Cage culture of Mozambique tilapia, *Oreochromis mossambicus* without artificial feeding in maturation ponds of the Phuthaditjhaba sewage system

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Abstract

Oreochromis mossambicus was cultured in floating cages without artificial feeding in the final maturation pond of the Phuthaditjhaba sewage system from October 1981 to March 1982. Environmental factors were monitored. It showed that water temperatures are suitable for tilapia culture for a period of about 120 days per annum. Water quality in terms of NH_4-N, $NO_2 + NO_3$-N, PO_4-P and COD generally improved through the system during normal operation but toward the end of November this pattern was disrupted by overloading which caused high fish mortalities. The fish grew well except during the month following overloading. Plankton was generally abundantly available as food.

Introduction

It is common practice in South Africa to treat municipal wastewater in a series of maturation ponds after solids removal by settling and primary treatment in trickling filters. Studies by Hey (1953), Mackenzie and Campbell (1966) and Gaigher and Krause (1983) showed that maturation ponds in this country contain abundant natural food and suitable environmental conditions for tilapia production. However, fish is not produced for human consumption in these systems in South Africa due to the potential health hazards involved (Gaigher and Cloete, 1981). Controlled conventional fish farming in existing maturation ponds is also impossible due to the fact that the ponds cannot be emptied for harvesting, netting of fish is difficult because of sludge accumulation and fish are subject to predation by the common platanna, *Xenopus laevis*, and in some cases by sharptooth catfish, *Clarias gariepinus*.

Due to the factors discussed by Conroy and Gaigher (1982), wastewater recycling is becoming increasingly important in South Africa and means will have to be found to overcome the problems mentioned. Toerien (unpublished) found that pathogenic bacteria on fish from local maturation ponds can be removed by depuration in chlorinated tap water. Nupen (1983) is of the opinion that this can be achieved with proper processing techniques. This study investigated the feasibility of fish culture in maturation ponds in Qwa-Qwa and cage culture as a means of preventing predation and facilitating harvesting. Mozambique tilapia (*Oreochromis mossambicus*) was chosen due to its tolerance of high density cage culture, high ammonia and low oxygen concentrations and ability to utilize plankton. Cage culture prevents reproduction which can be a serious problem in the culture of this species. Although *O. mossambicus* cannot survive the low winter temperatures at Phuthaditjhaba, it was assumed that the fish would grow to a marketable size of 100 g (Gaigher and Krause, 1983) during the warmer months. Environmental factors were monitored in order to evaluate the suitability of the system for fish culture.

Materials and methods

The sewage of Phuthaditjhaba is settled, treated in trickling filters and finally matured in a series of five ponds with surface areas of 0,8 ha to 0,9 ha and depths of 1,2 m at retention times of 4 to 6 d per pond. During the last week of November 1981 problems were encountered with the trickling filters and raw settled sewage had to be let directly into the maturation ponds for several days.

The fish were cultured in square 2 m^3 (depth of 0,9 m) cages manufactured from 6 mm reinforcing and 12 mm chicken mesh covered with two layers of non-toxic bituminous paint. Square pieces of polystyrene on two sides provided flotation.

A preliminary study showed that only the fifth, and possibly the fourth, ponds would be suitable for fish production due to high un-ionized ammonia concentrations. One cage was placed near the outlet in pond four and six at even distances apart over the length of the fifth pond with cage 1 near the outlet and cage 6 at the opposite end. During the survey in February one side of cage 4 tore open and all the fish of this cage were added to cage 5.

Two size groups of *O. mossambicus* were obtained from the hatchery of the Tompi Seleka Agricultural College in Lebowa and stocked on 28 October 1981. Cages 1, 2 and 3 were stocked with fish with mean masses of 37,2 g, 28 g and 28 g at densities of 400, 200 and 100 per cage respectively. Cages 4, 5 and 6 were stocked at the same densities with 9 g fish. The cage in the 4th pond received 100 fish of 9 g each.

During routine investigations, which were done on 28 November 1981, 6 January and 4 February 1982, subsamples of fish from each cage were weighed individually. All fish were removed, measured and weighed on 29 March. Daily relative growth rates (R) were calculated with the standard equation $R(\%\ d^{-1}) = (\ln w_t - \ln w_0)/t \times 100$ where ln = natural log, w_0 = average original mass, w_t = average final mass and t = time in days. The following environmental parameters were determined for each of the five maturation ponds during and after visits to the system:

- Water temperature (at a depth of 10 cm), pH and dissolved oxygen concentrations.

