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DATA SHEET ON BIOLOGICAL CONTROL AGENTS: TILAPIINE FISH[1]

CONTENTS

[1] Information document produced by Ronald J. Roberts and David R. T. Sampson, Institute of Aquaculture, University of Stirling, Stirling, Stirlingshire, United Kingdom, for WHO Division of Vector Biology and Control.

1. INTRODUCTION

Because of the present concern of the effects of insecticides on the environment, the use of biological agents for controlling the vectors of human disease are becoming increasingly popular. The two vectors of perhaps greatest importance in tropical medicine - the aquatic snail and the mosquito - are both water-borne for at least part of their life cycle. The latter can transmit diseases such as malaria, yellow fever and dengue, as well as carry filaroid nematodes and approximately 80 viruses (Mattingley, 1969). Specific tropical snails (Biomphalaria, Bulinus, Oncomelania) can transmit schistosomiasis and serve often as an intermediate stage for other parasites infecting man.

The use of chemical methods to control water-borne vectors of disease has been losing favour recently because of the possibility of long-term detrimental effects on the environment. The use of biological control agents provides an alternative, but their effect on the environment must first be carefully assessed and then monitored following their introduction. The use of fish as biological control agents has been an option for some time, and research has shown that they can be effective for controlling a number of mosquito larvae (Davey et al., 1974; Legner & Fisher, 1980; Legner & Medved, 1973) or snails (McMahon, Highton & Marshall, 1977) present in a water body.

However, the transfer of fish of proven ability in mosquito control to a new environment may not give the expected results and perhaps cause the decline of other desired fish populations. It is thus preferable to use species that are already present in a locality even if their ability to control the vectors is not well documented. If there are no suitable local species, then the use of exotic species under strict control may be the alternative, but with full awareness of potential risks.

The fish known as tilapia (including the genera Tilapia, Sarotherodon and Oreochromis) originated in the lakes and rivers of Africa (Trewavas, 1983). A few of the species have now become widespread partly because of their ease of culture and the quality of the flesh, but more often because of their ability to rapidly colonize all water bodies to which they have access. The reason for this can be attributed to their capability to consume a wide range of nutrients and their capacity for continuous reproduction. Tilapia do not produce large numbers of eggs at each spawning compared to carp or catfish, but when conditions are good (and there are a wide range of suitable conditions), a female may spawn every few weeks (Macintosh & Sampson, 1986). Moreover, because of the high degree of parental care, the percentage of fry surviving is often high. Of the several hundred species which can be classed as tilapia, only about 10 are cultured in any number outside their place of origin. These species are:

Tilapia zillii (Gervais)
T. rendalli (Boulenger)
Sarotherodon galilaeus (Linnaeus)
Oreochromis mossambicus (Peters)
O. niloticus (Linnaeus)
O. aureus (Steindachner)
O. (Urolepis) honorum (Trewavas)
O. spilurus (Gunther)
O. macrochir (Boulenger)

To the uninitiated the taxonomy of the tilapias can be very confusing. Several of the important aquaculture species are referred to variously under the three generic names: Tilapia, Sarotherodon and Oreochromis (e.g., Tilapia mossambica and Sarotherodon mossambicus are the same as Oreochromis mossambicus). Particularly in older publications on tilapia culture all species may be referred to as Tilapia.

The tilapia mentioned above are all very similar, with distinctions being made according to behaviour and geographical origin as well as differences in body structure or colour. The matter is now further complicated by the natural occurrence of hybrids in areas where two or more species have been introduced. Hybrids such as the red or golden tilapia (a cross between Oreochromis mossambicus and Oreochromis niloticus), found in China (Province of Taiwan), Indonesia, the Philippines and Thailand, are now being selected for commercial on-growing in preference to the fish with normal grey-silver coloration.

Tilapia are a useful aid in the fight against diseases spread by snails or mosquitos. The wide range of natural material that can be part of tilapia's diet allows them to feed on and destroy the environment of the vector as well as the vector itself. The wide range of conditions under which tilapia breed means that they can be bred and cultured with the simplest of facilities. Thus even in the most remote areas, tilapia can be cultivated and used as a biological control agent.

2. LIFE CYCLE

Tilapia are characterized by their high degree of parental care for their eggs and juveniles. The main distinction between the three genera included within the tilapia is the type of parental care. Tilapia can be initially divided into those which lay their eggs and attach them to the substrate, "substrate spawners" (these are the true *Tilapia* (e.g., *Tilapia zillii*)), and those which after laying their eggs collect them and brood them within one or both of the parents' mouths, "mouth brooders." Mouth brooders are subdivided: the group where the female mouth-broods the eggs is classified as *Oreochromis* (e.g., *Oreochromis niloticus*), the group where the male or both parents mouth-brood is classified as *Sarotherodon* (e.g., *Sarotherodon galilaeus*).

2.1 Courtship, spawning and parental care in *Oreochromis* and *Sarotherodon*

Before courtship can take place, the male will select a site and then, using his mouth, dig a depression in the substrate. This is called a nest. The male will defend his nest and the territory around it from all other males and immature tilapia, but will try to drive any ripe female into the nest. Ripe females may enter the territories of several males before choosing the nest in which they will spawn.

During courtship the fish swim close to each other, often in the head to tail position with the male nipping the flanks of the female. His fins stand erect and his body quivers. In some species the male genital papilla will become quite obvious (e.g., *O. macrochir*). The pair may not spawn straight away, interruptions from other excited males may occur, or the female or male may stop to make alterations to the nest.

Eventually spawning will take place. This can occur during any part of the day, but is most common during the afternoon or evening (Sampson, 1981). The female will shed her eggs into the nest where the male will fertilize them. The female (and male in the case of *Sarotherodon*) parent will pick up the eggs. The female *Oreochromis* will then leave the nest and will not return. The male is now able to spawn with other females.

The parents that brood the eggs and young will not feed during this period (Rothbard, 1979), although in ponds and tanks they may be attracted to food thrown into the water in their vicinity. They tend to keep away from other fish, particularly males in nests, by swimming near the surface or in the corners of ponds.

