COMPARISON OF CARBON SEQUESTRATION ABILITY AND EFFECT OF ELEVATION IN FENCED WETLAND PLANT COMMUNITIES OF THE XILIN RIVER FLOODPLAINS: A MODEL CASE STUDY

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ABSTRACT

Floodplain habitats of the Xilin River in Inner Mongolia, China, were overgrazed by sheep and cattle until fencing of the floodplains was implemented in 2000. Carbon cycling of three plant communities of differing floodplain elevation after fencing showed that biomass in low-elevation wetlands increased fastest until reaching its maximum at 20 years in the future, while a slower increase in biomass existed in high-elevation and ‘hummock’ wetlands. Modelling and field experiments revealed differences between the three plant communities that were primarily attributed to different elevation levels and inundation periods. This study also determined the carbon sequestration capacity of the three floodplain wetland types (0.18 kg C m⁻² year⁻¹ in low-elevation wetlands, 0.09 kg C m⁻² year⁻¹ in high-elevation wetlands, and 0.05 kg C m⁻² year⁻¹ in hummock wetlands). Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: Xilin River; floodplain grazing; wetland plant communities; carbon sequestration; elevation

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INTRODUCTION

More than 53% of wetlands worldwide have been degraded and/or lost over the past decades because of human activities (Prescott and Tsanis, 1997; Mitsch and Gosselink, 2007). Recent wetland restoration efforts focus primarily on maintaining the natural diversity of wetland plant communities of a given wetland habitat along with their spatial and seasonal variability (Leibowitz, 2003). It is therefore important for successful wetland restoration to better understand the succession of site-specific plant communities under natural conditions.

Wetland plant communities respond strongly to site-specific habitats and hydrology (Meyer et al., 2010). Plant communities differ at different elevation levels because of gradients in hydrology, soil and biota, which result in distinct plant zonation at different elevations (Kennedy et al., 2003; Henszey et al., 2004; Davis et al., 2006). Elevation-level-specific restoration of wetlands is complicated and requires understanding of plant community variations and growth characteristics of site-specific plant populations under natural conditions (Currier, 1997; Whitney, 1997; Currier, 1998).

Carbon sequestration is an important ecological service function of wetlands. Current studies on carbon sequestration in restored wetlands focus on sediment, soil and living plant communities (Brevika and Homburg, 2004; Ned et al., 2006; Alongi et al., 2007; Kayranli et al., 2010), but this approach allows the recognition of changes only after several decades (Adhikari et al., 2009; Kayranli et al., 2010). Because plant biomass, standing dead plants, photosynthesis, litter decomposition, and soil respiration are the main components of the carbon cycle in wetland habitats (Wynn and Liehr, 2001; Mitsch et al., 2013), their quantification provides information on developing improved carbon sequestration by restored wetlands. Computer models are valuable decision tools for wetland restoration, and the simulation of the flows of C, N and P in wetlands allows the understanding and evaluation of the restoration process (Prescott and Tsanis, 1997; van der Peijl et al., 2000; Mitsch et al., 2013).

Carbon is a primary component of plant growth; hence, an emphasis on studying carbon enhances the study of plant community dynamics and increases the understanding of wetland ecosystem functioning. We developed a carbon model and simulated the growth characteristics and dynamics of three plant communities located on different elevations in a fenced floodplain wetland of the Xilin River in Inner Mongolia, China, using field data and the STELLA™ programme. Our modelling approach focused on the following research questions:

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(1) What are the differences in growth characteristics among different plant communities during the process of floodplain wetland restoration?

(2) Do different plant communities located on differing elevations affect carbon accumulation in floodplain wetlands?

MATERIALS AND METHODS

Study sites

The Xilin River basin is an important grazing area in Inner Mongolia, China. Because of overgrazing, the riparian floodplain wetland has been in different states of degradation. In order to protect and to restore the riparian floodplain wetlands, fences have been erected to prevent sheep and cattle from grazing. Experimental field sites of fenced floodplain wetland (43°37′40″N, 116°41′11″E) were located in the middle Xilin River catchment of the Inner Mongolia Plateau (Figure 1). The study site is a complex of riparian floodplain wetlands, consisting of three types: high-elevation floodplain wetland, low-elevation floodplain wetland and the hummock areas of intermediate elevation (Figure 2).

