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Effects of Fish Culture on Water Quality of an Integrated Mariculture Pond System

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***Abstract*—**Six mariculture ponds were flooded with seawater since 1996. During this time the ponds were stocked with finfish (milkfish and rabbitfish), which were fed on locally produced fish feed. Some water quality parameters such as temperature, salinity and oxygen saturation were measured twice a day for three years (1998 – 2000), while nutrient concentrations were measured weekly for one year. Both nutrient concentration and oxygen saturation levels have shown a trend indicating eutrophication. Oxygen concentration changed from an average of 7.16 mg/l in October 1998 to 2.2 mg/l in March 2000 with a negative linear regression of 0.69 during the morning hours. From August 1998 to April 1999 dissolved inorganic ammonia concentration increased by 9 µg-at N/l, from 8.91 to 18.02 with a positive linear regression of 0.79. During this period soluble reactive phosphorus increased by 3.55 µg-at P/l from 4.36 to 7.91 with a positive linear regression of 0.75. In this paper the rate of eutrophication and the limit at which the ponds have to be dried/limed before restocking are discussed.

INTRODUCTION

Aquaculture is a fast-expanding mode of food production in the world. Currently fish farming accounts for more than one-quarter of the total fish directly consumed by humans, using about 220 finfish and shellfish species (Naylor et al., 2000). Global production of farmed fish and shellfish has more than doubled in the last 10 years (Naylor et al., 1998). Ninety percent of the world's aquaculture is undertaken in Asia, with China producing two-thirds of the world total while Europe, North America and Japan, which produce only 10 %, consume the bulk of the seafood traded internationally (Naylor et al., 2000). The markets for highly valued species, such as salmon and shrimp, which require animal sources of protein as food, are increasing in developed countries. Furthermore, the consumption of shellfish species such as Pacific cupped oysters, blue mussel, New Zealand mussel and yellow scallop is also increasing in the developed world. Tilapia, milkfish, catfish, carps and marine molluscs contribute 80 % of the global aquaculture output amounting to 29 million tonnes in 1997 (Naylor et al., 2000).

Conversion of wetlands into aquaculture ponds has resulted in increase in nutrients and organic wastes, leading to general deterioration of water quality. The water quality problem is associated with both physical and chemical factors such as high or low dissolved oxygen, high concentration of nitrogenous compounds (ammonia-N and nitrate-N) and high levels of hydrogen sulphide. An excess or shortage of dissolved oxygen causes mass mortality in fishponds (Krom et al., 1985a).

The water quality in aquaculture fishponds is controlled by a complex interplay of many factors.The amount of dissolved oxygen is controlled by factors such as photosynthesis, respiration by fish and microorganisms, air-water

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exchange and oxygen input in the water flowing into the pond (Gulliver & Stefan, 1984). On the other hand, large amounts of organic matter consume oxygen in the decomposition process, causing its depletion. Too high dissolved oxygen levels cause death due to emboli that occur as a result of bubble formation in the blood vessels of fish (Krom et al., 1985a). Excretion of nitrogenous compounds by cultured fish and microbial decomposition of organic matter due to food leftovers are the main source of ammonia, nitrates, nitrites, phosphates and other inorganic substances (Neori et al., 1989; Hall et al., 1992). High concentrations of carbon dioxide (CO_2), ammonia and related nitrogenous compounds are often found in the water column after phytoplankton bloom collapse. During blooms and collapses, both ammonia and CO_2 are liberated into the water column. In freshwater with low buffering effect, CO_2 lowers the pH considerably, thus reducing the amount of un-ionised ammonia (Tucker et al., 1984). In marine fishponds, although a similar quantity of CO_2 may be produced, the large carbonate alkalinity buffers its effects, resulting in relatively higher levels of un-ionised ammonia (NH_3), which is toxic (Krom et al., 1985b). Krom & Neori (1989) showed that the daily dissolved oxygen maximum in semi-intensive marine fishponds with no artificial aeration was reduced from 16 ppm during a phytoplankton bloom to less than 7 ppm during the crash. They also reported that ammonia toxicity increases as the level of dissolved oxygen decreases.

Initially, aquaculture was confined to freshwater fish farming. In most cases this was done in lakes and dams where the water supplies were from upstream or ground water. Increase in population, habitation, water pollution and desertification have caused estuarine and marine aquaculture (mariculture) to become more attractive. However, aquaculture in Africa is still largely freshwater.