The buccal cavity provides a protective chamber for the developing embryos, but to accommodate the eggs the lower fleshy part of the bottom jaw expands to form the brood pouch. The fish can be seen moving their jaws to encourage water exchange, circulation and to turn the eggs so that they can develop correctly. The eggs are brooded orally through all the stages of embryonic development until the fry are free-swimming and able to feed on particulate matter in the water. The rate of development depends on the temperature, with the optimum being 27–30°C. The eggs hatch after a couple of days, but remain in the female's mouth for a total of 12-16 days after spawning before the fry are first released from the buccal cavity. The fry are incubated for a further 5-7 days, remaining outside for longer and longer periods until they no longer return (Rana, 1986).

2.2 Courtship, spawning and parental care in *Tilapia*

Unlike the *Oreochromis* or *Sarotherodon*, most of the *Tilapia* species are monogamous. Thus the fish may pair and remain together for a long period of time. The nest site is chosen usually by the male but both sexes participate in its construction (Rothbard, 1979). When the female is ripe, the male will stimulate her to release the eggs by nipping her flanks and shaking his body in a similar manner to *Oreochromis*. Eventually the female will lay the eggs in straight lines, stuck to the bottom of the nest. The male will then pass over the eggs and fertilize them.

The Tilapia can feed during the development of the young since the parents will take turns to guard the nest, and maintain the flow of "new" water over the eggs. After the eggs hatch, which typically takes 4-6 days, the hatchlings remain at the bottom of the nest. After a further 4-6 days, the yolk sac is reabsorbed and the fry are able to swim away from the bottom. They soon start feeding, and venture away from the nest. The parents will collect any fry that swim too far in their mouths and return them to the nest. After approximately 10 days the parents will no longer return the fry, which are then independent. Total development time to this stage can be 10-20 days, depending on species and temperature.

2.3 Maturation and sexual development

Tilapia that are cultured in ponds or tanks tend to develop sexual characteristics at a much smaller size (between 6-10 cm) than they do in a natural lake or river habitat (about 15-20 cm); this is called stunting (Iles, 1973). In culture systems stunting can occur when the pond is not harvested for a period of six months or more, or when the largest fish are cropped on a continuous basis (Hepher & Pruginin, 1982). Eventually the pond has a large population of small fish, a situation which is not advantageous if the pond owner intends to market the fish for human consumption since the small fish are generally difficult to sell. However, the occurrence of large numbers of small tilapia may be of benefit when they are to be used as biological control agents.

As the fish reach sexual maturity their coloration changes, becoming brighter and more diverse (Rothbard, 1979). The males quite often have a stronger and more distinct coloration than the females. A size difference between males and females may occur, although this only becomes really noticeable with fish that have been spawning for some time. Sexing fish based on size and colour is not very successful when the fish are small (5 cm or less and weighing less than 20 g) but the accuracy improves as the fish get larger (5 cm + or 20-50 g) (Hepher & Pruginin, 1982).

Sexual differentiation can be made from observations of the genitalia and with practice fairly high levels of accuracy can be achieved.

2.3.1 Males

Situated forward of the anal fin are two orifices. The larger and more forward of the two is the anus, and the second between the anus and the anal fin is the urogenital aperture. The latter is often located at the end of the papilla. In some species (e.g., Oreochromis macrochir) the papilla is very well developed and quite large.

2.3.2 Females

Situated forward of the anal fin are three orifices. The most forward of the three is the anus, the second is a transverse genital aperture, which may be situated at the middle of a fleshy papilla. At the tip of the papilla is a tiny opening which is the urinary orifice.

The differences in the genitalia combined with differences in size and colour can allow sexing to be fairly accurate.

Once the fish have reached maturity (a minimum of 100 days from when they first feed), they start to breed. The size of the brood is initially small (100-200 eggs/spawn). Some females are able to spawn between 6-10 times the following year and as their size increases, so does the number of eggs. In mouth brooders there may be more than 1000 eggs per spawn. The numbers of eggs produced by the substrate spawners may be considerably higher - up to 5000 per spawn from a large female (Lowe-McConnell, 1955).

