Design and preliminary results of an integrated mariculture pond system (IMPS) at Makoba, Zanzibar, Tanzania

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ABSTRACT

Mariculture development in Zanzibar Island, Tanzania, is limited by the lack of appropriate technology for local conditions and cost-effective solutions for preventing nutrient enrichment of the marine environment. An integrated mariculture pond system (IMPS) concept originally developed in Israel is considered as a possible model for mariculture development in Zanzibar. An experimental IMPS has been established near the estuary of Kiwani Creek at Makoba on the west coast of the island. Water supply is provided by a reservoir fed by tidal fluctuations in the creek. The experimental system consists of six ponds of 170m^3 each, for the culture of fish, shellfish and seaweed. The ponds were stocked during June and July 1998 with 4000 fingerlings of rabbitfish (*Siganus* sp.) and with different species of shellfish and seaweed. Water quality parameters in the ponds, such as temperature, oxygen and salinity, were kept within acceptable limits by a periodic water supply. Fish were fed daily with a diet developed for this project. Preliminary results indicate reasonable growth of the fish but also mortality of fish, shellfish and seaweed.

INTRODUCTION

Following the success of seaweed mariculture in Zanzibar (Msuya and Mmochi, 1995; Msuya et al., 1996), there is local interest in starting fish, shellfish and crustacean mariculture. A few rudimentary ponds already exist at Nungwi and Chwaka on Zanzibar Island and elsewhere on Pemba Island (Mmochi and Jiddawi, 1996; Mmochi et al., 1997). However, the lack of artificial feed and environmentally sustainable methodologies has kept these operations at a very small scale and limited the development of mariculture in Zanzibar.

One of the main challenges for the development of mariculture in Zanzibar (and Africa in general) is to avoid the mistakes that have been made in Asia and South

America (Mafwenga, 1994). In these regions pollution, uncontrolled elimination of mangrove forests and saltwater intrusion into land have ruined many nearshore ecosystems, especially mangroves (Kapetsky, 1986).

Mariculture experiments at the Institute of Marine Sciences (IMS) of the University of Dar es Salaam began in the early 1980s (Bwathondi, 1981, 1982, 1986; Bwathondi and Ngoile, 1982; Jiddawi, 1989, 1995). More recently, IMS has received increasing numbers of requests for advice on fish, shellfish and crustacean culture (Mmochi and Jiddawi, 1996). The Institute saw the need to develop human and laboratory capabilities for mariculture research and development, so that sound advice could be given to potential farmers and policy makers. Toward this end, IMS conducted a series of studies on the possible impact of mariculture on the environment, in preparation for developing pond mariculture in coastal areas of the Zanzibar Islands (Mmochi, 1995; Mmochi et al., 1996, 1997).

The project described in this paper is a result of collaboration between IMS and scientists from the National Centre for Mariculture (NCM) in Eilat, Israel, beginning in July 1995. It deals with the adaptation of NCM's Integrated Maricultue Pond System (IMPS) concept to local conditions in Zanzibar.

The IMPS was designed to create an economically viable production system with reduced organic and inorganic output to the environment. IMPS utilises a modular flow system of ponds for production of fish, shellfish and seaweed, in which shellfish remove particulate matter from fish pond effluents, algae remove dissolved nutrients, and clean water is returned to the environment (Mozes and Saban, 1995; Shpigel et al., 1993).

The aims of this project have been to demonstrate a prototype IMPS within the environmental, socioeconomic and technological conditions that prevail in Zanzibar, and to enhance IMS' capabilities for mariculture research and development. Of the three basic requirements for sustainable mariculture, i.e. adequate water quality, reliable supply of formulated feeds and reliable source of seed stock, the project focused on finding solutions to the first two. Fingerlings are, at this stage, collected from the wild.

SYSTEM DESIGN AND INSTALLATION

The site of the IMPS pilot project in Zanzibar is at Makoba, on the west side of Kiwani Creek (Figure 1). A set of existing salt evaporation pans spread over five to six hectares was made available to the project (Figure 2). The salt pans are owned by the local government and had not been in use for several years. Infrastructure included a water reservoir, channels to direct water to the pans, broken water gates, and earthen dykes and embankments.

The site is located in a mangrove estuary fed by two rivers, the Zingwezingwe and the Mwanakombo, which flow into the creek (Figure 3). When the site was first visited by project staff in 1996, the spring tide filled the salt pans with seawater because the gates were broken. In 1997, several gates were reconstructed (Figure 4), and water

