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ORIGINAL RESEARCH

A comparison of diurnal dynamics of water quality parameters in Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) monoculture and polyculture with African sharp tooth catfish (*Clarias gariepinus*, Burchell, 1822) in earthen ponds

Amon P. Shoko · Samwel M. Limbu · Hillary D. J. Mrosso · Yunus D. Mgaya

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Abstract The overall performance of an aquaculture system is partly determined by its water quality parameters. Poor water quality stresses and adversely affects fish growth causing low production, profit and product quality. Diurnal dynamics of water quality parameters were investigated in Nile tilapia (*Oreochromis niloticus*) monoculture and polyculture with *Clarias gariepinus* in earthen ponds. Dissolved oxygen, temperature and pH were measured and monitored for 24 h. Water samples for nutrient analysis were collected from the middle of ponds in triplicate at about 30–35 cm below the water surface using a plastic bottle. Nitrite–nitrogen (NO_2–N), nitrate–nitrogen (NO_3–N), unionised ammonia (NH_3–N), soluble reactive phosphorus and free carbon dioxide were analysed following standard methods and procedures. The results show that dissolved oxygen concentrations during the past midnight and pre-dawn hours were significantly lower than the levels in the morning and afternoon hours (ANOVA, $F = 45.709$, $P < 0.05$) which is dangerous to the life of the cultured fishes. The levels of unionised ammonia and temperature were higher and lower, respectively, than the acceptable levels for optimum growth of *O. niloticus* and *C. gariepinus*. Nitrite–nitrogen, nitrate–nitrogen, pH, soluble reactive phosphorus and free carbon dioxide were within the recommended limits for fish growth in aquaculture. Growth parameters, feed conversion ratio and survival rate were not significantly different between culture systems ($P > 0.05$). Fish yield was relatively higher in polyculture (45.74 ± 0.44 tons/ha) than monoculture (30.77 ± 0.54 tons/ha). During fish farming, optimum fish growth and hence economic benefits can be accrued by devoting some efforts on monitoring the fish pond water at regular intervals. This quality assurance process will ensure that fish farmers produce fish with maximum growth and yield without polluting pond water and the surrounding environment.

Keywords Aquaculture · Fish pond management · Monoculture · Polyculture · Pond water quality dynamics

A. P. Shoko
Tanzania Fisheries Research Institute, Institute Headquarters, P. O. Box 9750, Dar es Salaam, Tanzania

S. M. Limbu · H. D. J. Mrosso · Y. D. Mgaya (✉)
Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, P. O. Box 35064, Dar es Salaam, Tanzania
e-mail: yunusmgaya@gmail.com; ymgaya@udsm.ac.tz

H. D. J. Mrosso
Tanzania Fisheries Research Institute, Mwanza Centre, P. O. Box 475, Mwanza, Tanzania

Introduction

Water is a critical factor in the life of all aquatic species. In aquaculture, any characteristic of water that affects the survival, reproduction, growth, or management of fish or other aquatic creatures in any way is a water quality variable (Boyd 2003). In all culture systems, fish performs its physiological activities such as breathing, excretion of wastes, feeding, maintaining salt balance and reproduction in the water medium. Accordingly, the overall performance of any aquaculture system is partly determined by its water quality (Alam and Al-Hafedh 2006). Poor water quality stresses and adversely affects fish growth with consequently low production, profit and product quality (Iwama et al. 2000). Production is reduced when the water contains contaminants that can impair development, growth, reproduction or even cause mortality to the cultured species. As a result, fish farmers are obliged to manage the water quality so as to provide a relatively stress-free environment that meets the physical, chemical and biological standards for the fishes' normal health and growth performance (Isyiagi et al. 2009).

The levels of most water quality parameters in any aquaculture system fluctuate diurnally and daily (Iwama et al. 2000). These changes in the limnological variables are caused by biological and chemical processes that occur in the ponds (Keppeler et al. 2012). Thus, monitoring of water quality parameters entails a routine activity to fish farmers. Freshwater aquaculture in Tanzania is mostly undertaken in earthen ponds raising Nile tilapia (*Oreochromis niloticus*) in monoculture systems. Fish polyculture system involving *O. niloticus* and African sharp tooth catfish (*Clarias gariepinus*) is also practised to a lesser extent. These two species are the most important groups of fishes cultured in Tanzania. Previous assessment of fish pond performance in Tanzania reported low fish growth and yield mainly due to poor pond management such as water quality parameters (Shoko et al. 2011).

Apart from the results of the assessment above, there have been no further studies performed to investigate the diurnal dynamics of water quality parameters and their influence on growth performance and survival of fish. Studies have shown that subjecting fish to constant low water quality parameters reduce food consumption, growth and feed conversion ratio (Buentello et al. 2000; Hargreaves and Steeby 1999). It has also been pointed out that fish raised in ponds exhibit reduced feed intake in the morning and evening due to oxygen stress (Tucker et al. (1979). Thus, farmers are supposed to know the fluctuating levels of water quality to enable them monitor accordingly. These dynamics of water quality parameters that occur in locally managed fish ponds in Tanzania are not well known.

Given the dynamics of pond environment and the lack of applied data upon which farmers can rely to make decisions, it is no surprise that water quality management varies widely among fish farmers in the country (Shoko et al. 2011). Most farmers do not routinely monitor water quality parameters, whereas others assess them occasionally and without taking into account the periods of peak and low levels (Shoko et al. 2011).

The objective of the present study was to assess and compare the diurnal cycles of water quality parameters in rural fish farmers' ponds culturing *O. niloticus* in monoculture and polyculture with *C. gariepinus*. The study intended to understand the periods of peak and low levels for major water quality parameters. Moreover, the study evaluated the growth performance, survival rate and yield of fish under the varying water quality parameters to gain an insight into the influence of the latter.

