




# Effects of Nile Tilapia (*Oreochromis niloticus*) on phytoplankton community structure and water quality: a short-term mesocosm study

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**Abstract** – Nile tilapia is a highly invasive fish species, deliberately introduced into many lakes and reservoirs worldwide, sometimes resulting in significant ecosystem alterations. A short-term mesocosm experiment with and without Nile tilapia (*Oreochromis niloticus*) was designed to test the hypotheses that the presence of tilapia may affect phytoplankton community structure, increase nutrients availability in water column and deteriorate water quality. Nutrients, total suspended solids (TSS) and biomass of phytoplankton in different size classes (as Chl *a*) were measured. We found that tilapia increased the total nitrogen (TN), total dissolved nitrogen (TDN), NH<sub>4</sub><sup>+</sup> and TSS concentrations, deteriorating the water quality. In addition, under tilapia presence, the biomass of phytoplankton, as well as that of micro- and nano-phytoplankton, increased leading to a change in the structure of the phytoplankton assemblage. Moreover, a reduction in the biomass of periphyton was observed. Omnivorous tilapia is often dominant in tropical and subtropical waters, and removal of this fish may represent an effective management tool to improve the water quality.

**Keywords:** Tilapia / nutrient / phytoplankton community / periphytic algae / water quality

## 1 Introduction

The Nile Tilapia (*Oreochromis niloticus*), an omnivorous fish species, is native to Africa and the southwestern Middle East. It feeds on a variety of foods, including, among others, phytoplankton, zooplankton, suspended detritus, macrophytes and insect larvae (Gurgel and Fernando, 1994; Drenner *et al.*, 1998;

Starling *et al.*, 2002; Canonico *et al.*, 2005). Due to its wide tolerance to environmental constraints, plasticity in feeding behavior, high reproductive rate, year-round spawning and parental brood care, tilapia is considered an extremely invasive species (Kolding, 1993; Canonico *et al.*, 2005; Kour *et al.*, 2014). For nearly a century, it has been introduced in many lakes, reservoirs and rivers worldwide for biological control of insects (especially mosquitos) and aquatic weeds, as bait for some fisheries, and for aquaculture purposes (Starling *et al.*, 2002; Canonico *et al.*, 2005; Figueredo *et al.*, 2005).

Tilapia invasion into non-native freshwater ecosystems may alter phytoplankton community structure, nutrient

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availability and water quality, causing the deterioration of the ecological state of the impacted ecosystems (Peterson *et al.*, 2005; Vicente and Fonseca-Alves, 2013; Charvet *et al.*, 2021). Some data show that omnivorous tilapia can reduce phytoplankton biomass by direct consumption (Saha and Jana, 1998; Lazzaro *et al.*, 2003; Figueredo and Giani, 2005; Lu *et al.*, 2006). The fish can feed on large phytoplankton (Getachew and Fernando, 1989; Turker *et al.*, 2003a; Turker *et al.*, 2003b) using a remarkable array of specialized gill rakers and a cross-flow filtration system (Sanderson *et al.*, 2001). However, some other studies have shown that the omnivorous tilapia may enhance phytoplankton growth in tropical lakes (Attayde and Menezes, 2008).

Omnivorous tilapia, particularly juveniles (Tudorancea *et al.*, 1988), can also consume zooplankton, which is the principal grazer of phytoplankton (Hansson, 1992a; Jeppesen *et al.*, 2004; Figueredo and Giani, 2005), thus exerting an effective control of phytoplankton abundance (Cordero *et al.*, 2015). In fact, when large-bodied zooplankton, such as *Daphnia*, is abundant, phytoplankton biomass is generally low (Lynch and Shapiro, 1981; Attayde and Hansson, 1999; Vakkilainen *et al.*, 2004). Tilapia feeding selectively on zooplankton prefers large-bodied zooplankton including cladocerans and copepods, shifting zooplankton community towards smaller species which are relatively inefficient grazers (Christoffersen *et al.*, 1993; Iglesias *et al.*, 2011; Chen and Liu, 2012). Thus, this consumption of tilapia may result in changes in zooplankton community structure which not only affects the biomass of phytoplankton, but also its community structure due to the selective feeding by zooplankton of different size.