- Dissolved nitrogen and phosphorus. Five hundred ml water from each pond was transported to Bloemfontein in a darkened and heat-isolated container (~ 4 h), kept in a darkened room at 4 °C overnight, filtered through a 0,45 μm membrane filter and analysed for NH_4-N, PO_4-P and NO_2-N plus NO_3-N according to Standard Methods (1967).

- The chemical oxygen demand (COD) of unfiltered samples was determined during the last three surveys (Standard Methods, 1967).

- Algal density and dominance. Two hundred ml water was

TABLE 1
WATER TEMPERATURE, DISSOLVED OXYGEN AND pH RECORDED IN FIVE MATURATION PONDS OF THE PHUTHADITJHABA SEWAGE SYSTEM

Date	Parameter	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
	Time	18h15	18h07	17h59	17h51	18h28
28/10/81	Water temp (°C)	16,0	16,0	16,0	16,0	16,1
	Dissolved O_2 (mg ℓ^{-1})	12,5	12,5	11,8	12,4	N.D.
	Time	11h40	11h45	11h28	11h00	10h30
28/11/81	Water temp (°C)	22,3	22,3	23,4	21,9	22,3
	Dissolved O_2 (mg ℓ^{-1})	3,4	4,7	4,5	2,9	9,8
	pH	7,3	7,9	7,8	7,4	7,9
	Time	13h30	13h15	12h00	11h00	10h30
06/01/82	Water temp (°C)	25,8	26,2	25,5	27,0	27,5
	Dissolved O_2 (mg ℓ^{-1})	11,8	11,2	6,8	12,0	10,4
	pH	8,6	9,3	9,2	9,4	9,2
	Time	10h35	10h40	09h35	09h00	08h35
04/02/82	Water temp (°C)	26,9	26,8	26,8	26,8	25,4
	Dissolved O_2 (mg ℓ^{-1})	12,5	11,7	11,8	10,3	9,8
	pH	8,3	9,5	9,7	10,0	10,3
	Time	09h08	09h27	09h15	09h40	09h50
29/03/82	Water temp (°C)	19,5	19,3	19,5	19,4	20,5
	Dissolved O_2 (mg ℓ^{-1})	15,1	13,7	14,1	10,2	21,9
	pH	7,4	8,7	8,6	9,3	9,5

N.D. = not determined

preserved in 2 % formalin and a subsample of 0,1 ml investigated for generic composition and density.

- Zooplankton density and dominance in pond 5. Five litres of water was filtered through a 100 μm plankton net and preserved in 5 % formalin. The dominant taxa were later identified and the total dry mass determined by drying at 90 °C to constant mass.

Results

Environmental conditions

Water temperatures recorded in October were still low due to a cold front and rainy weather at that time (Table 1). During the remainder of the study period day-time water temperatures apparently remained above 20 °C but it started declining towards the end of March. Dissolved oxygen concentrations were high in all ponds during day-time except on 28 November after the addition of raw sewage, when low concentrations were recorded in the first four ponds. The pH was also generally high with lower values on 28 November (Table 1).

Figures 1 to 5 show a general decline in NH_4-N concentrations from pond 1 to pond 5 during all surveys except on 28 November. The same applies to $NO_2 + NO_3$-N. During the first three surveys orthophosphate did not decline through the system as would be expected. Concentrations of phosphate were generally low in all the ponds during October. The effect of the addition of raw settled sewage is clearly evident in higher concentrations in all the ponds on 28 November. The treatment system was obviously ineffective during this period. On 6 January concentrations were still high but started to decline through the system. During the last two surveys the pattern was back to normal.

The COD declined rapidly through the system on 6 January and 4 February (Fig. 3 and 4). On 29 March the COD was low in all the ponds indicating lowered organic loading. Figure 6 clearly illustrates the negative effect on environmental conditions of the addition of untreated settled sewage (in November) to the pond system in pond 5.

