Aquatic Botany 106 (2013) 35–41

Contents lists available at SciVerse ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

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

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ARTICLE INFO

Article history:
Received 7 March 2012
Received in revised form
17 December 2012
Accepted 21 December 2012
Available online 23 January 2013

Keywords:
Irrigation return runoff
Marsh
Sediment
Inundation
Seed germination
Seed bank
Vegetation

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 condition. 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

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0304-3770/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.aquabot.2012.12.008

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 $\mathrm{g\,m^{-2}\,yr^{-1}}$, 0.3–1.0 $\mathrm{cm\,yr^{-1}}$ (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.

Newly emerged seedlings were identified, counted, and removed from the pots. If a seedling could not be identified, it was removed from the original pot and grown in a separate pot until it could be identified. The seedling germination assays continued until no additional seedlings emerged. The germination assay lasted approximately 5 months. Nomenclature follows Yi et al. (2008).

2.4. Vegetation survey

We conducted a vegetation survey in the study sites on 20, July 2011. Three 1-m^2 quadrats were randomly placed over the top of each plant community. Species name, number and height of each individual, the coverage of each species, and water depth were recorded.

2.5. Data analysis

Three-way analysis of variance (ANOVA) including vegetation type, sediment addition, water regime and their interaction was conducted for species richness and the seedling density. Then a one-way ANOVA and a subsequent Tukey's test were used to test the difference in mean number of species, the mean seedling density and number of seedlings of each species among the sediment additions in each vegetation community. Significance was determined at an alpha level of 0.05. Data of species richness and seedling density were transformed ($\log(x+1)$) to satisfy the assumption of homogeneous variances. All statistics were conducted using SPSS version 16.0. We used the similarity index to compare the species similarity between the vegetation and seed banks, and used importance value to investigate species importance in each community (Perry and Hershner, 1999).

$$\text{Similarity index}: \ I = \frac{2c}{a+b} \times 100\%$$

$$\text{Importance value}: \ IV = RD + RC + RF$$

where a and b are the number of species present in communities A and B, respectively. C is the number of species present both in communities A and B. Factor IV is the importance value which is the sum of relative density (RD), relative coverage (RC) and relative frequency (RF) of the plant community.

3. Results

The number of species germinated from seed banks under different sediment loads and water regimes varied among the three plant communities. There were many species with extremely low numbers of seedling emergence across water regimes and sediment loads (Tables 2–4). Our analysis focused on those species with more than 1 seedling in 0 cm of sediment level.

3.1. Effects of water regime and sediment loads

Vegetation type, sediment and water regime significantly affected the number of species and seedlings germinated from seed banks respectively (Table 1). The number of species and seedlings decreased significantly with increasing depth of sediment (Fig. 1a and b). The number of species and seedlings in 2 cm depth of sediment were considerably lower than those in 0 cm. Even sediment loads as low as 0.25 cm significantly reduced the number of seedlings in the three communities (Tables 2–4). The number of species and seedlings germinated in the community dominated by *P. korshinskyi* was significantly lower than in communities dominated by *G. spiculosa* and *Z. latifolia* (Fig. 1a and b). The number of species and seedlings germinated in the non-flooded condition was significantly greater than those in the flooded condition and showed a similar response compared to the sediment load in the two water depth treatments (Tables 2–4).

Nineteen species germinated from the seed banks of the *G. spiculosa* dominated community, and the number of species under the non-flooded treatment was higher than the flooded treatment (16 vs. 5) (Table 2). Sediment loads as low as 0.5 cm significantly reduced the number of species. However, there was no significant difference in the mean number of species per pot when sediment depth increased from 0.5 cm to 2 cm (Fig. 1a; Table 2). The mean number of seedlings was much lower in 0.75–2 cm of sediment addition than at 0 cm sediment addition (Fig. 1b; Table 2). The number of seedlings from *P. korshinskyi, Sagittaria trifolia, Alisma orientale, Monochoria vaginalis* decreased gradually with the increase in sediment addition from 0 cm to 2 cm, while the number of seedlings from *Carpesium macrocephalum, Saussurea* sp., *Echinochloa crusgalli* decreased significantly or disappeared when exposed to 0.25–0.5 cm of sediment depth.

