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Research Article

Effects of water quality, flooding episode and management variables on the fish yield from self-stocked ponds in lower Rufiji floodplain, Tanzania

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ABSTRACT

A study was conducted to determine fish yields from flood depended ponds in Rufiji floodplain, Tanzania. Eight ponds were constructed during dry season in two sites besides two floodplain lakes, Ruwe and Uba. These ponds were self-stocked with different fish species from the lakes. More than eight species were trapped and *Oreochromis urolepis, Labeo congoro and Clarias* species were considered as good candidates for aquaculture. Other small fish species were harvested immediately after flood recession and the three key species were cultured for the maximum of seven months. However, other species in small quantities were remained in the ponds for the whole period of experiment. Water quality parameters were monitored throughout the study period. The relationships between water quality variables and flooding events were determined using canonical correspondence analysis (CCA). Other parameters included in the relationships were fish density, manure and number of species trapped and cultured. Dissolved oxygen and pH decreased with time in both sites. Fish yields were influenced by some water quality, flooding episode and other management variables. Chlorophyll-*a* was the only environmental variable that showed a significant correlation with fish yield ($P< 0.01$). Fish density and number of species trapped showed a significant effect on the fish yield ($P<0.05$). Re-connectivity between ponds and lakes was strongly positively correlated with yield. It can be concluded that some water quality variables, flooding and management parameters were responsible for the observed yield.

INTRODUCTION

Aquaculture in east Africa contributes significantly in food security and income for poor communities. Aquaculture research on mixed fish species from self-stocked ponds in floodplains in east Africa is limited. Most of the studies have been concentrated on few tilapiine species for example, *Oreochromis niloticus* (Liti *et al*., 2005a, b; Kaliba *et al*., 2006; Kaliba *et al*., 2007) and *Oreochromis variabilis* (Shoko, 2002). Kagwa *et al*. (2010) conducted a study on nitrogen cycling and fish productivity in earthen ponds stocked with different fish species in Lake Victoria wetlands. Small scale aquaculture have been contributing significantly on fish production (Bondad-Reantaso and Prein, 2009; Rutaisire *et al*., 2009; Murshed-e-Jahan et al., 2010; De Silva and Davy, 2010) as capture fisheries continuing to decline. Therefore, there is need of conducting research on the aquaculture of indigenous fish species. Brummet and Katambalika (1996) developed protocols and emphasized on culture of indigenous species under local conditions. Unlike East Africa, studies on aquaculture of polyculture and small indigenous fish species have been emphasized and conducted extensively in some Asian countries (for example, Alim *et al*., 2004; Alim *et al*., 2005; Kadir *et al*., 2007; Milstein *et al*., 2008; Rose *et al*., 2008; Mikolasek *et al*., 2010).

Unlike normal polyculture in this study more than ten species were self-stocked in eight ponds through floods (Lamtane, 2008). These ponds were constructed along the wetlands adjacent to floodplain lakes and utilized the Junk *et al*. (1989) concept for their function. Construction of ponds in the wetlands followed the idea developed by Deny and Turyatunga (1992) in Ugandan as one way of sustainable and wise use of wetlands and a new aquaculture system diversity (Lazard *et al.,* 2010). These ponds were regarded as Fingerponds (Denny *et al*., 2006) due to their finger-like appearance projected in the ecotone of wetlands. Due to its preference to consumers *Oreochromis urolepis*, *Clarias* species and *Labeo congoro* were regarded as key species in these ponds and most of the other fish species trapped were harvested immediately after flood recession. Therefore, this study aimed at determining the influence of water quality and flood events on fish productivity. Also, the influence of other management variables such as manure, culture period and number of species on fish yields was investigated.

METHODS AND MATERIALS

Experimental set up and data management

Experiment was conducted in two sites whereby four earthen ponds in each site were constructed in Rufiji floodplain, Tanzania. In both sites the ponds were filled with flood water and self stocked with fish from the adjacent lakes. Immediately after the ponds became isolated after flooding, the removal or depletion method was used to estimate fish densities. The ponds were seined three times with 2 x 12 m seine nets of 6.5 mm mesh size. The fish caught on each seine pull were identified, weighed, and counted. The first two catches were not returned to the ponds until the third netting was completed. Each seine pull was performed in the same direction and manner with the same team of up to six operatives to take out seining as a variable (Cowx, 1983; Killian *et al*., 1998).

Oreochromis urolepis was identified as key species as it is well known fish growing under aquaculture conditions. Clariid catfish were identified as possible key species for all sites to control tilapia recruits. *Labeo congoro* was trapped only at Ruwe site therefore was retained for the duration of the study. At one site, 50 kg of green manure were applied in three ponds at an interval of one week. One pond acted as control. At the second site all ponds were not treated due to high trophic level indicated in the ponds. The culture period last from 4-7 months depending on water level in the ponds.

