in the Ivory Coast, Costa Rica and Puerto Rico; commercial/freshwater in the Philippines and El Salvador and commercial/brackishwater in the Ivory Coast.

The tilapias most commonly used are *S. mossambicus* (in Asia and Latin America), *S. niloticus* (especially in Africa) and *S. aureus* (especially in North and Latin America). Six other species are also listed (Table 1), but of these only *Tilapia rendalli*, as a phytophagous fish in Latin America and *S. melanotheron* (formerly *T. heudelotii*) as a brackishwater species in the Ivory Coast are likely to become important. The hybrid *S. niloticus* x *S. mossambicus* is being tried in a few Asian countries where it may have better qualities than *S. mossambicus* for cage culture.

There is a definite potential for tilapia cage culture in the rivers and lakes of many Latin American countries (ADCP 1978) and Africa (Coche 1979; ADCP 1980), both on a commercial scale and as subsistence fish culture for local people. Plans for expansion of cage culture are contemplated in several Asian countries including China (Song pers. comm.) and the Philippines (Guerrero 1979a and Castro pers. comm.). It looks, therefore, as if tilapia cage culture has a bright future, particularly in tropical, developing countries. In colder climates, the utilization of thermal effluents may also lead to the development of tilapia cage culture (Philippart et al. 1979).

Technological Aspects of Tilapia Cage Culture

The general technological aspects of cage culture have been discussed elsewhere (Coche 1978, 1979). The purpose here therefore is to stress those aspects which are particularly relevant to tilapia cage culture, although some repetition appears unavoidable.

1. TYPE AND SIZE OF CAGES

Surface standing cages, resting on the bottom, are used in shallow water bodies such as ponds and streams. Floating cages are preferable, however, wherever the water depth permits such as in lakes and rivers. In all such cases, the floor of the cage should be kept at least 0.5 to 1.0 m above the bottom sediment, where wastes may accumulate and dissolved oxygen (DO) is lowered. A water depth of 5 to 10 m is recommended to reduce parasitism and disease outbreaks.

The size of cages varies for different operations. Breeding cages and fingerling production cages are smaller than growout cages. Experimental cages do not generally exceed a few cubic metres until the pilot-scale stage is reached. At the subsistence level relatively small cages are also preferred. For commercial exploitation, medium-sized cages (6 to 20 m^3) should first be used at the artisanal level while larger cages (50 to 100 m^3) may be envisaged for the industrial level. Very large cages (1,000 m^3 or more) have also been used (Table 2).

Table 2. Construction costs for tilapia cages in the Philippines and Ivory Coast, 1976 to 1978.

		US$
(a)	Philippines, 1978 (Guerrero 1979a):	
1)	Experimental cage, capacity 1 m^3, wooden frame with polyethylene netting of 25 mm mesh using styrofoam floats	10
2)	Commercial cage, capacity 6,250 m^3 (50 x 25 x 5 m), bamboo and wood with nylon netting bag of 12.7 mm mesh	2,000
(b)	Ivory Coast, 1976 (De Kimpe 1978):	
1)	Experimental cage, capacity 20 m^3, wooden surface structure with nylon netting bag of 14 mm mesh and 200 l metal drums as floats	185
(c)	Ivory Coast, 1978 (Campbell 1978a):	
1)	Experimental cage, capacity 1 m^3, wooden frame with plastic netting of 8 mm mesh and styrofoam floats	55
2)	Experimental cage, capacity 6 m^3, floating wooden frame with plastic netting bag of 25 mm mesh and 20 l plastic barrels as floats	100
3)	Experimental cage, capacity 20 m^3, floating wooden frame with nylon netting bag of 14 mm mesh in 210/18 twine mounted 33 per hundred meshes and 60 l plastic barrels as floats	170

The size chosen for cages should reflect the level of technology available. In principle very large cages can result in the loss of several inherent advantages of cage culture, mainly flexibility and maneuverability. With tilapias however, a relatively large cage environment results in better growth rates, in reduced feed losses and in improved survival at very low DO's (Campbell 1978a). It seems that there is also a minimum cage size for guaranteeing a good feed conversion ratio (FCR). Cages have to be sufficiently large to

reduce feed losses through the walls from the turbulence created as the tilapias feed voraciously.

The water depth in the cages has been shown to influence growth and reproduction (Maruyama and Ishida 1976). When comparing the growth of *S. mossambicus* in water depths ranging from 0.5 to 1.5 m in square cages of 6 m side, the best growth and the highest fry production were observed in the deepest cage. A depth of at least 0.75 m was recommended.

For *S. niloticus* in the Ivory Coast, Campbell (1978a) recommends the simultaneous use of various sizes of floating cage. For fingerling production, 0.5 and 1.0 m^3 cages should be successively used as the fish grow. For market fish production at the artisanal level 20 m^3 cages (3 x 3 x 2.5 m) are the most suitable. He believes that the maximum cage sizes above which handling becomes a problem without special equipment are 22.5 m^3 (3 x 3 x 2.5 m) for plastic netting and 30 m^3 (3.5 x 3.5 x 2.5 m) for synthetic-fibre netting.

2. Cage Construction

Standing cages have a supporting frame extending 0.2 to 0.3 m below the cage floor to keep it away from the bottom sediment. The mesh walls are attached to the upper part of this frame. Floating cages are made of two components. The surface structure consists of a floating rigid frame and the subsurface structure of either a rigid frame with mesh walls or a flexible mesh bag designed to retain a rectangular shape. In the presence of strong water currents (above 20 to 30 cm/sec), a rigid construction is preferred over a flexible bag with heavy corner anchors. The choice of materials is important (see below), but the mesh size of the walls remains the most important factor. This should be as large as possible, according to the size of the fish being raised, to allow a free circulation of water through the cage at all times.

Accessory items are used according to each particular situation. For *S. niloticus* culture, Campbell (1978a) observed no advantage in using cages with either a solid bottom or an opaque top cover. A feeding ring is also unnecessary under normal circumstances. Against bird predation, a light covering net should be used. If the subsurface structure includes fibre netting (rather than more resistant plastic or metal netting), additional protection against aquatic predators may be required either as a second stronger fibre net with larger meshes added to each cage or a larger anti-predator net around the culture site.

There are definite advantages in grouping several cages (e.g., four to six) together with a stable working platform, to form a raft. When poaching is a major problem, a watchman can be housed on this, as is commonly done in Asia. As the structure increases in size, however, more attention should be paid to the design of an effective anchoring system, adapted to the local water conditions.

3. Materials and the Working Life of Cages

The choice of materials for the construction of cages varies greatly from country to country. Local materials such as wood and bamboo may be used, but generally their working life is short when continuously submerged. Boring insects such as *Povilla adusta* in the Ivory Coast (Coche 1979) readily attack light wooden frames. Mahogany frames are more resistant but rather heavy. Some bamboos are more resistant to attack than others.

For the subsurface structure, there is a tendency to eliminate supports and to use a net bag either of synthetic fibre or plastic.

Fibre netting with a nylon twine size R 470 tex (e.g., 210/18) has been successfully used in the Ivory Coast, mounted on nylon ropes at 33 per hundred meshes and spread at the bottom by a steel frame (Campbell 1978a). Knotless netting with square rather than diamond-shape meshes is preferred. In brackishwater, considerable damage may be experienced due to crabs. Chua and Teng (1977) recommend in such a case an R 1150 to 1300 tex polyethylene netting (21 to 24-ply threads). Compared to nylon netting such material is not only much cheaper but it also appears to be able to better withstand the tropical sun for a considerable period of time. Treating the netting with tar may also increase its resistance and reduce fouling (Coche 1979).

Plastic netting combines the advantages of being light and durable with some extra rigidity. It should, however, contain ultra-violet stabilizers for longer-lasting performance. Its only drawback might be its price, especially in countries where it has to be imported. Even then, careful consideration should be given to plastic netting because of its inherent advantages, particularly durability.

The working life of cages and their depreciation period vary greatly with the materials used for their construction and the local conditions, e.g., climate, limnology, handling, maintenance, etc. Under careful management the components of floating cages used in Lake Kossou (Ivory Coast) had the following estimated working life (Campbell 1978a): surface floating frame, (ordinary wood, 6 x 6 cm) 5 years; floats, (empty plastic barrels, 20 to 60 l) 3 years; subsurface wooden frames (mahogany, 5 x 5 cm) 3 years; subsurface wooden frames (ordinary wood) 1 year; nylon fibre netting (210/18 twine, 14 mm mesh) 3 to 5 years and plastic netting (8 and 25 mm mesh, Netlon) 5 to 10 years.

4. Cage Prices

The prices of some cages being used for tilapia culture illustrate the magnitude of the initial investment to be made (Table 2). The average cost/m^3 varies from US$55 to US$8.50 according to the size of the cage and the material used. The larger the size, the cheaper the unit volume cost but also the lower the recommended (see below) fish density. The average fish production/m^3 therefore decreases as the cage volume increases.

Campbell (1978a) therefore recommends the following cage dimensions for artisanal tilapia culture in the Ivory Coast: for 15 to 30 g fingerlings

successively use (a) small cylindrical 0.5 m^3 cages made entirely of 4 mm mesh plastic netting hanging from a small, rigid, floating frame; (b) 1 m^3 cubic cages of the same design with 8 mm mesh plastic netting; for 200 to 300 g growout, use medium size cages of about 20 m^3 with either nylon fibre netting (20 mm mesh; R470 tex twine) or plastic netting (18 to 25 mm mesh) as in Table 2.

Cage Culture: General Considerations

1. Site Selection

Good water circulation and adequate protection against floating debris and wave action are normally the two essential requirements for a culture site. Other factors, e.g., water quality, site accessibility, security and distance to markets, are also important. A water depth sufficient to place the cages at least 2 to 5 m above the bottom sediments is preferred.

In lake environments, wind-induced surface currents and fish movements should provide a continuous exchange of the water in the cages, keeping the DO high and removing wastes. Knowledge of seasonal limnological cycles will help to identify any critical periods during which cage culture might have to be discontinued. Such periods correspond to the seasonal turnover of the water mass, when the thermal stratification breaks down. Deep deoxygenated water is suddenly brought to the surface where it may cause heavy fish mortalities in the cages. A period follows during which very low DO's may persist for several days.

Tilapias are relatively tolerant of low DO. Caged *S. niloticus* in the Ivory Coast have survived concentrations as low as 0.7 mg/l or 9% saturation for several days (Coche 1977). In 1976, however, 64% of the adult fish and all the fingerlings suddenly died within 3 days, when the DO dropped below 0.5 mg/l (Traore and Campbell 1976). From recent observations during similar periods, it would appear that a DO of 3 mg/l should be considered the limit in cage culture below which adverse effects begin to appear: feed digestion stops, the growth rate decreases sharply and stress intensifies.

In the presence of such critical periods, it might be advisable to suspend culture if no adequate artificial aeration can be supplied to the caged fish. If such a suspension is not feasible, the following practices are suggested to minimize the mortality risks: space the cages further apart, several meters away from each other; use larger cages providing a relatively larger air/water interface; use lower fish stocking rates, never exceeding 15 to 20 kg/m^3 and low densities not exceeding 200 to 250 fish/m^3; stop feeding the fish (Coche 1977, Traore and Campbell 1976).

2. Management of Caged Tilapia Stocks

The management of caged fish stocks encompasses the stocking of juvenile fish, feeding during growout and cage maintenance. During a cage production

cycle, several interacting factors have to be optimized to give maximum production efficiency.

The supply of seed (fry and/or fingerlings), must be adequate both in quantity and in quality and available as and when required. There should be as little as possible variation in size. This remains the major limitation to the further development of tilapia cage culture. Existing breeding practices are inadequate and a new technology should be developed for selected tilapias (Coche 1977, 1979).

Adequate feeding is essential for growth and survival. In some cases, natural food (plankton, aufwuchs or benthos) may be sufficient and no supplementary feeding is required. When natural food is insufficient but still an important part of the diet, supplementary feeding is practiced with relatively low-cost ingredients. Under intensive rearing conditions at high stocking densities, the natural food available for the caged fish becomes insignificant and a complete artificial food is required.

The choice of the daily feed ration which will optimize the utilization efficiency particularly for costly food is of crucial importance: much more so in cages than in earth pond culture. Very little information exists on the relationship between feeding rate and FCR for a particular type of feed as a function of interacting factors such as species, fish size, fish density and water quality.

Cage maintenance should be regular and geared towards increasing the working life of equipment, maintaining the water quality by fouling control and reducing fish losses from escapes, mortalities and predation. Both the environment and the fish stock should regularly be monitored.

3. Growth and Production

The biomass of the caged fish per unit volume (B kg/m^3) is related to: 1. the individual growth rate which tends to decrease as the biomass increases; 2. the average monthly production (MP kg/m^3) which increases as the biomass increases until the carrying capacity of the cage is reached and decreases thereafter and 3. the FCR which decreases as the biomass increases until an optimum biomass is reached, above which FCR increases. The average individual weight of the caged fish (Pm) is related to:

1. the individual growth rate which decreases as Pm increases and
2. the FCR which, for a constant daily feed ration, increases as Pm increases.

The maximum carrying capacity of a cage (MCC in kg/m^3) is mainly determined by the DO throughout the cage. This varies with the mesh size and cage size. Campbell (1978a) has defined the MCC's (in kg/m^3) for *S. niloticus* reared in well-oxygenated water with good circulation (at least 2 cm/sec) as follows: with plastic netting of 25 mm mesh, 90 for 1 m^3, 70 for 6 m^3 and 40 for 20 m^3; with nylon fibre netting of 14 mm mesh, 40 for 20 m^3. Therefore, as cage size increases, MCC decreases. In practice, it is always safer to stock below the MCC, as the risks of diseases and mortalities greatly increase as the MCC is approached. For 1 m^3 cages, the recommended safe limit is about 73 kg (FAO 1976).

Cage production increases as the initial biomass (B_i kg/m^3) at stocking increases until it reaches an optimum value. For this B_i optimum, the final biomass (B_f) will equal the MCC at the end of the production cycle. In the Ivory Coast, in 1 m^3 cages, the MCC = 90 kg/m^3 was reached in 4 months from B_i of 20 kg/m^3 *S. niloticus* (at 250 to 350 fish/m^3). The corresponding maximum production was about 70 kg/m^3 or a monthly average of 17 kg/m^3 (Coche 1977).

It is well known that male tilapias grow faster than females. Any shift in the sex ratio of the cultivated population towards a male predominance will therefore accelerate production. In cage culture, increases in growth rates and production as well as decreases in FCR's have been recorded for monosex male populations (Coche 1977). Campbell (1978a) has also observed good production with 84% male *S. niloticus* following size grading of the juveniles. In both monosex male and mixed sex *S. niloticus* cage culture at Auburn University, Alabama, male growth rates were about 2.4 times than those of females (Anon. 1979c).

Seed Production

1. Fry and Fingerling Production in Cages

Most tilapia cage culture is concerned with growout to market size and takes advantage of the fact that reproduction is usually suppressed by the cage environment. Tilapias may, however, spawn in cages under certain conditions, depending mainly on the mesh size and on the fish density. For example, in Lake Atitlan (Guatemala), *S. mossambicus* have produced larvae in floating cages (Bardach et al. 1972) and Guerrero (1975) has observed in the Philippines female *S. mossambicus* mouthbrooding in cages with 200 fish/m^3. I have also found mouthbrooding *S. niloticus* in floating cages with 25 mm mesh but these were only a few individuals within a large population and the young fry disappeared rapidly from the cages through the netting. Suwanasart (1972) observed that *S. aureus* spawned successfully at densities of 500 fish/m^3 in cages with a small mesh screen placed on the bottom. In Indonesia, Rifai (1979, 1980) has also bred *S. niloticus* in cages with 3 mm mesh but "the occurrence of reproduction was relatively low"—only 5 out of 27 cages. Therefore to use cages with the definite purpose of producing tilapia fry is unpromising and a better technique is required.

In the Philippines, Guerrero (unpublished data) uses fine mesh nylon or mosquito net cages, termed hapas, to breed *S. niloticus* and *S. niloticus* x *S. mossambicus* hybrids. The broodstock live in these cages, breeding continuously, and the fry produced are collected once a month. These fry are then grown on to fingerling size, either in another cage or in a nursery pond.

The hapas (1.5 x 1 x 1 m) are suspended just above the pond bottom from poles in water about 1 m deep, from a good quality supply. The water depth inside the cages is about 0.6 m giving a rearing volume of about 0.9 m^3. Table 3 summarizes some results of fry production in hapas for 5 weeks. For

both crosses, the most advantageous sex ratio was three females to one male and the breeding success was much higher for the intraspecific *S. niloticus* cross. The average monthly production of *S. niloticus* fry was 1,320/cage: equivalent to 880/m^2 or 1,466/m^3.

Table 3. Some results of tilapia fry production in 0.9 m^3 mosquito net cages (hapas) at total stocking rates of 8 to 12 fish of individual weight 90 to 135 g per cage. This stocking rate approximates to 5.3 to 8.0 fish/m^2 or 8.9 to 13.3 fish/m^3 (Guerrero 1979a).

Spawning Cross Male	Female	Sex ratio (Male:Female)	No. of fry produced per cage	No. of fry produced per female	% of spent females
S. niloticus x *S. niloticus*		1:5	1,660	309	53
		1:3	1,647	407	67
S. niloticus x *S. mossambicus*		1:5	509	280	18
		1:3	527	458	19

A similar system has been proposed by the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC) for small-scale operators of *S. niloticus* cages in the eutrophic lake Laguna de Bay, Philippines (Radan 1979). Six to seven broodstock/m^3 of water are placed in hapas at the 1:3 sex ratio. Every 3 to 4 weeks, an average of 250 fry/spawner are collected. These are sorted by size and reared in further hapas at densities of either 500/m^3 (no supplementary feeding) or 1,000/m^3 (feeding with algal cake), until ready for transfer to growout cages after 1 to 2 months.

2. Fry Production in Earthen Ponds Followed by Fingerling Production in Cages

At Lake Kossou (Ivory Coast), *S. niloticus* fry were regularly produced in relatively large numbers using two earth ponds, 30 x 20 x 0.4 m deep (Campbell 1978b). Large female fish and smaller males (mean weights 700 and 200 g) were stocked at an average density of 0.5/m^2 with a 1:4 to 5 sex ratio in one pond. Intense supplementary feeding on a diet exceeding 30% protein was provided for one month. The broodstock were then removed with a cast net and transferred to the second pond where the treatment was repeated. Intense supplementary feeding was continued in the first pond for one more month at the end of which about 5,000 3 to 4 cm fry were harvested. This pond was then immediately restocked with the broodstock removed from the second pond. Such a culture system can therefore produce each month an equivalent of 4.2 fry/m^2 pond or 10.4 fry/female, much lower production figures than those reported above from hapas.

The fry produced in the ponds in two months were then transferred to 1 m^3 floating cages with 8 mm mesh at a stocking density of 1,000 fry or more per cage. For two months, a complete feed (25% protein) was given at the daily rate of 10 to 8% of the biomass. A first selection of 20 to 30 g

fingerlings was made at the end of the first month and a second one month later. Such selections based on growth rate resulted in populations which were on average 84% males. The slower growing fry, mostly females, were discarded after two months. Up to 50 kg of fingerlings was produced per 1 m^3 cage.

