Wetlands Ecol Manage (2009) 17:257–277
DOI 10.1007/s11273-008-9105-7

ORIGINAL PAPER

Increasing fish production from wetlands at Lake Victoria, Uganda using organically manured seasonal wetland fish ponds

Rose C. Kaggwa · Anne A. van Dam · John S. Balirwa · Frank Kansiime · Patrick Denny

Received: 5 May 2008 / Accepted: 8 June 2008 / Published online: 29 June 2008

Abstract The processes driving primary productivity and its impacts on fish production were investigated in field trials in eight seasonal earthen wetland ponds 'Fingerponds' (192 m^2) in Uganda between 2003 and 2005. The ponds were stocked by the seasonal flood with predominantly *Oreochromis* spp. at densities ranging from 0.1 to 0.5 fish m^{-2}. Chicken manure (521, 833 or 1,563 kg ha^{-1}) was applied fortnightly. Results showed that primary productivity was enhanced with maximum average net primary productivity (±Standard Error) of 11.7 (±2.5) g O_2 m^{-2} day^{-1} at the Gaba site and 8.3 (±1.5) g O_2 m^{-2} day^{-1} at the Walukuba site. Net fish yields were higher in manured ponds with up to 2,670 kg ha^{-1} yield for a 310 day growth period compared to less than 700 kg ha^{-1} in unmanured ponds. Fish production was limited mainly by high recruitment, falling water levels, light limitation from high suspended solids and turbidity, and low zooplankton biomass. It was concluded that Fingerponds have a high potential for sustainable fish production and can contribute to the alleviation of protein shortages amongst the riparian communities around Lake Victoria. Production can be enhanced further with improved stock management.

Keywords Fingerponds · Fish production · Manure · Integrated production systems · Water quality · Sustainable wetland management · Wise use · Papyrus wetland · Lake Victoria

Introduction

Hunger continues to be widespread in Africa with over 200 million people suffering from malnutrition (Clover 2003). With high population growth and the continuing need for economic development, there are immense pressures on natural resources. Furthermore, declining inland fisheries have led to decreased fish consumption of 6.7 kg $person^{-1}$ $year^{-1}$ in comparison to 16 kg $person^{-1}$ $year^{-1}$ for the rest of the world (WFC 2005). Wetlands are of great ecological importance and are probably the most important zone for inland freshwater fisheries as they support a large invertebrate fauna, act as a feeding ground for young and growing fish and provide refugia against

R. C. Kaggwa (✉)
National Water and Sewerage Corporation,
P.O. Box 7053, Kampala, Uganda
e-mail: rckags@yahoo.com

A. A. van Dam · P. Denny
UNESCO-IHE Institute for Water Education,
P.O. Box 3015, 2601 DA Delft, The Netherlands

J. S. Balirwa
National Fisheries Resources Research Institute,
P.O. Box 343, Jinja, Uganda

F. Kansiime
Makerere University Institute of Environment and Natural
Resources, P.O. Box 7062, Kampala, Uganda

predators (Denny 1985; Balirwa 1998). They have been described as a typical habitat for tilapia species particularly in the East African lakes (Lowe-McConnell 1975). The expansion of fisheries into the wetland areas and floodplains is an avenue for increased yields in African waters and can be exploited further through fish farming (Welcomme 1979; Halwart and van Dam 2006). Although aquaculture can contribute to the alleviation of poverty and improve food security and the nutritional status of rural communities (Edwards 1999), in Sub-Saharan Africa this has not happened despite favourable conditions (e.g. abundant natural resources, inexpensive labour, high demand for fish and good climate). Reasons for this plight are mainly poor infrastructure, inadequate production inputs and little traditional aquaculture knowledge (Machena and Moehl 2001). Consequently, there is need for simple culture technologies that build on traditional knowledge and use locally available inexpensive inputs.

Fingerponds are seasonal earthen fish ponds dug at the edge of natural wetlands and stocked naturally with wild fish during flooding. After flood recession, fish stay behind in the pond and the water levels gradually decline. Depending on rainfall and seepage, culture periods of several months to one year can be achieved (Denny et al. 2006; Kipkemboi et al. 2007a). When introduced and operated with care, Fingerponds do not impact on the natural functioning of the wetland and contribute to the livelihoods of the riparian communities through provision of much-needed protein (Kipkemboi et al. 2007c). Preliminary studies of Fingerponds stocked with *Oreochromis* species in two localities in Uganda showed that the factors conducive for fish survival included dissolved oxygen values above 2 mg l^{-1} and no ammonia toxicity found. However, the flood waters that filled these ponds contained insufficient amounts of essential nutrients and were low in plankton biomass (Kaggwa et al. 2005). Similar results were found with Fingerpond trials in Kenya (Kipkemboi et al. 2007b).

Stimulation of the production of natural foods in fish ponds through the use of organic manures to increase fish yields has been practiced widely (Green et al. 1989; Egna and Boyd 1997). Animal and green manures provide dissolved nutrients for algal production, are substrates for microbial production or serve as fish feeds directly (Colman and Edwards 1987). While organic manure can be a low-cost input, it should be applied carefully. Its indiscriminate use can lead to excessive phytoplankton production, induce low oxygen content and poor water quality, and be detrimental or lethal to fish. As primary productivity is enhanced it is important that the natural food produced is suitable for the fish and that no negative effects on water quality occur (Pechar 1995).

In view of the foregoing we investigated the environmental conditions that govern the biological productivity (notably light, temperature, clay turbidity and alkalinity) on water quality (oxygen, dissolved nutrients), biological productivity and fish production in Fingerponds. It was hypothesized that application of manure would increase the concentration of nutrients in the ponds, enhance primary production, diversify the food web, increase the availability of natural fish foods (e.g. phytoplankton, detritus) and lead to higher fish production. Because the effectiveness of Fingerponds can only be tested under realistic wetland conditions, participatory field trials were carried out to establish the potential of fish production in Fingerponds in fringing wetlands around the northern shores of Lake Victoria.

Methods

Study area and period

The field trials were carried out in Fingerponds (four at each site) in Gaba (near Kampala, N 0°14′59.9″, E 32°38′14.4″) and Walukuba (near Jinja, N 0°25′58.1″, E 33°13′59.8″) on the northern shores of Lake Victoria, Uganda. All ponds (24×8 m, depth ranging from 1 m at the edge of the wetland to 2 m at the landward side) were stocked naturally by flooding from the lake with predominantly *Oreochromis* species at densities of 0.1–0.5 fish m^{-2}. The first culture period after flood recession (Period 1) started in May 2003 and lasted for a year. The second period (Period 2) started in October 2004 and lasted only five months in Gaba and 7 months in Walukuba. All pond water levels were allowed to fall naturally through the dry season and, before the next floods, any pond maintenance was undertaken. During Period 2, lake levels dropped suddenly, no flooding of the wetlands occurred and the ponds were filled mainly by ground water infiltration and rain water.

Fish

Each culture period consisted of an acclimatization phase (which allowed for the fingerponds to be disconnected from the flooded wetland and for fish to adjust to their new pond conditions) and then a grow-out phase. Following the natural stocking of ponds during seasonal flooding and then isolation of the ponds on flood recession, an initial population census was carried out. The fish were then returned to the ponds and left to acclimatize to their new environment for a period of 6 weeks after which another census was carried out. Fish were then distributed equally over all ponds for the grow-out phase.

For Period 2, which was not preceded by a flood, the first fish census revealed the presence of fish which had probably escaped the final harvest at the end of Period 1. After the acclimatization phase, there were enough fish in the ponds to allow re-distribution of fish for the grow-out phase in October 2004. To reduce the population of small fry and encourage production of zooplankton and zoobenthic invertebrates, only males were selected through hand sexing, and fish smaller than 5 cm were removed monthly using a fine-mesh seine net (50 mm).

Fish population censuses were done by depletion sampling using a seine net (12 × 2 m, mesh size 6.5 mm). For each census, three successive catches were made in each pond and individual fresh weights and total lengths (TL) were determined for fish greater than 5 cm. Fish smaller than 5 cm total length were measured in batches of known numbers. Total fish biomass was estimated by extrapolation of the catches. Fish were classified according to TL as follows: Class I (0–5 cm), Class II (5.1–10.0 cm), Class III (10.1–15.0 cm), Class IV (15.1–20.0 cm) and Class V (20.1–30.0 cm).

At the onset of the dry season, ponds had nearly dried out and the remaining water was drained. Fish were then harvested and weights and TLs measured. The sex ratio was determined for fish with TL above 10 cm by inspection of the urogenital pores and secondary characteristics. Fish species were identified on site, except for the *Haplochromine* species which were preserved in 5% formalin and identified later.

To determine the composition of food ingested by the fish, gut content was analyzed once in Period 1 during the census (56 and 59 fish in the four ponds in Gaba and Walukuba, respectively) and monthly in Period 2, starting October 2004 (a total of 21 and 61 fish from the four ponds in Gaba and Walukuba, respectively). Fish samples were preserved in 10% formalin for fish with TL greater than 10 cm and 5% formalin for fish smaller than 10 cm. Gut analysis was carried out in the laboratory using the percentage occurrence method as described by Hyslop (1980) and Balirwa (1998).

Pond fertilization

Air-dry chicken manure (nitrogen, phosphorus, potassium content 1.3–1.9%, 1.2–1.4%, 0.1–1.8% in dry matter, respectively) purchased from a local market was applied to selected ponds fortnightly. The manure was put into a bamboo crib at a corner of the shallow end. The application rates in kg ha^{-1} (2 weeks)$^{-1}$ were 521 (low manure, LM), 833 (medium manure, MM) and 1,563 (high manure, HM). Manuring in Period 1 commenced in August 2003 (Gaba) and October 2003 (Walukuba) following the adapatation phase. During this period, different manure levels were employed in the two locations; LM and MM in Gaba Ponds 1 and 2, respectively while in Walukuba LM, MM and HM were applied to Ponds 2, 4 and 3, respectively. Ponds 3 and 4 (Gaba) and Pond 1 (Walukuba) were left unmanured (referred to as NM).

Due to low pond water levels in Period 2, the LM level was applied to three ponds at each location with one pond (Pond 4 in Gaba and Pond 1 in Walukuba) left unmanured. Manuring in Period 2 commenced in October 2004 in both sites following the acclimatization phase as described above and was continued until February 2005 in Gaba and April 2005 in Walukuba.