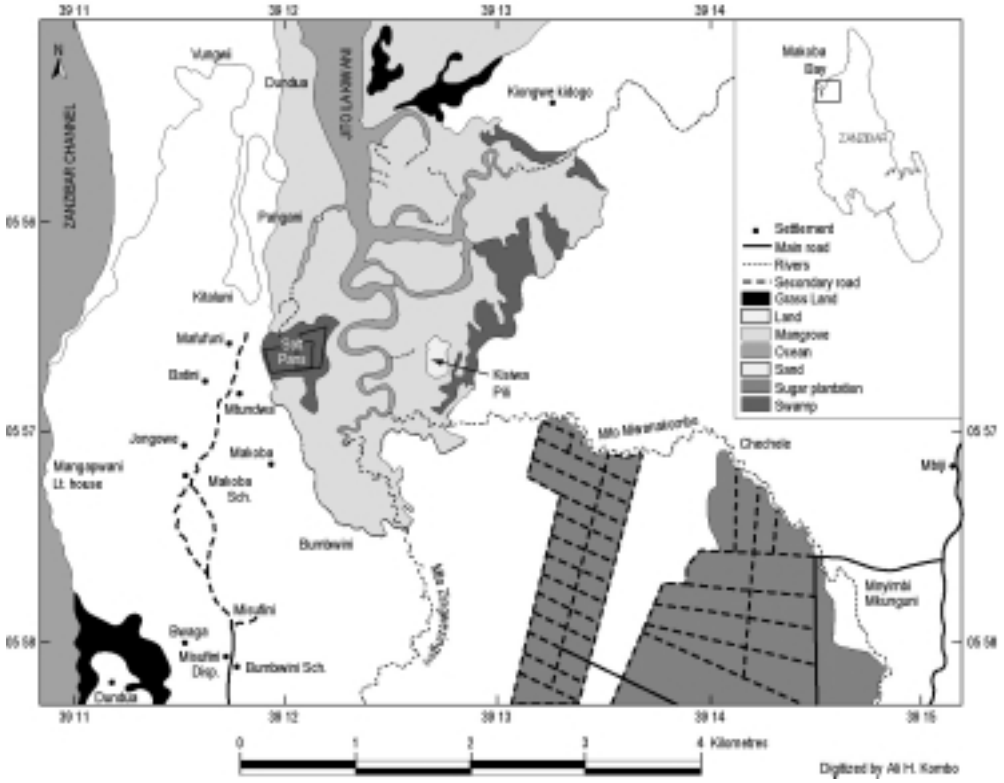


Figure 1. Makoba Bay showing the salt pans and the rivers

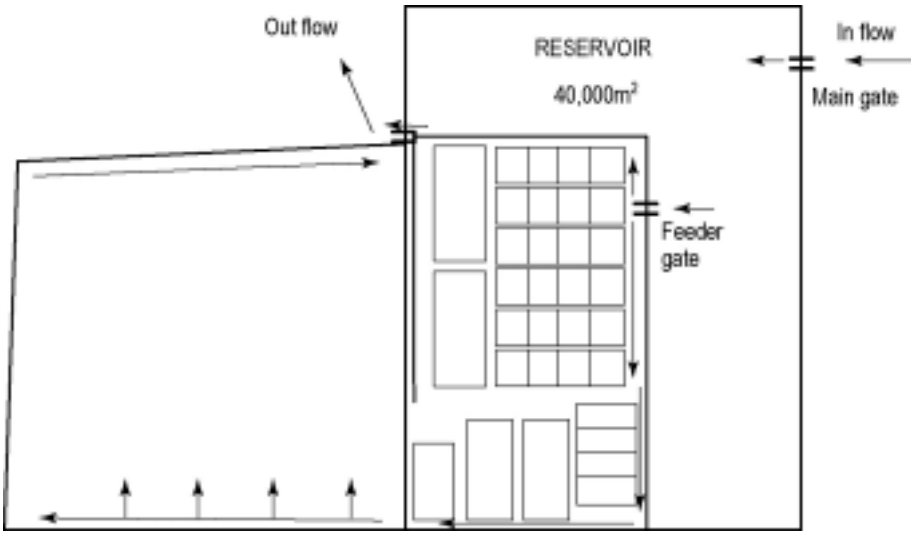


Figure 2. Evaporation salt pans at Makoba

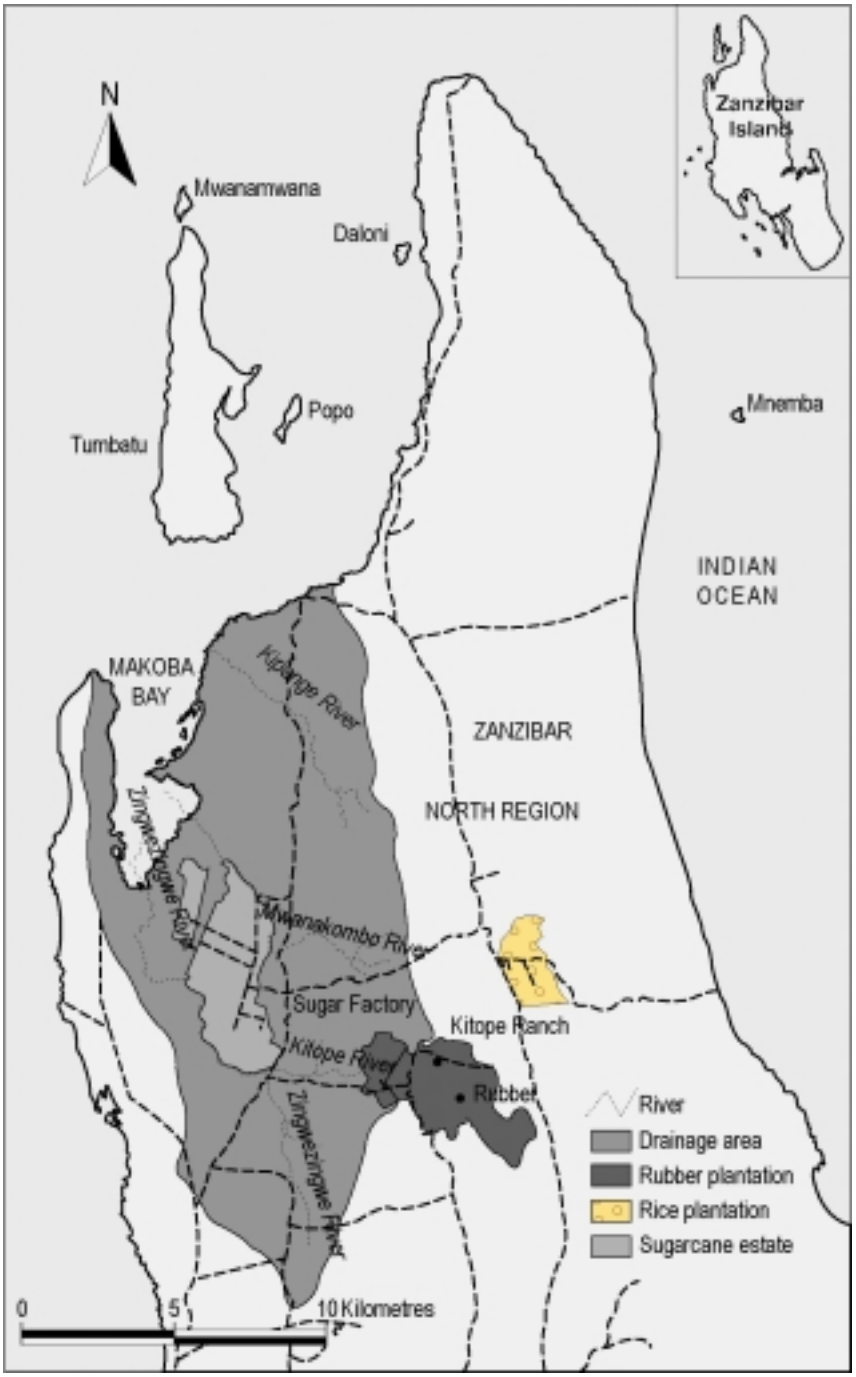


Figure 3. Mahonda-Makoba drainage basin



Figure 4. The newly constructed main gate

from the ocean now comes into the pans/ponds only through the reservoir. Water flow through the ponds is controlled by opening and closing a gate between the reservoir and the ponds.

The maximum tide range in the estuary is about 4.4m. The river basin is also home to a rubber farm, a sugarcane plantation, several rice farms, a sugar factory and a rubber factory. The farms and factories may occasionally introduce fertilisers and toxic materials into the river (Mohammed, 1990; Mmochi and Mberek, 1998). However, a rough estimation of the river's flow rate made on 1 August 1996 found the water flow to be 1000 to 2000m^3/h. This is about three orders of magnitude lower than the flow rate at mid-high tide (1.4 million m^3/h), suggesting that contamination would be diluted to acceptable levels during high tides.

Water quality measurements revealed that during flood tide, salinity in the estuary increases to approach that of seawater. At the same time, dissolved oxygen (DO) levels increase to saturation values and nutrient concentrations decrease. The water quality values were below the maximum allowed for recreation and mariculture activities (DENR administrative order No. 34, 1990). These findings favour drawing water for the ponds from the estuary at high tide.

