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Effect of suspended solids on interaction between filter-feeding fish *Aristichthys nobilis* and zooplankton in a shallow lake using a mesocosm experiment

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ABSTRACT

Suspended solids (SS) resulting from sediment resuspension (SR) can impact ecosystems through direct and indirect effects on freshwater organisms and their interactions. This study was conducted to determine whether the SS can affect the interaction between filter-feeding fish (*Aristichthys nobilis*) and zooplankton using a mesocosm experiment with sediments from Lake Taihu, a large shallow lake in China. SR using pump was divided into three intensities: strong, weak and no SR representing different concentrations of SS. Zooplankton abundance was significantly higher in the no-fish treatments than in the fish treatments under all three SR conditions. SR intensity had significantly negative effect on zooplankton abundance. There were interactions between fish and SR intensity on abundances of copepod, rotifer, total zooplankton and dominant zooplankton species except cladoceran abundance. The results indicate that SS had a lesser effect on zooplankton predation by filter-feeding fish, which suggests that zooplankton communities in shallow lakes can be affected by the filter-feeding fish even under high level of SS condition.

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Sediment resuspension; shallow lakes; zooplankton; filter-feeding fish; predation

Introduction

Sediment resuspension (SR) is an important feature in large shallow lakes, often resulting from wind disturbance. The direct consequence is an increase in suspended solids (SS), which directly and indirectly affect freshwater organisms and their interactions, thereby impacting ecosystem structure and function (De Robertis et al. 2003; Horppila & Liljendahl-Nurminen 2005; Liljendahl-Nurminen & Horppila 2006).

Zooplankton is an important primary consumer in ecosystems, which often leads to a decrease in algal population size. This characteristic can be used to control the algae during the lake restoration (Søndergaard et al. 2000; Benndorf et al. 2002). However, SS resulted from wind and benthivorous fishes can directly or indirectly affect the zooplankton community compositions, thereby impeding the control of algae (Levine et al. 2005; Horppila et al. 2009; Robinsonet al. 2010). SS affect zooplankton community compositions and biomass indirectly by altering phytoplankton compositions and biomass, predator-prey relationships and the outcome of competition among zooplankton, and directly by interfering with zooplankton feeding and inhibiting their growth and reproduction (Kirk & Gilbert 1990; Schulze et al. 2006; Nurminen et al. 2010). Different zooplankton responds

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differently to SS. SS can spur a shift in zooplankton from large to small size depending on the intensity of SR (Jiang et al. 2010). High concentrations of SS (e.g. 50 mg·DW·L^{-1}) can strongly decrease feeding of the cladocerans *Daphnia* and *Ceriodaphnia* (Hart 1988). Compared with large-bodied zooplankton such as *Daphnia* spp., some small cladocerans, copepods and rotifers, have a greater tolerance to SR (Krik & Gilbert 1990; Levine et al. 2005; Jiang et al. 2010).

SR also affects zooplankton indirectly by altering the relationship between predator and prey. In turbid water, SS can affect the gill structure, metabolism and behavior of fish, depending on the fish species and turbidity (Whitman et al. 1982; Bilotta & Brazier 2008; Lunt & Smee 2015). High SS or water color can decrease the feeding rate of visually oriented fish on zooplankton (Liljendahl-Nurminen & Horppila 2006; Estlander et al. 2010). A day–night investigation demonstrated, through the analysis of gut contents, that predation of a visually oriented fish, *Hemiculter leucisculus*, on zooplankton is light-dependent; there was an abundance of zooplankton in the digestive tracts of *H. leucisculus* during the daytime but very few at night (Lv et al. 2011). For filter-feeding fish, studies of the effect of SS on zooplankton predation are very limited. De Robertis et al. (2003) found that predation by two species of planktivorous fish (*Oncorhynchus keta* and *Theragra chalcogramma*) on oceanic zooplankton (*Artemia salina*) was much less sensitive to turbidity.

