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Short communication

Stocking of herbivorous fish in eutrophic shallow clear-water lakes to reduce standing height of submerged macrophytes while maintaining their biomass

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A R T I C L E I N F O

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A B S T R A C T

To balance the conservation value versus recreational use of shallow lakes, moderate herbivory may be needed in eutrophic lakes to avoid near surface growth while maintaining high vegetation biomass close to the sediment. However, over-grazing or even complete elimination of macrophytes by grass carp (*Ctenopharyngodon idella*) commonly used for control purposes has often been observed, leading to a shift from a clear to a turbid phytoplankton-dominated state. We hypothesized that slow-growing and smaller-sized herbivorous fish species might be more suitable than grass carp to obtain the desired moderate control because they consume the top part of the vegetation without severely affecting the lower plant parts. To test the hypothesis, the effects of Wuchang bream (*Megalobrama amblycephala*), an endemic medium-sized herbivorous cyprinid, and grass carp on the biomass, density and trait of the macrophyte *Vallisneria denseserrulata* were compared in an enclosure experiment. We found that *V. denseserrulata* grew less tall but did not lose biomass under moderate herbivory by Wuchang bream due to increased plant density and leaf weight per length, whereas excessive herbivory by grass carp had strong negative effects on the plant biomass. Moreover, the plant had more and thicker leaves in the fish treatments than in the fishless controls. The growth of grass carp was much faster than that of Wuchang bream. Our findings suggest that stocking of Wuchang bream in proper densities may be more useful than grass carp for the management of *V. denseserrulata* and likely also other macrophyte species. More tests, especially at different fish densities are, however, needed to draw any firm conclusions regarding this hypothesis.

1. Introduction

Submerged macrophytes play an important role in structuring freshwater ecosystems (Jeppesen et al., 1998) and have major effects on the productivity and biogeochemical cycles in freshwater lakes (Carpenter and Lodge, 1986). They reduce resuspension, sediment phosphorus release, and often also the internal nutrient loading and thus help to maintain a clear-water state (Carpenter and Lodge, 1986; Scheffer et al., 1993; Barko and James, 1998; Zhang et al., 2017). Excessive growth of submerged macrophytes, especially tall-growing plants may however, occur under eutrophic conditions, which potentially has a detrimental impact on the use of these for recreational and commercial activities such as swimming, boating, and fishing (Hilt et al., 2006). In eutrophic lakes, in order to hold the sediment in place and lower the phosphorus release, methods to ensure moderate control of vegetation, allowing high biomass close to the sediment but minimal that near the water surface, are therefore desired.

Today's methods for aquatic weed control include physical, biological, and chemical elements (Hussner et al., 2017). Considering the deficiencies of physical and chemical methods (Hilt et al., 2006; Hussner et al., 2017), biological methods involving use of aquatic herbivorous vertebrates or invertebrates, especially grass carp (*Ctenopharyngodon idella*), have been widely used, for instance in the USA (Mitchell and Kelly, 2006). Stocking of grass carp may, though, have undesirable side effects, among these a complete elimination of macrophytes leading to turbid conditions (Cassani, 1995; Petr, 2000; Pípalová, 2006), and in reality the desired objective of moderate control of aquatic vegetation is only rarely achieved (Petr, 2000; Bonar et al., 2002). The ideal relationship between the stocking density of grass carp and vegetation abundance is unpredictable, and the only

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certainty is that extensive stocking just results in total loss of submerged macrophytes (Hanlon et al., 2000; Dibble and Kovalenko, 2009).

Removal of only the top part of plants will limit seed production and force the plants to reproduce clonally in addition to or instead of sexually, thereby enhance clonal growth (Gardner and Mangel, 1999; Knight et al., 2005; Maron and Crone, 2006). In marine ecosystem, studies on the seagrasses *Thalassia testudinum* and *Posidonia oceanica* showed that meadow beds became much shorter and shoot density increased when the seagrasses were exposed to herbivory (Valentine et al., 1997; Planes et al., 2011). In freshwater ecosystem, some species like *V. natans* have shown a strong compensatory growth response after clipping (Li et al., 2010). European investigations have demonstrated that some widespread medium-sized herbivorous cyprinids, such as roach (*Rutilus rutilus)* and rudd (*Scardinius erythrophthalmus*), may slightly reduce vegetation biomass (Prejs, 1984). So, low or moderate grazing intensity by fish is suggested to reduce submerged macrophyte height but only moderately affect vegetation biomass; also, it may increase the shoot density of some clonal species like species from *Vallisneria*. The question to be elucidated is then if small or medium-sized herbivorous fish can be used as an alternative to large-sized species like grass carp to achieve the desired moderate reduction of meadow bed height without erasing the submerged macrophyte community. Such moderate reduction would maintain a clear-water state and minimize the conflict between natural conservation values and recreational users.

We conducted a field experiment to compare the effects of the two common herbivores – large-sized grass carp and medium-sized Wuchang bream (*Megalobrama amblycephala*) – on the plant biomass and traits of the meadow-forming submerged macrophyte *Vallisneria denseserrulata*. Wuchang bream is an endemic medium-sized species in some macrophyte-dominated lakes in the middle reaches of the Yangtze River (Cao, 1960), and *V. denseserrulata* is a perennial submerged macrophyte and frequently applied in lake restoration projects because of its fast clonal growth and developed root system that holds the sediment in place (Zhou et al., 2016).