The climate in the Xilin River basin is warm and wet in the summer, cold and dry in the winter and is classified as a continental temperate semi-arid steppe climate. Average, maximum and minimum annual temperatures are −0.1, 18.3, and −22°C, respectively. Average annual precipitation is 288 mm, with most of it occurring between June and September. Maximum and minimum annual precipitations are 371 and 166 mm, respectively.

The dominant species of each plant community, its individual plant height, aboveground biomass, and hydrologic regime of those three floodplain wetland types are displayed in Table I.

Modelling methods

Modelling description. This model is a dynamic simulation model based on the carbon cycle. In this model, there are four state variables, which include aboveground and belowground biomass, litter and organic matter in the soil. The state variables are C amounts in various plant and soil pools, expressed as grams of C per m². The state variables are connected through flows of carbon expressed as C g m⁻² * week. These flows describe primary processes including photosynthesis, respiration and decomposition. The structural framework of this model is illustrated in Figure 3. The programme STELLA™ was used for computer simulations (Wang et al., 2013).

Quantification of factors controlling carbon sequestration

Atmosphere and soil temperature. Temperature is one of the most important controlling factors for physical, chemical
and biological processes. To integrate temperature dependence in this model, sine functions [Equations (1) \((R^2 = 0.98)\) and (2) \((R^2 = 0.96)\)] were used to fit the fluctuation of the month average atmosphere temperature and soil temperature from 2000 to 2008 (Figure 4), obtained from the Xilin meteorological monitoring station.

\[
T_{\text{atmosphere}} = 1.52 + 20\pi\sin(2\pi I/53*(\text{time + 34.8})) \quad (1)
\]

\[
T_{\text{soil}} = 4.1 + 10\pi\sin(2\pi I/53*(\text{time + 34.8})) \quad (2)
\]

Time was in weeks, with 53 weeks being the simulated average length of a year.

Photosynthesis. The photosynthesis flow equation from van der Peijl and Verhoeven (1999) was used. In this study, aboveground biomass for the three plant communities was obtained by measuring aboveground biomass in 2010, and maximum growth rates were calculated by using photosynthesis rates measured by a LI-7000 CO\(_2\)/H\(_2\)O analyser produced by LI-COR Biosciences, USA, in 2010 (Li, 2009).

Respiration. Soil respiration is affected by such factors as soil temperature, soil type, soil moisture, root density, and soil microbial biomass (Lundegardh, 1927). In this study region, soil respiration was significantly correlated with soil temperature and root biomass, while soil microbial biomass and soil moisture were not significantly correlated with these factors.

Table I. The biological and hydrologic conditions of three floodplain wetland types in the Xilin River of 2007 to 2010

| Floodplain wetland | Dominant species of community | Plant height (cm) | Aboveground biomass (g m\(^{-2}\)) | Hydrologic regime |
|--------------------|--------------------------------|------------------|----------------------------------|------------------|
| High floodplain    | *Leymus chinensis*            | 34.5 ± 8.4       | 351.2 ± 103.0                    | Never submerged and not frozen during the winter and spring |
|                    | *Phragmites australis*        |                  |                                  |                   |
|                    | *Artemisia tanacetifolia*     |                  |                                  |                   |
| Hummock            | *Poa subfastigata*            | 41.4 ± 8.3       | 417.6 ± 78.1                     | Not submerged during growing seasons while frozen during the winter and spring |
|                    | *Lathyrus quinqueflorus*      |                  |                                  |                   |
|                    | *Geranium wlassowianum*       |                  |                                  |                   |
| Low floodplain     | *Glyceria triflora*           | 38.9 ± 10.7      | 419.2 ± 144.9                    | Submerged longer during growing season and frozen during the winter and spring |
|                    | *Poa subfastigata*            |                  |                                  |                   |
|                    | *Carex appendiculata*         |                  |                                  |                   |

Note: The growing season of the wetland plant community is from late May to mid-September.
measures (Gao, 2008). Hence, soil respiration was mainly performed by plant roots and controlled by soil temperature. In order to describe the relationship of soil temperature and soil respiration, Equations (3) \( R^2 = 0.93 \), (4) \( R^2 = 0.54 \) and (5) \( R^2 = 0.79 \) were used, which are shown in Figure 5.

