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SHORT COMMUNICATION

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Dominance of *Myriophyllum spicatum* in submerged macrophyte communities associated with grass carp

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Abstract – Re-establishment of macrophyte communities is a key to restore eutrophic shallow lakes. The species composition of the plant communities may change rapidly during the recovery period. A basin in subtropical Lake Qinhu (China) was restored by biomanipulation including fish removal followed by planting of submerged macrophytes in 2011. In September-December 2011, dominance of *Vallisneria spinulosa* and *Ceratophyllum demersum* shifted to dominance of *Myriophyllum spicatum*. Meanwhile, the CPUE (catch per unit effort) showed that the number and biomass of grass carp (*Ctenopharyngodon idella*) demonstrated a marked increase. Stable isotope analyses revealed that grass carp preferred *V. spinulosa* and *C. demersum* to *M. spicatum*. We propose that grazing by grass carp was responsible for the observed shift in dominance towards *M. spicatum* but as alternative explanations are possible, further tests by controlled experiments are needed to draw firm conclusions.

Key-words: grass carp / food preference / submerged macrophytes / community structure / stable isotope

Résumé – La dominance de *Myriophyllum spicatum* dans les communautés de macrophytes immergées associées à la carpe amour. La re-création de communautés de macrophytes est une clé pour restaurer les lacs peu profonds eutrophes. La composition des espèces des communautés végétales peut changer rapidement au cours de la période de récupération. Un bassin subtropical du lac Qinhu (Chine) a été restauré par biomanipulation avec l'enlèvement de poisson suivi par la plantation de macrophytes submergés en 2011. En septembre-décembre 2011, la prédominance des *Vallisneria spinulosa* et *Ceratophyllum demersum* s'est déplacée vers une dominance de *Myriophyllum spicatum*. Pendant ce temps, les CPUE (captures par unité d'effort) ont montré que le nombre et la biomasse de la carpe herbivore (*Ctenopharyngodon idella*) ont présenté une augmentation marquée. Les analyses des isotopes stables ont révélé que la carpe préfère *V. spinulosa* et *C. demersum* à *M. spicatum*. Nous proposons que le pâturage par la carpe amour fût responsable du changement observé dans la dominance vers *M. spicatum* mais comme d'autres explications sont possibles, d'autres tests par des expériences contrôlées sont nécessaires pour tirer des conclusions définitives.

Mots-clés : carpe herbivore / préférence alimentaire / macrophyte submergé / structure de communauté / isotopes stables

Submerged macrophytes play an important role in structuring aquatic ecosystems (Jeppesen *et al.*, 1998) and help maintaining clear water conditions (Scheffer and Jeppesen, 1998) by reducing resuspension (James *et al.*, 2004), suppressing algal growth (Gross, 2003), and providing a refuge for zooplankton against predation by planktivorous fish (Lauridsen and Lodge, 1996). Therefore, re-establishment of macrophyte communities is a key to restore eutrophic shallow lakes (Jeppesen *et al.*, 2012). Different species of macrophytes likely

have different effects on lake ecosystems. *Vallisneria* has a higher ratio of roots to total biomass and thus stronger effects on sediment-water interactions than less rooted species such as *Elodea* (Zhang *et al.*, 2010); therefore, particularly *Vallisneria* is often planted when restoring eutrophic shallow lakes in China (Chen *et al.*, 2010; Zhang *et al.*, 2012; Liu *et al.*, 2014). A basin (mean depth 1.5 m, surface area 8 ha) in subtropical Lake Qinhu was restored by biomanipulation including fish removal followed by planting of submerged macrophytes (*Vallisneria spinulosa*, *Hydrilla verticillata*, *Myriophyllum spicatum*, and *Ceratophyllum demersum*)