We hypothesized that the effects of Wuchang bream on the plants would be less damaging than those of grass carp as their grazing is more lenient and does not cut the plants to near the sediment surface; thus, plant clonal growth and plant density would increase, allowing moderate plant biomass under clear-water conditions.

2. Material and methods

2.1. Experimental design

The enclosure experiment was conducted from May to November 2015 in a 6000 m^2 fish-free pond located at Dushan town, Ezhou City, Hubei Province (China) near Lake Liangzi. *V. denseserrulata* individuals were evenly planted at 16–18 cm intervals in May at formerly macrophyte-free sites, and were left to grow undisturbed for about two months after which they formed a uniform carpet on the bottom. In July, 12 enclosures were established side by side. The enclosures (2.0 m × 2.0 m × 1.5 m height, water depth 1.0 m) were made of nylon nets with a mesh size of 1 cm × 1 cm, permitting water flow through in order to reach identical nutrient levels in all treatments, while excluding fish. The enclosures were open at the top and bottom and fixed in the sediment with four bamboo sticks.

On 10 August, fish were added to the enclosures. One 1-year grass carp weighing about 300 g and with a total length of 30 cm was added to each of four randomly selected enclosures. Two 1-year individuals of Wuchang bream weighing about 190 g and with a total length of 26 cm were added to another four enclosures, leaving four fish-free enclosures to serve as controls. According to Chen et al. (1993), the total food intake of two Wuchang bream would be about half that of one grass carp at the beginning of the experiment that ran for 102 days after stocking. The experiment ceased on 19 November when, the fish were caught by electrofishing, plants were removed by hand and fish and plants were measured.

2.2. Plant trait determination

To determine initial *V. denseserrulata* biomass, plants were harvested at eight random sites (0.5 m × 0.5 m) near the enclosures using a welded iron frame. Trait parameters of *V. denseserrulata* were established at the end of the experiment. Plant height in the water was determined by a ruler (to the nearest 1 mm) before ceasing the experiment. Plants were collected by hand and rinsed carefully to remove attached matter on leaves and roots. Total biomass (wet weight) was estimated for each enclosure using an electronic balance (to the nearest 50 g). Ten individuals were randomly chosen from each enclosure to determine plant traits. The fresh weight of each plant including leaves and roots was determined with an electronic balance (to the nearest 0.01 g). For each plant, the number of leaves was counted. The length of the three leaves randomly chosen from each plant was measured using a ruler (to the nearest 1 mm). Moreover, thickness at mid position of the three leaves was measured using a digital caliper (to the nearest 0.01 mm). Plant density in each enclosure was calculated as total biomass divided by average wet weight of ten plants. Leaf weight per length was calculated as total leaf weight of plant individual divided by total leaf length (the average length of the three randomly chosen leaves multiply by leaf number).

2.3. Data analysis

The relative growth rate (RGR) of fish in each enclosure was calculated using the following equation: RGR ($mg\,g^{-1}\,d^{-1}$) = 1000 × ln (W_f/W_i)/days, where W_f (g) and W_i (g) were final and initial total fish biomass in each enclosure, respectively. Repeated measures analysis of variance (One-Way ANOVA) was applied to elucidate the effect of herbivory by the two fish species on *V. denseserrulata* in the mesocosms. The statistical analyses of this study were performed using the statistical package SPSS 16.0, and the level of significance was set to $P < 0.05$ for all tests.

3. Results

3.1. Plant biomass and traits

The biomass (standing crop) of plants (wet weight) did not change in the control treatment ($P = 0.42$) (Fig. 1a). In contrast, in the grass carp treatment plant biomass significantly decreased by more than 50% ($P < 0.01$), whereas no significant changes occurred in the Wuchang bream treatment ($P = 0.89$) (Fig. 1a). Plant height in the water significantly decreased by more than 50% in the Wuchang bream treatment ($P < 0.01$) (Fig. 1b). The plants were cut to less than 10 cm, near the sediment surface in the grass carp treatment (Fig. 1b). Plant density increased more significantly in the fish treatments than in the control treatment ($P < 0.05$, both fish species) (Fig. 1c). Leaf weight per length increased significantly in both fish treatments compared with the controls ($P < 0.01$, both species) (Fig. 1d). The number of leaves per plant individual was similar in the fish treatments ($P = 0.14$), and higher than in the fish-free control treatment ($P < 0.05$, $P < 0.01$, respectively) (Fig. 1e). The leaves in the fish treatments were thicker than in the controls ($P < 0.01$, both fish species) (Fig. 1f).

3.2. Fish growth

The grass carp grew from 300 ± 10 g to 858 ± 30 g, and the two Wuchang bream grew from 190 ± 7 g to 302 ± 40 g each. The grass carp grew much faster than Wuchang bream, 10.5 $mg\,g^{-1}\,d^{-1}$ vs. 4.7 $mg\,g^{-1}\,d^{-1}$.