On the basis of this experience Campbell (1978a) has suggested some improvements. The use of smaller mesh (4 mm) cages would allow stocking with 10 to 15 day-old fry, about 1.5 cm long. This would make it possible to remove fry earlier from the ponds and increase their efficiency. With such small mesh, however, the water exchange inside the cages would be greatly reduced. Therefore, smaller cages should be used (0.5 m^3) and the stocking rate should be reduced accordingly. As soon as the fry reach 3 to 4 cm, they should be transferred to 1 m^3 cages with 8 mm mesh as above.

Some experiments towards this were performed in the Philippines (Guerrero 1980a) but at very low fish densities (100 fish/m^3). Fry of mean weight 2.6 g were stocked at 0.26 kg/m^3. They were fed daily for 56 days at 5% of the biomass with a mixture of fish meal and rice bran in the form of a mash. The mean weight at harvest was 15 to 20 g. The best feeding efficiency (FCR=1.7) was obtained with 25% fish meal. Similar results could probably have been obtained with higher densities.

3. Mass Production Technique

Mass production of fry and fingerlings of *S. niloticus* and *S. melanotheron (T. heudelotii)* is now being attempted in slightly brackish (4 to 8‰) water in Jacqueville (Ivory Coast) on the western Ebrie Lagoon (Campbell pers. comm.). The main characteristics of the culture system, which is still in the developing stage, are summarized here.

Four 3 x 18.3 m tanks are used for spawning. These have a water depth of 30 to 40 cm. The water supply (26 to 32°C) is sufficient to give a total exchange every 6 hours. Aeration equipment and automatic feeders are used. Examples of stocking rates for broodstock are as follows: *S. niloticus*, 4.4 to 6.5 200-400 g fish/m^2 with sex ratio 1:5; *S. melanotheron (T. heudelotii)*, 14.5 150-200 g fish/m^2 with sex ratio 1:1.

Every day at noon, about 1,250 to 2,500 fry (still in cloud formation) are harvested from the lower part of each tank and transferred to a plastic tank. The four tanks produce on average 5,000 to 10,000 fry/day.

The fry are grown on in 4 x 4 m plastic tanks with a lateral water inlet and central drain. The water depth is gradually increased as the fry grow over a 2-month period. Intensive hand feeding is first employed followed by automatic feeding. The water exchange rate is high. The fry harvest from one week (35,000 to 70,000) is concentrated at first into one tank. As they grow, they are regularly graded by size and transferred to other tanks. The stocking density therefore gradually decreases. Regular prophylactic treatment is given against parasites. The normal survival rate is 80 to 90%. Up to 30,000 fry, mean weight 2 to 3 g, can be grown in each tank. These are then transferred to fingerling production cages.

The stocking rate for fingerlings varies according to the availability of fry. The mesh size is 8 mm. With intensive hand feeding (5 times daily), 25 g fingerlings are produced in one month.

Extensive Culture

1. Commercial Cage Culture, including Eutrophic Lake Sites

In extensive cage culture there is no supplemental feeding. In most cases, the tilapias feed on the plankton either as natural blooms in eutrophic waters or in fertilized fish ponds.

The species used are microphagous *S. aureus*, *S. niloticus* and *S. mossambicus* whose natural diet normally includes algae.

The only large-scale, extensive, commercial tilapia cage culture in eutrophic waters is that of *S. mossambicus* in the Philippines in eutrophic natural lakes and in reservoirs. Guerrero (1980b) states, however, that *S. niloticus* is now the preferred species in Laguna de Bay where it may be raised at the density of 20 to 25 fish/m^2 without supplementary feeding, from 3 to 4 cm juveniles to 100 g adults in 4 to 5 months.

The eutrophication of these water bodies derives from the richness of local volcanic soils, e.g., Lake Bunot and Lake Sampaloc, or the large inflow of nutrients (N,P), e.g., Laguna de Bay. A rapid expansion of the tilapia cage culture industry is expected (Guerrero 1979a). In Lake Bunot more than 70 commercial-size cages were added from 1975 to 1978. Tilapia cage culture is now practiced also in Laguna de Bay, Lake Calibato, Lake Gunao, Lake Paoay, the Pantabangan Reservoir, Lake Sampaloc and Lake Sebu.

Some examples of the technology used and its results are grouped in Table 4. Very large floating cages (fibre netting) are used: more than 6,000 m^3. Small fingerlings (5 to 10 g) are generally preferred for stocking because of their greater availability and lower price. The stocking rate is relatively low: usually less than 0.5 kg/m^3, less than 70 fish/m^3. The average production rarely exceeds 1 kg/m^3/month, because of the large size of the cages, but up to 10 to 15 t of *S. mossambicus* can be harvested every 6 months, providing the farmer with a net income of more than US$3,000.

The success of the first cage farmers accelerated the development of the industry so much that it got out of control within a few years in most of these eutrophic lakes. In Lake Sampaloc for example, the water surface has become so congested with floating cages that the average original production of 3.8 kg/m^3/yr has drastically dropped today to 0.8 kg/m^3/yr and the growth rate of the tilapias has decreased by a factor of 9. It takes now as long as 12 months to produce 50 to 60 g fishes compared with earlier culture of fish to 150 to 200 g in 4 months. Some control has been introduced and a license is now required for cage culture.

Table 4. Extensive commercial cage culture of *S. mossambicus* in Philippine lakes.

Location environmental conditions; source	Floating cage data	Stocking data: Mean weight (g)	Stocking data: No. of fish/m^3	Stocking data: Biomass (kg/m^3)	Harvesting data: Mean weight (g)	Harvesting data: Biomass (kg/m^3)	Harvesting data: Production (kg/m^3)	Culture period (mo)	Remarks
Laguna de Bay 900 km^2; 2-8 m in depth; salinity up to 3-5 ppt hypereutrophic in the summer Sollows (pers. comm.)	20 x 10 x 2 m deep; 8 mm mesh	5 to 7	25 to 75	0.125 to 0.525	100 to 150	3.7 to 7.5	3.5 to 7.0	4 to 5	2 crops/year
Lake Sampaloc volcanic crater lake Sollows (pers. comm.)	500 m^2 x 4 m deep	25 to 30	25	0.700	150 to 200	4.5	3.8	4	— before congestion due to uncontrolled increase of cage numbers
					50 to 60	1.5	0.8	12	— under congested conditions
Lake Bunot volcanic soil region Garcia 1979 and Guerrero 1979	50 x 25 x 5 m deep	5 to 10	16	0.080 to 0.160	100 to 150	1.6 to 2.4	1.5 to 2.2	6	— occasional supplemental feeding with rice bran and water hyacinth — yield 10-15 tons/cage giving net income eq. US$3,378

2. Experimental Cage Culture

Some experimental results are also available from Laguna de Bay (Pantastico and Baldia 1979) for *S. mossambicus*. Three floating cages of about 9 m^3 capacity each (5.4 mm mesh) were stocked with fingerlings of mean weight 10 g at 50 fish/m^3 and grown for 3 months. The results were as follows: average growth rate of individual fish, 0.36 g/d; average monthly specific growth as a percentage of the original weight at the start of the month, 110%; average monthly production, 0.825 kg/m^3; daily rate of increase of the biomass,* 1.31%. Growth and production were relatively low when compared to those obtained in fertilized ponds with *S. aureus* (Table 5).

3. Cage Culture in Effluents, Fertilized Ponds and Canals

In Tihange (Belgium), a series of experiments were conducted in a pond fed by the heated effluent of a nuclear power plant (25 to 37°C) to quantify the monosex production of male *S. niloticus* in cages (Philippart et al. 1979). Populations of 200 males/m^3 were reared in floating 0.5 m^3 cages for 15 days. Three size classes of fish were used, giving a range of initial biomass (B_i) of 5.1 to 10.4 kg/m^3. The main results are given in Table 6. The quantities of plankton available were not recorded but the water exchange rate was high and it may be assumed that there were no blooms. The food supply was therefore probably inadequate and the results were rather poor, considering that only males were used: see Table 5 for comparison. These data can, however, be taken as a basis for obtaining true FCR's of trials using artificial diets by subtracting the production due to natural feeding.

In Alabama, U.S.A., *S. aureus* were cultured in experimental floating cages in ponds in which other fish were also cultivated. These ponds were fertilized regularly to develop either moderate or dense plankton blooms: average Secchi disc visibility depths were 64 and 37 cm. Table 5 summarizes the data. Dense plankton blooms produce much higher fish biomasses, especially with the small fish. For the larger fish, it appears that the MCC of the cages might have been exceeded (where B_i = 12.5 kg/m^3) which would explain the reduced MSG and DRIB values (compared to where B_i = 5 kg/m^3) but the Pmi difference also has an effect. The smaller the fish, the greater the benefit they are likely to derive from an algal diet. All these results demonstrate the real potential of *S. aureus* cage culture in the presence of plankton blooms.

In West Java (Indonesia), common carp *(Cyprinus carpio)* are cultured in fixed cages placed in streams and canals heavily enriched by domestic and agro-industrial effluents on a commercial scale. This technology is

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*The daily rate of increase of the biomass is given the acronym DRIB. The compound interest formula describing this is $B_f = B_i (1 + i)^n$, where B_f is the biomass at harvest; B_i is the initial biomass at stocking; n is the culture period in days and $i = \frac{DRIB.}{100}$

Table 5. Cage culture of *S. aureus* in fertilized ponds in Alabama, U.S.A. without supplementary feeding.

Density of plankton	Pm_i (g)	B_i (kg/m^3)	N/m^3	B_f (kg/m^3)	Culture period d	G (g/d)	MSG (%)	MP (kg/m^3)	DRIB (%)	Source
Moderate	2.9	1.7	600	17.9	70	0.39	400	6.9	3.4	Armbrester 1972
Dense	2.9	1.7	600	44.3	70	1.01	1,048	18.3	4.8	(cages 0.25 m^3)
Dense	10	5.0	500	43.1	87	0.78	235	12.7	2.5	Suwanasart 1972
Dense	25	12.5	500	54.8	87	0.72	86	14.1	1.7	(cages 0.21 m^3)

Pm_i : mean weight at stocking
B_i : biomass at stocking
B_f : biomass at harvest
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate as % Pm_i for 30 days
MP : average monthly production: ($B_f - B_i$) observed and recalculated on a 30-day basis
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i\ (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$

now being applied to tilapias also, although still on a relatively small scale (Rabelahatra 1979). For example, in Cianjur large submerged bamboo cages (5 x 4 x 0.7 m deep) are stocked with *S. mossambicus* fingerlings (mean weight 20 g; stocking rate 0.7 kg/m^3). This yields 50 to 60 kg of fish in six months, which corresponds to an average monthly production of about 0.55 kg/m^3: a little less than the production realized in Laguna de Bay by Pantastico and Baldia (1979), see above, but only about half of that obtained by commercial farmers in eutrophic lakes (see Table 4).

Table 6. Summary of data from the culture of all-male *Sarotherodon niloticus* stocked in 0.5 m^3 cages at 200 fish/m^3 in a pond receiving heated water effluent (25 to 37°C) from a nuclear power plant at Tihange, Belgium (after Philippart et al. 1979). Bracketed values are representative of the range of fish sizes.

Pm_i (g)	B_i (kg/m^3)	B_f (kg/m^3)	G (g/d)	MSG (%)	MP (kg/m^3)	DRIB (%)
25	5.1	6.8	0.6	68	3.5	1.94
32-35*	(6.7)	(7.3)	0.2	13-20	0.8-1.4	0.40-0.64
52*	10.4	(11.0)	—	2-18	0.2-1.9	0.06-0.61

* duplicate experiments

Pm_i : mean weight at stocking
B_i : mean biomass at stocking
B_f : mean biomass at harvest
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate as % Pm_i for 30 days
MP : average monthly production ($B_f - B_i$) observed and recalculated on a 30-day basis.
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$

Semi-Intensive Culture

1. Definition

In semi-intensive operations some supplemental feed is given but in contrast to intensive operations, this feed is usually relatively poor in protein (less than 10% dry weight) and made from local materials readily available at low cost. Semi-intensive cage culture of tilapias uses mainly phytophagous species which receive vegetable material or agricultural by-products as supplementary low-protein diets in the presence of algal blooms.

2. Semi-Intensive Culture using Aquatic and Terrestrial Plants

A caged monosex male population of *T. guineensis* in a thermal effluent

was fed at 4.8% of the fish biomass/day on the freshwater algae *Hydrodictyon* sp. (Chlorococcales) and *Cladophora* sp. (Ulotrichales) (Philippart et al. 1979). The average production was about 1 kg/m^3/month and the algae gave an FCR on a dry weight basis of 4.5 which is relatively good (Table 7). This points out the potential of a vegetable protein diet for caged tilapia, in this case 28% wet weight protein. The results are particularly good as *T. guineensis* usually performs less well under culture conditions than *S. niloticus* and *S. aureus.*

The comparative values of three aquatic macrophytes for growing adult *S. niloticus* in cages have been determined in Indonesia (Rifai 1979, 1980): *Hydrilla verticillata,* a submerged perennial growing to as much as 3 m long; *Lemna minor,* which is characterized by small, free-floating thalli and *Chara* sp., a coarse plant, usually coated with precipitated calcium carbonate. *Lemna minor* was preferred by the fish and gave the best growth, although with the lowest FCR (33). Table 7 summarizes the results. These were probably adversely affected by the very small mesh size used (reduced water exchange) and the shallow water depth in the cages.

Cage culture of *T. rendalli* has been proposed for rural areas in Colombia using tropical terrestrial plants as supplemental feed. The required characteristics of such plants are a high protein content in the leaves, edible tubers, vegetative reproduction and good growth even in poor soils. McLarney (1978) citing in part Prof. A.R. Patino's observations, suggests the following: 1) *Manihot esculenta* (Euphorbiaceae) commonly known as cassava which has edible tubers and leaves with 17.2% dry weight of protein; 2) *Alocasia macrorhiza* (Araceae) which has edible tubers and leaves with 23.2% dry weight and 6.25% wet weight of protein and 3) *Colocasia* spp. (Araceae) commonly known as taro which has edible tubers, large leaves and grows well on pond dykes.

Cnidosculus chayamansa, which has leaves with 24.2% dry weight of protein and *Xanthophyllum* spp. with edible tubers have also been recommended.

For tilapia culture, research seems to have concentrated on *Alocasia macrorhiza.* Data from three sets of experiments in Colombia using *T. rendalli ('T. melanopleura')* are summarized in Table 7 (Popma 1978). In one of these when 10 g fish were stocked there was no growth during the first month and for the next 14 weeks the growth was very slow. As a result, it took 7.2 months of feeding to produce 80 to 130 g fish. Ten grams is therefore obviously too small a size for stocking.

The food value of *Alocasia* leaves is better shown by the results for larger individuals (25 to 40 g) with an initial biomass (B_i) not exceeding 3 kg/m^3. For these the average individual growth remains relatively good at about 1 g/d and fishes weighing around 150 g can be produced in 4 to 5 months. When the B_i exceeds 4 kg/m^3 the individual growth rate decreases but the production increases. The best production (3.5 kg/m^3/mo) was obtained with a B_i of 6.6 kg/m^3.

The leaves of *Alocasia macrorhiza* and ipil-ipil *(Leucaena leucocephala,* Leguminoseae) (24.5% dry weight of protein) have also been used in combination with other ingredients, e.g., wheat bran or rice bran, as a source of relatively cheap vegetable protein for caged tilapias (see below).

Table 7. Semi-intensive cage culture of tilapias using aquatic and terrestrial plants. Bracketed values are representative within the size ranges of fish used.

Species and sexes used: country	Supplemental feed	Stocking data			Growth data			Harvesting data				Culture period (mo)	References and remarks
		Pm_i (g)	N/m^3	B_i (kg/m^3)	G (g/d)	MSG (%)	DRIB (%)	Pm_f (g)	B_f (kg/m^3)	MP (kg/m^3)	FCR		
T. guineensis, males: Belgium	Fresh algae (26% protein), DFR 4.8% B	42	86	3.6	0.4	26	0.82	53	4.6	0.97	46 dry 4.5	1	Philippart et al. 1979; cages, 0.5 m^3; average temperature 25.8°C
S. niloticus mixed sex: Indonesia	*Hydrilla verticillata* *Chara* sp. *Lemna minor* all at or above DFR 30% B	170 (96- 276)	5 or 15 or 45	0.8 to 6.6	0.44 0.43 0.73	— —	— —	170 to 218	1.1 to 7.6	(0.5) — (1.5)	23 19 33	3	Rifai 1979, 1980; cages, 1 m^3 with 3 mm mesh
T. rendalli, mixed sex: Colombia	*Alocasia macrorhiza* leaves, ad lib.	22.5	100	2.25	0.95	127	1.31	165	15.8	2.7	—	5	McLarney 1978; cages, 1 m^3; survival, 96%
	a. *Alocasia* *macrorhiza* leaves, DFR 10% to 20% B	10 10 10	50 100 200	0.5 1.0 2.0	0.55 0.46 0.34	164 136 100	1.16 1.09 0.97	128 108 82	6.0 10.5 16.0	0.79 1.33 1.98	10 to 13	7.2	Popma 1978; cages, 1 m^3; survival, 96.4%; a) complete trial with small fishes; b) same fish from week 19 to week 31
	b. *Alocasia* *macrorhiza* leaves, DFR 10 to 20% B	48 42 33	50 100 200	2.4 4.2 6.6	0.97 0.81 0.59	54 51 48	0.95 0.95 0.92	128 108 82	6.0 10.5 16.0	1.40 2.33 3.48	less than 10	3+	
	Alocasia *macrorhiza* leaves, ad lib	27.4 26.6	175 225	4.8 6.0	0.41 0.50	45 56	0.83 0.96	76.4 86.4	13.0 18.8	2.0 3.2	—	4	Corredor 1978; 4 cages, 1 m^3; complete trial over 6 mo but difficulties after 4 mo

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
Pm_f : mean weight at harvest
B_f : mean biomass at harvest
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated
DFR : daily feeding rate as % B (biomass)
B : biomass

3. Semi-intensive Cage Culture using Low Protein Mixed Feeds

Various feeds based on local ingredients have been used for caged tilapias. In some cases, such as in the eutrophic lake Laguna de Bay (Philippines), such feeds are used to augment natural feeding on well-developed algal populations. In other instances, they may constitute practically the only nutritional source available to the fish. The protein content of these feed is generally less than 10% of their total dry weight. Several ingredients may be combined as diverse as rice bran, snails, plant leaves, brewery waste, oil cake and cattle blood, according to local availability and price. In Lake Ilopango (El Salvador), the Fisherman's Cooperative, with 210 m^3 of cages, harvests about 900 kg of *S. aureus* and private operators sell another 2,500 kg annually (Street 1978) but no details are available on the exact nature of the diet.

Data related to various other tilapias are summarized in Table 8. *S. niloticus* and *S. mossambicus* were reared experimentally in floating cages in Laguna de Bay using rice bran alone (Anon. 1979a). *S. niloticus* gave a much better production (2.3 kg/m^3/month) than *S. mossambicus* (Pantastico and Baldia 1979), even though the latter was fed additional chopped snails (*Stenomelania canalis* and *Melanoides* sp.). The average initial biomass, although not clearly ascertained, was most probably higher than for *S. mossambicus* of which the production potential appears to be lower than that of *S. niloticus*. McLarney (1978) obtained good results in Colombia rearing *T. rendalli* in 1 m^3 cages in fish ponds. Starting with 22.5 g fingerlings and an average B_i of 2.25 kg/m^3, 21.6 kg/m^3 of 200 to 250 g fish were harvested after 5 months. *Alocasia macrorhiza* leaves and wheat bran were fed daily. The average individual growth (1.3 g/day) was good and the monthly production nearly 4 kg/m^3. In fact, these are the best results available for semi-intensive tilapia cage culture (Table 8).