Tilapia is also able to affect nutrient concentration in water column through its excretions and sediment disturbance through snuffling. Nutrients availability affects phytoplankton growth and ultimately the structure of phytoplankton assemblages (Persson, 1997; Vanni and Layne, 1997; Marañón, 2015). In particular, increased nutrient availability, by enhancing phytoplankton growth, causes a dominance shift from small cells to large cells (Li, 2002; Chen and Liu, 2010; Cui *et al.*, 2016).

Furthermore, omnivorous fish including tilapia can also consume periphyton which can compete for nutrients with phytoplankton, thereby favoring phytoplankton growth (Guariento *et al.*, 2010), but may potentially also improve macrophyte growth due to improved light conditions (Meerhoff *et al.*, 2012).

For the above listed reasons, tilapia may not only affect the phytoplankton biomass, but also the structure of its assemblages, and, ultimately, the water quality. Phytoplankton dynamics is a key factor affecting food web, water quality and even the ecosystem state (Kormas *et al.*, 2002; Finkel *et al.*, 2010; Hilligsøe *et al.*, 2011; Shiomoto *et al.*, 2018). However, the effects of tilapia invasion on the structure of plankton community and water quality are still controversial, and deserve further studies. Investigating the biological interactions arising from the presence of tilapia on the plankton community structure can offer important clues to better understand the functioning of aquatic ecosystems impacted by the invasion of this fish. We hypothesize that tilapia can (i) significantly increase nutrient concentration in the water column, (ii) cause a general worsening of water quality, and (iii) strongly affect plankton community structure by

consuming large phyto- and zooplankton. To test the hypotheses, mesocosms with and without tilapia were set up, to analyze the effect of fish presence on water quality parameters and on Chl *a* concentrations of different phytoplankton size-fractions.

## 2 Materials and methods

### 2.1 Set up of experimental mesocosms

Eight circular tanks (upper diameter, 57 cm; bottom diameter, 46 cm; height, 82 cm) were used as mesocosms containing sediment and water. The sediments (TN = 1.13 mg g<sup>-1</sup>; TP = 0.56 mg g<sup>-1</sup>) were collected from Ming Lake (23°13'70"-23°13'75" N, 113° 35'62"-113° 35'74" E), a small shallow eutrophic lake in Guangzhou, China, air dried, powdered and screened through a 0.5 mm stainless steel mesh to remove coarse grains, debris and clumps (Zhang *et al.*, 2016). The water consisted of collected rainwater (TN = 1.58 mg L<sup>-1</sup>; TP = 0.008 mg L<sup>-1</sup>). Each mesocosm had a 10 cm layer sediment added, then was filled with the collected rainwater and left untouched for two weeks.

After this period, in all the mesocosms the concentration of TN in the water column was similar to that of the rainwater, while TP increased to 0.011 mg L<sup>-1</sup>. An artificial leaf made of plastic (length 22.0 cm, width 1.2 cm) was placed on the sediments of each mesocosm as a substrate for periphyton growth. Then, one individual Nile tilapia *Oreochromis niloticus* (average length 12.6 ± 0.2 cm and weight 53.6 ± 4.2 g) was added in each of four mesocosms that represented the tilapia treatments. The fish, purchased from a market in Guangzhou, were maintained in 200-L tanks for two weeks before being introduced in the mesocosms. The tilapias were not fed and the mesocosms were checked every day. In the event of dead fish, they were replaced with a new specimen immediately. Two individuals died at the fourth day of the experiment and were replaced with living specimens of the same size. The other four mesocosms contained no fish as controls. Nitrogen (KNO<sub>3</sub>) and phosphorus (NaH<sub>2</sub>PO<sub>4</sub>) were added to each mesocosm at a rate of 1.5 mg N L<sup>-1</sup> wk<sup>-1</sup> and 0.1 mg P L<sup>-1</sup> wk<sup>-1</sup>, respectively (Zhang *et al.*, 2014). During the experiment, rainwater was added when needed to maintain the water level in each mesocosm. The experiment was carried outdoor from August 18 to October 27, 2020.