The experiences of aquaculture in Southeast Asia and Northern Europe have clarified different aspects regarding the economical and ecological effects of aquaculture. One of the main issues of contention is that the most profitable aquaculture is that of salmon and shrimps, both of which are carnivorous. They require large quantities of animal protein for their supply of essential amino acids such as lysine and methionine. It takes 2–5 kg of fish meal to produce 1 kg of the carnivorous farmed fish (Naylor et al., 2000). Furthermore, aquaculture competes with capture fisheries in habitat, nursery areas, and assimilation of wastes, feed and seed (larvae) supplies. There is further economic competition in markets, and biological competition due to exotic species introduction and transmission of pathogens.

From the biological, environmental and economic sustainability points of view, it is now becoming clear that it is more advantageous to farm herbivorous rather than carnivorous fish because of the lower amount of fishmeal required as well as conversion efficiency. It should be noted here that although the farmer benefits considerably from salmon and shrimp aquaculture the cost to the environment is very high. Salmon farming in Europe for example, requires 90 % of the primary productivity of the North Sea and consequently depends heavily on fish meal from South America (Naylor et al., 1998). It is therefore highly debatable whether aquaculture helps in the restoration of overfished areas in the long term and whether it enhances or diminishes fish supply. Despite the debates it is generally agreed that the farming of herbivorous finfish and filter feeders has a better chance of solving the world's food problems and protecting the environment than the farming of carnivorous fish.

The choice of location for aquaculture undertakings is site-specific, and local experience is still the best way of deciding whether the venture is economical and sustainable. Experiences from Southeast Asia has shown that [mainly shrimp] farmers migrate away from fish farms that have turned unproductive after initial high productivity at intervals of less than 10 years. The Rufiji Delta shrimp project crisis was indicative of the dilemma that the continent is facing in deciding whether and how fish farming should be gone about (Boyd, 1996).

The development of mariculture (fish farming) in Africa as a whole has experienced several setbacks including high cost of labour per unit output (Christensen, 1995). In most African countries, including Tanzania, lack of well documented information regarding possible

negative environmental impacts due to mariculture, and shortage of infrastructure and facilities, are among the drawbacks for the development of fish farming and other mariculture activities. The simplicity of the environmental impact statement for the Rufiji delta shrimp-farming project (Boyd, 1996) and complexities of the discussions on the execution of the project is an illustration of the dilemma. As such, fish aquaculture in Africa has remained freshwater and small-scale.

In Zanzibar, the major mariculture activity is the commercial cultivation of seaweeds of the genus *Eucheuma* (Mtolera, 1996; Mshigeni, 1992), while fish farming is still at its early stages of development, although it has potential for rapid expansion. Seaweed cultivation employs nearly 3 % of Zanzibar's population (Mtolera, 1996) and the industry has contributed considerably to the economic empowerment of women in Zanzibar, while exploitation of natural resources, particularly fish, is decreasing significantly (Jiddawi & Stanley, 1997). Farmed seaweed export contributed 27 % of foreign exchange earnings for Zanzibar in 1994 (Msuya et al., 1996). On the other hand, the demand for marine fisheries production is increasing with the expansion of tourism trade as well as the increase in human population (Anon, 1997).

With this in mind, the Institute of Marine Sciences of the University of Dar es Salaam decided to develop experimental integrated finfish, shellfish and seaweed farming since 1996. The integrated mariculture fish pond system (IMPS) approach cultures finfish together with shellfish and seaweed, the latter of which are intended to remove particulate organic matter and dissolved inorganic nutrients respectively from the fishpond water. The main water supply to the system depends on the natural tidal cycle of seawater, whereby seawater is allowed to enter into the big reservoir during the high tide and flows through the experimental ponds by natural gravitation. No artificial aeration is applied to the system.

To evaluate the environmental quality of the area, different environmental parameters were monitored and assessed regularly. The aim was to determine the water quality in terms of dissolved inorganic nutrients, temperature, dissolved oxygen saturations and concentrations. The study sought to provide information that could be used in further planning in mariculture development.

