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Effects of common carp (*Cyprinus carpio* Linnaeus, 1758) and the African catfish (*Clarias gariepinus* Burchell, 1822) on growth and reproductive performance of native tilapia *Oreochromis shiranus* (Boulenger, 1896)

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Abstract

A study was conducted to assess the effects of common carp and the African catfish on growth and reproduction of the native tilapia *Oreochromis shiranus* in Malawi. The study was done from 1 May to 1 October 2018 at the National Aquaculture Centre (NAC), Zomba. Four triplicated treatments were used: *O. shiranus* + carp (T1), *O. shiranus* + catfish (T2), *O. shiranus* + carp + catfish polyculture (T3) and *O. shiranus* monoculture (T4). Fish were stocked at uniform density of 0.8 fish/m^2. Data collection was done once every month. Results showed that *O. shiranus* mean weight gain (%), specific growth rate (% body weight/day), average daily gain (g $fish^{-1}$ day^{-1}) and condition factor (g/cm^3) were highest in T3 and lowest in T1 and T4 treatments. T3 had better water quality regime and higher tilapia biomass than T1 and T4 treatments. Tilapia fry production (no. fry $pond^{-1}$ day^{-1}) was highest in T4 but did not significantly differ ($p > .05$) between T2 and T3 treatments. It is concluded that the farming of common carp in aquatic ecosystems containing the African catfish may not adversely affect growth and reproduction of *O. shiranus* and that the polyculture of the African catfish, common carp and tilapia can be adopted to mitigate the potential adverse effects of carp on the environment and improve tilapia growth.

KEYWORDS

African catfish, common carp, polyculture, tilapia

1 | INTRODUCTION

The introduction of exotic fish species has often been labelled as a major threat to the integrity of the receiving aquatic ecosystem and native fish biodiversity (Bianco & Ketmaier, 2001; Helfman, 2007). However, in some cases, non-native fish species have resulted in tremendous socio-economic gains through increased capture fisheries and aquaculture production (Reynolds, Greboval, & Mannini, 1995). This has made fish introductions globally enticing and difficult to restrain (Gozlan, 2008). Part of the problem has been failure by researchers to effectively document the precise role of non-native fish species on native species (Copp, Tarkan, Godard, Edmonds, & Wesley, 2010).

Common carp (*Cyprinus carpio* Linnaeus, 1758), a benthivorous cyprinid fish native to Eastern Europe and central Asia, was the first fish species to be introduced outside its natural range (Alves, Vono, & Vieira, 1999). It is presently one of the most introduced fish species for aquaculture worldwide (Badiou, Goldsborough, & Wrubleski, 2011). Carp benthic feeding behaviour has been reported to affect native fish species through middle-out effects (i.e. a combination of top-down effects such as predation and competition and bottom-up effects such as sediment resuspension and

subsequent loss of transparency) (Kaemingk et al., 2016). In particular, dynamic rate functions such as reproduction, growth, survival and physiological condition of native fish have been thought to be affected (Giannetto et al., 2012). Lower carp abundance may boost native fish growth and biomass but carp of about 200 g size may adversely affect the environment and native fish when its abundance exceeds a threshold of 500 kg/ha (Lougheed, Crosbie, & Chow-Fraser, 1998). The median natural biomass of carp in the wild is 589 kg/ha (Crivelli, 1983).

Considering the potential threat to native fish biodiversity, some countries prohibit the introduction of common carp for aquaculture. In Malawi, common carp was introduced from Israel in 1976 to boost the country's aquaculture production (Msiska & Costa-Pierce, 1993). The fish was distributed to farmers for grow-out in ponds in the southern Malawi, outside the Lake Malawi catchment area. It was feared that if common carp were grown in the areas within the Lake Malawi catchment and accidentally escaped into the Lake, it would adversely affect the growth and reproduction of the Lake's native fish, especially the economically important tilapia species of the genus *Oreochromis* (Bandula, 1997). The fears were heightened by the reports of Lake Victoria's native fish disappearance as a result of the introduction of Nile Perch as well as reports that common carp was able to reproduce in fish ponds in the areas where it was grown in Malawi (Mkoko & Mutambo, 1993). Although the environmental fears about common carp in Malawi seemed speculative and no country in Africa had serious environmental concerns about the fish (Moreau & Cost-Pierce, 1997), Malawi decided to ban the farming of the fish in 1992 pending further research on the fish's effects on native fish species (Weyl, Ribbink, & Tweddle, 2010). Malawi's tilapia-dominated aquaculture has struggled since then, with farmers asking government to reverse the ban on carp farming (Mwale, 2009). Carp is still illicitly farmed in some parts of the southern Malawi (Russell, Grötz, Kriesemer, & Pemsl, 2008) and is farmed in many countries in Africa including Malawi's neighbouring countries (Moreau & Cost-Pierce, 1997).