In the first experiment with tilapia cage culture in Africa in 1972, *S. esculentus* and *T. zillii* were reared, either separately or together in Lake Victoria, Tanzania (Ibrahim et al. 1975). Feeding mostly on brewery wastes and some fish meal plus plant leaves (for *T. zillii*), the fish's average B_i's were very low (0.2 to 0.4 kg/m^3). The resulting average growth rates and production were relatively low to medium, probably due in part to poor feed value.

Trials to raise tilapia (probably *S. mossambicus*) in floating cages in the inlet to the Negombo Lagoon, north of Colombo, Sri Lanka were started recently with relatively good results (Sollows pers. comm.). Some water is added to the feed components (see Table 8) to form a mash.

Intensive Cage Culture

1. Feed Composition

As the quality of supplemental feed—in particular its protein content and its nutritional balance—are improved so cage culture of tilapias may be intensified. From the economic point of view, the cost of feeding gains in importance, and can account for more than 50% of the production costs

Table 8. Semi-intensive cage culture of tilapias using mixed feeds. Bracketed entries are representative of the range of fish sizes used.

Species and location	Feed composition and feeding rate	Stocking data			Growth data			Harvesting data				Culture period	References and remarks
		Pm_i (g)	N/m^3	B_i (kg/m^3)	G (g/d)	MSG (%)	DRIB (%)	Pm_f (g)	B_f (kg/m^3)	MP (kg/m^3)	FCR	(mo)	
1. *S. niloticus*, Laguna de Bay (Philippines)	rice bran in the presence of algal blooms	(10)	(100)	(1.0)	(0.8)	—	—	150	15	2.3	—	6	Anon. 1979a; Floating cages; 20 x 25 x 2.5 m deep; 1,000 m^3 capacity
2. *S. mossambicus*, Laguna de Bay (Philippines)	Rice bran, 70%; chopped snails, 30%; equivalent to 41% protein; in the presence of algal blooms	10	50	0.50	0.52	157	1.9	57.1	2.8	0.77	6	3	Pantastico and Baldia 1979; 6 cages (5.4 mm mesh) 25 x 25 x 1.5 m deep; each with 9.4 m^3 capacity
3. *S. aureus*, Lake Ilopango (San Salvador)	Undefined	—	—	—	—	—	—	—	—	2.25	—	—	Street 1978; 7 commercial cages; each with 30 m^3 capacity
4. *T. rendalli*, Ponds (Colombia)	*Alocasia* leaves + 0.5 to 1.0 kg wheat bran daily	22.5	100	2.25	1.3	173	1.5	200 to 250	21.6	3.87	—	5	McLarney 1978; 1 m^3 cages; survival 96%
5. *S. esculentus*, Lake Victoria (Tanzania)	Brewery waste, 99%; fish meal, 1%; DFR = 15 to 30% B	19	18.9	0.36	0.16	25	0.4	46.6	0.70	0.06	—	< 6	Ibrahim et al. 1975; cage, 42 m^3; (8 mm mesh)
6. *T. zillii*, Lake Victoria (Tanzania)	as 5. above plus plant leaves	2.56	84.2	0.21	0.14	164	1.6	15.6	0.92	0.23	—	3	as 5. above
7. *S. esculentus* + *T. zillii*, Lake Victoria (Tanzania)	as 6. above	16.3	22.9	0.37	0.45	83	1.1	(80)	1.78	0.30	—	4.7	Ibrahim et al. 1975; cage, 125 m^3 (20 mm mesh)
8. *S. mossambicus* ? Negombo Lagoon inlet (Sri Lanka)	Rice bran, 16/21; coconut oil cake, 4/21; cattle blood, 1/21; plus wheat flour, 450 g/21 kg;	1.5 to 3.0	—	—	—	—	—	80 to 250	—	—	—	6	Sollows pers. comm.: floating cages

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG : average monthly spcific growth rate
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
Pm_f : mean weight at harvest
B_f : mean biomass at harvest
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated

(Coche 1978, 1979). The utilization of a high initial biomass then becomes not only possible but also necessary if production costs are to be minimized and net profits maximized.

Researchers have used either commercial fish feeds or self-made compounded feeds. Commercial fish feeds have a very high protein level (e.g., Purina Trout Chow, 40%; Trouvit, 46%), a balanced composition including essential minerals and vitamins (at least for the target fish species), and a high price. Self-made feeds, however, have used mixtures of locally available ingredients, giving lower protein levels (usually 20 to 30%) and lower costs. Several empirical feed formulations have been evaluated but none has been developed from scientific data.

Table 9 gives examples of artisanal feeds which have been found satisfactory under various local conditions. Their composition is largely based on relatively cheap materials, such as rice bran and cotton seed oil cake, enriched with either fish meal or blood meal. The actual price of the mixed ingredients is now about US$0.15 to 0.20/kg, and the cost of pelleting probably adds another US$0.10/kg. The Campbell formula B4 (Table 9) is particularly attractive because of its relatively high protein content (25%), low cost (currently US$0.20/kg) and high efficiency (FCR = 2.0), at least for *S. niloticus*.

In the Philippines, Pantastico and Baldia (1979) have used a feed combining 20% ipil-ipil leaf meal *(Leucaena leucocephala*, Leguminoseae), 20% fish meal and 60% rice bran for *S. mossambicus* cage culture. This feed contained 27.3% dry weight of protein and cost only US$0.09/kg. Unfortunately the adverse conditions under which these experiments were conducted (small-size mesh, low density, low biomass, high feed ration) prevented a realistic demonstration of the efficiency of this feed (FCR = 4.0).

For *S. niloticus* in particular, an omnivore with a vegetarian tendency in its natural environment, Coche (1977) stressed that the ideal artificial diet *a priori* should contain a relatively high percentage of carbohydrates as an energy source. This appears to have been confirmed by Campbell (1978b) for *S. niloticus* in Lake Kossou, Ivory Coast. In his B4 formulation (Table 9) the 25% protein includes at least some of animal origin (i.e., 4% fish meal). The addition of a mineral/vitamin premix to B4 did not improve the results.

2. Feeding Rate

The feeding rate is usually quantified as the daily feed ration (DFR), the amount of feed (wet or dry) being fed daily (generally six days a week) to the fish, expressed as a percentage of the best available estimate of the fish biomass (%B). Such estimates, based on cage sampling, are usually made every 15 to 30 days.

It is well known in fish husbandry that food requirements per unit weight of fish decrease as the fish increase in size, but for the tilapias there is little information on this. In intensive cage culture of *S. niloticus* in the Ivory Coast, it was shown that the DFR had to be decreased from 6 to

4% B after the fish had reached 40 g average weight, to improve the feeding efficiency (Coche 1977). Since then, this problem has been tackled by other researchers.

Table 9. Satisfactory artisanal feeds for the cage culture of tilapias, using local ingredients, with feed conversion ratios (FCR) and costs where available.

A. Guerrero 1979a and Anon. 1979a for *S. niloticus* and *S. mossambicus* culture in the Philippines

1. Ingredients (% by weight)

Rice bran	77%
Fish meal	23%

2. Cost (1979) US$0.17/kg[a]
3. FCR 2.5

B. Campbell 1978b and pers. comm. for *S. niloticus* culture in the Ivory Coast

	Feed formulation			
1. Ingredients (% by weight)	B1	B2	B3	B4
Misc. carbohydrates[b]	—	—	—	45
Rice polishings	65	61	65	—
Wheat middlings	12	12	12	12
Peanut oil cake	18	18	—	—
Cottonseed oil cake	—	—	18	38
Fish meal	4	8	4	4
Oyster shell	1	1	1	1
Total protein content (as % dry weight)	20	22	20	25
2. Cost (1978) in US$/kg[c]	0.11	0.13	0.07	0.09
3. FCR (approx.)	2.4	2.0	2.2	2.0

C. N'Zimasse 1979 for *S. niloticus* in the Central African Republic

1. Ingredients (% by weight)

Cottonseed oil cake	82%
Wheat flour	8%
Cattle blood meal	8%
Bicalcium phosphate	2%

2. Cost (1979) US$0.17/kg[d]
3. FCR 3.2[e]

[a]Moist pellets have higher costs than this. This is the cost of ingredients only.
[b]E.g., brewery waste, maize and rice bran mixed according to availability.
[c]This gives the cost of ingredients only. The pelleting cost to less than 10% moisture pellets was about US$0.07/kg.
[d]This gives the cost of ingredients only. Dry pellets cost an extra US$0.06/kg.
[e]Poor, due partly to oxygen deficiency.

Campbell (pers. comm.), experimenting empirically with *S. niloticus* and a 25% protein feed, reached the conclusion that DFR's should be adjusted with size as follows: fry/fingerlings less than 25 g, 10 to 8% B; 25 to 150 g, 6 reducing to 4% B; 150 to 200 g, 3% B; and over 200 g, 2% B. He has even reduced the DFR to 1% B for fish larger than 200 g to increase the efficiency of pelleted feeds. Taking a more scientific approach, Mélard and Philippart (1980) estimated the optimum DFR for *S. niloticus* in tanks and cages using a 46% protein commercial feed at 27 to 31°C. Table 10 summarizes their recommendations. In the Philippines, Guerrero (1980a) has also proposed a progressive reduction of DFR with increasing size for *S. niloticus:* from 5% B (fish less than 50 g) to 4% B (50 to 100 g) and 3% B for larger fish. These are smaller DFRs than those in Table 10 and also refer to lower protein feeds.

Table 10. Recommended daily feeding rates (DFR) expressed as percentage fish biomass (% B) for *Sarotherodon niloticus* in tanks and cages at 27 to 31°C, fed a 46% protein commercial fish food (after Mélard and Philippart 1980).

Mean fish weight (g)	DFR (% B)
0 to 5	30 reducing to 20
5 to 20	14 reducing to 12
20 to 40	7 reducing to 6.5
40 to 100	6 reducing to 4.5
100 to 200	4 reducing to 2
200 to 300	1.8 reducing to 1.5

When fixing the DFR for a particular operation, one should also take into account the natural productivity of the environment. In Alabama, *S. aureus* were fed 40% protein floating pellets (DFR, 3% B) for 10 weeks in 0.25 m^3 cages placed in fertilized ponds (Armbrester 1972). Although the feeding efficiency was very good in presence of moderate algal blooms (Net FCR = 1.1 to 1.5), it decreased considerably in ponds with dense algal blooms (Net FCR = 3.3 to 6.3). This was attributed to the abundant availability of natural food.

3. Feeding Techniques

The methods used to distribute feed to caged tilapias may greatly influence the results. This depends on numerous factors including digestive physiology and feeding behavior relative to fish size; the shape and size of the cage; the water circulation through the cage and the stocking density. There are three major variables: feeding frequency, feed presentation and distribution methods.

Increasing feeding frequency by dividing the DFR into several meals may allow increased DFRs and give improved production and feeding efficiency. Although no scientific evidence exists to support such practices, in one commercial cage farm *S. niloticus* are fed their DFR as five meals (Campbell pers. comm.).

4. Feed Presentation

Caged tilapias have been grown using mash or pelleted feeds, the pellets being wet or dry, sinking or floating. Guerrero (1980a) regards *S. niloticus* as an avid surface feeder in cages and advises the use of mash feeds for small fish only. With large fish, the water agitation is so strong that much of the mash feed is washed out of the cage and lost. Pelleted feeds are therefore more efficient for large fish but the simplicity and low cost of mash make it still attractive for artisanal farmers. Rather than pelleting compounded feed, they could prepare meal in advance, in the form of "balls" or mash and air-dry them. Such feed "balls" can be placed in the middle of the cage-covering net, which is then slightly lowered under the surface of the water to give the fish access to the food (Campbell pers. comm.). A similar feeding method can also be used with fresh mash balls, particularly if the area of the cage is of the order of several square meters.

Guerrero (1980a) fed *S. niloticus* moist and dry compounded artisanal feeds (65% rice bran, 25% fish meal, 10% copra meal) at DFR 4% B as two meals per day in 1 m^3 cages (mesh 2.5 cm) placed in a pond for 24 days. The results are summarized in Table 11A. He concluded that moist pellets were better utilized by the fish. The FCR was slightly higher with the moist pellets, but there was no significant statistical difference between the two treatments. Moist pellets were easier and cheaper to produce.

Table 11B gives the results of feeding floating and sinking pellets (40% protein) to *S. aureus* in 0.12 m^3 cages placed in fertilized ponds for 87 days at DFR 3% B for 70 days of this period. The floating pellets gave better growth, higher production and a lower FCR. This holds true particularly for small cages with high fish densities and biomass. The difference may be less for larger cages (several m^3), at lower densities (below 400/m^3) and with a smaller biomass (up to 40 kg/m^3). In such cases, the extra cost of floating pellets might not even prove economical, but good data are missing.

Dry pellets may be distributed in cages either by hand or mechanically. In the latter case, automatic rather than demand feeders are preferable, especially if the fish density is high. Again, economical considerations should guide the choice. If labor is expensive, automatic feeders can reduce costs. They also facilitate dividing the DFR. On the contrary, in artisanal cage farms, hand feeding may be more advantageous. It also gives the opportunity to monitor the fish stocks more closely. No comparative data exist for tilapia cage culture.

5. Feed Conversion

The efficiency of feed conversion is generally quantified as the feed conversion ratio (FCR): the weight of feed required to produce unit weight of live fish during a determined feeding period. Some authors calculate a "Net FCR" where the production due to the natural feed is taken into consideration. In intensive cage culture particularly (Coche 1978, 1979) FCR is determined by the interactions between the fish (individual size, sex ratio and density), the feed (quality, DFR and distribution) and the

Table 11. Summary of experiment trials on the intensive cage culture of *Sarotherodon niloticus* and *S. aureus*: A. comparison of moist and dry pelleted feed (after Guerrero 1978); B. comparison of floating and sinking pellets (after Suwanasart 1972).

A. *S. niloticus* receiving moist and dry feed (65% rice bran, 25% fish meal, 10% copra meal on a dry weight basis) at a daily feeding rate of 4% fish biomass split into 2 meals in 1 m^3 cages (2.5 cm mesh).

Type of pellets	Pm_i (g)	N/m^3	B_i (kg/m^3)	B_f (kg/m^3)	Pm_f (g)	G (g/d)	Survival (%)	MP (kg/m^3)	FCR	Culture period (d)
Moist	96	150	13.8	25.5	179	3.63	95 to 97	14.5	2.7	24
Dry	96	150	15.0	23.4	161	2.54	95 to 97	10.6	2.5	24

B. *S. aureus* receiving floating and sinking pellets (commercial feed, 40% protein) at a daily feeding rate of 3% fish biomass in 0.12 m^3 cages.

Type of pellets	Pm_i (g)	N/m^3	B_i (kg/m^3)	B_f (kg/m^3)	Pm_f (g)	G (g/d)	MP (kg/m^3)	FCR	Culture period (d)
Floating	25	500	12.5	79.5	172	1.7	22.3	1.33	Total 87:fed for 70
Sinking	25	500	12.5	60.6	127	1.2	16.0	1.86	Total 87:fed for 70

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
B_f : mean biomass at harvest
Pm_f : mean weight at harvest
G : average growth rate of individual fish during the culture period
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated

rearing environment (cage size, water exchange rate, DO and temperature). To maximize the feeding efficiency, every one of these factors should be maintained at its optimum level for the particular species being cultured. Most of these aspects have already been reviewed above.

Feed losses through the cage walls should be kept to a minimum by adapting feeds and feeding to the particular conditions prevailing. Excessive water movement either caused by the fish themselves or due to a strong water current may wash a great proportion of the feed out of the cages. A dense wild fish population may even learn how to create the water current necessary to achieve this. The fish density should be kept below a threshold value, above which the FCR increases. For *S. niloticus* in 1 m^3 cages this was 400 fish/m^3 (Coche 1977).

With protein-rich compounded feeds, good feeding efficiencies in tilapia cage culture are usually demonstrated by FCR's close to or lower than 2. FCR's between 1.0 and 2.0 are now attained by Campbell (pers. comm.) in the Ivory Coast with 25% protein sinking pellets and *S. niloticus*. With 36% protein floating pellets (about 10% moisture), FCR's below 1.0 have been attained with *S. aureus* in Puerto Rico (Jordan and Pagán 1973), probably in the presence also of additional natural food.

The presence of such additional food in the environment may, however, have a negative rather than a positive effect on the efficiency of utilization of the artificial feed. In the fertilized Alabama ponds (Table 12), 40% protein floating pellets fed at DFR 3% B to caged *S. aureus* gave a net FCR of 1.1 to 1.5 in the presence of moderate plankton blooms, but with dense blooms the net FCR rose to 3.3 to 6.3 (Armbrester 1972). As far as possible, one should, therefore, also take into account the natural productivity of the environment when fixing the DFR.

6. Examples of Intensive Culture

Some data for the intensive cage culture of *S. aureus* are summarized in Table 12. The fish densities used were usually high (above 400/m^3) and relatively small fish were harvested (130 g or less) because of the small sizes stocked (3 to 10 g) and/or the short culture period (2.5 to 3.0 months).

Growth rates and production were definitely higher in fertile fish ponds than in the rock quarry pond (Table 12D) although the feeding efficiency was best in the latter. It is worth noting that the FCR's were below 2.0, for all the examples given except in heavily fertilized ponds with dense algal blooms (Secchi disc depth visibility, 37 cm) and with 2.9 g fry as stocking material (Table 12A).

Table 13 summarizes data on the intensive cage culture of *S. niloticus*. The data for 20 m^3 cages (Campbell 1978b) are the first on intensive tilapia cage culture at the artisanal level. In all cases except the Philippine work (Guerrero 1979a, 1980a) sinking pellets were fed with a medium (20%) to high (40% or over) protein level mostly at DFR 4 to 6% B. The fish densities were generally low to medium: below 300 fish/m^3. In the Ivory Coast, a particular effort was made to produce commercial size fishes, averaging at least 200 g, which called for culture periods in the growout cages of 4 to 5 months. Some brief notes follow concerning each set of trials (Table 13).

Table 12. Summary of stocking, growth and harvesting data for the intensive cage culture of *Sarotherodon aureus*: using floating pellets unless otherwise stated.