The study hypothesised that there is no significant difference in water quality parameters between monoculture and polyculture fish ponds. It was assumed that the parameters would be within the optimum levels for fish growth and survival throughout day and night. Determination of the peak and low levels for major water quality parameters would help fish farmers to maintain proper water quality standards and consequently achieve maximum fish growth and production for economical and profit maximisation.

Materials and methods

Description of the study site

The study was conducted in the Lake Victoria basin at Kimusi Village, Tarime District, Mara Region in Tanzania (Fig. 1). The site is situated between latitudes 1°10″–1°36″ south of the equator and longitudes 34°08″–35°01″ east of the Greenwich meridian at an altitude ranging from 1,500 to 1,800 m above sea level.

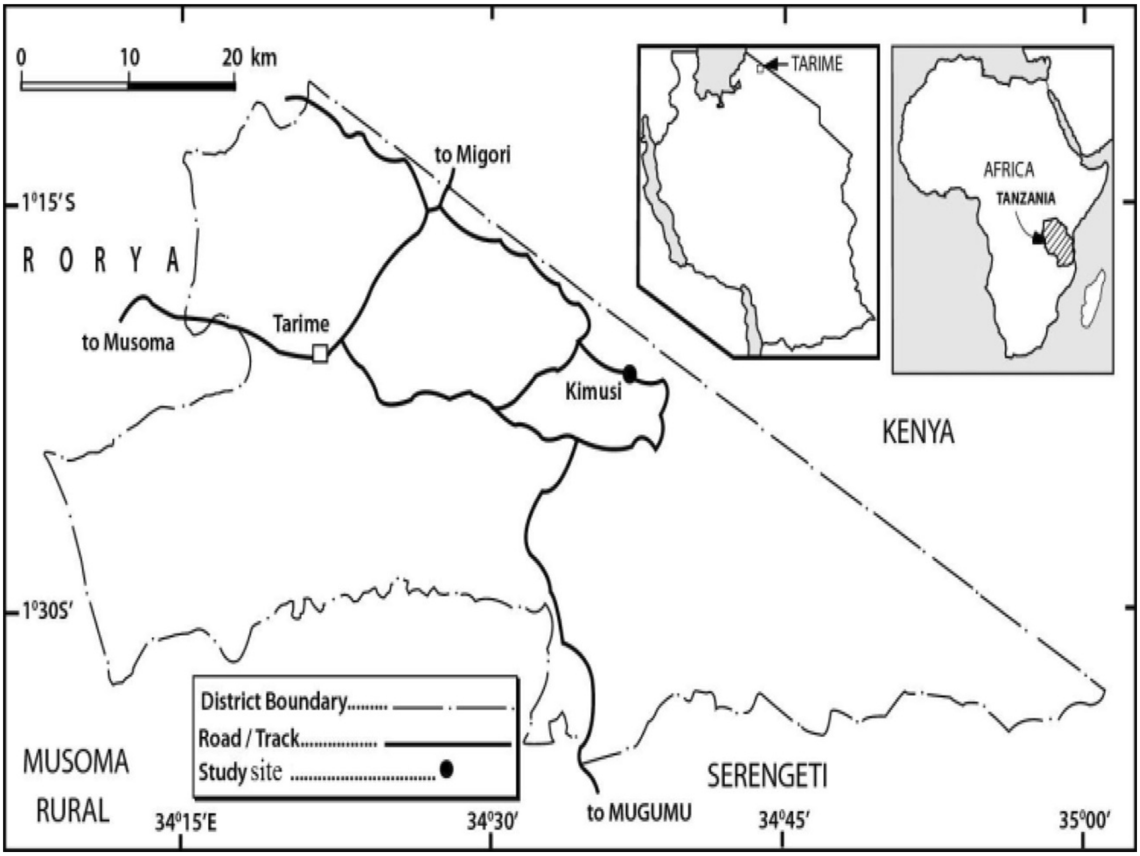

Fig. 1 Map of Tarime, Tanzania showing the study site (source: University of Dar es Salaam Cartographic Unit)

It receives a mean annual rainfall of 1,200–1,500 mm and the mean annual temperature ranges from 18 to 26 °C. The site has deep, well-drained, red or brown soils on the gentle hillsides, but frequently become shallow and stony on the steeper slopes and dark-grey or brown clays with impeded drainage on the valleys. This site has the greatest agricultural potential because of its fertile soils (URT 1998).

Experimental design

Six earthen fish ponds (150 m^2, mean depth 1.25 m each) were used in this study. The main source of water to the ponds was a stream originating from Mori River, one of the rivers that drain water to Lake Victoria. Three ponds were stocked with *O. niloticus* in monoculture, while the other three ponds were stocked with *O. niloticus* and *C. gariepinus* in polyculture. For polyculture treatment, a stocking ratio of 3:1 for *O. niloticus* and *C. gariepinus* was adopted. In both culture systems, fingerlings of mean (±SE) initial weights of 5.01 ± 0.01 g were stocked at a stocking density of 9 fish m^{-2}. Stocking of similar initial weights of *C. gariepinus* in the polyculture ponds was intentionally delayed for 30 days to allow *O. niloticus* to grow to a size (12.26 ± 9.49 g) such that *C. gariepinus* were unable to prey on. The high stocking density of 9 fish m^{-2} where water quality data were collected was part of the general objective of a study aimed to establish the optimum density that will give higher yield of *O. niloticus* in monoculture and *O. niloticus* and *C. gariepinus* in polyculture.