Water quality monitoring

Water quality measurements were made on a monthly basis. Surface water temperature, dissolved oxygen, conductivity and pH were determined with portable meters. Visual transparency was assessed using a secchi disc. Chlorophyll-*a* was determined spectrophotometrically after ethanol extraction. Water samples were filtered before nutrient analysis. Analysis of nitrate, nitrite, phosphates and ammonia were carried out according to standard methods (APHA, 1995).

Fish data

At the initial census large tilapias greater than 150-200 mm TL, and 130-200 g weight were harvested and stocks of smaller fish reduced. The aim was to achieve about 1 tilapia >50 mm TL per square meter. Small clariids where they occurred in sufficient numbers were redistributed equally between ponds. All other small species were harvested. It should be noted that where equalisation was attempted it could not be totally efficient since census operations did not remove all fish. Periodic harvesting was carried out by marginal or full pond netting aimed at reducing and further removal of non-key species. At the end of the experiment all ponds were seined by repeated net hauls.

Specific growth rates (% body weight day-1) for *Oreochromis urolepis* and *Labeo congoro* were calculated using the formula:

$SGR = (\ln WT_F - \ln WT_I) \times 100/T$
Where: WT_F = final fish weight (g)
WT_I = initial fish weight (g),
T = days between initial and final weight

Data analysis

The direct gradient canonical correspondence was used for the evaluation of the variability of fish assemblage structure in relation to the selected environmental factors. Multivariate statistical analyses were performed using CANOCO version 4.5 (ter Braak and Šmilauer, 2002). Five environmental parameters (distance from the water source, % macrophyte cover, flooding period, line straight distance (LSD) and flood height) measured during initial fieldwork were used for analyses. The direct gradient canonical correspondence was also used to evaluate the factors controlling the fish growth and yields. These parameters were water quality (temperature, dissolved oxygen, pH, turbidity, conductivities, chlorophyll-a, phosphate, nitrate, nitrite and ammonia) and management variables (fish density and weight after equalisation, manure, re-connectivity, culture period, water levels, specific growth rate of key species and flood period).

RESULTS

Table 1: Growth performance of *Oreochromis urolepis* and *Labeo congoro*

		Pond				
		1	2	3	4	Mean
Ruwe	*O. urolepis*					
	Initial weight (g)	5.8	4.0	2.5	9.8	5.5±1.6
	Final weight	34.9	41.6	39.8	47.4	40.9±2.6
	SGR ((% day^{-1})	0.9	1.1	1.3	0.8	1.0±0.1
	Labeo congoro					
	Initial weight (g)	6.2	8.2	9.3	6.0	7.4±0.8
	Final weight	41.2	67.8	58.7	73.1	60.2±7.0
	SGR (% day^{-1})	0.9	1.0	0.9	1.2	1.0±0.1
Uba	*O. urolepis*					
	Initial weight (g)	13.0	29.7	18.4	30.6	22.9±4.3
	Final weight	101.8	92.0	62.5	76.2	83.1±8.7
	SGR ((% day^{-1})	1.4	0.9	1.0	0.8	1.0±0.1

Table 2: Finger ponds management data

Site	Pond	Flooding date	Fish density		culture length	Fish harvest	Inputs
			Fish/m^2	Weight (kg)	(months)	Yield (kg/pond)	Green manure (kg/pond/week)
Ruwe	1	Apr./May 04	0.5	0.8	7	7.3	50
	2	Apr./May 04	0.5	0.9	7	9.8	50
	3	Apr./May 04	0.5	0.7	7	6.3	50
	4	**Apr./May 04**	**0.5**	**0.6**	**6**	**10.8**	**Control**
	1	**Apr./May 02**	**1.2**	**1.3**	**5**	**19.2**	**-**
Uba	**2**	**Apr./May 02**	**1**	**3**	**4**	**16.5**	**-**
	3	**Apr./May 02**	**1.8**	**1.8**	**4**	**23.5**	**-**
	4	**Apr./May 02**	**1.1**	**3.1**	**4**	**16.3**	**-**