Lake Taihu is a large shallow lake in China in which SS is often high because of SR from wind disturbance. Previous studies have shown a direct effect of SS on zooplankton communities (Song 2008; Jiang et al. 2010). Those results demonstrated that *Daphnia*, *Ceriodaphnia*, *Moina* and calanoids were negatively affected by strong SR with a SS of 40 mg·L^{-1}, whereas a lesser effect was observed on *Bosmina*, nauplii and rotifers. In this study, we conducted a mesocosm experiment to evaluate the effect of SS on interactions between filter-feeding (*Aristichthys nobilis*) fish and zooplankton. Our previous study has demonstrated that the visually oriented fish has a weak predation on zooplankton under higher SS conditions (Zhou & Chen 2015). Our aim in the present study would be to determine whether SS can affect the interactions between filter-feeding fish and zooplankton. If this effect was different from visually oriented fish, our result can further illustrate that SS would alter the relationship between fish and zooplankton at the community level. Thus, the fish community should be regulated in the management of the shallow lakes.

Materials and methods

Experimental design

The experiment was conducted from 31 July to 14 August in 2014. The SR was regulated by inflator pumps. The experiment was carried out in glass fiber tanks with a top diameter of 1.2 m, a bottom diameter of 1.0 m and a height of 1.2 m. To avoid significant fluctuations in water temperature, the tanks were placed in one shallow pond. The top of the tank was 20 cm above the water surface of the pond. Prior to the experiment, a 10 cm layer of sediment from the eastern part of Lake Taihu, which had been filtered through a 6 mm mesh screen to remove snails and large detritus, was placed into the tanks. After the sediment was added, 950 L of water, also from the eastern part of Lake Taihu, was added to each tank. The tanks then stood for two days prior to the start of the experiment.

Based on our previous study on the effects of the SR on zooplankton (Jiang et al. 2010) and monitoring by the Taihu Laboratory for Lake Ecosystem Research, Chinese Ecosystem Research Network (CNERN TLLER), we selected three concentrations of SS for the SR treatments. The SS concentrations were approximately 40 and 30 mg·L^{-1} for strong SR and weak SR, respectively. Pumps of different powers were used to control the different levels of SS. No pumps were placed in the no SR tanks.

The filter-feeding fish *Aristichthys nobilis* was used in this experiment. Six treatments were created as follows: (1) strong SR + one *A. nobilis*, (2) strong SR + no fish, (3) weak SR + one *A. nobilis*,

(4) weak SR + no fish, (5) no SR + one *A. nobilis* and (6) no SR + no fish. No SR indicated no regulation by inflator pumps, and not meaning no SS. Each treatment was created in triplicate. *A. nobilis* with a body length of 15 cm were obtained from the Freshwater Fisheries Research Center of the Chinese Academy of Fishery Sciences, Wuxi.

Sampling and analysis

Samples were taken at the beginning and the end of the experiments. Water temperature was measured using a YSI 6600 meter. Samples were taken from the upper and lower layers for chemistry and zooplankton analyses. Total nitrogen (TN) and total phosphorus (TP) concentrations were analyzed by colorimetry after digestion of samples (Ebina et al. 1983). Samples were filtered through pre-dried Whatman GF/C filters, dried (105 °C for 4 h) and weighed to determine the concentration of SS. Chlorophyll *a* (Chl *a*) was extracted with 90% acetone for 24 h, and its concentration was subsequently determined by colorimetry and calculated according to the equation of Jin and Tu (1990).

Planktonic crustaceans (cladocerans and copepods) were collected by filtering 10 L of mixed water collected at the two depths through a 64 μm net and preserved in 4% formaldehyde. For microscopic counting of rotifers, 1 L water samples mixed from the two depths were treated with 10 mL of Lugol's iodine and sedimented for 48 h. The supernatant was removed and the residue was collected. Planktonic crustaceans and rotifers were counted at 40× magnification. Species identification was based on Wang (1961), Chiang and Du (1979) and Shen and Du (1979). Zooplankton biomass (dry weight) was estimated using equations from Huang (1999).