The interactions of common carp with native fish species have been poorly understood (Howell, Weber, & Brown, 2014; Wolfe, Santucci, Einfalt, & Wahl, 2009). Given the limited information about the interactions of common carp and native fish species, the cause–effect relationship frequently remains hypothetical and speculative (Giannetto et al., 2012). The aim of the present study was to assess the effects of common carp on growth and reproductive performance of Malawi's native phytophagous tilapia *Oreochromis shiranus* in a fish pond ecosystem. To determine whether the effects of carp amount to a serious concern, a comparison was made with the effects of a trophically analogous benthivorous fish, the African catfish *Clarias gariepinus* (Burchell, 1822). The African catfish is native to Malawi and much of Africa where it is widely farmed. However, the African catfish is banned in some non-native areas such as India where the fish is feared to adversely affect native fish biodiversity while the common carp is widely farmed (Krishnakumar, Ali, & B & Raghavan, R., 2011).

2 | MATERIALS AND METHODS

2.1 | Experimental site and design

The study was conducted at the National Aquaculture Centre, Zomba, Malawi (15°17′0′′S; 35°24′0′′E) for 5 months (150 days from 1 May to 1 October 2018). The duration of the study allowed for the examination of carp effects on native tilapia over a broad range of carp's mean body weight (196.6–376.4 g) and biomass density (589–966 kg/ha). The experiment involved four treatments (T1: *O. shiranus* + Common carp; T2: *O. shiranus* + African catfish; T3: *O. shiranus* + Common carp + African catfish; T4: *O. shiranus* only, control) arranged in completely randomized design (CRD). Each treatment was replicated three times. The treatments were allocated to ponds using simple random technique. Existing, shallow drainable earthen ponds (10 × 20 × 1 m) were used. Before starting the experiment, all ponds were completely drained, cleared of aquatic plants and fish, and exposed to the sun for 7 days to dry. After drying, the ponds were filled to 1.0 m depth with water from Domasi stream through a canal and left to mature for 14 days.

2.2 | Fish stocking

A total of 1,200 *O. shiranus* with mean body weight (BW) of 57.16 ± 23.63 g and total length (TL) of 14.3 ± 2.09 cm (mean ± standard deviation) were stocked in experimental ponds on 23 April 2018. A week later (30 April), 360 catfish (mean BW: 195.88 ± 33.75 g; mean TL: 31.8 ± 3.5 cm) and 360 carp (mean BW: 196.63 ± 52.24 g; mean TL: 22.7 ± 2.9 cm) were added to some of the ponds as described in Table 1. All the fish were procured from NAC in Zomba, Malawi. The fish were counted, sexed, measured and weighed (to the nearest 0.01 g) before stocking. The fish were randomly assigned to treatment ponds and stocked at a uniform total density of 0.8 fish/m^2. Common carp were stocked at a biomass density of 589 kg/ha, the median natural density observed in the wild (Crivelli, 1983). The catfish were stocked at a similar biomass density (588 kg/ha). Carp were stocked in T1 and T3 whereas catfish were stocked in T2 and T3. The fish were not exogenously fed after stocking them in the experimental ponds to allow for natural feeding behaviour. Water depth was checked weekly, and any water lost through evaporation or seepage was replaced to maintain a 1 m water depth in the ponds. The study was conducted for 5 months.

2.3 | Environmental monitoring

The environment of the fish in the ponds was monitored monthly by measuring the following water quality parameters: temperature (Temp), pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), Secchi disc depth (Z_{SD}), turbidity, nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), total phosphorus (TP),

TABLE 1 Stocking density and species composition ratios of fish in experimental ponds

Treatment	Species	BW (g) (mean ± *SD*)	TL (cm) (mean ± *SD*)	Density (fish/m^2)	Sex ratio (male: female)
T1	*O. shiranus*	57.16 ± 13.63	14.3 ± 2.55	0.5	1:3
	C. carpio	196.6 ± 52.24	22.7 ± 2.9	0.3	1:1
T2	*O. shiranus*	57.16 ± 13.63	14.3 ± 2.55	0.5	1:3
	C. gariepinus	195.8 ± 33.75	31.8 ± 3.5	0.3	1:1
T3	*O. shiranus*	57.16 ± 13.63	14.3 ± 2.55	0.2	1:3
	C. carpio	196.6 ± 52.24	22.7 ± 2.9	0.3	1:1
	C. gariepinus	195.8 ± 33.75	31.8 ± 3.5	0.3	1:1
T4	*O. shiranus*	57.16 ± 13.63	14.3 ± 2.55	0.8	1:3