Table 3: Yields (kg) of individual fish species

		Ponds				Yield
		1M	**2M**	**3M**	**4C**	**Total (kg)**
	Oreochromis urolepis	**2.8**	**4.4**	**3.7**	**6.7**	**17.5**
Ruwe	***Labeo congoro***	**2.9**	**1.7**	**1.3**	**2.6**	**8.5**
	Clarias spp.	**0.8**	**2.4**	**0**	**0.7**	**3.9**
	Other species	**0.8**	**1.3**	**1.2**	**0.8**	**4.3**
	Total yield (kg)	**7.3**	**9.8**	**6.2**	**10.8**	**34.2**
	Number of species	**6**	**7**	**4**	**5**	
		1	**2**	**3**	**4**	**Total (kg)**
	Oreochromis urolepis	**17.2**	**13.1**	**7.3**	**9.2**	**46.7**
	Clarias spp.	**1**	**2.5**	**2**	**1.8**	**7.3**
Uba	***Synodontis spp.***	**0.5**	**-**	**9.3**	**3.3**	**13.2**
	Other species	**0.5**	**0.9**	**4.7**	**2**	**8.3**
	Total yield (kg)	**19.2**	**16.5**	**23.5**	**16.3**	**75.5**
	Number of species	**5**	**3**	**9**	**8**	

Table 4: Canonical correlation analysis showing the influence of water quality on fish yields

Parameters	**CCA axis 1**	**CCA axis 2**	**CCA axis 3**
Temperature	**0.592**	**-0.719**	**-0.092**
pH	**0.632**	**-0.421**	**-0.359**
DO ((mgl^{-1})	**0.706**	**-0.611**	**-0.174**
Transparency (cm)	**-0.511**	**0.343**	**0.562**
Conductivity (µS/cm)	**0.626**	**-0.635**	**-0.075**
Chlorophyll-a (µgl^{-1})	**-0.682**	**0.688**	**0.100**
Ammonia ((µgl^{-1})	**0.115**	**0.713**	**0.362**
Nitrite (µgl^{-1})	**0.635**	**-0.667**	**-0.135**
Nitrate (µgl^{-1})	**0.710**	**-0.583**	**0.010**
Phosphate (µgl^{-1})	**0.724**	**-0.595**	**-0.044**

❖ **Bolded figures indicate the most important coefficient**

Table 5: Canonical correlation analysis showing the influence of flooding episodes, management variables and growth performance on fish yields

Parameters	SPEC AX1	SPEC AX2	SPEC AX3
Number of species	0.621	0.628	0.094
Culture period	-0.741	0.511	-0.001
Initial density	0.917	-0.198	-0.141
Initial weight	0.448	-0.492	0.325
Manure	-0.508	0.588	0.261
Initial water level	0.284	0.324	0.587
Final water level	0.318	0.101	0.620
SGR (*O. urolepis*)	-0.128	-0.356	-0.308
SGR (*L. congoro*)	-0.671	0.628	0.030
Re-connectivity	0.893	0.028	0.133