Statistics

A two-way ANOVA was used to compare the effects of fish, SR intensity and their interaction on SS, Chl *a* and the abundance and biomass of zooplankton. The data used in statistical was not transformed in any way. In the present study, ANOVA results conform to the assumption of ANOVA that the distributions of the residuals were normal and the variances were homogeneity. After ANOVA analysis, we used a *t*-test to compare the results of fish and no-fish treatments with the same SR condition. All analyses were conducted using SPSS 17.0.

Results

The initial water temperature and concentrations of TN and TP were 33.3 °C, 1.36 mg·L^{-1} and 120 μg L^{-1}. At the end of the experiment, the water temperature had dropped to 32.3 °C. TN increased by 62.5% and TP decreased by 41.7%. SS and Chl *a* concentrations were significantly different (ANOVA, $p < 0.001$) among the three SR treatments. *Aristichthys nobilis* and SR had no interaction effect on SS and Chl *a*. Chl *a* concentrations were significantly higher under the strong and weak SR conditions than under the no SR condition (*t*-test, $p = 0.001$, Figure 1). No significant difference was observed in the concentrations of SS and Chl *a* (*t*-test, $p > 0.05$) between the filter-feeding fish *A. nobilis* and the no-fish treatments under the same SR conditions except significant difference under the no SR conditions (*t*-test, $p = 0.028$).

The composition of zooplankton was the same across treatments at the beginning of the experiment. Initial zooplankton abundance was not significantly different (*t*-test, $p > 0.05$). The initial dominant species in this experiment were the cladocerans *Bosmina longirostris* and *Ceriodaphnia cornuta*, the copepod *Mesocyclops* sp. and the rotifer *Brachionus* spp.

The two-way ANOVA indicated that *A. nobilis* and SR had significant independent effects as well as an interaction effect on the abundance of all taxa, except there was no interaction effect for cladocerans (ANOVA, $p = 0.775$) (Table 1). By the end of the experiment, *t*-test analysis indicated that

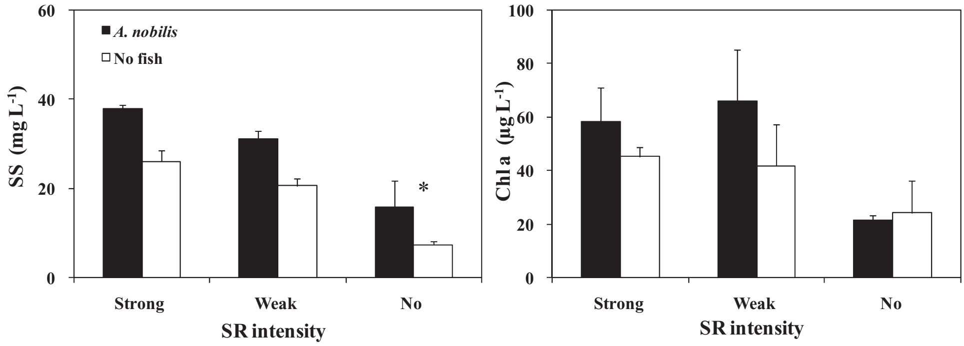

Figure 1. Concentrations (average ± SD) of suspended solids (SS) and chlorophyll *a* (Chl *a*) in the different intensities of the sediment resuspenison (SR) at the end of the experiment with filter-feeding fish (*Aristichthys nobilis*). The asterisk indicates the difference significance of values (*t*-test) between fish and no-fish treatments under the same intensity of SR at the level of $p < 0.05$ (*).

zooplankton abundance was significantly higher in the no-fish treatment than in the fish treatment, with the exception of rotifer abundance under conditions of the weak and no SRs (Figure 2).

The large-bodied cladoceran *Daphnia galeata* was documented at the beginning of the experiment. By the end of the experiment, *D. galeata* had a very low biomass in the presence of the weak and no SRs. In the fish treatment, the biomass of *C. cornuta, B. longirostris* and *Mesocyclops* sp. were all very low and decreased as the intensity of SR weakened. These three crustaceans showed a higher biomass in the no-fish treatments.

