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Effects of sediment load and water depth on the seed banks of three plant communities in the National Natural Wetland Reserve of Lake Xingkai, China

Guo-dong Wang[a,b], Ming Jiang[a], Xian-guo Lu[a,*], Ming Wang[a,b]

[a] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, Jilin 130102, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100039, China

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ABSTRACT

The discharge of agriculture irrigation runoff containing large amounts of suspended particles resulted in a high sediment accumulation rate (0.3–1.0 cm yr^{-1}) in the receiving wetland upstream of Lake Xingkai, Northeast of China and may create negative ecological impacts to the wetland system, particularly the vegetation community. In this study, we conducted a germination experiment and a vegetation survey to evaluate the effects of different sediment loads on the seed banks of three wetland communities (dominated by *Glyceria spiculosa*, *Zizania latifolia* and *Pycreus korshinskyi*, respectively) under two hydrological regimes (0 and 10 cm water depth). Results revealed significant differences in seed germination rates among the three plant communities and significant effects of sediment load on the germination rates. Species richness and seedling emergence decreased significantly at 0.5–0.75 cm of sediment addition. Species responded differently to the addition of sediment. The number of seedlings of *P. korshinskyi, Sagittaria trifolia, Alisma orientale, Monochoria vaginalis, Carpesium macrocephalum* decreased gradually as the sediment addition increased from 0 to 2 cm, while the number of seedlings of *Fimbristylis dichotoma, Eleocharis ovata, Bidens bipinnata* decreased to zero at 0.5 cm of sediment addition. The number of species germinated under the non-flooded conditions was significantly higher than that under flooded conditions. All plant communities showed a similar response to the sediment load under the two water regimes. Despite low similarity, the number of species germinated from seed banks was higher than the original number of species present in each plant community. To protect and restore the wetland vegetation community in the Sanjiang Plain, irrigation and land management strategies will need to be implemented to reduce the sediment load from the paddy fields to the wetlands.

1. Introduction

Wetlands provide significant environmental functions and play an important role in controlling soil erosion and alleviating pollution. Wetlands within agricultural landscapes are increasingly receiving higher sediment inputs (Piao and Wang, 2011). In many cases, wetlands are purposely being used to remove sediments and pollution from rivers and irrigation return flow or runoff (Zhao et al., 2009; Piao and Wang, 2011). In addition, with increasing deforestation, urbanization and land reclamation during the past several decades, especially in the developing countries, resulting soil erosion provides high sedimentation rates to aquatic systems. This could have increasingly negative impacts on these wetlands if the loadings of sediments exceed sustainable levels. Most research indicates that the addition of sediment may reduce the germination rates of seeds from wetland seed banks and affect wetland vegetation re-establishment (Jurik et al., 1994; Dittmar and Neely, 1999; Peterson and Baldwin, 2004), but also may result in more vigorous growth for some species and alter plant species composition. The specific response depends on the plant species, hydrology, depth of burial and the mass of the seeds (van der Valk et al., 1983; Leck, 1996). Seed germination requires a suitable microenvironment; some species require light for germination while others may require darkness or very little light, and an alternating temperature requirement may be necessary for some species. Sedimentation reduces the amount of light reaching the seeds and has also been implicated in decreasing the amplitude of the daily temperature fluctuation (Galinato and van der Valk, 1986; Jurik et al., 1994). In a freshwater wetland in central Iowa, USA, sediment loads as low as 0.25 cm significantly reduced the number of species and the total number of individuals recruited from the wetland seed bank, and the addition of sediment decreased the number of individuals appearing for most, but not all, species (Jurik et al., 1994). Survival of vegetative tubers of *Vallisneria americana*, a submersed aquatic plant, declined 90% or more when buried in 10 cm and exhibited no survival in greater than 25 cm of sediment (Rybicki

* Corresponding author. Tel.: +86 043185542216; fax: +86 043185542298.
E-mail address: luxg@neigae.ac.cn (X.-g. Lu).

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and Carter, 1986) while *Typha* was greatly affected by 0.25 cm of sediment.

Wetland hydrologic regime has been shown to be a major determinant of the type of plant community developing and establishing from the seed bank (van der Valk, 1981), and species have been shown to have different responses to water levels (Liu et al., 2005). Flooding may decrease the light levels and available oxygen, leading to lower survival under dormancy than under non-flooded conditions. Atmospheric oxygen levels are required for germination and early seedling growth, although some species are exceptions (Nicol et al., 2003). These impacts on germination may influence vegetation structure. As the water level fluctuates, species composition changes quickly; some populations may disappear and other populations may become established. Flooding regime is probably the most important factor affecting the distribution of canopy, community type and biodiversity (Nicol et al., 2003; Liu et al., 2005; Capon, 2007).The response to sedimentation by different plant species could also vary as a function of life-history characteristics. In many perennial-dominated wetlands, annuals are more capable of tolerating sedimentation and the total seedling density of annuals is many times greater than perennials (van der Valk et al., 1983; Dittmar and Neely, 1999). Seed mass is also a trait that influences a plant's regeneration niche and thus vegetation structure. It plays a role in competition/colonization trade-offs, and the ability to tolerate various environmental hazards (Strombery et al., 2011). Flood-borne sediments can kill newly emerged seedlings or can prevent seedlings from emerging if the seeds are buried too deeply. The capacity to emerge from sediment depth typically increases with seed mass (Thompson et al., 1993; Jurik et al., 1994), with the patterns complicated by seed shape, light requirements and seed longevity (Grundy et al., 2003).

