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Influence of Environmental Variables on Planktonic and Phytobenthic Communities in Earthen Ponds at Makoba, Zanzibar

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Abstract—A study was conducted between July 2002 and June 2003 to assess the role of salinity, temperature, pH and dissolved oxygen on the abundance of planktonic (phyto- and zooplankton) and phytobenthic (algal mats) communities in shallow (40 cm depth) earthen ponds at Makoba, Zanzibar. Among the zooplankton, rotifer abundance peaked during the rainy period (salinity of 27–42‰) while protozoa and copepods were most abundant during the dry period (max salinity of 70‰). However, no season effects were seen on the phytobenthos. The most abundant genera were *Pseudonitzschia* sp., *Schizothrix* sp., *Microcoleus* sp. and *Oscillatoria* sp. and in general, algal mats were available throughout the year. Other variables such as temperature, pH and oxygen concentration did not show significant fluctuations over the study period.

INTRODUCTION

Planktonic communities have long been recognised in natural aquatic ecosystems as being a keystone group for energy (Alikuhi et al., 1955; Mitra & Mohapatra, 1956). Similarly, a healthy zooplankton community in many aquaculture systems is also recognised as necessary for good final production from the system (Estudillo et al., 1998). Previous studies show considerable variation in population dynamics (Milstein et al., 1995; Gerald, 2000), which may reflect the configuration of the aquaculture systems and influence zooplankton production (Minkoff et al., 1983; Schlüter and Groeneweg, 1985, Lubzens et al., 1993).

Over the last five years, a number of studies have examined variations in water quality in the Makoba mariculture system in Zanzibar. The majority have focused on the effects of finfish on water quality, and the use of macroalgae as biofilters to improve the water quality in earthen ponds (Mmochi et al., 2002; Mmochi & Mwandya, 2003; Msuya, 2001; Msuya & Neori, 2002; Mwandya, 2001; Mwandya et al., unpubl. data). Other studies have examined the effects of pond fertilisation on zooplankton such as rotifers, protozoa and copepods, and their potential as a food source for fish fry (Kyewalyanga & Mwandya, 2002; Kyewalyanga, 2003; Kyewalyanga et al., 2004).

Many factors influence the production of zooplankton in aquaculture systems. For instance, the use of chicken or horse manure as fertiliser in rotifer or *Artemia* production has been studied by Edwards (1980), Lubzens (1981), Milstein et al. (1991) and Zmora (1991). Environmental variables such as temperature, salinity, oxygen levels, water pH and nutrient concentrations may also influence the production of rotifers (Pourriot et al., 1981; Schlüter & Groeneweg, 1981), copepods (Grice & Marcus, 1981) and *Artemia* (Sorgeloos, 1980; Torrentera & Dodson, 2004).

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As finfish aquaculture has developed in Zanzibar, there has been a concomitant intensification of the search for cheaper food sources for the industry. One clear possibility is the use of natural food sources such as zooplankton, phytoplankton, and phytobenthos. This study examined the role of environmental variables on natural pond organisms used as food for aquaculture in the Zanzibari context. Thus, emphasis was placed on rotifers, copepods and protozoa (zooplankton) and on dominant genera of benthic microalgae and water-column phytoplankton.

Initial studies conducted at Makoba reported on the organisms' presence and succession in natural ponds (Kyewalyanga & Mwandya 2002; Kyewalyanga, 2003; Kyewalyanga et al., 2004), but did not assess the impacts of environmental variables. However, it has been determined at Makoba that significant rotifer production requires low salinity, while protozoa prefer higher salinities (Kyewalyanga & Mwandya, 2002).

The objectives of the study reported in this article were twofold:

- to identify, to generic level, the phytoplankton, zooplankton and benthic microalgae in the ponds.
- to assess the influence of environmental variables on the succession of the water-column phytoplankton and zooplankton fauna, as well as benthic microalgae.

The results of this study will further our understanding of the optimal conditions for mass production of natural feed for fish fry and fingerlings (Schlüter and Groeneweg, 1981).