❖ **Bolded figures indicate most important coefficient**

Water quality monitoring

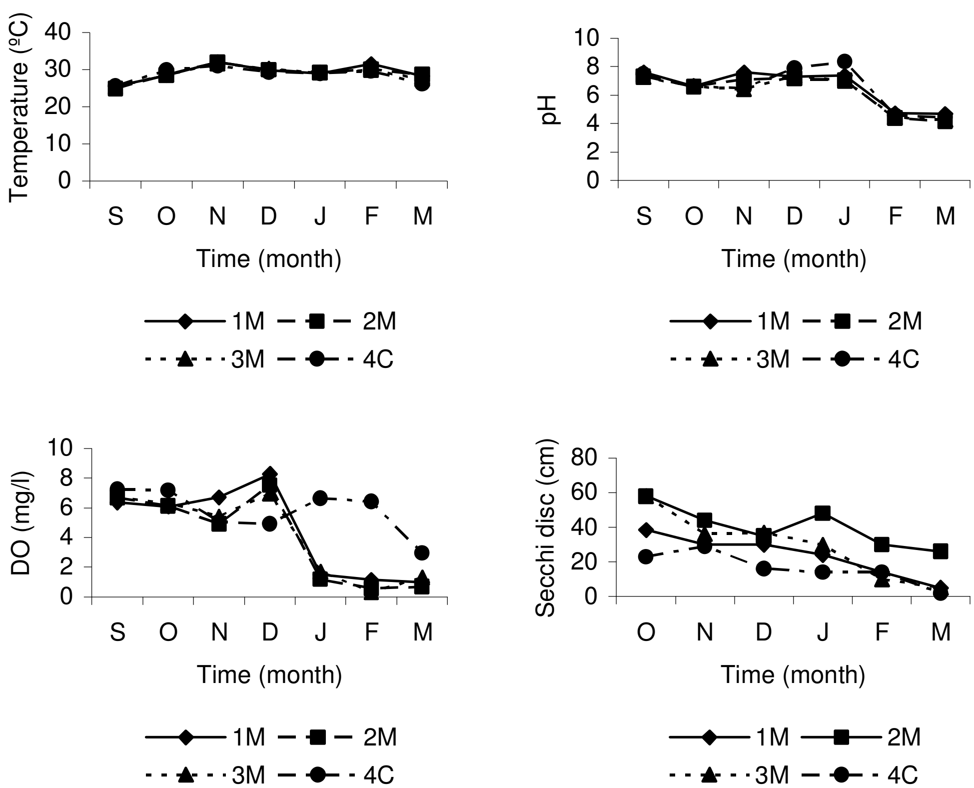

Figure 1: Monthly variations of physico-chemical parameters from Ruwe ponds

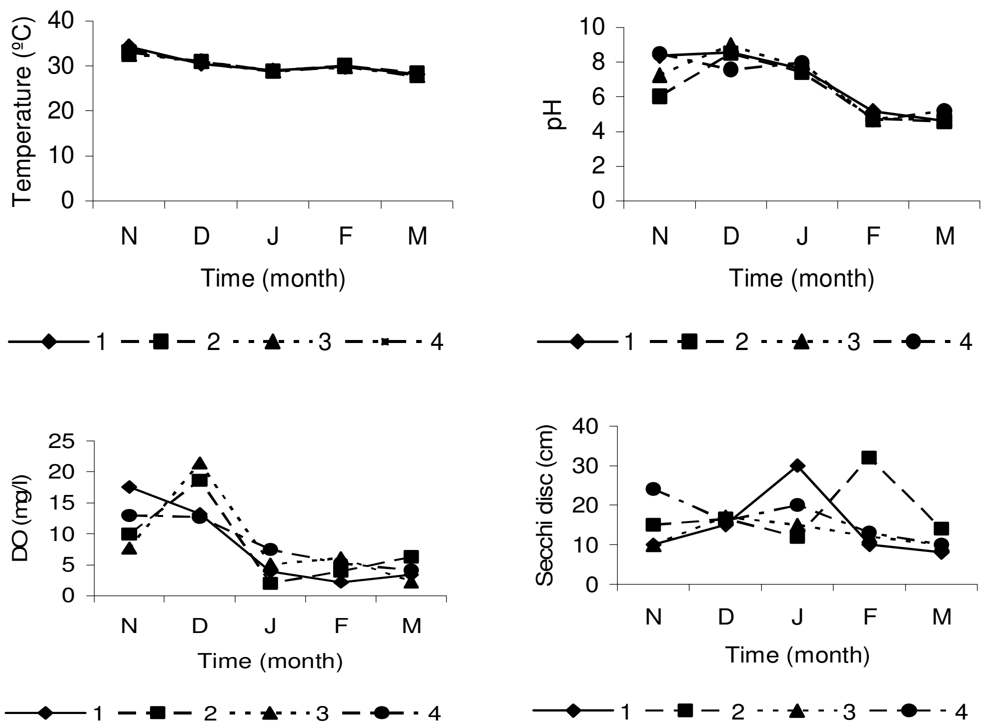

Figure 2: Monthly variations of physico-chemical parameters from Uba ponds

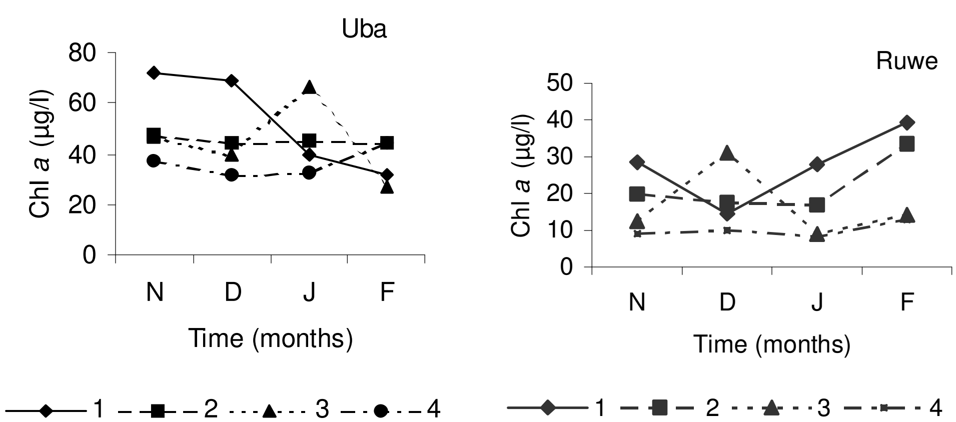