orthophosphate (PO_4^{3-}), total suspended solids (TSS) and total alkalinity (TA). Temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), Secchi disc depth (Z_{SD}) and turbidity were measured on site. Portable water quality checkers were used to measure DO (Hanna Instruments, models HANNA HI 9146), pH (HANNA HI 9125), temperature, EC, TDS (HANNA HI 99300) and turbidity (HANNA HI 98703). A weighted, black-and-white, 20-cm-diameter Secchi disc attached to a graduated rope was used to measure Secchi disc depth. Water samples were collected and transported to the Central Government Water Laboratory in Lilongwe for the determination of TP, PO_4^{3-}, NO_3^-, NH_4^+, TSS, TA and chlorophyll *a* following standard methods (APHA, 2005). Determination of water quality parameters started before fish stocking and was carried out between 09:00 and 14:00 hr on each sampling day.

2.4 | Sampling and data collection

Fish were sampled for growth and reproduction data once every month for 5 months (150 days). Monthly collection of fish was done by using baited fish traps. Terminal sampling of fish was done by complete draining and seining the ponds repeatedly until all the fish were collected. A target of 10% of stocked fish of all species was analysed for growth, survival, condition and reproductive performance analysis. Biomass increase (%) was computed for *O. shiranus* as well as common carp and the African catfish using biomass data collected at stocking and harvesting. The fish were counted, sexed, measured and weighed using top pan digital scale (Mettler Toledo model PG 5002-SDR, Japan).

Growth performance of the tilapia *O. shiranus* was assessed by using mean weight gain (MWG) (%) (Equation 1), specific growth rate (SGR) (% body weight/day) (Equation 2), mean length gain (MLG) (%) (Equation 3) and average daily gain (ADG) (g fish^{-1} day^{-1}) (Equation 4). Condition of the fish was evaluated by using condition factor (k, g/cm^3) (Equation 5), survival by survival rate (SR) (%) (Equation 6) and biomass increase as percentage change in weight of fish (kg/ha) between final and initial biomass (Equation 7). Reproductive performance of *O. shiranus* was measured by gonadosomatic index (GSI) (%) (Equation 8), absolute fecundity (AF) (number of eggs female fish^{-1}) (Equation 10), relative fecundity (RF) (number of eggs per gram of body weight) (Equation 11) and fry production (number of fry pond^{-1} day^{-1}).

All collected fish were returned to ponds, but female *O. shiranus* were sacrificed by immersing them in an ice slurry before dissecting them to remove ovaries. The ovaries and eviscerated body were weighed. The ovaries were then preserved in labelled bottles of 4% formaldehyde for fecundity determination. Three subsamples (anterior, middle, posterior) were excised from each ovary and weighed. Each subsample was opened, and eggs from it brushed into a 50-ml vial where they were mixed with water. Using a dropper, one ml of the water with eggs was sucked and a drop placed on microscope slide, covered with a coverslip and the eggs counted to determine subsample fecundity (Equation 9). Counting of eggs was done under ordinary light microscope (model XS2-107T, made in Kenya) using Lackey's Drop Counting technique (Gajanan & Satish, 2014; Lackey, 1938).

Fry were skimmed daily using a fine meshed scoop net, counted and batch-weighed using analytical balance (model HR-120, made in Japan; precision 0.1 mg). Ten per cent of the fry were randomly selected for length measurement using fish measuring board. All the fry then were placed in a separate nursery pond.

2.5 | Data analysis

2.5.1 | Mean weight gain

Mean weight gain (MWG) was calculated using the formula:

$$\text{Mean weight gain (\%)} = \frac{\text{Final weight } (g) - \text{Initial weight } (g)}{\text{Initial weight (g)}} \times 100 \quad (1)$$

2.5.2 | Specific growth rate

Specific growth rate (SGR) (% body weight/day) was determined according to equation:

$$\text{SGR} = [\ln \text{WTF} - \ln \text{WTi}] \times \frac{100}{T} \quad (2)$$

where:

ln WTF = the natural logarithm of the average final weight (g).

ln WTi = the natural logarithm of the average initial weight (g).

T = time (days) between lnWTf and lnWTi or culture period.

2.5.3 | Mean length gain

Mean length gain (MLG) was worked out using the formula:

$$\text{Mean length gain (\%)} = \frac{\text{Final length (mm)} - \text{Initial length (mm)}}{\text{Initial length (mm)}} \times 100 \quad (3)$$

2.5.4 | Average daily gain

Average daily gain (ADG) was determined as:

$$\text{ADG}\,(g\,d^{-1}) = \frac{\text{Final weight}\,(g) - \text{Initial weight}\,(g)}{\text{Culture period or Number of days}} \quad (4)$$

2.5.5 | Condition factor

Condition Factor (*k*) is used to compare the condition (weight-at-length), fitness or well-being of fish. Heavier fish at a given length are often in better condition (Bagenal, 1978). The value of the condition factor (*k*) was determined following Froese (2006):

$$k = \frac{W}{L^3} \times 100 \quad (5)$$

where:

W = whole body wet weight of the fish (g).