Before stocking, ponds were drained and limed with dolomite at a rate of 0.25 kg m^{-2} (Engle and Neira 2005) to regulate pond water pH and water chemistry in general. Fish were fed on 297.50 g kg^{-1} crude protein diet made using locally available cotton seed cake 683.40 g kg^{-1} and maize bran 316.60 g kg^{-1} of dry feed (Table 1). They were fed at a constant daily feeding rate of 5 % body weight for Nile tilapia (*O. niloticus*) or for the combined body weights of Nile tilapia (*O. niloticus*) and African sharp tooth catfish (*C. gariepinus*) in the case of polyculture. The use of a constant daily feeding rate (5 % body weight) throughout the study was

Table 1 Formulation and proximate composition (dry matter basis) of feed used in the study

	Composition (g kg^{-1}) dry feed
Ingredients	
Cotton seed cake meal	683.40
Maize bran meal	316.60
Total	1,000.00
Proximate analysis of feed	
Dry matter	924.70
Crude protein	297.50
Crude fibre	136.70
Crude fat	109.60
Ash	68.10
Carbohydrate	388.10

done intentionally to reflect the practice by rural fish farmers in Tanzania. The ration was divided into two meals and fed twice daily in the morning between 0900 and 1000 hours and evening between 1500 and 1600 hours. The growth experiment lasted 8 months.

Data collection

Since the study focused on diurnal dynamics of water quality, sampling was conducted during the dry season from late June to early September to take care of the season effects. Water levels in each pond were monitored weekly and maintained at the same level to avoid the effect of water level fluctuations. Any decrease in water level in the ponds due to evaporation and/or leakage was offset by abstraction of water from Mori River which flows near the site of the ponds. Sampling of water started in the fourth month after stocking when the system was expected to have approached the carrying capacity. Temperature, pH and dissolved oxygen (DO) measurements were monitored from each of the fish rearing pond by using a conductivity meter kit (model KTO, HQ, 40D PHC 101-LD 101-01 by Hach Company Ltd, USA) from 0900 hours till 0500 hours of the following day at an interval of 4 h. During the same sampling hours, water samples for nutrient analysis were collected from the middle of ponds in triplicate at about 30–35 cm below water surface by using a 250 ml wide-mouthed plastic bottle. Nitrite–nitrogen (NO_2–N), nitrate–nitrogen (NO_3–N), unionised ammonia (NH_3–N), soluble reactive phosphorus (SRP) and free carbon dioxide (CO_2) were analysed following standard methods and procedures (APHA 2005). Data on the water quality parameters measured at 0900 and 1700 hours were used to determine the daily levels in relation to fish growth, survival and yield in both systems. During the experiment, 30 fish were randomly seined on a monthly basis from each pond for individual body weight and length measurements to the nearest 0.01 g and 0.01 cm using a sensitive weighing balance (Electronic Precision Balance Model EJB-KD-3000 g, Endel Global Weighing Company) and a measuring board, respectively. The weight data were used to calculate individual daily weight gain (DWG, g day^{-1}) and specific growth rate (SGR, %). Fish weight and feed data were used to determine feed conversion ratio (FCR). At the end of the experiment, water was drained in each pond and fish were counted and weighed to obtain net yield (ton ha^{-1}). The initial and final numbers of fish were used to calculate the survival rate of the fish. The following formulae were used to calculate the above parameters:

$$\mathrm{DWG}\ (\mathrm{g\ day^{-1}}) = \left(\frac{W_\mathrm{f} - W_\mathrm{i}}{\mathrm{Time\ (days)}}\right)$$

where W_f and W_i are the final and initial mean weights for each sampling, respectively.

$$\mathrm{SGR}\ (\%) = \left(\frac{\ln W_\mathrm{f} - \ln W_\mathrm{i}}{\mathrm{Time\ (days)}}\right) \times 100$$

$$\mathrm{FCR} = \frac{\text{Total amount of dry feed fed (g)}}{\text{Total wet weight gain of fish (g)}}$$

$$\text{Survival rate \%} = \left(\frac{\mathrm{TF_f}}{\mathrm{TF_i}}\right) \times 100$$

where $\mathrm{TF_f}$ and $\mathrm{TF_i}$ refer to the total final and initial number of fingerlings and fish, respectively.

$$\text{Net fish yield} = \frac{W_h - W_s}{P}$$

where W_h is the total weight of fish harvested (ton), W_s the total weight of fish stocked (ton) and P is the pond area (ha).

Statistical analysis

Two-way analysis of variance (ANOVA) was used to evaluate any significant differences in water quality parameters among different sampling hours. Post hoc analysis was done by using Tukey HSD test (Zar 1999). The significance of difference in unionised ammonia, carbon dioxide and pH was determined using 95 % confidence intervals plotted as error bars. Growth performance parameters and the difference in water quality parameters between culture systems were tested using two-sample t test. All statistical analyses were performed using SPSS 13 for Windows (Landau and Everit 2004). Significant differences were judged at a probability level of $P < 0.05$ (Zar 1999). The means of all individual values of water quality parameters are presented with the standard error of the mean (SEM).

Results

Fluctuations of some water quality parameters over a 24-h period are presented in Table 2. Dissolved oxygen was significantly higher during the afternoon to pre-sunset than past midnight to pre-dawn hours in both monoculture and polyculture systems (ANOVA, $F = 45.709$, $P < 0.05$, $df = 5$) (Table 2). Similarly, dissolved oxygen differed significantly between the two culture systems ($t = 2.018$, $P < 0.05$, $df = 34$) (Table 3). Temperature was significantly higher during the afternoon than at the rest of the time (ANOVA, $F = 5.611$, $P < 0.05$, $df = 5$) (Table 2) with no significant difference between culture systems ($t = 0.807$, $P > 0.05$, $df = 34$) (Table 3). The values of pH were significantly higher in the afternoon than at the rest of the time for both systems except in the morning hours for monoculture system (ANOVA, $F = 44.162$, $P < 0.05$, $df = 5$). However, the difference between culture systems was statistically insignificant ($t = -0.016$, $P > 0.05$, $df = 34$). Furthermore, there was no significant difference in free CO_2 concentrations among sampling hours (ANOVA, $F = 1.226$, $P > 0.05$, $df = 5$) and between culture systems ($t = -0.223$, $P > 0.05$, $df = 13$) (Table 3).