MATERIALS AND METHODS

Study area

Mahonda, Zingwezingwe and Makoba-Mahonda factory and sugarcane plantation is located in Zanzibar North Region. The 1200-ha sugar plantation produces an average of 6000 tonnes of sugar per year. The Mahonda-Makoba drainage basin also contains rice farms, a rubber plantation and a cattle ranch. Fertilisers, used in the plantations, and fusel oil and burgesses produced by the sugar factory are likely to pollute the rivers and the fish farms, although the high dilution by the sea water which is tapped only at high spring tide suggests little effect.

The sugar estate is drained by rivers Mwanakombo and Zingwezingwe. Zingwezingwe River has three tributaries namely, Kitope, Zingwezingwe and Mchanga, which join in the sugar plantation. The main Zingwezingwe river is also joined by a trench of effluent waters from the factory at the point where the river leaves the sugar estate. Rivers Mwanakombo and Zingwezingwe meet as Kiwani creek in Makoba Bay (Fig. 1). The ponds which are abandoned salt pans are located in Makoba close to Kiwani. Figure 2 is a schematic representation of the Makoba ponds.

Experimental design and culturing

A total of about 5000 fingerlings of rabbitfish and milkfish were stocked in the ponds and after 8 months 300 rabbitfish and 1000 milkfish were harvested at 200 to 500 g respectively in two ponds (about 300 m^2). About 2000 milkfish are still in the ponds at Makoba. The fish are feeding at approximately 1 kg of feed/day .

Two species of seaweed, *Eucheuma spinosum* (*E. denticulatum*) and *Euchema cottonii* (*Kappaphycus alvarezii*) were collected from the inter-tidal zone on the east coast of Zanzibar at Matemwe, transferred and stocked in Makoba on the same day. Approximately 20 kg of each species were stocked using the traditional method of tying branches of seaweed

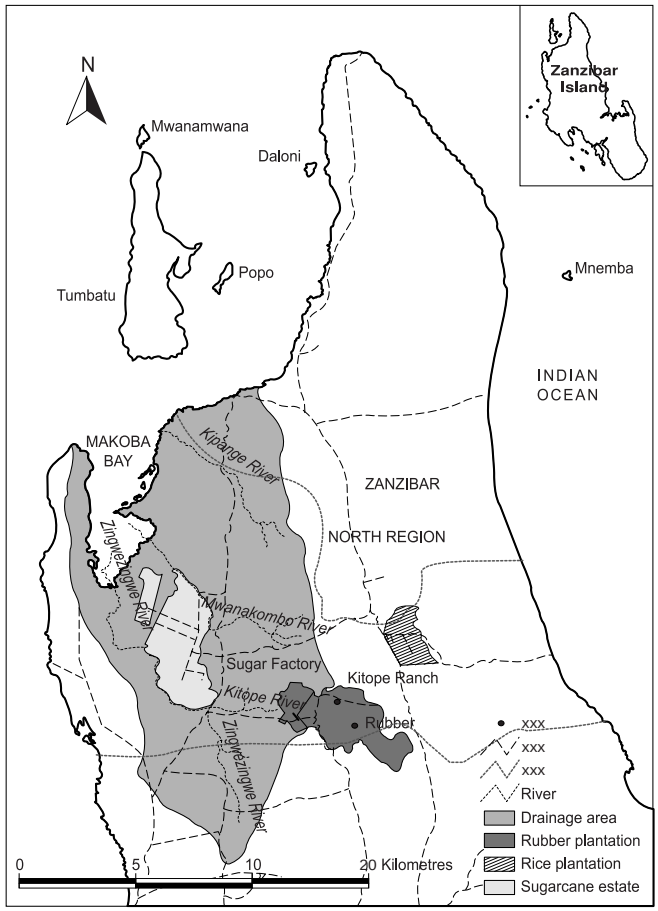


Fig. 1. Mahonda Makoba Drainage Basin showing plantations and drainage system (after Mmochi et al., 2001)