L = Total length of the fish (cm).

k = the Condition Factor or Coefficient of Condition; often simply referred to as the "*k* factor"; The factor 100 is used to bring *k* close to unity. The condition factor (*k*) is a useful metric for the evaluation of fish wellbeing, feeding intensity, environmental conditions, age and growth rates (González et al., 2016).

2.5.6 | Survival rate

Survival rate (SR) was calculated with the formula:

$$\text{Survival rate (\%)} = \frac{\text{Total number of fish harvested}}{\text{Total number of fish stocked}} \times 100 \quad (6)$$

2.5.7 | Biomass increase

Biomass increase (%) was calculated using the formula:

$$\text{Biomass increase (\%)} = \frac{\text{final biomass}\,(\text{kg ha}^{-1}) - \text{Initial biomass}\,(\text{kg ha}^{-1})}{\text{Initial biomass}\,(\text{kg ha}^{-1})} \times 100 \quad (7)$$

2.5.8 | Gonadosomatic index

Gonadosomatic index (GSI) is a measure that describes the state of maturity of a fish by expressing the weight of the gonad as a percentage of the somatic or body weight. Normally, GSI values as gonads ripen, but they start to fall once the fish begins to spawn. Female gonadosomatic index (GSI) was calculated using the equation:

$$\text{GSI} = \frac{\text{Gonad weight}}{\text{Eviserated Body weight}} \times 100 \quad (8)$$

2.5.9 | Fecundity

Fecundity refers to the number of ripe oocytes in the ovary female fish prior to the next spawning (Bagenal, 1978). Absolute fecundity is the total number of ripe eggs prior to the next spawning period. Relative fecundity is the total number of ripe eggs per gram of female body weight. Fecundity is determined from the ovary in the final stage of maturation (V) by counting oocytes that have the largest diameter (Shoko, Limbu, Mrosso, & Mgaya, 2015). For the determination of fecundity, ovaries of females were removed and weighed. Three subsamples were taken: one from the front, mid and rear sections of each ovary and weighed. The total number of eggs in each subsample of ovary (i.e. subsample fecundity) was proportionally estimated according to the equation:

$$\text{F1} = \frac{\text{Gonad weight(g)} \times \text{number of eggs in the subsample}}{\text{Weight of the sample}} \quad (9)$$

2.5.10 | Absolute fecundity

Absolute (or total) fecundity (AF) for each female was estimated by taking the mean number of the three subsample fecundities (F1, F2, F3) as follows:

$$\text{AF (number of eggs per individual fish)} = \frac{\text{F1} + \text{F2} + \text{F3}}{3} \quad (10)$$

2.5.11 | Relative fecundity

Relative fecundity (RF) was estimated by dividing the individual total fecundity by the body weight of the fish as follows:

$$\text{RF (number of eggs per gram body weight)} = \frac{\text{AF}}{\text{Eviscerated body weight (g)}} \quad (11)$$

2.6 | Statistical analysis

Measured and estimated fish growth, reproduction, survival, condition and biomass data were recorded in MICROSOFT EXCEL spreadsheets (EXCEL 2013). Mean and standard deviation (mean ± *SD*) of each parameter was calculated for each treatment. Data exploration and analysis were done by using version 3 of Paleontological Statistics (PAST) software

(Hammer, Harper, & Ryan, 2001). As most data did not meet the assumptions of ANOVA, the data were tested for significant differences by using the non-parametric Kruskal–Wallis rank sum test (α = 0.05). A significant Kruskal–Wallis test was followed with a non-parametric Dunn's post hoc test for multiple comparisons (α = 0.05). Fish biomass data for common carp and the African catfish were tested for significant difference by using Mann–Whitney *U* test (α = 0.05).

3 | RESULTS

3.1 | Water quality conditions

Kruskal–Wallis test showed that, except for temperature, all water quality parameters differed significantly between treatments ($p < .05$) (Table 2). Turbidity, total dissolved solids, electrical conductivity, total suspended solids, total phosphorus, nitrates, orthophosphate and ammonia were highest in ponds with carp (T1) and lowest in ponds lacking carp and catfish (T4). In contrast, Secchi disc depth, dissolved oxygen, pH, total alkalinity and nitrites were highest in ponds lacking carp and catfish (T4) and lowest in T1 ponds. Dunn's post hoc test for multiple comparisons showed that these parameters did not differ significantly between T2 and T3 ponds ($p > .05$).