During Period 1, artificial substrates for the culture of periphyton, made from *Phragmites* (*Phragmites mauritianus* Kunth) reed stems, diameter 0.7–3.5 cm; bamboo (*Oreobambos* sp.) poles, diameter 1.2–2.5 cm; and *Raphia* (*Raphia farinifera*) palm fronds were installed in Gaba in Ponds 1 and 2 (manured) and Pond 3 (unmanured) for a period of 6 weeks between October and November. Ten plant frames (1 m^2 each) of *Raphia*, *Phragmites* and bamboo (total 60 m^2 surface area for periphyton attachment, equivalent to 31% of pond surface) were suspended vertically (see Kaggwa et al. 2006). In Walukuba in Period 2, *Phragmites* frames were introduced in two manured ponds (2 and 4) in February 2005, equivalent to 43% and 70% of the pond surface area, respectively. Findings on these artificial substrates are reported elsewhere (Kaggwa 2006).

Sample collection (water and plankton)

Samples were taken monthly between 10.00 and 14.00 h. Sub-surface water samples were taken monthly from the shallow and middle areas of the ponds and at 10 cm vertical intervals at the deep end using a Van Dorn sampler. An integrated water sample at the deep end was also taken. Samples were stored in a cold box with ice prior to and during transport to the laboratory. Phytoplankton samples of known volumes were collected using a 1-l Van Dorn sampler (Kahl Scientific Instruments Corp. El Cajon, California, USA) from the upper 30 cm water layer in the deep ends of the ponds and preserved with 1% Lugol's iodine solution. Zooplankton samples were collected from the shallow, middle and deep ends by horizontal hauls using an Apstein net (80 µm mesh) and pooled into a composite sample. Primary productivity was determined monthly using the modified Winkler's dark and light bottle method (Wetzel and Likens 1991). Net primary productivity (NPP), gross primary productivity (GPP) and respiration rates were calculated from differences in oxygen concentrations.

Analytical methods

In situ measurements for pH, temperature, dissolved oxygen (DO) and electrical conductivity (EC) were taken using WTW handheld meters (MODEL 340i, WTW GmbH, Weilheim, Germany). Water transparency was measured daily as secchi depth at 12.00 h. Water depth was measured daily at 12:00 h in the middle of the ponds using a measuring gauge fixed in the pond bottom. Total suspended solids (TSS), turbidity, alkalinity, ammonium nitrogen (NH_4–N) (APHA 1992), total nitrogen (TN), nitrate nitrogen (NO_3–N), soluble reactive phosphorus (SRP) and total phosphorus (TP) were determined according to Standard Methods (APHA 1995). Chlorophyll *a* was determined using an acetone: methanol mixture as described by Pechar (1987).

Sedimentation and enumeration of phytoplankton using an inverted microscope followed the modified Utermöl method (Nauwerck 1963). Identification was to genus level (Mosille 1994; John et al. 2002). Zooplankton densities and dry weight biomass were measured according to methods described by Duncan (1975) and Fernando (2002).

Statistical analysis

Direct comparison between treatments was not possible due to lack of replicate ponds in this participatory field experiment. Relationships between the measured variables were identified through factor analysis (Milstein 1993). A data set was created with 140 cases from the two sites with each record consisting of monthly water quality and productivity measurements. Five factors with eigenvalue ≥ 1 were extracted from the principal components calculated from the correlation matrix using Varimax rotation. Factor loadings were used to interpret the importance of each variable using sign and relative size as an indication. Factor loadings >0.5 were considered practically significant and used for interpretation. The factor scores were then analysed using site (dummy variable $0 =$ Gaba, $1 =$ Walukuba), manure input (dummy variable $0 =$ no manure, $1 =$ manure) and time (coded as $1 =$ May 2003, $2 =$ April 2003 etc.) as explanatory variables in a multiple regression analysis. *F*-tests and *t*-tests were used to assess significance of regression models and partial regression coefficients, respectively. Effects of variables were considered significant when $P < 0.01$ and not significant when $P \geq 0.01$. With $0.01 \leq P < 0.05$, a tendency for the presence of the effect was assumed. All analyses were performed using SPSS 11.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Water level and natural fish stocking

Pond water levels were higher in Gaba than in Walukuba with maximum monthly median values of 0.96 and 0.89 m, respectively in Period 1. Over Period 1, pond water levels gradually decreased but did not drop below 0.4 m. This was due to periods of high precipitation, inflow of ground water and fluctuation of the ground water table. In Period 2, water levels dropped dramatically in both locations to below 0.3 m by the end of the grow-out phase

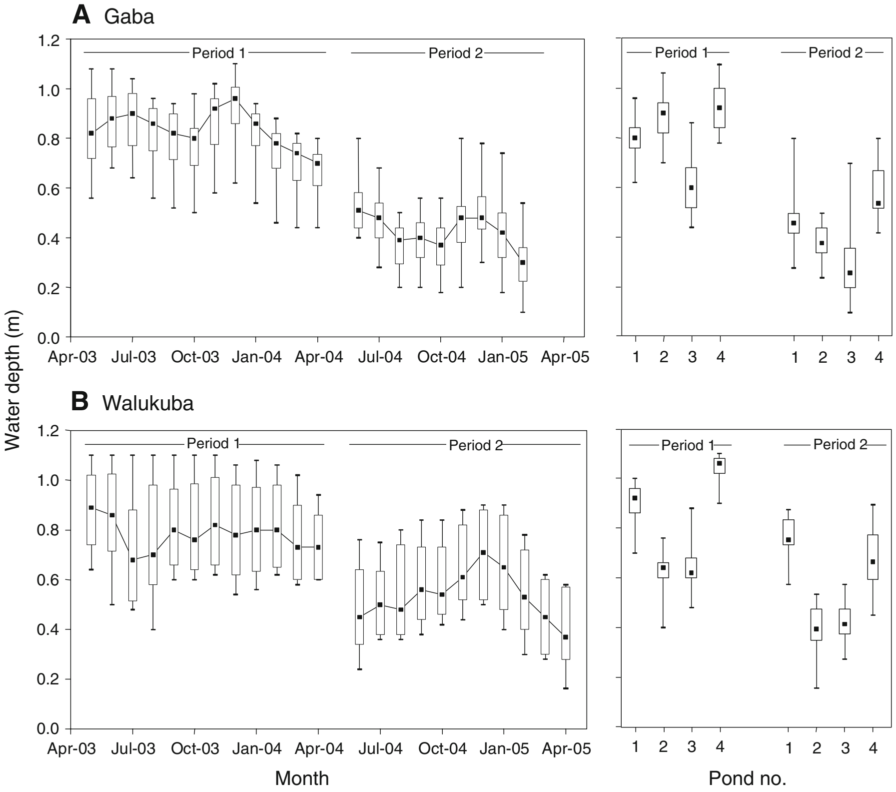


Fig. 1 Median water depth in Fingerponds in Gaba (**A**) and Walukuba (**B**) during experimental Periods 1 (May 2003–April 2004) and 2 (June 2004–February or April 2005), by month (left) and by individual pond (right). Black squares connected by lines represent median values of daily depth measurements in the middle of the pond. Upper and lower box edges represent 25% and 75% quartiles and bars indicate minimum and maximum values. Between April and June 2004, ponds were dry so no values for May 2004 were available

(Fig. 1). In Walukuba, Ponds 2 and 3 had distinctively lower levels (median values about 0.6 and 0.4 for Periods 1 and 2, respectively) whilst in Gaba Pond 3 consistently showed the lowest depth (median value 0.60 and 0.26 in Period 1 and 2, respectively) (Fig. 1).

In Period 1, the ponds in Gaba were stocked naturally largely by *O. niloticus* and *O. leucostictus*. A minor part of the stock consisted of *Haplochromine* species, *Aplocheilichthys pumulis* and *Protopterus aethiopicus* (Table 1). In Walukuba, no connectivity was achieved for Pond 4, but 2 fish were found. *O. leucostictus* dominated both locations with 95% and 68% abundance in Gaba and Walukuba, respectively. *O. niloticus* was more abundant in Walukuba (21% on average). In both locations, fish sizes at the start were variable with bigger fish (10–15 cm) in Walukuba and individual weights ranging from 2 to 40 g for the majority of fish. The overall initial fish biomass density for all the ponds was 92.3 kg ha^{-1} in Gaba and 97.2 kg ha^{-1} in Walukuba (Table 1). Stocking densities ranged from 1.1 to 2.2 fish m^{-2} in both locations except for Pond 4 in Walukuba.

Pond turbidity, fertility and nutrients

Water quality in the ponds over the two periods was generally stable although some differences were noted between periods in both locations. TSS (50–300 mg l^{-1}) and turbidity (50–300 NTU) were high in all ponds in Period 1, resulting in low pond transparencies with Secchi depths less than 20 cm for most of the time (Fig. 2). In Period 2, the same phenomena was observed with even higher TSS and turbidity and lower Secchi depths. There was no clear relationship between manure input and turbidity. For example, Pond 4 in Gaba (NM) had consistently high turbidity and low transparency whilst Pond 1 in Walukuba (NM) had the lowest turbidity and highest transparency during Period 2. Temperatures ranged from 22 to 27°C in Gaba and 23–29°C in Walukuba (Fig. 2).

Conductivity was higher in Walukuba (800–2,000 μS cm^{-1}) than in Gaba (200–1,000 μS cm^{-1}) (Fig. 3). Alkalinity in both locations was high with higher values in Walukuba (400–900 mg l^{-1}) than in Gaba (200–400 mg l^{-1}). pH values ranged from

Table 1 Initial Fish stock composition in Fingerponds in Gaba (a) and Walukuba (b), Uganda after natural stocking, Period 1 (May 2003)

Variable	Percentage of population			
	Pond 1	Pond 2	Pond 3	Pond 4
(a) Gaba				
Oreochromis niloticus	11.2	0.8	0	0
Oreochromis leucostictus	82.4	93.2	100.0	95.9
Protopterus aethiopicus	1.9	0	0	0
Haplochromine spp.	0.9	0	0	0
Aplocheilichthys pumulis	3.7	6	0	4.1
Total biomass (g)	3,580	1,714	1,012	781
Population (n)	205	278	419	266
Fish total length range (cm)	<5–20	<5–15	<5–15	<5–15
(b) Walukuba				
Oreochromis niloticus	49.0	23.4	11.9	0
Oreochromis leucostictus	49.0	74.0	37.6	0
Protopterus aethiopicus	0.4	0	0	0
Haplochromine spp.	0.8	2.4	1.2	0
Aplocheilichthys pumulis	0.8	0	0	0
Total biomass (g)	2,410	2,455	2,147	456
Population (n)	250	410	222	2
Fish total length range (cm)	<5–15	<5–10	<5–15	20–30

Each pond measured 192 m^2 and had an average construction depth of 1.5 m

neutral to alkaline (7.0–9.7) with slightly higher values in Walukuba. Whilst in Gaba there was no clear effect of manure input on conductivity, alkalinity and pH, Walukuba Pond 1 (NM) had consistently lower values than the ponds with manure. Dissolved oxygen (DO) concentrations were not significantly different between ponds. All ponds had DO concentrations greater than 2 mg l^{-1} but in Walukuba values as high as 12.8 mg l^{-1} were attained in Pond 3 (Fig. 3).