### 2.2 Sampling and analysis

Every two weeks, water samples (1L) were collected from 10 cm below the water surface of each mesocosm to measure nitrogen (TN, TDN, NO<sub>3</sub><sup>-</sup>-N, NH<sub>4</sub><sup>+</sup>-N), different size-classes of phytoplankton biomass and periphyton biomass as Chl *a*, total suspended solids (TSS). Nutrients were measured according to American Public Health Association (APHA, 1998). Chl *a* was measured according to Jespersen and Christoffersen (1987). Water samples (200 mL) were filtered on cellulose acetate filters (0.45 µm, 0.2 µm, 2 µm, 20 µm) to measure the Chl *a* concentration in phytoplankton, pico-phytoplankton, nano-phytoplankton and micro-phytoplankton, respectively (Rong *et al.*, 2017). TSS was measured by drying the filters at 105 °C for 24 h to calculate TSS (Zhang *et al.*, 2017). Water temperature was measured by a YSI Model multi-parameter probe. Periphyton growing on the

artificial leaf from each mesocosm was collected using a soft brush. After samples of water and periphyton were collected, nutrients were added to each mesocosm and the artificial substrates for periphyton growth were replaced. The weight and length of each fish were recorded at the end of the experiment.

### 2.3 Statistical analyses

Repeated measures analysis of variance (RM-ANOVAs) was used to assess the differences in nutrient concentrations, different sizes of phytoplankton, periphytic algae biomass and TSS between the controls and the tilapia treatments, with time as the repeated factor after a check of the descriptive statistics and homogeneity of variance. One-way analysis of variance (one-way ANOVA) was conducted to analyze the differences on every sampling occasion between treatments. If the difference was significant, Least Significant Difference (LSD) test was used to detect different treatments. Data were  $\log_{10}$  transformed, if necessary, to meet the assumptions of normality and homogeneity of variance. Statistical analyses were carried out using IBM SPSS Statistics 26. All data are presented as mean values  $\pm$  SD (standard deviation).

## 3 Results

### 3.1 Nitrogen

Concentrations of TN, TDN and  $\text{NH}_4^+$ -N, but not  $\text{NO}_3^-$ -N (Fig. 1) were higher in the tilapia treatments than in the controls (RM-ANOVAs, treatment effect,  $p < 0.05$ ). In addition, TN, TDN and  $\text{NO}_3^-$ -N varied significantly over time (RM-ANOVAs, time effect,  $p < 0.05$ ), while  $\text{NH}_4^+$ -N did not. ( $p > 0.05$ ).

### 3.2 TSS

Concentrations of TSS were higher in the tilapia treatments than in the controls (RM-ANOVAs, treatment effect,  $p < 0.05$ , Fig. 2), especially at week 2 and week 4 (one-way ANOVA, treatment effect,  $p < 0.05$ ). The TSS concentrations did not vary significantly over time (RM-ANOVAs, time effect,  $p > 0.05$ ).

### 3.3 Biomass of phytoplankton

Concentrations of Chl *a* in the water column were higher in the tilapia treatments than in the controls (RM-ANOVAs, treatment effect,  $p < 0.05$ ; Fig. 3). Its values were higher in the tilapia treatments than in the controls on each sampling occasion except at week 4 and week 8 (one-way ANOVA, treatment effect,  $p < 0.05$ ). The phytoplankton biomass varied significantly over time (RM-ANOVAs, time effect,  $p < 0.05$ ).