3.2 | Growth and reproductive performance of *Oreochromis shiranus*

A total of 662 tilapia fish were sampled for growth and reproductive performance assessment. Of these, 397 female tilapia were sampled for fecundity and gonadosomatic index determination. A total of 36 common carp and 36 African catfish individuals were also sampled for the determination of biomass increase over the study period. Tilapia body weight (g) (Figure 1a), total length (cm) (Figure 1b), specific growth rate (% body weight/day) (Figure 1c) and fry production (no. of fry $pond^{-1}$ day^{-1}) (Figure 1d) ranged 46–81.2, 12.2–21.8, 0.002–0.21 and 22–235, respectively, over the experimental period. Tilapia body weight, specific growth rate, mean weight gain, average daily gain and condition factor differed significantly between treatments ($p < .05$) being highest in T3 (*O. shiranus* + carp + catfish) treatment and lowest in T1 (*O. shiranus* + carp) treatment ponds (Table 3). Total length and mean length gain were significantly lower ($p < .05$) in T3 (*O. shiranus* + carp + catfish) treatment but significantly higher ($p < .05$) in T1 (*O. shiranus* + carp) treatment. Male *O. shranus* had significantly higher ($p < .05$) body weight, mean weight gain, average daily gain, specific growth rate and condition values than females. Fry production and survival rate were significantly higher ($p < .05$) in T4 (*O. shiranus*-only) monoculture treatment but were significantly lower ($p < .05$) in all the polyculture treatments. Fecundity and gonadosomatic index did not differ significantly between treatments ($p > .05$).

Fish biomass increased for all fish species over the experimental period but differed between species (Table 4). Average fish biomass increase (%) was 63, 4 and 2 for common carp, *O. shiranus* and the African catfish, respectively, over the experimental period. Fish biomass increase for *O. shiranus* differed significantly between treatments ($p = .000$) with T3 (*O. shiranus* + carp + catfish) registering the highest and T1 (*O. shiranus* + carp) the lowest biomass increase over the experimental period. Male *O. shiranus*

TABLE 2 Water quality parameters (range, mean ± standard deviation, Kruskal–Wallis H and *p*-values) in experimental ponds

			Treatment					
	Units	Range	T1	T2	T3	T4	H	*p*-value
Tem	°C	25.1–29.5	25.4 ± 2.8^a	25.6 ± 3.0^a	25.5 ± 2.8^a	25.4 ± 3.1^a	1.287	.732
Z_{SD}	cm	12–42	13.9 ± 1.7^a	22.3 ± 4.9^b	20.7 ± 3.2^b	33.5 ± 5.8^c	182.4	.000
Tur	NTU	12–146	132 ± 18^a	83 ± 38.2^b	84.8 ± 8.3^b	25.8 ± 7.9^c	201.0	.000
TDS	mg/L	8–22.5	21.0 ± 3.2^a	16.3 ± 2.9^b	17.5 ± 2.7^b	12.2 ± 3.7^c	122.9	.000
EC	µS/cm	18–41	35.4 ± 4.6^a	27.1 ± 2.7^b	28.2 ± 2.1^b	19.4 ± 3.3^c	180.1	.000
DO	mg/L	5–9.05	5.7 ± 0.55^a	6.7 ± 0.81^b	6.6 ± 0.3^b	7.5 ± 0.8^c	116.7	.000
pH	–	5.01–8.54	5.9 ± 0.34^a	6.9 ± 0.43^b	6.61 ± 0.4^b	8.04 ± 0.6^c	182.0	.000
TSS	mg/L	15.3–135.9	88.5 ± 13^a	66.2 ± 10^b	69.6 ± 9.2^b	29.6 ± 6.3^c	200.8	.000
TP	mg/L	0.041–0.251	0.22 ± 0.0^a	0.15 ± 0.0^b	0.16 ± 0.0^b	0.14 ± 0.0^c	165.2	.000
NO_3^-	mg/L	0.152–0.373	0.35 ± 0.0^a	0.28 ± 0.0^b	0.29 ± 0.0^b	0.23 ± 0.0^c	168.5	.000
PO_4^{3-}	mg/L	0.004–0.147	0.12 ± 0.0^a	0.08 ± 0.0^b	0.09 ± 0.0^b	0.04 ± 0.0^c	170.8	.000
TA	mg/L	48–138	65.5 ± 4.1^a	83.8 ± 3.2^b	82.3 ± 2.2^b	121 ± 6.7.^{c}	204.2	.000
NO_2^-	mg/L	0.03–0.07	0.02 ± 0.0^a	0.04 ± 0.0^b	0.03 ± 0.0^b	0.05 ± 0.0^c	134.7	.000
NH_4^+	mg/L	0.01–0.05	0.03 ± 0.0^a	0.02 ± 0.0^b	0.04 ± 0.0^c	0.01 ± 0.0^d	174.2	.000

Note: Values with the same superscript in a row are not significantly different at $p = .05$. T1: carp + *shiranus*; T2: catfish + *shiranus*; T3: carp + catfish + shiranus; and T4: *shiranus* only (control).