Figure 3: Monthly variations of chlorophyll *a* from Uba and Ruwe ponds

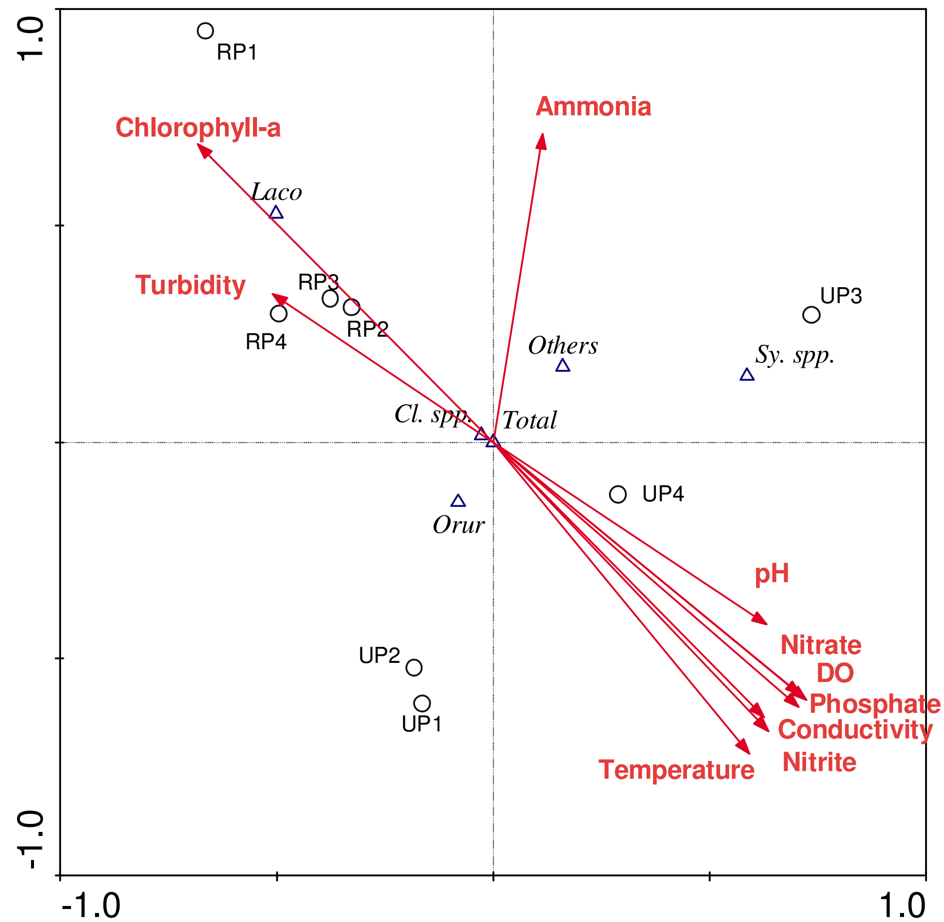

Figure 4: Canonical correspondence analysis (CCA) showing the effect of water quality on finger ponds fish yield. RP1-4 is Ruwe ponds and UP1-4 is Uba ponds. Orur: *Oreochromis urolepis*, Laco: *Labeo congoro*, Cl. spp.: *Clarias* spp. and Sy. spp.: *Synodontis* spp.