Location	Feeding details	Stocking data: Pm_i (g)	Stocking data: N/m^3	Stocking data: B_i (kg/m^3)	Growth data: G (g/d)	Growth data: MSG (%)	Growth data: DRIB (%)	Harvesting data: Pm_f (g)	Harvesting data: B_f (kg/m^3)	Harvesting data: MP (kg/m^3)	FCR	Culture period (mo)	References and remarks
A. Alabama, U.S.A.	40% protein DFR 3% B	2.9	600	1.7	0.56	579	4.65	39	41.0	15.7	1.1 to 1.5[c]	2.5[a]	Armbrester 1972: 0.25 m^3 cages (23 mm mesh) in fertilized ponds; mean values
	As above	2.9	600	1.7	0.76	790	5.13	73	56.4	21.9	3.3 to 6.3	2.5[b]	
B. Alabama, U.S.A.	40% protein DFR 3% B	10	500	5.0	1.36	408	2.99	128	64.7	20.6	1.3	2.9	Suwanasart 1972: 0.31 m^3 cages in fertile ponds; mean values; fed for 70 d only
		25	500	12.5	1.72	207	2.20	150	83.3	24.4	1.4		
	40% protein DFR 3% B	25	500	12.5	1.07	128	1.80	118	58.9	16.0	1.9	2.9	Suwanasart 1972: 0.12 m^3 cages in fertile ponds; mean values; fed for 70 d only; sinking pellets
C. Alabama, U.S.A.	40% protein DFR 3% B	13	857	11.2	1.03	238	1.67	174	149	26.5	1.8	5.2	Pagán 1973: 1 m^3 cages in fish ponds; an FCR of 1.2 was obtained for N286 fish/m^3
D. Puerto Rico	36% protein DFR 5% B	10	300	3.0	0.68	204	2.53	57	17.2	6.1	0.95	2.5	Jordan and Pagán 1973: 1 m^3 cages (mesh 8 mm) in a rock quarry pond
		10	400	4.0	0.55	165	2.28	48	19.4	6.6	0.90		
		10	500	5.0	0.52	156	2.21	46	23.1	7.8	0.91		

[a] in the presence of moderate plankton blooms
[b] in the presence of dense plankton blooms
[c] net values

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG: average monthly specific growth rate

DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
Pm_f : mean weight at harvest
B_f : mean biomass at harvest
MP : average monthly production ($B_f - B_i$) observed and recalculated on a 30-day basis
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated

Table 13. Summary of stocking, growth and harvesting data for the intensive cage culture of *S. niloticus* including monosex male populations.

Country	Feeding details	Stocking data: Pm_i (g)	Stocking data: N/m^3	Stocking data: B_i (kg/m^3)	Growth data: G (g/d)	Growth data: MSG (%)	Growth data: DRIB (%)	Harvesting data: Pm_f (g)	Harvesting data: B_f (kg/m^3)	Harvesting data: MP (kg/m^3)	FCR	Culture period (d)	References and remarks
Philippines	10% copra meal; 20% fishmeal and 70% rice bran as a mash: DFR 4% B	36	150	5.4	0.56	46	1.01	67	10.1	2.5	3.6	56	Guerrero 1980a: 1 m^3 cages (mesh 2.5 cm) in pond; mean results
	25% fishmeal and 75% rice bran as a mash: DFR 4% B	55	150	8.3	0.80	44	0.96	95	14.2	3.2	3.1	56	
Philippines	23% fish meal and 77% rice bran as moist pellets (24.2% dry weight of protein): DFR 5% B	20	250	5.0	1.33	200	2.72	100	25.0	10.0	2.5	60	Guerrero 1979a: 1 m^3 cages (mesh 1.9 cm) in pond
Ivory Coast	chicken feed as dry pellets (24.7% protein): DFR 4 to 6% B	16	268	4.3	1.05	197	1.52	175	41.9	7.6	2.8	151**	Coche 1977: 1 m^3 cages (mesh 2.5 cm) in the artificial Lake Kossou at 27 to 30°C; * DO < 5 mg/L for about 30 days; ** DO < 3 mg/L for about 20 days and < 5 mg/L for 2 to 2.5 mo
		22	218	4.8	1.20	164	1.29	207	34.6	5.8	3.4	154*	
		29	257	7.5	1.33	138	1.32	232	56.1	9.3	3.3	153**	
		29	349	10.1	1.18	122	1.27	197	60.9	10.8	3.2	142*	
		40	355	14.2	1.54	116	1.36	228	73.6	15.5	3.2	122*	
		40	488	20.5	1.39	104	1.37	168	71.9	16.7	3.0	92*	
		55	215	11.8	2.21	121	1.59	265	53.0	13.4	3.1	95	
Ivory Coast	see Table 9-B1 (20% protein): DFR 6 to 4% B	22	71	1.6	1.77	241	1.81	213	13.3	3.7	2.2	118**	Campbell 1978b: * 6 m^3 cages (mesh 2.5 to 1.4 cm); ** 20 m^3 cages (ibidem) in artificial Lake Kossou; sex ratio, average 84% males; DO >5 mg/L
		23	73	1.7	1.63	213	1.78	236	17.2	3.6	2.3	131**	
		33	185	6.1	2.33	212	1.97	308	49.9	9.8	2.4	108*	
	see Table 9-B2 (22% protein): DFR 6 to 4% B	32	177	5.6	1.98	186	1.64	278	42.1	8.8	2.1	124*	
		36	182	6.6	2.03	169	1.68	284	50.3	10.7	1.9	122*	
	see Table 9-B3 (20% protein): DFR 6 to 4% B	22	86	1.9	1.44	196	2.04	163	13.7	3.6	2.0	98**	
		23	74	1.7	1.22	159	2.08	118	8.5	2.6	2.0	78**	
		31	186	5.8	1.72	166	2.00	184	33.7	9.4	2.2	89*	
Central African Republic	see Table 9-C (41% protein): DFR 6% B	43	247	10.6	0.81	57	1.28	89	18.4	4.2	5.5	56	N'Zimasse 1979: 1 m^3 cages in fertilized pond; DO deficient (especially at night)

Table 13 (cont'd)

Country	Feeding details	Stocking data: Pm_i (g)	Stocking data: N/m³	Stocking data: B_i (kg/m³)	Growth data: G (g/d)	Growth data: MSG (%)	Growth data: DRIB (%)	Harvesting data: Pm_f (g)	Harvesting data: B_f (kg/m³)	Harvesting data: MP (kg/m³)	FCR	Culture period (d)	References and remarks
Belgium	commercial pellets (46% protein): DFR 7% B	55	600	33.2	1.0	56	1.73	86	55.5	18.3	3.3	30	Philippart et al. 1979: 0.5 m³ cages in thermal effluent, average temperature 27.9°C
		54	400	21.7	1.2	67	1.69	91	36.0	14.2	2.8		
		59	100	5.9	1.6	83	2.00	107	10.7	4.8	2.2		
Ivory Coast	chicken feed pellets (24.7% protein): DFR 4 to 6% B	49	300	14.7	1.8	110	1.36	271	75.9	15.1	3.3	122	Coche 1977: 1 m³ cages (mesh 2.5 cm) in lake; DO < 5 mg/L; monosex males
Central African Republic	see Table 9-C: DFR 6% B	82	122	10.0	1.25	46	0.96	187	22.5	4.5	5.6	85	N'Zimasse 1979: 1 m³ cages in fertilized ponds; monosex males; low DO's
Belgium	commercial pellets (46% protein): DFR 7 reducing to 3% B	25	200	5.1	1.40	168	4.01	46	9.2	8.3	1.1**	15	Philippart et al. 1979; 0.5 m³ cages in thermal effluent, average temperature 25 to 27°C; monosex males; ** DFR = 7% B; *DFR = 3% B
		32	200	6.2	0.93	87	2.67	46	9.2	6.0	1.4		
		46	200	9.2	0.73	48	1.38	57	11.3	4.3	1.7*		
		53	200	10.7	1.07	60	1.66	69	13.7	6.0	1.4*		
		68	200	13.7	0.93	41	1.21	82	16.4	5.5	2.0*		

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
Pm_f : mean weight at harvest
B_f : mean biomass at harvest
MP : average monthly production: ($B_f - B_i$) observed and recalculated on a 30-day basis)
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated
DFR : daily feeding rate as % B (biomass)
B : biomass
DO : dissolved oxygen

In the Philippines, using a relatively cheap feed (moist pellets at US$0.17/kg), Guerrero (1979a) appears confident of producing within 2 to 4 months 80 to 100 g marketable tilapias with FCR 2.5 after stocking at 5 to 20 g. An average production of 12 to 20 kg/m^3/month is attainable, giving an estimated monthly net income of US$6.75 to 10.80/1 m^3 cage.

Coche (1977) reports culture trials in the artificial Lake Kossou (Ivory Coast), from 1974 to 1975 beginning with 1 m^3 cages and pelleted chicken feed (24.7% protein). These demonstrated the excellent potential of *S. niloticus* intensive cage culture. Although reduced DO's were encountered for most of the culture periods, growth rates were usually about or above 1.2 g/day and the monthly production ranged from 9 to 15 kg/m^3, with fish densities and initial biomasses in the normally accepted range. Low feeding efficiencies were due mostly to the inadequate feed (which contained up to 30% undigested maize middlings) and to excessive DFR's. Campbell (1978b) used three improved feeds (Table 9—B1, B2, B3) and reduced DFR's in larger cages. His lower initial biomasses and densities (relative to cage size) resulted in better growth rates (1.4 to 2 g/day) but gave lower average productions with increasing cage size. Smaller cages (6 m^3) produced 9 to 11 kg/m^3/month and larger ones (20 m^3) 2.6 to 3.7 kg/m^3/month. Feeding efficiency was much better than Coche's (1977) results: FCR's, 1.9 to 2.2. It should be remembered, however, that Campbell used on average 84% male populations.

N'Zimasse (1979) used a heavily manured fish pond in the Central African Republic. The results are difficult to assess because of DO deficiencies, but the survival of *S. niloticus* was excellent. The growth rate, production and feeding efficiency were poor, especially for all-male populations.

Philippart et al. (1979) used increasing densities (up to 600 fish/m^3) and biomasses in pond-based cages in a thermal effluent. The feed was very rich in protein (46%). Neither growth rates nor FCR were as good as could have been expected in such small cages. The DFR was probably too high considering the size of the fish and the food quality. Good production was obtained with the two highest densities/biomasses, but at the cost of low feeding efficiencies.

Only limited data are available on the intensive cage culture of all-male *S. niloticus*. Coche (1977) suggested this as one way of increasing production: his fish, stocked at average weight 49 g, grew at an average rate of 1.8 g/day and gave a production of 15.1 kg/m^3/month on relatively poor quality feed. In the Central African Republic, N'Zimasse (1979) obtained poor results because of deficient environmental conditions and in Belgium (Philippart et al. 1979), the results for all-male culture were not as good as expected, although the feeding efficiencies were increased by adapting the DFR's to the fish sizes. Strangely enough, higher average production was experienced with smaller biomasses, which calls for some caution in interpreting these results. The relative brevity of the experiments might be partly responsible. It appears that further data are needed to assess the potential of monosex cage culture.

Table 14 summarizes the results of the intensive cage culture trials with

Table 14. Summary of feeding, stocking, growth and harvesting data for intensive cage culture of *Sarotherodon mossambicus*, *Tilapia guineensis* and mixed culture of tilapias with *Cyprinus carpio*.

Location	Species	Feeding details	Stocking data			Growth data			Harvesting data				Culture period	References and remarks
			Pm_i (g)	N/m^3	B_i (kg/m^3)	G (g/d)	MSG (%)	DRIB (%)	Pm_f (g)	B_f (kg/m^3)	MP (kg/m^3)	FCR	(d)	
Philippines	*S. mossambicus*	60% rice bran, 20% fish meal, 20% *Leucaena leucocephala* leaf meal: DFR, 10% B	10	50	0.5	0.65	195	2.15	68.4	3.4	0.97	4.0	90	Pantastico and Baldia 1979: cage mesh size, 5.4 mm; feed cost, US$0.09/kg.
Belgium	*T. guineensis*	Pellets (46% protein): DFR, 4.8% B	42	86	3.6	0.60	43	1.23	60	5.2	1.60	2.9	30	Philippart et al. 1979: 0.5 m^3 cages in thermal effluent; monosex males
		Soya pellets (30% protein): DFR, 4.8% B	42	86	3.6	0.40	26	0.82	53	4.6	0.96	5.0	30	
Taiwan	Hybrid (probably *S. mossambicus* x *S. niloticus*) with	Regular feeding	30	56	1.7	2.8	280	2.21	338	18.8	4.70	—	110	de la Cruz 1979; cage size 144 m^3; polyculture of two species.
	Cyprinus carpio	Regular feeding	150	21	3.2	16.8	338	2.36	2,000	41.7	10.50	—	110	

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
Pm_f : mean weight at harvest
B_f : mean biomass at harvest
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis
FCR : feed conversion ratio, on a net weight basis unless otherwise indicated
DFR : daily feeding rate as % B (biomass)

results are also poor: the soya pellets did not improve on results obtained with fresh algal feeds (see F2 above) and animal protein pellets gave only slightly better results. This suggests that *S. mossambicus* and *T. guineensis* have low potential for cage culture.

7. Cage Culture of Mixed Species

In Indonesia, 10 to 25% *S. niloticus* are cultured with *Cyprinus carpio* in cages in a 20 ha lake at the Lido Station (Pedini pers. comm.). The cages are relatively large (9 m^2 x 1.25 m deep and 81 m^2 x 1.25 m deep) and a pelleted feed (32% protein) is given to the carps only at DFR 3% carp biomass. *S. niloticus* is here considered as a secondary crop. In Taiwan also an experimental cage (144 m^3) was stocked with tilapia (probably *S. niloticus* x *S. mossambicus* hybrids) and *C. carpio* (see Table 14). The growth of the tilapias was very good, even though far below that of common carp. The carp were so infested with parasites, however, that the local farmers now prefer tilapias for cage culture, even though their growth is slower and production smaller (de la Cruz 1979).

8. Brackishwater Culture

In the Ivory Coast *S. niloticus* is being cultured in cages placed in coastal lagoons where the salinity may reach 20‰. Some experiments are in progress, but until now results have been rather disappointing, the average growth rate varying from 0.20 to 1.17 g/day on a 15.5% protein feed (De Kimpe 1978). However, British Petroleum has established a commercial farm for intensive tilapia cage culture in Jacqueville (about 64 km west of Abidjan), including a hatchery/nursery and a feed mill. Both *S. niloticus* and *S. melanotheron (T. heudelotii)* are being tried in commercial size cages (27 and 54 m^3). The production potential of the farm is estimated at about 500 t/year (Campbell pers. comm.) but only preliminary data are available. Although *S. niloticus* has demonstrated an excellent growth rate (1.8 to 2.1 g/day), great mortalities have been experienced due to heavy parasitism. *S. melanotheron (T. heudelotii)*, a species endemic in the local lagoons, has also been tried with very little mortality but its real potential for cage culture has not yet been established.

Advantages, Constraints and Research Needs

1. Advantages

When compared with the more traditional methods of fish culture in ponds and tanks, cage culture presents some definite advantages (Coche 1978, 1979). In the particular case of tilapias, the major advantage is the possibility of controlling unwanted recruitment (Pagán 1975).

The other major advantages of cage culture include relatively high growth rates due to the continuous water exchanges, the limited space requirements, the production of large fish of a more uniform size than pond systems, and the possibility of greatly reducing production costs through a more precise adjustment of feeding rates.

2. CONSTRAINTS

Table 15 summarizes the major constraints to culturing tilapias in cages. The relative importance of these varies with location. The most important water quality parameter is the DO. Low DO's may appear once or twice a year as a periodical feature of the limnological cycle of the water body. At water temperatures from 26 to 30°C, special measures should be taken if the DO of surface water drops below 3 mg/L for several consecutive days, including lowered DFR or cessation of feeding and reduction in stocking density. In Lake Kossou, heavy *S. niloticus* mortalities have been recorded when DO's suddenly fell to 0.4 mg/L (Traore and Campbell 1976). Important mortalities in pond cages have also been observed for *S. aureus* following a DO reduction (Pagán 1973). This could be caused, in certain cases, by the cages and fish themselves, for example, in water bodies where the water circulation is limited, where the total cage volume has become proportion-

Table 15. Constraints to the cage culture of tilapias and suggested remedial action.

Constraint and target	Remedial action
A. Environmental	
1 Water quality	Modify the culture technique
2 Weather	Site selection/Anchoring system
3 Wild fish populations	Control wild fish populations
4 Aquatic predators	Control/Materials selection/Barrier
B. Inputs	
1 Equipment	Design/Construction/Durability/Cost
2 Fry/Fingerlings	Develop new methodology for mass production
3 Fish feeds	Formulation/Develop production methods
C. Fish Stocks	
1 Diseases/Parasites	Site selection/Control wild fish/Management
2 Security	Site selection/Full time watchmen
3 Marketing	Transport/Processing/Organization
D. Policy	
1 Research	Financial support/Training
2 Planning	Environmental potential/Inputs availability/ Market potential
3 Development	Control/Extension service

ately too high, or where overfeeding takes place.

Regarding weather constraints, storm damage may occur if the farm site is not sufficiently protected. Such losses have occurred on Lake Ilopango in El Salvador (Hughes 1977) and in the Ebrie Lagoon in the Ivory Coast (Campbell pers. comm.).

Jordan and Pagán (1973) reported incursions and residence of wild *S. mossambicus* in cages for growing *S. aureus*. This greatly reduced feeding efficiency and production. The wild fish could also be vectors of parasites and diseases.

The shortage of tilapia seed is considered as one of the major present constraints to the development of the culture industry (Coche 1977, Guerrero 1979a, Anon. 1979a). A new methodology for the mass production of tilapia fry and fingerlings should be developed. Moreover, caged tilapias have practically no access to natural feed (apart from filter feeders in eutrophic water) and require essentially complete supplemental feed. The two main constraints here are the formulation of such feeds, e.g., in El Salvador (Hughes 1977) and Africa (ADCP 1980), and their availability and cost to the farmers.

3. Cage Design

The design and construction of adequate cages is still considered as a major problem in the Philippines (Anon. 1979a) and large cages used in El Salvador have proved difficult to harvest (Hughes 1977). In the Ivory Coast, the utilization of weak fibre netting material has resulted in great fish losses (Campbell 1978a). *S. niloticus* grazing on the settled algae on R250 tex nylon twine damaged it within 8 months sufficiently to necessitate a complete replacement by stronger netting (R470 tex). Following serious damage to fibre netting by crabs in brackishwater, imported plastic netting will replace this for future commercial production in the Ivory Coast (Campbell pers. comm.).

Damage to underwater structures by predators may also result in important losses, including the escape of the cultured fish. Such problems have been encountered in Indonesia with monitor lizards and turtles (Pedini pers. comm.) and in the Ivory Coast with iguana and large Nile perch *(Lates niloticus)*. In brackish water, crabs have heavily damaged cage nets (Campbell pers. comm.). In such cases, either a predator net barrier should be used or the cage construction should be reinforced.

4. Disease Aspects of Cage Culture

Caged fish living in confined conditions are probably under greater stress than pond fish and are more susceptible to attack by parasites and diseases. Fortunately, the various tilapias cultured in cages have generally demonstrated high disease resistance. Only a few cases of health problems have been documented, mostly following increased stress due to elevation of salinity or fish biomass. In Puerto Rico, caged *S. aureus* reared in sea water (35‰ salinity) suffered chronic mortalities with open body lesions, fin rot and

exophthalmus (Miller and Pagán 1973; Miller and Ballantine 1974). Pathogenic bacteria (*Aeromonas* and *Vibrio* spp.) were thought to be implicated. There is heavy pollution from raw sewage in the area.

In the Ivory Coast, a great decrease in *S. niloticus* production was observed in several cages where mycosis occurred (Coche 1977). Later, Campbell (pers. comm.) also observed cages with a high proportion of blind fish (*Diplostomum* ?). Susceptibility to all infections was higher in 1 m^3 cages when the biomass exceeded 73 kg/m^3. *S. niloticus* reared in shallow brackishwater (4 to 20‰ salinity) and relatively close to the lagoon sediments (0.5 m) suffered high parasitic burdens and mortalities (Campbell pers. comm.).