\[
R_{\text{high}} = -0.0004 \cdot \text{temp}^3 + 0.0153 \cdot \text{temp}^2 + 0.0004 \cdot \text{temp} + 1.3691
\]

\[
R_{\text{tower}} = -0.0004 \cdot \text{temp}^3 + 0.0072 \cdot \text{temp}^2 + 0.1429 \cdot \text{temp} + 1.2866
\]

\[
R_{\text{low}} = -0.0007 \cdot \text{temp}^3 + 0.0315 \cdot \text{temp}^2 - 0.0505 \cdot \text{temp} + 0.1222
\]

Decomposition. In our model, temperature was used as the only independent variable in the decomposition rate formulas (Wang, 2009). Equations (6) \( R^2 = 0.84 \), 7 \( R^2 = 0.63 \) and 8 \( R^2 = 0.54 \) were used to simulate decomposition in different plant communities based on experimental data measured from 2007 to 2008 (Figure 6).

\[
D_{\text{high}} = 0.00007 \cdot \exp(0.31 \cdot \text{temp})
\]

\[
D_{\text{tower}} = 0.00005 \cdot \exp(0.32 \cdot \text{temp})
\]

\[
D_{\text{low}} = 0.00008 \cdot \exp(0.31 \cdot \text{temp})
\]

Verification of the model

The models for the three plant communities were calibrated by using the average measured aboveground biomass in the 2008 growing season. The degree of fit \( 1 - (\sum(\text{measured} - \text{simulated})^2/\sum(\text{measured})^2)^{1/2} \) between simulated and measured aboveground biomass were 0.92, 0.86 and 0.80 for high floodplain, hummock areas and low floodplain wetlands, respectively. Simulated results accurately modelled the distribution characteristics of measured aboveground biomass (Figure 7). Hence, this model can be applied to predict the growth and change of these three plant communities in riparian floodplain wetlands.

RESULTS

Comparison of biomass and soil organic matter among three plant communities

Analysis of variance (ANOVA) showed that there were significant differences between aboveground and belowground biomass and soil organic matter in plant communities.

Figure 3. Structural model of the plant community ecological system. This figure is available in colour online at wileyonlinelibrary.com/journal/rra

Figure 4. Fitted line for monthly average atmosphere and soil temperature.
of the three different wetland types \( p < 0.05 \). Aboveground and belowground biomass and soil organic matter of plant communities were the highest in the low-elevation floodplain wetland (Figures 8 and 9) and were the lowest in the hummock wetland. By second-order polynomial fitting of aboveground and belowground biomass and soil organic matter, aboveground and belowground biomass increased to a maximum, while soil organic matter continued to increase for 20 years.

**Comparison of different C flows among three plant communities**

In our model, inflow (photosynthesis) and outflow (decomposition and respiration) were predicted and modelled 20 years into the future (Figures 10, 11 and 12). ANOVA showed that there are significant differences in photosynthesis, respiration and decomposition flows among the three different wetlands \( p < 0.05 \). The fitted line of Michaelis–Menten indicated that photosynthesis and respiration increased for 15 years, reaching a maximum, while decomposition increased for 20 years. Among the three plant communities, photosynthesis, respiration and decomposition were the highest in low-elevation floodplain wetlands and lowest in hummock floodplain wetlands, with intermediate values in high-elevation floodplain wetlands.

**DISCUSSIONS**

**Effects of elevation difference in riparian floodplain wetland**

In this study, the simulated results showed that aboveground and belowground biomass of plant communities in low-elevation floodplain wetlands were higher than that in high-elevation floodplain wetlands and in hummock wetlands. Aboveground biomass was similar in high floodplain and hummock wetlands, while belowground biomass in high floodplain wetlands was relatively higher than that in hummock wetlands. Some studies demonstrated that elevation differences could produce gradients in hydrology, soil and biota in riparian wetlands in the central Platte River Valley, USA (Henszey *et al*., 2004; Davis *et al*., 2006). Elevations varying from 10 to 25 cm can cause community structure and dominance to change (Galatowitsch and van der Valk, 1996; Rheinhardt and Fraser, 2001). Elevation differences led to vegetation with distinct zonation (Odland, 1997). Consistent with these studies, the three plant communities studied here were distributed in specific habitats with elevations varying from 40 to 60 cm, with each characterized by their own vegetation zonation. Differences in topography and hydrology resulted in frequent inundation of the plant community in low floodplain wetlands (Li *et al*., 2012). Inundation would provide enough water and nutrients for...
plant growth in low floodplain wetlands (Lamers et al., 2006). Water inundation increased biomass and photosynthetic acclimation of riparian species in comparison with control treatments with no flooding in greenhouse experiments (Luo et al., 2009), similar to our simulated results that found that biomass and photosynthesis in the low floodplain wetland were significantly higher than that in high floodplain and hummock wetlands. In peatland ecosystems, warmer and drier conditions can stimulate respiration (Cai et al., 2010), which may explain respiration patterns in hummock wetlands in our study. Generally, wetland plant communities were structured according to the conditions of particular wetland zones, keeping their functional stability across an environmental gradient (Mitsch and Gosselink, 2007). Therefore, in the Xilin River floodplain wetlands, elevation difference is a very important environmental gradient to consider during the process of vegetation restoration, as elevation differences led to differences in the distribution of plant communities. These plant communities after restoration by fencing have separated because of their different adaptive physiological mechanisms for living under different environmental factors such as temperature, soil moisture, and groundwater level.