### 3.4 Biomass of phytoplankton in different size classes

The Chl *a* concentrations in micro-phytoplankton and in nano-phytoplankton were higher in the tilapia treatments than in the controls (RM-ANOVAs, treatment effect,  $p < 0.05$ , Fig. 4). However, pico-phytoplankton biomass (as Chl *a*) values were

generally not significantly different between the treatments (RM-ANOVAs, treatment effect,  $p > 0.05$ ); significantly higher values were recorded in tilapia treatments only at week 6 and week 10 (one-way ANOVA, treatment effect,  $p < 0.05$ ). Micro-phytoplankton biomass varied significantly over time (RM-ANOVAs, time effect,  $p < 0.05$ ), being higher in the tilapia treatments on each sampling occasion (one-way ANOVA, treatment effect,  $p < 0.05$ ), while nano-phytoplankton and pico-phytoplankton biomass did not vary significantly over time ( $p > 0.05$ ).

### 3.5 Periphytic algae

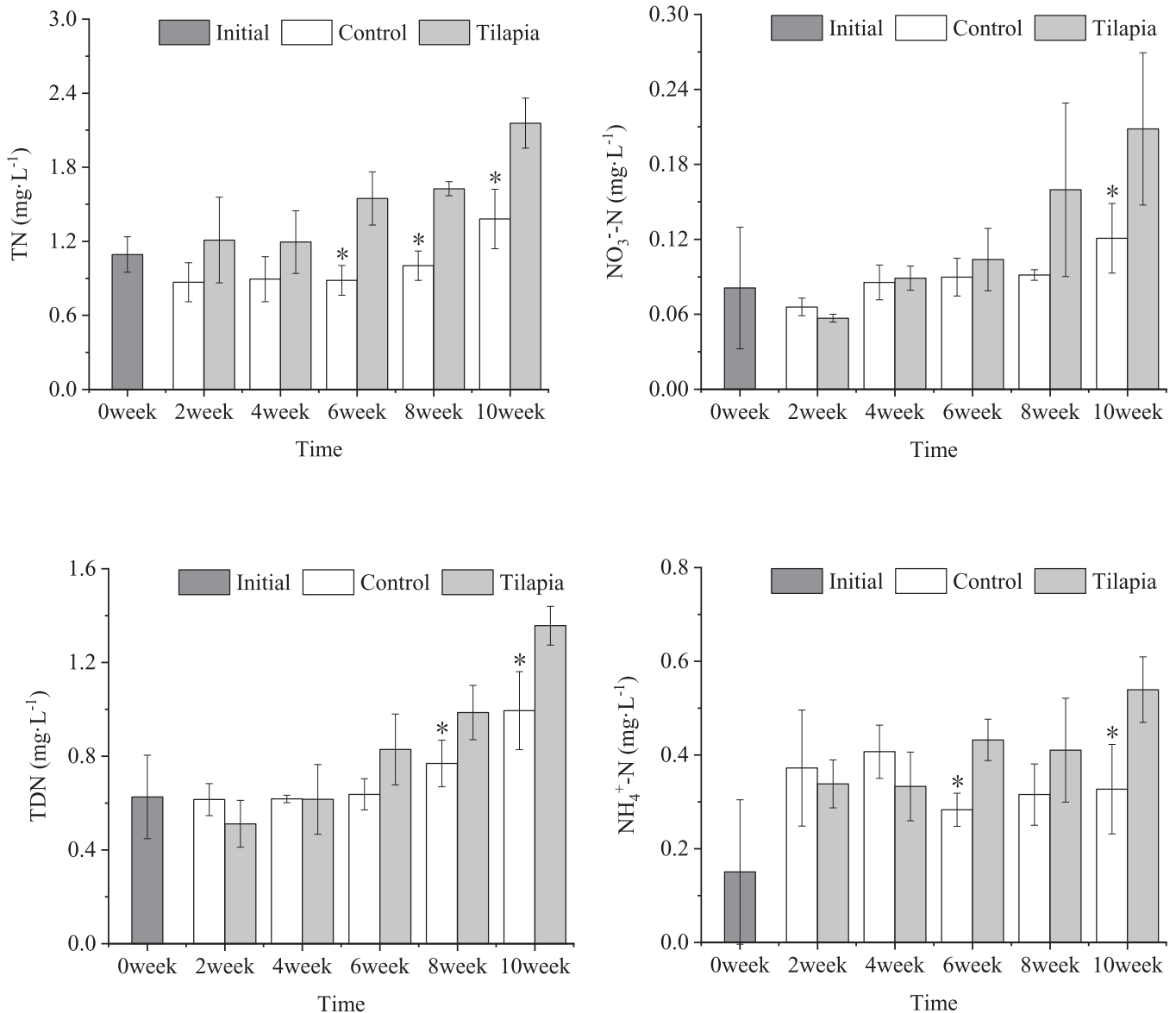
The chl *a* values of periphytic algae in the tilapia treatments were lower than in the controls (RM-ANOVAs, treatment effect,  $p < 0.05$ , Fig. 5), especially at week 6 and week 8 (one-way ANOVA, treatment effect,  $p < 0.05$ ). In addition, the chl *a* values varied significantly over time (RM-ANOVAs, time effect,  $p < 0.05$ ).

