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Research Article
African Catfish as Biocontrol Agent of Common Carp's Adverse Effects on Water Quality

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Abstract

Background and Objective: As common carp (*Cyprinus carpio*) can adversely affect water quality in aquatic ecosystems through its benthivory, its introduction is widely considered an environmental concern. This study aimed to investigate the potential use of the African catfish (*Clarias gariepinus*), another benthivorous fish species native to Africa as a biocontrol agent of carp's adverse effects on water quality. **Materials and Methods:** The study was conducted at the National Aquaculture Center, Zomba, Malawi. Four treatments were involved: Ponds with carp (T_1), ponds with African catfish (T_2), ponds with both carp and African catfish (T_3) and ponds lacking both carp and African catfish (T_4). **Results:** Turbidity, dissolved solids, suspended solids, nutrients and chlorophyll-a were highest in T_1, lowest in T_4 and similar between T_2 and T_3 ($p>0.05$). This indicated that carp's effects on water quality were reduced when carp were raised together with the African catfish in the same pond. **Conclusion:** The African catfish can be used as a biocontrol agent to mitigate the adverse effects of common carp on water quality and the farming of carp in ecosystems where the African catfish is native may not adversely affect water quality as the catfish will reduce carp's ability to stir the bottom sediments into the water column.

Key words: African catfish, biocontrol, benthivorous, common carp, water quality, sediment resuspension, competitive exclusion

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Common carp (*Cyprinus carpio* Linnaeus, 1758) (or "carp"), a benthivorous cyprinid fish native to Eastern Europe and Central Asia, was the first fish species to be introduced outside its natural range for aquaculture and remains the most introduced fish species worldwide[1]. Carp adversely affects water quality through their benthic feeding activities by physically resuspending sediments and mobilizing nutrients[2]. Adult carp spends much time rooting in the bottom sediments in search of benthic macro invertebrates and other food items, in the process stirring up the sediments and releasing sediment-bound nutrients into the water column[3]. In turn, sediment resuspension increases turbidity and nutrient concentration in the water column[1]. Increased water column nutrients promote phytoplankton bloom, which together with increased turbidity, shade light penetration and suppresses submerged macrophytes and periphyton[4]. These alterations in water quality may negatively affect the growth and reproduction of native fish species[5]. In light of the potential adverse effects on the environment, carp biocontrol is a routine management action in regions where carp populations are already established and becoming problematic[6].

In general, biocontrol of invasive species has included traditional methods such as physical removal, predation as well as modern techniques like the use of microbes and genetic engineering[7]. These biocontrol approaches have met with limited success and low adoption by developing countries due to the high cost of implementation. Some of the developing countries have opted to ban the introduction of carp altogether as a cheaper option than having to manage the fish[8]. Biocontrol options that target behavioural or developmental weaknesses of carp have been recommended but have not been tried[9].

Carp preferentially feeds on benthic macroinvertebrates[10]. In presence of a superior benthic competitor, carp alters its feeding behaviour from benthivory to planktivory[11,10]. As carp affects the environment through its benthic feeding behavior[2], a fish that can displace carp from its benthic foraging makes a potential biocontrol agent mitigate carp's effects on aquatic ecosystems. Such biocontrol agents can be searched from fish species of similar feeding niche as carp, considering the utility of the 'competitive exclusion principle, also known as Gause's law, which states that two species with identical niches (i.e., sharing and competing for the same limiting resources) cannot stably coexist[12]. By separating their feeding niche, competing species can live together[13]. The African catfish, native to Malawi and much of Africa, is also benthivorous, known for its benthic feeding and predatory behavior[14]. The present study investigates the potential use of the African catfish (*Clarias gariepinus* Burchell, 1822) in regulating carp's ability to affect water quality in ponds.

MATERIALS AND METHODS

Experimental design: The study was conducted at the National Aquaculture Centre (NAC), Zomba, Malawi (15°17'0"S, 35°24'0"E) for 5 months from May to October, 2018. Four treatments were involved: T_1 = Ponds with common carp, T_2 = Ponds with African catfish, T_3 = Ponds with common carp+African catfish, T_4 = Ponds with neither common carp nor African catfish (control). The treatments were arranged in a Completely Randomised Design (CRD). Each treatment was replicated three times. Ponds were used as experimental units. The treatments were allocated to ponds using a simple random technique. Existing, shallow drainable earthen ponds ($10\times20\times1$ 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 m depth with water from the Domasi stream through a canal and left to mature for 14 days before stocking them with fish.