Twelve species germinated from the seed banks of *P. korshinskyi* dominated the community with 11 species under the non-flooded condition and 2 under the flooded condition (Table 3). The average number of species germinated at the 0.5 cm depth of sediment addition was the highest, and decreased when sediment addition reached 0.75 cm or greater (Fig. 1a; Table 3). The number of seedlings from *P. korshinskyi* decreased gradually as the sediment addition increased from 0 to 1 cm. The number of seedlings of

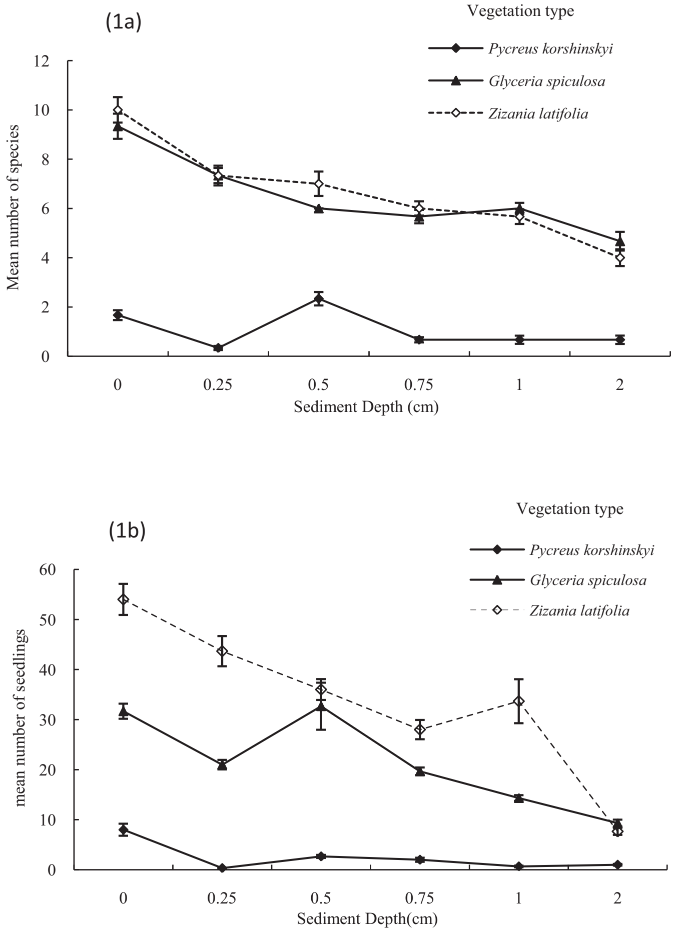

Fig. 1. (a) Effect of sediment depth on the mean number of species emerging in the seed banks of the three vegetation type. Values are means ± SE ($n = 9$ pots per treatment). (b) Effect of sediment depth on the mean number of seedlings emerging in the seed banks of the three vegetation type. Values are means ± SE ($n = 9$ pots per treatment).

Table 1
A summary of analysis of variance (ANOVA) on the effects of vegetation type, sediment addition and water regime for mean number of species and seedling emergence.

	Seedling number			Species number		
	df	*F*	*p*	df	*F*	*p*
Vegetation type	2	94.376	<0.001**	2	117.365	<0.001**
Sediment	5	5.672	<0.001**	5	4.606	<0.001**
Water regime	1	21.602	<0.001**	1	61.074	<0.001**
Vegetation type × Sediment	10	0.998	0.453	10	1.139	0.346
Vegetation type × Water regime	2	1.375	0.259	2	3.237	0.045*
Sediment × Water regime	5	0.104	0.991	5	0.507	0.770
Vegetation type × Sediment × Water regime	10	1.133	0.350	10	1.269	0.264

* Difference was significant at $P < 0.05$.
** Difference was significant at $P < 0.01$.