MATERIALS AND METHODS

Study area

The study was carried out at the Makoba aquaculture site, located 25 km northwest of Zanzibar town. Formerly, the site was used for salt production by the Prisons Department of Zanzibar, when many shallow saltpans, measuring 12 x 15 m and less than 30 cm deep, were excavated, but later abandoned. The Institute of Marine Science (IMS) is now using these abandoned pans for an integrated pond culture system of finfish, shellfish and seaweed. The ponds for grow-out experiments of finfish were deepened, whereas those for experiments on live food for fry or fingerlings were left at the same depth. The ponds are influenced by the same natural/weather conditions of rainfall, sunshine, flooding by tides, etc., and thus are appropriate experimental replicates.

The ponds are supplied from a reservoir, which holds water entering during each spring high tide. Owing to its larger size and depth in comparison to the shallow ponds, the reservoir was used as a control. Even under extended dry conditions the reservoir's level is not significantly affected, while the water level in the shallow ponds is reduced and their salinity increases significantly. Similarly, during the heavy rains the dilution of the reservoir by fresh rainwater is less pronounced.

The reservoir and five shallow ponds were used in this study. The reservoir was taken as a control, and designated as Pond A, while the five shallow ponds out of the 15 present were selected randomly for sampling. These were named B, C, D, E and F and only natural conditions such as rainfall or flooding during spring high tide influenced these ponds. Sampling for abiotic and biotic variables was conducted once a week, from July 2002 to June 2003. During this period, both dry and rainy periods were experienced.

Measurements and data analysis

In each of the five ponds and the reservoir salinity, oxygen concentration and saturation, temperature, water pH and conductivity were measured. Salinity was determined using a handheld refractometer; oxygen concentration, oxygen saturation and temperature using an oxygen meter (Oxy-Guard International); while pH and conductivity were determined directly using a portable pH meter (Hanna Instrument: HI 8014).

Similarly, duplicate samples were collected from Ponds A to F for identification of water-column phytoplankton as well as for the identification and counting of rotifers, copepods and total protozoa. For algal mats, the top 1-cm small slabs (in duplicates) were collected from each of the ponds for identification.

For identification of phytoplankton and algal mats, a light microscope (BHT system Olympus, Japan) was used. Zooplankton counts were made using a dissecting microscope and a custom-made counting chamber. Triplicate samples were counted and the average calculated with 95% confidence limits. Identification for both phytoplankton (Bryceson, 1977; Sundström, 1986; Lugomela, 1996) and algal mats of cyanobacteria (Rippka et al., 1979) was made to genus level.

To assess the effects of seasonality on the dominance of a genus in a given period of the year (dry against rainy season), data were pooled into the two periods i.e., dry and rainy seasons, although weekly and monthly variations were also assessed. The rainy period was from July to November 2002 and the end of May 2003, while the dry period included the months of December 2002 through mid-May 2003.

Sampling for identification of the microalgae and enumeration of zooplankton was carried out from July 2002 to March 2003, except April–June 2003. In each period, the dominance of a given genus was determined by calculating its occurrence as a percentage of the total number for all genera. For each season, three months were selected as representatives, for detailed analysis: July, September and November for the wet season, and January, February and April for the dry season. Differences in number of organisms per ml (rotifers, copepods or protozoa) for both within-ponds (between months) and between-ponds (within months) in a given season were assessed using one-way analysis of variance (ANOVA) with a post-hoc comparison (Tukey's honest test) performed where differences were found.

A monthly average of each abiotic variable was calculated in each of the five ponds and the reservoir, and plotted against time. Salinity and temperature data had a similar general trend with time for all the ponds, thus, the monthly averages were pooled, and an average value for each pond was calculated. Nevertheless, some examples of monthly variations in biotic variables are presented, to portray their short-time variation.

RESULTS

Monthly variation

Rotifers

During the rainy season, with the exception of Pond B ($P = 0.0001$), no significant differences were seen in the number of rotifers within ponds ($P > 0.05$; Fig. 1a).

