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Short term succession of artificially restored submerged macrophytes and their impact on the sediment microbial community

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ABSTRACT

Artificially supported colonization of submerged macrophytes was tested *in-situ* in Maojiabu, a sublake of West Lake (Hangzhou City, China). Multiple species, including *Hydrilla verticillata*, *Vallisneria natans*, *Myriophyllum spicatum* and *Ceratophyllum oryzetorum*, were artificially restored in two enclosures that differed in water depth. The multiple species community existed less than a year, but the colonization of *Vallisneria natans* was successful and reached a biomass of 430.6 g m^{-2} in the shallow enclosure after one year of succession. Redundancy analysis indicated that plant biomass was most closely correlated with total nitrogen (TN) concentration of the water column, which is the limiting factor for the trophic state of West Lake. Plant biomass was correlated with water depth, though water transparency reached the bottom. The growth of *Potamogeton crispus*, a species that spontaneously germinated in the wintering stage, was promoted by the macrophyte species that grew before winter. The microbial community characterized by fatty acid methyl esters (FAMEs) showed that the proportion of aerobic microbes and fungi in sediment was closely related with macrophyte biomass, which might be a response of the microbial community to the nutrient demand of macrophyte growth. The results implied that restoration of submerged macrophytes could be enhanced by artificially supported colonization which further modified the microbial community in the sediment. Although the presence of multiple vegetation species could not be sustained at this time, *Vallisneria natans* is a suitable pioneer species for large-scale ecological engineering in West Lake.

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1. Introduction

Submerged macrophytes, capable of increasing transparency, sheltering macro-invertebrates, and preventing sediment resuspension, are a key factor in maintaining the vegetated clear state in eutrophic shallow lakes (Engel, 1988; Scheffer et al., 2001). Macrophyte recolonization has been recognized as a critical step for ecological restoration of shallow lakes. Successful cases of submerged macrophyte recovery have been reported. For example, in Lake Væng and Lake Arreskov, the coverage of submerged macrophytes increased from <1% to 60% and 80%, respectively within 2–5 years following biomanipulation (Lauridsen et al., 2003). Submerged macrophyte abundance increased abruptly in an English shallow lake (Little Mere) after nutrient loading reductions (Jeppesen et al., 2005). However, delayed recovery or lack of re-colonization of submerged macrophytes are common in lake restoration. An investigation of 58 lakes in north-eastern Germany showed that while summer total phosphorous (TP) concentrations were below 0.1 mg L^{-1}, a reduction compared with 40 years ago, submerged macrophyte re-colonization or expansion was only found in six lakes (Korner, 2002). In Lake Albufera (Spain), no changes in submerged macrophytes were observed during 10 years of oligotrophication (Jeppesen et al., 2005). After a strong reduction in phosphorous loading, there was an unstable recovery of charophytes in Lake Veluwe (Netherlands) for 10 years (Ibelings et al., 2007).

Most studies on the artificial recovery of submerged macrophytes have been conducted in laboratories, where environmental variables are easier to control (Crossley et al., 2002; Wu et al., 2015; Xiong et al., 2005). Restoration trials in the field have been limited due to factors such as unfavorable sediments, waves or currents,

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herbivory, and water level fluctuations that could prevent successful colonization of submerged macrophytes (Hilt et al., 2006).

West Lake is a typical shallow lake and a tourist resort, with a water area of approximately 6.5 km^2 and a mean water depth of 2.27 m. It was listed as a World Heritage Site in 2011. Integrated lake management includes water diversion from the Qiantang River since 1986 (You et al., 2015), which has resulted in a decrease in TP to less than 0.05 mg L^{-1}. Although this level could allow re-establishment of submerged macrophytes (Hilt et al., 2006), the submerged macrophyte coverage was still less than 15% by July 2013 (Zuo et al., 2015). It has been shown that water level drawdowns and a temporary severe reduction in fish biomass are efficient in increasing light availability for submerged macrophytes, and have resulted in successful recolonizations (Coops and Hosper, 2002; Donabaum et al., 2004). However, these strategies are not applicable for a World Heritage Site. West Lake is unique in water quality, sediment, and hydrology characteristics due to the large-scale water diversion from the Qiantang River (Li, 2006). A previous study indicated that plants increase water clarity, thereby enhancing their own growing conditions (Scheffer et al., 1993). Therefore, artificial measures for submerged macrophyte colonization were used to accelerate the recovery process.