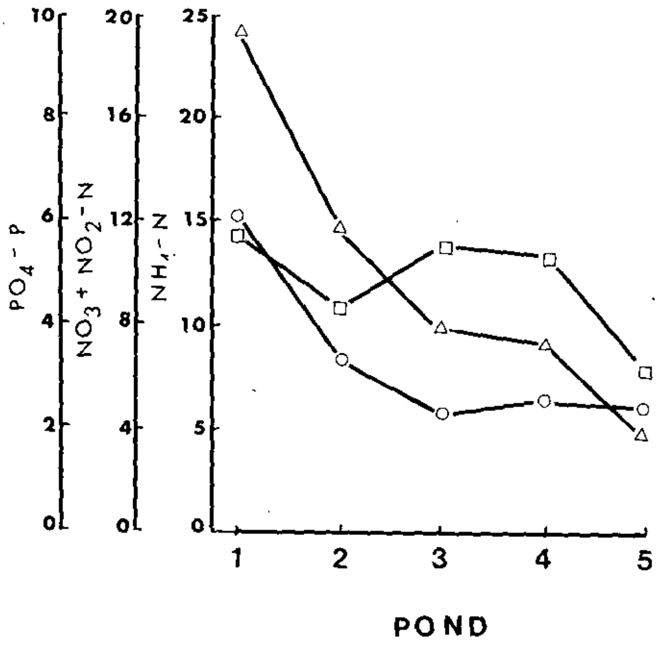

Figure 1
NH_4-N (Δ), $NO_2 + NO_3$-N (○) and PO_4-P (□) concentrations (mg ℓ^{-1}) in ponds of the Phuthaditjhaba sewage system on 28 October 1981.

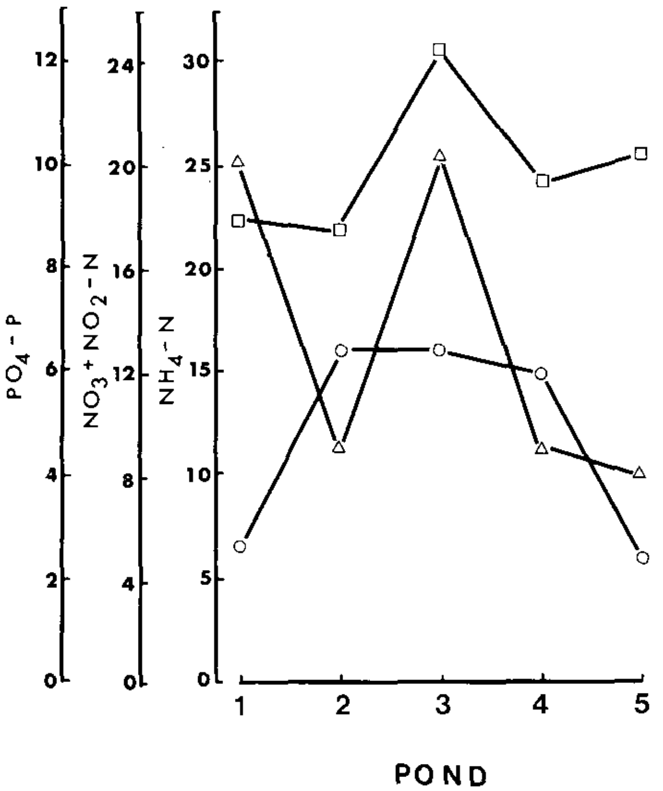

Figure 2
NH_4-N (Δ), $NO_2 + NO_3$-N (○) and PO_4-P (□) concentrations ($mg\ \ell^{-1}$) in ponds of the Phuthaditjhaba system on 28 November 1981.