Tide measurement and analysis

A pressure gauge was installed in the vicinity of the main water gate in late 1996. One month's records (18/9/96–16/10/96) were analysed and compared with British Admiralty Tide Tables for Zanzibar Harbour. High tides at Makoba were found to lag behind high tides at Zanzibar Harbour by about 30 to 50 minutes. The tidal amplitudes and fluctuations (at high tide) were found to be about the same. It is not possible to compare the time of low tide because the pressure gauge was situated above the low water level. Anecdotal

observation suggests that there is a delay of about two hours in the low tide at the estuary compared with Zanzibar Harbour, but this has not been confirmed. The tide and pressure gauge data are presented in Figure 5. A Tide Table datum (TTd) was marked at the Makoba site, and the tide table was then used for tidal forecasts at the site and for the design of the water supply to the project ponds.

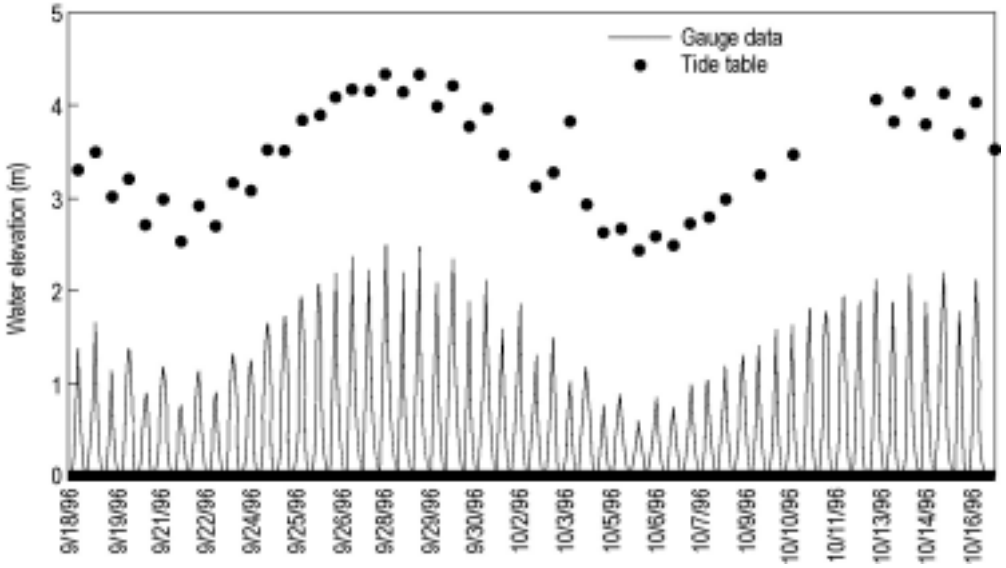


Figure 5. Tide measurements at Makoba site (water gate) Sep–Oct 1996, Tide Table datum

Pond and gate design

The main gate connects the reservoir to the tidal creek and regulates the exchange of water between the reservoir and the creek. The elevation of the floor of the main gate is 0.5m below the lowest reservoir bottom elevation (9m in topographical survey datum). The height of the main gate is designed to be at the same elevation as the main ridge. The main gate rests on a 2-m-deep box-type foundation. Side walls are built across the ridge to strengthen the walls. The flow from the creek to the main gate and on to the reservoir is provided by wing walls. These walls also help to retain the earth on both sides of the gate. Two horizontal walking platforms of thick wooden planks, one on either side of the gate provide for easy operation of the flush-boards. The amount of water allowed through the gate is controlled by flush-boards made of wooden planks, 50mm thick and 300mm wide, inserted into the groove. A mesh screen is attached to a wooden rectangle and inserted into a groove of the secondary gate connecting the reservoir and the ponds. The screen is intended to prevent the exit of the cultured fish and entry of predators into the ponds.

The size of the opening of the main gate is designed such that the water flow speed is not lower than 0.3m/s to avoid silting and not greater than 1m/s to avoid scouring. For example, if the reservoir is filled to 0.9m above its bottom and the average

time to fill it is 6.2 hours (diurnal tides), the area (A) of the sluice opening for a water speed (V) of 1m/s is about 3m^2, requiring a minimum opening of 1.2m with a gate height of 2.5m.

Water supply

The existing reservoir has a surface area of approximately 40,000m^2, and an average bottom elevation of 3.6m above sea level (TTd). Spring tides range from 0.25 to 0.9m above this average reservoir bottom elevation (using British Admiralty Tide Tables for 1997). The reservoir is filled at each spring tide, providing at least 10,000m^3 of water. This water must last through the neap tide cycle, until high tides again exceed the reservoir bottom elevation, in about 10 days. Thus, the reservoir can provide 1000m^3 of water per day at the minimum (30% of the time).

A simple dynamic model was developed to guide the operational management of the reservoir. An example of simulation of the flow and water level in the reservoir during four days surrounding a spring tide is presented in Figure 6.

Ground water observations

The high ground-water table at Makoba raised concerns of fresh water intrusion into the ponds after they were deepened. On 21 and 23 March 1997, ground water was sampled at Makoba to determine its depth, salinity, and changes over the tide cycle.

A 1-m-deep hole was made in the middle of the salt pan area. Salinity and water level were measured simultaneously in this hole and at the main reservoir gate. Water

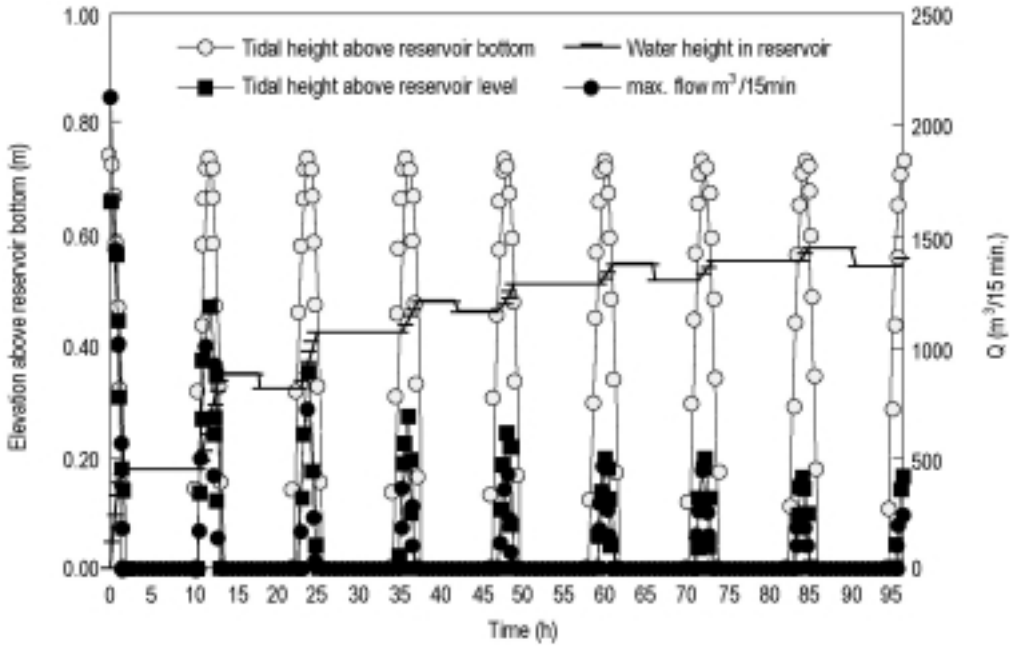


Figure 6. Flow model—Tide at Makoba IMPS. Simulation of 4 days at spring tide

level and salinity in the hole were found to be largely constant over the tidal cycle (Figure 7). The findings suggested that fresh groundwater intrusion at Makoba will not be a problem for aquaculture.