Table 2
Mean number of seedlings per pot in each sediment depth treatment in the community dominated by *Glyceria spiculosa*. Species are listed in order of decreasing abundance in the 0-cm sediment addition treatment. Values followed by the same superscripted letter were not significantly different (Tukey's test; $p > 0.05$; $n = 9$ pots per treatment). *Means of species germinated both in flooded and non-flooded conditions.

Water regime	Sediment depth (cm)					
	0	0.25	0.5	0.75	1	2
Non-flooded						
*Sagittaria trifolia**	5.67^{a}	3.67^{b}	3.67^{b}	3.67^{b}	3.00^{b}	3.00^{b}
*Alisma orientale**	4^{a}	4.33^{a}	2.67^{b}	3.33^{a}	1.67^{b}	0.33^{c}
Pycreus korshinskyi	3^{a}	2^{a}	0.67^{b}	2^{a}	0.67^{b}	0.33^{b}
Carpesium macrocephalum	2^{a}	0.33^{b}	0.11^{b}	0.33^{b}	0^{b}	0^{b}
Saussurea sp.	1.67^{a}	0.33^{a}	0.22^{a}	0^{a}	0^{a}	0^{a}
Juncus effusus	0.67^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Ranunculus cymbalaria	0.67^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Zizania latifolia	0.33^{a}	0^{a}	0^{a}	0.67^{a}	0.33^{a}	0^{a}
Chamaenerion angustifolium	0.33^{a}	0.11^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Rorippa palustris	0^{a}	0.56^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Carex sp.	0^{a}	0^{a}	14.67^{a}	0^{a}	0^{a}	0^{a}
Salix rosmarinifolia	0^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}	0.22^{a}
Eleocharis ovata	0^{a}	1.67^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Cyperus glomeratus	0^{a}	0^{a}	0^{a}	0.33^{a}	0.67^{a}	0.33^{a}
Populus sp.	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	1.33^{a}
Carex sp.	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.22^{a}
Flooded						
*Sagittaria trifolia**	7^{a}	5.33^{b}	5.33^{b}	5.33^{b}	4.33^{b}	2.67^{c}
*Alisma orientale**	2.67^{a}	2^{a}	2.33^{a}	2.33^{a}	1.67^{ab}	0.67^{b}
Monochoria vaginalis	2.67^{a}	2.67^{a}	2.33^{a}	1.67^{a}	0.67^{b}	0.11^{b}
Echinochloa crusgalli	1^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Poa palustris	0^{a}	0^{a}	0^{a}	0^{a}	1^{a}	0.11^{a}
Total	31.67^{a}	23^{b}	32.67^{a}	19.67^{b}	14.33^{bc}	9.33^{c}

Table 3
Mean number of seedlings per pot in each sediment depth treatment in the community dominated by *Pycreus korshinskyi*. Species are listed in order of decreasing abundance in the 0-cm sediment addition treatment. Values followed by the same superscripted letter were not significantly different (Tukey's test; $p > 0.05$; $n = 9$ pots per treatment). *Means of species germinated both in flooded and non-flooded conditions.

Water regime	Sediment depth (cm)					
	0	0.25	0.5	0.75	1	2
Non-flooded						
Calamagrostis angustifolia	4.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Pycreus korshinskyi	2.67^{a}	0.11^{b}	0.33^{b}	2^{a}	0.11^{b}	0^{b}
Populus sp.	0.67^{a}	0.22^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}
*Alisma orientale**	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Salix rosmarinifolia	0^{a}	0^{a}	1^{a}	0^{a}	0^{a}	0^{a}
Poa palustris	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Comarum palustre	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Saussurea sp.	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Cyperus glomeratus	0^{a}	0^{a}	0^{a}	0^{a}	0.22^{a}	0^{a}
Melilotus suaveolens	0^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}	0^{a}
Chenopodium glaucum	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}
Flooded						
Monochoria vaginalis	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
*Alisma orientale**	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}
Total	8^{a}	0.33^{b}	2.67^{b}	2^{b}	0.67^{b}	1^{b}

