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The relationship of seed banks to historical dynamics and reestablishment of standing vegetation in an aquaculture lake

Chan Xiao, Guihua Liu*

Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China

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ABSTRACT

We analyzed the development of submerged macrophytes and seed banks under an intense pen culture since the 1980s in Lake Honghu, China. We determined the relationship between depth distribution of seed banks and the historical dynamics of standing vegetation and evaluated the restoration potential of persistent soil seed banks at an abandoned pen-culture area. Eleven submerged macrophytes were recorded in the standing vegetation during 5 survey years, and mean wet biomass increased from 2760 g m^{-2} in 1961 to a maximum of 5269 g m^{-2} in 1992, and then declined to 1157 g m^{-2} in 2010. Seeds of 8 macrophytes were found in the seed banks in 28 of the 32 sampling sites, with a mean density of 1936 seeds m^{-2} over the entire sediment profile of 0–40 cm. Significantly more total seeds and viable seeds were present in the non-pen-culture area (2729 and 914 seeds m^{-2}, respectively) than in the pen-culture area (902 and 255 seeds m^{-2}, respectively). Our results showed a straightforward but small quantitative relationship between depth distribution of seed banks and historical variation of standing vegetation, suggesting that the depth distribution of the seed bank was a significant but relatively weak predictor of historical vegetation. The soil seed bank can potentially play an important role in vegetative restoration in the abandoned pen-culture area.

1. Introduction

Submerged macrophytes are of vital importance for sustaining proper ecosystem function in lakes (Scheffer et al., 1993; Jeppesen et al., 1998). With accelerating degradation and disappearance of submerged macrophytes over past decades (Scheffer et al., 1993; Sand-Jensen et al., 2000, 2008), many shallow lakes have turned into a turbid, phytoplankton-dominated regime.

Fish aquaculture within retiary boxes (pen culture) is one of the major causes of submerged macrophyte disappearance in shallow freshwater lakes along the middle and lower reaches of the Yangtze River, China (FAO, 1977; Fang et al., 2005). Over the course of 20 years, the coverage of submerged vegetation has decreased from 100% to 67% to 9% in 4 aquacultural lakes (Peng et al., 2004). In Lake Honghu, the pen-culture area increased from 7.9% in 1985 to 59.4% in 2000 (Sun et al., 2009), while the coverage of submerged vegetation decreased from approximately 100% in 1981 to 16.4% in 1999 (Peng et al., 2004). More recently, the local government implemented a lake restoration project by abandoning the use of pen-culture enclosures in the middle and lower Yangtze floodplain. Restoring the submerged vegetation is therefore becoming popular in those lakes (Qin, 2009; Ye et al., 2011).

It has been suggested that seed banks accumulated in surface sediment can be considered a potential seed source for the restoration of plant communities (Templeton and Levin, 1979; Bakker and Berendse, 1999); however, there is conflicting evidence to support this suggestion. The majority of previous studies have concluded that soil seed banks play an important role in restoring former species diversity (Bakker et al., 1996; Thompson et al., 1997; Pärtel et al., 1998; Bisteau and Mahy, 2005; Bossuyt et al., 2006; Valkó et al., 2011; Kalamees et al., 2012); however, the results of several other studies produced skepticism that successful restoration could occur merely through seed germination from the seed banks, as evidenced by the absence of target species and the high dominance of early successional species (Bakker et al., 2005; Beatrijs and Olivier, 2008). It is still unclear how sediment seed banks respond to historical succession stages of submerged vegetation and contribute to vegetative reestablishment.

A previous study reported a significant effect of historical changes in standing vegetation on sediment seed banks in Lake Dianchi, a eutrophic plateau lake that is intensely disturbed by human activities (Lu et al., 2012); however, the study failed to detect more specific details on the relationships between the depth distribution of seed banks and the historical changes in the standing vegetation because of a low seed density and species richness in

* Corresponding author. Tel.: +86 027 87510392; fax: +86 027 87510251.
E-mail address: liugh@wbgcas.cn (G. Liu).

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sediment seed banks. Further studies in shallow lakes to investigate the responses of seed banks to historical changes in standing vegetation are warranted and might provide insights into restoration and management of degraded lakes.

In our study, we investigated the effects of pen culture on standing vegetation and sediment seed banks across a lake and separated the areas into 3 categories: non-pen-culture, pen-culture, and abandoned pen-culture. We focused on 3 questions: (i) Does pen culture affect seed density and species richness of seed banks? (ii) How does the depth distribution of seed banks respond to changes in the standing vegetation associated with pen-culture? (iii) Do the viable seeds in the seed banks have the potential to be a source for restoration of submerged vegetation in the abandoned pen-culture area?

2. Materials and methods

2.1. Study area

Lake Honghu (29°45′ to 52′ N, 113°13′ to 29′ E) is a subtropical shallow lake located in the middle reaches of the Yangtze River, China. The lake has been separated from the Yangtze River since the 1950s by several regulation sluices, leading to reduced water depth. After 20 years of reclamation, the water area of Lake Honghu decreased from 661.9 km^2 in the 1950s to 344.4 km^2 in the 1970s (Wang and Dou, 1998). The lake has an average water depth of 1.9 m; the maximum depth is 2.2 m. The retention time of water averages 68 days. In 2010, the average total nitrogen concentration in Lake Honghu was 1.28 $mg\,L^{-1}$ and total phosphorus concentration was 0.05 $mg\,L^{-1}$. The lake is rich in fine-grained sediments (sapropel, silt, sand).