A high rate of mortality has been recorded in Alabama following outbreaks of bacterial diseases in pond cages with *S. aureus* (Pagán 1973). In Tanzania, a generalized *Saprolegnia* infection spread through a caged *T. zillii* population (Ibrahim et al. 1975).

5. Security

Poaching constitutes a major problem in cage culture. To ensure the security of commercial operations, Street (1978) has recommended in El Salvador the employment of full-time watchmen. Locating the cages close by the farmer's residence may also help solve the problem. In the Philippines, poaching is also mentioned among the main problems facing cage farmers (Guerrero 1979a).

6. Policy

Research support and rational planning of the development for tilapia cage culture are essential. Development should be supported by an adequate Extension Service, through which a continuous two-way flow of information can be established between farmers and researchers. Dramatic examples of the results of a lack of careful planning are available from the Philippines. In the 50 ha Lake Calibato, 170 fish cages containing about 10 million tilapias were present in 1978 (Anon. 1978). Within only a few years, the profit expected from tilapia cage culture fell by 50% because of such overcrowding. A similar situation has arisen in Lake Sampaloc (Sollows pers. comm.): see above. To bring such wild development under control, several planning steps are required: a survey of the lake's capacity for cage culture; setting guidelines for the siting/operation of the cages and licensing legitimate operators (Anon. 1978). A competent technical body is needed to oversee the development.

7. Research Needs

The research needs for tilapia cage culture in the Philippines have been recently reviewed (Anon. 1979a) and the following identified: the design

and construction of the cages; the standardization of cage materials (which should ideally be sturdy, attract less fouling organisms and be nontoxic both to the fish and consumers) and the proper layout and positioning of the cages in water bodies.

Both in Latin America (ADCP 1978) and in Africa (ADCP 1980), tilapia cage culture has been selected as a priority culture system in the research programs of the future United Nations Development Programme (UNDP/ Food and Agriculture Organization of the United Nations (FAO) Aquaculture Regional Centres. The research needs identified include: design of cages suitable both from the functional and economical points of view; testing of construction materials; design of rafts, floats, anchors and other requirements for cage installations; feed formulation and preparation; feeding procedures; biology of the cultured stocks; economic evaluation and possible fish health hazards and their control.

Attention should also be given to the effects of cage culture on the environment. In particular, estimates of the optimum cage volume relative to that of the water body should be obtained, both for closed and open aquatic systems. These should become the basis for the rational future development of tilapia cage culture. Finally, a new methodology for the routine mass production of fry and fingerlings should be developed.

Prospects

1. Culture Potential of the Major Tilapia Species

Tables 16 and 17 summarize the culture potential in terms of production of the four main cultured species; *S. mossambicus* and *T. rendalli* have been both mostly raised in extensive and semi-intensive systems and *S. aureus* and *S. niloticus* in intensive systems. This probably reflects the geographical distribution of their cage culture (see Table 1) and makes it rather difficult to assess the real future potential of each of these four tilapias for cage culture on a worldwide basis. Further experiments will be required, especially for the semi-intensive cultivation of *S. aureus* and *S. niloticus* and the intensive cultivation of the other two species.

As the culture system is progressively intensified, growth and production increase, but, in the presence of moderate to dense algal blooms, relatively high values are attainable for *S. aureus* even in extensive systems. Indeed these results are even better than for the other tilapias in more intensive systems. Therefore, the extra cost of feeding should always be weighed against the production obtainable from natural foods for a given species and location. Such comparative data are lacking for *S. niloticus* which might also provide good results with algal blooms.

The current relative production potential for the four species may be summarized as: for extensive systems, *S. aureus* > *S. niloticus* > *S. mossambicus;* for semi-intensive systems, *T. rendalli* > *S. mossambicus* and for intensive systems, *S. aureus* > *S. niloticus* > *S. mossambicus. T. rendalli* fed with *Alocasia* leaves and wheat bran has shown a relatively good produc-

Table 16. Production performance of the four main species of tilapias used in cage culture systems: *Sarotherodon aureus; S. niloticus; S. mossambicus* and *Tilapia rendalli*. Bracketed entries are representative of the range of values reported.

	Stocking data			Growth data			Harvesting data		Culture period	
	Pm_i (g)	N/m^3	B_i (kg/m^3)	G (g/d)	MSG (%)	DRIB (%)	B_f (kg/m^3)	MP (kg/m^3)	(mo)	References and remarks
A. Initial stocking with small-size fingerlings										
S. aureus										
Extensive, with dense algal blooms	10	500	5.0	6.78	235	2.5	43.1	12.7	3.0	Suwanasart 1972
Intensive, 36% protein, floating pellets	10	500	5.0	0.5	156	2.2	23.1	7.8	2.5	Jordan and Pagán 1973
Intensive, 40% protein, floating pellets in fertile ponds	10	500	5.0	1.36	408	3.0	64.7	20.6	2.9	Suwanasart 1972
S. niloticus										
Semi-intensive, eutrophic lake + rice bran feeding	10	100	1.0	0.8	—	—	15	2.3	6.0	Anon. 1979a
Intensive, artificial lake, 25% protein feed	16	268	4.3	1.05	197	1.5	41.9	7.6	5.0	Coche 1977
S. mossambicus										
Extensive, eutrophic lake, experimental	10	50	0.5	0.36	110	1.3	1.3	0.8	3.0	Pantastico and Baldia 1979
Extensive, eutrophic lake, commercial	5 to 10	16 to 75	0.1 to 0.5	—	—	—	1.6 to 7.5	1.5 to 7	4 to 6	see Table 2
Semi-intensive eutrophic lake + 4% protein feed	10	50	0.5	0.5	157	1.9	2.8	0.8	3.0	Anon. 1979a
Intensive, eutrophic lake + 27% protein feed	10	50	0.5	0.65	195	2.2	3.4	1.0	3.0	Pantastico and Baldia 1979
T. rendalli										
Semi-intensive, fed *Alocasia* leaves	10	200	2.0	0.34	100	(1.0)	16.0	20	(7.2)	Popma 1978
B. Initial stocking with medium-size fingerlings										
S. aureus										
Extensive, with moderate algal blooms	25	500	12.5	0.72	86	1.7	54.8	14.1	3.0	Suwanasart 1972
Intensive, fertile ponds + 40% protein floating pellets	25	500	12.5	1.72	207	2.2	83.3	24.4	2.9	Suwanasart 1972
Intensive, fertile ponds + 40% protein sinking pellets	25	500	12.5	1.07	128	1.8	58.9	16.0	2.9	Suwanasart 1972

Table 16 (cont'd)

	Stocking data			Growth data			Harvesting data		Culture period	
	Pm_i (g)	N/m^3	B_i (kg/m^3)	G (g/d)	MSG (%)	DRIB (%)	B_f (kg/m^3)	MP (kg/m^3)	(mo)	References and remarks
S. niloticus										
Extensive, unfertilized pond, all males	25	200	5.1	0.60	68	(1.9)	6.8	3.5	(0.5)	Philippart et al. 1979
Intensive, 24% protein moist pellets	20	250	5.0	1.33	200	2.7	25.0	10.0	2.0	Guerrero 1979a
Intensive, artificial lake, 25% protein sinking pellets	22	218	4.8	1.20	164	1.3	34.6	5.8	5.1	Coche 1977
Intensive, artificial lake, 25% protein sinking pellets	29	257	7.5	1.33	138	1.3	56.1	9.3	5.1	Coche 1977
Intensive, artifical lake, 20% protein sinking pellets	31	186	5.8	1.72	166	2.0	33.7	9.4	3.0	Campbell 1978b
Intensive, unfertilized pond, 46% protein, all males	25	200	5.1	1.40	168	(4.0)	9.2	8.3	(0.5)	Philippart et al. 1979
Intensive, unfertilized pond, 46% protein, all males	32	200	6.2	0.93	87	(2.7)	9.2	6.0	(0.5)	Philippart et al. 1979
Intensive, artificial lake, 22% protein sinking pellets	32	177	5.6	1.98	186	1.6	42.1	8.8	4.	Campbell 1978b
T. rendalli										
Semi-intensive, fed *Alocasia* leaves	23	100	2.3	0.95	127	1.3	15.8	2.7	5	McLarney 1978
Semi-intensive, fed *Alocasia* leaves	27	225	6.0	0.50	56	1.0	18.8	3.2	4	Corredor 1978
Semi-intensive, fed *Alocasia* leaves + wheat bran	23	100	2.3	1.30	173	1.5	21.6	3.9	5	McLarney 1978

Pm_i : mean weight at stocking
N : number of fish
B_i : mean biomass at stocking
G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$
B_f : mean biomass at harvest
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis

Table 17. Comparison of the production performances of *Sarotherodon aureus*, *S. niloticus*, *S. mossambicus* and *Tilapia rendalli* in three cage culture systems: extensive, semi-intensive and intensive. Bracketed entries are representative of the values reported. Data obtained from all authors cited in Table 16.

	Extensive culture				Semi-intensive culture				Intensive culture			
	G g/day	MSG (%)	MP (kg/m^3)	DRIB (%)	G (g/d)	MSG (%)	MP (kg/m^3)	DRIB (%)	G g/day	MSG (%)	MP (kg/m^3)	DRIB (%)
A. Initial stocking with small-size fingerlings (10 to 15 g)												
S. aureus	0.78	235	12.7	2.5	—	—	—	—	0.5 to 1.4	156 to 408	7.8 to 20.6	2.2 to 3.0
S. niloticus	—	—	—	—	0.8	—	2.3	—	1.05	197	7.6	1.5
S. mossambicus	0.36	110	0.8 to 4	> 1.3	0.5	157	0.8	1.9	0.65	195	1.0	2.2
T. rendalli	—	—	—	—	0.34	100	2.0	(1.0)	—	—	—	—
B. Initial stocking with medium-size fingerlings (20 to 30 g)												
S. aureus	0.72	86	14.1	1.7	—	—	—	—	1.1 to 1.7	128 to 207	16.0 to 24.4	1.8 to 2.2
S. niloticus	0.60	68	3.5	(1.9)	—	—	—	—	0.9 to 2.0	87 to 200	5.8 to 10	1.3 to 2.7
S. mossambicus	—	—	—	—	—	—	—	—	—	—	—	—
T. rendalli	—	—	—	—	0.5 to 1.3	56 to 173	2.7 to 3.9	1 to 1.5	—	—	—	—

G : average growth rate of individual fish during the culture period
MSG : average monthly specific growth rate
MP : average monthly production: $(B_f - B_i)$ observed and recalculated on a 30-day basis
DRIB : daily rate of increase of the biomass calculated from $B_f = B_i (1 + i)^n$ where n is the culture period in days and i is $\frac{DRIB}{100}$

Table 18. A comparison of the production potentials of *Sarotherodon aureus, S. niloticus, Cyprinus carpio, Ictalurus punctatus* and *Salmo gairdneri* in intensive cage culture. Data averaged from various authors: see Table 16 for *Sarotherodon* spp. and Coche 1978, 1979 for other species.

	Growth (g/d)	Best average production ($kg/m^3/mo$)	Actual average production ($kg/m^3/mo$)	Estimated annual production potential (kg/m^3*)	Feeding	FCR
S. aureus	1.0 to 1.7	> 25 over 5 mo	10 to 20	200 to > 300	40% protein floating pellets	1.0 to 1.8
S. niloticus	1.0 to 2.3	> 15 over 4 mo	5 to 10	200 to > 300	25 to 30+% protein sinking pellets	1.9 to 2.2
C. carpio	3.3 to 7.7	> 35 over 3.5 mo	5 to 30	> 420	30 to 35+% protein	1.6 to 2.3
I. punctatus	1.5 to 2.2	25 over 8 mo	10 to 20	240	36% protein floating pellets	1.0 to 1.7
Salmo gairdneri	0.3 to 1.9	25 over 4 mo	1 to 10	300	40 to 46% protein	1.4 to 2.5

*mainly based on data from small cages (1 to 6 m^3); these values would be lower for larger cages.

tion potential, at low input cost. In intensive systems, both *S. aureus* and *S. niloticus* provide high production. It may be concluded that these tilapias have good production potentials, particularly in culture systems with low-energy inputs, where production costs may be kept relatively low. Even then, the average monthly production is above that experienced for super-intensive pond culture in Israel: estimated at about 0.5 kg/m^3/month, i.e., about 60 t/ha/year (Sarig and Arieli 1980).

2. Comparison with other Cultured Species

The production potential of the *S. aureus* and *S. niloticus* in intensive systems is compared with that for *Cyprinus carpio*, *Ictalurus punctatus* and *Salmo gairdneri* in Table 18 (Coche 1978, 1979). The two tilapias can outperform *I. punctatus* and *Salmo gairdneri*, especially considering both the relative ease of tilapia culture and its efficient use of low-cost feed. *C. carpio* grows faster and has a definitely higher production potential, although this alone might not justify its preference as a cultured species over *S. aureus* or *S. niloticus*.

Discussion

MORIARTY: How much of a problem is there with fouling of the cages by filamentous algae and other organisms growing on the walls of the cages and restricting the water flowing through them?

COCHE: It depends on the environment where you are keeping your cages. In very rich environments, you can have problems, but in general tilapias help to clean the cages.

PULLIN: In the Philippines, tilapia actually eat the filamentous algae growing on the sides of the cages, so much so that it may be an important source of extra food for them.

COCHE: It can also be a problem for the cage netting. During this process, we have had tilapia damaging some of the netting.

NASH: Just a comment. I do not altogether accept your interpretation that as the cage size increases, the production tends to go down. I think that it does in regular, either hexagonal, square, or circular cages, but certainly in the early days of marine cage development in Scotland we found that the elongated cage opened up new dimensions of production for you, although structurally it was easier to make the square, hexagonal, or circular cage. Secondly, we cut down a great deal on food loss by having about two-thirds of the bottom being covered with some sort of plate which stopped the food going right through. The only problem was then that as we moved many of these cages up and down in the water, particularly if they were submerged cages, the phugoid motion often put the cages under tremendous stress and in fact cracked several of them. But certainly, if you have floating cages, I think that plates up to about 2/3 of the bottom structure are a help to reduce food loss.

HEPHER: Dr. Nash, could you explain the superiority of the elongated cage over the round one with respect to yield and production?

NASH: I think one is just more limited with a round or regular cage because it is largely the movement of the fish within the cage that maintains good circulation. With a regular

cage, you can get more dead pockets in the center as the fish can only move the water around so much. Also the cage area which can be made to face the water flow is limited. With an elongated cage, you can put the long side across the water flow and so maintain much better conditions, although putting it across a strong flow can give you additional structural problems.

ROBERTS: As Dr. Nash has indicated, we have had considerable experience of cage culture, particularly with salmonids in Scotland. Because of the very rapid development of freshwater cage culture in Scotland, we now have several 2 to 300 t units in relatively small lochs. We have a project at the Institute of Aquaculture measuring the environmental impact of cage culture in Scottish lochs. We are already finding that there is a very significant effect of having a 300 t unit in a loch. The effect seems principally to be not only in terms of the chemical water quality, but a more general effect on the fish fauna of the loch, for example, enlarged eel populations. Of course, the entrepreneur who has the fishing rights on the loch can say, "That's fine; I will put eels in the cages as well because the price of eels is so much higher than the price of trout!" But there are limits, certainly, as to safe stocking levels.

We have also studied samples from cage culture mortalities in the Philippines where the obvious cause was anoxia associated with a very highly eutrophic system. As biologists interested in cage culture we should hold back the entrepreneur as he will double and triple and quadruple his production without giving thought for tomorrow and tomorrow may be a very long day of misfortune if we are not careful.

One other thing which Dr. Coche raised in terms of cage culture was the possible differing risks of cage culture and other systems. We are not completely convinced that there is a significantly higher stress in cages compared with other high density culture systems. Stress of course would increase disease risks. But two particular groups of parasitic copepods, *Argulus* species in fresh water and salmon lice in salt water can hide out in the cage structures. They are not obligatorily living on the fish. As soon as you stress the fish, the adrenalin surge seems to give the parasites a message that they had better leave their hosts and they all disappear off the fish on to the cage-netting; so that if you pull fish out to treat them, you only get a small proportion of the parasites. When you put the fish back in, the parasites come back and reinfest the fish. Obviously, their hiding places are multiplied on fouled netting.

We have also experienced problems of wild fish infecting the cultured fish in the cages. In Scotland, the parasitic burden of the wild fish in the lakes with cages may increase to a significant extent and this annoys the anglers or capture fishermen. Part of the problem is that birds fishing in the cages facilitate the cycle of the fish parasites and spread them. Cages in our view have a very big future in aquaculture terms, but they have some specific disease problems, and must be monitored very carefully in terms of their environmental impact.

Diseases of Tilapias

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Studies on intensively cultured and wild tilapias have shown that although they are more resistant to diseases than many other species, there is nevertheless a wide range of disease problems which can occur. To date no viral problems other than lymphocystis have been recorded. The bacterial pathogens include aeromonads, myxobacteria and particularly *Edwardsiella tarda*. A wide range of parasitic problems occur including particularly trichodinids, *Ichthyophthirius* and various intermediate stages of digenean flukes. Nutritional problems are a major difficulty in intensive culture, with aflatoxicosis a major cause of losses associated with poor quality storage of food ingredients.

Introduction

There are two principal reasons why diseases of the tilapias (genera *Tilapia* and *Sarotherodon*) have been less well studied than those of many other groups of cultured fishes. The first is that such fish are generally farmed in countries where diagnostic facilities are less than adequately developed, so that losses cannot be investigated properly; the second is that the culture of tilapias has only been intensified recently. At low stocking densities, environmental water quality is usually high and opportunities for infections to build up are thus limited. Equally, the observation of disease conditions is much more difficult at low densities in large water bodies than under the controlled conditions of the high density tank or cage systems.

Most of the early observations on diseases of tilapias have related to parasitic infections, often from wild fish and at low levels (Khalil 1971; Sarig 1971). These have generally shown no evidence of clinical effects on the fish and in most wild populations of tilapias it would seem that parasitism is a normal occurrence of little consequence. The present paper is restricted to a review of diseases of tilapias which occur in culture systems or those of wild fishes which have a clinical manifestation or potential significance for culture. Although the literature has been surveyed, and references are quoted where relevant, the majority of the information has been derived

from the diagnostic files of the Institute of Aquaculture of the University of Stirling and from unpublished research by the authors and their students in the Institute.

Parasitic Diseases

Although a vast array of parasites has been recorded from tilapias and other cichlids most of them are from wild fish and no evidence of clinical effect is given. The number of reports from cultured fish is much smaller but clinical disease is much more frequently associated with infection in these circumstances. It is with clinical infection in cultured fish that the aquaculture industry is concerned, but in many cases such infections are derived from wild stock in the water supply and other hosts such as birds or invertebrates, or are introduced with fish brought in from wild sources for ongrowing or breeding.