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	September		December		F	P
	Mean	SD	Mean	SD		
WT (°C)	22.50	0.19	4.60	0.04	54938.46	< 0.001
DO (mg·L ⁻¹)	8.88	0.78	13.27	0.87	30.78	0.005
pН	8.72	0.08	8.50	0.24	2.63	0.180
SD (m)	0.67	0.15	0.98	0.42	0.18	0.693
WD (m)	1.15	0.26	1.20	0.40	0.03	0.865
SD/WD ratio	0.62	0.29	0.64	0.19	0.01	0.925
TN (mg·L ⁻¹)	0.73	0.04	0.79	0.07	1.24	0.327
$TP (\mu g \cdot L^{-1})$	41.79	8.36	41.95	22.20	0.05	0.830
TSS (mg·L ⁻¹)	5.70	1.64	6.48	2.17	0.25	0.644
Chl-a (µg·L ⁻¹)	7.11	2.31	8.07	2.92	0.20	0.677

Table 1. Physical and chemical parameters of the restored part of Lake Qinhu during the sampling months.

in Spring of 2011. After this, submerged macrophyte flourished and a clear water state was established in the restored basin. Here we reported a shift in dominance of *V. spinulosa* and *C. demersum* to dominance of *M. spicatum* occurring in September-December 2011 associated with a major increase in abundance of grass carp. We also studied the feeding habits of grass carp in December using stable isotope analyses and community changes of fish associated with the changes in macrophytes in order to explore the possible interactions between macrophytes and these fish.

The physical and chemical parameters of the lake were measured at three different sites along a mid-lake gradient. Water temperature (WT), dissolved oxygen (DO) and pH were measured using a YSI sonde (YSI 6500, YSI Company, USA). A Secchi disk was used to measure standard depth (SD), and water depth (WD) was recorded with a sensor (SM-5, Speedtech Instruments, USA). Total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and chlorophyll a (Chl a) were determined using Chinese standard methods (Jin and Tu, 1990). The submerged macrophyte community was investigated with a 0.25 m² clamp at four lake sites located along a mid-lake gradient in the restored part, and two samples were taken at each side of a boat at each sampling site. Fish were collected using a 80×1.5 m gillnet with multiple mesh sizes: 10, 15, 25 and 40 mm at each sampling event, one gillnet being set at the central area of the lake in the morning (around 9:00 a.m) and retrieved after 2 h.

For stable isotope analyses, the leaves of the macrophytes (one sample per site of each species) were washed repeatedly with distilled water in the laboratory to ensure that all the attached organic matter was removed, after which the plants were oven-dried at 60 $^{\circ}$ C for 36–48 h for further stable carbon and nitrogen analysis. For fish samples, the dorsal white muscle was removed and dried at 60 $^{\circ}$ C for further stable isotope analysis.

Fish and macrophyte samples were analyzed to determine $^{13}\text{C}/^{12}\text{C}$ and $^{15}\text{N}/^{14}\text{N}$ ratios using a SerCon 20-20 isotope ratio mass spectrometer at the Department of Ecology and Institute of Hydrobiology, Jinan University, Guangzhou, China. Isotope abundance was expressed using the conventional delta notation against conventional international standards (Pee Dee Belemnite for $\delta^{13}\text{C}$ and atmospheric nitrogen for $\delta^{15}\text{N}$):

$$\delta X(\%e) = (R_{\text{sample}}/R_{\text{standard}} - 1)/1000$$

where $X = {}^{13}\text{C}$ or ${}^{15}\text{N}$ and R is the ratio of ${}^{13}\text{C}$: ${}^{12}\text{C}$ or ${}^{15}\text{N}$: ${}^{14}\text{N}$. The precision of repeated measurements was $ca. \pm 0.3\%$.

To determine the relative contribution of different primary producers to the diet of consumers, an isotopic mixing model, IsoSource (Phillips and Gregg, 2003), was used. In our study, the four sampling sites were regarded as replicates, and the variations in the submerged macrophyte community between the two months were analyzed by one-way ANOVA. All comparisons were made with the statistical package SPSS version 22.0 (IBM Corporation, Somers, New York, USA).

The physical and chemical data on the restored basin of Lake Qinhu for the two sampling periods are given in Table 1. The water of the basin was clear with generally low concentrations of TSS, Chl a, TN, and TP. The water temperature in December was significantly lower than that in September (P < 0.001), while the DO concentration was higher in September (P < 0.05); no significant differences were found for the other physic-chemical parameters (Table 1).