Pen culture of commercial fish and crab was introduced in Lake Honghu in the 1980s, and by 2004, pen culture peaked at 60% of total water surface area (Sun et al., 2009). After 2005, the local government implemented a restoration project for Lake Honghu. As a result of this project, in 2005, approximately 87 km^2 of pen-culture enclosure were removed, which allowed submerged macrophytes to reestablish naturally in the abandoned pen-culture area.

2.2. Vegetation survey

Earlier data on submerged macrophytes of Lake Honghu were from literature investigated in 1960 by Chen (1963), in 1981 by Li (1982), and in 1992 by Li (1995). In all surveys, vegetation was collected by raking 25 to 34 sampling sites along 8 to 10 transects distributed evenly across the lake.

Our investigations of submerged macrophytes were carried out on 30 sites over the entire lake in September 2001 and October 2010 (Fig. 1), of which 15 sites were in a non-pen-culture area, 7 in a pen-culture area, and 8 in an abandoned pen-culture area. Ten random samples at each station were collected using a rake 20 cm × 20 cm in an approximately 500-m^2 area. Each sample was washed and separated into species, and wet weight was determined.

2.3. Seed bank sampling

Seed banks were sampled in April 2010. The sediment samples were collected at the same sites from which macrophyte samples were obtained. Each site was composed of four 40-cm-deep sediment cores, randomly taken within a 20- to 50-m^2 area, using a steel sediment corer of 5.0 cm in diameter. The cores were then divided into 10 series sections with a thickness of 4-cm-deep sediment strata.

The seed banks were determined by sieving. (For further information, see Lu et al., 2012.) Seed viability was determined by tetrazolium assay with 1% (v/v) aqueous solution of 2,3,5-triphenyltetrazolium chloride (TTC).

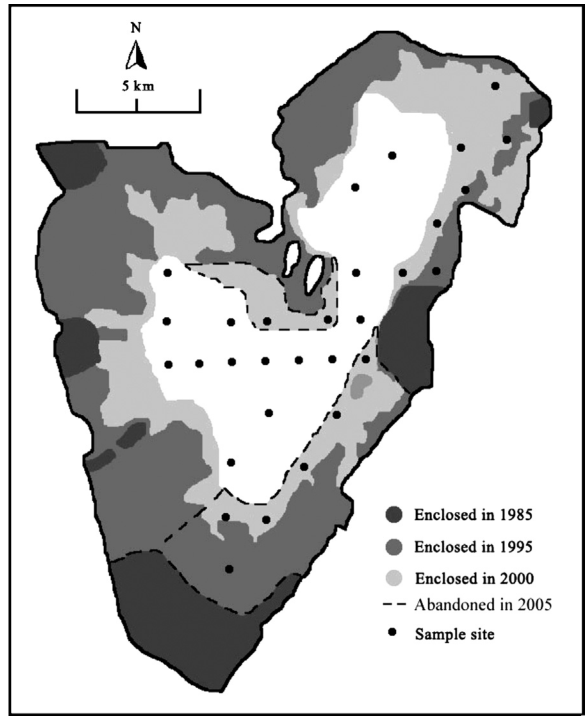

Fig. 1. Sample sites and variation of pen-culture area in 4 selected years between 1985 and 2005.

2.4. Data analyses

The number of seeds in the soil samples was standardized to seeds m^{-2}. One-way ANCOVAs were performed to test the differences in seed densities between the non-pen-culture and pen-culture areas at the entire 40-cm soil profile for the total seed bank and for seed banks of individual species of *Potamogeton maackianus* and *P. malaianus*. Water depth of each site was used as the covariate in the analysis to separate spatial autocorrelation effects given that the areas of pen-culture and non-pen-culture might be spatially clustered. Separate analyses for each soil layer or for other less-dominant species were not possible because of low density and frequency of seed emergence. For each area and each species, a logarithmic regression was conducted between mean seed density and depth distribution. SPSS 16.0 was used for all statistical analyses.

Detrended correspondence analysis (DCA) was applied to detect the corresponding relationship between the depth distribution of the seed banks and the historical vegetation in 5 survey years based on species composition and their relative abundance. The analysis was performed using PC-ORD (MjM Software Design, Gleneden Beach, OR, US).

3. Results

3.1. Submerged vegetation

Eleven submerged macrophytes were recorded in Lake Honghu in 5 survey years (Table 1). Submerged macrophytes were absent at the pen-culture area in 2 survey years (2001 and 2010). Mean wet biomass of submerged macrophytes increased from 2760 $g\,m^{-2}$ in 1961 to a maximum of 5269 $g\,m^{-2}$ in 1992, and then declined to 1157 $g\,m^{-2}$ in 2010. The dominant macrophyte species