There were significant differences in the number of rotifers between ponds in July (Fig. 1b; $P < 0.05$) and September ($P < 0.001$) but not in November ($P > 0.05$).

In the dry season, the number of rotifers between months was significantly different in Ponds D and F ($P < 0.05$). No significant differences were observed for Ponds B, C and E. Between ponds, significant differences in the number of rotifers occurred only in April (data not shown).

Protozoa

Significant differences in the number of protozoa per ml were noted between the rainy-season months of July and September only in Pond D (P

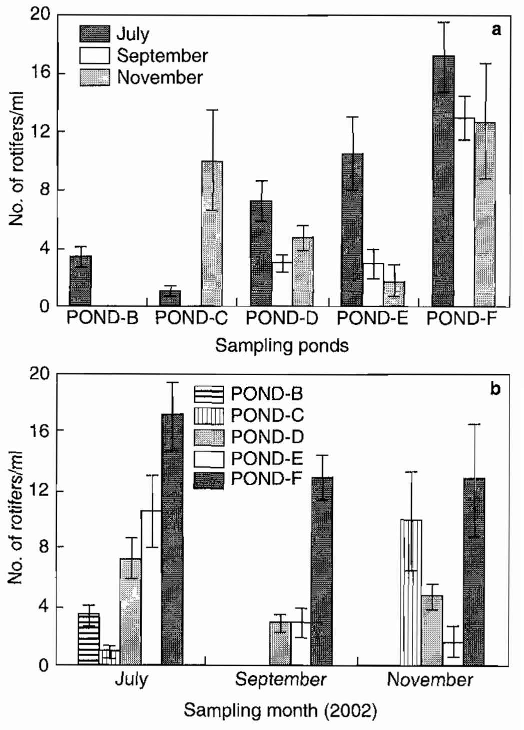

Fig. 1. (a) Variation in the number of rotifers per ml within ponds B to F during the rainy period, represented by the months July, September and November (2002). Statistically, this variation is not significant, except in Pond B. (b) Variation in rotifer numbers within months (between ponds). Rotifer numbers differed significantly in July. Bars indicate standard error.

= 0.008). Between ponds (within months) protozoa abundance was significantly different only in July (P = 0.021).

During the dry season, significant differences were recorded between months only in Ponds B and C (P < 0.05; Fig. 2a). Between-pond differences were found to be significant only for February and April (Fig. 2b).

Further monthly analyses for the biotic and abiotic variables, as exemplified above for rotifers and protozoa, were performed. However, the data are not presented here to avoid repetition of the same results several times. In summary, in most cases, there were no significant differences between ponds (within months) and between months (within ponds) for a given season. Eventually, the data were pooled into the two major periods of rainy and dry conditions for ease of presentation. The following section looks at seasonal changes in the variables, considering all the months in a given season.

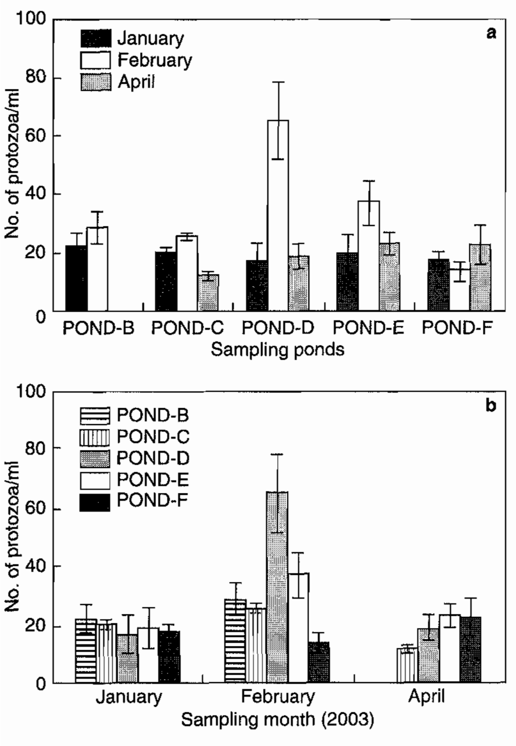

Fig. 2. Variation in the number of protozoa per ml during the dry-season months of January, February and April (2003) (a) within ponds and (b) within months. Bars indicate standard errors.