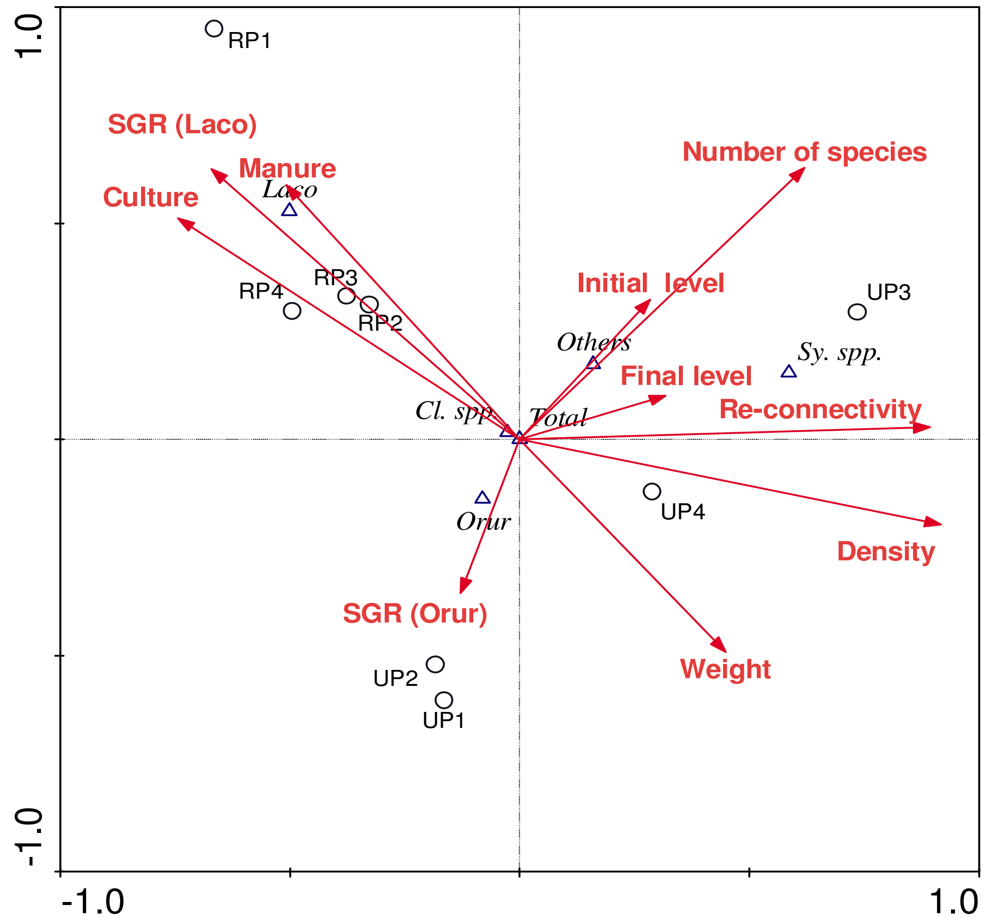

Figure 5: Canonical correspondence analysis showing the effect of some variables on finger ponds fish yield. RP1-4 and UP1-4 are Ruwe and Uba ponds respectively. Orur: *Oreochromis urolepis*, Laco: *Labeo congoro*, Cl. spp.: *Clarias* spp. and Sy. spp.: *Synodontis* spp.

Different water quality parameters were monitored throughout the ponds functional period. Monthly variations of water quality parameters are given in Figs. 1, 2 and 3. Water temperatures at Ruwe were almost the same throughout the rearing period with a mean of 29 ºC. pH fell in all four ponds in the last 2 months. Dissolved oxygen (DO) dropped rapidly during the last three months (January-March) except in the non-manured control pond. Also water clarity diminished with time (Fig. 1). At Ruwe the highest chlorophyll *a* for each pond was observed in the last month. Control pond had slightly lower chlorophyll-*a* compared to manured ponds (Fig. 3). Like in Ruwe, at Uba temperatures were almost equal in all ponds with a mean of 30.6 ºC. pH again fell to about 4 in last two months. Dissolved oxygen decreased with time in all ponds. Visual transparency showed no common pattern (Fig. 2). Maximum and minimum chlorophyll *a* values at Uba were observed in pond one and four respectively (Fig.3).

Growth performance of two key species

The specific growth rate of *Oreochromis urolepis* and *Labeo congoro* is given in Table 1. Mean initial weights were calculated at the initial census after flood recession. Final mean weights were obtained after 4-7 months when the final harvesting was carried out. Both species were found to have SGRs of 1% of growth rate/day.

Fish yields

Fishponds management data and yields are given in Table 2 and yields of individual species are given in Table 3. At Uba all ponds were untreated and produced almost the same amount of fish in terms of biomass. At Ruwe the untreated control pond produced more biomass compared to the other ponds treated with green manure but statistically there were no differences in yields among ponds in both sites (ANOVA, F = 0.87, P > 0.05). At Uba the yield was more than 2-3 times greater than yield at Ruwe, although only functioned for 4-5 months but there was no significant difference in yield between the sites (t = 0.99, P > 0.05). No management measure, were applied but equalisation was attempted in all ponds. Both tilapia and *Clarias* were redistributed equally. Pond 3 with four months functional time gave best total yield. The contribution of individual species to the final yield is given in Table 3. At Ruwe yields was predominated by *Oreochromis urolepis, Labeo congoro* and *Clarias* spp. in descending order. Similarly at Uba the tilapia predominated with the substantial yields from *Synodontis* spp. and *Clarias* spp.

Water quality and fish yields

The canonical correlation coefficients for axis one, two and three are given in Table 4. The first yield canonical correlation accounts for 58% of variance. The major factors contributing to the final yields are phosphate, nitrate, nitrite, dissolved oxygen, temperature, pH and conductivity all with positive coefficient on first axis. Positive values of canonical correlation on axis two corresponded to the ponds with the yield of *Labeo congoro* in Ruwe ponds. Thus, chlorophyll-*a*, turbidity and ammonia concentrations favoured the yield of *Labeo congoro* at Ruwe. The yield of *Oreochromis urolepis* at Uba was favoured by nutrients (phosphate, nitrite and nitrate), pH, dissolved oxygen and temperature (Fig. 4). Chlorophyll-*a* was the only environmental variable that showed a significant correlation with fish yield (P< 0.01). The second canonical correlation accounts for further 34% of the variance and the third one accounted for only 8% of the variance.