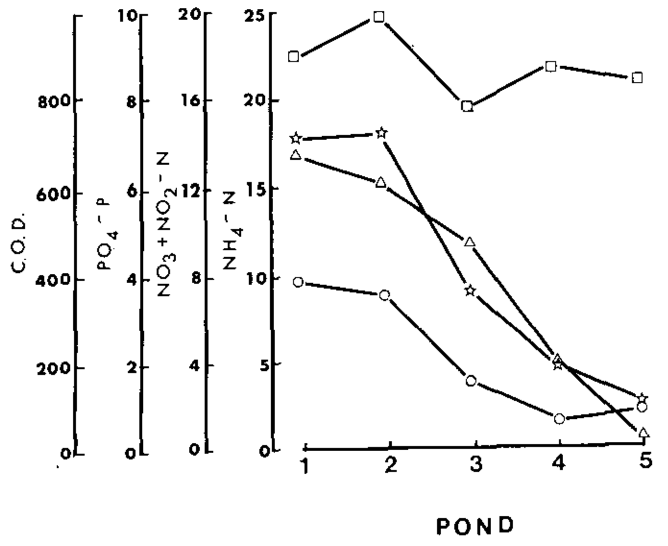

Figure 3
NH_4-N (Δ), $NO_2 + NO_3$-N (○), PO_4-P (□) and COD (☆) concentrations ($mg\ \ell^{-1}$) in ponds of the Phuthaditjhaba sewage system on 6 January 1982.

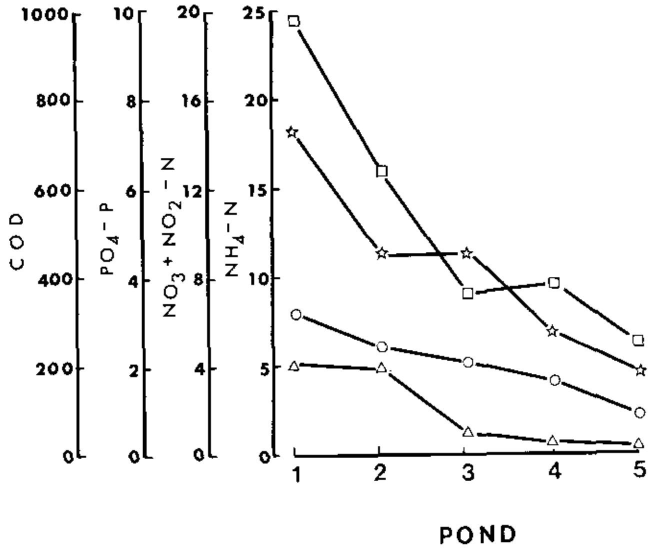

Figure 4
NH_4-N (Δ), $NO_2 + NO_3$-N (○), PO_4-P (□) and COD (☆) concentrations ($mg\ \ell^{-1}$) in ponds of the Phuthaditjhaba sewage system on 4 February 1982.

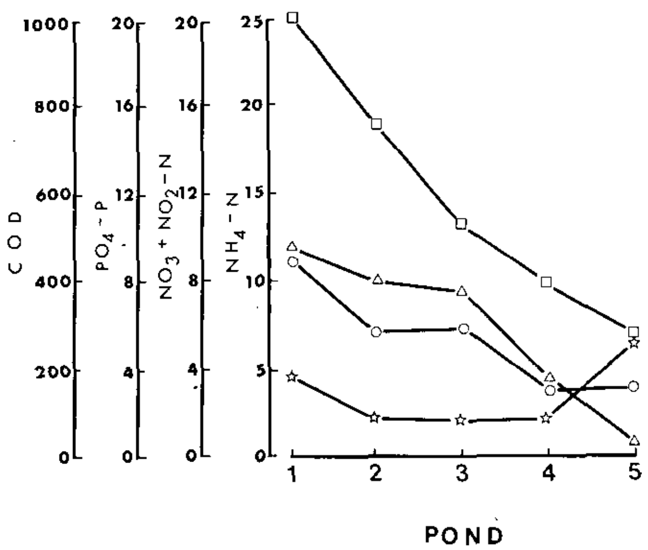

Figure 5
NH_4-N (Δ), $NO_2 + NO_3$-N (○), PO_4-P (□) and COD (☆) concentrations ($mg\ \ell^{-1}$) in ponds of the Phuthaditjhaba sewage system on 29 March 1982.

The results of algal studies are summarized in Figure 7. The densities recorded can be misleading, because some refer to cells and others to colonies, but do give a superficial indication of density fluctuations. The highest densities were recorded in October. After the addition of raw sewage the densities were much lower but increased again from January onwards. Green algae were dominant in numbers throughout the system during all surveys except in pond 1 during October when a euglenoid, *Lepocinclis* dominated. Blue-green algae were only recorded during the last survey when a bloom occurred in pond 5.

