The culture of *Tilapia* species in tropical and subtropical conditions

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Summary

Although since long known by African fishermen it is only in the last 40 years that Tilapia has been recognized as one of the most promising groups of fish species for culture. The initial successes for culture in Central Africa were followed by several failures mainly because of excessive breeding and early sexual maturity in shallow waterbodies as ponds.

From the present knowledge it appears that tilapia has a great future for increasing the productivity in unmanaged environments as man-made lakes and reservoirs primarily destined for the production of hydroelectricity. Careful stocking of paddies and irrigation canals can solve a number of biological problems associated with them and provide an additional though valuable high-protein food source. Great future offers also the culture of tilapia in traditional pond culture especially in polyculture with members of the carp family, mullets and waterfowl in areas of the tropical and subtropical belt. In coastal ponds T. mossambica *is a valuable species for sanitary reasons.*

The culture of tilapia in small farm ponds often meets with failure owing to excessive breeding and stunting unless the all-male technique can be applied through government input and encouragement. As a rule this type of production will be the least attractive.

Although Tilapia *spp. do not achieve the largest individual growth their tolerance towards adverse conditions and their acceptance of a wide variety of foodstuffs, primarily waste products from agriculture, their resistance to diseases and (at least in some species) their tolerance of crowded environments make them suitable subject for cultures in raceways, circular tanks and cages. Through heavy inputs of water and pelletized feeds nearly incredible annual yields as 2 000 tonnes per ha of water surface (1) and more were realized. This means that this type of production surpasses by far any other known form of animal husbandry but it needs high technological input (thus capital) and skill which are seldom available in developing countries where the need for fish is the greatest.*

Tilapias gained rapid popularity as cultured species in many parts of the world but their often indiscriminate transplantation and the fact that cross-breedings between species occur very easily resulted in hybrids which are often impossible to identify. In view of the genetic work for producing fastgrowing and late maturing stock lines it is necessary to conserve what pure stocks still remain in the world. This can only be achieved by an international institute.

Résumé

Bien que les espèces de Tilapia *soient déjà connues depuis longtemps par les pêcheurs africains, ce n'est que depuis quelques 40 années qu'elles ont été reconnues très propices à la culture intensive. Les succès initiaux en Afrique centrale ont été suivis par de nombreux échecs dus à la reproduction prolifique et la maturité sexuelle précoce dans des milieux peu profonds comme les étangs.*

Des connaissances actuelles il ressort que les tilapias ont un grand avenir pour augmenter la productivité de milieux non-aménagés comme les lacs artificiels et les réservoirs destinés en premier lieu à la production d'énergie hydroélectrique. La mise en charge soigneuse de paddies et de canaux d'irrigation peut résoudre un nombre de problèmes biologiques et en même temps apporter une source additionnelle mais non négligeable de protéines animales. Un grand avenir attend aussi la culture en étangs traditionnels spécialement en polyculture avec des membres de la famille des cyprins, mulets et d'oiseaux aquatiques dans les régions tropicales et subtropicales. Dans les étangs côtiers T. mossambica *est une espèce de grande valeur due à son rôle écosanitaire.*

La culture des tilapias en exploitation familiale est souvent décevante à cause de la reproduction prolifique et du nanisme. Ce problème peut être résolu par l'application de la culture monosexe (mâles) avec l'aide et l'encouragement de la part d'instances gouvernementales. En général ce type de production sera le moins attractif.

Bien que des espèces de tilapias ne réalisent point la croissance individuelle maximale, leur tolérance envers des conditions adverses et leur capacité d'utiliser des nourritures variées, en premier lieu des déchets de l'agriculture, leur résistance à des maladies et (au moins dans quelques espèces) leur tolérance aux conditions de surpeuplement les rendent des sujets intéressants pour la culture en «raceways», étangs circulaires et cages. Par des apports importants d'eau et d'aliments en forme de pellets, des productions annuelles pratiquement incroyables de 2 000 tonnes à l'hectare de surface d'eau (1) ont été réalisées. Ce type de production n'est à présent surpassé par aucun élevage connu mais un apport considérable technologique (donc de capital) et de connaissances est indispensable. Ces deux facteurs manquent en général dans les pays en voie de développement où les besoins en poissons sont les plus grands.