The composition and total biomass of submerged macrophytes changed significantly from September to December. In September, C. demersum and V. spinulosa were the dominant submerged macrophyte species, while M. spicatum constituted, on average, <2% of the biomass (Figure 1) (managers harvested H. verticillata). However, in December, M. spicatum became the dominant submerged macrophyte (>95% of biomass) (Figure 1), while the average biomass of C. demersum and V. spinulosa constituted <10%. The total biomass of submerged macrophytes also declined significantly (P < 0.05) (Figure 1).

A total of six fish species were caught in the restored part of Lake Qinhu, namely silver carp *Hypophthalmichthys molitrix*, bighead carp *Hypophthalmichthys nobilis*, sharpbelly *Hemicculter leuciclus*, crucian carp *Carassius auratus*, common carp *Cyprinus carpio*, and grass carp *Ctenopharyngodon idella*. The total number (NPUE, Figure 2A) and biomass (BPUE, Figure 2B) of fish caught increased from September to December. In September, the omni-planktivorous species, sharpbelly and bighead carp, dominated the fish community in both abundance and biomass (Figure 2, C and D), whereas no grass carp were caught. However, in December, grass carp constituted 44% of total abundance and 46% of total biomass, respectively (Figures 2C and 2D).

The carbon stable isotope ratio (δ^{13} C) was closer to the values of *V. spinulosa* and *C. demersum* than to *M. spicatum*

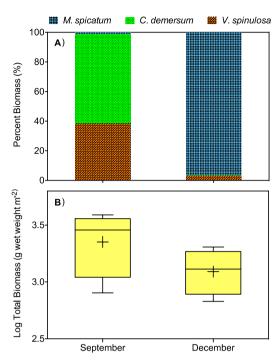


Fig. 1. Composition and total biomass of submerged macrophytes in the restored part of Lake Qinhu in September and December. Error bars represent the standard deviation (SD) of different sampling sites.

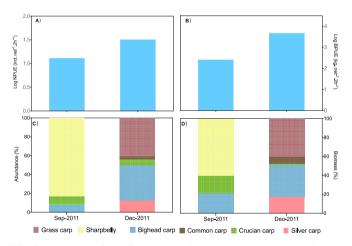


Fig. 2. Structure of the fish community in the restored part of Lake Qinhu in September and December, 2011. (A) total fish number per unit effort, NPUE; (B) total fish biomass per unit effort, BPUE; (C) per cent abundance of each fish species; (D) per cent biomass of each fish species.

(Figure 3A). IsoSource model estimation revealed that the relative contributions of *V. spinulosa* and *C. demersum* to the diet of grass carp were 54.8% and 40.3%, respectively, while the contribution of *M. spicatum* was only 4.9% (Figure 3B), suggesting that the grazing intensity of grass carp on *V. spinulosa* and *C. demersum* was much higher than that on *M. spicatum*.

Pípalová (2002) showed a shift from dominance of *Eleocharis acicularis*, *Potamogeton pusillus* and *P. pectinatus* to *M. spicatum* after grass carp stocking. High phenolic concentration of *M. spicatum* may discourage grass carp feeding

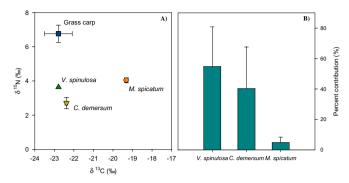


Fig. 3. Stable isotopic signatures of grass carp and macrophytes (A) and the per cent contribution of macrophytes to the carbon source of grass carp (B) estimated using the IsoSource model. Error bars represent the standard deviation (SD) of different individuals.

(Dorenbosch and Bakker, 2011), resulting in a lower grazing effect on this plant species. We therefore propose that grazing by grass carp was responsible for the observed shift in dominance towards *M. spicatum* but the changes could potential also reflect natural seasonal variations. However studies in natural (Liu *et al.*, 2007) and biomanipulated subtropical shallow lake (Guan *et al.*, 2011, unpublished data), located in the same climatic zone as Lake Qinhu, showed consistent composition and high biomass of submerged macrophytes in September-December. Nevertheless, further tests by controlled experiments are needed to draw firm conclusions.

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