Figure 4 presents nitrogen and phosphorous concentrations. There were only small differences in nitrogen concentrations (NH_4–N and TN) between ponds during Period 1 in both locations. TN increased steadily during Period 1 (never exceeding 10 mg l^{-1}) and further increased during Period 2 in Gaba but varied widely in Walukuba. There was no clear relationship of nitrogen with manure input into the ponds. SRP concentrations were stable in Gaba between 0.1 and 0.3 mg l^{-1} without much difference between ponds. In Walukuba, SRP was more variable and increased strongly in Period 2 with Ponds 2 and 4 reaching concentrations of 3.2 and 4.3 mg l^{-1}, respectively. TP concentrations increased gradually during Period 1 to about 1 mg l^{-1} in Gaba and to 3.8 mg l^{-1} in Walukuba. In Period 2, TP concentrations were higher with values up to about 2 mg l^{-1} in Gaba and as high as 9 mg l^{-1} in Walukuba, except in the ponds without manure where TP concentrations were as in Period 1 (Fig. 4).

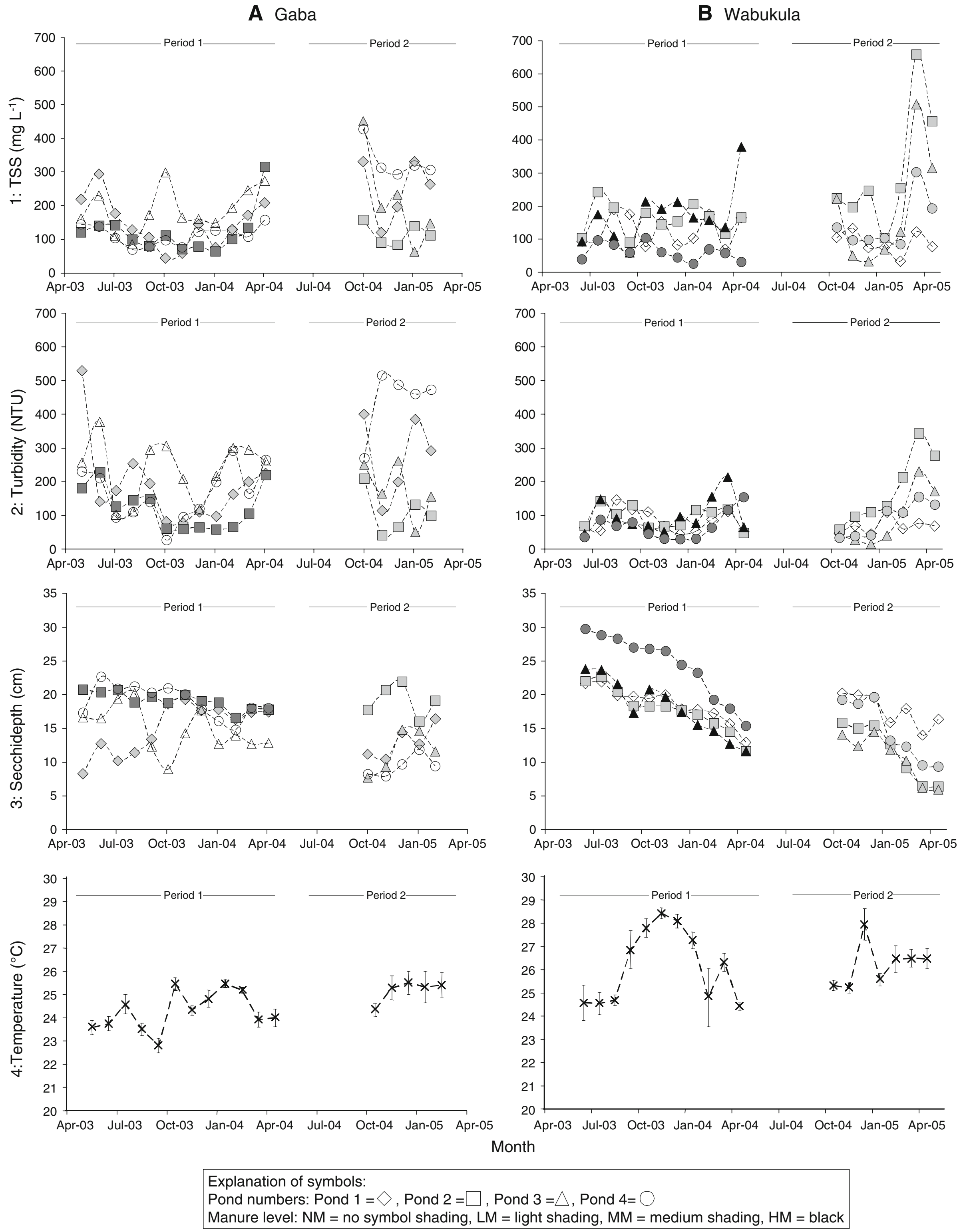
Fig. 2 Total suspended solids (TSS), turbidity, Secchi depth ▶ and temperature in Fingerponds in Gaba (**A**) and Walukuba (**B**) during experimental Periods 1 (May 2003–April 2004) and 2 (June 2004–February or April 2005). Symbols (see key below for pond numbers and manure treatment) represent monthly measurements in individual ponds, except for Pond 4: temperature where symbols represent means and bars represent standard error of the mean

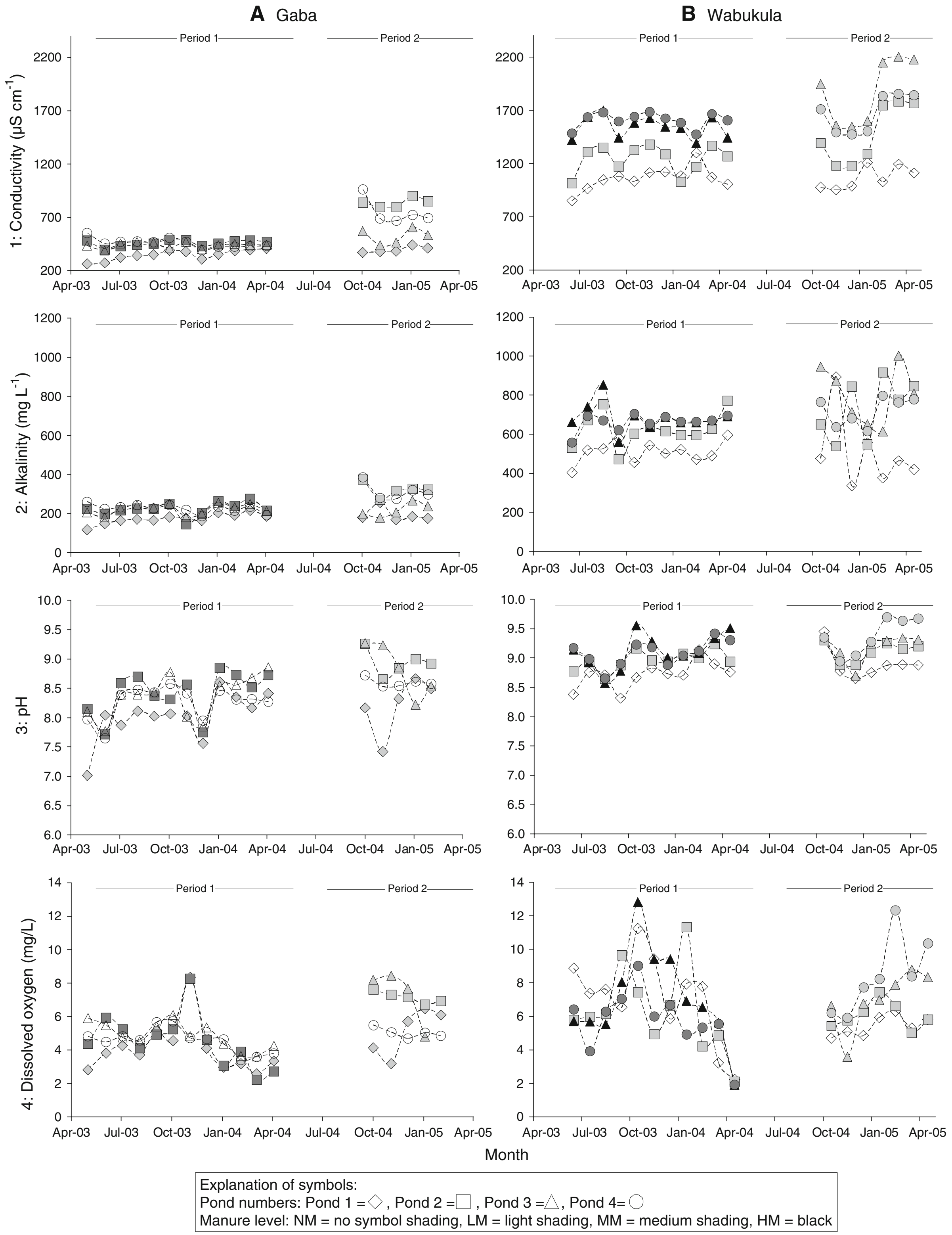
Primary productivity and natural fish food

Chlorophyll *a* concentrations in Gaba and Walukuba in Period 1 were similar but in Period 2 in both locations were higher in the manured ponds with mean values between 99 and 172 μg l^{-1} in Gaba and between 266 and 297 μg l^{-1} in Walukuba (Table 2). The highest phytoplankton biomass densities were obtained in Period 2 in Pond 4 in Walukuba with mean values for Cyanobacteria of 52,224 μg l^{-1} (see Appendix Table 1). Some differences were noted between phyla and periods; Euglenophyta were higher in manured ponds in Gaba in Period 1 whilst in Walukuba they were higher in Period 2 in all ponds. In Period 2 in both locations, Cyanobacteria biomasses were highest in the manured ponds. In Walukuba, no major differences were noted between phytoplankton biomasses in the ponds in Period 1. Phytoplankton diversity was similar for both locations and periods with 26 and 34 genera in Gaba and 30 and 35 genera in Walukuba (Period 1 and 2, respectively).

Net primary productivity (NPP) was around 5 mg O_2 m^{-2} day^{-1} in most ponds during Period 1 (Table 2). The highest mean NPP of 11.7 mg O_2 m^{-2} day^{-1} occurred in Pond 2 in Gaba (HM). In Period 2, NPP was very low in Pond 4 in Gaba (NM) but reached 10.5–11.1 mg O_2 m^{-2} day^{-1} in Ponds 2 and 3 in Gaba (LM). In Walukuba, mean NPP in Period 2 ranged from 2.5 to 7.2 mg O_2 m^{-2} day^{-1}.