Les tilapias ont gagné une très grande popularité dans plusieurs régions du monde mais leur transplantation sans discernement et la fréquence de croisements interspécifiques ont provoqué des hybrides pratiquement non-identifiables. En vue de travaux génétiques pour la production de lignées à croissance rapide et à maturation sexuelle tardive, il est nécessaire de préserver les souches pures encore existantes. Ceci ne peut être réalisé que par une institution internationale.

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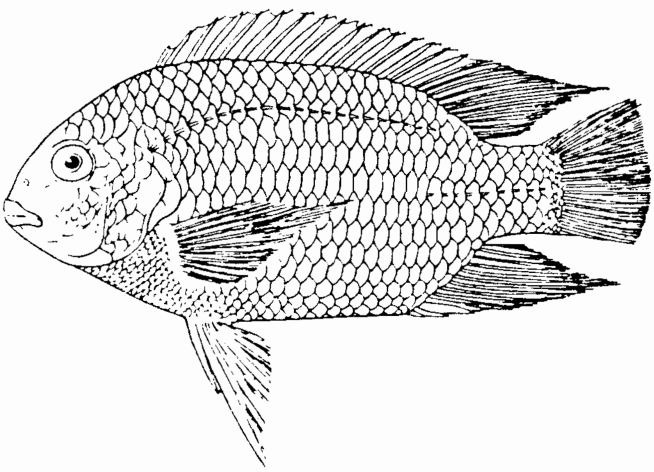
The old genus *Tilapia*, which was recently split in three new genuses *Tilapia*, *Sarotherodon* and *Oreochromis* (†), formerly occurred only in Africa. The species *O. mossambicus* was found in Indonesia in 1939 and after World War II more species were brought to the Far East and Papua-New Guinea (1954). Their introduction in tropical Middle and South America is still more recent. At present *Tilapia* spp. are found in over 120 countries. Because of their great external resemblance the above-mentioned new generic names will not be used here-after and will be termed simply "tilapia" under which name the group is best known among fish culturists.



Tilapia rendalli (from POLL, 1957)

Biological characteristics of *tilapias*

Common feature of all tilapias is their dependence on high temperatures. Most species even die at prolonged exposures to temperatures about 10° C. Optimal temperatures for growth rate and food conversion generally are in the vicinity of 25° C and tilapia culture is only interesting if temperature does not drop below 22° C during its growth and reproduction cycle. Figure 1 displays the temperature range for the most important species.

A second common feature of these species is the parental care which is displayed in their characteristic nest-building and in most species in mouth-breeding. Because of this parental care, survival of their progeny is very high which in the absence of density controlling factors leads to high numbers and stunted growth.

A third economically important feature is their tolerance of low oxygen levels. This characteristic makes them particularly suitable for culture in tropical water. An oxygen level of 1 ppm becomes critical to most species although some can tolerate less, e.g. *T leucosticta* which can survive in virtually oxygenless waters.

This low tolerance level of oxygen makes tilapia culture interesting if mechanical aeration is to be used. Indeed from the formula for oxygen transfer rate

(†) *Tilapia* spp substrate spawners, *Sarotherodon* biparental or paternal mouth brooders *Oreochromis* spp maternal mouth brooders

$$OT = OT_{20} \frac{\lambda C_s - C_p}{C_{s,20}} (1.024^{T-20})\,\alpha$$

in which: OT = actual oxygen transfer rate

OT_{20} = standard oxygen transfer rate (given by the constructor of the device, assumed to be 2 kg O_2/kWh)

$\lambda = \alpha = 1$

C_s = oxygen saturation level at ambient temperature (= 9.87 mg/l at 16° C and 8.26 mg/l at 25° C)

C_p = desired minimum oxygen level to be maintained in the pond (= 5 mg/l for trout and 2 mg/l for tilapia)

$C_{s,20}$ = oxygen saturation value at 20° C

T = temperature (= 16° C for trout and 25° C. tilapia)

the OT-values for trout and tilapia-cultures can be compared. They are 0.9744 kg O_2/kWh for trout and 1.5511 kg O/kWh for tilapia respectively. This means that in tilapia the energy input can be more efficiently used than in trout culture.