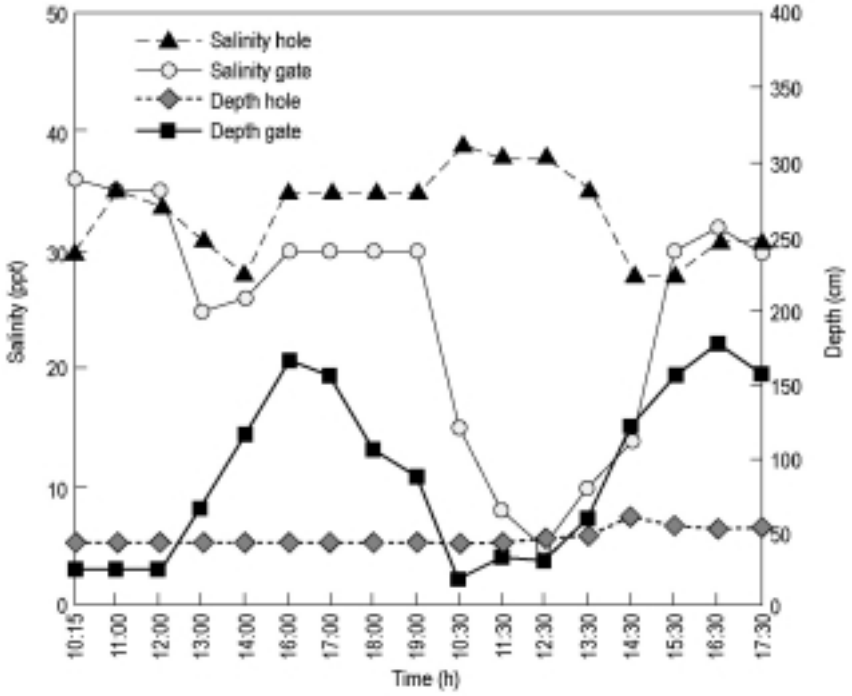


Figure 7. Water depth and salinity of the water hole and main gate 22–23 March 1997, Makoba

Pond construction

Six of the existing salt pans at Makoba were divided into two series of three ponds each, and dug to accommodate a water depth of 0.6–0.7m. The final size of the ponds is 20 x 13m (260m^2) with an estimated volume of 170m^3. Sediment in the ponds was black mud, probably containing high levels of organic matter, which originated from the mangrove swamp that existed before the salt works were built.

Each set of three ponds was arranged in a row so that water released from the tidal reservoir enters the 1st (fish) pond, pushing the water from that pond into the 2nd the (shellfish) pond and the water from the shellfish pond into the final (seaweed) pond. From the last pond, water travels to a holding basin for return to the sea when the tide is appropriate. Wooden gates with mesh windows separate the ponds from each other and prevent movement of fish between the ponds. A concrete gate with wooden doors at the exit of the seaweed pond determines the water level for the three ponds.

Oxygen considerations and water flow regime

The water exchange rate (ER), is determined by the water flow rate (Q) and the water volume (V) of the pond (ER=Q/V). At low ER (ER<0.5 per day) the water quality is

dominated by phytoplankton activity. At a higher ER (ER>1.5) the water quality conditions are more stable and are dominated by the fish biomass (Mozes and Argaman, 1995). Since mechanical aeration for oxygen supply was not to be used at the Makoba site, the water exchange rate was designed to maintain reasonable water quality and oxygen levels for the culture of the fish. An ER of 1 to 2 exchanges per day was assumed to allow final fish density of 1kg/m^3.

Diet development and feeding experiments

Farming of rabbitfish under semi-intensive or intensive conditions requires the use of formulated fish feeds to guarantee that the fish will receive the necessary nutrients to grow. In this project, rabbitfish (*Siganus* sp.) were to be raised for local use in Zanzibar. Therefore, the cost had to be low enough to compete with local market prices. This meant that a fish feed manufactured from locally available feed ingredients was preferred, as it was most likely to keep the cost of growing the fish at an affordable level.

In 1997, a survey and evaluation of feed ingredients available in Zanzibar to identify raw materials that could be used to formulate rabbitfish feed was conducted. Available feed ingredients were shipped to the NCM nutrition laboratory and analysed for approximate compositions. The ingredients included 8 species of legumes from genus *Leucaena* and 2 species of algae from genus *Eucheuma*. Other ingredients were anchovy, coconut cake, sardines, rice bran, broiler mash and growers mash. Ingredient prices and availability throughout the year were also considered. The results of ingredient analyses are shown in Table 1.

Based on the composition and price data for ingredients from Zanzibar, two diets were formulated using a computer least cost formulation program developed for the feed industry. The diets formulated were for a primary herbivore whose main source of dietary protein is plants. The composition of the diets are given in Table 2.

Dietary trials were conducted at the NCM, using locally available rabbitfish species (*Siganus canaliculatus* and *Siganus sutor*), which are also present in Zanzibar. The results obtained in the NCM trials were then tested on a larger scale in the ponds in Zanzibar. 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. Rabbitfish are grazers and spend most of their time feeding. As a result, it is important to know whether they require large volumes of feed or can thrive on smaller quantities of food of a higher total nutrient concentration.

Within 10 days of the start of the feeding trial, fish started to die in all of the fish tanks. Pathological examination indicated no obvious parasitic or bacterial infections, suggesting the possibility of a toxin in the feed. To test the feed ingredient toxin hypothesis, each of the feed ingredients was individually combined with known ingredients routinely used at NCM. These five new diets were then tested on healthy rabbitfish in the same type of feeding trials. Within 10 days of the start of this trial, the tanks fed with the legume 5 developed the same pathology as in the initial study, and fish began to die. It was then clear that the cause of the mortality was from legume 5

Table 1. Composition of feed ingredients from Zanzibar (in percent as fed)

Ingredient	Moisture	Protein	Lipid	Ash	Carbo-hydrate	Energy-(cal/g)	Phosphorous
Legume 1	11.1	23.32	4.38	12.27	11.07	4128	0.29
Legume 2	12.82	26.71	2.59	12.48	11.58	4238	0.36
Legume 3	11.17	24.94	4.42	9.32	12.23	4474	0.424
Legume 4	10.18	21.93	14.13	12.59	17.28	4458	0.24
Legume 5	11.1	26.23	6.5	10.12	24.67	4139	0.26
Legume 7	12.83	24.51	5.03	9.61	15.88	4293	0.17
Legume 8	4.41	33.67	4.84	13.43	12.31	4392	0.17
Anchovy	11.14	73.45	9.88	11.87	–	4555	2.55
Coconut cake	11.24	24.04	8.06	5.94	24.07	4305	0.84
Sardines	19.36	63.72	6.61	12.65	–	4028	2.04
Rice bran	9.37	5.64	4.56	18.96	26.85	3452	0.58
Maize bran	11.26	10.35	8.84	2.07	55.51	4424	0.35
Broiler mash	11.19	16.92	6.93	7.37	47.23	4027	0.59
Growers mash	11.25	13.62	6.83	6.48	50.74	3899	0.51
Eucheuma cottonii	14.23	0	0.87	42.54	25.36	1847	0.09
E. spinosum	16.33	0	0.84	52.42	21.28	1687	0.04
E. cottonii washed	16	–	–	24.18	–	–	–
E. spinosum washed	8.4	–	–	18.43	–	–	–

Note: Analyses were carried out at National Centre for Mariculture, Israel.
– not analysed.