Zooplankton biomass in all ponds was less than 120 μg l^{-1} and showed little variability between


A Gaba
B Wabukula
1: TSS (mg L-1)
2: Turbidity (NTU)
3: Secchidepth (cm)
4:Temperature (°C)
Period 1
Period 2
0
100
200
300
400
500
600
700
0
5
10
15
20
25
30
35
20
21
22
23
24
25
26
27
28
29
30
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Month
Explanation of symbols:
Pond numbers: Pond 1 = ◇ , Pond 2 = □ , Pond 3 = △, Pond 4= ○
Manure level: NM = no symbol shading, LM = light shading, MM = medium shading, HM = black


A Gaba
B Wabukula
Period 1
Period 2
1: Conductivity (μS cm-1)
200
700
1200
1700
2200
2: Alkalinity (mg L-1)
0
200
400
600
800
1000
1200
3: pH
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
4: Dissolved oxygen (mg/L)
0
2
4
6
8
10
12
14
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Month
Explanation of symbols:
Pond numbers: Pond 1 = ◇, Pond 2 = □, Pond 3 = △, Pond 4= ○
Manure level: NM = no symbol shading, LM = light shading, MM = medium shading, HM = black

◀ **Fig. 3** Conducivity, alkalinity, pH and dissolved oxygen in Fingerponds in Gaba (**A**) and Walukuba (**B**) during experimental Periods 1 (May 2003–April 2004) and 2 (June 2004–February or April 2005). Symbols (see key below for pond numbers and manure treatment) represent monthly measurements in individual ponds

locations. In Gaba in Period 1, ponds without manure had lower zooplankton biomass than manured ponds but the differences were small. In Period 2, the NM pond also had the lowest zooplankton biomass but the difference was only slight with one manured pond. In Walukuba, differences in zooplankton biomass were also small (Table 2).

Fish diet

There were very small differences in diet between the *Oreochromis* species and pooled results of stomach content analysis are presented. Stomach contents were dominated by detritus and algal material in both periods, though in Period 1, debris was also found (Table 3). The large percentage of fish containing detritus and debris indicated that the fish fed mainly on the pond bottom. Among the fish containing detritus and algae, several had stomachs containing only these items. Among the ingested algae, Cyanobacteria and Chlorophyta were dominant with the exception of the unmanured pond in Walukuba where Bacillariophyta dominated (Fig. 5). In Period 2, fewer fish in Gaba ingested Cyanobacteria than in Period 1 whereas in Walukuba the reverse occurred. In both locations there was a general increase in Chlorophyta in the gut contents in the second period. Only a few guts contained insects (*Chironomidae*) or higher plant material.

Fish growth and yield

Overall fish yields in Period 1 ranged from 68 to 2,580 kg ha^{-1} in Gaba (310 days) and from 456 to 951 kg ha^{-1} in Walukuba (219 days). In Period 2, net fish yields (including periodical harvests) ranged from 25 to 116 kg ha^{-1} in Gaba (186 days) and from 580 to 1,422 kg ha^{-1} in Walukuba (281 days) (Table 4).

During the acclimatization phase, fish biomass decreased in five ponds, mostly during Period 1 in Gaba. In most of these ponds, fish numbers increased so the decline in biomass was due to mortality or predation of the bigger fish in the population. In the other ponds, the fish biomass increased mostly due to increasing fish numbers (see Appendix Tables 2 and 3). Fish biomass increased in all ponds during the grow-out phase. Biomass increase in Period 1 ranged from 1,476 to 50,654 g per pond in Gaba (220 days) and from 9,605 to 19,418 g in Walukuba (185 days). In Period 2, this was −252 g (decrease) to 9,301 g (Gaba, 123 days) and 4,577 to 19,810 g (Walukuba, 179 days).

Mean fish size at harvest was below 10 g in many ponds. When excluding the fry and fingerlings (Class I fish), the size of fish increased from 6.8 to 55.5 g (manured ponds) and from 4.9 to 22.0 g (unmanured ponds) in the grow-out phase of Period 1 in Gaba (220 days). In Period 2, mean weights increased during the grow-out phase from 58.0 to 81.7 g (manured ponds) and from 58.1 to 101.8 g (unmanured ponds) over 123 days. In the grow-out phase in Walukuba, Period 1, mean fish weights rose from 20.0 to 46.8 g (manured ponds) and from 20.0 to 37.2 g (unmanured ponds) over 185 days. In Period 2, weights increased from 26.5 to 36.6 g (manured ponds) but decreased in the unmanured ponds from 42.7 to 35.1 g over 179 days.

In most ponds, fish numbers increased during the acclimatization phase but in some instances a drop was observed (Appendix Tables 2 and 3). In the grow-out phase however, fish numbers increased in all ponds. In both periods and locations final harvests were dominated by small fish in Class I (mainly *O. leucostictus* with proportions of 12–42% and 2–69% in Gaba, and 1–10% and 10–44% in Walukuba in Periods 1 and 2, respectively) (Fig. 6). *Oreochromis* spp. accounted for 39–100% (Gaba) and 79–100% (Walukuba) of the overall fish biomass in the two periods. Excessive recruitment occurred in all ponds with fry and fingerlings (Class I) accounting for 26%, 40% and 20% of the total fish biomass in Gaba in Ponds 1, 2 and 3 respectively (Period 1); and 80% and 61% of biomass in Ponds 1 and 3 (Period 2) with none found in the other ponds. In Walukuba they accounted for 89%, 26%, 82% and 30% (Period 1) and 62%, 35%, 78% and 32% (Period 2) of the biomass for ponds 1, 2, 3 and 4, respectively. In the final harvests, more fish in Classes III–V were found in the ponds in Period 1 compared to Period 2 and occurred mostly in manured ponds (Fig. 6).

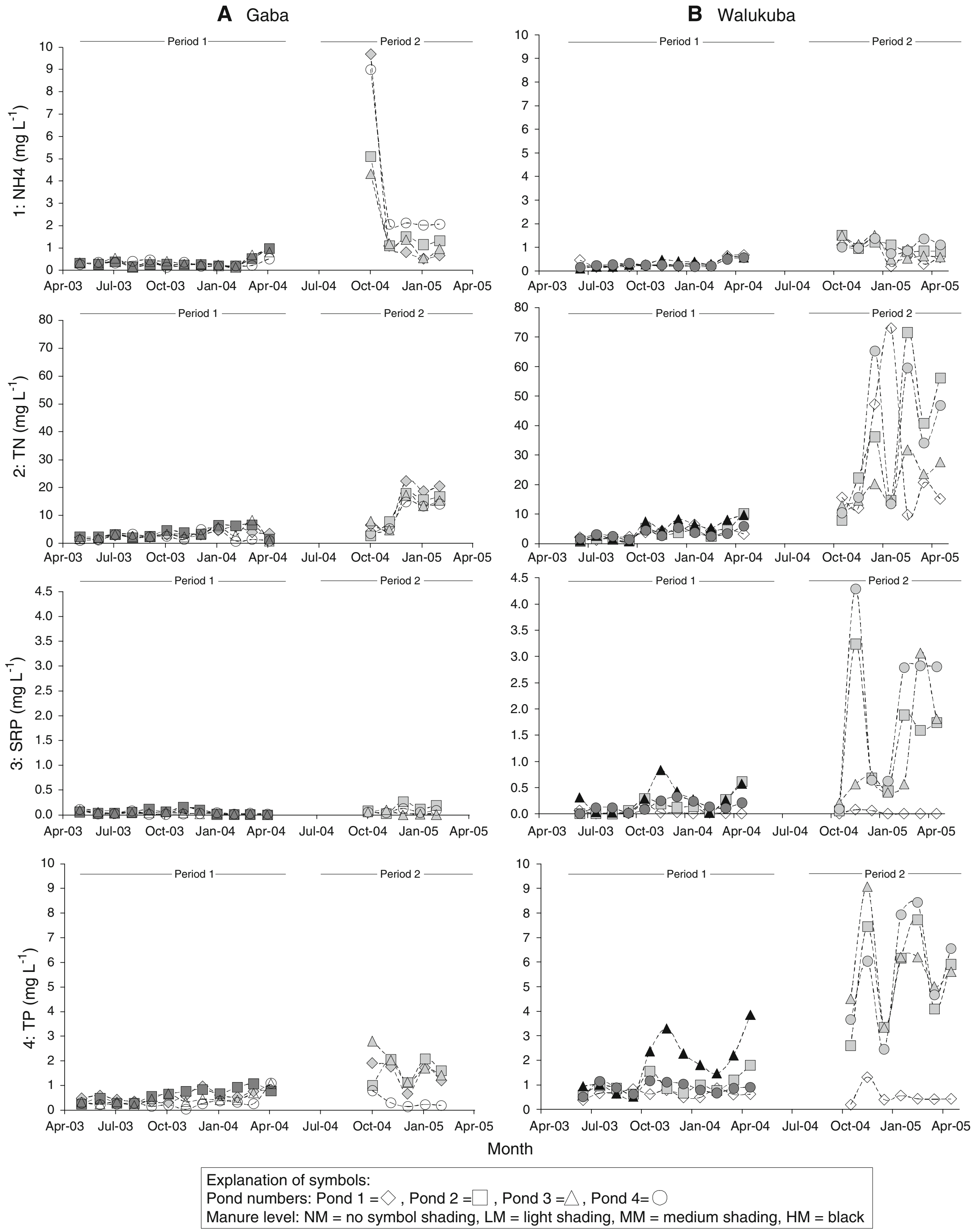


Fig. 4 Ammonia nitrogen, total nitrogen, soluble reactive phosphorous and total phosphorous in Fingerponds in Gaba (**A**) and Walukuba (**B**) during experimental Periods 1 (May 2003–April 2004) and 2 (June 2004–February or April 2005). Symbols (see key below for pond numbers and manure treatment) represent monthly measurements in individual ponds

Table 2 Chlorophyll *a*, primary productivity and zooplankton biomass in Fingerponds in Gaba (a) and Walukuba (b), Uganda between May 2003 and April 2004 (Period 1) and October 2004 and February 2005 (Period 2)