Although elevation differences could affect the growth of different plants in riparian floodplain wetlands, fencing used in heavily grazed wetlands can be a feasible restoration measure. Because the Xilin River basin is an important grazing area, we can use our knowledge of elevation differences to establish different zones for grazing, which are analogous to crop rotation and periodic pasture management practices used in the USA.

**Carbon sequestration in riparian floodplain wetlands**

Most studies on carbon sequestration within wetlands focus on living plant communities and soil (Bedard-Haughn et al., 2006; Ned et al., 2006). The net C accumulation of living plant and organic matter depends on the balance between C uptake during the photosynthesis and C loss during respiration (Cai et al., 2010), and between primary productivity and the corresponding decomposition rate (Mitsch and Gosselink, 2007), respectively. Generally, high productivity, high water tables and low decomposition rates increased carbon storage within soil, sediment and detritus of wetlands (Whiting and Chanton, 2001). In this study, all three plant communities in riparian floodplain wetlands displayed a net biomass increase, with biomass in low floodplain wetlands increasing significantly. This indicated that riparian floodplain wetlands along the Xilin River could become a carbon sink after restoration, and periodic inundation could promote a faster accumulation of carbon.

Soil organic matter is a very important carbon source in wetlands. Vegetation and microbial decay can promote organic matter accumulation (Quanrud et al., 2004; Li et al., 2008). Organic matter is stored in the soil by...
accumulation and decomposition (Kayranli et al., 2010). In this study, we primarily focused on simulating organic matter accumulation by the processes of plant decay and microbial decomposition and found that elevation affected the accumulation of organic matter, especially in low floodplain wetlands with periodic inundation. According to the simulation results, we calculated average carbon accumulation for three wetland types: 0.18 kg C m\(^{-2}\) year\(^{-1}\) in low floodplain wetland, 0.09 kg C m\(^{-2}\) year\(^{-1}\) in high floodplain wetland, and 0.05 kg C m\(^{-2}\) year\(^{-1}\) in hummock wetlands. Compared with carbon accumulation in different wetlands worldwide (Kayranli et al., 2010), carbon accumulation in low floodplain wetlands was similar to a riparian ecosystem in Maryland (USA; 0.16–0.22 kg C m\(^{-2}\) year\(^{-1}\); McCarty and Ritchie, 2002) and in horizontal subsurface-flow constructed wetlands (Estonia; 1.5–2.2 kg C m\(^{-2}\) year\(^{-1}\); Mander et al., 2008). Carbon accumulation in high floodplain wetlands and hummock wetlands approached levels similar to temperate peatlands (Finland; 0.01–0.046 kg C m\(^{-2}\) year\(^{-1}\); Turunen et al., 2002). This further illustrates the benefits of depressional wetland for carbon sequestration. Carbon accumulation differences in different wetlands emphasize the roles of water table level and vegetation composition in carbon sequestration (Webster et al., 2013).