Seasonal variation

Environmental variables

Salinity showed the greatest seasonal variation. However, the values decreased to below 30‰ in some months during the rainy season (Fig. 3). The mean values between the dry and rainy months showed significant differences (t-test, P < 0.05, Table 1). However, temperature, pH and oxygen concentration did not show any significant differences between the two seasons (Table 1). Oxygen concentrations ranged from 6–8 mg/l, except in September when the average reached 9 mg/l, while the values of pH were between 8 and 9 (Fig. 4).

Rotifer, protozoa and copepod abundance

The number of rotifers per ml recorded in all ponds was higher during the rainy period, reaching a peak of 13.0 ± 5.1 in August 2002 (Table 1, Fig. 5), when salinity was relatively low (from 27–40 ‰, average 34.2 ± 5.6 ‰, Table 1). The abundance of rotifers decreased during the dry period when the salinity was high (41–70‰, average 54.1 ± 15.4‰). However, there was an abrupt peak in rotifer abundance in April 2003, which was within a dry period. The peak abundance of protozoa (28.0 ± 7.3/ml) appeared during the dry period in February 2003, when the number of rotifers had decreased. There was no clear pattern for the peak of copepods, although there appeared a single peak of 11.0 ± 5.0/ml in February 2003 (Fig. 5).

The overall mean numbers per ml of rotifers, protozoa and copepods collected throughout the study period were 5.7 ± 1.1, 7.4 ± 2.6 and 1.4 ± 0.9 respectively. One-way ANOVA showed a significant difference in their mean abundance (f = 3.42; df = 2; p = 0.044). Multiple comparison (Tukey/SN) tests revealed significant difference between the abundances of protozoa and that of copepods (p = 0.044), but no significant differences between numbers of rotifers and protozoa or copepods were found (p > 0.05) during the one-year study period.

Phytoplankton and phytobenthos

Unlike for the zooplankton, salinity had no strong observable influence on the biomass of the phyto-benthic organisms; the values could not be clearly

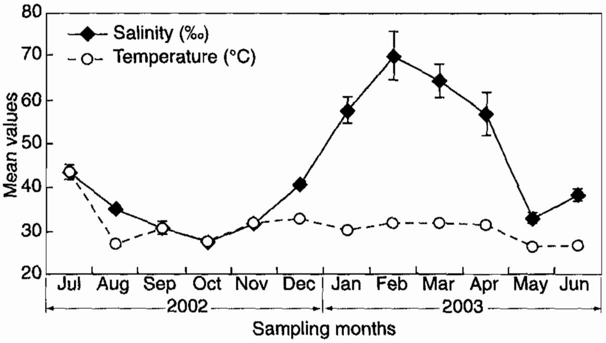

Fig. 3. Salinity (‰) and temperature (°C) during the rainy season (July–November 2002) and dry season (December 2002–May 2003). Bars indicate standard error.

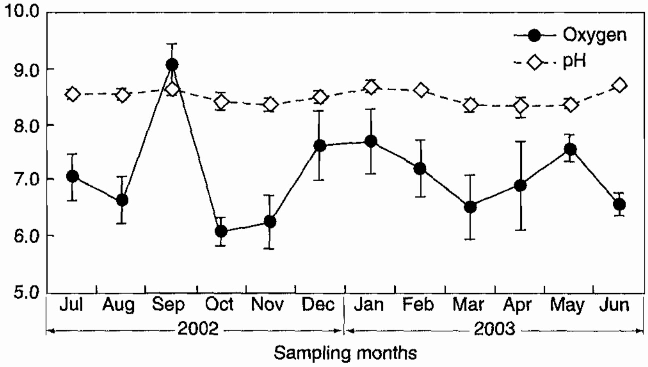

Fig. 4. Oxygen concentration (mg/l) and pH during the rainy season (July 2002–November 2002) and dry season (December 2002–May 2003). Bars indicate standard error.