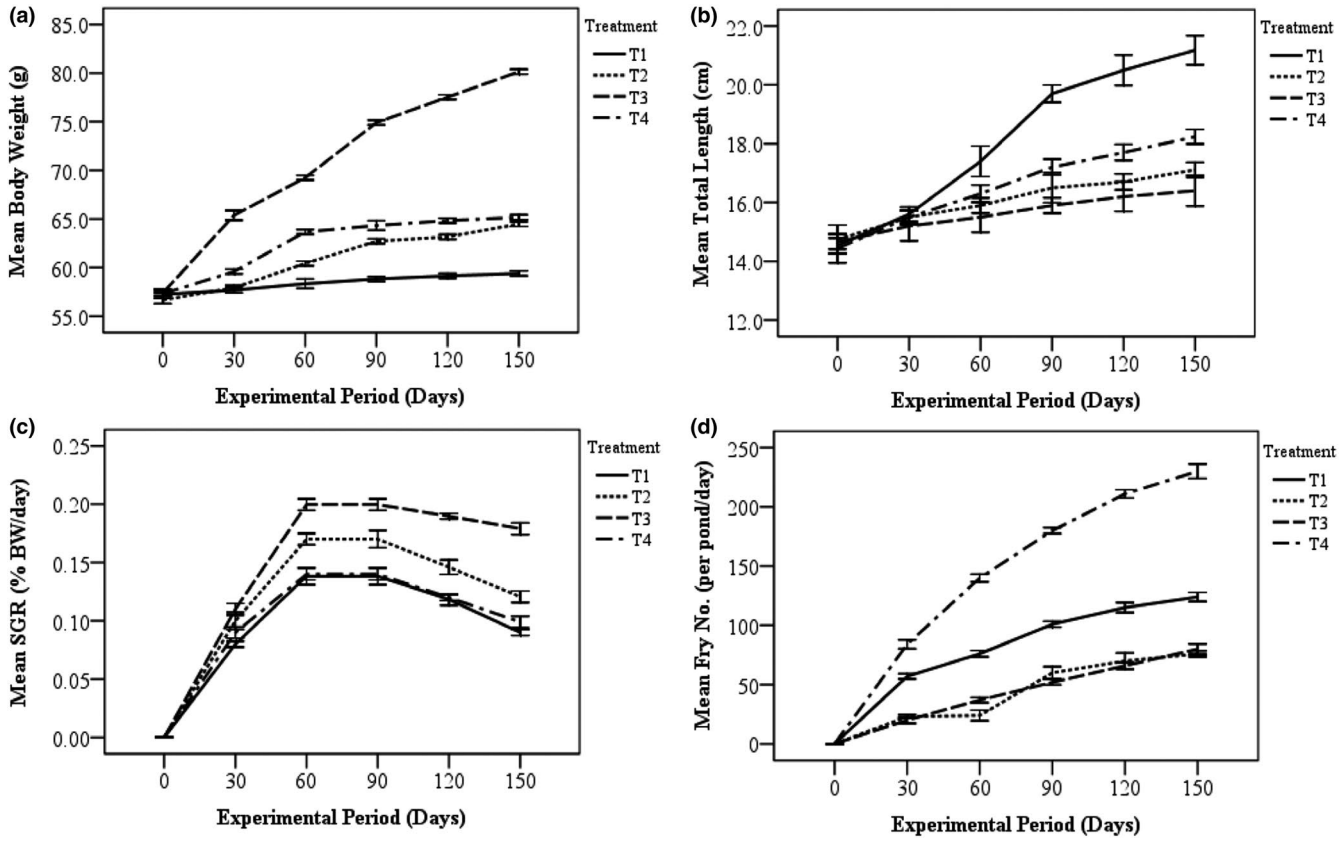

FIGURE 1 Trends in growth and reproductive performance of *Oreochromis shiranus* reared under different treatments during the experimental period. Body weight (a), total length (b), specific growth rate (c) and fry production. Error bars represent standard deviation

TABLE 3 Growth and reproductive performance parameters (mean ± standard deviation, Kruskal–Wallis H and *p*-values) of *Oreochromis shiranus* in experimental ponds under different treatments