The CCA triplot showed a distinctive group of Ruwe ponds, an indication that yield of *Labeo congoro* was associated with two factors; turbidity and chlorophyll-*a*. The position of pond one indicated the slightly higher yield of *Labeo congoro* compared to other ponds (Table 3). The yield of *Oreochromis urolepis* was slightly similar in pond one and two with a minor influence from water quality parameters. Similarly Fig. 4 showed a separate position of pond three at Uba dominated with *Synodontis* spp. with minor influence from water quality parameters.

Flooding episode, management variables and fish yields

The canonical correlation coefficients on fish yield with flooding events and management variables are given in Table 5. The first yield canonical correlation accounts for 58 % of variance. The yield of *Labeo congoro* at Ruwe ponds was influenced by its specific growth rate, manure and culture period. This has been shown by forming a distinctive group in Figure 5. The three parameters formed a strong positive correlation with the second CCA axis. The second yield canonical correlation was accounted for 33 % of the variance. The yield of *Oreochromis urolepis* at Uba was negatively influenced by its growth rate in pond one and two while the yield from pond four was positively influenced by initial weight and density (Fig.5). The third canonical axis explained only 9 % of variance and the major contributing factor on yield was final water level. Fish density after equalisation and number of species were the only variables that showed a significant effect on the total fish yield (P<0.05). These two variables formed strongly positively correlation with first canonical axis. Re-connectivity of ponds to lakes during rainy season also showed strong positive correlation with first axis and had an influence on the yield of *Synodontis* spp. in pond three.

DISCUSSION

The quality of water determines how well the fish will grow in the ponds and indeed, if they will survive. In formal aquaculture, maintenance of suitable water quality greatly reduces the likelihood of a disease problem. Critical water quality parameters include dissolved oxygen (DO), water clarity, pH, temperature and nitrogenous wastes (unionised ammonia, NH_3; nitrites, NO_2). Many of these parameters are interrelated (Durborow *et al*., 1992; Buttner *et al*., 1993). There was some variability between ponds in any month, notably DO and water clarity. At Ruwe ponds most of water quality parameters were at optimum for the first three months after ponds were disconnected. All water quality variables except ammonia showed a strong correlation with total fish yields. Only turbidity and conductivity showed a positive correlation. Decrease of dissolved oxygen in the last three months of sampling was probably due to the excessive organic matter from fermented green manure, decomposition of marginal vegetation as water levels decreased and algal die off particularly at Uba ponds. It has been reported that organic loading affects biological processes in pond water (Little and Muir, 1987). Decomposition of organic matter through heterotrophic activity decreases pH and oxygen hence liberating dissolved minerals into water (Milstein, 1993).

According to Balarin and Hatton (1979) tilapia can survive under extremely adverse DO condition and the lowest limit, which has been recorded, is 0.1 mg/l for *Oreochromis mossambicus* and *O. niloticus*. It is possible that all tilapias seem to be able to survive oxygen levels as low as 1mg/l. Xu *et al*. (2006) reported a significant change in swimming behaviour for Nile tilapia under three hypoxia levels, 0.3, 0.8 and 1.5 mg/l. Decrease in dissolved oxygen at Uba in the last three months was probably due to the die off marginal vegetation as water level dropped and the collapse of algal blooms. However, the higher mean dissolved oxygen and percentage saturation recorded at Uba throughout the study period indicated higher water productivity.

At Ruwe low conductivity and turbidity favoured the growth rate and yield of *Labeo congoro*. Chlorophyll-*a* showed a significant effect on fish yield particularly for *Labeo congoro.* Yields of tilapia were associated with environmental factors apart from conductivity and transparency with different degrees, and this was evident at Uba ponds. The relatively high levels of suspended organic matter at Uba ponds probably contributed to low water clarity. In some circumstances, the high level of suspended solids with reduced transparency could be due to the stirring of bottom sediments by fish seeking food. Suspended particles may scatter light and sometimes cause mechanical damage to fish. Low water clarity or high turbidity reduces primary production and oxygen levels in ponds (Balarin and Hatton, 1979). It has been reported that *Sarotherodon spilurus* exhibited lower growth due to high turbidity as it reduces phytoplankton production (van Someren and Whitehead (1959) in Balarin and Hatton, 1979). By contrast to Ruwe, reduced water clarity at Uba was generally due to high phytoplankton biomass. Also these ponds contained relatively richer nutrient water and they were visibly green with phytoplankton throughout the rearing period. These ponds received rich nutrient water from the lakes. Mwaitega (2003) and Msokwa (2004) reported high nutrient levels from lakes Uba and Ruwe located adjacent to the ponds. Similar to the present study Rahma *et al*. (2008) demonstrated strong relationships between water quality and fish yields using a multivariate approach.