## 4 Discussion

The results of our study show that the presence of tilapia increased the concentrations of TN, TDN and  $\text{NH}_4^+$ , TSS and the biomass of phytoplankton, deteriorating water quality. In addition, in the tilapia treatments, higher values of micro-phytoplankton and nano-phytoplankton biomass occurred, showing a modification in the size-structure of phytoplankton assemblage compared to controls. Moreover, the biomass of periphyton in the treatments with tilapia was lower than in the controls.

As an omnivorous species, tilapia can increase nutrient concentrations in several different ways (Huang *et al.*, 2000; He *et al.*, 2018; Yu *et al.*, 2020). The fish can promote sediment resuspension, and therefore transfer nutrients from the benthic to pelagic habitat, when searching for benthic food or when digging holes for building nest (Jiménez-Montealegre *et al.*, 2002; Vanni, 2002; Mayer, 2020). It can also excrete nutrients directly to the water column (Starling *et al.*, 2002). The increase of TN, TDN and  $\text{NH}_4^+$  concentrations observed in the tilapia treatments during our study, strongly support the hypothesis that this fish exerts a positive effect on nutrient availability. Unfortunately, P concentrations were not measured in this study, but previous investigations showed that TP also increases when tilapia is present (Zhang *et al.*, 2017).

It is well known that increased nutrient can enhance growth of phytoplankton (Schindler, 1974) and influence the size-structure of the assemblage (Naselli-Flores, 2014). Phytoplankton assemblages are usually dominated by pico-phytoplankton in nutrient poor conditions (Stockner, 1988; Agawin *et al.*, 2000), while micro-phytoplankton generally dominates in nutrient-rich waters (Stockner *et al.*, 1986; Cui *et al.*, 2016). Tilapia can ingest phytoplankton, especially larger species, such as green algae, diatoms, and even small cyanobacteria (Turker *et al.*, 2003a; Lu *et al.*, 2006). It has been shown that tilapia feeding can significantly reduce phytoplankton number with larger species being filtered proportionally more than smaller ones (Turker *et al.*, 2003b). Furthermore, tilapia can also consume large-bodied zooplankton (Carpenter and Kitchell, 1993; Menezes *et al.*, 2010;



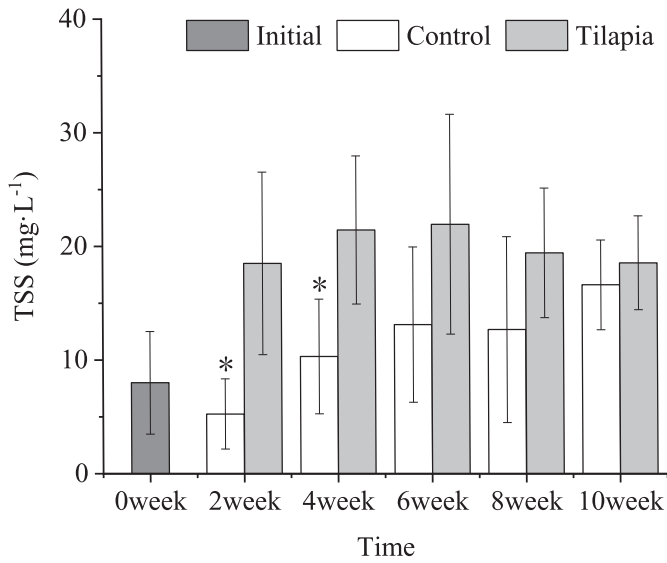
**Fig. 1.** Nitrogen (TN, TDN, NH<sub>4</sub><sup>+</sup>-N, NO<sub>3</sub><sup>-</sup>-N, mean±SD) in different treatments over time. Asterisks indicate significant ( $p < 0.05$ ) differences between the tilapia treatments and the controls.