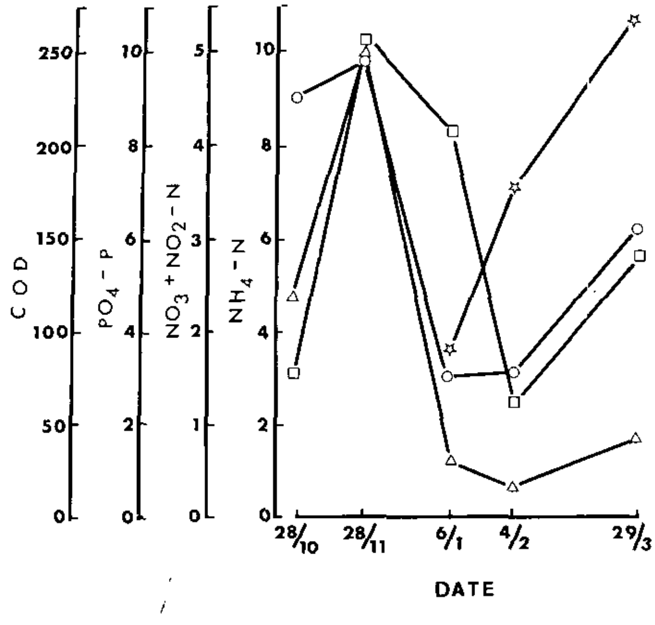

Figure 6
NH_4-N (Δ), NO_2+NO_3-N (○), PO_4-P (□) and COD (☆) concentrations (mg ℓ^{-1}) in pond 5 of the Phuthaditjhaba sewage system.

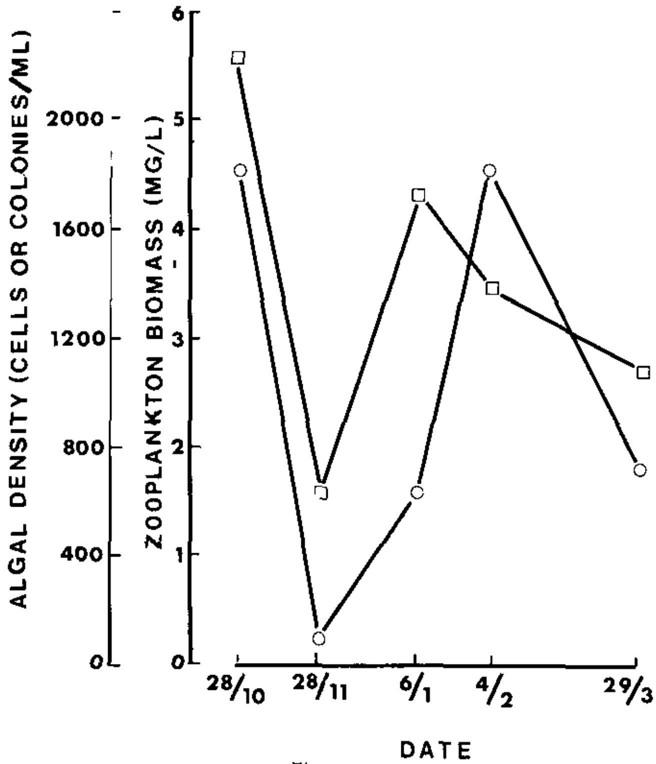

Figure 8
Variations in zooplankton biomass (□) and algal density (○) in pond 5 of the Phuthaditjhaba sewage system.