FIG. 1. MORPHOLOGICAL DIFFERENCES BETWEEN MATURE MALE AND FEMALE
OREOCHROMIS MOSSAMBICUS

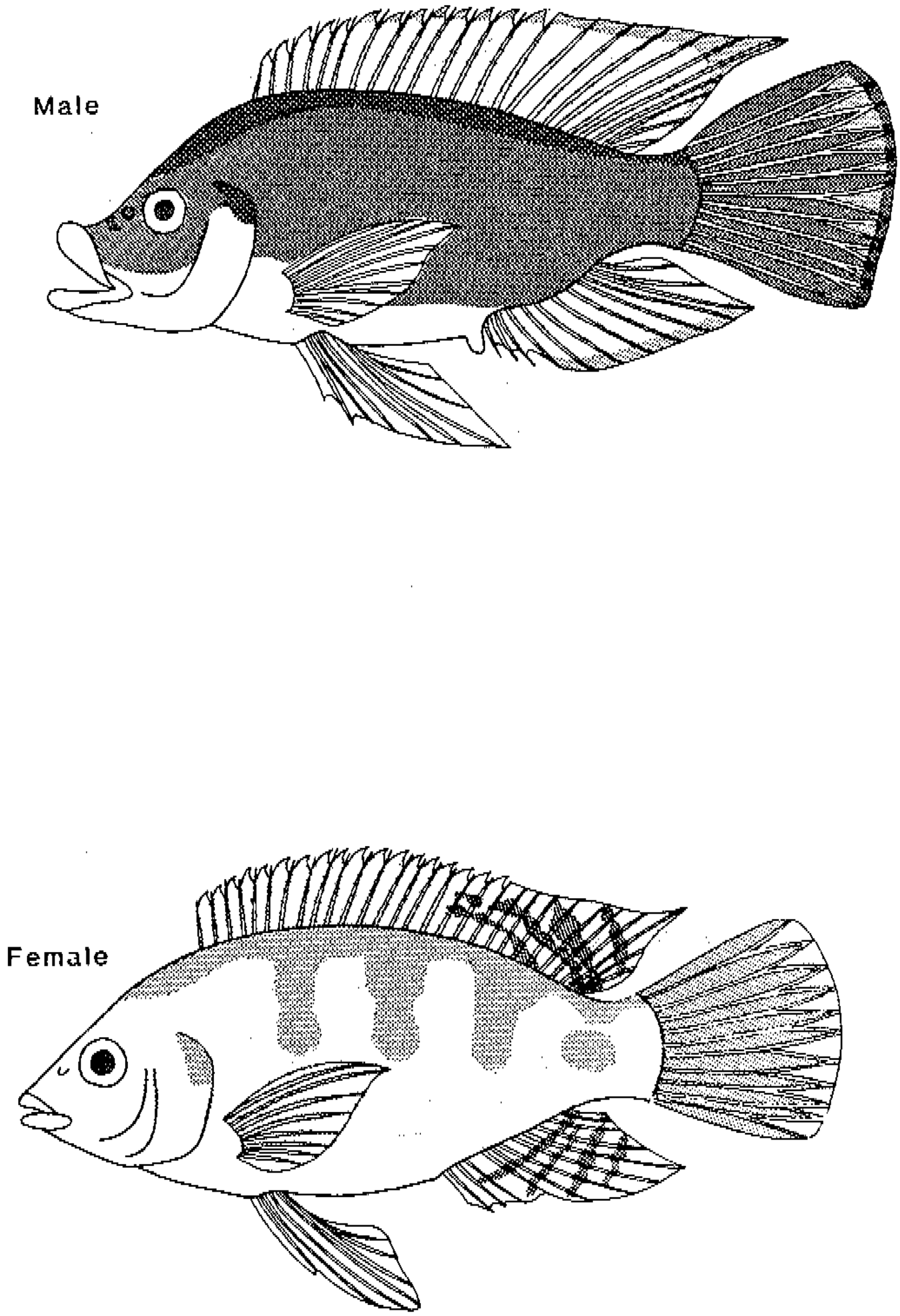


FIG. 2. MORPHOLOGICAL DIFFERENCES BETWEEN MATURE MALE AND FEMALE
<u>OREOCHROMIS NILOTICUS</u>

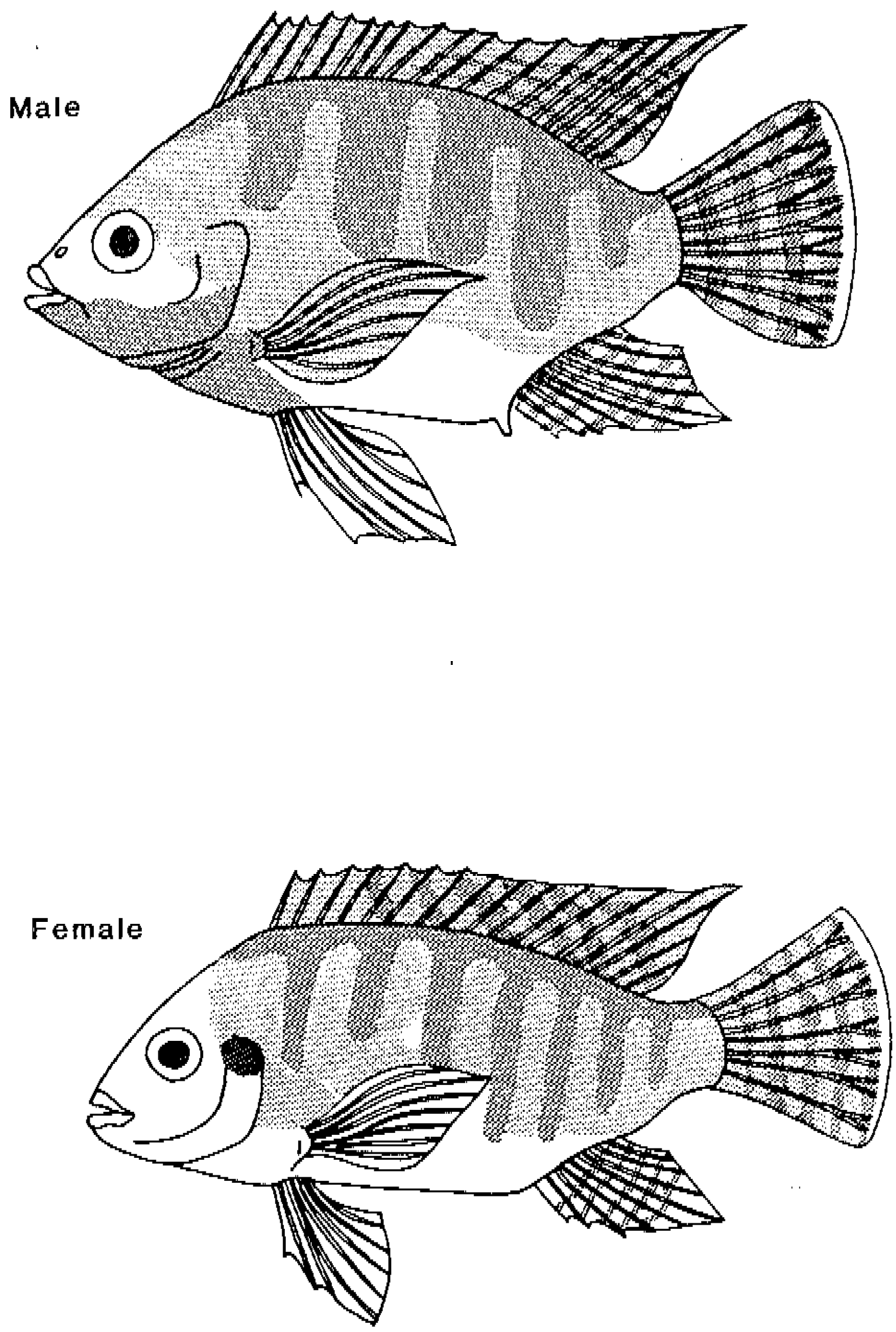
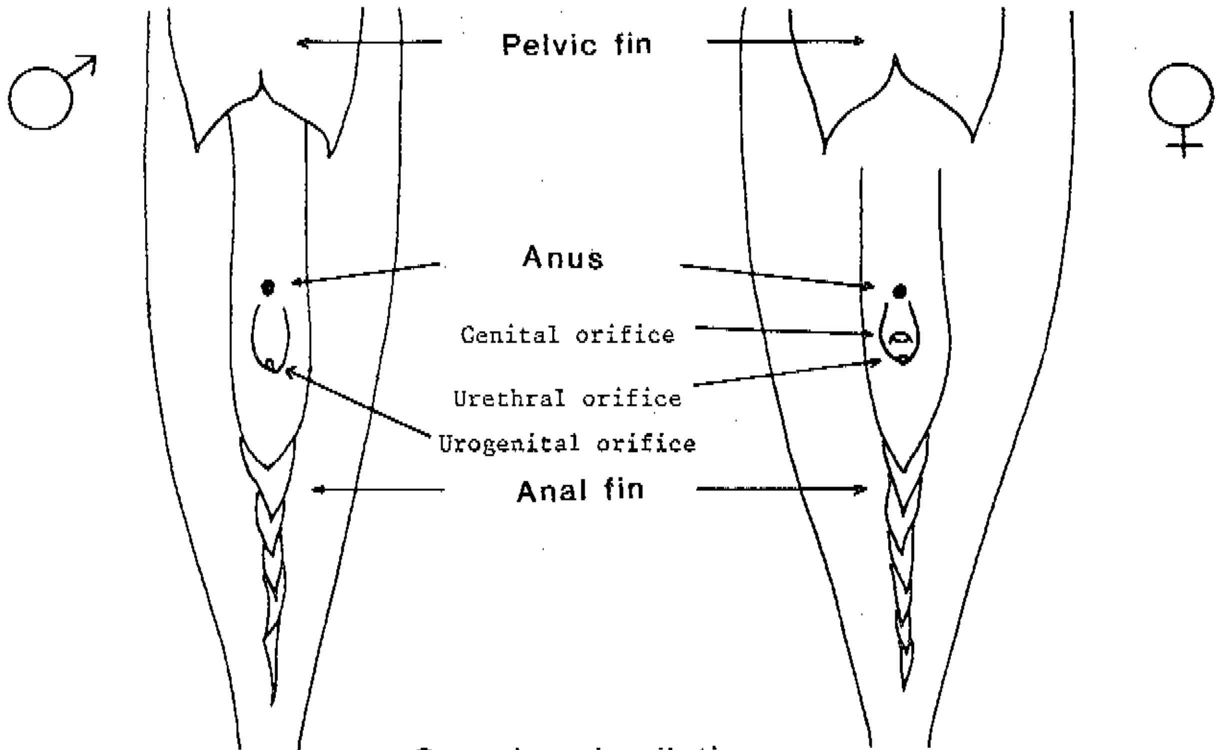
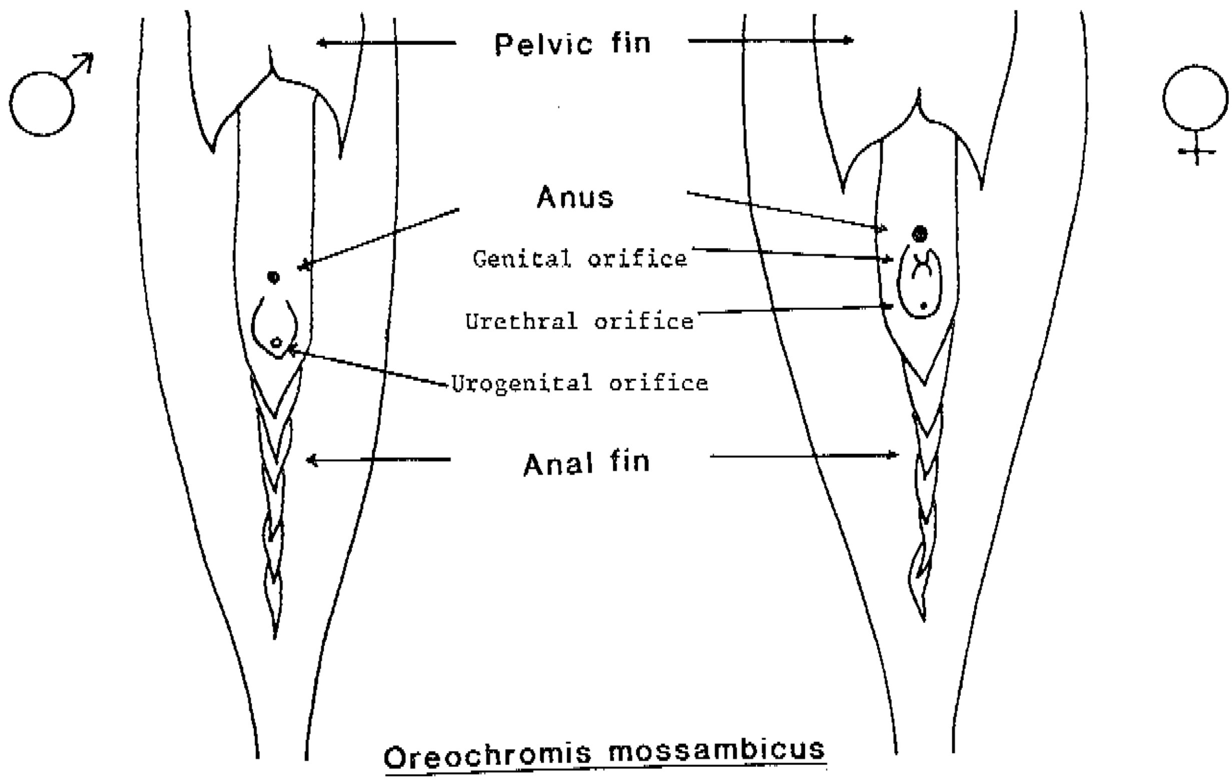


FIG. 3. GENITAL DEVELOPMENT OF MATURE MALE AND FEMALE TILAPIA



Oreochromis niloticus



Oreochromis mossambicus

3. CULTURE

Methods for culturing tilapia span the whole range of aquaculture techniques presently in use around the world. These include the annual restocking of large natural water bodies, pond culture, cage culture as well as intensive culture in concrete raceways with a high water exchange rate and the feeding of high protein level "complete diet" pellets. The most common method of culturing tilapia is in ponds, with the addition of an "input" from locally available products or by-products - tilapia thrive on what is often described as waste such as sewage slurry or animal manure or products that are only of limited use (e.g., rice bran, rice polishings, mustard-oil cake, hydrolysed feather meal, bone meal, blood meal, or chopped or composted vegetation such as water hyacinth, grass, rice, straw, etc.). Because of this wide range, tilapia culture is seldom limited by the unavailability of suitable supplementary nutrients or fertilizers. As a result of the low value of the input, production cost is also low. The action of added input to the pond is twofold: direct feeding of fish and fertilization of pond (and thus increase of nutrient levels within). The latter will enable algae and zooplankton populations to become very abundant, often with an associated green or brown coloration of the water. This is referred to as a bloom. The production of tilapia in a pond is improved when an algal or zooplankton bloom takes place. Once a bloom has started, it can be maintained throughout the culture period by frequent and continual additions of the nutrient source.