(a) Gaba	Period 1 ($n = 12$)				Period 2 ($n = 5$)			
Variable	Pond 3 (NM)	Pond 4 (NM)	Pond 1 (LM)	Pond 2 (MM)	Pond 4 (NM)	Pond 1 (LM)	Pond 2 (LM)	Pond 3 (LM)
Chlorophyll *a* (μg l^{-1})	41.1 ± 6.07	38.9 ± 14.37	46.9 ± 8.73	83.3 ± 19.02	51.7 ± 9.68	98.9 ± 27.20	157.0 ± 25.08	171.6 ± 24.76
NPP (g O_2 m^{-2} day^{-1})	4.2 ± 1.48	2.7 ± 0.70	4.9 ± 1.16	11.7 ± 2.49	0.2 ± 0.07	2.2 ± 1.00	10.5 ± 2.24	11.1 ± 1.52
GPP (g O_2 m^{-2} day^{-1})	6.3 ± 1.57	3.2 ± 0.89	6.8 ± 1.35	13.3 ± 2.29	0.4 ± 0.06	5.3 ± 1.27	13.3 ± 2.78	15.5 ± 1.50
Zoo biomass (μg l^{-1})	57 ± 17.25	53 ± 12.07	114 ± 29.84	74 ± 17.68	24 ± 8.75	59 ± 26.31	119 ± 30.03	37 ± 15.33

(b) Walukuba	Period 1 ($n = 11$)				Period 2 ($n = 7$)			
Variable	Pond 1 (NM)	Pond 2 (LM)	Pond 4 (MM)	Pond 3 (HM)	Pond 1 (NM)	Pond 2 (LM)	Pond 3 (LM)	Pond 4 (LM)
Chlorophyll *a* (μg l^{-1})	96.9 ± 24.02	89.9 ± 23.92	58.5 ± 15.27	121.9 ± 82.02	98.7 ± 15.31	292 ± 38.18	297 ± 92.84	266 ± 73.20
NPP (g O_2 m^{-2} day^{-1})	5.4 ± 1.63	8.3 ± 1.47	5.7 ± 1.50	5.4 ± 1.33	3.9 ± 1.06	6.3 ± 1.15	7.2 ± 1.22	2.5 ± 1.99
GPP (g O_2 m^{-2} day^{-1})	7.5 ± 1.96	9.6 ± 1.03	6.4 ± 1.62	7.8 ± 1.67	7.3 ± 0.94	7.8 ± 0.83	10.5 ± 1.44	5.8 ± 1.31
Zoo biomass (μg l^{-1})	82 ± 9.82	82 ± 15.31	39 ± 3.93	69 ± 13.36	32 ± 2.32	64 ± 9.14	35 ± 7.74	17 ± 1.98

Figures are means ± SE (standard error mean) of monthly samplings. NPP and GPP are net and gross primary production values respectively

Factor analysis

Five factors were extracted and accounted for 72.1% of the overall variability in the water quality and productivity data (Table 5). The first factor (F1) (20.3% of the overall variability) showed strong positive correlation with alkalinity, EC and pH. It was also related positively to temperature and DO, and negatively to nitrate concentration. Alkalinity, EC and pH are all related to the buffering capacity of the water, which is determined by site-specific characteristics (notably soil type), as is temperature. We interpret F1 as "site-determined buffering capacity".

Factor 2 (F2, 18.5%) was correlated strongly and positively with nutrient concentrations (PO_4, TP and TN) and chlorophyll *a*. High values represent a state of nutrient enrichment, therefore we interpret F2 as "enrichment level". Factor 3 (F3, 16.1%) was correlated negatively with water level and Secchi visibility, and positively with suspended solids, turbidity and NH_4 concentration. Obviously this factor represents the relationship between the declining water and increasing turbidity in the ponds, which leads to low light penetration. High turbidity leads to light limitation for the phytoplankton and reduced uptake of ammonia, which explains the positive correlation of F2 with NH_4 concentration. We call this factor "turbidity".

Factor 4 (F4, 9.3%) was correlated strongly and positively with N/P ratio, and somewhat less strongly with Si/P-ratio. We interpreted F4 as the "N/P-ratio". Factor 5 (F5, 8.0%) was related postively with gross primary production. We call this factor "primary productivity".

Significant regression models were derived for the scores of all five factors, with adjusted R^2 ranging from 0.185 to 0.599 (Table 6). Site-determined buffering capacity (F1) was explained best (adj. $R^2 = 0.599$) with significant differences among the two sites (higher in Walukuba), as shown by the significant partial regression coefficient ($P < 0.001$). Time or manuring did not have significant effects ($P > 0.01$). Enrichment level (F2, adj. $R^2 = 0.336$) showed significant differences for site, time and manuring. Ponds in Walukuba scored higher on this factor, ponds became more enriched with time and manuring also had a positive effect on enrichment level. Turbidity (F3, adj. $R^2 = 0.399$) was significantly different among sites ($P < 0.001$, lower scores in Walukuba)

Table 3 Gut contents of fish in Fingerponds in Gaba and Walukuba in Periods 1 and 2

(a) Gaba	Period 1				Period 2			
Pond no. (manure level)	3 (NM)	4 (NM)	1 (LM)	2 (MM)	4 (NM)	1 (LM)	2 (LM)	3 (LM)
No. of fish	2	3	3	3	4	8	5	6
% *Oreochromis niloticus*	0	0	0	33	0	25	15	17
% *O. leucostictus*	100	100	100	67	25	38	60	50
% *O. variabalis*	0	0	0	0	75	28	15	33
Mean total length (cm)	11.5	9.2	19.5	10.6	16.6	15.0	15.4	14.0
% Fish containing food item								
Macrophytes	0	0	67	33	25	25	40	17
Detritus and algae	100	33	100	33	75	25	20	0
Debris e.g. sand	100	0	100	67	0	0	0	0
Fry	0	0	0	0	0	0	0	0
Chironomids	0	33	33	0	0	13	40	17

(b) Walukuba	Period 1				Period 2			
Pond no. (manure level)	1 (NM)	2 (LM)	4 (MM)[a]	3 (HM)	1 (NM)	2 (LM)	3 (LM)	4 (LM)
No. of fish	4	4		3	16	16	13	16
% *Oreochromis niloticus*	75	25		100	19	13	0	31
% *O. leucostictus*	25	75		0	19	31	69	38
% *O. variabalis*	0	0		0	62	57	31	31
Mean total length (cm)	12.0	11.1		11.5	12.9	10.9	12.9	10.0
% Fish containing food item								
Macrophytes	75	25		67	6	6	15	6
Detritus and algae	25	50		67	63	56	77	63
Debris e.g. sand	100	25		100	0	0	0	0
Fry	0	0		0	1	0	0	0
Chironomids	25	0		67	2	0	0	0

[a] No fish caught

and in time ($P < 0.001$, higher scores as the months passed). N/P-ratios (F4, adj. $R^2 = 0.185$) were not affected by site but increased with time ($P < 0.001$) and decreased with manuring ($P < 0.001$). Primary productivity (F5, adj. $R^2 = 0.196$) was only affected significantly by manuring ($P < 0.001$).

Discussion

As we worked under natural field conditions where true replication was not feasible, data revealed variability and inconsistencies. However, by factor analysis, trends emerge that give a clearer understanding of the Fingerpond systems and their benefits.

Fingerponds are susceptable to high turbidity, decreasing water levels and low oxygen concentrations, all factors that might affect fish production negatively. In both locations the ponds were very turbid, with Secchi disk visibility ranging from 7.7 to 22.7 cm in Gaba to 5.9–29.8 cm in Walukuba. This limited light penetration and photosynthesis and reduced phytoplankton primary productivity. However, dissolved oxygen concentrations in the ponds were always above 2 mg l^{-1} at 06.00 h and above 4 mg l^{-1} between 10.00 and 14.00 h and therefore are acceptable for aquaculture. High phytoplankton densities can pose water quality risks; e.g. low oxygen levels at night that trigger fish kills and, at pH values >8.0, unionized ammonia (NH_3) can reach

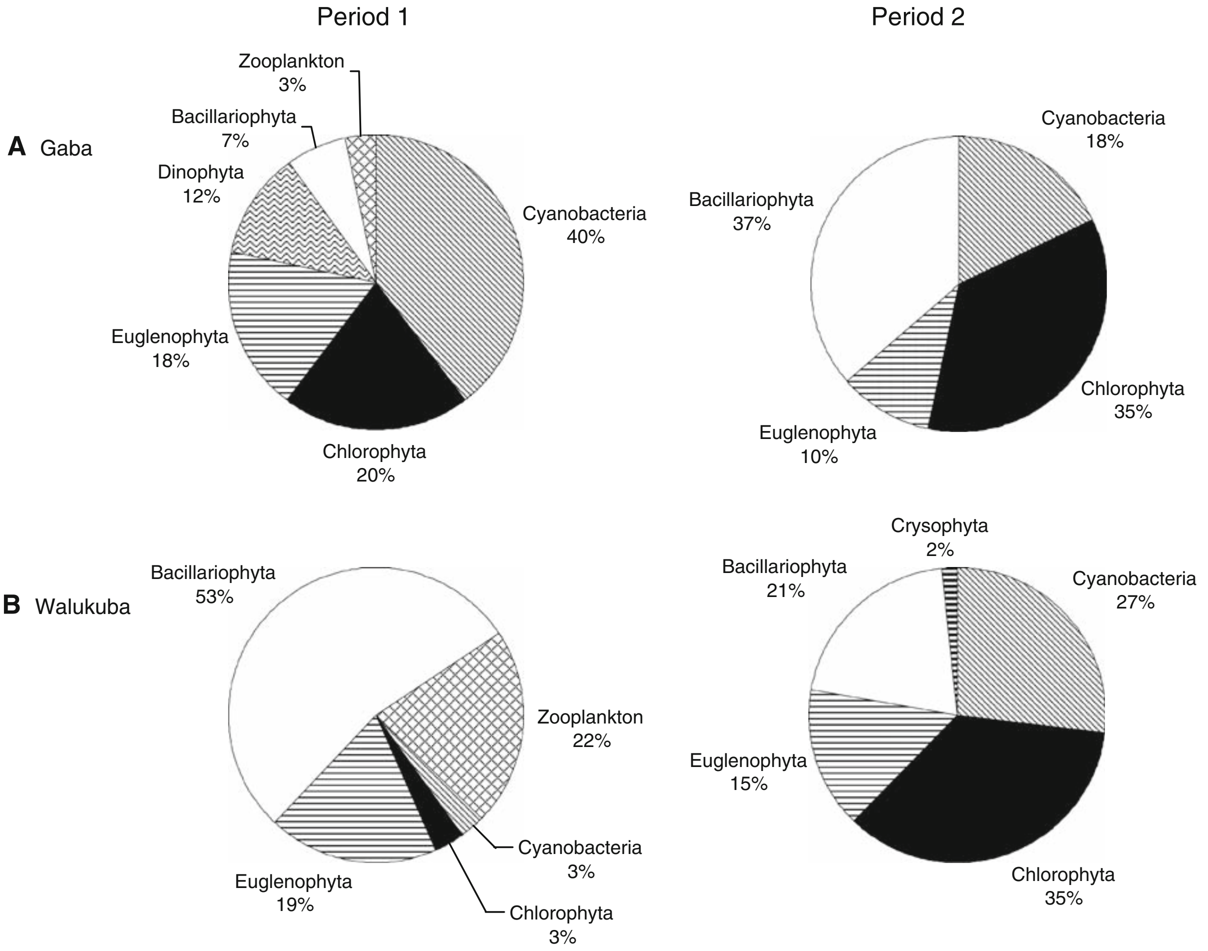


Fig. 5 Planktonic composition of the fish diet. Values represent percentage number of fish found with specific plankton group in their guts. Number of samples for Periods 1 and 2 were 56 and 21 in Gaba and 59 and 61 in Walukuba respectively