Comparison of the levels of nitrite–nitrogen and nitrate–nitrogen among the sampling hours did not show significant differences (ANOVA, $F = 1.499$, $P > 0.05$, $df = 5$ for nitrite–nitrogen and $F = 1.456$, $P > 0.05$, $df = 5$ for nitrate–nitrogen). Moreover, no significant difference was found in nitrite–nitrogen ($t = -0.806$, $P > 0.05$, $df = 13$) and nitrate–nitrogen ($t = 0.496$, $P > 0.05$, $df = 13$) between culture systems. The levels of soluble reactive phosphorus from both monoculture and polyculture ponds were lower than the acceptable ranges for fish growth with no significant difference among sampling hours (ANOVA, $F = 1.635$, $P > 0.05$, $df = 5$). Equally, these levels were insignificant between the culture systems ($t = 0.306$, $P < 0.05$, $df = 13$) (Table 3).

Generally, the levels of unionised ammonia from both systems were higher than the acceptable levels for aquaculture (Table 2), though with no significant difference among sampling hours (ANOVA, $F = 1.238$, $P > 0.05$, $df = 5$) as well as between culture systems ($t = -0.229$, $P > 0.05$, $df = 34$) (Table 3).

The relationships between unionised ammonia and pH, and CO_2 and pH during the day and night are shown in Figs. 2 and 3. Contrary to expectations, in both monoculture and polyculture systems, unionised ammonia

Table 2 Mean diurnal fluctuations of dissolved oxygen (DO), temperature (T), pH, nitrite, nitrate, unionised ammonia (NH_3–N) and free carbon dioxide (CO_2) from monoculture and polyculture earthen ponds

Culture system	Parameters	Time (hours)					
		0900	1300	1700	2100	0100	0500
Monoculture	DO (mg/1)	5.311 ± 1.330^{b}	13.846 ± 1.078^{a}	13.464 ± 0.423^{a}	5.599 ± 0.618^{b}	2.724 ± 0.643^{c}	1.312 ± 0.491^{c}
Polyculture	DO (mg/1)	5.102 ± 1.438^{b}	13.512 ± 1.846^{a}	12.533 ± 1.449^{a}	5.790 ± 0.985^{b}	2.301 ± 0.598^{c}	1.236 ± 0.414^{c}
Monoculture	Temperature (°C)	21.311 ± 0.794^{b}	26.144 ± 0.619^{a}	26.244 ± 0.301^{a}	23.1889 ± 0.343^{b}	21.167 ± 0.428^{b}	19.056 ± 0.513^{b}
Polyculture	Temperature (°C)	20.350 ± 0.786^{b}	25.789 ± 0.410^{a}	25.467 ± 0.948^{a}	23.778 ± 0.678^{b}	20.833 ± 0.361^{b}	18.611 ± 0.299^{b}
Monoculture	pH	7.740 ± 0.109^{d}	7.676 ± 0.438^{a}	7.947 ± 0.310^{a}	7.110 ± 0.320^{b}	6.632 ± 0.330^{e}	6.516 ± 0.210^{c}
Polyculture	pH	7.750 ± 0.186^{d}	7.780 ± 0.409^{a}	7.821 ± 0.346^{a}	6.889 ± 0.200^{b}	6.724 ± 0.170^{e}	6.650 ± 0.151^{c}
Monoculture	NO_2 (mg/1)	0.005 ± 0.003^{a}	0.003 ± 0.002^{a}	0.002 ± 0.002^{a}	0.004 ± 0.002^{a}	0.004 ± 0.002^{a}	0.023 ± 0.009^{a}
Polyculture	NO_2 (mg/1)	0.000 ± 0.000^{a}	0.005 ± 0.005^{a}	0.002 ± 0.002^{a}	0.004 ± 0.002^{a}	0.004 ± 0.002^{a}	$0.023 \pm 0.0.009^{a}$
Monoculture	NO_3 (mg/1)	0.001 ± 0.00^{a}	$0.002 \pm 0.\ 002^{a}$	0.001 ± 0.001^{a}	0.001 ± 0.001^{a}	0.001 ± 0.001^{a}	0.000 ± 0.000^{a}
Polyculture	NO_3 (mg/1)	0.000 ± 0.000^{a}	0.009 ± 0.006^{a}	0.004 ± 0.002^{a}	0.001 ± 0.001^{a}	0.000 ± 0.000^{a}	0.001 ± 0.00^{a}
Monoculture	NH_3–N (mg/1)	0.211 ± 0.084^{a}	0.211 ± 0.113^{a}	0.254 ± 0.093^{a}	0.080 ± 0.032^{a}	0.185 ± 0.088^{a}	0.259 ± 0.065^{a}
Polyculture	NH_3–N (mg/1)	0.238 ± 0.106^{b}	0.256 ± 0.420^{b}	0.290 ± 0.103^{b}	0.199 ± 0.095^{b}	0.191 ± 0.079^{b}	0.414 ± 0.056^{b}
Monoculture	SRP (mg/1)	0.016 ± 0.009^{a}	0.016 ± 0.009^{a}	0.012 ± 0.00^{a}	0.082 ± 0.060^{a}	0.065 ± 0.048^{a}	0.016 ± 0.010^{a}
Polyculture	SRP (mg/1)	0.014 ± 0.007^{b}	0.014 ± 0.012^{b}	0.010 ± 0.004^{b}	0.010 ± 0.004^{b}	0.010 ± 0.003^{b}	0.014 ± 0.004^{b}
Monoculture	Free CO_2 (mg/1)	1.667 ± 0.439^{a}	0.889 ± 0.123^{a}	1.078 ± 0.172^{a}	1.111 ± 0.176^{a}	1.144 ± 0.232^{a}	1.044 ± 0.159^{a}
Polyculture	Free CO_2 (mg/1)	1.167 ± 0.232^{a}	1.056 ± 0.238^{a}	0.844 ± 0.133^{a}	1.144 ± 0.161^{a}	1.711 ± 0.320^{a}	1.356 ± 0.288^{a}