Table 2. Percent composition of formulated diets for rabbitfish

Ingredient	25% protein diet	32% protein diet
Legume 5	19.0	16.0
Coconut cake	21.0	18.0
Maize ban	21.0	18.0
Broiler mash	21.0	18.0
Sardines	18.0	30.0
Total feed	100	100
Estimated cost (TSh.)	35	42

(*Leucaena*). A meal made from the leaf of this plant contains an antinutrient called mimosine that is known to retard growth in fish and can be removed through pretreatment of the plant before use in feeds (Coche and Edwards, 1989). The feed was remade using presoaked *Leucaena* and used successfully. However, *Leucaena* was later replaced with *Ulva reticulata*, which has the same protein: carbohydrate composition.

In June 1998, a trial production of fish feed was undertaken in Zanzibar. As a replacement for legume 5, fresh seaweed from the local beaches was obtained. The seaweed (*Ulva reticulata*) was rinsed with fresh water, sun dried, milled and mixed with the other ingredients. Initially, pellets were made using a kitchen meat mincer (commercial meat mincers or industrial pelleting machines might be used in future).

Later, an experiment was done with the feed in the form of balls. The balls (approximately 70g each) were made from the mixed ingredients using 5% cassava as a binder, and dried in the sun to harden. Initial feeding trials with the balls indicated the fish ate them enthusiastically. Since this is also a cheaper option for the fish farmers, the making of the balls was continued. Table 3 provides data on the feed's composition and cost in Zanzibar.

Table 3. Feed content and cost

Component	Price (TSh./kg)	Fraction (%)	Cost (TSh./kg food)	Percentage of cost
Copra cake	30	17.4	5.1	1.9
Fish meal	450	28.6	128.7	48.9
Broiler mash	156	17.14	26.7	10.1
Ulva	500	15.2	76.0	28.9
Maize bran	100	17.14	17.1	6.5
Cassava	200	4.8	9.6	3.6
Total		100.0	263.2	100.0

Stocking of ponds

Approximately 4000 rabbitfish (a mixture of *S. canaliculatus* and *S. sutor*) fingerlings were collected and transferred to the project's pond during June and July 1998. The fingerlings were collected with the aid of a 25m beach-seine net at high tide on the beach next to the Institute of Marine Science in Stone Town, Zanzibar. Transportation of the fish to Makoba was carried out using a compressed air supply from scuba tanks and an air diffusing system. All fish were successfully transported and stocked in the two fishponds with no mortality (about 2000 fish in each pond). Samples of about 50 fish each were weighed individually before the two separate transports, yielding average fish weights of 5.7 and 7.1g.

Two species of locally occurring shellfish—*Anadara* sp. and *Cardium* sp.—were collected from the inter-tidal zone south of Stone Town. They were kept alive in the IMS aquarium tanks for a few days before weighing, sorting and stocking during June 1998 at Makoba. During their stay at IMS, a power failure occurred one night, and oxygen levels in their holding tanks dropped significantly. It is not known whether the mortality observed at a later date was related in part to this oxygen depletion.

Measurement of the shellfish indicated a weight range of 10 to 45g and length range between 20 and 50mm. Both species were of similar average weight and their length/weight relationship was calculated as:

$W = 0.0025 \times L^{0.248}$ ($R^2 = 0.84$) for *Anadara* sp. (n=346)
and $W = 0.0024 \times L^{0.251}$ ($R^2 = 0.93$) for *Cardium* sp. (n=182)

The shellfish were stocked using three different methods:

(1) Suspended above the pond bottom on plastic trays, which were supported by wooden stacks embedded in the pond mud (400 individuals of *Anadara* sp. and 100 of *Cardium* sp.).
(2) Placed directly on the pond bottom at a density of 400 ind./m^2 (200 ind. of *Anadara* sp. and 200 of *Cardium* sp.).
(3) Put on nylon fishing net on the bottom of the pond (200 ind. of *Anadara* sp. and 200 of *Cardium* sp.). Total stocking in the pond was 800 ind. of *Anadara* sp. and 600 ind. of *Cardium* sp.).

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 in the area of Matemwe and stocked in Makoba the same day. Approximately 20kg of each species were stocked using the local method of tying branches of seaweed along a string at a depth of 20cm above the bottom. The estimated stocking density was 1kg/m. *Ulva fasciata*, *U. reticulata* and *Gracilaria crassa* were also stocked. *Ulva* and *Gracilaria* were cultured in small chambers made of netting material of 1 inch mesh size.

Data collection and daily operation

During each spring tide, the reservoir was filled with seawater from the estuary. Water was supplied from the reservoir to the fish ponds every day in the afternoon, when oxygen levels were high due to photosynthesis in the reservoir. The planned water flow to each pond was 200m^3/day, and was accomplished by flushing water until the reservoir water level (RWL) dropped 0.5cm. Fish were fed three times a day by hand, at about 1% of body weight per day. Seaweeds were weighed once a week using a commercial weighing balance. Temperature and dissolved oxygen were measured three times a day in all ponds and the reservoir using an Oxyguard DO meter, calibrated for seawater salinity. Salinity was also measured thrice a day, using a hand-held refractometer.

PRELIMINARY RESULTS AND DISCUSSION

Water supply and salinity

The tidal flow supply model was useful as a design tool for the operation of the reservoir. In practice, however, several limitations became apparent. The reservoir bottom was not even, and only part of the water volume could be utilised for supplying the ponds. As a result, the water supply to the ponds was limited and most of the time the supply was about half of what was planned (0.25cm drop in the RWL to each fish pond, instead of 0.5cm, meaning about 100m^3/day instead of 200m^3/day). In addition, leaks in the reservoir walls and gates were estimated to cause a loss of 100–130m^3/h. On one occasion (17–21 August 1998) the wall of the reservoir broke at one point and no sea water was supplied to the fish ponds for two weeks. The loss of water led to very low oxygen saturation (less than 50%), which is thought to have led to fish mortalities.