Although the carbon cycle still relies on the cycling and bioavailability of phosphorous and nitrogen (Craft and Richardson, 1998), cycles of N and P were not considered in this model. No limit of N and P simplifies the simulation of the C cycle and has a benefit in understanding the nature of carbon change in riparian wetlands. In future studies, we will add N and P limits to observe how different plant communities in riparian floodplain wetlands grow and if limits to N and P are important in affecting carbon accumulation.
CONCLUSIONS

In the Xilin River floodplain wetlands, carbon cycles of three plant communities were simulated. We found that the increase in biomass in low floodplain wetlands was significantly higher than that in high floodplain and in hummock wetlands. There were more similarities between high floodplain and hummock wetlands. This can be attributed to elevation differences and the extent of inundation. Low elevations with periodic inundation enhanced carbon sequestration in riparian floodplain wetlands. After fenced restoration, riparian floodplain wetlands along the Xilin River could become a carbon sink, and periodic inundation could promote the fast accumulation of carbon.

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REFERENCES

Adhikari S, Bajracharaya RM, Sitaula BK. 2009. A Review of Carbon Dynamics and Sequestration in Wetlands. Journal of Wetlands Ecology 2: 42–46.

Alongi DM, Trott LA, Pfiztnier J. 2007. Deposition, mineralization, and storage of carbon and nitrogen in sediments of the far northern and northern Great Barrier Reef shelf. Continental Shelf Research 27: 2595–2622.

Bedard-Haughn A, Jongbloed F, Akkerman J, Uijl A, Jong E, Yates T, Pennoek D. 2006. The effects of erosional and management history on soil organic carbon stores in ephemeral wetlands of hummocky agricultural landscapes. Geoderma 135: 296–306.

Brevika EC, Homburg JA. 2004. A 5000-year record of carbon sequestration from a coastal lagoon and wetland complex, Southern California, USA. Catena 57: 221–232.

Cai T, Flanagan LB, Syed KH. 2010. Warmer and drier conditions stimulate respiration more than photosynthesis in a boreal peatland ecosystem: Analysis of automatic chambers and eddy covariance measurements. Plant, Cell and Environment 33: 394–407.

Craft CB, Richardson CJ. 1998. Recent and long-term organic soil accretion and nutrient accumulation in the everglades. Soil Science Society of America Journal 62: 834–843.

Currier PJ. 1997. Woody vegetation expansion and continuing declines in open channel habitat on the Platte River in Nebraska. Proceedings of the North American Crane Workshop 7: 141–152.

Currier PJ. 1998. Wetland restoration on the Platte River floodplain in Nebraska. In Ecology of wetlands and associated systems, Mujdar SK, Miller EW, Brenner FJ (eds). Pennsylvania Academy of Sciences: Easton; 611–627.

Davis CA, Austin JE, Bulh DA. 2006. Factors influencing soil invertebrate communities in riparian grasslands of the central Platte River floodplain. Wetlands 26: 438–454.

Glatowitsch SM, van der Valk AG. 1996. Characteristics of recently restored wetlands in the prairie pothole region. Wetlands 16: 75–83.

Gao J. 2008. The study on soil respiration of wetland plant communities on riparian floodplain in the Xilin river. Inner Mongolia University: Hohhot.

Henssey RJ, Pfeiffer K, Keough JR. 2004. Linking surface- and groundwater levels to riparian grassland species along the Platte River in Central Nebraska, United States. Wetlands 24: 665–687.

Kayral B, Schulz M, Mustafa A, Hedmark Å, Storage C. 2010. Carbon storage and fluxes within freshwater wetlands: a critical review. Wetlands 30: 111–124.

Kennedy MP, Milne JM, Murphy KJ. 2003. Experimental growth responses to groundwater level variation and competition in five British wetland plant species. Wetlands Ecology and Management 11: 383–396.

Lammers LPM, Loeb R, Antheunisse AM, Miletto M, Lucassen ECHET, Boxman AW, Smolders AJP, Roeolfs JGM. 2006. Biogeochemical constraints on the ecological rehabilitation of wetland vegetation in river floodplains. Hydrobiologia 565: 165–186.

Leibowitz SG. 2003. Isolated wetlands and their functions: an ecological perspective. Wetlands 23: 517–531.

Li L. 2009. Middle reaches of the Xilin River floodplain wetlands of different communities of photosynthesis research. Inner Mongolia University: Hohhot.

Li J, Wen Y, Zhou Q, Zhang XJ, Li X, Yang S, Lin T. 2008. Influence of vegetation and substrate on the removal and transformation of dissolved organic matter in horizontal subsurface-flow constructed wetlands. Bioresource Technology 99: 4990–4996.

Li JW, Wang LX, Wang W, Liang CZ, Liu HM. 2012. Characterization of degradation of wetland plant communities on floodplain in typical steppe region of Inner Mongolia Plateau, China. Chinese Journal of Plant Ecology 36: 10–18.