1. Protozoan Parasites

a) Ichthyophthirius multifiliis. This parasite, which causes "Ich" or "white spot" is a relatively large ciliate which causes heavy losses in a wide range of cultured fish. It was first reported from tilapias by Paperna (1970) who recorded it in wild tilapias from east African rift valley species. It was believed to have been introduced to the area with mollies *(Mollienesia sphaenops)* brought in for mosquito control. Brock and Takata (1955) reported its introduction to the Hawaiian islands with imports of *S. mossambicus* from Singapore. Thus any area where it is not presently found would be advised to resist such importations very strenuously, unless in the form of young fish which have been comprehensively treated with formalin and securely quarantined before distribution. *Ichthyophthirius* has a closely defined optimal temperature range for growth of 20 to 24°C (Meyer 1970) and thus for tilapias it is unlikely that significant epizootics will occur in tropical areas unless the fish are highly stressed. It is in the subtropical areas when winter temperatures are both stressful to the tilapias and also pass through the optimum range for the parasite as they rise in spring that severe problems with this parasite will arise. It is a significant problem for fry since they are particularly susceptible to infection and lesions may be found in the nares, pharynx and gill as well as the skin. In intensive culture using recirculation systems, it is a particular problem because of the difficulty of treating the filter without destroying its bacterial flora. If the filter is isolated during treatment the parasite is able to lodge, and survive within it for a considerable period and thus infections can flare up when the circulation is restored. (Richards pers. comm.). Efforts to induce infections experimentally produce very variable results but natural infections can build up extremely rapidly, with the entire body surface of fry being covered with trophonts and tomites within 48 hr of their first being observed.

b) Trichodinids and Chilodonella spp. There are a number of ubiquitous protozoan parasites which commonly cause disease in cultured fish including

Trichodinella spp., *Tripartiella* spp., *Trichodina* spp. and *Chilodonella* spp. Only the latter pair has been reported as being of significance to cultured tilapias but it is likely that the others will also assume importance in the future. They all have a direct life cycle and reproduce by binary fission on the skin and gills. They are present on most fish in small numbers and characteristically cause problems in fish stressed by handling, poor feeding and especially where there has been a drop in temperature. As the temperature rises again, as with *Ichthyophthirius*, the parasites multiply on the stressed and debilitated fish.

Thus, they are a problem in Israel (Sarig 1971) and the Southern U.S.A. (Avault et al. 1968) where it is necessary to provide heated water facilities to overwinter fish and high fish density/low flow rates and minimal temperatures are the norm from economic necessity.

Sommerville (unpublished) has induced severe *Chilodonella* infection in *S. galilaeus* subjected to severe nutritional deficiency in a static water system. It was not possible to establish the infection by direct transfer to healthy, well-fed fish or to fish in clean water with good exchange. Fryer and Iles (1972) consider *Trichodina* to be a particular problem in mouthbrooders as these ciliates can invade the mouth and transmit the infection to fry. Sarig (1975) has also reported heavy infection from cultured tilapias in Ghana, stating that in many cases such infections were highly pathogenic and caused heavy losses, especially of small fish. Guerrero (pers. comm.) has also frequently implicated trichodinids in heavy, and often lethal infections of *S. mossambicus* fry undergoing hormone sex-reversal treatment.

c) Bodonid parasites. Ichthyobodo (=Costia) necatrix is a well recognized and highly pathogenic parasite of young, or severely stressed, salmonids (Robertson 1979). In tilapias, bodonids have been associated with disease in Alabama (Plumb, cited by Scott 1977) and in Israel (Sarig 1971). Sarig reported that they occurred infrequently in late autumn and winter and only on the gills of the affected fish, accompanied by *Trichodina* and *Glossatella*. In experimental populations of *S. mossambicus* held in recirculating systems at Stirling, Mohd-Shaharom (unpublished) has found mortalities associated with a bodinid parasite closely resembling *Ichthyobodo necatrix* in heavily stocked populations held at 26° C, which is a much higher temperature than previous reports.

d) Sporozoa. Myxosporidia occur commonly as cysts replete with spores in the tissues of most wild tilapias. Generally they are of the *Myxobolus/ Myxosoma* group. Baker (1963), Fryer (1961a, 1961b) and Sommerville (unpublished) have all recorded myxosporidians from wild tilapias. They rarely show any evidence of significant pathological effect but in view of their life cycles, they are potentially highly significant for intensive earth pond culture, as is the case with *Myxobolus* and *Henneguya* infections in cultured carps in Bangladesh (Sommerville and Iqbal, unpublished). Earth pond culture greatly facilitates the parasite's life cycle since spores are released during decomposition of a fish carcass (or possibly from living fish) and for all known species require a period of potentiation in mud prior to the development of infectivity. These parasites are more likely to be a problem in countries where the height of the water table precludes seasonal drainage and desiccation of the ponds.

a) Monogenea. Monogenean parasites are found on both the gills and the skin of tilapias and a specific genus for the monogeneans of cichlid fish, *Cichlidogyrus*, was erected by Paperna in 1960. Paperna and Thurston (1968) found 16 different species from rift valley tilapias and Mohd-Shaharom and Sommerville (unpublished) have performed extensive studies on the incidence and pathogenesis of these monogeneans in cultured populations. *Cichlidogyrus sclerosus* was found to be the most widely spread, being commonly observed in fish from Southeast Asian origins such as Philippines (Duncan 1973) and Hong Kong, Singapore and Thailand (Sommerville, unpublished) as well as from Africa. Studies on the population dynamics and growth rate effects of *C. sclerosus* and *C. tubicirrus minutus* indicate that they are normally of low pathogenicity with little or no effect on growth rate. Pathological effects were quite obvious, however, in the form of focal hyperplasia of the branchial lamellae.

Gyrodactylus spp. are potentially of great significance to tilapias in culture. Clinical outbreaks of gyrodactyliasis have been recorded by Fryer and Iles (1972) in pond-reared tilapias in Uganda, where they were associated with corneal damage and by Sommerville and Haller (unpublished) from intensively cultured tilapias in Kenya. In the latter case mortalities appeared to be associated with handling and moving of fish from ponds to tanks. Mortalities always developed two weeks after transfer, tailing off after 5 to 6 weeks. This pattern was presumed to be related to the viviparous life cycle of the gyrodactylids. The increase in transmission opportunity was associated with the higher stocking density of a concrete tank system and the debility of badly handled fish.

b) Digenea. A great variety of digenean parasites are potentially capable of causing heavy losses in cultured tilapias. All, however, have a basically similar life cycle which involves three hosts: the first intermediate host, an aquatic or amphibious gastropod mollusc; the second intermediate host, a fish and the final host, a piscivorous vertebrate. The stage occurring in the fish is known as the metacercarial stage and is generally found encysted in the fish tissues. Virtually any part of the body can be involved but the metacercariae of many species of digeneans are site specific. The molluscan hosts are particularly common in water supply dams, inlet channels and drainage canals, where waste food and organic material accumulate. The fish may be infected on the farm or, as is frequently the case, in ponds or dams where fry are collected for stocking of rearing tanks. A wide range of metacercariae is observed in tilapias and because of the difficulty of identifying the larval form to species, they usually remain unspecified. Sommerville (unpublished) has investigated a wide range of digenean infections in intensively cultured tilapias and carried out experimental infections of final hosts to determine species. The principal groups of significance were clinostomes, neascids, haplorchids and diplostomulae and all were significant in different ways. Although the following are currently the only named digenean metacercariae to have been associated with disease in cultured tilapias, it seems likely that many others will be shown to be of significance as controlled intensive tilapia culture develops:

i) Clinostomes. (Family *Clinostomatidae*) The metacercariae of *Clinostomum* and *Euclinostomum* spp. are notable particularly for their large size—hence the common term "white grub" or "yellow grub" for the mature metacercariae *in situ*. In fry the growth of such a large parasite causes bulging and distortion of the body profile. As well as spoiling the appearance of the fish there is some evidence that in intensive culture, fish infected with clinostomes are also more susceptible to handling stresses (Balarin pers. comm.). The adult worms lie in the pharynx of a piscivorous bird and *Ardea goliath* has been recorded as being a particularly prevalent carrier of the infection.

ii) Neascus metacercariae. (Larval genus of Superfamily *Strigeoidea*, all belong to Family *Diplostomatidae*) A group of neascus metacercariae stimulate the accumulation of large numbers of melanocytes in the host capsule. Since they usually accumulate in the skin, the resulting black spots become very obvious even to the casual observer. However, although they have been reported from a wide range of tilapias from east and west Africa (Paperna and Thurston 1968; Sommerville unpublished;) they probably have only a limited effect on the fish host *per se* and their real significance is that they render fish unmarketable where infection is heavy.

iii) *Haplorchis* sp. (Family *Heterophyidae*) Metarcercariae of this genus are found in a wide range of freshwater food fishes including tilapias. They have a wide geographic distribution and have already been a cause for concern in the Philippines, Israel, Africa, India, Egypt, China and Japan (Sommerville in press).

Haplorchis pumilio was first recorded from tilapias by Witenberg in 1929 in Palestine. Like other species of this genus it has a wide distribution, summarized by Sommerville (in press) who has also recently found it in an intensive *S. spilurus* culture system in Kenya. Its cercariae were found in a high proportion of *Melanoides tuberculata:* the dominant mollusc in the tanks, drains, and ponds of the farm system. Experimental infections of tilapia fry showed that mortalities could result directly from penetration of the skin and muscle of fry by large numbers of cercariae and the migrations of metacercariae to accumulate at fin bases. It is assumed that the mortalities associated with mass penetration are related to loss of skin function, but other organs may be damaged as the parasites penetrate over the entire skin surface and migrate indiscriminately through tissues.

With less severe infections, experimental studies (Sommerville unpublished) have shown that the infected fish suffer no disadvantage when compared with uninfected fish as far as growth rate, condition or food conversion are concerned. However, the presence of this parasite in cultured food fish cannot be tolerated because of the risk it represents to human health when inadequately cooked fish are eaten. The main pathological effect when man is the final host is associated with the distribution of the eggs in the circulatory system, where they lodge in end-arteries, causing infarction. This can cause a variety of syndromes but the most significant are related to obstruction of myocardial, cranial or optic vessels. Since it is non-specific in its final host, piscivorous vertebrates other than birds, e.g., otters, dogs, cats, or even monitor lizards, can act as final hosts. Other larval heterophyids have been reported in tilapias in the Middle East, Paperna (1960) reporting *Heterophyes*

heterophyes as well as *Haplorchis pumilio* as common parasites of man and dogs in Egypt and Israel.

iv) Diplostomulae. (Larval genus of Family *Diplostomatidae*) The metacercariae of these strigeoids lodge in a variety of tissues within their second intermediate fish host, depending on the particular *Diplostomum* species involved. The most noticeable in clinical terms, however, are the metacercariae which are associated with blindness: the so-called eye flukes. There is a wide range of species of eye fluke, with a remarkable degree of site specificity so that some species localize in the lens, others in the retina and yet others in the aqueous or vitreous humour. Where only small numbers of unencysted metacercariae are involved, the sight is not significantly affected, but when large numbers of metacercariae locate in the eye they can produce total blindness (Plate 1). This causes loss of reflex pigmentation control and affected fish are thus more vulnerable to predation than would otherwise be the case, as well as being unable to find their food by visual means.

c) Cestodes, Nematodes and Acanthocephalans. Cestodes have not as yet been reported to cause any serious problems in cultured tilapias, although their presence in wild fish has been reported (Fryer and Iles 1972). Several nematode species have also been reported (Fryer and Iles 1972; Goldstein 1971) but apart from reports by Paperna (1964) and Scott (1977) of larval *Contracaecum* infection causing pathological effects, little is known of their significance. Scott found that in *S. alcalicus (S. grahami)* in Kenya up to 7 parasites might be found in the pericardial cavity (Plate 2) and that they had a significant effect on the growth of the fish. *Contracaecum* is a particularly unattractive parasite to the consumer as it can occur as large encysted worms throughout the muscle. Like some other anisakid parasites, it can also be zoonotic and it would seem important that it be excluded from cultured fish. Its life cycle involves ingestion of the egg by a free living crustacean which is ingested by the fish. When this then is eaten in turn by a piscivorous bird the life cycle is completed, and it would seem that it is only at this stage that the cycle can be readily broken. Since piscivorous birds are also responsible for many digenean infections of fish and also cause direct losses of cultured fish by predation, the netting or wiring of sites, tank coverings, and an active predator elimination policy, would seem to be highly desirable.

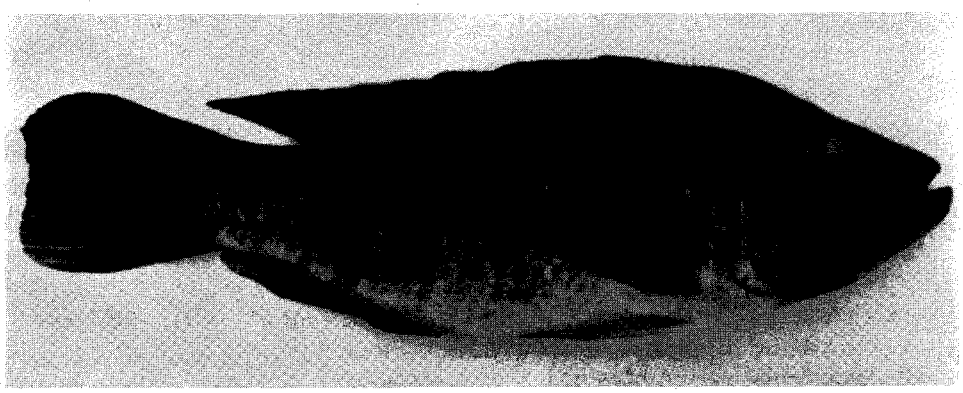

Plate 1. *Sarotherodon mossambicus* **with bilateral cataract caused by a heavy diplostomulid metacercarial infection.**

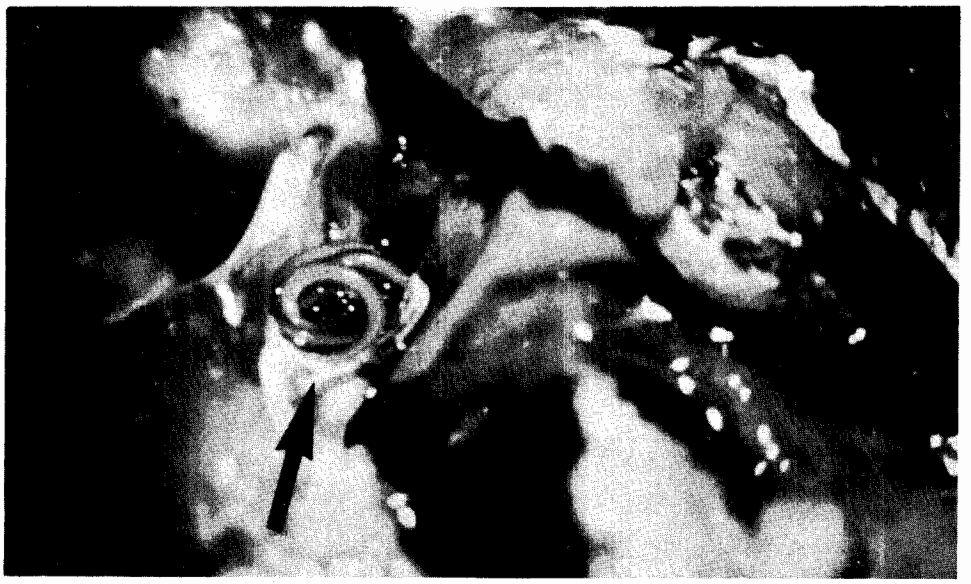

Plate 2. *Contracaecum* within the pericardium of *Sarotherodon alcalicus (S. grahami)*. Photograph courtesy of Mr. P.W. Scott.

3. PARASITIC CRUSTACEANS

Numerous species of parasitic crustaceans have been reported from tilapias. Of these the most serious pathogens are the branchiuran *Argulus* spp. and the copepods *Ergasilus* spp. and *Lernaea* spp.. Sarig (1971) summarizes the reports of Fryer and Paperna and describes the problems experienced with infestations by these parasites. Fryer (1961b, 1965a, 1968) and Paperna (1969) found *Lernaea* to cause serious losses in ponds in Nigeria and Israel and in Malawi (Roberts unpublished), they were found to be a significant cause of mortality in *T. rendalli ('T. melanopleura')* culture in ponds. The parasites are deeply embedded in the dermis or musculature of the fish, and cause a severe necrotic ulcerative granulomatous response. The lesions render the fish unmarketable, and fish with even a single parasite feed poorly, and lose weight. *Lernaea tilapiae* is restricted to tilapias of Lake Malawi and has been described by Fryer and Iles (1972) as inhabiting the mouth and penetrating the tissues of the palate. In view of the finding of as many as 9 parasites in this site, all causing severe inflammatory lesions, they conclude that it must also interfere with feeding and mouthbrooding in addition to the more general effects of "anchor" penetration. The infective stage is the free swimming copepodid (the second larval instar) but a further four moults, accompanied by a final sexual differentiation and mating are necessary for the adult female to become pathogenic and insert her head into the skin where the feeding activity and growth of the "anchors" causes the severe reaction.

Argulus spp., the fish lice, are very mobile, unlike the sedentary *Lernaea*. Several species have been found on tilapias (Paperna 1964; Fryer 1968; Sarig 1971). Its life history is more simple than that of *Lernaea* and although it is

an obligate parasite it can survive off the host for a limited period and since it lays its eggs on vegetation, it is a serious problem in standing waters. It can readily seek refuge around a pond if fish are removed for treatment. It can cause mortalities in its own right but usually it is responsible for facilitating secondary bacterial and fungal invasion by its feeding method, which causes open wounds.

Ergasilus spp. have been reported to cause epizootics in polyculture fish ponds in Israel (Sarig 1971) where carps, mullets, and tilapias are farmed together. Although the tilapias do become infected in such conditions, their parasite burdens are usually very low compared to those of the other two groups of fish species, possibly reflecting the higher resistance to skin penetration of the tilapias.

Bacterial Diseases

Tilapias are generally kept in water with a high organic load. This may be due either to deliberate fertilization to increase the production of food organisms in the water or to agricultural or sewage run-off. Such water conditions allow most of the recognized aquatic bacteria to occur at significant levels and under intensive culture conditions especially heavy mortality can result from infections with any of a wide range of recognized facultative pathogens.

Three clinical syndromes are associated with bacterial diseases of tilapias: a predominantly skin lesion syndrome associated with pathogenic myxobacteria; haemorrhagic septicaemia; and chronic granulomatosis associated with *Mycobacterium tuberculosis* infection.

1. Myxobacterial Infections

Myxobacteria, or 'slime' bacteria, are aquatic bacteria commonly found as commensals on fish skin. A few species are capable of becoming pathogenic under particular circumstances of environmental stress. The most common stressors inducing myxobacterial infections are high or low temperatures, but traumatic damage and low water quality, such as that caused by excessive silt or high ammonia levels associated with filtration failure in recirculation systems, can also induce the qualitative or quantitative changes in mucus secretion from the skin or gills which appear to trigger infection.

Flexibacter columnaris is the commonest myxobacterial pathogen in tilapia culture and is usually associated with high temperature stress. The lesions are opaque white, raised and whorl-like, or may take the form of a saddle-back of grey white epithelial necrosis over the dorsum of the back with a red haemorrhagic rim. These develop rapidly to form crateriform ulcers. The affected fish become very dark, slow moving and die quickly. Myxobacterial infection of the gills, particularly of fry is usually associated with heavy mucus production and the bacteria may be doing little more than obstructing gaseous exchange since treatment with surfactants, whether bacteriostatic or not, serves to remove both the mucus and the problem,

provided environmental conditions are also improved. Both gill myxobacterial infection and dorsal fin-rot (also associated with myxobacteria) are usually associated with low water temperatures and Avault et al. (1968) stress the importance of maintaining overwintering temperatures of at least 14°C for this reason.