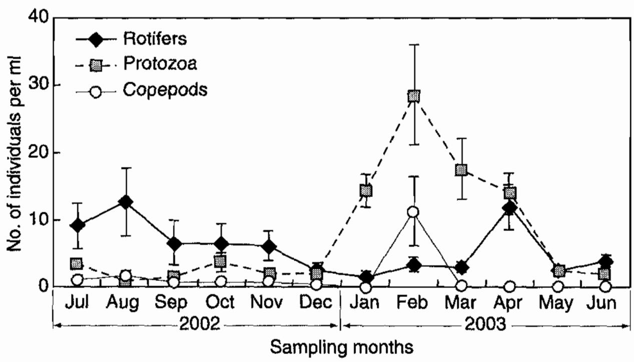

Fig. 5. Number of rotifers, protozoa and copepods (per ml) during the rainy season (July –November 2002) and dry season (December 2002 – May 2003). Bars indicate standard error.

Table 1. *t*-test for environmental parameters between raining months and dry months

	Mean ± SE				
Environmental parameter	Rainy	Dry	*t*-value	df-value	P-value
Salinity (‰)	34.20 ± 5.56	54.06 ± 15.40	-6.09	34	< 0.001
Temperature (°C)	30.86 ± 5.68	30.73 ± 2.03	0.15	34	0.882
pH	8.52 ± 0.26	8.47 ± 0.28	0.76	34	0.455
Oxygen conc. (mg/l)	6.94 ± 1.32	7.2 ± 1.41	1.08	34	0.286

separated into dry and rainy seasons. The water-column phytoplankton fauna was dominated by *Pyramimonas sp.* (16%), *Odontella* sp. (10%), and *Coscinodiscus* sp. (9%) during the rainy months, and by *Triceratium* sp. (18%), *Amphora* sp. (15%) and *Rhizosolenia* sp. (11%) during the dry months (Fig. 6). However, the most abundant genus in the planktonic community, *Pseudonitzschia* sp., was found during both the dry and rainy periods, having composition of 29% and 32%, respectively.

Among the phytobenthos, the most abundant genus in the algal mats was *Schizothrix* sp., at 14% and 20% during the dry and rainy periods, respectively. Others were *Microcoleus* sp. (13% and 15%) and *Oscillatoria* sp. (12% and 14%), (Fig. 7). A number of other uncommon genera were found in both the water-column and the benthic substrates. In the water-column, there were about 26 genera, covering a total of 37.2% composition (Fig. 6); while for the benthic microalgae the uncommon genera were about 28, with percentage composition of 22.4 (Fig. 7). All the genera of phytobenthos and water-column phytoplankton observed during both the rainy and dry periods are given in Appendix 1.

DISCUSSION

The availability and quality of food, especially for the larval stage, is an important determinant of growth and production, and thus the success of a fish culture. For example, it has been reported that plankton density, composition and succession patterns can greatly affect fish production at the earliest stage of their life (Parmley & Geiger, 1985; Harrell & Bukowski, 1990). Thus, it is important to understand the availability, type and succession patterns of potential live food, as influenced by environmental factors (see e.g., Schlüter & Groeneweg, 1981, 1985; Lubzens et al., 1993;