Salinity of the water in the ponds ranged from 36 to 40ppt, indicating that the water was coming from the marine tidal flow and not from a fresh water source such as the river or ground water. In general, the daily water exchange prevented any significant drop in salinity due to rain, except on one occasion (20–26 October 1998) when unusually heavy rains coincided with low water level in the reservoir. The salinity dropped to 22 – 20ppt in the ponds and to about 10ppt at the surface of the reservoir. This salinity drop was probably the cause of mortality of about 700 fish in both ponds.

Water quality

Water quality measurements in the fishponds and the reservoir showed daily fluctuations in dissolved oxygen (DO) and water temperature, with greater fluctuation in the reservoir.

Preliminary results indicate that long residence time and shallow water depth effects occur in the reservoir. The long residence time and greater clarity of water in the reservoir probably results in greater photosynthesis, and hence in larger DO fluctuations. The smaller water depth contributes to high temperature variations.

Dissolved oxygen

Dissolved oxygen (DO) showed rather low levels in the morning and high levels in the afternoon and evening (Figure 8). DO levels in the fishponds generally ranged from about 2.5mg/l at 0600 to about 12mg/l at 1800hrs. Average values of DO for all ponds (Table 4) show a range of about 80% of saturation in the morning to about 125% in the evening, with minimum and maximum values of 40 and 196%, respectively.

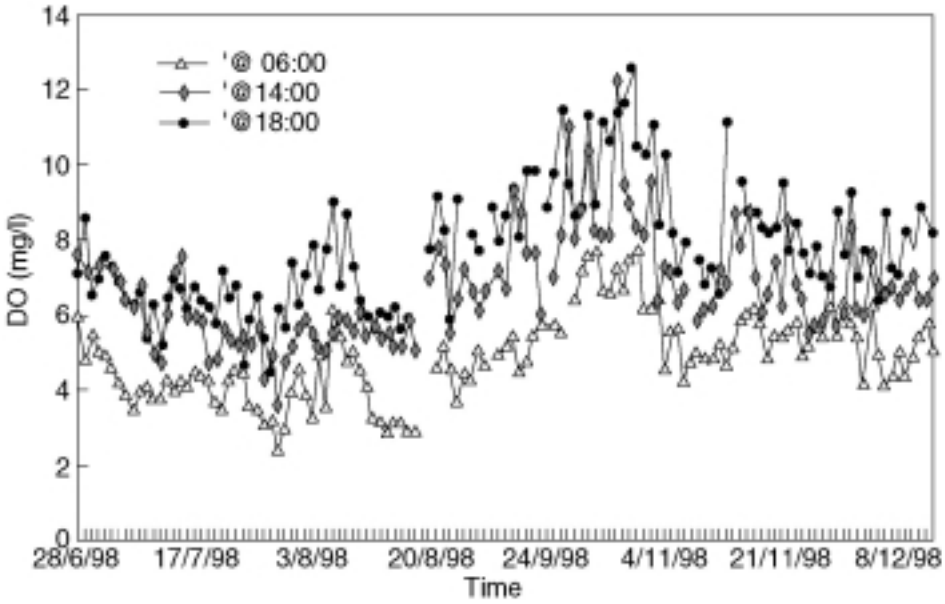


Figure 8. Dissolved oxygen (DO) (mg/l) levels in fish pond 1 at the Makoba IMPS, Jun 1998–Dec 1998

Table 4. Dissolved oxygen concentration, in percentage of saturation, mean values for June–December 1998 in the two rows of ponds (IMPS 1 and 2). SD values are in parentheses

	0600 hrs	1400 hrs	1800 hrs	Average	Min.	Max.
IMPS 1						
Fish	76 (16)	109 (21)	126 (25)	104 (29)	40	196
Shellfish	84 (12)	114 (15)	125 (17)	107 (22)	62	180
Seaweed	85 (8)	108 (12)	116 (12)	103 (17)	62	154
IMPS 2						
Fish	79 (14)	105 (17)	120 (21)	101 (24)	46	176
Shellfish	94 (10)	112 (13)	125 (17)	110 (19)	68	181
Seaweed	90 (8)	112 (12)	121 (14)	108 (18)	73	165

In both sets of ponds, the fluctuations in DO indicated by the SD values in Table 4 and respiration rates (Figure 9) are more pronounced in the fish ponds and slightly less so in the shellfish and seaweed ponds.

Temperature

Temperatures also fluctuated during the day (Figure 10), with an average increase of about 2 to 4°C from morning to afternoon and an average drop of 0.5 to 1°C in the