Oxygen consumption per unit weight depends on fish species, individual weight, temperature, dissolved oxygen content and stomach fullness. Generally, the relationship between oxygen consumption rate (R) and individual weight (W) is described by the relationship:

$$R = \alpha W^{v}$$

wherein: α = constant depending on temperature, dissolved oxygen content and stomach fullness

v = constant.

Several authors demonstrated that between 20 and 30° C oxygen consumption of fed tilapia is independent of temperature and can be described by the relationship

$$R = 0.001\ W^{0.82}$$

wherein: R: oxygen consumption per fish (g O_2/h)
W: live weight of individual fish (g).

This means that in a 1 hectare pond with an average depth of 1 m, 10 000 specimens of each 250 g would consume about 11, 104 g O_2 in 12 h The equivalent figure for rainbow trout at 20° C is 9 875 g O_2 in 12 h. This means that in 12 hours these tilapias would reduce the oxygen content with about 1.11 mg/liter.

As a whole tilapias seem to consume less oxygen than their European counterparts under the same conditions. This is particularly useful in intensive culture since with tilapia the nighttime dissolved oxygen decline will be less pronounced than with European fish (e.g. carp).

Among the tilapias several species can tolerate remarkably high salinities, especially as full-grown specimens, and in fact a species as *T mossambica* is used

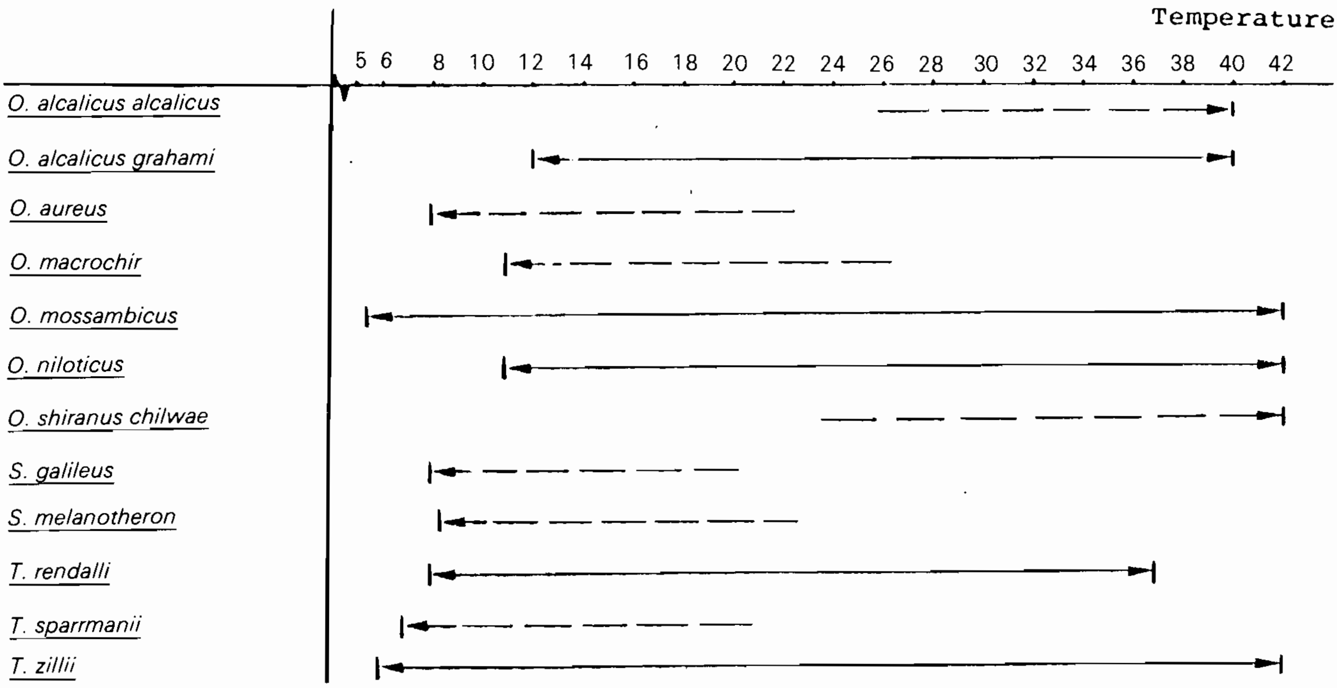


Figure 1 · Temperature tolerances of the most important Tilapia spp. for survival

as a secondary species in brackish milkfish ponds "tambaks" in Indonesia for removing floating algal mats and mosquito larvae.