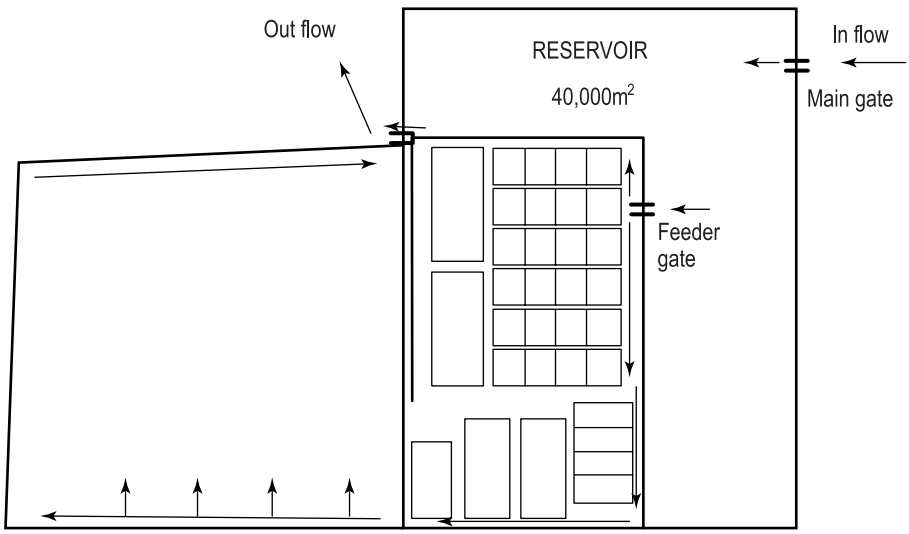


Fig. 2. Makoba abandoned saltpans

in seawater along a string tied between pegs at a depth of 20 cm above the bottom. The estimated stocking density was 1 kg/m^2. *Ulva fasciata*, *Ulva reticulata* and *Gracilaria crassa* were also stocked. *Ulva* and *Gracilaria* spp. were cultured in small chambers made of netting material of 1 inch mesh size. There was little success when seaweeds were grown in the ponds (Mwandya, 2001) but when they were grown in the channels where there was some water movement, *Ulva fasciata* increased by 50 % in two months (Msuya, 2001).

IMS developed a fish feed formula based on the dietary requirements in terms of proteins, carbohydrates and moisture content, using local materials. The feed was used for growth of fingerlings of the milkfish and rabbitfish. Fish were fed three times a day by hand, at about 1 % body weight per day. Dietary trials were conducted at the National Centre for Mariculture (NCM) in Israel, using locally available rabbitfish species (*Siganus rivulatus*), which occur also in Zanzibar (Mozes & Mmochi, 1997). The results obtained in the NCM trials were then tested on a larger scale in the ponds in Zanzibar (Mwangamilo & Mmochi, 1997). The feeding trials were designed to test each of the two diets at two different feeding levels: maximum consumption and 50 % of the maximum, representing 1 and 2 % of the fish's body weight respectively. The diet composition is shown in Table 1.

Table 1. Composition of fish feed used at Makoba IMPS

Component	Price (TSh/kg)	Fraction (%)	Cost (TSh/kg food)	Percentage of cost (%)
Copra cake	30	17.4	5.2	2.0
Fishmeal	450	28.6	128.7	48.9
Broiler mash	156	17.0	26.5	10.1
Ulva sp.	500	15.2	76.0	28.9
Maize bran	100	17.0	17.0	6.5
Cassava flour	200	4.8	9.6	3.6
Total		100	263.0	100.0

Daily operations, sampling, sample storage and analyses

During each high spring tide, the reservoir was filled with seawater from the estuary. Water was supplied from the reservoir to the fishponds every day in the afternoon, when oxygen levels were high due to photosynthesis in the reservoir. The planned water flow to each pond was 200 m^3/day, and was accomplished by flushing water until the reservoir water level (RWL) dropped 0.5 m.

Temperature and dissolved oxygen were measured three times a day in all ponds and the reservoir using an Oxyguard DO meter, calibrated for pond water salinity. Salinity was measured thrice a day using a hand-held refractometer (ATAGO) calibrated with deionised water. Samples for dissolved inorganic nutrients analyses were collected weekly in 250 ml plastic bottles and fixed with 3 drops of chloroform.

The samples were immediately transported to the pesticides analysis laboratory at the Institute of Marine Sciences, where they were stored and/or analysed. The water samples for nutrient analyses were refrigerated at 4 ^{o}C. Nutrient samples were analysed within a week of sampling. Dissolved inorganic nutrients were measured using a Lambda Polynom 1201 UV/VIS spectrophotometer (Parsons et al., 1984) using blanks and standards for fresh and sea water.