Table 4 Overall fish yields (acclimatization phase and grow-out phase) for Fingerponds in Gaba and Walukuba, Uganda in Periods 1 and 2

Pond no.	3 (NM)	4 (NM)	1 (LM)	2 (MM)	4 (NM)	1 (LM)	2 (LM)	3 (LM)
(a) Gaba	Period 1 (310 days)				Period 2 (186 days)			
Initially trapped (kg ha^{-1})	53	41	186	89	10	20	17	27
Final biomass (kg ha^{-1})	252	108	891	2,670	69	344	30	133
Periodically harvested (kg ha^{-1})	0	0	0	0	8	91	12	125
Gross total fish yield (kg ha^{-1})	252	108	891	2,670	77	435	42	258
Net final fish yield (kg ha^{-1})	199	68	705	2,580	67	415	25	231
(b) Walukuba	Period 1 (219 days)				Period 2 (284 days)			
Initially trapped (kg ha^{-1})	126	128	24	112	13	48	15	25
Final biomass (kg ha^{-1})	675	1,079	677	568	344	30	133	69
Periodically harvested (kg ha^{-1})	0	0	0	0	259	246	282	366
Gross total fish yield (kg ha^{-1})	675	1,079	677	568	603	276	415	435
Net final fish yield (kg ha^{-1})	549	951	653	456	590	228	400	410

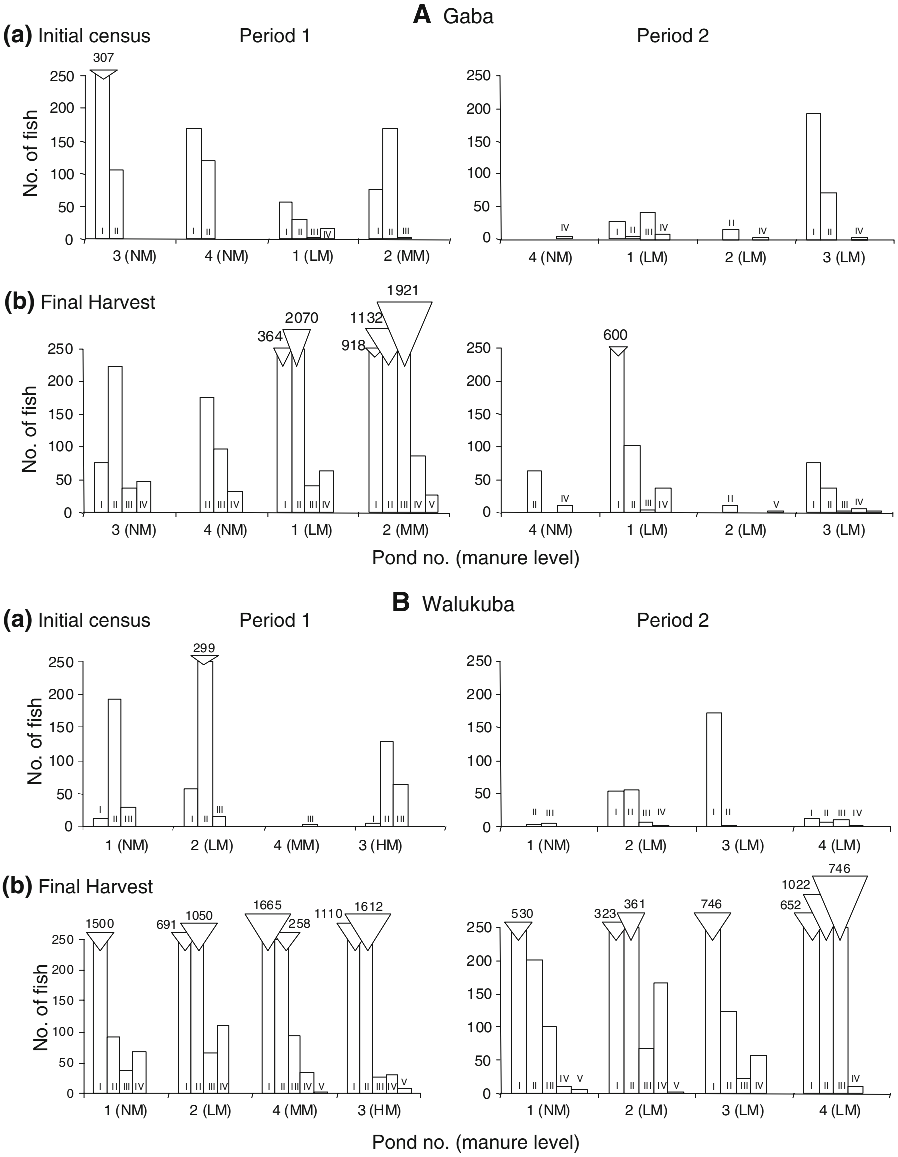


Fig. 6 Length frequency distribution for fish in Gaba (**A**) and Walukuba (**B**) from beginning of adapatation period (a: initial stock) to end of grow-out phase (b: final harvest), Periods 1 and 2. Bars represent number of fish in ponds as per selected total length range. Class 1 refers to fish with total length (cm) ranging from 0.0 to 5.0 cm, Class II (5.1–10.0 cm), Class III (10.1–15.0 cm), Class IV (15.1–20.0 cm) and Class V (20.1–30.0 cm). Bar labels with a triangular symbol indicate the number of fish for bars that exceeded the *Y*-scale

toxic levels. In Fingerponds, NH_3 is most likely to occur in the late afternoon and early evening when pH values are highest. Since this period is short, no toxicity was experienced during the investigative period. However, extra caution must be taken when algal blooms develop.

Adequate water levels are crucial in sustaining a suitable environment for fish in terms of water quality and natural food production. As levels fall fish can be put under considerable stress. In the Fingerponds, when water decreased to a critical level, particularly in Period 2, chlorophyll *a* concentrations and Cyanobacteria numbers increased as nutrients became more concentrated whereas no significant increments in fish biomass were noted.

Table 5 Factor analysis results for water quality and productivity in Gaba and Walukuba, Periods 1 and 2

Variables	F1[a]	F2	F3	F4	F5
pH	0.827				
EC (μS cm^{-1})	0.805				
Alkalinity (mg $CaCO_3$ l^{-1})	0.769				
NO_3 (mg l^{-1})	−0.664				
Temperature (°C)	0.610				
DO (mg l^{-1})	0.557				
PO_4 (mg l^{-1})		0.798			
TP (mg l^{-1})		0.794			
TN (mg l^{-1})		0.694			
Chlorophyll *a* (μg l^{-1})		0.676			
Water level (m)			−0.759		
TSS (mg l^{-1})			0.752		
Secchi depth (cm)			−0.734		
NH_4 (mg l^{-1})			0.697		
Turbidity (NTU)			0.644		
N/P-ratio (–)				0.947	
Si/P-ratio (–)				0.604	
GPP (g O_2 m^{-2} day^{-1})					0.903
% Variance explained ($N = 140$)	20.3	18.5	16.1	9.3	8.0

F*x* denotes factor number, N = number of cases. Only factor loadings greater than 0.500 are shown (see text for explanation)

[a] Interpretation of factors (see text): F1, Site-determined buffering capacity; F2, Level of eutrophication; F3, Turbidity; F4, N/P-ratio; F5, Primary productivity

Table 6 Regression results for factor scores with site (dummy 0 = Gaba, 1 = Walukuba), time (month number with 1 = May 2003, 2 = April 2003 etc.) and manuring (dummy 0 = no manure, 1 = manure) as explanatory variables

Factor	Interpretation	Adj. R^2	*F*-value	Intercept	b_{site}	b_{time}	b_{manure}
F1	Site-determined buffering capacity	0.599	70.159***	−0.979	1.495***	0.018*	−0.005ns
F2	Enrichment level	0.332	24.024***	−1.070	0.496**	0.050***	0.499**
F3	Turbidity	0.392	30.853***	−0.506	−0.687***	0.084***	−0.232*
F4	N/P-ratio	0.196	12.291***	−0.269	−0.158ns	0.059***	−0.706***
F5	Primary productivity	0.171	10.535***	−0.467	−0.293*	0.028*	0.631***

Significance levels: ns (not significant, $P \geq 0.05$); tendency to significance, * $0.01 \leq P < 0.05$, ** $0.001 \leq P < 0.01$, *** $P < 0.001$

Manure application stimulated primary productivity (but not in Walukuba) and zooplankton production; and, in Period 2, chlorophyll *a* concentrations were notably higher. Manuring increased total phosphorous but did not increase nitrogen concentrations in the ponds. Manure had a significant positive effect on enrichment of the ponds and a negative effect on N/P-ratio (see Fig. 7a). Average N/P-ratios were 15.2 and 6.4 in ponds without and with manure, respectively. N:P-ratios below 7 generally indicate N limitation (Knud-Hansen et al. 1991). However, manure encouraged Cyanobacteria development that can assimilate dissolved atmospheric nitrogen (Bíro 1995). Possibly some Cyanobacteria species were not palatable to the fish although tilapias, including *O. niloticus,* have been observed to digest them (Moriarty and Moriarty 1973; Colman and Edwards 1987). It might be interesting to explore the possibilities for using higher-quality manure with a higher N-content.