In table 1 one finds the maximum salinity level for reproduction, larval survival and growth of the most important species.

The resistance of several species to higher salinities is attributed to the fact that they evolved from marine ancestors which penetrated fresh water (5, 15). In fact growth of juvenile *T. mossambica* is better in 50% sea-water than in fresh-water.

As to the feeding regime, the tilapia -group falls in two categories. A first one feeds mainly on aquatic and terrestrial macrophytes *(T rendalli, T. zillii)* whereas the second larger group is omnivorous and can digest large quantities of micro-algae. *T. mossambica* eats blue-green algae, filamentous algae, Charaphyta, mosquito larvae, mayflies, beetles, worms and *Gambusia;* it readily accepts a variety of cheap, easily obtainable foodstuffs of vegetable origin. *T. nilotica* feeds mainly on algae (blue-greens, green algae, diatoms, nanno-plankton), rotifers, copepods, insect larvae. Cladocerans are only consumed by small specimens up to

TABLE 1

Highest salinity levels for several cultured *Tilapia* spp. at different stages

Species	Transfer from freshwater	Reproduction	Larval survival	Growth	Reference
T. nilotica	20,2-25 ‰ (direct) 53,5 ‰ (gradual)	17,5 ‰ (slightly less than in freshwater	17,5 ‰	17,5 ‰ (normal)	Lotan, 1960 Chervinski, 1961
T. mossambica				17,5 ‰ (highest growth rate)	Canargaratnam, 1966
		30 ‰		30 ‰ +	Vaas & Hofstede, 1952
		35 ‰			Hora, 1955
		35 ‰	35 ‰	35 ‰	Canargaratnam, 1966
T hornorum		35 ‰	35 ‰ß	35 ‰	Talbot & Newel, 1957
T. zillii		29 ‰	29 ‰	29 ‰	El Zarka, 1956
		42,7 ‰	42,7 ‰	42,7 ‰	Bayoumi, 1969
T. galilea		⩾13,5 ‰	⩾13,5 ‰	⩾13,5	El Saby, 1951
T. aurea	21 ‰	19‰		53,5 ‰	Wohlfarth & Hulata, 1981
			Less survival at increasing salinity up to 17,5 ‰		Payne & Collinson, 1983
T. rendalli				dies at 13,5‰	Wolfarth & Hulata, 1981
T, sparmanni				dies at 17‰	Wolfarth & Hulata, 1981

50 mm total length whereas *Euglena*, filamentous algae and higher plants are found in the guts of all but the smallest fish of up to 20 mm total length. In ponds this species consumes also epiphytic diatoms and bottom organic debris. Cotton-seed cakes are readily ingested even by juveniles of only 2.5 g weight. *T. nilotica* is able to digest blue-green algae (4).

T. esculenta feeds almost entirely on phytoplankton (diatoms, blue-green algae, filamentous green algae) and rotifers. Blue-greens, though ingested, are not digested and can even cause growth retardation. This species only consumes "artificial" food when the natural supply is virtually exhausted.

T. macrochir changes its feeding habits with length. Fish smaller than 30 mm eat periphyton (70%) and plant debris, chironomids, coleopterans and some higher plants (30%); 30-75 mm long fish eat progressively smaller amounts of micro-organisms (50% at 75 mm total length). Above 75 mm, the quantity of organic debris ingested increases and only 30% of micro-organisms are found in the gut content.

T. aurea changes its food with length. Small fish eat water fleas, copepods, dipterans, ostracods, rotifers whereas larger fish eat oligochaetes, phytoplankton and organic debris though *Microcystis* spp. are not digested.