Table 4
Mean number of seedlings per pot in each sediment depth treatment in the community dominated by *Zizania latifolia*. Species are listed in order of decreasing abundance in the 0-cm sediment addition treatment. Values followed by the same superscripted letter were not significantly different (Tukey's test; $p > 0.05$; $n = 9$ pots per treatment). *Means of species germinated both in flooded and non-flooded conditions.

Water regime	Sediment depth (cm)					
	0	0.25	0.5	0.75	1	2
Non-flooded						
*Sagittaria trifolia**	5.67^{a}	3.67^{b}	3.67^{b}	5^{a}	4.33^{b}	2.33^{c}
*Alisma orientale**	14^{a}	20.67^{a}	13^{b}	11.33^{b}	16.33^{b}	1.33^{c}
Pycreus korshinskyi	4.67^{a}	3^{a}	1.33^{b}	1.33^{b}	0^{b}	0.11^{b}
Eleocharis ovata	1^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Carpesium macrocephalum	0.67^{a}	1^{a}	0.33^{a}	0.33^{a}	0.33^{a}	0^{a}
Bidens bipinnata	0.67^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
*Echinochloa crusgalli**	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Gnaphalium mandshuricum	0.33^{a}	0.33^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Saussurea sp.	0.33^{a}	0^{a}	0.33^{a}	0^{a}	0.33^{a}	0^{a}
Labiatae sp.	0.33^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Ranunculus cymbalaria	0.33^{a}	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}
Fimbristylis dichotoma	0.33^{a}	2^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Sonchus brachyotus	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Epilobium palustre	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Saussurea sp.	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Zizania latifolia	0^{a}	1^{a}	0.67^{a}	0^{a}	0.44^{a}	0.67^{a}
Populus sp.	0^{a}	0.33^{a}	0^{a}	0^{a}	0.33^{a}	0.33^{a}
Rorippa palustris	0^{a}	0.33^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Commelina communis	0^{a}	0^{a}	0^{a}	0.67^{a}	0.33^{a}	0^{a}
Chenopodium glaucum	0^{a}	0^{a}	0.33^{a}	0^{a}	0^{a}	0^{a}
Trifolium lupinaster	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.55^{a}
Typha latifolia	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.33^{a}
Flooded						
*Sagittaria trifolia**	10.33^{a}	4.33^{b}	3^{b}	5.67^{b}	4.67^{b}	1.67^{c}
*Alisma orientale**	11.33^{a}	6.67^{b}	9.67^{a}	6^{b}	6^{b}	0.33^{c}
Monochoria vaginalis	2^{a}	0.33^{b}	2.33^{a}	1.67^{a}	0.22^{b}	0^{b}
*Echinochloa crusgalli**	0.33^{a}	0^{a}	0.33^{a}	0^{a}	0.33^{a}	0^{a}
Poa palustris	0.33^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Total	54^{a}	43.67^{b}	36^{bc}	28^{c}	33.67^{c}	7.67^{d}

Calamagrostis angustifolia decreased to zero at 0.25 cm of sediment addition (Table 3).

Twenty-four species germinated from seed banks of the *Z. latifolia* dominated community with 22 species under the non-flooded condition and 5 under the flooded condition (Table 4). The mean number of species decreased gradually as the sediment addition increased (Fig. 1a; Table 4), and was significantly higher at 0 cm of sediment addition compared to 0.25–2 cm. The mean number of seedlings decreased significantly when the sediment increased from 0 to 2 cm (Fig. 1b; Table 4). The number of seedlings from *S. trifolia, P. korshinskyi, M. vaginalis* decreased gradually when the sediment addition increased from 0 cm to 2 cm while the number of seedlings from *A. orientale* decreased significantly when the sediment addition was 2 cm.