The two-way ANOVA indicated that fish and SR had significant independent effects as well as an interaction effect on the biomass of the three taxa (Table 2). By the end of the experiment, *t*-test analysis indicated that significant differences between fish and no-fish treatments were observed for *C. cornuta* under weak and no SRs, for *B. longirostris* with no SR and for *Mesocyclops* sp. under all three SR conditions (Figure 3).

Table 1. Results of two-way analysis of variance performed on suspended solids (SS), chlorophyll *a* (Chl *a*) and abundance of zooplankton in relation to fish and the intensity of the sediment resuspension (SR).

	df	*F*	*P*
SS			
Fish	1	57.01	<0.001
SR	2	79.11	<0.001
Fish × SR	2	0.61	0.56
Chl *a*			
Fish	1	4.02	0.068
SR	2	12.52	0.001
Fish × SR	2	1.92	0.19
Cladoceran			
Fish	1	70.06	<0.001
SR	2	5.46	0.021
Fish × SR	2	0.26	0.775
Copepod			
Fish	1	328.2	<0.001
SR	2	124.1	<0.001
Fish × SR	2	57.8	<0.001
Rotifer			
Fish	1	136.5	<0.001
SR	2	76.7	<0.001
Fish × SR	2	12.2	0.001
Total			
Fish	1	449.7	<0.001
SR	2	50.2	<0.001
Fish × SR	2	35.4	<0.001

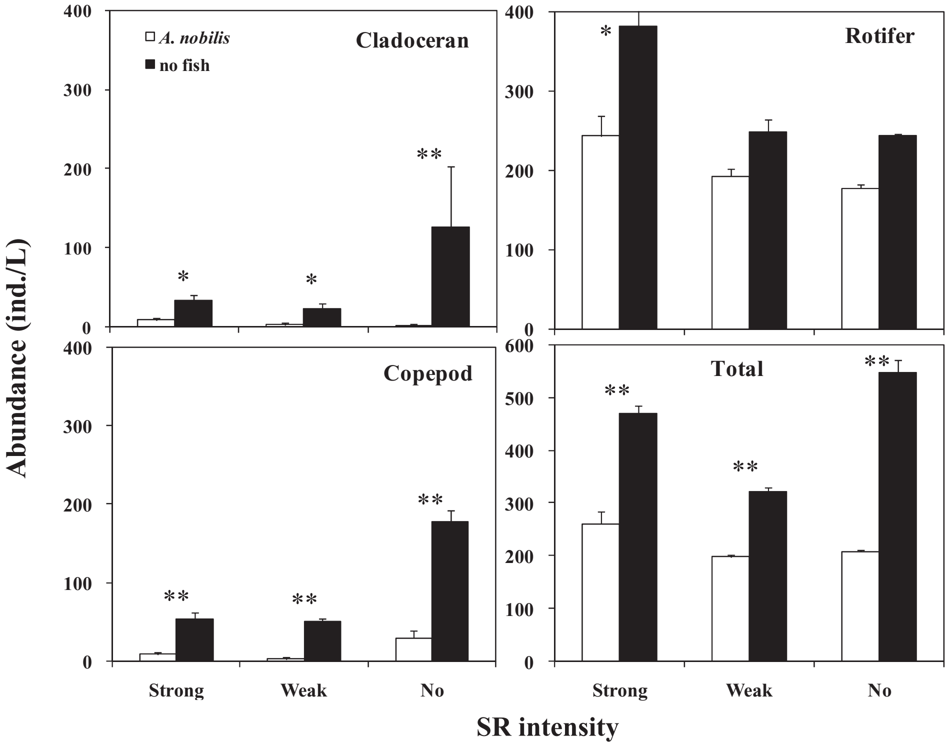

Figure 2. Abundance (average ± SD) of cladoceran, copepod, rotifer and total zooplankton in the different intensities of the sediment resuspensison (SR) at the end of the experiment with filter-feeding fish (*Aristichthys nobilis*). The asterisks indicate the difference significance of values (*t*-test) between fish and no-fish treatments under the same intensity of SR at the level of $p < 0.05$ (*) and $p < 0.01$ (**).