2. HAEMORRHAGIC SEPTICAEMIA

Gram-negative bacterial septicaemias are the commonest bacterial causes of mortality in tilapia culture. Infection may arise from introduction of infected fish into a system but more often it is a function of the environmental conditions of that culture system.

Aeromonas hydrophila infection is the most common of the septicaemias and usually manifests itself by causing affected fish to darken, lose appetite, and cluster around exit screens. When examined they may have ulcers, or more frequently, areas of hyperaemia at the base of the pectoral and pelvic fins, and at the margins of the orbit (Haller 1974; Scott 1977). Internally the liver is usually pale and there may be focal haemorrhages over the visceral and peritoneal surfaces. Histologically there is haemopoietic necrosis and focal necrosis in the liver, heart or skeletal muscles, with accumulations of gram-negative bacteria ranged along strands of fibrin. The cellular inflammatory infiltrate is rarely marked but when it is present it generally comprises macrophages which often contain ingested melanosomes. Generally the condition is predisposed by handling trauma, poor nutrition, heavy parasitism or excessive fertilizing of ponds but sometimes severe outbreaks may occur without any obvious predisposing factor.

Occasionally pseudomonads, such as *Proteus* spp., β-haemolytic streptococci (Wu 1970) or *Edwardsiella tarda* (Roberts unpublished) may be associated with the condition. These are particularly common in ponds newly fertilized with human or animal faeces. Coliforms and *Salmonellae* of human health significance may also be ingested from such sources and there is therefore a risk of outbreaks of human gram-negative infections, although considering the extent to which night soil is used to fertilize fish ponds in Asia, their significance as a source of human infection would seem unlikely to be high.

Edwardsiella tarda infection provides a particularly intractable problem in intensive systems. Although clinically and histologically this condition is a typical bacterial septicaemia, losses are usually sporadic. It is extremely difficult to eradicate from the system and over a period of time such infections can be responsible for the loss of significant numbers of fish. Food medication with oxytetracycline or potentiated sulphonamides eliminates losses during the feeding period but they often recur once treatment has ceased. Ruthless culling of all poor growing, sluggish or darkened fish from the system and maintenance of best possible water quality and feeding standards are the most effective means of preventing losses.

Experimental infections with *Aeromonas salmonicida* (Almeida et al. 1968; Roberts unpublished) have shown that both the pigmented and the achromogenic strains of this common pathogen of temperate fishes can cause

similar syndromes in tilapias and there seems no reason to suppose that further studies will not also reveal its presence in cultured tilapias as a significant pathogen.

3. TUBERCULOSIS

Infection with *Mycobacterium fortuitum*, commonly known as fish tuberculosis, is well known in all cichlids kept in aquaria (Nigrelli and Vogel 1963). In the wild it has been recorded only infrequently in tilapias, e.g., Roberts and Matthiesen (1979) recorded it in *S. andersonii* and *T. sparrmanii* from the Okavangu swamp in Botswana. In intensive culture it has only been recorded once in *S. niloticus* in intensive culture in Kenya (Roberts and Haller unpublished). Affected fish showed small focal granulomata in the liver, spleen and kidney. Mortalities were limited but again it seems likely that under certain circumstances, particularly if trash fish are fed, this condition could be a potential source of severe losses.

Mycotic Infections

Only two fungi are recognized as serious pathogens of tilapias although various others, such as dematecacious moulds, are suspected of causing occasional mortalities. Phycomycetes of the genus *Saprolegnia* can be a cause of severe losses as with other cultured fish: again in association with traumatic damage from handling, from sexual aggression or at temperatures approaching the minimum range for the tilapias. Thus in Israel handling is avoided between October and May (Sarig 1971) and prophylactic spraying of ponds with malachite green is often carried out. *Saprolegnia* fungal growths are usually disposed as grey mats arranged in whorls over the surface of affected fish. Such infections are usually seen much more easily while the fish are in the water than when they are removed.

Infection with *Branchiomyces* spp. can be a significant cause of mortality when fish are reared in poor quality water with a very high level of decaying vegetable or other organic material. The fungus may invade the gill via the branchial vessels or the epithelium and cause massive destruction of the respiratory surfaces. Liming of the pond has been suggested as means of reducing losses but improvement of the water quality is a much more rational approach.

Viral Diseases

The only validated report of a viral disease of tilapias is the report by Paperna (1974) of lymphocystis infection of wild tilapias in east African lakes. This condition has caused severe problems in marine fish culture in Europe and in tropical aquaria and it represents a potential hazard for intensive culture systems. However, experimental vaccination studies have shown that susceptible marine fish can be readily protected (Roberts 1975

and unpublished) and it is likely that this would also apply to tilapias in culture.

Although only one virus infection has been recorded in tilapias it is inconceivable that a similar range of commensal and pathogenic viruses as found in the salmonids and other intensively cultured species is absent from the tilapias. It would seem to be only a matter of time before these are manifested in intensive culture given the rate of the development of the industry and the improvement of diagnostic facilities.

Toxic Conditions

Toxic conditions may arise from toxic substances in the diet or in the water. They range from high levels of metabolic wastes such as ammonia to gaseous supersaturation of the medium. The range of potential toxic agents is very wide but only small numbers have been definitely associated with losses.

1. Gaseous Supersaturation

In intensive culture systems, pumping or piping faults can result in supersaturation of the water with dissolved gases. When absorbed into the fish during respiration the change in partial pressure can result in the gas coming out of solution and blocking or rupturing blood capillaries. Bubbles of gas then accumulate at sites which vary depending on the age of the fish. In tilapia fry these supersaturation bubbles can form anywhere but are found particularly in the area of the yolk sac or, in older fish, in the gill and skin. In adults the scale and skin structure is such that normally the only clinical location of gas bubbles is on the gill although it is likely that small occlusive emboli are also distributed unnoticed, throughout the tissues, since affected stocks rarely grow particularly well thereafter.

2. Toxic Effects of Algae

Although some freshwater algae such as *Prymnesium parvum* are toxigenic *per se* the main deleterious effect of algae in tilapia culture is death from anoxia following an algal bloom. Generally the microorganisms responsible are of the genera *Microcystis*, *Anabaena*, *Oscillatoria* and *Spirulina*. According to Swingle (1967) the anoxia results from a sudden dominance of one particular species which multiplies phenomenally under favorable conditions to form a thick scum on the surface. This prevents light penetration, causes death of all submerged vegetation and restricts oxygenation to the upper 6 cm of the pond. Although fish can live in this upper layer any sudden drop of temperature, or other weather changes such as wind or rain, can induce overturn or mixing of the layers with resultant anaerobiosis of the entire pond and mass mortality of the fish. These usually die with the characteristic features of anoxia: a wide open mouth and dilated branchial chambers.

3. AFLATOXICOSIS

Aflatoxins are toxic compounds produced by the mould *Aspergillus flavus*. In salmonids they are now recognized as producing hepatomata at very low levels in supplementary feeds. In tilapia culture, storage of feed in poor conditions leads readily to growth of *Aspergillus*. Recent work has shown that tilapias receiving feeds with a high level of aflatoxins B_1 and B_2 show a haemorrhagic syndrome, characterized by severe haemorrhage into the branchial musculature below the dorsal commissure of the operculum, a wide range of internal haemorrhages, distinct depression of haemopoiesis and massive accumulation of haemosiderin in both the splenic and renal melanomacrophage centers (Haller and Roberts unpublished). Frank hepatic neoplasia is not seen but pre-neoplastic islands of well-defined hepatocytes, as described in rainbow trout *(Salmo gairdneri)* by Wales (1970) are seen. Given the problems of food storage in those humid tropical areas where intensive tilapia production has its greatest potential, this condition seems likely to be recorded with increasing frequency.

Neoplasia

Mawdeslay-Thomas (1972) suggested, somewhat flippantly, that visceral neoplasia of *Sarotherodon niloticus*, which he diagnosed from Egyptian tomb paintings, represented the earliest example of a documented fish disease. However there has been very little in the way of descriptions of neoplasia in tilapias since then. Haller and Roberts (1980) have described dual neoplasia in the form of a lymphocytic lymphoma and a renal tubular adenoma in the same specimen of *S. spilurus* but otherwise there have been no descriptions of neoplasia in the group. Again this is almost certainly a reflection of the lack of detailed observation rather than a true picture of incidence.

Anomalies and Deformities

Although the incidence of congenital anomalies in cultured tilapias would be expected to be similar to that in other genera, the following two specific conditions occur with a frequency which makes them a particular problem.

1. SPINAL DEFORMITIES

Spinal malformations are not uncommon in small numbers in any intensively reared species but in the tilapias a particular form of spinal deformity has been studied by Tave (1980 pers. comm.) and by Pullin and Roberts (unpublished). Although occasionally seen in *S. spilurus*, *S. mossambicus* and *S. niloticus*, the anomaly seems most frequent in the Auburn strain of *S. aureus*. Tave has defined two aberrant types, which he calls "saddle back"

and "stump body" (Plate 3). "Saddle back" fish lack all or part of the dorsal fin and in extreme cases, some or all of the pectoral, pelvic and anal fins also. Such fish were, from his studies, also less resistant to diseases such as *Saprolegnia* fungus infection. In the "stump body" the body is compressed anteroposteriorly, with no two fish showing the same skeletal anomaly. The saddle back form has not been described elsewhere than in the Auburn fish and it is the stump body anomaly that is the one which is widely observed.

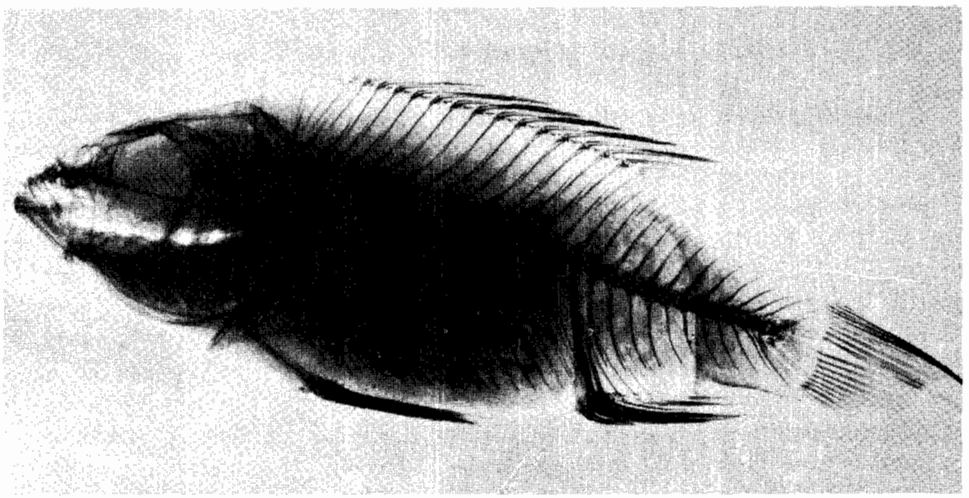

Plate 3a. Normal *Sarotherodon aureus* radiograph.

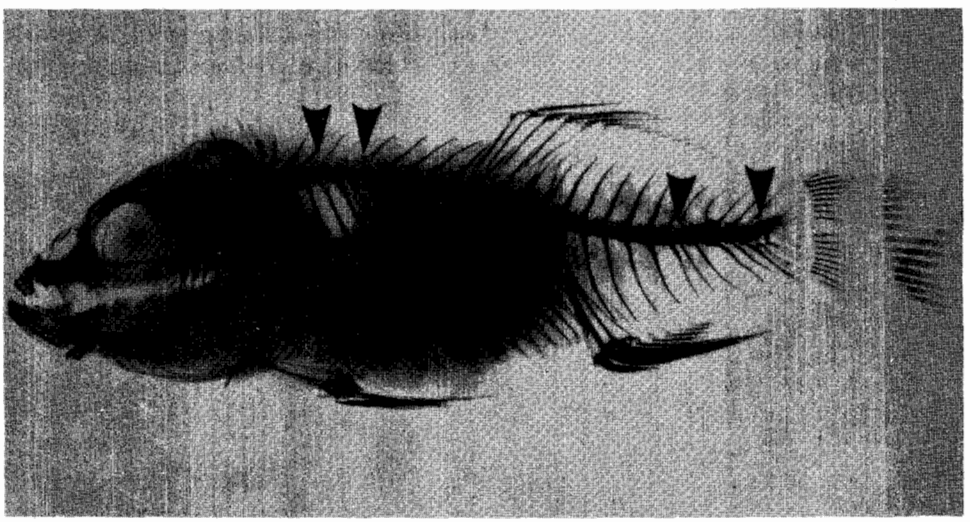

Plate 3b. Fish showing the saddle back spinal deformities (arrowed) and dorsal fin anomaly. (From material kindly supplied by Dr. D. Tave).

In intensive culture, the establishment of hatchery technology, which allows detailed observations to be made on young fishes, has shown the prevalence of particular larval anomalies. Rothbard et al. (1980) have described the commonest of these in *Sarotherodon niloticus*, but others are also found.

Mortality Associated Specifically with High Density

It has long been a recognized phenomenon that in high density culture the growth rates of many tilapias tail off and there are unexplained mortalities. Such growth inhibition has been attributed to the presence of some inhibitory factor in the water. The phenomenon was first defined for *Tilapia* by Chen and Prowse (1964) and is discussed by Balarin and Hatton (1979) in relation to the "space factor" requirement defined by Swingle (1956) for goldfish *(Carassius auratus)* and other extensively farmed species. Recently some more specific information on the phenomenon (which is not universally recognized) has become available with the publication of preliminary findings by Henderson-Arzapalo et al. (1980) on a biochemical compound which they isolated from mucus and culture water of intensively cultured *S. mossambicus* which induced a syndrome suggestive of an acute anaphylactic reaction in *S. mossambicus*, *S. aureus*, *S. niloticus* and *T. zillii* but had no such effect on *Ictalurus punctatus*. This phenomenon shows a number of similarities with the findings of Scott (1977) who described a phenomenon which he called "shock syndrome" in *Sarotherodon spilurus spilurus* which he observed to go into an anaphylactoid state in high density stocking in Kenya (Plate 4).

Plate 4. *Sarotherodon spilurus* in state of shock from high density intensive tank culture. Photograph courtesy of Mr. P.W. Scott.

Disease Prevention and Control

Since tilapia culture is still largely undeveloped despite the great potential of many of the species and their hybrids for culture in the developing countries, transglobal movements of fish are unfortunately still quite common. Indiscriminate transfers of young fish for on-growing or as broodstock hold dangers of many kinds. They have already led to problems from a fisheries point of view in countries such as Australia (Moriarty pers. comm.) but possibly even more significant, from the point of view of aquaculture and of native fish stocks, is the risk of the transfer of microbial pathogens from one area to another. Already two significant pathogens, *Ichthyophthirius multifiliis*, and the iridovirus of lymphocystis (see above), have been introduced in this way to stocks in Africa and Hawaii and, with increasing intensification of farm systems, may become constraints on production.

Thus, there is justification on both disease prevention and ecological grounds for national controls on stock transfers and importations. Where no such national regulations exist, the prudent importer will insist on fry importations being from a known and trusted source, will insist on heavy formalin and malachite green treatment on the farm prior to export and will perform similar prophylactic treatment within a secure and closed quarantine water system, (isolated and downstream from any production facility) within which such fish will be kept under close observation for at least a month, prior to release into a production system.

Ideally, on disease grounds a country, region or even an individual tilapia farm should be self-sufficient in fry production, but in view of the economic and management justifications, it seems likely that as in many other livestock production systems, the industry will stratify into high quality fry producers and fattening farms. The least that can be expected under these circumstances is that the aforementioned minimal quarantine and hygiene recommendations will be adopted as an insurance both for the individual and his national fisheries ecosystem.

The indiscriminate use of antibiotics in tilapia culture is a subject of some concern to medical and veterinary science. There is justification, on clinical grounds, for the use of oxytetracycline, or the potentiated sulphonamides, at *therapeutic* levels, in specific bacterial conditions. There is also some validity in using these drugs, again at therapeutic levels, in the specific traumatic situation involved in transporting large brood fish to overwintering facilities, in sub-tropical countries. The practice of indiscriminate so-called prophylactic use of antibiotics, however, is to be most severely deprecated and in view of its significance in human pathogen drug resistance induction, should in the authors' view be illegal in all countries. The use of the antibiotic chloramphenicol, which is the only reliable specific therapeutic for typhoid infections in man cannot be condoned at any time in fish culture.

Acknowledgments

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Discussion

LOVSHIN: I don't think you mentioned anything about myxosporidian parasites. In cage culture in the Ivory Coast, they have just about had to stop using *Sarotherodon niloticus* because myxosporidians wipe them out. They are changing to a local species, *S. melanotheron (T. heudelotii)*.

ROBERTS: I did mention those in terms of pond culture, but I have only just learned of the example which you quote.

PULLIN: Dr. Roberts, can you say anything more on the reasons why cold temperatures always seem to bring disease problems, because this is not just so with tilapias, but for many different fish.

ROBERTS: Perhaps Dr. Avtalion could comment on this?

AVTALION: We have not performed a comprehensive study of this problem in tilapia, as we did in carp. We know that cold temperatures inhibit the immune response, namely, the ability to respond to different antigens. We found that the inhibitory threshold for antibody production was between 16 and 18°C in tilapia and 15°C in carp. At these low temperatures, both activities of bacteria and immune system are considerably inhibited. When spontaneous increase of environmental temperature occurs, the bacteria multiply faster than the immune system could react. This seems to be different when viral and parasitic diseases are considered.

ROBERTS: I think that it is temperature change that is a problem. If you have specific pathogen-free tilapia or carp or salmon or trout and if you can reduce the temperature very slowly, you can usually get away with it. Going down in temperature, each pathogen seems to have an optimum temperature range and you go through those ranges for particular strains or species of micro-organisms. At the same time your fish, particularly warmwater species like tilapias have to switch enzyme systems on and off at different temperatures and it would appear that for fishes in general the ability to do this is a little slower than the ability of micro-organisms to adjust and take advantage of the situation.

Fishes also have a very nice mechanism for repairing skin damage. If we damage our skin, then the cells round about proliferate and fill the hole. Fish have to use a different system since at low temperatures their rate of metabolism and therefore rate of cell multiplication is so low. In fish, the epidermis which is a thick layer, donates cells which migrate from a wide surrounding area to cover the lesion. This happens even at low temperatures within a few hours. In two or three hours, a reasonably small lesion will be completely covered by a layer one cell thick. This is probably important to both freshwater and marine fish, including carps. A problem remains, however, that if aeromonads and pseudomonads are deposited in the middle of a large lesion, then the epidermal cells come in a certain distance and then stop. Presumably, therefore, there is a secondary defense mechanism against such microorganisms for large lesions and for situations where fish are not able to make their cell migration system work fast enough (e.g. at the bottom of their temperature range). With large lesions, the whole skin gets very thin.

MIRES: What is your opinion of the use of antibiotics as prophylactics? Why do you say use these during fish transfers only?