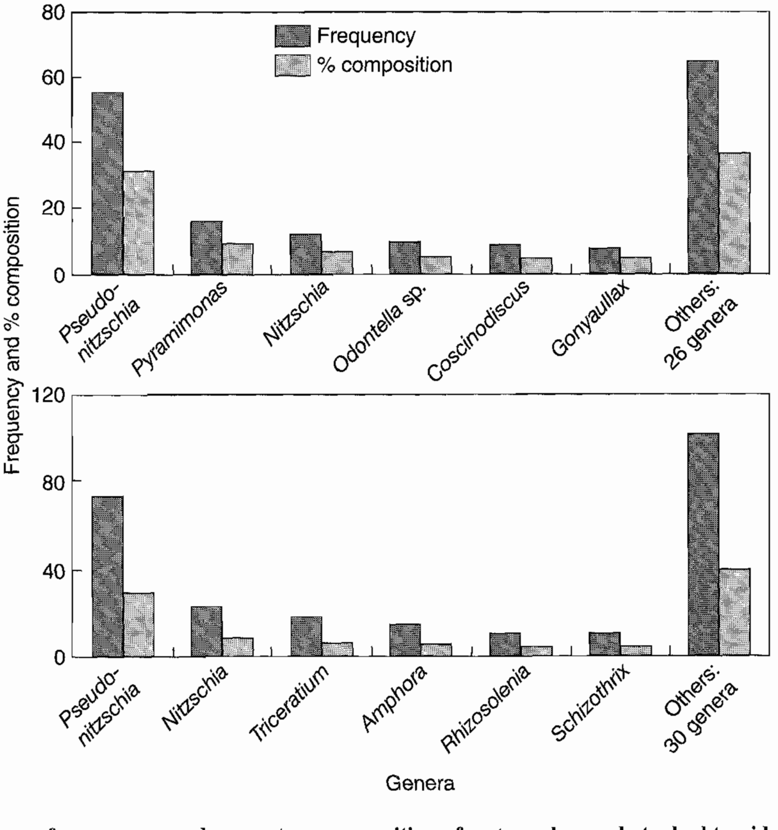

Fig. 6. Frequency of occurrence and percentage composition of water column phytoplankton identified to genus level. (a) during the rainy season (July–November 2002), and (b) during the dry season (December 2002–May 2003)

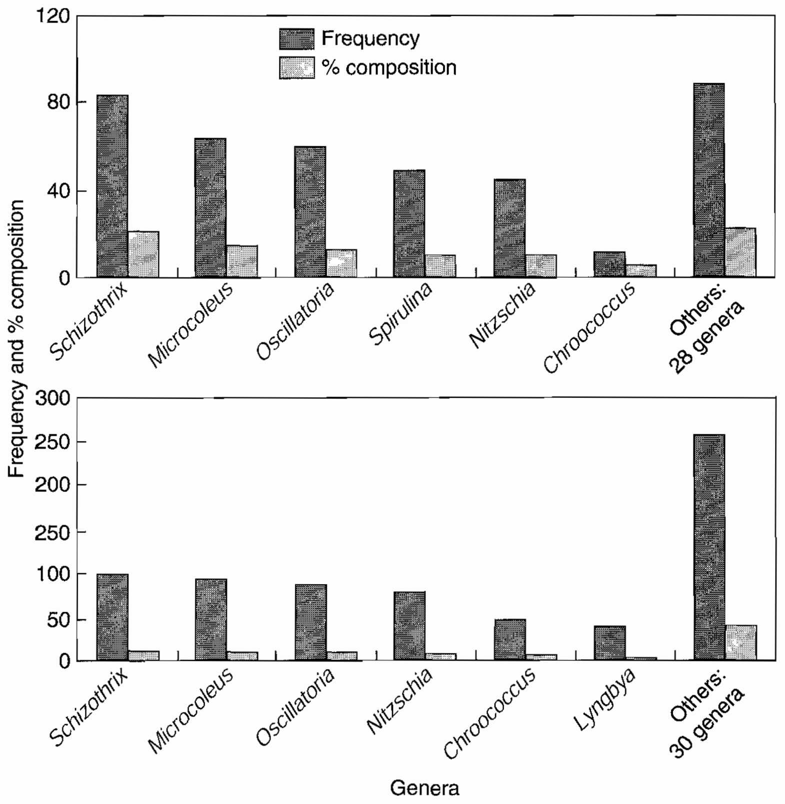

Fig. 7. Frequency of occurrence and percentage composition of benthic phytoplankton identified to genus level. Fig 7a indicates frequency and percentage during the rainy season (July – November2002), while 7b shows the same for the dry season (December 2002–May 2003).

Gerald, 2000; Kyewalyanga & Mwandya, 2002).