There were no seedlings germinated in the pots with 1 cm or 2 cm of sediment addition, but without wetland soil, indicating that all seeds present in the sediment were killed during sample processing (i.e., oven drying).

3.2. Seed bank and vegetation

The number of species were 9, 6, 10, for the three communities dominated by *G. spiculosa, Z. latifolia* and *P. korshinskyi*, respectively. Species numbers germinated from the seed banks were significantly higher than that present in the original vegetation assemblages, and the similarity between them was low (Fig. 2). *S. trifolia, Poa palustris, Z. latifolia, Carex* sp. were present both in the seed bank and in the vegetation for the community dominated by *G. spiculosa*. *Z. latifolia, Poa palustris, S. trifolia* were present both in the seed bank and the original vegetation in community dominated by *Z. latifolia*. Only *P. korshinskyi* and *C. glomeratus* were present both in the seed bank and the original vegetation in community dominated by *P. korshinskyi*. The original dominant species, *G. spiculosa*, did not germinate from the seed banks (Table 5).

4. Discussion

4.1. Effects of sedimentation and inundation on seedling emergence and taxon density

Sedimentation rates vary in different wetlands and geographical regions due to natural factors such as the hydro-geological conditions and due to human factors such as agricultural activities (van der Valk et al., 1983; Kleiss, 1996; Greiner and Hershner, 1998;

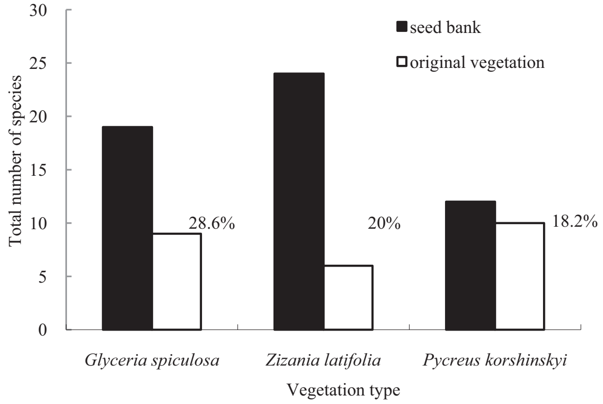

Fig. 2. Number of species present in the original vegetation and emerging from the seed bank. The similarity between both communities is provided for each of the three vegetation types.

Table 5
Species that emerged in the vegetation plots and their importance values.

Glyceria spiculosa		*Zizania latifolia*		*Pycreus korshinskyi*	
Species	Importance value	Species	Importance value	Species	Importance value
Glyceria spiculosa	1.129	*Zizania latifolia*	0.782	*Pycreus korshinskyi*	1.342
Equisetum fluviatile	0.301	*Glyceria spiculosa*	0.73	*Cyperus glomeratus*	0.428
Carex spp.	0.233	*Poa palustris*	0.277	*Iris laevigata*	0.176
Zizania latifolia	0.077	Unknown1	0.098	*Lysimachia thyrsiflora*	0.16
Scirpus tabernaemontani	0.07	Unknown2	0.06	Unknown2	0.062
Sagittaria trifolia	0.064	*Sagittaria trifolia*	0.054	*Thelypteris palustris*	0.062
Poa palustris	0.056			*Galium dahuricum*	0.062
Unknown1	0.056			*Caltha palustris*	0.05
Stachys japonica	0.028			*Sium suave*	0.05
				Stachys baicalensis	0.039