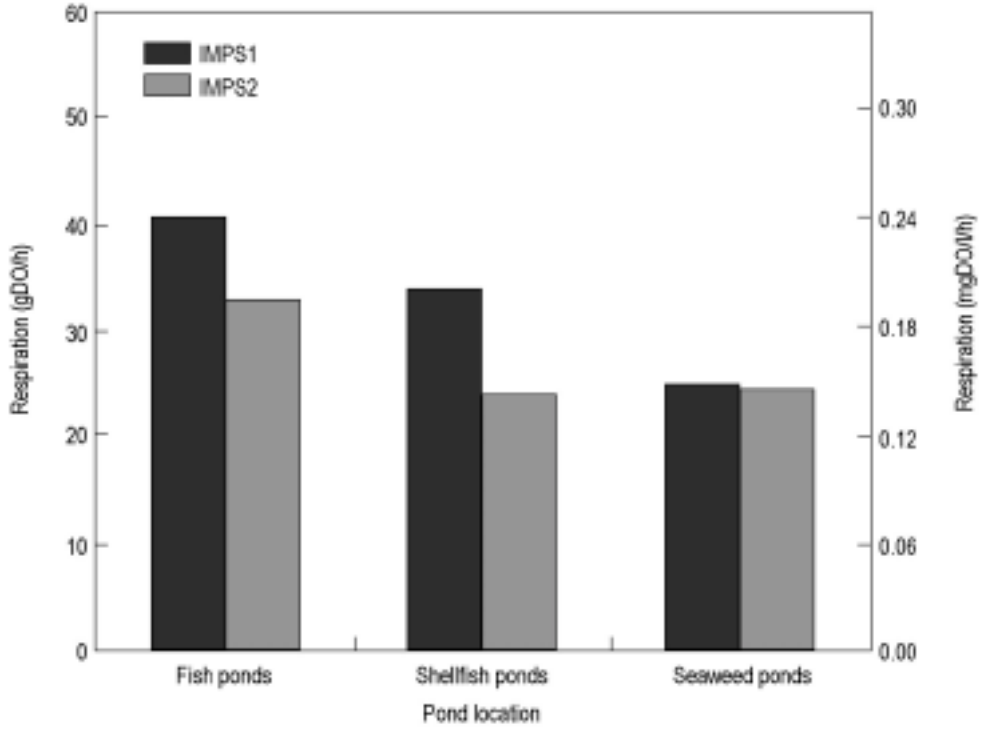


Figure 9. Average night respiration rate at Makoba IMPS 1&2

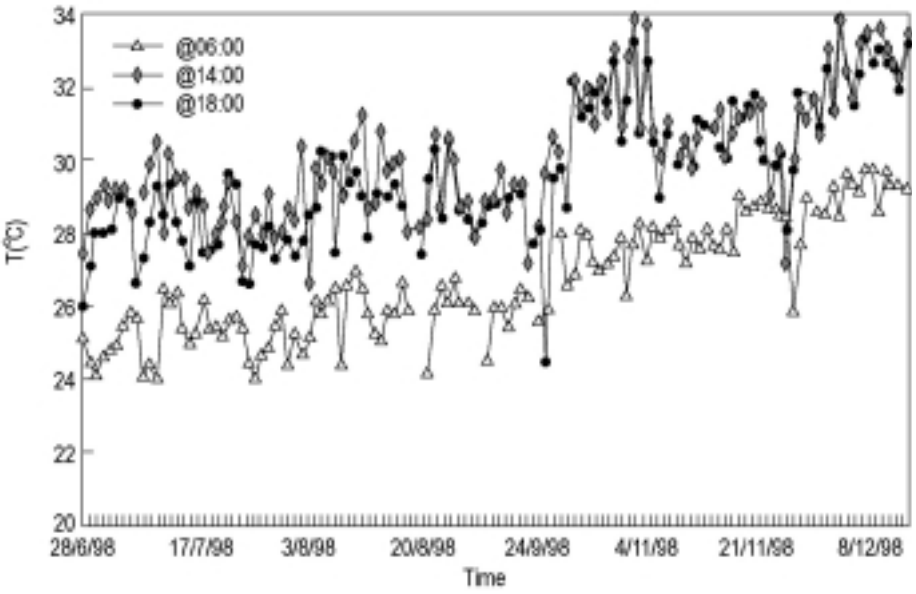


Figure 10. Temperature at Makoba IMPS fish pond 1, Jun 1998–Dec 1998

evening. The average temperature increased during the year from 26.6°C in June to 31.5°C in December (Figures 11a, 11b).

CULTURE RESULTS

Fish culture

The fish in both ponds (*Siganus* sp.) showed reasonable growth during five months of culture. In the first fish pond, fish grew from 5.7g to 34.4g (Jun to Nov 1998) and in the second pond from 7.1g to 66g (Jul to Dec 1998). The difference in growth is attributed to the difference in stocking size and to the higher water temperature during the later months of the year.

Comparison of the results of the fish growth data to a growth rate model (Figures 12a, 12b) shows that the results are slightly lower (by 7 and 16% for IMPS1 and 2, respectively) than the model prediction.

The model equation is based on the feeding experiments done at NCM, Eilat with *Siganus argenteus* using the same feeding diet (NCM Nutrition Dep. internal report, 1998):

$$WG = 0.0098 \times W^{0.605} \times e^{(0.055 \times T)}$$

where WG is the daily weight gain of one fish (g/day), W is the fish weight (g), T is temperature (°C) and the coefficients are empirical. It appears that this equation can be used for growth prediction until there is sufficient data to formulate the growth rate equation for the local conditions.

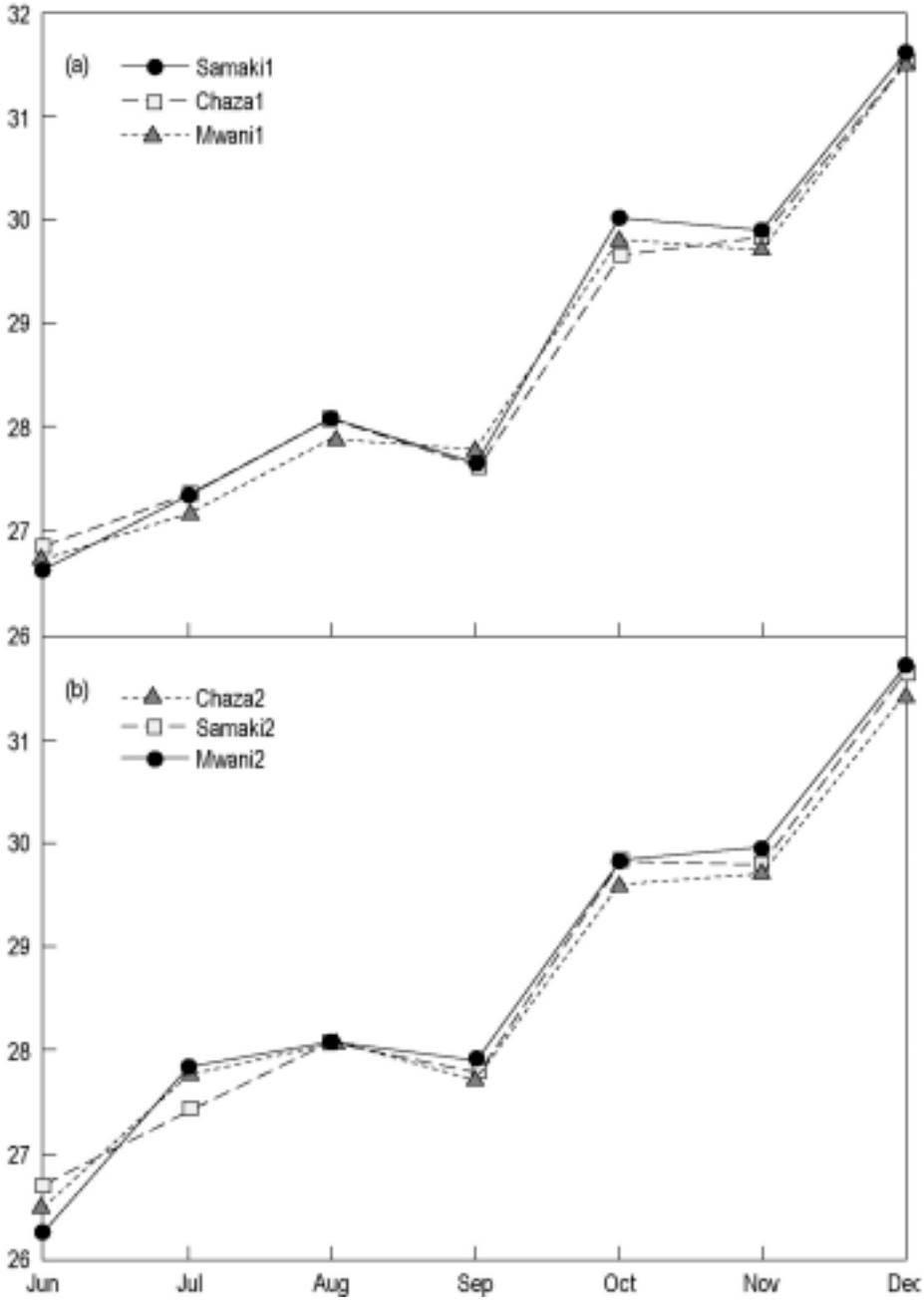


Figure 11. Temperature changes in (a) the water column and (b) pond 2 at Makoba IMPS