Torres *et al.*, 2015) whose grazing is important in controlling the size spectrum of phytoplankton assemblages (Cordero *et al.*, 2015), shifting zooplankton community towards smaller species. Because the body size of an individual zooplankton is well related to its grazing rate and to the range of particle sizes it can ingest (Cyr and Curtis, 1999). So, large-bodied zooplankton, such as *Daphnia*, can exert an effective control on phytoplankton with big size. Conversely, small-sized zooplankton, consuming small phytoplankton, is less able to exert an effective control on phytoplankton (Tönno *et al.*, 2016). Thus, the shifting of zooplankton community may not only affect the biomass of phytoplankton, but also affect the phytoplankton in different size-classes due to their selected feeding.

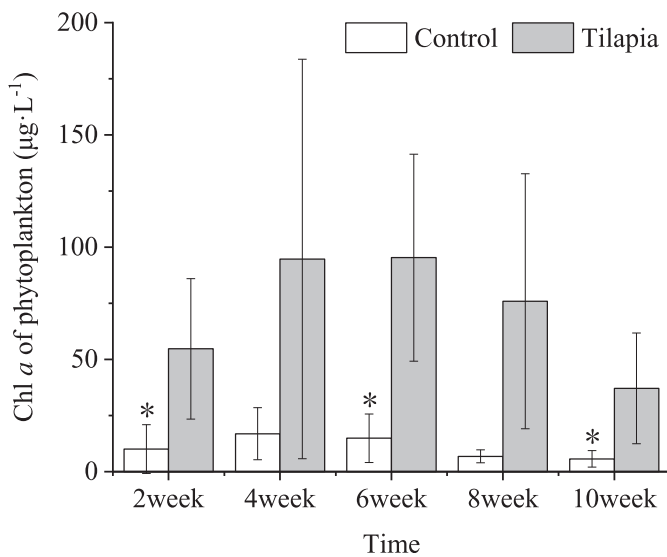
Our study shows that the biomass of micro-phytoplankton and nano-phytoplankton in the tilapia treatments increased

significantly as compared with the controls, while the biomass of pico-phytoplankton was similar in both the experimental groups of mesocosms. The average proportion of micro-phytoplankton biomass in the control and in the tilapia treatment was 31.3% and 62.5% respectively, while the proportion of pico-phytoplankton in the control and in the tilapia treatments was 59.8% and 29.1%, respectively. However, the proportion of nano-phytoplankton biomasses was relatively stable in both tilapia treatments and controls. The increased proportion of micro-phytoplankton biomass and decreased proportion of pico-phytoplankton biomass in the fish treatments indicated that the fish contributed to modify the size structure of phytoplankton assemblages.

The effects of omnivorous tilapia on biomass of phytoplankton can be either positive or negative (Attayde *et al.*, 2010) depending on trophic state. Some studies have