		Treatment					
	Units	T1	T2	T3	T4	H	*p*
BW_i	g	57.2 ± 1.7^a	56.6 ± 3.2^a	57.3 ± 1.2^a	57.3 ± 5.2^a	4.00	.259
BW_f	g	59.3 ± 2.1^a	64.5 ± 1.6^b	80.1 ± 0.6^c	65.1 ± 2.3^b	56.29	.000
TL_i	cm	14.5 ± 0.2^a	14.7 ± 0.7^a	14.6 ± 0.3^a	14.4 ± 0.6^a	3.03	.386
TL_f	cm	21.2 ± 0.5^a	17.1 ± 0.6^b	16.4 ± 0.1^c	18.2 ± 6.8^b	55.12	.000
MWG	%	14.6 ± 0.7^a	20.7 ± 0.7^b	30.4±0.6^c	15.7 ± 1.1^a	157.7	.000
SGR	%BW d^{-1}	0.09 ± 0.0^a	0.12 ± 0.0^b	0.17 ± 0.0^c	0.09 ± 0.0^a	149.3	.031
MLG	%	1.32 ± 0.6^a	0.47 ± 0.2^b	0.34 ± 0.1^c	0.75 ± 0.2^a	139.4	.006
SR	%	70.5 ± 3.0^a	61.0 ± 4.0^b	62.5 ± 5.0^b	87.0 ± 2.5^b	28.6	.030
ADG	g $fish^{-1}$ d^{-1}	0.01 ± 0.0^a	0.05 ± 0.0^a	0.15 ± 0.1^b	0.05 ± 0.0^a	40.3	.007
k	g/cm^3	0.94 ± 0.3^a	1.42 ± 0.1^a	1.84 ± 0.02^b	1.31 ± 0.2^a	174.1	.004
AF	eggs $fish^{-1}$	527 ± 129^a	556 ± 117^a	572 ± 28^a	576 ± 42^a	0.9	.819
RF	eggs/gBW	10.5 ± 3.7^a	16.6 ± 9.2^a	15.3 ± 4.7^a	13.9 ± 4.0^a	51.3	.503
GSI	%	2.96 ± 1.5^a	2.23 ± 2.1^a	2.73 ± 1.1^a	2.50 ± 1.6^a	3.8	.281
Fry	fry $pond^{-1}d^{-1}$	76.7 ± 28.0^a	42.2 ± 28.6^b	43.8 ± 26.0^b	141.5 ± 70.5^c	26.7	.000

Note: Superscripts with the same letter in a row indicate no significant difference at 0.05 alpha level. T1: carp + *shiranus* polyculture; T2: catfish + *shiranus* polyculture; T3: carp + catfish + shiranus polyculture; T4: *shiranus* only.

Abbreviations: ADG, Average daily gain; AF, Absolute fecundity; BW, Body weight; BW_f, Final body weight; BW_i, Initial body weight; d, day; Fry, Fry production; GSI, Gonadosomatic index; k, Fulton's condition factor; MLG, Mean length gain; MWG, Mean weight gain; RF, Relative fecundity; SGR, Specific growth rate; SR, Survival rate.

TABLE 4 Fish biomass (kg/ha) in experimental ponds under different treatments

		Treatment					
Species	**Period**	**T1**	**T2**	**T3**	**T4**	**Statistic**	***p*-value**
Tilapia	At stocking	287.1[a]	282.2[a]	132.8[b]	471.5[c]	H = 155.3	.000
	At harvest	294.0[a]	297.3[a]	141.2[b]	485.2[c]	H = 149.7	.000
	% increase	2.3[a]	5.3[b]	6.3[c]	2.9[a]	H = 188.1	.000
Carp	At stocking	589.3	–	588.6	–	M-W U = 32.5	.197
	At harvest	966.1	–	959.4	–	M-W U = 18.5	.018
	% increase	63.9	–	62.9	–	M-W U = 40.3	.206
Catfish	At stocking	–	587.9	588.3	–	M-W U = 24.2	.269
	At harvest	–	599.2	597.6	–	M-W U = 37.1	.174
	% increase	–	1.9	1.5	–	M-W U = 42.4	.115

Note: Superscripts with the same letter in a row indicate no significant difference at 0.05 alpha level.
H = Kruskal–Wallis test statistic; M-W *U* = Mann–Whitney *U* test statistic. A dash (–) means not applicable.

had significantly higher ($p < .05$) biomass increase than females. There were no significant differences in terms of biomass increase between treatments for common carp ($p = .206$) and the African catfish ($p = .115$).

4 | DISCUSSION

Environmental conditions in terms of water temperature, Secchi disc depth, electrical conductivity, dissolved oxygen, pH, total alkalinity, nitrates, nitrites, chlorophyll *a* and ammonium were within acceptable ranges for proper growth and reproduction of tropical fish (Bhatnagar & Devi, 2013; Boyd, 2003; Lazur, 2007). Ranges of turbidity, total suspended solids, total dissolved solids and phosphorus were higher in tilapia-carp polyculture but were in agreement with Azad et al. (2004) and Wolfe et al. (2009) who reported similar ranges in the polyculture of carp and other fishes.