Tilapia spp. display a great adaptability to available food. If a shortage in their preferred food items occurs they readily switch to whatever is present in their biotope: this is the main reason of their eating almost anything which is given to them, also all kinds of food of terrestrial origin (mainly remnants of processed food-stuffs and leaves of several plant species).

Tilapias as cultured species

The main problem encountered in the culture of tilapia is their excessive reproduction under several climatic conditions. Whereas in large waterbodies sexual maturity is reached at greater length (± 20 cm), the number of eggs is smaller and the eggs are larger the reverse is true in smaller, shallower waters as ponds. Owing to this unique feature nanism (dwarf growth, stunting) resulted in the early attempts of tilapia culture. This problem was approached by cultural methods, distribution of large quantities of "artificial" food, introduction of piscivorous fish species. Neither of these measures proved successful in all instances and in fact many failures were recorded. The following step in the controlling of the excessive reproduction was the all-male culture either by selecting of males from wild stocks (which proved to be difficult to achieve), by cross-breeding of tilapia species resulting in all-male offspring (which is only applicable with a very limited number of crossings) or by sex-reversal through the administration of male hormones with the food such as methyltestosterone and similar substances.

Another approach to this ever-existing problem in pond raised tilapia is polyculture with other fish species as is done in Israël. The simultaneous presence of such species as common carp, silver carp, tilapia and mugils has proven to give excellent results probably by the interference of the nest-building by the bottom-dwelling common carp. Moreover such a system provides the best possible use of all available food sources and makes it possible to have the best profit of the synergism between the different fish species. In other regions (Indonesia, USA, Taiwan, Kenya) other polycultures proved equally successful.

Cage culture of tilapias is also possible with some species. In such conditions breeding is virtually impossible and if so eggs are lost through the meshes of the screens or cages. In very intensive culture systems such as raceways egg production is inhibited because of the unsuitability of the substrate for building nests and the mutual interference by the individual fish.

As in other fish cultures, different levels of intensification can be envisaged

1. Extensive systems

Tilapias can be a valuable asset in the exploitation of water bodies such as artificial reservoirs e.g. in Sri Lanka; (8, 12), pools and reservoirs left after the cessation of mining operations and, though of a more controlled nature, paddies. Generally breeding is subjected to natural control and some increase of the natural productivity is achieved by irregular dumping of agricultural wastes or manure. Yields are moderate (less than 1.5 t/ha/yr) and harvested by different methods such as cast-nets, seines, hook-and-line etc.

2. Subsistence ponds

These are generally small surfaces which are stocked with fingerlings and are situated near the house of the farmer. They are mostly a part of the area used by a small-holder who grows different crops and raises also some livestock. Kitchen waste, cut grass, weeds and manure from chickens, swines or cattle are dumped into the pond. Although in the beginning the result can be quite encouraging owing to government input, it is in this type of production that the disadvantage of tilapia becomes very obvious. The fairly high yield (2t/ha/yr) consists of numerous stunted fish because of the prolific nature of tilapia and by the counter-selection exerted by the continuous harvesting of the largest fish for domestic use. The individual weight will drop to a discouraging 50 g. Moreover failures owing to oxygen deficiency, accumulation of toxic compounds, lack of water supply, biological problems such as snails and the aversion against the use of animal wastes for a product destined for human consumption will aggrevate the situation resulting in complete neglection of the pond. Growers unfamiliar with fish raising, as in

Africa, will soon abandon the system since it does not fullfil the expectations of a high-quality final product.

3. Intensive culture

Intensification of tilapia (and of fish culture in general) involves the application of different measures resulting in the improvement of the habitat and in controlling the excessive reproduction of the tilapias. These measures are:

- foreseeing a constant supply of water to account for losses through evaporation and seepage, and in a more advanced stage for removing toxic excretory products.
- improvement of the water quality mainly to increase the alkalinity of the water in order to prevent too high pH-values under conditions of high photosynthesis.
- application of mineral or organic fertilizers in order to increase the production of natural food items, Organic fertilizers can be supplied by the simultaneous culture of pigs and/or ducks.
- polyculture with species that interfere with the nest-building of the tilapias.
- polyculture with predators that feed on the numerous small fish.
- all-male cultures made possible either by screening of the males of a mixed-sex population or by introduction of sterile male hybrids or by sex reversal techniques.
- controlling the oxygen levels by suitable construction of the pond, and in a more advanced stage by mechanical devices.
- use of pelletized feeds of standard composition and sizes together with automatic or auto-feeders.