The present study found some level of succession in rotifers, protozoa and copepod abundance, such that as the rotifer abundance increases to the maximum, the population of protozoa and copepods tend to decrease and vice versa. Such a trend has also been reported by Gerald (2000). This may reflect the fact that the mechanism controlling the three planktonic communities are different, and therefore, they are affected differently by the changes in weather conditions. For example, Pond B showed a significant difference in the number of rotifers within months during the rainy season, while other ponds did not. This is probably because Pond B was used in fertilization experiments using chicken manure up to six months before the start of the experiments, such that the release of nutrients changed with time and consequently influenced the production of rotifers. It seems that effect of fertiliser may last for longer than six months. Thus it is important to know the history of earthen ponds used for such studies.

The influence of environmental variables such as temperature, salinity, oxygen levels, water pH and nutrients on the production of rotifers and copepods has also been reported by Pourriot et al. (1981), Schlüter & Groeneweg (1981) and Grice & Marcus (1981), while that for Artemia was reported by Sorgeloos (1980).

Although the number of protozoa per ml was higher compared to that of rotifers and copepods during their peak period (dry months), both rotifers and protozoa seemed to appear throughout the year at abundances above 5 individuals/ml, which is a good indication that the natural ponds at Makoba provide favourable conditions for these organisms. This is perhaps due to the natural flooding with seawater of the ponds, which stimulates the detrital food chain, as well as dilutes the high-salinity pond water, and consequently stimulates hatching of resting eggs of rotifers (Kyewalyanga & Mwandya, 2002). The observed inverse relationship between the number of rotifers per ml and salinity is in agreement with the results reported in other studies. Lubzens et al. (1993) observed higher sexual reproduction in rotifers cultured at salinities below 35‰, whereas Pascual & Yufera (1983) observed instantaneous growth rates of rotifers in seawater with salinity between 2 and 35‰.

Unlike the zooplankton, the development and succession of species in the phytoplankton and benthic algal mats was not affected significantly by changes in environmental variables or weather conditions. The water column in the earthen ponds was dominated by the genus *Pseudonitzschia* during both rainy and dry months. The benthic algal mat coverage was high throughout the year and was dominated by the genus *Schizothrix* followed by *Microcoleus* and *Oscillatoria* in terms of percentage composition of the total genera. *Spirulina*, which are among the most important benthic microalgae in natural pond food chain, was only found during the rainy months (Fig. 7).

The reared fish species at Makoba (milkfish and mullet) have been observed to feed on algal mats. In fact, they have been successfully grown on purely natural (live) food for about six months without supplementary fish feed (Jiddawi et al., 2003). Their growth rate was good (increasing from 10 g to an average of 450 g in six months), although not as high as in those fed supplementary food. Thus, availability of algal mats throughout the year would support fish culture at this study site.

These results are in agreement with other findings, that an understanding of the effect of environmental variables on the natural food sources in ponds is vital to their operation, either as nursery ponds or for extensive and polyculture farming systems (Sorgeloos, 1980; Schlüter & Groeneweg, 1981, 1985; Pourriot et al., 1981; Grice & Marcus, 1981; Lubzens et al., 1993; Gerald, 2000; Torrentera & Dodson, 2004).

Salinity values in this study were above what has been commonly reported for tropical estuarine waters (34 – 41‰) during the dry months (Mmochi et al., 2002; Mmochi & Mwandya, 2003).The results obtained, especially on the influence of salinity on the succession of potential live food for fish fry and fingerlings was previously observed under controlled, i.e., flooded, fertilised and diluted earthen ponds (Kyewalyanga & Mwandya, 2002; Kyewalyanga, 2003; Kyewalyanga et al., 2004), implying that the observation is consistent whether the earthen ponds are manipulated or not. Knowledge of seasonal variation therefore would enable fish farmers to synchronise live food production and stocking of fry or fingerlings in the ponds.

These results support the use of natural ponds at Makoba for aquaculture, using natural/live food sources. Manipulation of some environmental parameters could further enhance availability of natural food for fry and fingerlings. For example, once salinity is lowered, mass production of live food for fish fry and fingerlings would be possible. This implies that interested local farmers could cheaply feed their fry and fingerlings, simply by fertilising the ponds. Therefore, the Makoba site is recommended as one that has the potential to support large-scale fish production.