Discussion

Effect of SS on zooplankton

Our results showed that cladoceran and copepod rather than rotifer were significantly negatively affected by SR. SS can spur a shift in zooplankton from a large to a small body size depending on the intensity of SR (Jiang et al. 2010). In the present study, the large-bodied cladoceran *D. galeata* was documented at the beginning of the experiment, but the low abundance of *D. galeata* at the end of the experiments appeared in all treatments, even in no-fish treatment. The low abundance of *D. galeata* may be attributable to high temperature (Huang & Hu 1984; Benndorf et al. 2001).

Table 2. Results of two-way analysis of variance performed on biomass of zooplankton species in relation to fish and the intensity of the sediment resuspension (SR).

	df	*F*	*P*
Ceriodaphnia cornuta			
Fish	1	97.4	<0.001
SR	2	8.5	0.005
Fish × SR	2	19.5	<0.001
Bosmina sp.			
Fish	1	7.6	0.017
SR	2	4.9	0.028
Fish × SR	2	5.3	0.022
Mesocyclops sp.			
Fish	1	220.4	<0.001
SR	2	67.3	<0.001
Fish × SR	2	72.1	<0.001

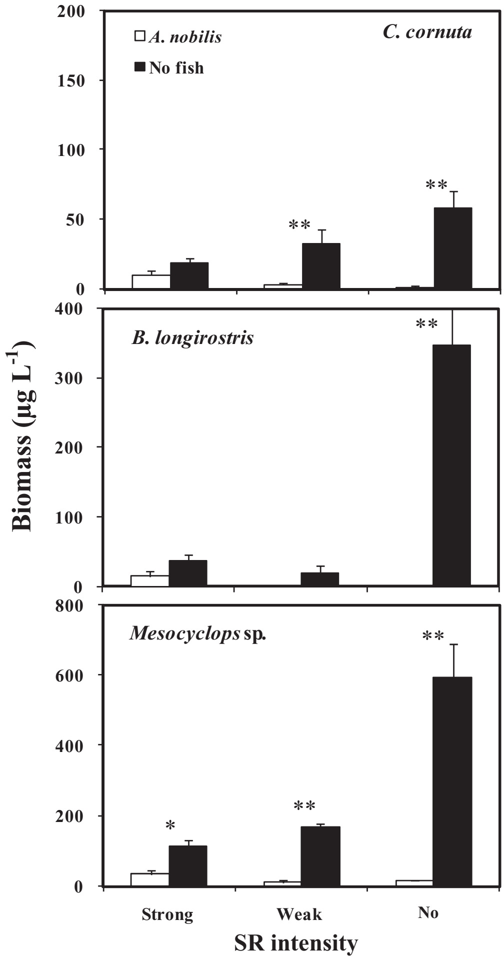

Figure 3. Biomass (average ± SD) of dominant zooplankton species in the different intensities of the sediment resupensison (SR) at the end of the experiments filter-feeding fish (*Aristichthys nobilis*). The asterisks indicate the difference significance of values (*t*-test) between fish and no-fish treatments under the same intensity of SR at the level of $p < 0.05$ (*) and $p < 0.01$ (**).

Compared with large-bodied zooplankton such as *Daphnia* spp., some small cladocerans, including copepods and rotifers, are more tolerant to SR (Kirk & Gilbert 1990; Levine et al. 2005; Jiang et al. 2010). SS negatively affect zooplankton through interfering with their feeding and inhibiting their growth and reproduction (Kirk 1991; Schulze et al. 2006; Nurminen et al. 2010).