Unlike many temperate climate fish species, tilapia are not endangered by an active bloom, although problems may occur should the algae or zooplankton die off en masse, leading to areas of low or zero oxygen levels within the pond. Because the production of a bloom depends on the presence of sufficiently high levels of nutrients, specifically phosphate and nitrate, there is no need for any water exchange in the pond. However, in areas where evaporation from the pond is high, the availability of water to "top-up" the level is an advantage and will extend the growth period in areas where rain-fed ponds dry up completely.

3.1 Pond hatcheries

The size of ponds used for producing fry varies considerably from 100 m^2 to 10 000 m^2. In the larger ponds higher numbers of fry are produced more consistently than in smaller ponds, but of course the level of management required is much higher. Ponds of about 200 m^2 can be easily managed and can produce in excess of 20 000 fry per month (a more usual figure would actually be between 5000-10 000), but whatever the pond size regular feeding and correct management lead to a higher fry output.

Pond depth is critical for good production since all tilapia require to use the substrate for nesting. Depths can vary from 0.5 m to 1.2 m although 0.7 m appears to be the optimum. Should a pond be too deep, it will be obvious when it is drained or pumped dry since some nests will be clustered around the edges. Ponds that are too shallow will have a good spread of nests on the bottom (typically one every 1 m^2), but few fry will be produced. This may be due in part to the rapidity of fluctuation of temperature within the pond but more likely because of the continual disruption of breeding fish by non-breeding fish.

3.1.1 Stocking and harvesting

The original stocking density in small ponds (200 m^2) should not normally exceed two fish/m^2 and may be as low as one fish/2 m^2 particularly when larger ponds are used. The density which produces the most fry is, on the one hand, linked to the amount of food available and the amount of space for each nest and, on the other hand, the total size of the breeding population present within the pond. It is normal to bias stocking towards females since reproduction in a pond is seldom limited by the inability of males to fertilize females. Because the pair bonding in *Tilapia* is very strong, the normal sex ratio of males to females is 1:1 or 1:2. Within the genera *Oreochromis* and *Sarotherodon* the relationship between males and females is more limited and thus the male to female ratios used are generally between 1:2 and 1:7, 1:4 being the most common.

Stocking the pond with well grown adults of 10-15 cm (150-250 g) is beneficial since breeding can commence rapidly after introduction. The first harvesting of fry of 3-5 cm length can begin 40-60 days after the initial stocking, with harvesting continuing after a further 20-30 days, the exact period being dependent on the species and conditions of the environment.

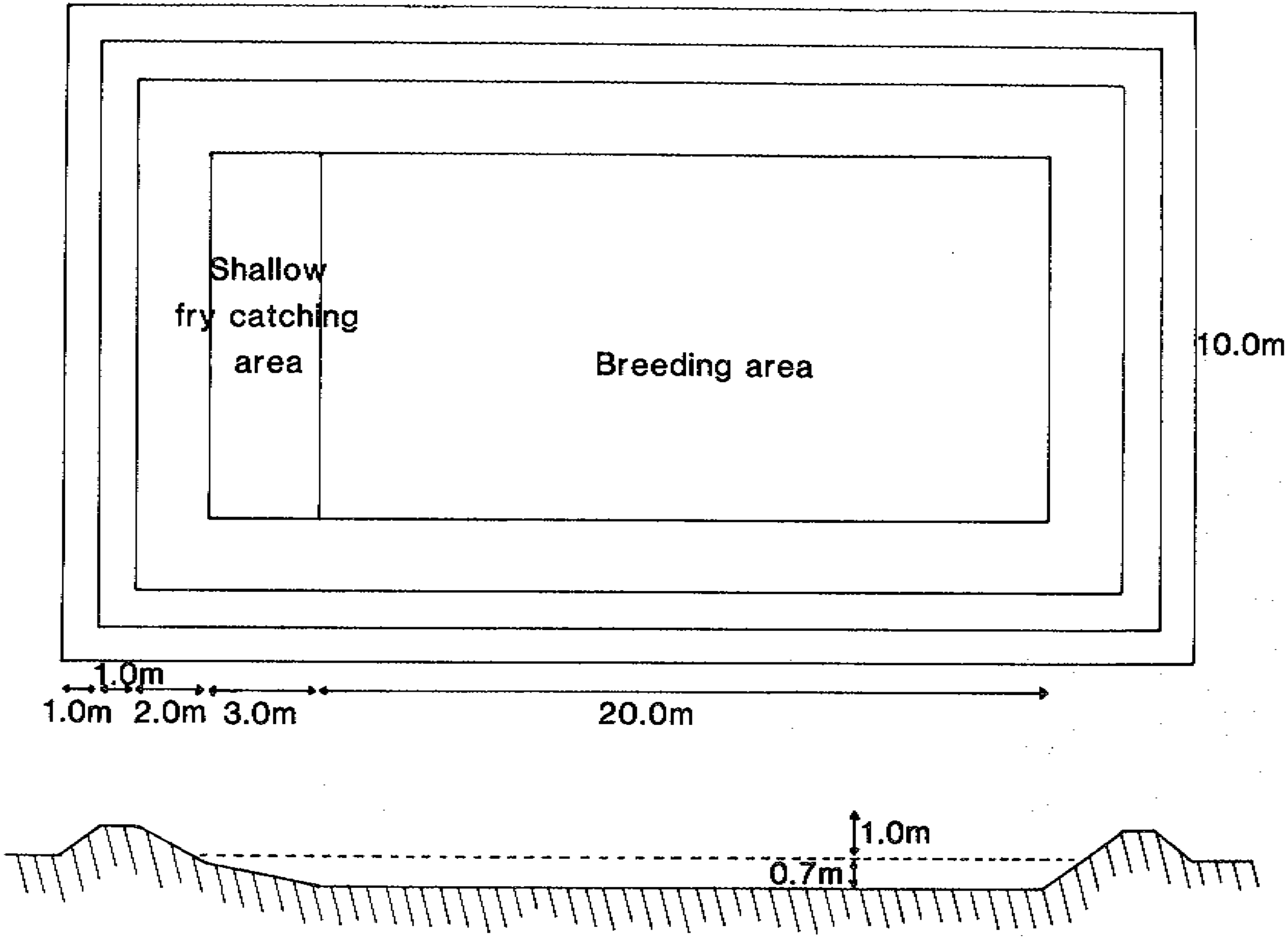


Diagram showing earth pond adapted for catching fry

Harvesting can be carried out by either of two methods. In larger ponds, fry can be caught near the banks of the ponds, in the shallow warmer water where they tend to congregate. The pond could have one end shallower than the other in order to facilitate the capture of fry. In smaller ponds it may be easier to use a seine net, netting the whole pond. However, this may disturb some of the fish that are mouth-brooding eggs or fry and, consequently, great care must be exercised while returning adults caught into the pond. One technique that would reduce the number of adults caught while retaining the majority of the fry consists of letting the bottom rope of the net lie several cm above the bottom. Since the fry tend to swim near the surface they will not escape the net, but adults swimming near the bottom can escape through the gap under the net.