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Appendix 1. Genera of water-column and benthic phytoplankton found in Makoba earthen ponds during the study period (July 2002–June 2003), for the rainy season (July to November 2002) and dry season (December 2002 to May 2003)

	WATER-COLUMN PHYTOPLANKTON		BENTHIC PHYTOPLANKTON	
No.	Rainy season	Dry season	Rainy Season	Dry season
1.	*Amphidinium*	*Amphidinium*	*Amphidinium*	*Amphidinium*
2.	*Amphisolenia*	*Amphisolenia*	*Amphiphora*	*Amphisolenia*
3.	*Amphiphora*	*Amphiphora*	*Anabaena*	*Amphiphora*
4.	*Bacillaria*	*Anabaena*	*Aphanocapsa*	*Anabaena*
5.	*Biddulphia*	*Bacillaria*	*Ceratium*	*Aphanocapsa*
6.	*Chaetoceros*	*Biddulphia*	*Chroococcus*	*Chroococcus*
7.	*Chroococcus*	*Cerataulina*	*Coscinodiscus*	*Coscinodiscus*
8.	*Coscinodiscus*	*Chaetoceros*	*Donkinia*	*Diploneis*
9.	*Euglena*	*Coscinodiscus*	*Fragilaria*	*Glenodinium*
10.	*Gonyaulax*	*Deplineis*	*Gloeocapsa*	*Gloeocapsa*
11.	*Hantzschia*	*Dinophysis*	*Gonyaulax*	*Gloeocapsa*
12.	*Isthmia*	*Dissodinium*	*Katodinium*	*Gonyaulax*
13.	*Katodinium*	*Euglena*	*Lyngbya*	*Gymnodinium*
14.	*Licomophora*	*Gonyaulax*	*Leptocylindrus*	*Isthmia*
15.	*Microcystis*	*Guinardia*	*Merismopedia*	*Katodinium*
16.	*Monodus*	*Gymnodinium*	*Microcoleus*	*Licomophora*
17.	*Nannochloris*	*Hantzschia*	*Naviculata*	*Lyngbya*
18.	*Nitzschia*	*Isthmia*	*Nitzschia*	*Merismopedia*
19.	*Odontella*	*Katodinium*	*Nostoc*	*Microcoleus*
20.	*Ornithocerus*	*Lyngbya*	*Odontella*	*Navicula*
21.	*Oscillatoria*	*Microcoleus*	*Oscillatoria*	*Nitzschia*
22.	*Pleurosigma*	*Microcystis*	*Phormidium*	*Oscillatoria*
23.	*Protoperidinium*	*Monodus*	*Pleurosigma*	*Other diatoms*
24.	*Pseudonitzschia*	*Nitzschia*	*Prolocentrum*	*Phormidium*
25.	*Pyramimonas*	*Odontella*	*Pseudonitzschia*	*Pleurosigma*
26.	*Rhizosolenia*	*Oscillatoria*	*Pyramimonas*	*Prorocentrum*
27.	*Richelia*	*Phormidium*	*Rhizosolenia*	*Protoperidium*
28.	*Schizothrix*	*Pleurosigma*	*Schizothrix*	*Pseudonitzschia*
29.	*Streptotheca*	*Prorocentrum*	*Spirulina*	*Rhabdonema*
30.	*Triceratium*	*Pseudonitzschia*	*Synechococcus*	*Rhizosolenia*
31.	*Trichodesmium*	*Pyramimonas*	*Triceratium*	*Schizothrix*
32.	*Tropidoneis*	*Rhizosolenia*	*Trichodesmium*	*Spirulina*
33.		*Schizothrix*	*Tropidoneis*	*Synechococcus*
34.		*Spirulina*		*Triceratium*
35.		*Synechococcus*		*Trichodesmium*
36.		*Thalassiothrix*		*Tropidoneis*
37.		*Triceratium*		
38.		*Trichodesmium*		
39.		*Tropidoneis*		
40.				
Total	32	39	33	36