The most important factors affecting total and species yields were culture period, initial density and weight after equalisation, manure, and specific growth rate of key species. The main predominant components in the fingerponds were *Oreochromis urolepis* and *Labeo congoro* at Ruwe and *Oreochromis urolepis* at Uba. Therefore the total yield was influenced by these two species. Manure, culture period and specific growth rate of *Labeo congoro* favoured the yield of *Labeo* in Ruwe ponds. The yield of *Oreochromis urolepis* at Uba was favoured by its initial density and weight in pond 1, 2 and 4. In pond 3 the yield of *Synodontis* spp. was favoured by re-connectivity while other species were influenced strongly with the number of species present in the ponds.

The use of organic fertilizers has a long tradition in tropical semi-intensive aquaculture. When added to ponds, they may ultimately increase fish yields through soluble and/or particulate pathways. Release of soluble nitrogen and phosphorus stimulates algal production, which in turn can be consumed by fish directly or after intermediate processing by zooplankton or microbes (detritus formation). The rationale of manuring treatments was to establish a good level of pond productivity. However, when added to ponds, organic fertilizer may exert an oxygen demand and excessive application may result in depletion of dissolved oxygen. Qin *et al*. (1995) observed that ponds with organic fertilizer had lower dissolved oxygen than those without organic fertilizer.

In the present study green manure showed a negative correlation with fish yield although it was not significant. The highest fish yields were recorded from the untreated control pond. This might be contributed by the green manure added which lowered dissolved oxygen. Das and Jana (2003) emphasized the use of fertilizer to increase fish production from aquaculture. Milstein *et al*. (1988) reported a minor influence of manure on fish yield compared to other management factors like stocking density and weight. Kang'ombe *et al*. (2006) reported a high yield of fish due to application of different organic manure in earthen ponds. In this study although a high dose of green manure was applied it did not produce enough nutrients into the ponds to maintain the total fish biomass by increasing the natural pond production. According to Little and Muir (1987), accumulation of green fodders in the ponds can lead to oxygen stress because green manures become oxidised after 5 days. Therefore, in ponds fertilized by green manure oxygen problem may occur over a number of days.

Fish yield in self-stocked ponds were largely influenced by initial density and weight. Fish density after equalization showed a significant correlation with fish yield. Milstein *et al*. (1988) used canonical correlation analysis of relationship between management inputs and fish growth and yields and reported that the most important factors affecting growth and yield were initial weight and density. In the present study fish density after equalization showed a strong positive correlation with yields. In aquaculture fish growth and yields depends on initial density and weight. The higher the initial density and weight the higher the yield. However, when the density exceeds the optimum level growth rate will be affected as well as the final yield.

Culture period showed a strong negative correlation with yields and this was evident in Ruwe ponds. The ponds with longer culture length had relatively lower yield compared to those with relatively shorter culture period. However, Uba ponds produced higher fish yields because of late disconnection and tenuous re-connection in some of the ponds during rainy seasons. During final harvest, Ruwe ponds had slightly less number of fish species compared to Uba. There were three key species at Ruwe and two at Uba, which contributed to the final yields. The numbers of species showed a significant effect on the fish yield. The ponds with less number of key species produced higher yield. Small effects of water levels were noticed in the first axis.

In general terms, the natural productivity of a fishpond in the tropics is considered to be about 500 kg/ha/year (Haylor, 1989). Fish farming in wetlands has shown benefits in some regions e.g. in the managed fish holes and drain-in ponds of Benin, with the annual yields of 1.5-2 t/ha (Rothius *et al*., 1994; Roggeri, 1995). Pant *et al*. (2004) reported a yield of about 500 kg/ha from rain fed lowland integrated agriculture systems in Northeast Thailand. Extrapolated yield of 2-5 t/ha/year have been reported from ponds fertilized by fresh chopped weed in Asia (Edward, 1985). The same author recommended 40 kg wet weight of chopped freshwater plants in ponds with area of 200 m^2 in order to produce 110 kg/pond/year. For comparison of the fish yields from the present study with other studies elsewhere the yields should be extrapolated. The extrapolated yields (in the brackets) from Ruwe and Uba ponds ranged from 7.3-10.8 kg (487-787 kg/ha) and 16.3-23.5 kg (1779-2326 kg/ha) respectively. Chikafumbwa (1996) reported a yield of 560 kg/ha extrapolated from 2.00 m^2 pond from ponds fertilized by Napier grass (*Pennisetum purpureum*) only. From the present study it can be concluded that fish yields from fingerponds were probably influenced by some water quality parameters like dissolved oxygen and management variables such as manuring. Also, culture time and flooding time were responsible for variations in fish yields.

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