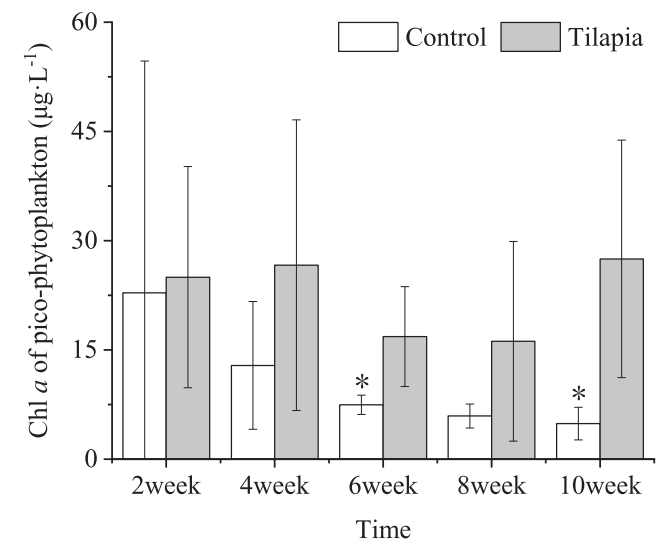
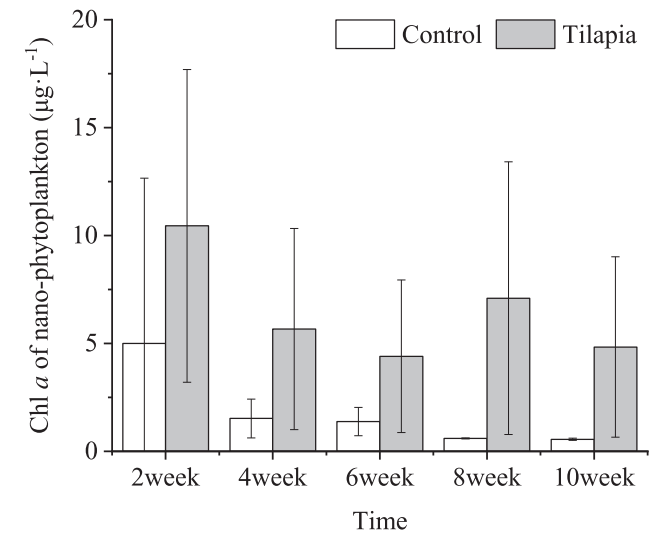
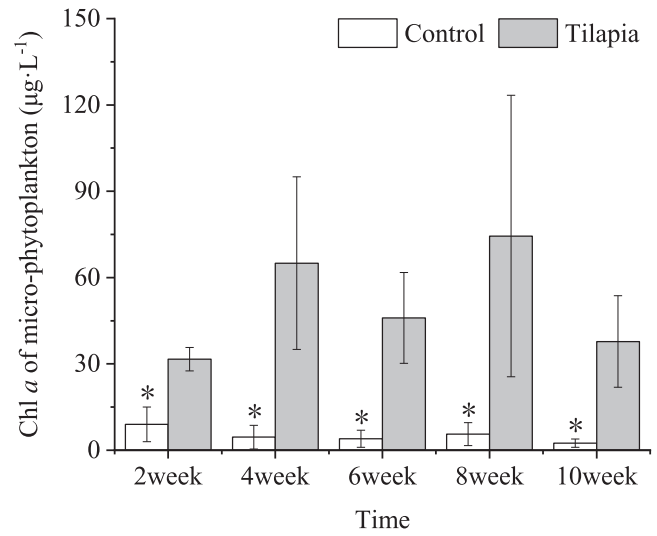
**Fig. 2.** Total suspended solids (TSS, mean ± SD) in different treatments over time. Asterisks indicate significant ( $p < 0.05$ ) differences between the tilapia treatments and the controls.



**Fig. 3.** Phytoplankton biomass (chl *a*, mean ± SD) in the different treatments over time. Asterisks indicate significant ( $p < 0.05$ ) differences between the tilapia treatments and the controls.