RESULTS AND DISCUSSION

Water column dissolved inorganic nutrient concentration

Milkfish have been grown successfully in the ponds and additional growth experiments of milkfish and rabbitfish are underway (Mmochi et al., 2001). The results of water column dissolved inorganic nutrients (ammonia-N, nitrate and nitrite-N and phosphate-P) concentrations during the sampling period from August 1998 to April 1999 are given in Figs 3–6. The results from the finfish ponds indicated a substantial increase in concentrations for each of the three inorganic nutrients. The source of the dominant nutrient input in the finfish ponds was the fish feed and possibly fish excretion. The water column in the reservoir

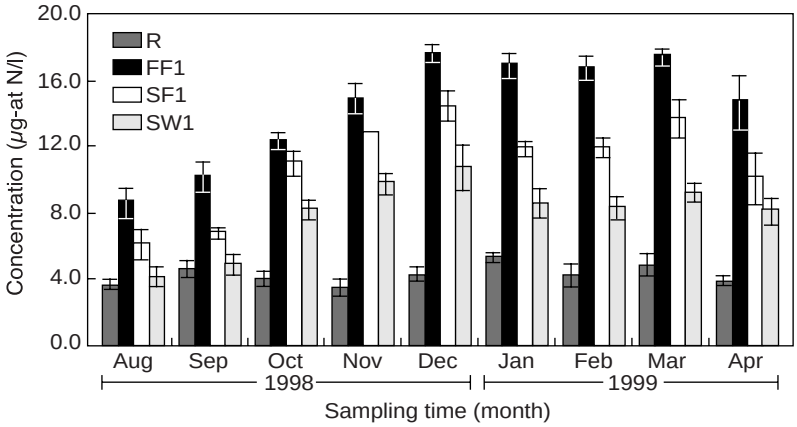


Fig. 3. Changes in ammonia concentration in ponds, series 1. R, reservoir pond; FF1, finfish pond1; SF1, shellfish pond; SW1, seaweed pond

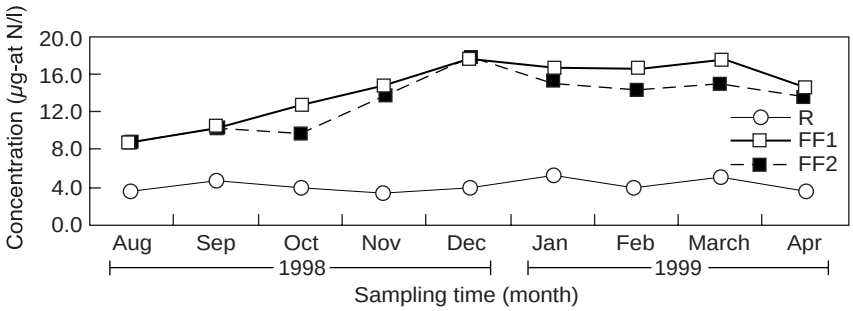


Fig. 4. Changes in ammonia concentration in the finfish ponds. R, reservoir pond; FF1, finfish pond1; FF2, finfish pond2

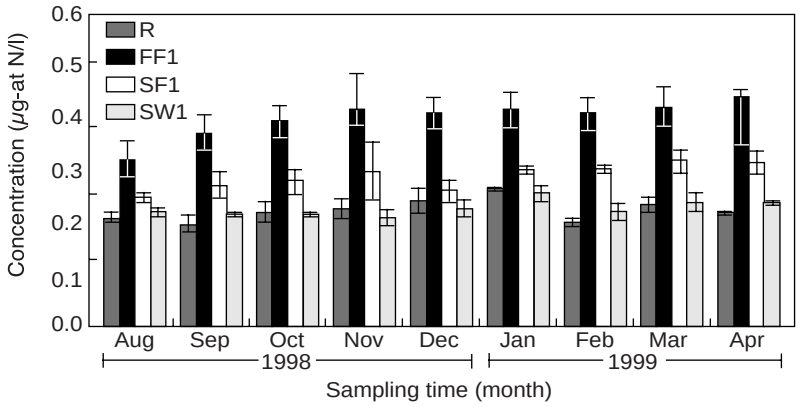


Fig. 5. Change in nitrates concentrations in ponds, series 1. R, reservoir pond; FF1, finfish pond1; SF1, shellfish pond; SW1, seaweed pond