Fish stocking: A total of 360 African catfish with a mean body weight (BW) of 195.88$\pm$33.75 g and mean total length (TL) of 31.8$\pm$3.5 cm were stocked in T_2 and T_3 ponds. On the same day, 360 carp (mean BW: 196.63$\pm$52.24 g, mean TL: 22.7$\pm$2.9 cm) were stocked in T_1 and T_3 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 treatments and stocked at a uniform density of 0.3 fish m^{-2} (about 589 kg ha^{-1}) per species. The stocking density used reflected carp's median natural density observed in the wild[15]. The fish were not exogenously fed after stocking 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.

Water quality monitoring: Water quality in fish ponds was monitored by measuring water temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), Secchi disk depth (Z_{SD}), turbidity, nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), total phosphorus (TP), phosphate(PO_4^{3-}), total suspended solids (TSS), total alkalinity and chlorophyll a (Chl-a), a measure of phytoplankton biomass[16]. Temperature, pH, DO, TDS, EC, Z_{SD} and turbidity

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

Treatments	Species	BW (g) (Mean±SD)	TL (cm) (Mean±SD)	Density (fish m^{-2})	Sex ratio (male : female)
T_1	*C. carpio*	196.6±52.2	22.7±2.9	0.3	1:1
T_2	*C. gariepinus*	195.8±33.7	31.8±3.5	0.3	1:1
T_3	*C. carpio*	196.6±52.2	22.7±2.9	0.3	1:1
	C. gariepinus	195.8±33.7	31.8±3.5	0.3	1:1
T_4	Lacking both carp (*C. carpio*) and African catfish (*C. gariepinus*) (control)				

T_1: Ponds with common carp, T_2: Ponds with African catfish, T_3: Ponds with common carp+African catfish, T_4: Ponds with neither common carp nor African catfish (control), BW: Body weight and TL: Total length

Table 2: Biometric data of carp and African catfish sampled from the experimental ponds in different treatments

	Treatments and species			
Parameters	T_1 carp	T_3 carp	T_2 catfish	T_4 catfish
Sample size	12	12	12	12
Range BW (g)	229-238	227-236	304-312	301-308
Mean BW (g) ±SD	235±22.7	233±31.5	309±44.2	305±22.3
Mean TL (cm) ±SD	24.9±0.6	24.8±1.3	33.4±4.2	34.2±2.2
Range gut wt (g)	1.6-2.9	1.1-2.5	2.9-3.8	2.0-2.8
Full stomach wt (g)±SD	2.4±0.7	1.7±0.6	3.4±0.8	2.5±0.4

T_1: Ponds with common carp, T_2: Ponds with African catfish, T_3: Ponds with common carp+African catfish, T_4: Ponds with neither common carp nor African catfish (control), BW: Body weight, TL: Total length and wt: Weight

were measured on-site between 9 and 14 hrs by using portable water quality checkers (Hanna Instruments: Model HANNA HI 9146 for DO, HANNA HI 9125 for pH, HANNA HI 99300 for temperature, EC, TDS, HANNA HI 98703 for turbidity). A weighted, black and white, 20 cm diameter Secchi disk attached to a graduated rope was used to measure Secchi disk depth. For the determination of TP, PO_4^{3-}, NO_3^-, NO_2^-, NH_4^+, TSS, alkalinity and chlorophyll a (Chl-a), water samples were collected from four random stations in each pond, 2 m away from the pond dyke according to Li *et al.*[17]. The samples were collected by using the discrete grab sampling technique at 30 cm depth using a 2 L polythene bottle attached to a bamboo handle at the same time and place as on-site water quality monitoring. The samples were transported to the laboratory in an iced cooler box for immediate processing and analysis. The Central Government Water Laboratory in Lilongwe was used for the analysis of TP, PO_4^{3-}, NO_3^-, NO_2^-, NH_4^+, TSS and alkalinity following standard methods[17]. Chl-a was analyzed at the NAC laboratory. For the determination of chl-a concentration, samples were shaken and a 60 mL volume of sample water was filtered using a vacuum filtration pump and 47 mm GF/F filter. Thereafter, the filter was pulverized with 90% acetone using a tissue grinder to extract chlorophyll pigment. The resulting mixture was centrifuged at 3000 rpm for 10 min. (centrifuge model H-11n, made in Japan) and the supernatant was poured into a glass cuvet with a 1 mm light path. The optical density (absorbance) was read at 630, 645, 663 and 750 nm using a Jenway spectrophotometer (model 6300, made in Japan) and results were corrected for phaeopigments by acidification. Chl-a concentration (mg L^{-1}) was calculated for each pond according to the equation of SCOR-UNESCO[18]:

$$\text{Chlorophyll a (mg L}^{-1}) = 11.64\left(A_{663} - A_{750}\right) - 2.16\left(A_{645} - A_{750}\right) + 0.10\left(A_{630} - A_{750}\right)\frac{v}{1000V}$$