ROBERTS: Well, antibiotics work and they are very important, but I am very fearful for the future of mankind if we carry on the way we are with the use of antibiotics. Antibiotics have revolutionized medicine, but aquaculturists, in attempting to revolutionize protein production, are going well on the way towards preventing us from keeping our ability to use some antibiotics, particularly in regions like Southeast Asia. Antibiotics are active against human bacterial pathogens as long as they are used at an adequate dosage. If they are used at lesser dosages, this selects for antibiotic-resistant strains. They can also pass on this resistance to completely different bacteria during reproduction. The most serious prospect is that aquatic bacteria in culture systems receiving low dosages of prophylactic will pass this resistance to human pathogens or animal bacterial pathogens. In manured farms, of course, we have very large amounts of human and animal enteric pathogens. In Southeast Asia, the development of drug-resistant strains of typhoid and cholera are serious possibilities.

MIRES: What about limited use of antibiotics during fish transfers, for example between tanks?

ROBERTS: Responsible culturists will of course use antibiotics sensibly and carefully in such situations, but in the developing countries, people don't understand the risks. It is very difficult to explain to a fish farmer in a developing country who has saved some fish with antibiotics why he should not continue low level treatments all the time. I can easily envisage the first chloramphenicol-resistant typhoid strain (and this is the only drug we have against typhoid) arising from its misuse in, for example, Southeast Asian catfish culture in ponds receiving human or animal wastes. Now, as far as using antibiotics during transfer, the first thing is, particularly for species such as silver carp which have very delicate skins and are big and very active fish, it is almost impossible to transport them without significantly damaging their skin. Also tilapias, particularly the large individuals with big strong spines can damage each other's skin and suffer spine breakage. It would, therefore, seem reasonable to treat such fish either by adding antibiotics to the transport water or as a pre-treatment by food incorporation to lessen infection of these lesions caused by transportation. I must stress, however, that this must be done with effective therapeutic levels of antibiotics, not lesser amounts. Again, I stress the dangers of the development of resistant strains of animal and human pathogens through ineffective dosage.

to tilapia hybridization and then discovering methods to overcome these barriers."

There is another area where it seems to me that fish culturists have been slow to make use of available scientific knowledge. Genetic selection work cannot proceed efficiently without good knowledge of the pedigree of parental stocks, nor is it very effective if based on highly inbred stocks. In reviewing the various experiments cited in the papers on hybridization work in tilapias, I wondered how often contradictory reports on the effectiveness of selection for growth and other characters have been the result of very different levels of heterozygosity in the individuals used for the different experiments. It is very evident among those who have been working with experimental tilapia populations that (1) so-called pure strains have several times been derived from unrecognized accidental hybrids, and (2) many research stocks have passed through one or more "genetic bottlenecks" where the number of breeding pairs in the line has been reduced to well below twenty-five.

It would seem to me very valuable if, in the course of these discussions, we could identify other areas where "basic science barriers" stand in the way of efficient development of tilapia culture. I gather that Dr. Avtalion's work on electrophoretic markers was undertaken to determine the identity of farmed stocks. The work is clearly encouraging and the discovery of a male-specific protein is an exciting bonus.

I will turn now to some of the more specific aspects of fry and fingerling production, for example, the high cost of overwintering fry in temperate areas. Mr. Mires noted that *Sarotherodon* fry must be grown to at least 20 g to be successfully overwintered. Drs. Hepher and Pruginin remark that overwintering is economically feasible in Israel if all male fingerlings are selected for growout in the following summer: the market prefers large fish (400 g or more).

In Belgium, there is considerable interest in using warm water industrial effluents for tilapia culture. Dr. Coche tells me that in Belgium the restaurants want tilapias weighing at least 300 g and preferably about 350 g. There is possibly a similar market in the U.K. In many areas, however, thermal effluents may be more profitably utilized to produce hybrid male seed for growout elsewhere. Given that the cost of hybrid 50 g fingerlings is about 35% of all growout costs for large tilapias, as reported by Dr. Lovshin (quoting Tal and Ziv 1978), it would seem that the availability of inexpensive, heated water could make specialization in seed production quite profitable in some locations.

It was interesting to note, from Hepher and Pruginin's paper, that a late spring warmup could prove advantageous in the combined culture of mixed sex progeny (from natural spawnings) and hatchery-produced males, because of the suppression of spawning below 20°C. Where cold water is readily available to hold temperatures between 18° and 20° through the culture season, the advantages of the resulting depression of breeding might offset the reduced growth that would also occur.

Grading and sorting fry and fingerlings also seems to be an area where economies could be achieved by mechanization or simplification. Dr. Lovshin describes pen systems, as used by Pruginin in Uganda, and interconnected

ponds, as used in Brazil, to allow the easy separation of hybrid fingerlings from their parents. The latter incorporated a set of screens between the ponds to sort out different sizes. Dr. Coche reports the separation of fingerlings by size to be an effective means of increasing the percentage of males in mixed sex culture in the Ivory Coast. Dr. Guerrero notes that Pruginin and Shell used a mechanical grader for this purpose.

The design of efficient structures for screening and sorting fish can be a complicated process. Solid gratings may be preferred to soft mesh as the geometry of flow can be quite important when they are operated in flowing water. Much more work of this sort seems to have been done in connection with the design of fish passes than by aquaculturists. The behavior of the species being sorted is also important. Tilapia fishermen tend to agree that adult fish, at least, are extremely wary of gill nets, but it is probably not known whether this is a question of retreat from a "new" object in the environment, or from some more specific stimulus.

In the control of reproduction of tilapias, it may be useful to make a distinction between the requirements for hybrid seed production systems, where almost complete control over wild spawning is needed, and the requirements of growouts where less control may be needed. Perhaps more work should be done on combining the various methods of inhibiting natural spawning and/or of increasing the male/female ratio of progeny. We should also determine whether the faster growth of males is genetically controlled.

Genetic Markers in *Sarotherodon* and Their Use for Sex and Species Identification

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Enzyme and other protein genetic markers in *Sarotherodon* and *Tilapia* are reviewed with special emphasis on their use for the identification of species and hybrids. Three different groups of markers: transferrins, esterases and male sex-protein (MSP) were found to be useful for the control of *Sarotherodon* parental breeding stocks used in Israel for the commercial production of F_1 all-male hybrids. Understandably, the tests for these markers were restricted to serum proteins, which could be collected from broodstock without damaging them. These serum markers were found to be species-specific, providing a tool for the identification of both parents and their hybrids, and therefore permitting the elimination of xenogeneic contaminants from the breeding stock.

The possible biological importance of MSP is discussed as a sex and species-specific marker and as a possible gene-product involved in sex regulation. Finally, an autosomal theory of sex determination in *Sarotherodon* is summarized and discussed.

Introduction

Sarotherodon species, the mouthbrooding tilapias, are currently being cultured in fish ponds in tropical and subtropical countries, and constitute an important source of animal protein in developing countries. A free-breeding culture of tilapias in a limited water space gives rise to an enormous quantity of small fish having no economical importance. Thus, the economic feasibility of *Sarotherodon* culture is essentially based on monosex culture of males. However, the manual separation of males from females is expensive and time consuming.

The culture of these fish made significant progress when it was shown that hybridization between some unrelated species of this genus gives rise to fertile F_1-hybrid broods, which present unusual sex ratios, including 100% males. This result was consistently obtained by different authors mainly in the crosses of *S. mossambicus* and *S. niloticus* ♀♀ with *S. hor-*

norum, *S. aureus*, *S. macrochir* and *S. jipe* ♂♂. Sex ratios (♀:♂) of 1:3 were consistently obtained in reciprocal crosses (Hickling 1960, 1963; Fishelson 1966a, 1966b; Chen 1969; Jalabert et al. 1971; Pruginin et al. 1975; Lovshin and Da Silva 1975; Haller pers. comm.). On the other hand, the back cross of the F_1 male hybrids and their female parents gives rise to equal numbers of males and females. In general, male hybrids give rise to progeny with a low percentage of males when crossed with their parents or grandparents. In practice, the infiltration of broodstocks by hybrids seems to be the reason for the decrease in the percentage of males in group spawning. Actually, for many reasons (e.g., human error, transfer of fry from one pond to another by predatory birds, occurrence of fry in the water used to fill the pond prior to stocking) it is quite impossible to avoid contamination of the parental species in large-scale commercial operations.

The main purpose of our work was to establish criteria, based on genetic, biochemical, electrophoretic and immunological markers, to identify parental species and their hybrids, in order to control broodstocks and to eliminate individuals presenting xenogeneic markers, and to carry out a comprehensive study on blood markers in tilapia.

Sampling for Serum Markers

For the commercial production of F_1-male hybrids in group spawning in Israel, *S. aureus* males are currently crossed with females of *S. niloticus* of different origins: *S. niloticus* (G) (originating from Ghana) and *S. niloticus* (V) (otherwise called *S. vulcani*, originating from Kenya). It is a matter of opinion whether to designate these as separate subspecies. In practice, it is difficult, if not impossible, to differentiate between the F_1 hybrid progeny of these crosses and their parents on the basis of external morphometric criteria. For this reason, a systematic check on the broodstocks is carried out using several blood protein markers. Once or twice a year, in various farms which produce F_1-male hybrids for commercial purposes, we test all the selected broodstocks (which are normally kept in aquaria) and take samples from *S. aureus* ♂♂ and *S. niloticus* ♀♀ destined for the mass production of F_1 male hybrids in ponds.

The test consists of withdrawing a small quantity of blood (0.1 to 0.4 ml) from the hemal arch of tagged fish, and testing their sera by polyacrylamide gel electrophoresis. Since the tested fish are destined for reproduction, the blood sampling is performed carefully to minimize injury. The mortality following sampling is normally very low, or zero, and even small fish of 8 to 10 g can be sampled.

The serum markers which were found significant for this purpose, and which are routinely tested using 6 and 7% polyacrylamide gels, are the transferrins, male sex-protein (MSP) and esterase isoenzymes. These markers, which exhibit sex and/or species-specific polymorphism, enable an easy identification of *S. aureus* and *S. niloticus* parents and their hybrids (Avtalion et al. 1975, 1976).

Serum Transferrins

Transferrins represent a major protein fraction in the serum of tilapias (4 to 8 mg/ml) and are involved with iron transport for the formation of hemoglobin. Tilapias exhibit marked polymorphism in their transferrin patterns (Chen and Tsuyuki 1970; Avtalion et al. 1976). This polymorphism seems to be controlled by different alleles, the genetics of which have still to be studied. The reading of transferrin patterns is difficult from 7% polyacrylamide gel, because their relative mobility (Rm 61 to 72.4%) is the same as that of the albumins and they are therefore often masked by that fraction. However, transferrin bands can be easily seen in 6% polyacrylamide gels, where the albumin spot (Rm 77 to 86%) runs faster than the transferrins (Rm 65 to 77%). At least 5 distinct transferrin bands in various combinations were identified in the above-mentioned species. They were numbered as bands 5 (Rm 78%) to 9 (Rm 64.6%) on the basis of their relative position in the electropherogram (Avtalion and Wojdani 1971). Plate 1 shows bands 6 to 9.

All the species present a slight intraspecific polymorphism. However, there are several interspecific differences which permit distinction between the different species (Avtalion et al. 1976). These interspecific differences were made more pronounced by eliminating from the parental stocks, individuals exhibiting overlapping transferrin markers (e.g., transferrin 9 in *S. aureus*) (Plate 2). After five years of selection, *S. aureus*, an endemic Israeli species, always presents transferrin 8 while the presence of transferrin 6 is still variable. On the other hand, *S. niloticus* from different origins always have the transferrins 7, 8 and 9: up to now it has not been

S. niloticus (Ghana)

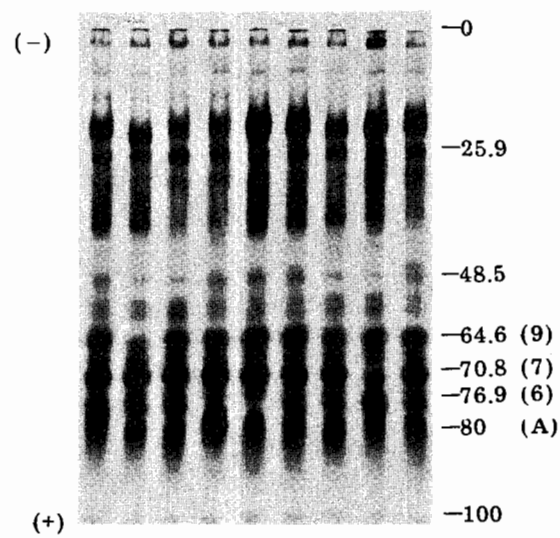

Plate 1. Electropherogram of *S. niloticus* (Ghana) in 6% polyacrylamide gel. Note the homogeneity of transferrins (7)-(9). (A) = Albumin; the figures are % relative mobilities.

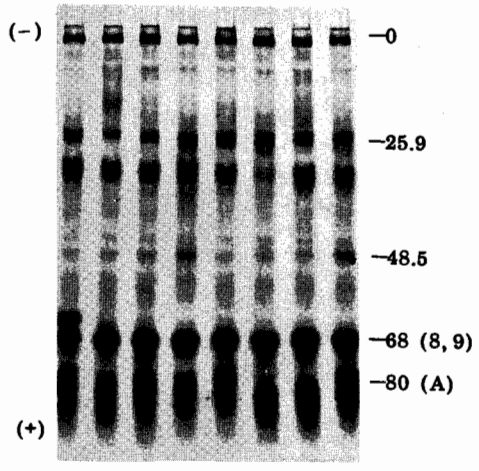

Plate 2. Electropherogram of *S. aureus* in 6% polyacrylamide gel. Individuals presenting xenogeneic bands (arrow) are normally eliminated from the breeding stocks. (A) = Albumin; (9) (8) are transferrins; the figures are % relative mobilities.

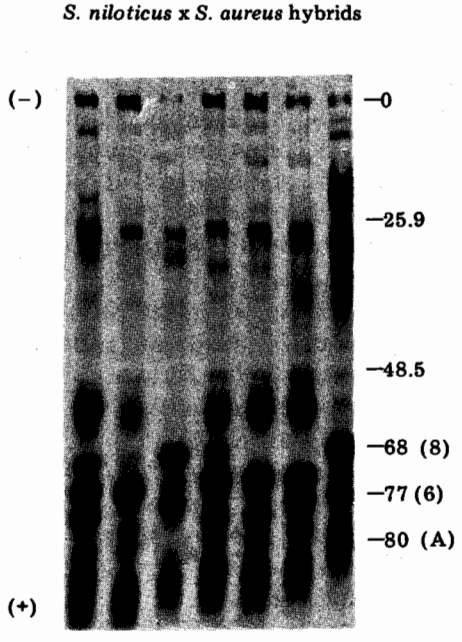

Plate 3. Electropherogram of *S. niloticus* ♀ x *S. aureus* ♂ hybrids in 6% polyacrylamide gel. All the possible transferrin combinations are found in F_1 hybrids. (A) = Albumin; (6) (8) are transferrins; the figures are % relative mobilities.

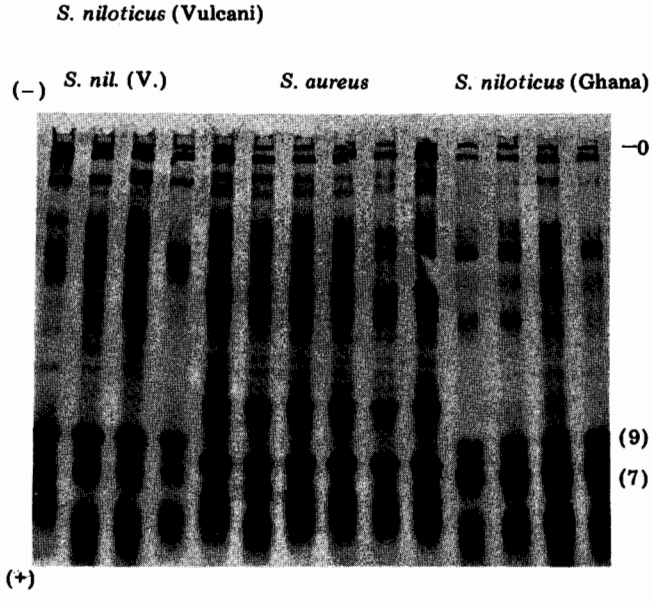

Plate 4. Differential identification of the selected monomorphic lines of *Sarotherodon* spp. From left to right: *S. niloticus* (Vulcani) where band 9 presents the higher density, *S. aureus*, where band 8 is constantly present and *S. niloticus* (Ghana) where band 7 is quantitatively more intense than the other transferrins.

possible to select for the elimination of band 8 in order to avoid any overlap with *S. aureus*. Bands 5 and 6 are sometimes present. The differential identification of these two species and their hybrids is based on the constant presence of bands 7 and 9 in all *S. niloticus* and their total absence in *S. aureus*. In the hybrids, however, all possible combinations occur (Plate 3). There are also some slight differences in this respect between *S. niloticus* (G) and *S. niloticus* (V). While both of them possess bands 7, 8 and 9, band 7 is quantitatively more intense in *S. niloticus* (G), whereas band 9 is more intense in *S. niloticus* (V) (Plate 4).

Enzymes

A study of some allozymic variations in *Tilapia* and *Sarotherodon* was carried out by Chen and Tsuyuki (1970). They studied serum esterase (SE), glucose-6-phosphate dehydrogenase (G6PD) in the liver and erythrocytes and lactate dehydrogenase (LDH) from serum and other tissues (muscle, eye, intestine, liver, ovary, heart, kidney and erythrocytes). Two species of mouthbrooder, *S. mossambicus*, *S. hornorum* and their hybrids, and two other species of substrate-spawners *(Tilapia zillii* and *T. rendalli)* were tested. No significant interspecific variations, in both SE and LDH were obtained within the *Sarotherodon* species, although enough variability was found to distinguish between *Tilapia* and *Sarotherodon*. On the other hand, the erythrocyte and liver G6PD showed significant interspecific polymorphism.

Isoenzymic variations in different cichlids from the sea of Galilee were investigated by Kornfield et al. (1979). Six different species were tested, three tilapias *(S. aureus*; *S. galilaeus* and *T. zillii)*, two *Tristamella* species *(Tr. sacra* and *Tr. simonis)* and a species of *Haplochromis (H. flaviijosephi)*. The interspecific similarities within these species were determined, mainly by investigating the interspecific variations in different enzyme systems (e.g., adenylate kinase, esterase, isocitrate dehydrogenase, lactate dehydrogenase, 6 phosphogluconate dehydrogenase). Twenty-one allozyme loci were resolved in all these species. Using Nei's coefficient (I_N) of genetic identity (Nei 1972), interspecific similarities, ranging from $I_N = 0.95$ within *Tristamella* and 0.92 within *Sarotherodon* to less than 0.25 for *Haplochromis*, were determined. A phenogram derived from these similarities shows that *Tristamella* is closely related to, but equidistant between, *Sarotherodon* and *Tilapia*.

Two serum enzyme systems (LDH and SE) are being studied in our laboratory in order to evaluate the interspecific variations in *Sarotherodon* spp. (Avtalion et al., in prep.). At least three different LDH bands could be shown, presenting an interspecific polymorphism, but no species-specific pattern could be shown. For this reason, LDH is not utilized in our systematic control test of broodstocks. The SE system shows no intraspecific polymorphism but *S. aureus* has a unique species-specific esterase band, located in the transferrin region of the electropherogram, having an Rm of 77.6%. The most interesting finding was that all the different *S. niloticus* tested,