Sanjiang Plain is a vast complex of marshes, meadows and forests, which is located in the northeast area of Heilongjiang Province, China. Over the past five decades, the natural wetlands in this region have been extensively reclaimed for agriculture with a total loss of nearly 80% of the surface area (Wang et al., 2011). Lake Xingkai, the largest freshwater lake in northeast China, is situated at the downstream of the Sanjiang Plain and plays an important role in providing water for irrigation. However, farming causes soil erosion, severe water pollution and other environmental problems. During the irrigation return flow (runoff) period, vast amounts of irrigation flow with high sediment load were drained to the river and wetlands, and then returned to the lake (Piao and Wang, 2011). Although soil erosion was serious and the sediment accumulation rate was high, we found no studies regarding the effects of sediment load on the vegetation in the freshwater marshes at the mid-high latitudes, northeast of China. In order to understand the effects of sediment load and inundation on the seedling emergence of different communities in wetlands, we selected three wetland communities (dominated by *Glyceria spiculosa, Zizania latifolia* and *Pycreus korshinskyi*, respectively) which received irrigation return flow to the study site. Results from this study shall provide important insight into the responses of major wetland plant communities in mid-high latitudes to environmental disturbances such as increasing sediment load and changing water regimes. This information is important to the protection of aquatic plants and the restoration of impaired wetlands.

2. Methods

2.1. Study site

The study site is located in the National Natural Wetland Reserve of Lake Xingkai (45°21.937N, 132°18.863E) of the Sanjiang Plain in northern China. The annual mean precipitation is 750 mm and the annual mean temperature is approximately 3.1 °C (Wang et al., 2006). A large area of the original wetland was converted to a paddy field for agriculture. However, the wetland immediately adjacent to the lake is relatively intact. Water is pumped from Lake Xingkai to the paddy field for irrigation. During the irrigation return flow period, large amounts of irrigation flow with sediment are drained to wetlands which are purposely used to remove sediments and pollutants from the irrigation return flow. During a recent study, the sediment accumulation rate for our study site was estimated at 3298–12,889 g m^{-2} yr^{-1}, 0.3–1.0 cm yr^{-1} (Professors Wang Guoping and Zou Yuanchun, 2011, unpublished data).

The study site is dominated by a freshwater marsh with shallow and intermittent water levels, varying from no standing water to an average depth of approximately 12 cm. The flora mainly consists of *G. spiculosa* (Fr. Schmidt.) Rosh. and *P. korshinskyi* (Meinsh.) V. Krecz. with less dominant, but common species such as *Z. latifolia* (Griseb.) Stapf., *Equisetum fluviatile* L. *Carex* spp., *Poa palustris* L., *Cyperus glomeratus* L., and *Iris laevigata* Fisch. We chose three wetland communities (dominated by *G. spiculosa*, *Z. latifolia* and *P. korshinskyi*, respectively) as the sampling sites which were the main vegetation types and which also received agriculture irrigation return flow.

2.2. Seed bank collection

The seed bank was sampled during 25–26 April, 2011. Soil samples from 5 replicate plots (25 cm × 25 cm × 5 cm) at each of the three dominant vegetation types were taken and placed into soil bags. Sediment (top 5 cm) was collected from an irrigation ditch adjacent to the study site using a shovel. All samples were taken back to the greenhouse. In the laboratory, each soil sample collected from the three types of plant communities was sieved to remove stones and plant fragments, and mixed thoroughly. Sediments collected from the irrigation ditch were placed in an oven at 105 °C for 10 h to kill seeds, and then ground to a fine powder and passed through a 2 mm soil sieve.

2.3. Seedling germination assays

Seed banks from the three wetland communities were studied with two treatment factors, water regime and sediment addition. Two levels of water regime were used: two tanks were assigned to the non-flooded (moist soil) treatment and two tanks to a flooded treatment of 5 cm of continuous inundation. For each water regime treatment, six levels of sediment addition: 0, 0.25, 0.5, 0.75, 1.0 and 2.0 cm depth were used. Nine replicates were used for each level of sediment addition and water regime, resulting in a total of 324 replicates. The oven-dried sediment was also placed into experimental pots (13.4 cm diameter and 11 cm depth) void of wetland soil with a depth of 1 and 2 cm respectively to determine if any seeds germinate. Nine replicates were used for each treatment for a total of 36 replicates.

The seedling germination assays were conducted in the greenhouse during 2–5 May, 2011. The greenhouse had a glass roof that did not significantly attenuate or disrupt visible or near-infrared radiation. It was also well ventilated to maintain an inside temperature comparable to that of the outside. Monthly air temperature in the greenhouse during the study period ranged from 16.4 °C in May to 23.8 °C in July. Each soil sample was spread as an even layer, 2 cm thick, in pots previously filled with washed vermiculite to an 8 cm depth, a procedure similar to that described by van der Valk and Rosburg (1997) and Middleton (2003). The depth of sediment desired in each pot was achieved by calculating the volume of sediment required to fill the pot to the depth of each treatment level. The volume was measured with a graduated cylinder and sprinkled on top by hand and smoothed evenly over the seed bank sample.