pond (R) was characterised by low levels of dissolved inorganic nutrient concentrations. Ammonia-N was generally below 5 µg-at N/l and did not show much fluctuation throughout the sampling period (Fig. 3). In the two series of finfish ponds (FF1 and FF2), the concentration of ammonia-N was low at the beginning of sampling time and started to increase from September 1998, reaching the maximum of 17.83 µg-at N/l in FF1 and 18.02 µg-at N/l in FF2 in December 1998 (Fig. 4). Maximum allowable concentrations of ammonia for salmonid and cyprinid waters in Europe is 70 µg-at N/l (Macdonald, 1994). Ammonia concentrations in Makoba may therefore not be considered a problem at the moment.

Nitrate-N concentration in R did not exceed 0.25 µg-at N/l at any time during the study. It dropped to below 0.2 µg-at N/l in February 1999 (Fig. 5). In the finfish ponds, the nitrate-N concentrations increased with time and reached the maximum values of 0.51 µg-at N/l in FF1 and 0.44 µg-at N/l in FF1 in January 1999 and April 1999 respectively. These levels are very low compared to the maximum allowable concentration of 700 µg-at N/l for protection of coastal aquatic systems in the Philippines (DENR, 1990). Phosphate-P concentration in R was below 2.5 µg-at P/l and did not change much (Fig. 6). It, however, increased and reached the maximum concentrations of 7.66 µg-at P/l in FF1 and 7.97 µg-at P/l in FF1 in April 1999 (Fig. 6). These concentrations are lower than the maximum acceptable concentration of 13 µg-at P/l for coastal waters in the Philippines (DENR, 1990).

The rate of change of dissolved inorganic nutrients was highest in the rainy seasons, April–May and October–November. The changes were most marked for ammonia and phosphates but not as much for nitrates. The concentrations of dissolved inorganic nitrates were proportionally low compared to ammonia in other areas of Makoba Bay (Mmochi et al., 1997) indicating that there are some reducing conditions in the sediments that may be favouring the conversion of nitrates and nitrites to ammonia. This is further substantiated by a strong negative relationship (correlation coefficient of 0.71) between ammonia and oxygen concentrations (Fig. 7). From August 1998 to April 1999 dissolved inorganic ammonia concentration increased by 9 µg-at N/l, from 8.91 µg-at N/l to 18.02 µg-at N/l with a positive linear regression of 0.79 in FF1. During the same period soluble reactive phosphorus increased by 3.55 µg-at P/L from 4.36 µg-at P/l to 7.91 µg-at P/l with a positive linear regression of 0.75 in FF1.

There was notable increase in the concentrations of the three nutrients as the water moved from the reservoir to the finfish ponds. This was followed by gradual decrease across the three ponds (finfish, shellfish and seaweed), even when there had been only a few shellfish in the shellfish ponds and with no recorded success in the growth of macroalgae in the ponds. From the figures therefore, the aspect of bio-filtration by the farmed

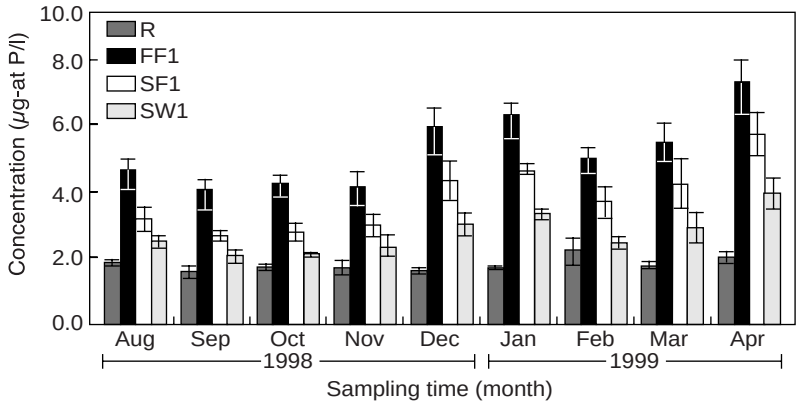


Fig. 6. Changes of phosphate-P concentration in ponds, series 1 R, reservoir pond; FF1, finfish pond1; SF1, shellfish pond; SW1, seaweed pond