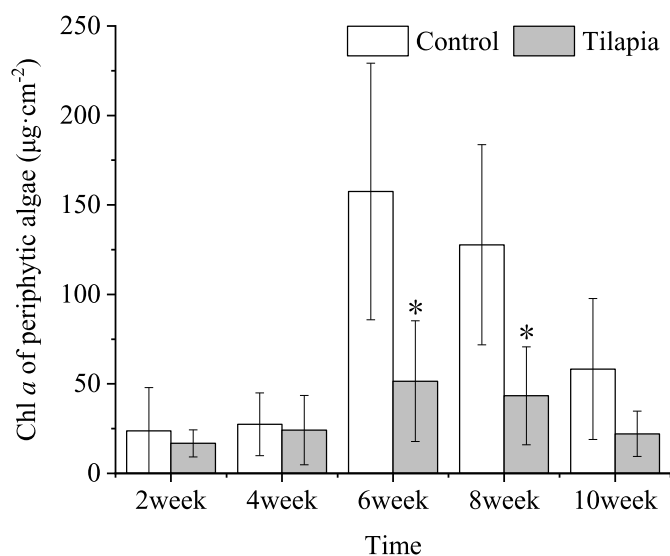
shown that tilapia can reduce the biomass of phytoplankton by direct grazing, and tilapia stocking is considered an effective method to control algal blooms in eutrophic waters (Lu *et al.*, 2006; Menezes *et al.*, 2010). Conversely, other studies have confirmed that tilapia negatively affect on water quality, enhancing nutrient availability and phytoplankton growth (Starling *et al.*, 2002; Figueredo and Giani, 2005; Søndergaard *et al.*, 2008; Zhang *et al.*, 2017). The results of the present investigation showed that the presence of tilapia significantly contributed to promote phytoplankton growth.

Our study also showed that tilapia increased the concentration of TSS and decreased periphyton biomass. The increased concentration of TSS also contributes to deteriorating water



**Fig. 4.** Micro-phytoplankton, nano-phytoplankton and pico-phytoplankton biomass as chl *a* concentration (mean ± SD) in the different treatments over time. Asterisks indicate significant ( $p < 0.05$ ) differences between the tilapia treatments and the controls.





**Fig. 5.** Chl *a* of periphytic algae (mean  $\pm$  SD) in the different treatments over time. Asterisks indicate significant ( $p < 0.05$ ) differences between the tilapia treatments and the controls.

quality (Hansson, 1992b; Vadeboncoeur and Carpenter, 2001; Zhang *et al.*, 2015; Razlutskiy *et al.*, 2021). The decreased abundance of periphytic algae may further benefit phytoplankton growth, lowering the competition for sediment-associated nutrients (Hansson, 1990).

No temperature difference was found between treatments and water temperature was  $27.8 \pm 2.1$  °C in the tilapia treatments and  $27.4 \pm 2.2$  °C in the controls. Density of tilapia ( $322.5 \pm 25.2$  g m<sup>-2</sup>) used in this experiments is realistic, as biomass of the fish in aquatic ecosystems can reach to 390–810 g m<sup>-2</sup> (Suresh and Lin, 1992). Length of the fish increased from  $12.6 \pm 0.2$  cm to  $14.9 \pm 0.7$  cm and weight increased from  $53.6 \pm 4.2$  g to  $55.8 \pm 10.6$  g during the experiment.

We acknowledge that the results obtained in this study is from a short-term (from August to October) mesocosm experiment. In other seasons, the degrees of the fish impact might vary because of the temperature, light and biological activity. We also acknowledge that applying results from the experimental conditions to natural lakes can be problematic due to the small size of the mesocosm used in this study but mesocosm experiments can be replicated and play an important role in the pursuit of ecological understanding. In addition, the general trend of the influence might be similar. However, tilapia would coexist with other fish species in the real world, these combined effects would influence nutrients and algal growth in natural aquatic ecosystems. So, more research is needed on these combined effects due to fish communities.

In conclusion, omnivorous fish as tilapia, which are often dominant in tropical and subtropical waters, can enhance the growth of phytoplankton and change the size-structure of its assemblages. The effects are obtained by combining manifold strategies: tilapia increases nutrients concentration as well as TSS, may decrease the impact of zooplankton grazers, lowers the competitive effects exerted by periphyton. All these effects synergically deteriorate water quality. Fish removal, although

difficult, probably represents an important step in some management plans aimed at improving water quality.

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