The factor analysis showed that turbidity was important, but not in the same way for the two sites. In Walukuba it was related to the low water levels in Period 2, whereas in Gaba the ponds were turbid in both periods. In Gaba, turbidity was due to fine clay

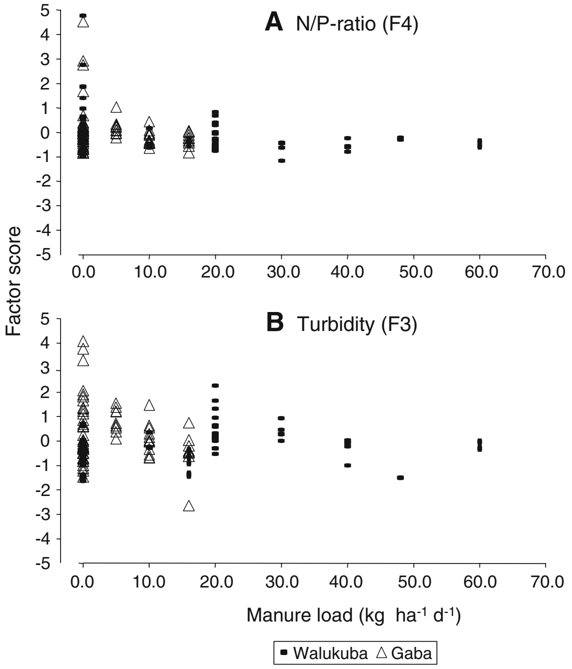


Fig. 7 Factor scores for Factor 3 (**A**: Turbidity) and Factor 4 (**B**: N/P-ratio), plotted against the manure input into the ponds. Turbidity in Gaba was high without manure input and decreased with increasing manure levels. Turbidity in Walukuba was lower without manure and increased with manure input. N/P ratios were high without manure input and more or less constant at higher manure input levels. For explanation, see text

particles that remained suspended in the water column irrespective of water levels whilst in Walukuba, turbidity was due mainly to phytoplankton and re-suspended organic matter from the pond bottom when water levels were low. A plot of the factor scores showed that manuring had a mitigating effect on the clay turbidity in Gaba, whereas it increased organic turbidity in Walukuba (see Fig. 7b).

The regression results show that manuring had a positive effect on the nutrient enrichment of the ponds (particularly phosphorous) and on primary productivity. This was reflected in higher concentrations of phytoplankton. The fact that zooplankton biomass did not play a role in the factor analysis, did not show a clear relationship with manure input and did not appear in the fish gut contents suggests that zooplankton was not important as a source of fish food in Fingerponds. Most fish showed a diet of vegetative material, detritus and macrobenthos (chironomids), confirming the herbivorous-detritivorous feeding habits of these *Oreochromis* species. This study could not confirm directly the relationship between manure input and increased fish yields, as variability among ponds was high and there was no clear relationship between manuring rate and fish yields. However, based on the effect of manure on the nutrient levels and the natural food of the fish (as shown in the gut content analysis), and on the highest fish yields obtained in manured ponds, it is safe to conclude that manuring had a positive effect on fish production. The highest biomass was obtained in the medium manured pond in Gaba in Period 1.

Despite the low average fish size (55 g), some bigger fish appeared in the final harvests. The normal size range at harvest for *Oreochromis* spp. from semi-intensive ponds in Uganda after 8 months is 100–200 g (GOU 2005). In our ponds, it was not possible to achieve this size but total yields are comparable with yields from ponds elsewhere in Africa (Delincé 1992; Egna and Boyd 1997).

Many small fish of less than 25 g and TL of 8–10 cm, particularly, *O. leucostictus*, were sexually mature and observed to be spawning. In Period 1, natural stocking densities after flooding were 1–2 fish m^{-2}. Initial stocking densities in Fingerponds can be as high as 12 fish m^{-2} (Porkorný et al. 2005) and in such cases, redistribution of the fish is necessary. Densities between 0.1 and 1 tilapia m^{-2} are effective in attaining fish of reasonable sizes assuming a constant supply of food (Glasser and Oswald 2001). Nonetheless, reproduction in the ponds led to high densities of small fish. During Period 2, stock management measures (manual sexing of fish, stocking only males, monthly removal of females and small fish) increased the ratio of male to female fish but did not reduce fish numbers, probably due to errors in sexing tilapia smaller than 30 g (Delincé 1992). Even small numbers of females are known to create high levels of recruitment in tilapia ponds (Mair and Van Dam 1996). In the littoral zone of Lake Victoria stunted fish have been observed (Lowe-McConnell 1979; Balirwa 1998): fish in our ponds could have been stunted right from the start.

These trials were carried out under difficult conditions, especially in Period 2 when the lake level fell unpredictably and dramatically—indeed, it caused serious problems around the entire lake basin

(Kiwango and Wolanski 2008). Despite this, our field experiments show that Fingerponds provide much-needed protein to communities in the Lake Victoria wetlands, particularly during the dry season. In protein-deficient communities any size fish, including all small ones, are eaten. In Fingerpond experimental sites in Kusa and Nygangera, Kenya, mean net fish yields in ponds manured with cow manure were similar, ranging from 402 to 1,069 kg ha^{-1} (Kipkemboi et al. 2006). This innovative technology provides an additional option for the wise use of wetlands, especially through increasing food security and diversity for the lower income households. More research is needed to reduce the variability in yields, overcome local problems of high turbidity and reduce the recruitment of tilapia to produce bigger fish.

Acknowledgements This research was funded by the EU/INCODEV Fingerponds Project (contract no. ICA4-CT-2001-10037) and by the Netherlands Fellowship Programme through UNESCO-IHE, Institute for Water Education, Delft, The Netherlands, in partnership with Makerere University Institute of Environment and Natural Resources (MUIENR), Uganda. We are indebted to the management and staff of National Water and Sewerage Corporation and the National Fisheries Resources Research Institute of Uganda for providing technical support and facilities. We are forever grateful to the laboratory and field assistants in Kampala and Jinja who worked tirelessly.

Appendix

Table 1 Phytoplankton densities by genera in Fingerponds in Gaba (a) and Walukuba (b), Uganda between May 2003 and April 2004 (Period 1) and October 2004 and February 2005 (Period 2)

(a) Gaba	Period 1 ($n = 12$)				Period 2 ($n = 5$)			
Pond no. (manure level)	3 (NM)	4 (NM)	1 (LM)	2 (MM)	4 (NM)	1 (LM)	2 (LM)	3 (LM)
Cyanobacteria (μg l^{-1})	443 ± 121	1,094 ± 423	1,077 ± 207	696 ± 117	584 ± 387	410 ± 193	4,992 ± 1650	9,312 ± 5,843
Cryptophyta (μg l^{-1})	309 ± 143	390 ± 250	897 ± 449	595 ± 418	70 ± 20	97 ± 33	228 ± 168	3,339 ± 2,407
Bacillariophyta (μg l^{-1})	169 ± 62	10,841 ± 10,499	746 ± 157	1,495 ± 800	99 ± 49	1027 ± 621	666 ± 312	1,231 ± 398
Dinophyta (μg l^{-1})	94 ± 45	206 ± 101	139 ± 69	462 ± 383	–	–	502 ± 355	548 ± 387
Euglenophyta (μg l^{-1})	1,175 ± 552	792 ± 170	9,647 ± 2,675	9,063 ± 3,452	695 ± 368	1,028 ± 670	16,110 ± 15,949	7,931 ± 4,042
Chlorophyta (μg l^{-1})	20,516 ± 20,025	213 ± 71	260 ± 56	285 ± 96	176 ± 165	691 ± 244	2,677 ± 1,330	1,044 ± 491

(b) Walukuba	Period 1 ($n = 11$)				Period 2 ($n = 7$)			
Pond no. (manure level)	1 (NM)	2 (LM)	4 (MM)	3 (HM)	1 (NM)	2 (LM)	3 (LM)	4 (LM)
Cyanobacteria (μg l^{-1})	1,333 ± 458	2,261 ± 809	1,458 ± 410	1,780 ± 661	11,267 ± 5,612	39,680 ± 23,373	38,721 ± 16,338	52,244 ± 42,128
Cryptophyta (μg l^{-1})	1,015 ± 688	1,502 ± 1,105	392 ± 152	619 ± 364	119 ± 75	1,048 ± 850	2,469 ± 1,541	5,303 ± 3,274
Bacillariophyta (μg l^{-1})	1,432 ± 976	1,151 ± 451	652 ± 181	2,091 ± 1,426	604 ± 99	614 ± 435	936 ± 734	1,124 ± 638
Dinophyta (μg l^{-1})	14 ± 7	12 ± 11	25 ± 21	27 ± 25	2,873 ± 1,438	–	–	–
Euglenophyta (μg l^{-1})	3,184 ± 1,190	1,890 ± 383	1,743 ± 539	4,635 ± 1,374	10,058 ± 4,666	5,498 ± 3,065	20,679 ± 16,440	7,632 ± 4,105
Chlorophyta (μg l^{-1})	1,903 ± 608	1,112 ± 357	852 ± 169	647 ± 323	1,879 ± 520	1,044 ± 533	165 ± 32	1,263 ± 301

Figures are means ± SE, where SE is the standard error mean of monthly samplings

Table 2 Fish numbers and biomass for Fingerponds in Gaba, Periods 1 and 2

Pond no.	3 (NM)	4 (NM)	1 (LM)	2 (MM)	4 (NM)	1 (LM)	2 (LM)	3 (LM)
Acclimatization phase	Period 1 (90 days)				Period 2 (63 days)			
Initial fish population (no.)	419	266	205	278	11	19	14	11
Initial biomass (g)	1,012	781	3,580	1,714	196	382	332	526
Initial mean fish weight (g)	2.4	2.9	17.5	6.2	17.8	20.1	23.7	47.8
Initial stock density (no. m^{-2})	2.2	1.4	1.1	1.4	0.1	0.1	0.1	0.1
Final fish population (no.)	369	328	900	1,009	5	188	3	1,590
Final biomass (g)	930	589	1,502	2,155	407	2,633	246	1,926
Final mean fish weight (g)	2.5	1.8	1.7	2.1	81.4	14.0	82.0	1.2
Final stock density (no. m^{-2})	1.9	1.7	4.7	5.3	0.0	1.0	0.0	8.3
Biomass increase (g)	−82	−192	−2,078	441	211	2,251	−86	1,400
Grow-out phase	Period 1 (220 days)				Period 2 (123 days)			
Initial fish population (no.)	100	100	100	100	20	20	20	20
Initial biomass (g)	604	604	604	604	907	813	547	606
Initial mean fish weight (g)	6.0	6.0	6.0	6.0	45.4	40.7	27.4	30.3
Initial stock density (no. m^{-2})	0.5	0.5	0.5	0.5	0.1	0.1	0.1	0.1
Final fish population (no.)	535	604	2,020	5,910	74	754	14	93
Final biomass (g)	4,842	2,080	17,114	51,258	1,324	10,114	577	354
Final mean fish weight (g)	9.1	3.4	8.5	8.7	17.9	13.4	41.2	3.8
Final stock density (no. m^{-2})	2.8	3.1	10.5	30.8	0.4	3.9	0.1	0.5
Biomass increase (g)	4,238	1,476	16,510	50,654	417	9,301	30	−252