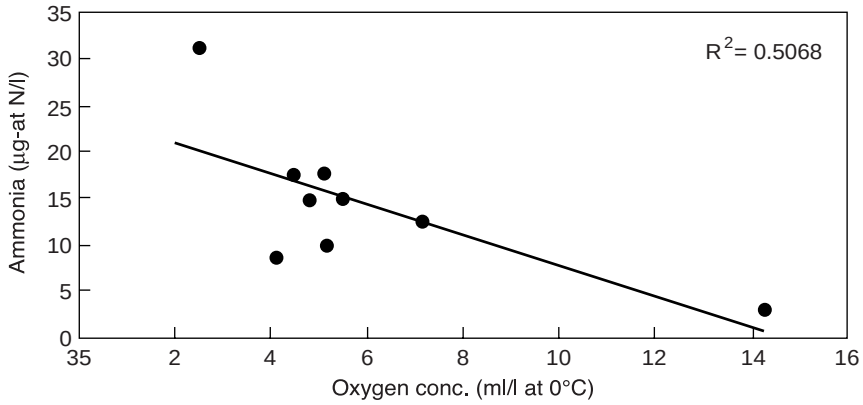


Fig. 7. Relationship between oxygen and ammonia concentrations at Makoba ponds

algae was not obvious and indicated that the decrease was more by sedimentation or bio-filtration by the bottom algal mat (Mwandya et al., manuscript). Indeed, relatively more nutrients were removed from the water column in the shellfish ponds than in the seaweed ponds (Figs 3, 5 and 6).

Water temperature, dissolved oxygen concentration and saturation and salinity

Water temperature (Fig. 8) showed a fluctuation of around 25 °C to 33 °C between January and March, decreasing from April to December to around 28 °C. Such trends were observed in all three measurements taken daily (i.e. around 7 am, 1 pm and 5 pm). Salinity values followed a regular annual cycle from the lowest of 34 $^{0}/_{00}$ to the highest of 41 $^{0}/_{00}$. The pattern seems to follow the temperature regime probably due to evaporation and rainfall patterns.

Oxygen concentration changed from an average of 7.16 mg/l in October 1998 to 2.2 mg/l in March 2000 with a negative linear regression of 0.69 during the morning hours. Dissolved oxygen concentration (mg/l) and saturation (%) were relatively high during the evening as compared to the morning and afternoon (Fig. 9). The maximum dissolved oxygen concentrations and saturation recorded in the evening were 10.5 mg/l and 160% respectively, in October 1998. Daily data showed that both concentrations and saturations of oxygen were low at the beginning of the sampling from July to August 1998, and increased to reach maximum values in October 1998, then decreased until January 1999. From

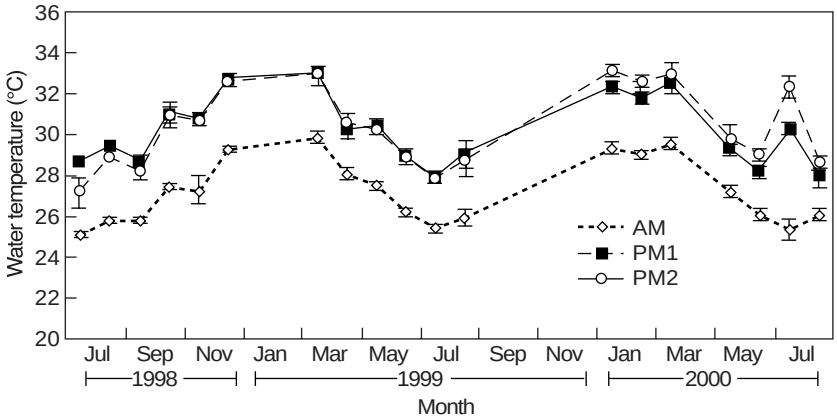


Fig. 8. Water temperature changes in finfish pond series 1. AM, 7 am; PM1, 1 pm; PM2, 5 pm