In order to restore a vegetated clear state in a landscape shallow lake, we undertook a pilot scale *in-situ* trial of submerged macrophyte recovery using artificial support measures. High species richness increases the stability of the macrophyte community through species interactions (James et al., 2005; Yachi and Loreau, 1999); therefore, artificially supported colonization of multiple submerged macrophyte species was conducted in Maojiabu, a sublake of West Lake (Hangzhou City, China), which presumably allowed for significant macrophyte coverage.

Besides the colonization effect of artificial support measures on submerged macrophytes, the relationships between submerged macrophytes and water environmental indices and between submerged macrophytes and the sediment microbial community were also evaluated. The aim of this study was to explore both the feasibility of restoring submerged macrophytes through artificially supported methods and the relationship between artificially aided colonization of submerged macrophytes and environmental variables in a scenery lake with nearly 30 years' history of water diversion.

2. Materials and methods

2.1. Study sites and submerged macrophytes planting

Two pilot-scale restoration areas located in Maojiabu were selected, and protective enclosures were constructed for these areas in May 2014. Restoration areas M1 and M2 were 30 m × 15 m and 36 m × 24 m, located in the southeast area of Maojiabu (Fig. 1). Adult plants of four submerged species were planted into the M1 and M2 areas. The roots of *Hydrilla verticillata* (*H. verticillata*) and *Vallisneria natans* (*V. natans*) were wrapped with loessal clay and non-woven fabrics, and then placed into the enclosed areas. *Myriophyllum spicatum* (*M. spicatum*) and *Ceratophyllum oryzetorum* (*C. oryzetorum*) were planted by cuttage. The initial planting density in each restoration area was approximately 30 whole plants m^{-2} and each species was equally distributed in the area. *Potamogeton crispus* (*P. crispus*) and *Najas major* (*N. major*) were not planted but spontaneously appeared in the M1 and M2 areas.

2.2. Sampling and monitoring

Floating plant shoots were removed from the water during the first three months until the vegetation community became relatively stable. Plant monitoring, water sampling, and sediment sampling were conducted in August 2014, October 2014, January 2015, April 2015, and August 2015, in accordance with plant growth stage.

The M1 and M2 areas were each divided into 12 plots by three rows and four columns. Species biomass in each plot was calculated using the coverage and height of each species and the fresh weight of a small amount of plant samples. Total fresh biomass for each macrophyte species was evaluated using the summed data for the 12 plots.

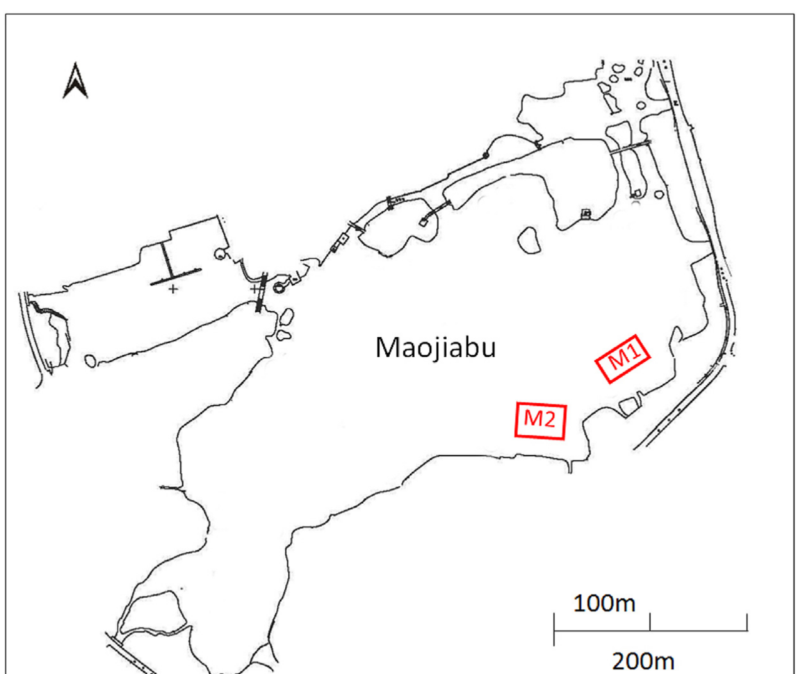

Fig. 1. Location of the submerged macrophyte restoration areas in Maojiabu.

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