Where:

- A_{663} = Optical density of the sample at the absorbance wavelength of 663 nm
- A_{750} = Optical density of the sample at the absorbance wavelength of 750 nm
- A_{645} = Optical density of the sample at the absorbance wavelength of 645 nm
- A_{630} = Optical density of the sample at the absorbance wavelength of 630 nm
- v = Volume (mL) of supernatant
- V = Volume (L) of water sample filtered

Diet analysis of carp and African catfish: To understand whether there was trophic niche displacement between the two benthivorous fishes (common carp and the African catfish) in the ponds where they were stocked together, a diet analysis was performed at the end of the experimental period. The fish were harvested by complete draining. Twelve healthy fish of uniform size were randomly selected from the harvested fish of each species for diet analysis. To halt stomach content decomposition, all fish were euthanised immediately after capture in an ice-water slurry, before being packed in ice and transported to the laboratory where biometric data such as total length (TL in cm), body weight (BW in g) and stomach weight (g) were taken for each fish specimen (Table 2). The fish specimens were then preserved in 10% buffered formalin before the examination. All fish were examined within 2 weeks of collection. Fish specimens were dissected from the anus to the pectoral fin to carefully remove their stomachs according to Dadebo *et al.*[19]. Wet weight (mg) of the removed full stomachs was recorded. Individual stomachs were preserved in well-labelled sterile bottles containing 5% buffered formalin solution. The stomachs were then blotted with tissue paper and opened longitudinally. Weight (mg) of empty stomachs was recorded. Contents of individual stomachs were emptied into separate Petri-dishes and rinsed into vials with 70% ethanol. They were subsequently sorted, identified to the lowest possible taxonomic level and enumerated. For each food type of each species of benthic fish, the percent of the total number of all prey eaten (N(%)) was calculated[20].

Statistical analysis: Data exploration and analysis was done by using R statistical software of the R foundation for statistical computing. Shapiro-Wilk test was used to test the data for normality whereas the Fligner-Killeen test was used to test the data for homoscedasticity. As most data did not meet the assumptions of ANOVA, the data were tested for significant differences by using the nonparametric Kruskal-Wallis rank-sum test ($\alpha = 0.05$). A significant Kruskal-Wallis test was followed with a non-parametric Dunn's *post hoc* test for multiple comparisons ($\alpha = 0.05$).

A cluster analysis was performed on diet to group the prey items into distinct categories based on their percent abundance (%N) data. The Euclidean similarity index and the paired group algorithm clustering methods were used to categorize the prey items and the fish species on basis of dominant food types[21]. The results of the cluster analyses were presented as dendrograms.

RESULTS

Water quality: All water quality parameters (except temperature) differed significantly between treatments ($p = 0.000$) (Table 3). Turbidity, total dissolved solids (TDS), electrical conductivity (EC), total suspended solids (TSS), total phosphorus (TP), nitrates (NO_3^-), phosphate (PO_4^{3-}), ammonia (NH_4^+) and chlorophyll-a biomass (as Chl-a in mg L^{-1}) were highest in T_1 and lowest in T_4 ponds. In contrast, Secchi disk depth (Z_{SD}), dissolved oxygen (DO), pH, total alkalinity (TA) and nitrites (NO_2^-) were highest in T_4 and lowest in T_1 ponds. However, Dunn's *post hoc* test for multiple comparisons showed that the water quality parameters did not differ significantly between T_2 and T_3 ponds ($p>0.05$).

Principal component analysis (PCA) showed that turbidity accounted for 67% of the total water quality variance. In ponds separately stocked with the common carp and the African catfish, there were significantly increased levels of turbidity, with carp ponds having the highest turbidity (Fig. 1). Turbidity was depressed in ponds where the African catfish were reared together with common carp (T_3 ponds).