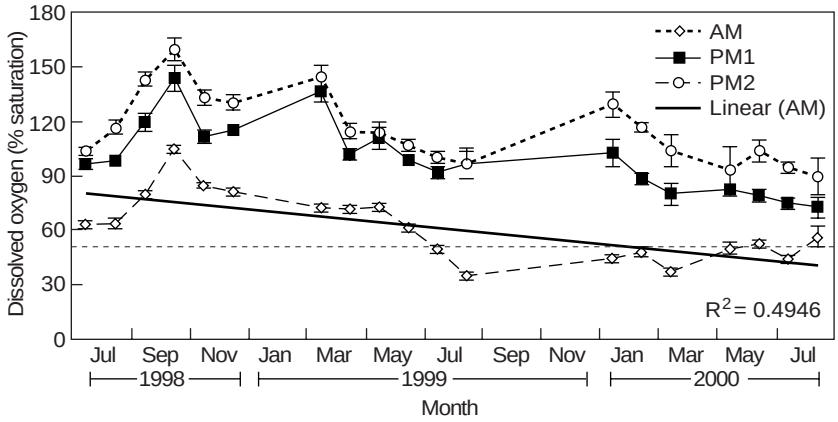


Fig. 9. Changes in dissolved oxygen (% saturation) in IMPS series 1. AM, 7 am; PM1, 1 pm; PM2, 5 pm

January 1999 to July 2000, the values continued to decrease with the exception of February 1999 and January 2000.

Ponds can reach limiting concentrations of nutrients and oxygen for fish culture, making treatment necessary. Intensification efforts in low-flow and intermediate-flow earthen ponds have been hampered by progressive eutrophication (Krom & Van Rijn, 1989). This process, which results from remineralisation of accumulated detritus on the bottom, is often followed by unstable water quality that may retard fish growth and occasionally cause mass mortalities (Rimon & Shilo, 1982). Despite the fact that most of the dissolved inorganic nitrogen exists in the form of ammonia, the concentrations of the dissolved inorganic nutrients in the ponds are well below the maximum allowed for protection of aquatic life. However, the limiting factor seems to be the dissolved oxygen, which is below the minimum thresholds for protection of aquatic life (MacDonald, 1994).

There were two mass rabbitfish mortalities on 17–21 August and 20–26 October, 1998 (Mmochi et al., 2001). The first occurred when the reservoir wall broke and there was no sea water supply for two weeks. During that period salinity rose to 41 $^{o}/_{oo}$ while oxygen concentration and saturation went down to 2.9 ppm and 46 % respectively. Both the salinity and oxygen concentrations were extreme and could have been the cause of fish mortalities. The second fish mortality occurred after heavy rain causing the dilution of the pond waters to a salinity of about 20 $^{o}/_{oo}$. Neither of these conditions caused any observable stress to milkfish. This has been the motivation for the Institute to put more effort into milkfish culture compared to rabbitfish. It is worth noting here that it is more difficult to produce hatchery or collect fingerlings of milkfish as compared to rabbitfish. In 2002 an experiment was carried out comparing growth rates of fish grown in these conditions to those grown in new ponds (with higher oxygen concentrations) to determine chronic effects of low oxygen concentrations. Following the criteria for protection of aquatic life in most countries, oxygen concentrations below 3 ppm or 50 % saturation are considered to be the minimum acceptable levels. For Makoba finfish ponds this concentration was reached after the first 12 months.

CONCLUSIONS AND RECOMMENDATIONS

- Nutrients concentrations in the IMPS system at Makoba are well below the maximum accepted for protection of aquatic life in most countries. However, the relatively higher concentrations of ammonia as compared to nitrates and nitrites may be a result of highly reducing conditions in the sediments.
- After the first 12 months oxygen concentrations and saturations were below the minimum recommended for protection of aquatic life. It is therefore suggested that the ponds are oxidised/treated annually to prevent anoxic conditions developing.

- Milkfish are seemingly capable of surviving at oxygen levels below the minimum concentrations recommended for protection of aquatic life. Extreme conditions may cause some retardation in growth or other chronic disturbances. It is suggested to conduct experiments to compare growth rates of milkfish under different dissolved oxygen concentration levels and to determine the minimum levels of oxygen concentrations that milkfish can tolerate.
- The sediments at Makoba are rich in algal mats and hence food for milkfish. However, so far no experiment has been done to determine the growth rate of milkfish without artificial food supply. This should be done in order to decide whether there is a real requirement for artificial feed.

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