Values in the same row with different superscripts (a, b, c, d and e) are statistically different ($P \leq 0.05$)

Table 3 Monthly growth performance, fish yield, water quality parameters and nutrient levels during the study period

	Monoculture	Polyculture	*P* value
Growth parameter			
Initial mean weight (g)	5.01	5.01	
Final mean weight (g)	123.64 ± 4.37	146.58 ± 5.99	0.04
Daily weight gain (g)	0.50 ± 0.11	0.59 ± 0.17	0.65
Specific growth rate (%)	1.34 ± 0.26	1.41 ± 0.31	0.87
Feed conversion ratio	3.13 ± 0.50	3.81 ± 1.14	0.60
Survival (%)	92.14 ± 1.69	83.34 ± 3.03	0.06
Net fish yield (tons/ha)	30.77 ± 0.54	45.74 ± 0.44	NA
Water quality parameters			
DO (mg/l)	9.16 ± 0.43	7.74 ± 0.55	0.05
Temperature (°C)	23.41 ± 0.36	22.93 ± 0.47	0.43
pH	7.66 ± 0.13	7.66 ± 0.17	0.99
NH_3–N (mg/l)	8.73 ± 2.28	9.66 ± 3.36	0.82
Free carbon dioxide (mg/l)	1.08 ± 0.20	1.14 ± 0.20	0.82
Nutrients			
NO_2 (mg/l)	0.00 ± 0.00	$9.84 \times 10^{-4} \pm 9.84 \times 10^{-4}$	0.43
NO_3 (mg/l)	$2.40 \times 10^{-4} \pm 1.02 \times 10^{-4}$	$1.78 \times 10^{-4} \pm 7.62 \times 10^{-5}$	0.63
SRP (mg/l)	$1.06 \times 10^{-2} \pm 1.02 \times$ 10-4	$8.73 \times 10^{-3} \pm 1.02 \times 10^{-4}$	0.76

apparently decreases with increasing pH during the night. During the day, unionised ammonia increases with increasing pH superficially under both monoculture ($R^2 = 0.94$) and polyculture ($R^2 = 0.99$) systems. In both cases, however, the high regression coefficients are overridden by their statistical insignificance as shown by the error bars (Fig. 2a, b). In both day and night, carbon dioxide and pH are not correlated under monoculture system (Fig. 3a), while, under polyculture system, the levels of CO_2 decreased with increasing pH (Fig. 3b). However, these relationships are very weak and statistically insignificant during the night ($R^2 = 0.31$) than during the day ($R^2 = 0.99$).

Generally, the relationships between unionised ammonia and CO_2 in both systems are statistically insignificant. However, the relationships are relatively stronger during the night ($R^2 = 0.33$ in monoculture; $R^2 = 0.86$ in polyculture) than during the day ($R^2 = 0.08$ in monoculture; $R^2 = 0.61$ in polyculture) (Fig. 4).

Growth performance and daily water quality parameters, survival rate, yield and daily nutrients are shown in Table 3. The final mean weight was significantly higher in fish cultured in polyculture than monoculture ($t = -3.095$, $P > 0.05$, $df = 4$) (Table 3). Similarly, fish yield was relatively higher in polyculture (45.74 ± 0.44 tons/ha) than monoculture (30.77 ± 0.54 tons/ha). There was no significant difference in DWG ($t = -0.465$, $P > 0.05$, $df = 14$), SGR ($t = -0.173$, $P > 0.05$, $df = 14$), FCR ($t = -0.546$, $P > 0.05$, $df = 14$) and survival rate ($t = 2.535$, $P > 0.05$, $df = 4$) between monoculture and polyculture systems (Table 3). With the exception of unionised ammonia, temperature, pH and free carbon dioxide did not differ during the study period and remained in the favourable range for growth and survival of *O. niloticus* and *C. gariepinus* (Table 3).

Discussion

The purpose of fish farming is to enable farmers to attain maximum fish growth and production for profit maximisation. The activity depends entirely on water for fish feeding, growth and performance of other biological functions. Therefore, it is no surprise that the success of fish farming depends greatly on the water quality management schemes. Water quality determines to a great extent the success or failure of fish culture operations. Physical and chemical characteristics such as suspended solids, temperature, dissolved gases, pH, nutrients and the potential danger of toxic elements must be considered for successful fish farming (Johnson

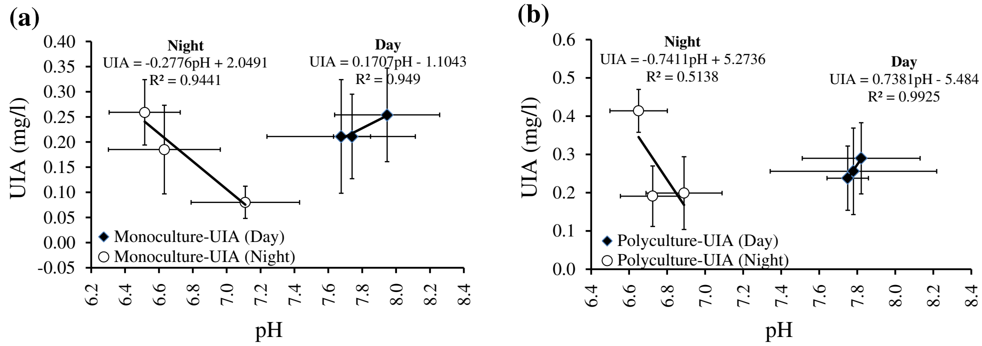

Fig. 2 Relationship between the levels of NH_3–N (mg/l) and pH during the day and night periods under **a** monoculture and **b** polyculture conditions