Lundegardh H. 1927. Carbon dioxide evolution and crop growth. Soil Science Society of America Journal 23: 417–453.

Luo FL, Nagel KA, Zeng B, Schuur U, Matsubara S. 2009. Photosynthetic acclimation is important for post-submergence recovery of photosynthesis and growth in two riparian species. Annals of Botany 104: 1435–1444.

Mander U, Lõhmusa K, Teiter S, Mauring T, Nurk K, Augustin J. 2008. Gaseous fluxes in the nitrogen and carbon budgets of subsurface flow constructed wetlands. Science of the Total Environment 404: 343–353.

McCarty GW, Ritchie JC. 2002. Impact of soil movement on carbon sequestration in agricultural ecosystems. Environmental Pollution 116: 423–430.

Meyer CK, Whiles MR, Baer SG. 2010. Plant Community Recovery following Restoration in Temporally Variable Riparian Wetlands. Restoration Ecology 18: 52–64.

Mitsch WJ, Gosselink JG. 2007. Wetlands. Wiley: New York.

Mitsch WJ, Bernal B, Nahlik AM, Mander UJ, Zhang L, Anderson CJ, Jorgensen SE, Brix H. 2013. Wetlands, carbon, and climate change. Landscape Ecology 28: 583–597.

Ned HE Jr., Gleason RA, Olness A, McDougall RL, Munkin HR, Roberts RD, Bourbonniere RA, Warner BG. 2006. North American prairie wetlands are important nonforested land-based carbon storage sites. Science of the Total Environment 36: 179–188.

Odland A. 1997. Development of vegetation in created wetlands in western Norway. Aquatic Botany 59: 45–62.

van der Peijl MJ, Vanhoen JTA. 1999. A model of carbon, nitrogen and phosphorus dynamics and their interactions in river marginal wetlands. Ecological Modelling 134: 169–184.

van der Peijl MJ, van Oorschot MMP, Verhoef JTA. 2000. Simulation of the effects of nutrient enrichment on nutrient and carbon dynamics in a river marginal wetland. Ecological Modelling 134: 95–130.

van der Peijl MJ, van Oorschot MMP, Verhoef JTA. 2000. Simulation of the effects of nutrient enrichment on nutrient and carbon dynamics in a river marginal wetland. Ecological Modelling 134: 95–130.

van der Peijl MJ, van Oorschot MMP, Verhoef JTA. 2000. Simulation of the effects of nutrient enrichment on nutrient and carbon dynamics in a river marginal wetland. Ecological Modelling 134: 95–130.

van der Peijl MJ, van Oorschot MMP, Verhoef JTA. 2000. Simulation of the effects of nutrient enrichment on nutrient and carbon dynamics in a river marginal wetland. Ecological Modelling 134: 95–130.
Rheinhardt RD, Fraser K. 2001. Relationship between hydrology and zonation of freshwater swale wetlands on lower Hatteras Island, North Carolina, United States. *Wetlands* **21**: 265–273.

Turunen C, Tomppo E, Tolonen K, Reinkainen E. 2002. Estimating carbon accumulation rates of undrained mires in Finland: application to boreal and subarctic regions. *Holocene* **12**: 69–80.

Wang H. 2009. Comparative study on litter decomposition between the typical steppe communities and the wetland communities of Xilinhe river. Inner Mongolia University: Hohhot.

Wang Q, Jørgensen SE, Lu JJ, Nielsen SN, Zhang JR. 2013. A model of vegetation dynamics of Spartina alterniflora and Phragmites australis in an expanding estuarine wetland: Biological interactions and sedimentary effects. *Ecological Modelling* **250**: 195–204.

Webster KL, McLaughlin JW, Kim Y, Packalen MS, Li C. 2013. Modelling carbon dynamics and response to environmental change along aboreal fen nutrient gradient. *Ecological Modelling* **248**: 148–164.

Whiting GJ, Chanton JP. 2001. Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. *Tellus* **53**: 521–528.

Whitney B. 1997. A Platte River country restoration. Part II: at work on the plains. *Restoration & Management Notes* **15**: 126–137.

Wynn TM, Liehr SK. 2001. Development of a constructed subsurfaceflow wetland simulation model. *Ecological Engineering* **16**: 519–536.