In our study, *C. cornuta* and *B. longirostris* belong to small cladoceran, whose biomass were significantly negatively affected by strong SR. High concentrations of SS from SR can strongly decrease feeding of *Ceriodaphnia* (Hart 1988). The mesocosm experiments in Lake Taihu showed that *C. cornuta* was negatively affected by higher level of SS of 40 mg·L^{-1} (Song 2008; Jiang et al. 2010). Inhibition of *Bosmina* by SS in our study contrasts with previously published results (Song 2008), in which *Bosmina* is less sensitive to SS. The experiments of Song (2008) and Jiang et al. (2010) were conducted in May and June, when water temperature was below 30 °C, while water temperature in our study was higher than 30 °C. So we inferred that negative effect of SS on *Bosmina* may contribute to interactions of SS and high temperature.

Song (2008) and Jiang et al. (2010) have found that strong SR has a lesser effect on nauplii. The effect of high level of SS on cyclopoids in those experiments is difficult to evaluate because of a very low abundance in the different treatments. In our experiment with no-fish treatments, the low biomass of *Mesocyslops* sp. in the strong and weak SRs treatment reflected the negative effects of SS on copepods.

Effect of SS on fish predation

Our study showed the strong predation of filter-feeding fish *A. nobilis* on zooplankton even under the strong and weak SRs treatments. In most cases, the abundance and biomass of zooplankton were significantly negatively lower in the fish treatment than in no-fish treatment under the same SR condition. Contrary to *A. nobilis*, predation on zooplankton by the visually oriented fish *H. leucisculus* was greatly affected by SS (Zhou & Chen 2015). In their study, the abundance and biomass of zooplankton were insignificantly higher in the fish treatment than in no-fish treatment under the same SR condition in most cases. High SS or water color can decrease the feeding rate of visually oriented fish (Liljendahl-Nurminen & Horppila 2006; Estlander et al. 2010; Schulze 2011). Another analysis of the gut contents also showed that predation by *H. leucisculus* on zooplankton is also controlled by natural light (Lv et al. 2011). In Lake Zixia, in which transparency was 2.1–3.4 m, there were obvious differences in the gut contents of *H. leucisculus* during the day and the night (Lv et al. 2011). During the daytime, there was an average of 196 planktonic crustaceans per fish, most of which were *Bosmina* sp., *Bosminopsis deitersi* and *Thermocyclops taihokuensis*. During the night, only 0.2 crustaceans per fish were found in the gut which was, however, full of detritus.

Aristichthys nobilis preferred zooplankton prey over another filter-feeding fish *Hypophthalmichthys molitrix*. This fish can strongly depress daphnid populations (Zhao et al. 2016), and other zooplankton such as *Bosmina* sp. are also its preferred food (Li et al. 2013). De Robertis et al. (2003) found that predation by two species of planktivorous fish on oceanic zooplankton was significantly less sensitive to turbidity. In the present study, the strong predation of *A. nobilis* on zooplankton under the strong SR conditions indicates that predation by *A. nobilis* is less sensitive to turbidity.

Thus, SS effect on fish is species-specific. SS can inhibit the predation of visually oriented fish on zooplankton (Schulze 2011) and piscivorous fish on fish prey (Shoup & Wahl 2009) while less inhibition to filter-feeding fish, e.g. *A. nobilis*. In China, *A. nobilis* and *H. molitrix* are important culture fishes in shallow lakes, in which the water was often turbid and zooplankton abundance were very few (Chen, unpublished data). Top-down control of zooplankton on the algae would be impossible in these lakes. So in shallow turbid lakes, it is necessary to regulate the fish community compositions through controlling the abundance of the cultured filter-feeding fishes in the lake managements.

In conclusion, in shallow lakes, high SS level is an important feature often resulting from SR owing to wind disturbance, which not only directly affects zooplankton abundance and compositions but also has indirect effects on zooplankton by altering the interaction between predator and prey. Our results showed that this indirect effect has less inhibition of predation by filter-feeding fish on zooplankton. Thus, filter-feeding fish still has negative effect on the compositions and abundance of zooplankton communities under the high level of SS conditions in shallow lakes, further impacting ecosystem functions.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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