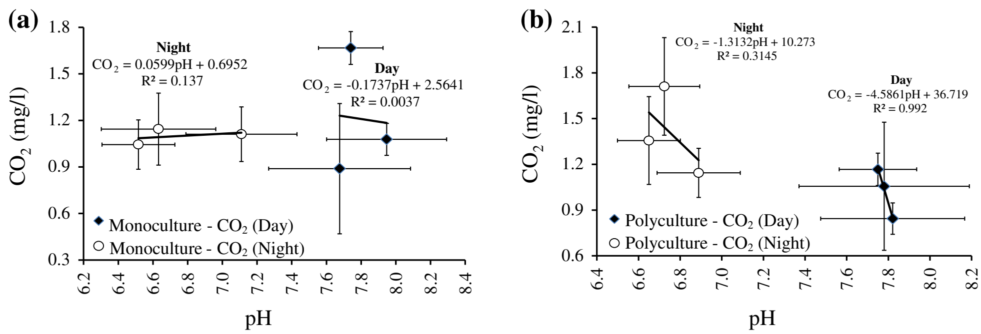

Fig. 3 Relationship between the levels of CO_2 (mg/l) and pH during the day and night periods under **a** monoculture and **b** polyculture conditions

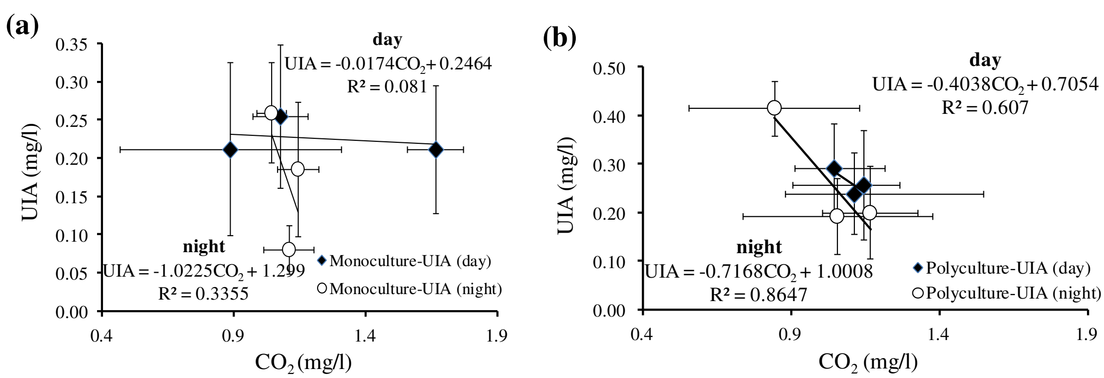

Fig. 4 Relationship between the levels of UIA (mg/l) and CO_2 (mg/l) during the day and night under **a** monoculture and **b** polyculture conditions

1995). The present study was undertaken to determine the diurnal dynamics of water quality parameters in *O. niloticus* monoculture and polyculture ponds. Interestingly, the results have partly supported the earlier set hypothesis that the ponds would have their water quality parameters within the recommended levels for aquaculture.

Dissolved oxygen (DO) is the most critical water quality parameter in freshwater aquaculture ponds where levels below 5 mg/l can retard fish growth in ponds (Boyd and Tucker, 1998). The observed lowest level of dissolved oxygen (1.2–2.7 mg/l) during past midnight through pre-dawn hours is an indication of fish stress during this period. Nevertheless, the values reported here are much higher than 0.9–1.7 mg/l reported by Liti et al. (2002), but lower than 4.1–4.3 mg/l reported by Yi et al. (2002) and Alam and Al-Hafedh (2006).

Respiration of fish and other aquatic organisms consume substantial quantities of dissolved oxygen at night. This process coupled with the absence of photosynthesis result in low levels of oxygen in pre-dawn hours (Boyd and Tucker 1998). Thus, dissolved oxygen concentration in pond water exhibits a diurnal pattern. The maximum dissolved oxygen levels occur during the peak of photosynthesis in the afternoon and the minimum occurs at dawn due to nighttime respiration as observed during the present study. In successive 24 h, the levels of DO should be higher than 5 mg/l for a period of 16 h and not lower than 3 mg/l for the remaining hours of the diurnal cycle. During the present study most levels of dissolved oxygen were within the acceptable limits for fish growth except for the past midnight and pre-dawn hours.

The present study has indicated higher DO in monoculture than polyculture systems. *Clarias gariepinus* is an active predator with higher metabolic rate, whereas *O. niloticus* is an omnivore with less metabolic rate (Solomon and Boro, 2010). Under monoculture conditions, DO was higher in concentration probably because of low consumption by *O. niloticus*, while the combination effect of the two species led to lower DO concentration in polyculture (Ibrahim and El Naggar 2010; Shrestha et al. 2011). In monoculture, DO consumption by *O. niloticus* alone did not utilise much of it resulting in higher concentration. Thus, the combined effect of DO consumption by the two species in polyculture resulted in a lower amount than in monoculture.

Ammonia is the most important water quality parameter that affects fish growth and production after dissolved oxygen. It causes stress and damages gills and other tissues, even in small amounts (Francis-Floyd et al. 2009). The present study showed that unionised ammonia increased both during the day and night. However, the rate of increase was lower during the day than night. The levels of 0.08–0.26 mg/l for unionised ammonia reported in this study are much higher than 0.05–0.1 mg/l recommended for aquaculture pond waters (Boyd 1990; Boyd and Tucker 1998; Francis-Floyd et al. 2009) and the levels of 0.002–0.026 mg/l reported by Alam and Al-Hafedh (2006). However, the results of the present study are corroborated by findings of Oz′orio et al. (2001).