The intensification of the output can be done in classical ponds (1-2 m deep) of different size, in artificial ponds (generally raceways with a high through-put of water) or in cages made of local materials such as bamboo sticks or of netting materials. These cages are kept floating by drums or expanded polystyrene blocks.

3.1. Ponds

Following Balarin (2), a maximum production of 5t/ha/yr can be attained in tropical countries under semi-natural conditions. The water level should be kept as stable as possible; fertilizers and/or manure are used to increase the production of natural food items which are often supplemented with feeds.

The maximum profit can be obtained by polyculture. Different types can be used depending on the fish species available in the region.

Indonesia:

Cyprinus carpio (common carp: 30%), *T. mossambica* (35%), *Osphronemus gouramy* (giant gurami: 15%), *Osteochilus hasseltii* (nilem: 20%).

also: *Cyprinus carpio* (10%), *Helostoma temmincki* (kissing gourami: 20%), *T. mossambica* (40%), *Osteochilus hasseltii* (15%), *Puntius gonionotus* (lampan jawa:15%).

Israel:

Cyprinus carpio (46%), *T. nilotica* (53%) or *Cyprinus carpio* (34/24%), *Mugil cephalus* (mullet: (36/45%), Tilapia-hybrid (30/31%)
or
Cyprinus carpio (67%), *T. aurea* + hybrid (8%), *Ctenopharyngodon idella* (grass carp: 5%), *Hypophthalmichthys molitrix* (silver carp: 20%)
or
Cyprinus carpio, Tilapia, Hypophthalmichthys molitrix, Mugil cephalus (variable percentages, experimental).

Taiwan:

Hypophthalmichthys molitrix (10%), *Mugil cephalus* (12%), *T. mossambica* (50%), *Anguilla japonica* (Japanese cel), *Aristichthys nobilis* (bighead), *Carassius auratus* (goldfish), *Chanos chanos* (milkfish) (last four species together: 28%).

Kenya:

Cyprinus carpio, Mugil cephalus, Tilapia zilli (all species at equal percentage).

Uganda:

Cyprinus carpio, Tilapia-hybrid (each 50%).

USA:

Ictalurus puntatus (channel catfish: 78%), *T. mossambica* (22%).

In some countries polycultures of tilapias with predators are used:

Hemichromis fasciatus: (5-10% of initial biomass)
Haplochromis darlingi
Hudrocynus brevis
H. forskahlii
Cichlasoma managuense (with *T. aurea:* 1/4-1/8)
(with *T. rendalli:* 1/4-1/8)
Elops hawaiiensis (with *T. mossambica:* 1/10-1/20)
Megalops cyprinoides (with *T. mossambica:* 1/10)
Micropterus salmoides (with *T. mossambica:* 1/10)
Lates niloticus (with *T. mossambica:* 1/30)
(with *T. nilotica:* 1/20-1/84)
Channa striata (100-150/ha with *T. nilotica*)
Cichla ocellaris (with *T. nilotica: 1/15*)
Clarias lazera (with *T. nilotica:* 1/10).

If problems with snails are encountered small numbers of snail-eating fish species can be added e.g. *Mylopharyngodon piceus* (black carp), *Haplochromis mellandi, Clarias alluaudi* and *C. lazera* and other species.

This type of production is the least sophisticated and requires minimal capital costs provided land is easily obtainable. In subtropical areas with long dry periods the productive period per annum can be lower than in the wet tropical zone. Consequently the production on a yearly basis will be lower and sometimes provisions should be made for the overwintering of cold-sensitive species.

More sophistication can be put in ponds involving all-male populations, aeration, pelletized feeds and water flow. Aeration is a prerequisite if production is pushed beyond 5t/ha/yr because the natural purification capacity is no longer able to maintain a suitable environment for the cultivated fish. This means that the pond manager will have to check periodically (daily or twice daily) the main environmental factors in aquaculture: oxygen and ammonia (together with temperature and pH). He will have to deal with stress and emergency situations and install alarm systems. The denser the population and the higher the yield which is envisaged the greater the risk of failure. Automatic feeders or autofeeders are an absolute necessity. With all this equipment and perfect knowledge of the constraints of aquacultural production 25 tons of fish were harvested per year per ha in ponds.