Mou and Sun, 2011). In general, the sedimentation rate is low in the natural wetland while it is high in disturbed and damaged wetlands. van der Valk et al. (1983) observed that the accumulation rates of sediment for wetlands in undisturbed landscapes were on the order of 0.3 cm yr^{-1} or less in Alaska. Greiner and Hershner (1998) reported 0.3–0.56 cm yr^{-1} of accumulation rates of sediment under natural conditions. Farming activities accelerate the rate of sediment accumulation. Sediment accumulations observed in wetlands influenced by agricultural activities were more than 1 cm yr^{-1} and even higher than 3–4 cm yr^{-1} (Johnston et al., 1984; Giroux and Bédard, 1995; Kleiss, 1996). To meet the water supply needs for the three large state agriculture farms located in the Lake Xingkai Natinal Reserve, 5.04×10^8 m^3 of water were pumped from Lake Xingkai for irrigation of the paddy field constructed around the lake. It is estimated that the bed elevation of Lake Xingkai was raised by 0.28–0.36 m compared to that of 1970s–1980s as the result the irrigation return flow which carried heavy sediment loads from the paddy field (Piao and Wang, 2011). Although a large portion of the sediment was deposited in the wetlands surrounding the lake, a significant amount of unsettled sediment was exported to the lake. The accumulation rates of sediment in our study areas were 0.3–1.0 cm yr^{-1}, which is similar to the values reported for disturbed freshwater wetlands (Fennessy et al., 1994).

Seed burial has both positive and negative consequences for seedling emergence, so there is an optimal range of burial depth to maximize the seedling emergence and subsequent seedling growth (Li et al., 2006). The most obvious negative consequence is burial so deep that seed germination is prevented. Germination sometimes occurs with deep burial but seed reserves may be exhausted before the seedling reaches the sediment surface, which leads to seedling death. In our experiment, emergence of seedlings decreased with the increase in sediment depth although this relationship differed slightly among communities. The optimal burial depth of seed germination occurred at 0 cm of sediment depth, and the seedling density decreased significantly at 0.5–0.75 cm of sediment addition in all the three communities. Similar relationships were also reported in some other studies (Galinato and van der Valk, 1986; Jurik et al., 1994; Wang et al., 1994; Gleason et al., 2003; Mou and Sun, 2011). The probable reasons may be the physiological requirements, the structural limitations of seeds and the microenvironment factors (such as oxygen, light, temperature, humidity and nutrients) surrounding the seeds. Increased sediment loadings would greatly change these microenvironment factors or create a physical barrier that significantly affects the germination of seeds, vegetation re-establishment and dominant vegetation types in wetlands (Jurik et al., 1994).

Different wetland species response differently to sediment loadings. The specific response depends on the species, hydrology, sediment depth and seed mass (van der Valk et al., 1983; Hartleb et al., 1993). Many studies have shown that there is a positive correlation between seed mass and emergence ability of seeds both within and between plant species, and sedimentation acts as an environmental filter to small-seeded species (Jurik et al., 1994; Dittmar and Neely, 1999; Li et al., 2006; Stromberg et al., 2011). A bigger seed contains more energy reserves and hence, has greater vigor and chances for emergence of the seedlings from deeper locations. This results in a greater tolerance to a wide range of environmental stresses such as sediment, predators, nutrient deprivation and prolonged periods in deep shade (Armstrong and Westoby, 1993). Galinato and van der Valk (1986) showed that species with seeds weighing 1 mg were more sensitive to sediment than species with seeds weighing 3 mg. As a very small-seeded species, *Typha* was greatly affected by 0.2–0.4 cm of sediment addition (Jurik et al., 1994; Wang et al., 1994; Gleason et al., 2003). Some species in our study showed a similar response to sediment addition as compared to other studies. For example, as small-seeded species, *J. effusus* and *C. angustifolia* disappeared with merely 0.25 cm sediment addition (Stromberg et al., 2011), and *E. ovata* disappeared at 0.5 cm of sediment (Gleason et al., 2003). As for *Sagittaria*, small amounts of sediment did not significantly hamper its seedling emergence until larger amounts of sediment (1–2 cm) were applied (Jurik et al., 1994; Gleason et al., 2003). As a large-seeded species, *A. orientale* was more resilient to sediment load (Gleason et al., 2003). So species responding differently to sediment in our study may be related to seed mass.