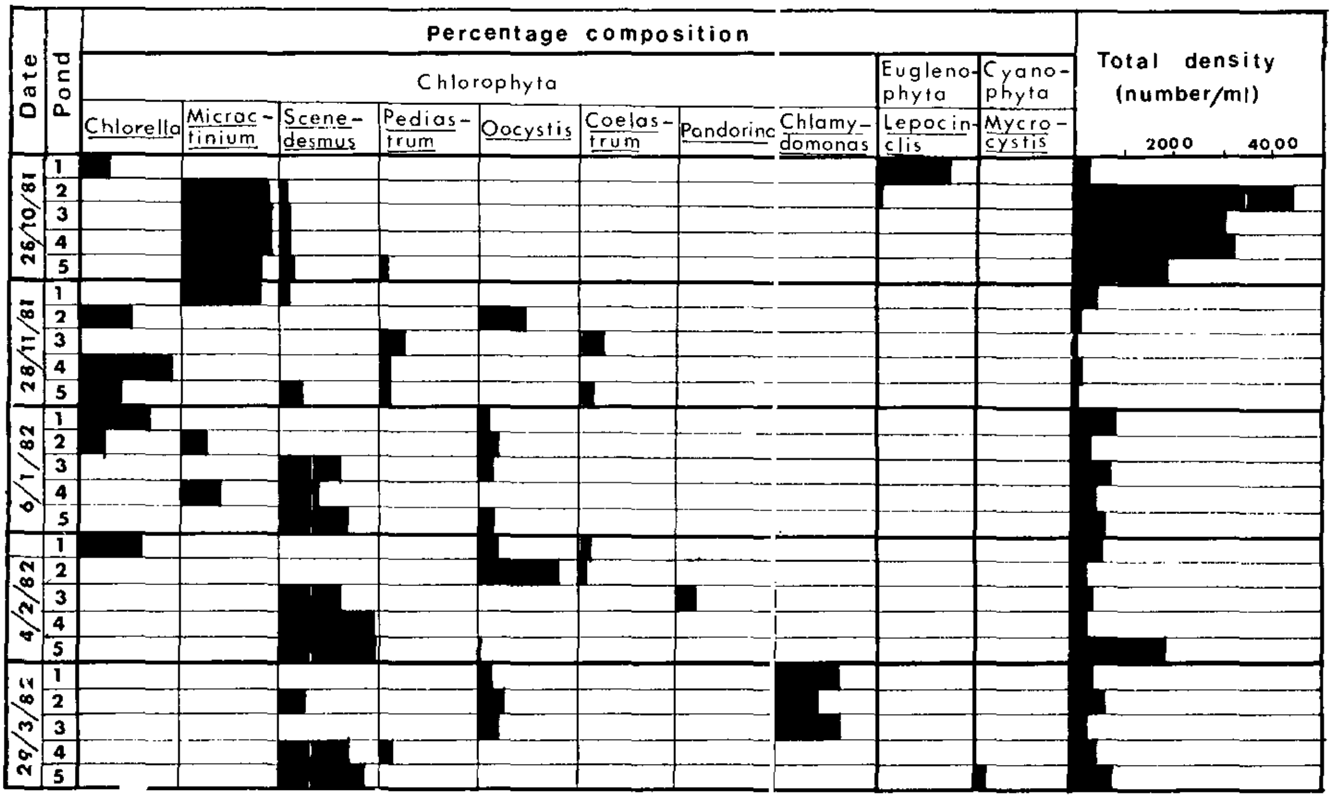

Figure 7
Percentage composition (on a scale of 1 % to 100 %) and total density of cells or colonies of dominant algae in ponds of the Phuthaditjhaba sewage system.

A high density of zooplankton occurred in pond 5 during the first survey in October but dropped drastically after the addition of raw sewage (Fig. 8). By the beginning of January numbers had increased again. A decrease in biomass was evident towards the end of the study period, but the pond still contained abundant zooplankton for fish nutrition. *Daphnia pulex* was the dominant zooplankton in this pond during all surveys. During March *Moina* spp. and cyclopoid copepods were also abundant.

Recorded algal densities in pond 5 followed the same general trends as that of zooplankton (Fig. 8).

Fish survival rates

All the fish stocked in pond 4 died before 28 November, probably due to unfavourable environmental conditions. Observation showed that large numbers of tilapia died in the fifth pond during the first month, probably due to the effects of raw sewage administration. However, dead or dying fish were observed during all surveys showing that unfavourable conditions were not only restricted to this period. The total mortality rates at the end of the study period in cages 1, 2, 3, 4 + 5 and 6 were 91, 75, 48, 97 and 94 % respectively.

Growth rates of fish

Figure 9 shows that the tilapia in all cages in pond 5 grew rapidly during the first month. Stocking density apparently did not influence growth rates. During the period after the administration of raw sewage virtually no growth took place. The average mass of larger fish (cages 1 to 3) actually declined. In January environmental conditions improved again resulting in rapid growth.

Daily relative growth rates were high during the first month (1,5 % to 3 %), declined to less than 0,3 % after the addition of raw sewage, increased to about 1,5 % in all cages except cage 1 during January and then declined again to less than 1 % (Fig. 10). Over the whole study period daily relative growth rates were 0,5 % in cage 1, 0,6 % in cages 2 and 3, 1,2 % in cages 4 + 5 and 1 % in cage 6. The lower relative growth rates of larger fish (cages 1, 2 and 3) can be ascribed to a natural decline in relative growth rate with increase in size (Gaigher, 1983).