Often the pond is not solely destined for the production of fish but the surface is also used for production of waterfowl, which by their droppings contribute greatly to the feeding of the fish.

3.2. High-density structures

In these totally unnatural constructions fish are maintained at high densities. Therefore these systems are the aquacultural counterpart of the feed-lots in livestock production in industrialized nations.

The system depends on the through-put of large amounts of water for excretory waste and unused feed removal and on the use of all technology necessary for intensive fish ponds. All-male populations will not be necessary since these habitats are not suitable for parental care and so will restrict breeding.
High-density structures are tanks, raceways, silos and cages kept floating in lakes or reservoirs.

It must be emphasized that not all fish species and especially some tilapia species are suitable for such crowded environments.

T aurea is a useful species because of its resistance to bacterial diseases. *T nilotica* is reported to perform well in crowded environments as cultures in thermal effluents from power plants have shown. *T. mossambica* on the contrary is unsuitable because this species displays hypersensitivity to a component present in mucus and culture water This substance induces cutaneous anaphylactic reactions resulting in steady low-level mortality (1-2% per day) in the most densely stocked tanks (1 specimen per liter; original weight not given by the authors). This reaction was not found in similar and simultaneous experiments with *T. aurea* but in mixed cultures the substance produced by *T. mossambica* adversely affected *T. aurea.* Similar reactions are known for other fish species too. This reaction limits the density at which *T. mossambica* can be stocked and also restricts this species' use in polyculture with other tilapias because it affects other species within the genus.

In high-density structures, the flow of water must be able to remove excretory waste products in order to keep the water quality at a minimum level. So regular checking of different chemical parameters as in intensive pond culture and of the behaviour of the fish will be compulsory. In the Baobab-system developed by Balarin (2) in Kenya, fry is raised in concrete raceways and fattening is done in self-cleaning circular tanks. These yield over 100 kg/m^3/yr under intensive feeding which means a production of 2 000 t/ha/yr. The system depends primarily on a reliable water source and intensive feeding with pelletized feeds.

The effluent of the production units can be used for irrigating agricultural crops since they carry nitrogen and phosphorus compounds which stimulate growth of cash crops. The by-products of these field crops can form the bulk ingredients in the feeds. Biogas can be generated from the fish faeces, prawns can be grown in effluent waters and crocodiles can be reared on rejected trash fish. So "total integration provides a highly viable commercial enterprise" (2). For more information the reader is referred to the excellent review of Ballarin & Haller (2).

In cage culture, problems can arise from reduced flow-through owing to the fouling of the structure. TATUM (20) claims these problems can be solved by introducing 30 *Mugil cephalus* (individual weight 20 g) per m^3 cage volume in brackish water With *T. nilotica* there seems to be no problem since this species was observed to browse on algal colonies (e.g. *Spirogyra* spp.) which may develop on the cage walls (6).

4. Irrigation ditches

The main channels of an irrigation system can be completely choked by submersed waterplants which hamper water flow and provide habitat for a number of nuisance causing creatures such as snails and mosquitoes, intermediate hosts of bilharziosis and malaria among others. Fish species such as *T. zillii* can radically combat the problem by eliminating the weeds and indirectly control the snails. *T. mossambica* destroys the floating patches of filamentous algae in which *Anopheles* spp. find ideal space for development. In an experiment in Southern California HAUSER et al. (1977) used 2 500 75 mm fish per ha for controlling a number of weed species with *T. zillii* but the Eurasian watermilfoil *(Myriophylleum spicatum)* was disliked by this species and so the latter can continue to develop and may reach nuisance proportions. So a careful choice of the *Tilapia* sp. in relation with the nuisance weed present is obligatory for successful control.

Through proper application and management of *Tilapia sp.*, eventually in combination with other fish species, the use of chemicals in this particular situation can be reduced, energy and fresh water can be saved and additional protein can be produced.

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