Increased tilapia growth performance in tilapia + carp + catfish polyculture was evident through higher final body weight, MWG, SGR, ADG, k and biomass increase. This finding was in agreement with Tibihika, Barekye, and Byakora (2014) who reported that growth rate, weight gain and yield of Nile tilapia grown in tilapia + carp + catfish polyculture were higher than the Nile tilapia grown in monoculture. Carp-driven resuspension increases nutrient availability in the water column and subsequently increases primary and secondary production which increases native fish growth (Bachmann et al., 1996; Wolfe et al., 2009). For example, Rahman (2015) reported that when planktivorous fish are grown together with common carp, the ponds generally require 20%–40% less fertilizer to maintain adequate natural food levels than those with planktivorous fish in monoculture. Thus, increasing fish production by the addition of common carp is a common practice in many parts of the world, including Asia and Europe. This advantage is lost when common carp biomass exceeds a threshold of 500 kg/ha because sediment resuspension becomes excessive (Lougheed et al., 1998). However, in presence of a stronger and more aggressive benthivorous fish, carp is displaced from its benthic niche, reducing its impact on sediment resuspension (Rahman, 2015). This may have maintained the advantage of carp's nutrient resuspension even when the carp density used in this study was higher than the threshold. Lower MLG and higher MWG in the tilapia + carp + catfish treatment accounted for increased *k*-values which indicate availability of optimal growing conditions including enough food for the tilapia. This result is consistent with Ekelemu (2010) and Chowdhary and Srivastava (2013) who reported higher k-values for the catfishes *Clarias gariepinus*, *Heterobranchus bidorsalis* and *Clarias batrachus* when they were provided with optimal food requirements. Rodríguez et al. (2017) also reported higher *k*-values for Nile tilapia when the fish was provided with enough food.

Tilapia survival and fry production were reduced in the presence of common carp and the African catfish. Reduction of native fish populations by common carp was also reported by Egertson and Downing (2004) and Jackson, Quist, Downing, and Larscheid (2010). Disruption of breeding nests, clogging of gills by increased turbidity and competition for invertebrate resources have been cited as principal mechanisms by which common carp may lead to decline in native fish populations (Parkos, Santucci, & Wahl, 2003; Weber & Brown, 2011). Water bodies with abundant common carp populations have been associated with increased turbidity, higher TDS, lower Secchi disc visibility and increased productivity as shown by higher chlorophyll *a* (Lougheed et al., 1998). Although native fish populations increase with increasing ecosystem productivity (Bachmann et al., 1996), carp biomass >500 kg/ha threshold is thought to be detrimental (Lougheed et al., 1998; Weber & Brown, 2011). The carp biomass used in our study was 589 kg/ha. Reduction of tilapia survival and fry production in ponds stocked with the African catfish was recorded in this study. The extent to which the catfish decreased tilapia fry production was higher than common carp. Mohsen (2005) also reported that the African catfish reduced populations of Nile tilapia and fry (2–3 g). This can be attributed to predation on tilapia fry and adults by the catfish (Khedkar et al., 2014; Kwei, 1999). This predatory behaviour, along

with sediment resuspension capability, has made the African catfish both loathed and loved, with some countries banning its use in aquaculture to conserve native populations (Krishnakumar et al.., 2011) and others recommending its use as a biological agent or 'police-fish' for the control of tilapia overpopulation to improve growth rates (Musa, Aura, Ngugi, & Kundu, 2012). Fecundity and gonadosomatic index of tilapia were not affected by carp or catfish.

5 | CONCLUSION

The study found that when common carp was added to ponds containing the tilapia and the African catfish (T3), growth performance of *O. shiranus* was not adversely affected but rather increased whereas reproductive performance as measured by fry production was not affected. Better water quality regime and higher tilapia biomass increase were also observed in ponds containing common carp, the African catfish and tilapia (T3). The study finds no evidence of negative effects of common carp on growth and reproductive performance of *O. shiranus* in presence of the African catfish. It is concluded that (a) the farming of common carp in aquatic ecosystems containing the African catfish may not adversely affect growth and reproduction of *O. shiranus*, and (b) the polyculture of the African catfish, common carp and tilapia can be adopted as a strategy to mitigate the potential adverse effects of carp on the environment and improve tilapia growth, total fish biomass and economic gains for fish farmers.

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CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in figshare data repository at http://doi.org/10.6084/m9.figshare.7929926.v1 (Chirwa,).

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