Two mass mortalities occurred on 17–21 August 1998 and 20–26 October 1998. The first event occurred when the wall of the reservoir broke and no seawater was supplied to the fishpond for several days. The second mass mortality occurred during a few days of

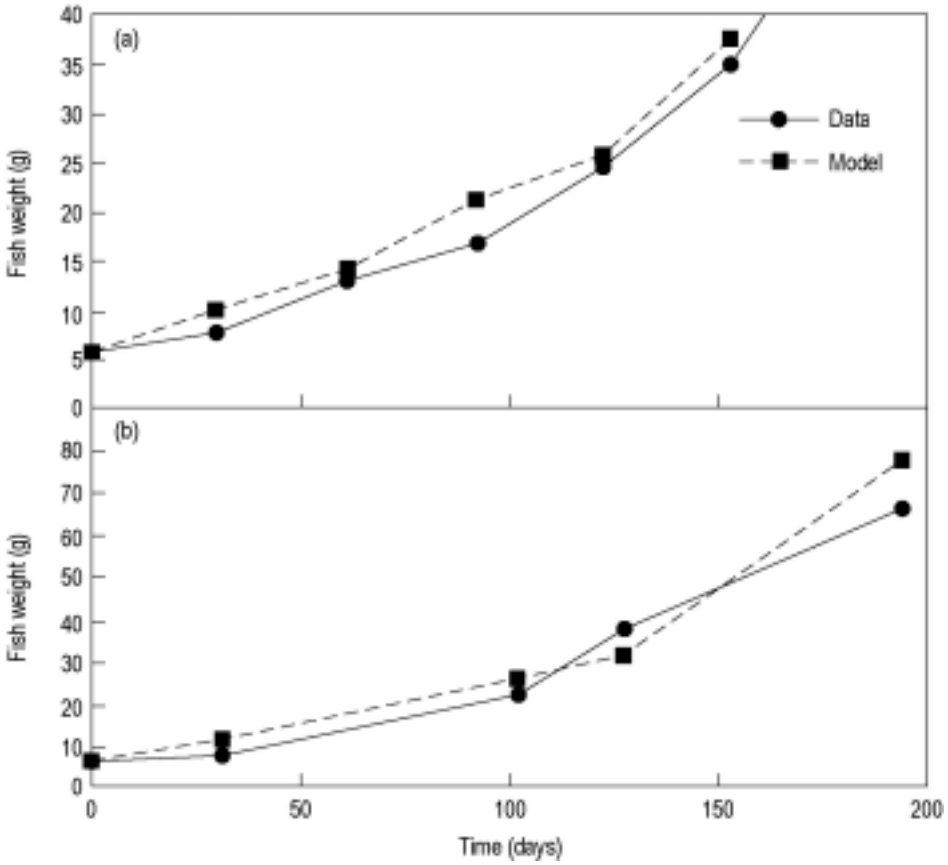


Figure 12. Fish growth rate at Makoba (a) IPS 1, Jun–Dec 1998, (b) IPS 2 Jul 1998–January 1999. Data and model results

heavy rains, leading to low salinity in the reservoir and the fishponds. In total, these events resulted in a loss of about 500 fish in pond 1 (25% mortality) and 830 fish in pond 2 (41% mortality). Re-suspension of the bottom sediments during fish sampling also seemed to cause mortality of fish.

All the fish that died were of the species *Siganus canaliculatus* (except for one specimen of *S. sutor*). Apparently, *S. canaliculatus* is more sensitive to extreme conditions and therefore may be less suitable for culture than *S. sutor*. In addition to the *Siganus*, a few specimens of milkfish and *Tilapia* were present; these were also in good condition.

Shellfish culture

Shellfish culture was attempted using several species: *Anadara* sp., *Cardium* sp. and oysters. The two species stocked initially (*Anadara* sp., *Cardium* sp.) did not survive the pond conditions under any of the culture techniques that were tested. Subsequently, a group of oysters (*Pinctada* sp.) were placed in the ponds, both inside trays and in

between trays. The oysters inside the trays showed limited growth (perhaps due to blockage of water circulation through the trays), while oysters outside the trays survived and grew.

Seaweed culture

All the seaweeds suffered from dramatic siltation from sediments and organic loads suspended in the pond. Growth rates decreased with time. Only the *Gracilaria* sp. showed some limited growth and resistance to siltation. *Eucheuma* was the most severely affected followed by *Ulva* and lastly *Gracilaria*. The first sign of stress in *Eucheuma* was the hardening of the fronds, followed by lightening of the colour and thinning of the seaweed fronds. One variety of *E. spinosum*, which was recently introduced in Zanzibar from the Philippines, and *E. cottonii* could not survive after two weeks of culturing, whereas the 'old variety' of *E. spinosum* survived for more than a month.

CONCLUSIONS

The idea of environmental friendly mariculture using the IMPS concept seems to be promising for marine aquaculture development in Zanzibar. It has been demonstrated the Makoba site, which has some unique characteristics that differ from other potential sites, creates special conditions that influence the system design and performance.

Existing infrastructure at Makoba, such as the reservoir, is not found anywhere else in Zanzibar or Pemba. The reservoir provides a daily supply of water to the ponds without any motorised pumping. On the other hand, the water that reaches the ponds is not fresh seawater, and changes in dissolved oxygen and salinity within the reservoir affect the ponds. In addition, the heavy and muddy bottom soil of the ponds, which probably contains high levels of organic matter, affects water quality and siltation in the ponds. Nonetheless, the methodology and information that have been gained from the Makoba experimental site can contribute to the development of mariculture in the region.

The tidal water supply method used at Makoba provided water quality conditions that fluctuated within the generally acceptable range of dissolved oxygen, temperature and salinity. Although the daily water flow rates were lower than planned, dissolved oxygen did not drop to levels that would cause fish mortality. Morning oxygen levels and night respiration rates were near typical levels for earthen ponds enriched with organic matter (Boyd, 1979). The results suggest that the main process governing the oxygen regime is photosynthesis, with a significant contribution to total pond oxygen demand coming from the muddy bottom. It is likely that an increase in water flow and a lower organic load from the bottom sediments would make the oxygen regime more favourable to fish culture.

The fish growth rate was relatively close to the model growth rate achieved in experimental tanks that had excellent water quality. Although massive fish mortality occurred during the operation, the fish culture results are encouraging. The reasons for the mortality are thought to be related to technical problems in the reservoir operation,

which can be corrected by deepening the reservoir and securing its walls.

The system at Makoba has not yet demonstrated the integration of shellfish and seaweed as part of the environmental approach since the culture of these two species is still not successful. The species and culture techniques that were tested for shellfish and seaweed did not offer an adequate solution. However, the nutrient levels in the ponds were still three orders of magnitude below the maximum levels allowed for recreational and mariculture activities (DENR administrative order no. 34, 1990), implying the experiment can go on while suitable species of shellfish and seaweed are identified. Additional experimental work is presently underway at Makoba to solve the difficulties identified in this study.

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