The mesh size used for harvesting the fry is important. If it is too small the net will become clogged with mud and debris. This can lead to quite a high mortality amongst the fry. A stretched mesh size of approximately 1 cm will allow most debris through while still retaining fish above 2-3 cm. Fry of this size are suitable for transport and stocking.

It will be necessary for a periodic change of the broodstock. The fish should be changed at least every 12-18 months or before if the number of fry being produced drops significantly, which may occur after only six or seven months. The only really successful way to remove all the tilapia from a pond is to drain it completely and allow the pond bottom to dry out. Carrying this out on a yearly basis also allows repairs of the pond and removal of predators.

3.1.2 Feeding and pond fertilization

The characteristic diet of adult tilapia consists of plant matter or detritus which may contain animal matter (e.g., worms or insect larvae). In general, tilapia of the genera Oreochromis and Sarotherodon are primarily herbivorous, eating algae and other small aquatic plants, but they are very opportunistic and will eat other food if vegetable matter is unavailable, whereas members of the genus Tilapia tend to feed on coarser vegetable matter, particularly larger aquatic plants and leaves that may fall into the pond. The diet of fry of all tilapia is more general than that of adults, tiny aquatic animals (zooplankton) often making up a greater part of the diet.

3.1.2.1 Tilapia

Since the adults of this genera feed on higher plants, addition of chopped or whole leaf material makes a good supplementary diet. The following plants are suitable food: ipil ipil, alfalfa, grass, water hyacinth leaves. Any leaf matter can be used and chopping or mincing it will often increase its acceptability. Small fry may not be able to derive any direct benefit from this type of food since they are not able to consume these plants. However, the effect of adding plants to the pond and their subsequent breakdown, as well as faeces excreted by the adults, will increase nutrient levels within the pond, allowing algae and zooplankton to grow on which the fry can feed.

3.1.2.2 Oreochromis and Sarotherodon

Vegetation can be used for the direct feeding of Oreochromis and Sarotherodon, but the fertilization effect of the plants or their provision of a substrate on which bacteria can grow, which can be rasped off and utilized by these two genera, may be as important.

The use of manure from pigs, chickens, ducks, cattle or even human sewage slurry (Edwards et al., 1984) has been very successful. The manure is put into the pond on a regular basis or the animal shed is situated in a way that allows manure to enter the pond directly (e.g., ducks housed over the fish pond). Supplementary food such as rice bran, mustard-oil cake, broken rice or food from animal sources - bone meal, blood meal, hydrolysed feather meal, fish silage or trash fish - can dramatically increase production. However, these by-products are often incorporated into diets for culturing more valuable fish or prawns and can therefore be quite expensive for the feeding of tilapia.

It is possible to use inorganic fertilizers alone (e.g., triple superphosphate or urea), but these are often expensive to buy and difficult to get hold of in remote areas.

The use of lime in ponds is very important, since pond productivity will be severely limited if the pH is acid (3-5); ideally, the pH should be from 7-9 (neutral-alkaline) to give the best production. Addition of lime will increase the pH and alkalinity and reduce wide fluctuations in the pH; lime also helps to precipitate suspended organic matter and will aid the nitrification of ammonium compounds. The following amounts are recommended for different soils, but this will depend to a very great extent on the quality of the lime (Maar, Mortimer & Van der Lingen, 1966):

Clay soils: 1120 kg/ha/culture period.
Sandy soils: 560-1120 kg/ha/culture period.
Where feeding or fertilization is intensive, a further 168-224 kg/ha may be spread monthly.

It must be noted that over-liming can also lead to a loss in productivity (Van der Lingen, 1967); thus it is advisable to have the pH checked regularly.

Approximate feed and fertilization rates

(For a 200-m^2 pond stock with 200 x 100 g fish)

Inorganic fertilizer	kg/wk
Urea	4
Single superphosphate	11
Double superphosphate	6
Triple superphosphate	4
Ammonium sulphate	4
Sodium nitrate	5

Organic fertilizer	kg/wk
Cow/horse manure	280-800
Pig manure	220-650
Poultry manure	45-90
Sewage slurry	250-300
Duckweed	30-40
Water hyacinth	200

(From Edwards et al., 1984; Edwards, 1980; Sharma & Manandhar, 1980; Boyd, 1982; Hey, 1959.)

N.B. If more than one of the above fertilizers are used, then the application rates may have to be reduced.

4. COMMON PROBLEMS DURING TILAPIA CULTURE

Tilapia thrive in a range of different environmental conditions and can survive quite adverse conditions such as low dissolved oxygen levels, widely fluctuating temperature, variable salinity and relatively high levels of organic pollution (Philippart & Ruwet, 1982). This is why they are an ideal animal to culture. However, problems can arise (usually if there are rapid changes in environmental conditions - a rapid drop in temperature or oxygen level, for instance). The fish then may show signs of distress, but because the water in which tilapia are cultured is generally coloured, most of the distress signals that occur below the surface will not be visible. Thus the surface of the pond must be watched carefully for fish showing any abnormal behaviour. Fish swimming erratically or in very shallow water or a lot of fish at the surface at one time are perhaps the common signs, but the sign of a major problem is when a few dead or dying fish appear at the surface.

4.1 Biological problems

One of the leading causes of the loss of fish in the tropics is predation. Three main groups of predators can be identified: human, avian, and aquatic. Aquatic predators are usually fish which are able to move from one water body to another during the onset of rain. Such fish include the snakehead (Channa) and catfish (Clarius), (Mystus) and featherbacks (Notopterus), although frogs, snakes and some lizards may cause fry mortality. Frogs, snakes and lizards are difficult to exclude from a pond, even if a net fence is erected around the perimeter. Fish can be removed by using a suitable poison (e.g., rotenone[1] powder mixed into a paste and scattered on the pond surface). The dose rate should be 4 mg/litre or 4 g/m^3 of water. Tilapia will surface within a few minutes, and can then be collected for transfer to another pond where they will recover. The pond will be safe to restock within 7-10 days.