Table 3 Fish numbers and biomass for Fingerponds in Walukuba, Periods 1 and 2

Pond no.	1 (NM)	2 (LM)	4 (MM)	3 (HM)	1 (NM)	2 (LM)	3 (LM)	4 (LM)
Acclimatization phase	Period 1 (34 days)				Period 2 (105 days)			
Initial fish population (no.)	250	410	2	222	10	119	173	34
Initial biomass (g)	2,410	2,455	456	2,147	242	925	284	496
Initial mean fish weight (g)	9.6	6.0	228.0	9.7	24.2	7.8	1.6	14.6
Initial stock density (no. m^{-2})	1.3	2.1	0.0	1.2	0.1	0.6	0.9	0.2
Final fish population (no.)	267	295	2	150	83	542	317	1,535
Final biomass (g)	1,921	2,847	515	2,541	3,969	3,672	1,742	5,732
Final mean fish weight (g)	7.2	9.7	257.5	16.9	47.8	6.8	5.5	3.7
Final stock density (no. m^{-2})	1.4	1.5	0.0	0.8	0.4	2.8	1.7	8.0
Biomass increase (g)	−489	392	59	394	3,727	2,747	1,458	5,236
Grow-out phase	Period 1 (185 days)				Period 2 (179 days)			
Initial fish population (no.)	70	70	70	70	60	60	60	60
Initial biomass (g)	1,300	1,300	1,300	1,300	1,224	1,794	1,426	967
Initial mean fish weight (g)	18.6	18.6	18.6	18.6	20.4	29.9	23.8	16.1
Initial stock density (no. m^{-2})	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Final fish population (no.)	1,950	2,528	2,772	1,550	848	924	953	2,054
Final biomass (g)	12,955	20,718	13,006	10,905	8,501	12,123	6,003	20,777
Final mean fish weight (g)	6.6	8.2	4.7	7.0	10.0	13.1	6.3	10.1
Final stock density (no. m^{-2})	10.2	13.2	14.4	8.1	4.4	4.8	5.0	10.7
Biomass increase (g)	11,655	19,418	11,706	9,605	7,277	10,329	4,577	19,810

References

APHA (1992) Standard methods for examination of water and wastewater, 18th edn. American Public Health Association, Washington

APHA (1995) Standard methods for examination of water and wastewater, 19th edn. American Public Health Association, Washington

Balirwa JS (1998) Lake Victoria wetlands and the ecology of the Nile Tilapia *Oreochromis niloticus* Linné. A.A. Balkema Publishers, Rotterdam, The Netherlands, 247 pp

Bíro P (1995) Management of pond ecosystems and trophic webs. Aquaculture 129:373–386

Clover J (2003) Food security in Sub-Saharan Africa. Afr Secur Rev 12(1):5–15

Colman JA, Edwards P (1987) Feeding pathways and environmental constraints in waste-fed aquaculture: balance and optimization. In: Moriarty DJW, Pullin RSV (eds) Detritus and microbial ecology in aquaculture. ICLARM Conf Proc 14:240–281

Delincé G (1992) The ecology of the fish pond ecosystem with special reference to Africa. Kluwer Academic Publishers, Dordrecht, 230 pp

Denny P (ed) (1985) The ecology and management of African wetland vegetation. Geobotany 6. Dr. W. Junk Publishers, Dordrecht, The Netherlands, 344 pp

Denny P, Kipkemboi J, Kaggwa RC, Lamtane H (2006) The potential of Fingerpond systems to increase food production from wetlands in Africa. Int J Ecol Environ Sci 32:41–47

Duncan A (1975) Production and biomass of three species of Daphnia coexisting in London reservoirs. Verh Internat Verein Limnol 19:2858–2867

Edwards P (1999) Aquaculture and poverty: past, present and future prospects of impact. Discussion paper prepared for the 5th fisheries development donors' consultation at FAO, 21–23 February 1999, Rome

Egna HS, Boyd CE (1997) Dynamics of pond aquaculture. CRC Press, Boca Raton/New York, 437 pp

Fernando CH (ed) (2002) A guide to tropical freshwater zooplankton. Identification, ecology and impact on fisheries. Backhuys Publishers, Leiden, The Netherlands, 291 pp

Glasser F, Oswald M (2001) High stocking densities reduce *Oreochromis niloticus* yield: model building to aid the optimization of production. Aquat Living Resour 14:319–326

GOU (2005) Aquaculture technical manual. An introduction to commercial fish farming. 1. Ministry of Agriculture, Animal Industry and Fisheries. Government of Uganda, National Agricultural Advisory Services (NAADS), Kampala, 65 pp

Green BW, Phelps RP, Alvarenga HR (1989) The effects of manures and chemical fertilizers on the production of

Oreochromis niloticus in earthen ponds. Aquaculture 76:37–42

Halwart M, van Dam AA (eds) (2006) Integrated irrigation and aquaculture in West Africa. Concepts, practices and potential. FAO, Rome, 196 pp

Hyslop EJ (1980) Stomach contents analysis—a review of methods and their application. J Fish Biol 17:411–429

John DM, Whitton BA, Brook AJ (eds) (2002) The freshwater algal flora of the British Isles. An identification guide to freshwater and terrestrial algae. Cambridge University Press, Cambridge, 702 pp

Kaggwa RC (2006) Fingerponds: managing nutrients and primary productivity for enhanced fish production in Lake Victoria's wetlands, Uganda. PhD thesis, UNESCO-IHE Institute for Water Education, The Netherlands. Taylor and Francis/Balkema, Leiden, 214 pp

Kaggwa RC, Kasule D, van Dam AA, Kansiime F (2006) An initial assessment of the use of wetland plants as substrates for periphyton production in seasonal wetland fishponds in Uganda. Int J Ecol Environ Sci 32(1):63–74

Kaggwa RC, Kansiime F, Denny P, van Dam AA (2005) A preliminary assessment of the aquaculture potential of two wetlands located in the northern shores of Lake Victoria, Uganda. In: Vymazal J (ed) Natural and constructed wetlands: nutrients, metals and management. Backhuys Publishers, Leiden, The Netherlands, pp 350–368

Kipkemboi J, van Dam AA, Denny P (2006) Biophysical suitability of smallholder integrated aquaculture-agriculture systems (Fingerponds) in East Africa's Lake Victoria freshwater wetlands. Int J Ecol Environ Sci 32(1):78–83

Kipkemboi J, van Dam AA, Mathooko JM, Denny P (2007a) Hydrology and the functioning of seasonal wetland aquaculture-agriculture systems (fingerponds) at the shores of Lake Victoria, Kenya. Aquac Eng 37:202–214

Kipkemboi J, van Dam AA, Ikiara MM, Denny P (2007b) Integration of smallholder wetland aquaculture-agriculture systems (fingerponds) into riparian farming systems on the shores of Lake Victoria, Kenya: socio-economics and livelihoods. Geogr J 173:257–272

Kipkemboi J, van Dam AA, Denny P (2007c) Environmental impact of seasonal integrated aquaculture ponds (fingerponds) in the Lake Victoria wetlands, Kenya: an assessment with the aid of Bayesian networks. Afr J Aquat Sci 32:219–234

Kiwango YA, Wolanski E (2008) Papyrus wetlands, nutrients balance, fisheries collapse, food security and Lake Victoria level decline in 2000–2006. Wetl Ecol Manage. doi: 10.1007/s11273-007-9072-4

Knud-Hansen DF, Batterson RR, McNabb CD, Harahat IS, Sumantadinata K, Eidman HM (1991) Nitrogen input, primary productivity and fish yields in fertilized freshwater ponds in Indonesia. Aquaculture 94:49–63

Lowe-McConnell RH (1975) Fish communities in tropical freshwaters: their distribution, ecology and evolution. Longman Inc, New York, 337 pp

Lowe-McConnell RH (1979) Ecological aspects of seasonality in fishes of tropical waters. Symp Zool Soc Lond London 44:219–241

Machena C, Moehl J (2001) African aquaculture: a regional summary with emphasis on Sub-Saharan Africa. In: Subasinghe RP, Bueno P, Phillips MJ, Hough C, McGladdery SE, Arthur JE (eds) Aquaculture in the third millennium. Technical proceedings of the conference on aquaculture in the third millennium, Bangkok, Thailand, 20–25 February 2000. NACA, Bangkok and FAO, Rome, pp 341–355

Mair GC, van Dam AA (1996) The effect of sex ratio at stocking on growth and recruitment in Nile tilapia (*Oreochromis niloticus*) ponds. In: Pullin RSV, Lazard J, Legendre M, Amon Kothias JB, Pauly D (eds) The third international symposium on tilapia in aquaculture. ICLARM Conf Proc 41:100–107

Milstein A (1993) Factor and canonical analyses: basic concepts, data requirements and recommended procedures. In: Prein M, Hulata G, Pauly D (eds) Multivariate methods in aquaculture research: case studies of tilapias in experimental and commercial systems. ICLARM Stud Rev 20:24–31

Moriarty CM, Moriarty DJW (1973) Quantitative estimation of the daily ingestion of phytoplankton by Tilapia nilotica and Haplochromis nigripinnis in Lake George, Uganda. J Zool Lond 171:15–23

Mosille OIW (1994) Phytoplankton species of Lake Victoria. In: Reports from the haplochromis ecology survey team (HEST). Report No. 30B, Zoologisch Laboratorium, Morphology Department, Leiden University, The Netherlands, 84 pp

Nauwerck A (1963) Die Beziehungen zwischen Zooplankton und Phytoplankton im See Erken. Symb Bot Ups 17(5): 1–163

Pechar L (1987) Use of an acetone:methanol mixture for the determination of extraction and spectrophotometric determination of chlorophyll-*a* in phytoplankton. Arch Hydrobiol Suppl 78:99–117

Pechar L (1995) Long-term changes in fish pond management as 'an unplanned ecosystem experiment': importance of zooplankton structure nutrients and light for species composition of cyanobacterial blooms. Water Sci Technol 32:187–196

Pokornỳ J, Přikryl I, Faina R, Kansiime F, Kaggwa RC, Kipkemboi J, Kitaka N, Denny P, Bailey R, Lamtane HA, Mgaya YD (2005) Will fish pond management principles from the temperate zone work in tropical Fingerponds. In: Vymazal J (ed) Natural and constructed wetlands: nutrients, metals and management. Backhuys Publishers, Leiden, The Netherlands, pp 382–399

Welcomme RL (1979) Fisheries ecology of flood plain rivers. Longman, London, 317 pp

Wetzel RG, Likens GE (1991) Limnological analyses, 2nd edn. Springer-Verlag, New York, 391 pp

WFC (2005) Fish and food security in Africa. World Fish Centre, Penang, Malaysia, 11 pp