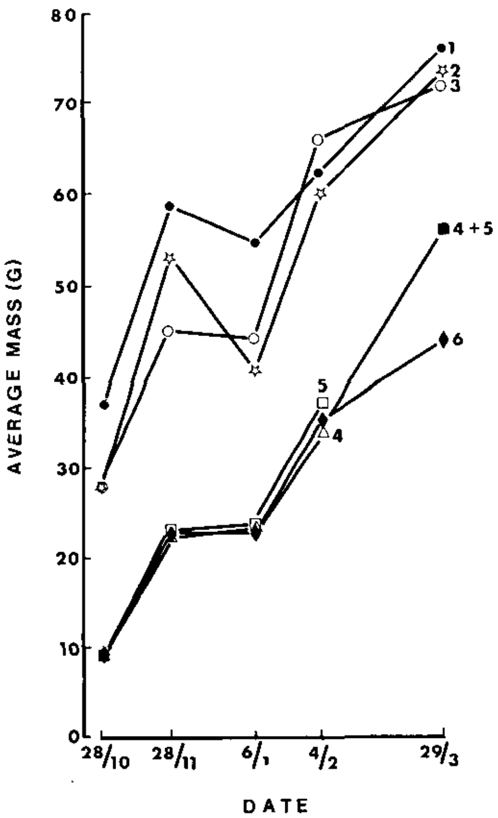

Figure 9
Growth of Oreochromis mossambicus in different cages in pond 5 of the Phuthaditjhaba sewage system.

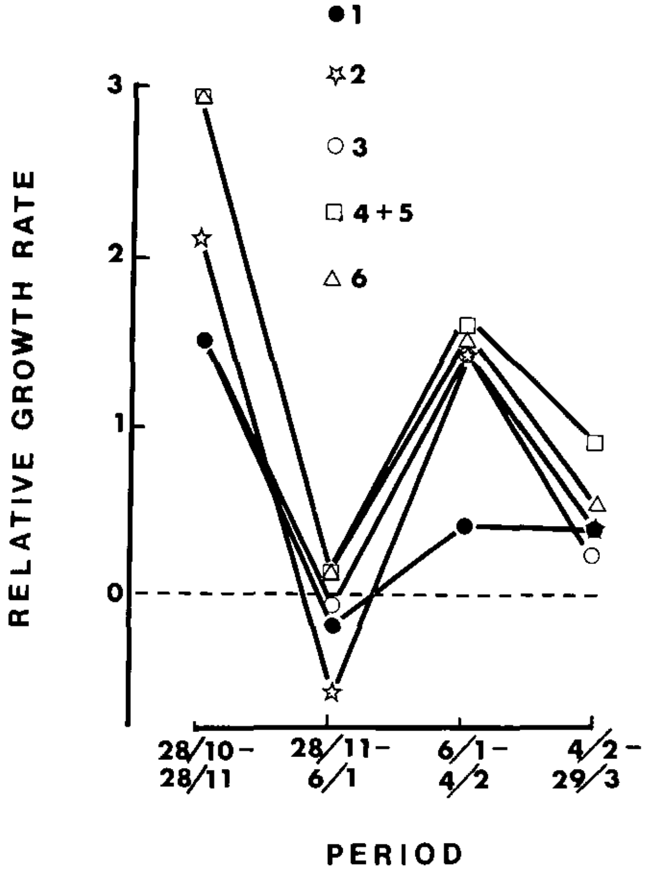

Figure 10
Relative growth rates of Oreochromis mossambicus in different cages in pond 5 of the Phuthaditjhaba sewage system.

Discussion

The study substantiated the finding of Gaigher and Krause (1983) that small *O. mossambicus* grow rapidly in cages in plankton-rich wastewater without artificial feeding. It also showed that temperatures at Phuthaditjhaba are suitable for rapid growth of this species for a period of about 120 days per year. However, conditions in the maturation ponds were periodically unsuitable for tilapia production due to organic overloading as evidenced by high mortalities and periodic reduced growth rates. If the administration of raw settled sewage to the pond system can be prevented, conditions might be suitable for fish production in the last pond but this will have to be determined experimentally. In spite of the negative factors the larger fish still grew at a rate of 0,5 % and the smaller fish at a rate of 1 % of body mass per day over the whole study period. Under normal conditions tilapia should therefore grow from 20 g to 100 g, which is considered to be a marketable size, within a summer season.