Species germinated from seed banks and their density, community type, biodiversity are significantly different in different water depths, fluctuation conditions and inundation durations in different types of wetlands (Nicol et al., 2003; Liu et al., 2005; Capon, 2007). In some instances, only 25% of species survived under flooded and non-flooded conditions. A change in water depth by as little as 2 cm could significantly affect seed germination (van der Valk and Davis, 1978; Liu et al., 2005). Water levels in our study site varied from no standing water to depths of approximately 12 cm. However, water depth was even greater when irrigation flow was returned to the wetlands (Piao and Wang, 2011). Our results showed significant differences in seed germination under flooded and non-flooded conditions and significantly more species and seedlings germinated under non-flooded condition. Our finding is consistent with other studies (Peterson and Baldwin, 2004; Johnson, 2004; Liu et al., 2005), indicating that wetland hydrologic regime was one of the major determinants of the type of community established from the seed bank in the National Natural Wetland Reserve of Lake Xingkai.

4.2. Seed bank and vegetation

As a reserve storage for propagules, wetland seed banks decrease the probability of extinction and play an important role in the renewal and succession of vegetation and the restoration of the impaired ecosystems. Typically more species are restored from seed banks than that were present in the original vegetation community (van der Valk and Davis, 1978). Our study showed that the similarity between the seed banks and original vegetation was less than 30%, and the biodiversity of seed banks was greater than that of the vegetation in the Lake Xingkai National Wetland Reserve. Common species (*S. trifolia, P. palustris, Z. latifolia, Carex* sp., *P. korshinskyi* and *C. glomeratus*) which were present both in the seed banks and in the vegetation, all germinated in the seed banks at 0.5 cm or greater sediment depth. The presence of several other species in the seed banks but the absence in the original vegetation might be the consequence of the high sediment load. As the dominant species, *P. korshinskyi* and *Z. latifolia* were present both in the seed banks and vegetation, but *G. spiculosa* was not found in the seed banks. This may be related to the reproductive strategy, seed production, seed germinability, viability and environmental factors (He et al., 1999). As a perennial herbaceous species, *G. spiculosa* mainly uses the rhizome as its reproductive strategy and seed germinability is very low even when the environmental conditions are suitable. As a perennial emergent herbaceous species, *Z. latifolia* also showed a low number of seedlings. As an annual herbaceous species, *P. korshinskyi* could only use seed production as its reproductive strategy, and thus seedling emergence in the seed bank is high. Our finding is consistent with studies in other regions of the world (Dittmar and Neely, 1999). Sediment loads could affect wetland vegetation reestablishment and composition. On the one hand, species respond differently to the sediment addition, annuals appear to be more capable of tolerating sedimentation and to take advantage of the available space created by the suppression of the perennials (Dittmar and Neely, 1999). By contrast, sediment addition may significantly affect species that reproduce only by seeds. When the sediment input exceeds sustainable levels, germination of these species may be restricted. For perennial species, they may still reestablish by vegetative propagation.

Our study revealed the negative impacts on seedling emergence by high sediment accumulation rates and high water levels from irrigation return flow in the National Wetland Reserve of Lake Xingkai. However, findings from this study should be interpreted with caution as the low seedling germination rates of some species may be also affected by low seed density in the natural wetland. Further studies with proper control are needed to elucidate the effects of different sediment depths on the germination success of the dominant wetland plants. Nevertheless, knowledge gained from this and other similar studies will provide important insights into irrigation and land management that should be promoted to sustain wetlands located downstream of agricultural lands.

Acknowledgments

We thank the reviewers and editors for their valuable advice, and Dr. Binhe Gu and Dr. Thomas Dreschel for suggestions and English editing. This study was supported by Chinese Academy of Sciences (grant # KZCX2-EW-319), National Natural Science Foundation of China (grant # 40901051 and 40830535) and CAS/SAFEA International Partnership Program for Creative Research Teams.

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