Avian predators can be very difficult to deter since larger birds such as cormorants and herons feed on all sizes of fish and kingfishers take fry. Having high, steep banks above the water level may dissuade the herons, especially in small ponds, since it will impede their take-off from and landing into the pond.

The poaching of fish by humans is perhaps the most difficult to stop unless the ponds are fenced off and guarded continually.

Tilapia not only tolerate adverse environmental conditions, but also appear to be quite resistant to diseases. Bacterial or fungal secondary infection may occur after damage to the skin, but it is not commonly seen. Parasite infection is more common, but is very difficult to stop or prevent when the fish are cultured in ponds and it would seem that even in the natural habitat parasitism is a normal occurrence of little consequence (Roberts & Somerville, 1982).

4.2 Chemical problems

The use of lime has already been mentioned for counteracting acidic water, but the problem can be persistent in areas that have an acid sulphate soil. As the pond is dug, these soils may be exposed on the surface of the dikes and pond bottom, and it may be some time before sufficient lime has been applied to reduce significantly the acidity to enable good pond productivity (Singh, 1985). However, should the pond bottom be disturbed by ploughing or some other method, the problem will return.

In some areas of the tropics the water, even well inland from the sea, may be saline to some degree. Although this presents difficulties for some species of freshwater fish, it does not constitute a problem for the tilapia. However, the salinity may reduce pond productivity and indirectly growth and reproduction rates.

The most common chemical problem is a low level of oxygen in the pond. When this happens, the tilapia can be seen at the water's surface passing the oxygen-rich surface layer over the gills. This may happen on a daily basis from 5.00 a.m. to 7.00 a.m. in a well-fertilized pond with good algae production and is not considered a problem. Should low oxygen levels remain for longer periods, then a reduction in growth rate may occur. Such is the case in a pond with a well-established and active algal bloom when thick cloud cover reduces the amount of sunlight reaching the pond. Without the use of mechanical or electrical aerators, little can be done to remedy this situation. Should the low level of sunlight persist, it may cause the algal bloom to die off completely (this may also be caused by irregular fertilization). The decaying algae will use up all the oxygen in the pond, and as the mass decays further it will also give of poisonous gases. Unless either the fish or the mass of algae can be removed from the pond, fish may die.

4.3 Physical problems

Temperature variation can be quite marked even in the relatively stable tropical climate, but it is unlikely to kill tilapia. However, should the temperature fall below 20°C then it is likely to stop the fish from reproducing. Should it fall lower than 16°C the fish

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[1] 1,2,12,12a,tetrahydro-2-isopropenyl-8,9-dimethoxy-[1] benzopyrano-[3,4-b] furo [2,3-b] [1] benzopyran-6(6aH)one.

will become very susceptible to infection and mortalities may occur. The highest temperatures that tilapia can survive are in excess of 40°C; this is seldom reached in ponds with sufficient depth. However, extremely high temperatures will result in rapid evaporation of water from the pond surface. "Topping up" the ponds will be necessary on a weekly basis, if a water supply is available. If there is no water supply, for instance, where ponds depend on rain for their water, it may be necessary to remove the fish to a pond that is well shaded, until rain falls and replenishes the water. If the ponds dry up completely, it is a good opportunity to repair any damage that has occurred. If the main source of food has been of plant origin, a thick layer of detritus may have to be removed from the bottom of the ponds. Then, if the latter is put on to the bank, when the rains come, nutrients trapped in the mud will leach out and back into the pond.

5. HANDLING AND TRANSPORTATION

5.1 Fish

Fish should only be transported to the target area if, before netting from the pond, they are healthy. After the fish are caught, they should be conditioned. This allows them time to release any undigested food or faeces from their guts in order not to foul the water during transportation. Ideally fish should be placed into a clean-water system for up to 12 hours for conditioning, but if this is not possible they can be placed into a net cage or hapa in the pond for 1-2 hours.

Tilapia are hardy fish, often able to survive much rougher treatment than carp or some of the catfish. However, in order to ensure the highest survival rates great care should be taken when handling and transporting the fish. The outer layer of fish skin (epidermis) covering the scales is delicate and is easily damaged, particularly during rough handling or netting. Because it is this layer which acts as a barrier preventing entry of bacteria and fungi, netting should be kept to a minimum but where necessary carried out carefully.

Fish can be transported by (a) open containers and (b) closed polythene bags. Open containers such as buckets or tanks are exposed to air. This method requires a fairly large volume of water compared to the number of fish being moved and can lead to problems when transporting fish over rough ground, the large volume of water being heavy and awkward to carry.

The second method consists of packing fish into polythene bags, inflating the latter with oxygen and sealing them. The disadvantage of this method is that it requires a supply of plastic bags and a source of oxygen. However, a lower volume of water is used than with an open system and transportation is possible over difficult ground.

5.1.1 Introduction of fish to a new environment

Although tilapia are hardy fish, introducing them to a new water body after several hours of transportation can lead to mortalities. The difference between the environment within the tank or bag, and the water into which the fish are being put can be large. The main difference will be in the temperature. Fish in polythene bags can be floated in the water for half an hour, to allow the temperature inside the bag to adjust. If the fish have been transported in a tank, new water should be added slowly until the temperature of the water in the tank has reached the same level as that of the new water.

5.1.2 Packing density

5.1.2.1 Tanks and open containers

The packing density that can be used depends to a large extent on the efficiency of the method of aeration. With limited aeration and a trip of a few hours, approximately 30 x 1-2 cm fish or 5-7 x 4-5 cm fish can be packed per litre.

5.1.2.2 Plastic bags

The packing density recommended for healthy fish in clean water is 50 g per litre. This is equivalent to about 10 x 4-5 cm fish or 50 x 1-2 cm fish per litre.

5.2 Water

If clean water is not available, it is possible to improve the quality of pond water by letting it stand in an urn or tank for a few days. Most of the algae and suspended solids will settle out. The cleaner surface water should be used for transporting the fish.