The principal metabolic waste product of fish is ammonia, which is the major source of ammonia in pond water. Ammonia occurs in two forms in water, which together are referred to as total ammonia nitrogen (TAN). TAN is composed of ionised ammonia (NH_4^+) and unionised ammonia (UIA or NH_3–N) of which the latter is the most toxic form of ammonia to fish (Francis-Floyd et al. 2009). Principally, in healthy fish ponds the levels of ammonia should always be zero. Otherwise, any presence of ammonia in fish ponds such as that reported in the present study is a sign that the system may be running out of control (Francis-Floyd et al. 2009). Exposure of fish to even low levels of ammonia over time makes them susceptible to bacterial infections, have poor growth and will not tolerate routine handling procedures (Francis-Floyd et al. 2009). Poor fish pond management including water quality was reported to have contributed to low fish pond yields in the Lake Victoria basin, Tanzania (Shoko et al. 2011).

Farmers should monitor the fish feeding behaviour and feed them only when the feed supplied is consumed. However, in the present study farmers did not monitor the feeding behaviour of the fish during feeding which may have contributed to accumulation of uneaten feed in the ponds. Consequently, accumulation of uneaten feed might have contributed to higher levels of unionised ammonia observed from the present study. Thus, the higher levels of unionised ammonia imply that most fish farms in Tanzania may have an elevated level of this parameter. To avoid this problem, fish should not be overfed and whoever feeds the fish must be sure that the feed offered can be completely consumed. This is both for practical and economic importance, since feed costs are a major portion of production costs in aquaculture operations (Durborow et al. 1997).

The higher levels of unionised ammonia reported from polyculture than monoculture system in the present study could be attributed to the presence of African sharp tooth catfish (*C. gariepinus*) in polyculture treatments. The argument is logical because catfish being a carnivore (Groenewald 1964) is considered as a predator in polyculture, targeting fish fry and fingerlings (Ibrahim and El Naggar 2010). Apparently, carnivorous fish excrete more ammonia than herbivorous fish such as tilapia (Ibrahim and El Naggar 2010). The present findings suggest that polyculture farmers can achieve relatively higher fish growth and production through maintaining acceptable levels of water quality parameters, particularly unionised ammonia. This can be done by replacing some amount of water with freshwater into the ponds on a weekly basis.

The levels of nitrite–nitrogen and nitrate–nitrogen from both monoculture and polyculture treatments ranged from 0.001 to 0.009 mg/l. These sources of nitrogen are products of ammonia oxidation. While nitrite–nitrogen is not as toxic as unionised ammonia, it is harmful to aquatic organisms and must be removed from the system. The reported findings are much lower than the 96-h median lethal concentration of 81 and 8 mg/l recommended for small and large *O. niloticus*, respectively (Atwood et al. 2001). The present levels are also within the recommended limits of less than 0.3 and 0.2–10 mg/l for nitrite–nitrogen and nitrate–nitrogen, respectively, for aquaculture pond waters (Boyd and Tucker 1998).

pH is an important water quality parameter in fish farming systems as it affects the toxicity of other compounds to fish such as ammonia and chlorine (Alam and Al-Hafedh 2006). The results show an average pH range of 6.5–7.9 which is within the recommended range of 6.5–9.0 for aquaculture pond waters (Wurts and Durborow 1992). The present results are supported by the pH ranges of 6.5–10.0 and 7.3–8.3 reported by Stone and Thormforde (2003) and Kamal et al. (2007) respectively. The present findings suggest that good pond productivity and fish health can be maintained from fish ponds studied at the current pH values.

In most aquaculture systems, the controlling factor for pH is the relationship among photosynthesis, carbon dioxide (CO_2) and the bicarbonate (HCO_3^-) buffering system. In the night, respiration by bacteria, aquatic animals and plants results in dissolved oxygen consumption and carbon dioxide production. Carbon dioxide produced combines with water molecules to produce carbonic acid (H_2CO_3), which then dissociates into bicarbonate (HCO_3^-) and hydrogen ions (H^+); the increase in H^+ concentrations lowers the pH. During the day, plants consume carbon dioxide while undergoing photosynthesis. The removal of carbon dioxide from the water causes bicarbonate and carbonate ions to react with hydrogen ions (H^+) forming more carbon dioxide. This loss of H^+ from the water causes the pH to increase. In turn, the dynamics of carbon dioxide and pH influence the levels of unionised ammonia, whereby elevated carbon dioxide concentrations and hence low pH result in higher levels of unionised ammonia. These dynamics have been explained by Wurts and Durborow (1992) and Wurts (2002).

The levels of free carbon dioxide (0.84–1.67 mg/l) recorded in this study are notably lower than the tolerable levels (1–10 mg/l) in aquaculture pond waters (Boyd and Tucker 1998). Carbon dioxide rarely causes direct toxicity to fish; however its high concentrations lower pond pH and limit the capacity of fish blood to carry oxygen by lowering blood pH at the gills (Grant 2010; Wurts and Durborow 1992). Furthermore, carbon dioxide and hence pH influence unionised ammonia levels. The former is an essential factor required for the photosynthesis process. During the night, photosynthesis is halted while respiration proceeds at low rate causing relatively constant levels of unionised ammonia, carbon dioxide and hence pH for both monoculture and polyculture systems. Clearly, during the day photosynthesis depletes carbon dioxide allowing high pH and thus elevated levels of unionised ammonia to exist in both systems. As revealed in this study, management of ammonia toxicity in a polyculture system employing a predatory fish such as *C. gariepinus* is relatively more crucial than in *O. niloticus* monoculture system.