Analysis of carp and African catfish diets: Euclidean similarity index and the paired group algorithm cluster analysis performed on percent prey abundance data (N (%)) indicated that the food items eaten by carp and the African catfish belonged to two main groups: Benthic and limnetic (Fig. 2). Benthic food items comprised those found on the bottom zone of the pond, whereas, the limnetic items are those food items normally distributed in the water column.

Results on dietary analysis of carp and the catfish indicated that 75% of prey in T_3 carp were limnetic, whereas, over 80% of prey in T_1 carp, T_2 catfish and T_3 catfish were benthic (Fig. 3). This shows that carp fed mainly on the bottom in absence of the African catfish but switched to the limnetic feeding in presence of the catfish. The African catfish predominantly fed on the bottom in the presence or absence of carp.

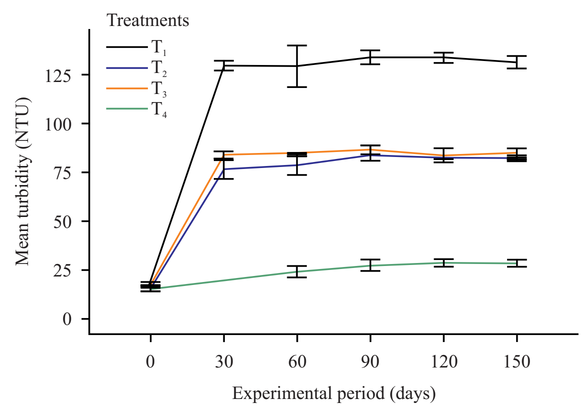

Fig. 1: Levels of turbidity as shown by turbidimeter over time in the four treatments

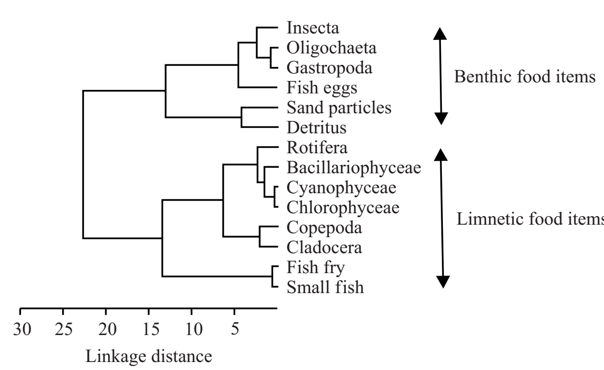

Fig. 2: Dendrogram obtained from a cluster analysis performed on percent abundance of fish stomach contents showing main categories of food items

Table 3: Water quality data (range, mean±standard deviation, Kruskal-Wallis H-values and p-values) in experimental ponds

		Treatments					
	Range	T_1	T_2	T_3	T_4	H-values	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	0.732
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	0.000
Tur (NTU)	12-146	132±18^a	83±38.2^b	84.8±8.3^b	25.8±7.9^c	201.0	0.000
TDS (mg L^{-1})	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	0.000
EC (μS cm^{-1})	18-41	35.4±4.6^a	27.1±2.7^b	28.2±2.1^b	19.4±3.3^c	180.1	0.000
DO (mg L^{-1})	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	0.000
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	0.000
TSS (mg L^{-1})	15.3-95.9	88.5±13^a	66.2±10^b	69.6±9.2^b	29.6±6.3^c	200.8	0.000
TP (mg L^{-1})	0.04-0.25	0.22±0.0^a	0.15±0.0^b	0.16±0.0^b	0.14±0.0^c	165.2	0.000
NO_3^- (mg L^{-1})	0.15-0.37	0.35±0.0^a	0.28±0.0^b	0.29±0.0^b	0.23±0.0^c	168.5	0.000
PO_4^{3-} (mg L^{-1})	0.01-0.15	0.12±0.0^a	0.08±0.0^b	0.09±0.0^b	0.04±0.0^c	170.8	0.000
TA (mg L^{-1})	48-138	65.5±4.1^a	83.8±3.2^b	82.3±2.2^b	121±6.7.^{c}	204.2	0.000
NO_2^- (mg L^{-1})	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	0.000
NH_4^+ (mg L^{-1})	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	0.000
Chl-a (mg L^{-1})	0.78-1.26	1.04±0.0^a	1.12±0.1^b	1.14±0.0^b	1.05±0.2^a	25.6	0.000

Values with the same superscript in a row are not significantly different at p = 0.05, T_1: Ponds with common carp, T_2: Ponds with African catfish, T_3: Ponds with common carp+African catfish and T_4: Ponds with neither common carp nor African catfish (control)