Temperature, dissolved oxygen, un-ionized ammonia concentration and available food are the most important environmental factors which might affect fish production in waste treatment systems. Toxicants like detergents, heavy metals and insecticides might also play a role (Hemens and Turner, 1980; Nupen, 1983) but concentrations of these were not determined in the present study and are therefore not considered in the discussion.

It is generally assumed that the South African strain of *O. mossambicus* cannot survive water temperatures below 10 °C (Allanson *et al.*, 1971) and are sensitive to infections at temperatures below 15 °C (personal observation). According to Allanson and Noble (1964) the upper lethal limit is 38 °C or 39 °C. Little is known about the specific influence of temperature on the growth rate of this species. Badenhuizen (1967) found that it prefers temperatures between 27 °C and 33,5 °C. Crass (1959) is of the opinion that growth ceases at temperatures below 15 °C and according to Caulton (1979) it only grows satisfactorily at temperatures above 20 °C. The superficial temperature record indicates that water temperatures at Phuthaditjhaba were adequate for good growth during the study period and that the mortalities which occurred cannot be ascribed to temperature.

A much more probable cause of poor growth and mortalities is dissolved oxygen and un-ionized ammonia. The effect of dissolved oxygen is dependent on water temperature because fish require less oxygen at low than at high temperatures. For example, Caulton (1978) found that *O. mossambicus* of 10 g mass requires about 1,4 mg O_2 h^{-1} for basal metabolism at 20 °C and 3,3 mg h^{-1} at 30 °C. Oxygen requirement also increases in relation to an increase in volume of the fish (Caulton, 1979). According to Caulton (*op. cit.*) this species can only survive concentrations below 2 mg ℓ^{-1} for short periods at 24 °C but several authors quoted by Colt *et al.* (1979) recorded survival at oxygen concentrations below 1 mg ℓ^{-1}. Food consumption and growth rates are also negatively affected by low oxygen concentrations (Payne, 1970). Critically low oxygen concentrations were never recorded during the study period but all the recordings were done during daytime and it is possible that low concentrations occurred overnight due to algal respiration. The fact that larger fish were affected more seriously than smaller fish by the addition of raw sewage in November (as evidenced by relative growth rates) indicates that oxygen might have been a limiting factor at times.

O. mossambicus can probably survive high concentrations of un-ionized ammonia but its tolerance has not been determined experimentally. This is substantiated by studies on other species of the same genus such as that of Redner and Stickney (1979) who found that *Oreochromis aureus* can survive un-ionized ammonia concentrations as high as 3,4 mg ℓ^{-1}. At the pH and temperatures recorded during this study the calculated un-ionized component of ammonia in pond 5 was never higher than 0,9 mg ℓ^{-1} during surveys. If we assume that *O. mossambicus* has the same tolerance as *O. aureus*, the levels recorded were not toxic. However, toxic concentrations of un-ionized ammonia could have occurred during the period after addition of raw sewage if the pH increased to over 8 at a total ammonia concentration of 10 mg ℓ^{-1} as recorded on 28 November. This is quite possible and ammonia is therefore considered to be the most probable cause of the high mortality rate.

Plankton was abundantly available and had the right composition as food during all surveys except on 28 November after the addition of raw sewage. Food shortage could therefore have limited growth during December but it is doubtful whether this was a major factor because zooplankton remained present in fair numbers. The fact that dead fish were present during all surveys shows that unfavourable conditions were not only limited to the period after raw sewage was added. Periodic low dissolved oxygen and high un-ionized ammonia concentrations or a combination of the two were probably responsible.

Due to unfavourable environmental conditions cage culture of tilapia in the existing maturation pond system at Phuthaditjhaba is not recommended. A possible alternative will be to construct a sixth pond in which conditions should be more suitable. The feasibility of using a species such as sharptooth catfish (*Clarias gariepinus*) which might be more tolerant of unfavourable conditions or of harvesting the zooplankton at the overflows from one pond to another and feeding it to fish in "clean" intensive systems should also be investigated.

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