Temperature is among the external factors, which have profound influence on the biota of aquatic ecosystems. It affects all chemical and biological processes and therefore has a direct effect on important factors such as growth, oxygen demand, food requirements and food conversion efficiency. The higher the temperature, the greater are the requirements for oxygen and food and hence faster growth rate of fish (Poxton 2003). Despite the significant differences in temperature among sampling hours, the average temperature (23 °C) was lower than the acceptable limits (25–32 °C) for warm water fish growth in aquaculture pond waters (Boyd 1990, 1998).

In the present study, monoculture treatments had significantly higher levels of soluble reactive phosphorus than the polyculture with no significant differences among sampling times. The soluble reactive phosphorus levels reported from monoculture treatments ranged from 0.016 to 0.082 mg/l. These levels are lower than the levels of 0.061–0.093 mg/l reported by Elnady et al. (2010) and the maximum recommended level of 0.2 mg/l for aquaculture (Boyd and Tucker 1998). Higher levels of soluble reactive phosphorus in culture systems are indications of pollution. Nevertheless, the soluble reactive phosphorus levels recorded in this study for both monoculture and polyculture systems were lower than the recommended value for aquaculture (Boyd and Tucker 1998).

The present study shows that there is diurnal difference in the way ammonia and carbon dioxide interact and pH is a manifestation of their interaction. Unionised ammonia in monoculture increased with pH during the day, while carbon dioxide remained constant, implying that the driving factor for changes in unionised ammonia may not be carbon dioxide. During the day, pH was high because most of the CO_2 was consumed during photosynthesis. This condition allowed unionised ammonia to dominate in the system (Grant 2010). It was noted previously in this discussion that the unionised ammonia is only a fraction of the total ammonia present and its toxicity is pH dependent. Thus, the higher portion of toxic ammonia was found at higher pH levels which normally occur during the day.

In polyculture, both unionised ammonia and carbon dioxide are strongly correlated with pH suggesting that the inclusion of *C. gariepinus* enhances production of ammonia. As stated earlier in this study, *C. gariepinus* is an efficient producer of ammonia. These observations were made in the daytime when carbon dioxide was kept low by photosynthetic activity. Carbon dioxide for both systems was relatively higher in the night than in the day; the opposite was the case for unionised ammonia. The influence of carbon dioxide on pH is relatively strong in the night than in the day under monoculture condition. The opposite is the case for polyculture where the relationship is strong in the day than in the night. The relationship between unionised ammonia and carbon dioxide shows that under polyculture condition, unionised ammonia decreases with increasing carbon dioxide. The presence of high amount of carbon dioxide lowers pH, which eventually increases H^+ ions that can combine with unionised ammonia to form less toxic NH_4^+.

Growth and survival which together determine the ultimate yield are influenced by a number of biological parameters such as genetic materials and managerial practices, including water and food quality, energy content of the food and stocking density (Ashagrie et al. 2008; El-Sayed 1999). In this study, *O. niloticus* reared in polyculture attained higher final mean body weight than those in monoculture. This difference in final mean weight between the two culture systems may be related to water quality since DO differed between the two culture systems. Food and dissolved oxygen are two interrelated factors that act to limit growth (Buentello et al. 2000) with higher DO levels expected to exhibit higher growth. Surprisingly although higher dissolved oxygen was found in the monoculture setup, the highest mean final weight was obtained in polyculture. The higher final mean weight obtained in polyculture is attributed to a reduced number of *O. niloticus* juveniles due to the presence of *C. gariepinus*. This provided for space and access to food for the adult *O. niloticus* to grow into bigger sizes (de Graaf et al. 1996).

The present study did not find any differences in SGR and FCR between monoculture and polyculture systems. However, the SGR values of 1.34 ± 0.26 and 1.41 ± 0.31 obtained in monoculture and polyculture, respectively, are lower than those of 3.09 and 2.97 % reported by Ahmed et al. (2013). On the other hand, the FCR values of 3.13 ± 0.50 and 3.81 ± 1.14 obtained in the same systems are higher than those of 1.51 and 1.40 reported by Ahmed et al. (2013). The obtained lower SGR and higher FCR may be attributed to differences in culture methods, i.e. monosex versus mixed sex and a constant feeding rate (5 %) adopted throughout the study. *O. niloticus* in mixed sex culture divert energy towards reproduction, whereas monosex culture does not (Dagne et al. 2013). The mixed sex fish loses some energy that was supposed to be used for growth and hence resulting in lower SGR and higher FCR. The constant feeding rate resulted in loss of feed because as fish grow, their growth rate decreases due to lowered metabolic rate (Jauncey 1998). Consequently, fish were overfed at larger sizes, which contributed to lower SGR and higher FCR. Thus, variation in growth performance and FCR of the fish appears to be related to culture methods and the constant feeding rate adopted.

Conclusion and recommendations

The present results have revealed diurnal variations in water quality parameters with peak values occurring during the afternoon to pre-sunset and the lowest from midnight to pre-dawn hours. The lower amount of DO in polyculture was caused by the combined effect of consumption by the two species than in monoculture. Of all the measured water quality parameters, unionised ammonia is the most critical and needs to be strictly monitored. Although most water quality parameters were within the recommended limits and did not affect the growth of the cultured fish, normally changes of one parameter affects the state of others. Thus, for maximum fish growth, survival and higher yields, fish farmers are advised to regularly monitor water quality parameters, particularly unionised ammonia to ensure that they are within the acceptable range. The monitoring should be done late in the evening and early in the morning owing to low values recorded.

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Author's contributions AP Shoko designed the study, collected and analysed data and drafted the manuscript. SM Limbu designed the study, collected and analysed data. HDJ Mrossso designed the study, collected and analysed data. YD Mgaya designed and supervised the study, collected and analysed data. All authors read and approved the final manuscript.

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