5.3 Dissolved oxygen

The level of dissolved oxygen in water from any natural source in tropical conditions will tend to be low even when saturated. The oxygen level can be increased by agitating the water. Transportation in an open system often requires the water to be agitated for the whole journey. This can be done by hand or by an electric air pump. If the fish are transported in polythene bags and the bags are inflated with oxygen (one part water to two parts oxygen), there should be sufficient oxygen for 10 hours (and in some circumstances 15 hours).

5.4 Problems during transportation

A major problem that occurs during the transportation of live fish in the tropics is overheating. Both methods mentioned expose water/fish to overheating; however, several techniques are used to reduce overheating. Transporting fish in the early morning or late evening is useful when journeys are over short distances. Often this is not possible and therefore in both cases tanks or bags should be kept in the shade as much as possible. Plastic bags can be covered with wet hessian sacks, the evaporation of water from the sacks will keep the bags cool. Ice can be used, but should be added to tanks of water in small amounts and at frequent intervals. Addition of a large amount of ice may reduce the temperature too much. Ice can be placed in plastic bags but the effect is often unpredictable, it is better to place the ice around the bags.

6. BIOLOGICAL CONTROL BY TILAPIINE FISH

6.1 Predation

The predation by tilapia on insect larvae and snails occurs most likely because of the tilapia's opportunistic feeding habits and because insect larvae and snails are found closely associated with the usual vegetable/detrital food of tilapia. Culex and anopheline larvae are most readily eaten by tilapia fingerlings, since the smaller fish (up to 5 cm), particularly those of the genera Oreochromis or Sarotherodon, have a diet biased towards zooplankton of which the larvae form a part. This fact can be exploited to control mosquitos in very shallow swamps or paddy fields. Once the growing shoots of any crops planted are above the water's surface, the fields can be stocked with tilapia. The stocking density should be about 1000 fish/ha of fish no more than 5 cm in length. To facilitate catching the fish at the end of the growing season, fish pits and ditches can be dug in the field. The pit dimensions recommended are 1-1.5 m^2 and 0.5 m deep. They should be situated in the centre of the field; ditches (0.25 m deep, 0.25 m wide) should be dug from the corners of the pit to the corners of the field. When the water level drops, the fish will eventually be concentrated in the central pit.

Larger adult fish of O. spilurus, O. mossambicus and S. galilaeus have all been recorded as feeding on adult snails, although only on those with a shell size of less than 10 mm. Other reports, however, stress that it is unlikely that these fish would choose to eat the snails exclusively when a selection of other softer prey is available (Coche, 1967; McMahon et al., 1972). The juveniles of Tilapia are likely to feed on insect larvae for the same reasons as those of Oreochromis or Sarotherodon fingerlings (but they are not recommended for stocking in paddy fields because of the herbivorous feeding habits of the adults). There is no evidence that Tilapia adults feed on insect larvae or adult snails. Because the strings of eggs laid by snails are often on the adult snails' food plant, it is likely that Tilapia will destroy snail eggs and juvenile snails during their normal feeding on plant material. Perhaps it is these early stages of a snail's life (i.e., before they have grown a tough shell) that are more responsive to the pressures that can be exerted by biological control agents.

The control of another group, the chironomids (midges), is possible by use of tilapia. The chironomid larvae normally inhabit detritus or sediments on the bottom of ponds, irrigation or drainage ditches, canals or slow-moving rivers. Fish of the genus Oreochromis (in particular O. honorum and O. mossambicus) feed on the detritus which includes any chironomid larvae present (Legner & Medved, 1973; Legner, Medved & Pelsue, 1980). In the United States of America work has shown that these two species are effective in controlling midges. The stocking density used for this purpose is 1000 fish/ha and 5000 fish/ha for lakes and rivers, respectively (Legner & Medved, 1973; Legner & Pelsue, 1977; Legner & Fisher, 1980; Legner, Medved & Pelsue, 1980).

Perhaps the ability of tilapia to predate on disease vectors is most effective when the choice of food available is limited. For example, in wells, water storage jars or tanks, where there is static clean water. High numbers of Culex larvae can accumulate under these conditions and if tilapia are stocked in the water, the mosquito larvae will often be the only source of food. Small fish up to 5 cm in length of the genera Oreochromis or Sarotherodon will probably be most effective for destroying the larvae. The stocking densities for controlling mosquito larvae in water bodies can be found by trial and error, and may involve a continual stocking programme. Since there will be little available food, a limit of 1-2 fish per 10 m^2 of surface water may well suffice. It will also be necessary to check the well or tank frequently to make sure that if the fish die they are not allowed to decay and pollute the water.

6.2 Competition

Both mosquito larvae and snails at many stages of their life cycle are found in close association with tilapia and in particular tilapia food. This leads to predation, accidental or otherwise, but more importantly it brings the organisms into direct competition for habitat and in the case of snails, food. Different species of snails feed on different types of algae and plant material found in the aquatic environment, but the tilapia cover a large range of feeding niches. As a general rule, Tilapia compete directly with those snails which feed on the higher aquatic plants, and Oreochromis compete with snails that feed on algae. In many situations snails and their food will be in abundance. To make an impact, it may be necessary to use very high initial stocking densities of 1-2 fish/m^2. For large areas of water (e.g., swamp, marshy areas or areas inundated during flood) the numbers of tilapia required may be enormous. If lower numbers are used, then any effect the fish have on the snail population will increase until the fish population reaches a maximum. It has been suggested that because of the territorial nature of tilapia, under certain circumstances the population maximum may be insufficient to control the snail population - thus the need for a very high initial stocking density. Continual monitoring of the snail and fish populations must be carried out to evaluate the effect of the biological control agents.

Tilapia and aquatic disease vectors not only compete for food, but they are also in competition for their habitat. Snails, for example, not only feed on plant material, but commonly use it as the substrate on which they live and lay their eggs. If it is removed, then the habitat of the snail is destroyed. The plant material also forms the habitat of anopheline mosquito larvae. The larvae inhabit water that is classed as "moving." This includes not only larger ponds where water movement is wind-initiated, but also streams, irrigation ditches, drainage canals and large, slow-moving rivers. The larvae require some form of protection from the full force of the current and it is often emergent or submerged aquatic vegetation which provides it. The use of tilapia such as Tilapia zillii or Tilapia rendalli which feed on the aquatic vegetation will cause the larvae to lose their protection, preventing their successful maturation as well as making them more accessible to predation by other fish.

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