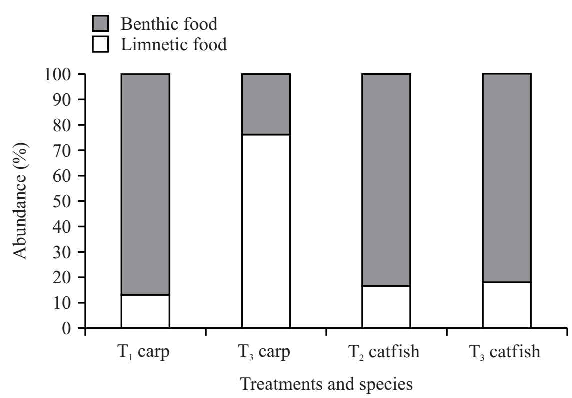

Fig. 3: Percent abundance of main groups of food items removed from stomachs of carp and African catfish in different treatments

T_1 carp: Carp grown in absence of the African catfish, T_3 carp: Carp grown together with the African catfish, T_2 catfish: Catfish grown in absence of carp and T_3 catfish: Catfish grown together with carp

DISCUSSION

Results on water quality indicated that turbidity, total dissolved solids, electrical conductivity, total suspended solids, total phosphorus, nitrates, phosphates and chlorophyll-a biomass were highest in ponds stocked with carp without the catfish (T_1 ponds) and lowest in control ponds which lacked both the catfish and carp (T_4 ponds). However, water quality did not differ significantly between ponds stocked with catfish without carp (T_2 ponds) and ponds stocked with both the catfish and carp (T_3 ponds). These results show that both the carp and the catfish affected water quality, consistent with previous findings[22]. Benthic fishes affect water bodies by modifying water quality and nutrient levels through their disturbance of sediments associated with bottom-feeding behaviour[1]. Increased nutrient levels from sediment resuspension by benthic fishes may result in increased phytoplankton growth[23]. These effects, however, depend on the type of fish in question[1]. Our knowledge was limited on the comparative and synergistic effects of common carp and the African catfish on water quality. As a result, countries that had natural populations of common carp could ban the farming of the exotic African catfish for considering it as more disturbing to water quality than the native carp[14]. On the other hand, countries that had natural populations of the catfish could ban the farming of the exotic carp as they regarded it more detrimental to water quality than the native catfish[8]. This study has shown that common carp affects water quality more than African catfish. Common carp dig deeper in the sediments when foraging on the bottom, causing greater sediment resuspension and nutrient mobilization, than many other benthivorous fishes[5].

However, the study also found that the adverse effects of carp on water quality were suppressed by growing carp together with the African catfish. The results on the dietary analysis of carp and the catfish helped to explain how the catfish controlled carp's effects on water quality. The results indicated that common carp fed predominantly on the bottom zone of ponds where the fish was the only benthic feeder without the African catfish (T_1 ponds). When the African catfish was added to the ponds containing common carp (T_3 ponds), the carp switched its feeding preference from the benthic food items to the limnetic items. Thus, the African catfish displaced common carp from its benthic feeding to water column feeding. This reduced carp's contact with the bottom zone, reducing its sediment resuspension ability and its subsequent effects on water quality. Rahman *et al.*[11] and Rahman[10] found that common carp alters its feeding behaviour from benthivory to planktivory in presence of a more aggressive benthic competitor. The results of the study imply that countries with natural populations of the African catfish may farm the common carp without worrying about adverse effects on water quality.

CONCLUSION

Both common carp and the African catfish affected water quality but the effects of carp were greater than those of the catfish when the two fishes were stocked in separate ponds. When common carp was raised in the same pond with the African catfish, the effects of carp on water quality were reduced. It is concluded that (1) The African catfish can be used as a biocontrol agent to mitigate the adverse effects of carp on water quality and (2) The farming of carp in ecosystems where the African catfish naturally occurs is not likely to adversely affect water quality.

SIGNIFICANCE STATEMENT

Common carp have been associated with adverse effects on water quality. For countries in which the species is exotic, control has often been limited to banning the growing of fish in aquaculture. As common carp is one of the world's most important aquaculture species, banning the fish from its farming has resulted in reduced growth in aquaculture production in some countries. The present study has discovered a new method of controlling the potential adverse effects of common carp on water quality in ponds. The discovery will enable countries with a ban on the farming of common carp to review their policy and permit the farmers to grow the carp to improve aquaculture production.

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