Ecological Engineering 96 (2016) 187–193

Contents lists available at ScienceDirect

Ecological Engineering

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

Effects of hydrologic mediation and plantation of *Carex schmidtii* Meinsh on peatland restoration in China's Changbai Mountain region

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ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 24 January 2016
Accepted 25 January 2016
Available online 12 February 2016

Keywords:
Degraded peatland
Ecological restoration
Hydrologic mediation
Carex schmidtii
Revegetation

ABSTRACT

Since large areas of peatlands in China have been degraded or reclaimed to cropland in recent decades, the conversion of these croplands to wetlands and the restoration of degraded peatlands by means of engineering have been attracting increasing attention. Hydrologic mediation and plantation of dominant peatland species were implemented to determine the effects of these two artificial measures on revegetation and soil property improvement in paddy fields in the Changbai Mountains in Northeast China. The results showed that after a three-year restoration, compared to natural restoration treatment, planting of *Carex schmidtii* significantly reduced aboveground biomass by 45% ($P < 0.05$), increased root biomass by 53% ($P < 0.05$), increased the Shannon–Wiener Index by 17%, enhanced concentrations of total soil organic matter by 28% ($P < 0.05$), reduced topsoil bulk density by 40% ($P < 0.05$), and improved water retention capacity of the topsoil. These results demonstrate the ability of *C. schmidtii* to inhibit the growth of weeds and other nontarget species through competition, and to increase the amount of residual roots in soil due to its well-developed rhizomes. Aboveground biomass and total organic matter in hydrologic mediation were 38% lower and 37% higher than in the natural restoration treatment, respectively. However, annual precipitation in this area is 704.2 mm, higher than most other area in Northeast China, and the Shannon–Wiener Index and soil bulk density were 4% and 29% lower than in the natural restoration treatment, respectively. Furthermore, the combined application of these two measures resulted in 35% lower aboveground biomass, 22% higher Shannon–Wiener Index, 16% higher topsoil organic matter, and 27% lower bulk density than in the natural restoration treatment. However, the growth of *C. schmidtii* was inhibited due to the reduction in its survival rate and basal width growth rate. Our results suggest that planting *C. schmidtii* is an effective way to promote the restoration of degraded peatland and enhance its carbon sink function in the Changbai Mountains. On the other hand, implementation of hydrologic mediation is not recommended for this rain-rich region.

1. Introduction

Peatlands constitute an important carbon sink, with the highest carbon reserve per unit area for all types of terrestrial ecosystems. The carbon they sequester is important for controlling the increases of atmospheric CO_2 concentration and slowing down global warming (Kim et al., 2012; Wang et al., 2013). In China, peatlands are found mainly in the Changbai Mountain and Tibetan Plateau regions (Chu and Jiang, 2012). From the perspectives of both ecology and economics, these peatlands are important ecosystems at both regional and national levels. Unfortunately, since the reclamation of large areas of peatlands as paddy fields or farmland in the Changbai Mountains and other regions, beginning in the 1950s, the area of wetlands has been greatly reduced (Li, 2013; Wang et al., 2015) and the original hydrological patterns have been destroyed, resulting in a dramatic decline in biodiversity and ecological services. Consequently, natural disasters have occurred frequently: there is flooding in the rainy season and depletion takes place in the dry season due to the weakened hydrological adjusting function of the wetlands. These conditions are seriously threatening the ecological security of Northeast China. An important method of restoring those ecosystems is returning these croplands to wetlands (Di et al., 2004). In response to the call from the International Mire Conservation Group, the Chinese government is

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http://dx.doi.org/10.1016/j.ecoleng.2016.01.015
0925-8574/

actively implementing ecological restoration policies and organizing projects in appropriate places to revert croplands to wetlands. According to *The National Wetland Protection Engineering Planning (2004–2030)* of China, 1,400,000 ha of wetlands will be restored by 2030 (State Forestry Bureau, 2003). Therefore, evaluation of the effects of different methods of peatland restoration is urgently needed.

Methods of peatland restoration mainly include ditch blocking, hydrologic mediation, alteration of microtopography, and plant reintroduction (Gorham and Rochefort, 2003; Tuittila et al., 2000, 2003). Although measures are selected based upon the different types of land use and peat mining in the regions, one of the main purposes is the restoration of hydrological conditions and plant communities to the undisturbed state (Money and Wheeler, 1999; Zhang et al., 2012). In most cases, native species cannot be restored by natural recolonization (Galatowitsch and van der Valk, 1996) due to the limitation of the current seed bank.

Reintroduction of common peatland species is widely implemented in vegetation restoration (Campbell et al., 2003). A dominant species in the peatlands of Northeast China is *Carex schmidtii*, a perennial rhizomatous species with a strong tillering capability that makes it possible to divide its rhizome and then plant it in restoration areas. Peatlands degraded by draining and reclamation can also be effectively restored through damming and ditch blocking (Zhang et al., 2012; González et al., 2014). Such anthropogenic rewetting engineering was the preference of participants of the Cancun Climate Change Conference (Hiraishi et al., 2014; Earth Negotiations Bulletin, 2010). While plantation and hydrologic mediation have already been carried out in some restoration projects (De Steven and Sharitz, 2007; Cagampan and Waddington, 2008), few studies have compared these two methods in terms of their restoration effects or evaluated their performance in reverting cropland to peatland.

The restoration of damaged peatland is normally evaluated by use of vegetation and soil indices. Vegetation indices include improvement in productivity, species diversity, and restored dominant species of natural communities that are undamaged (Zedler, 2000; Schipper et al., 2002), while soil indices include increase of soil organic matter and reduction of bulk density (Meyer et al., 2008). The vegetation and soil on natural and damaged peatlands have different characteristics. A natural peatland is an important "living C sequestration pool" and has greater porosity and a higher content of saturated water, so that plant residue cannot decompose efficiently under the condition of reduction, resulting in a higher capacity for accumulating organic matter (Li et al., 2010). Once it has been damaged, however, the peat soil layer decomposes and becomes compacted, causing an increase in density and a decrease in field moisture (Everett, 1971). Plant residue decomposes quickly in a degraded peatland, and the accumulation of organic matters ceases, causing it to become a "dead peatland" (You et al., 2014; Schouwenaars, 1993).

In this study, different restoration methods were implemented in paddy fields in the Changbai Mountains that were peatlands about 20 years ago and then reclaimed by local farmers, with the purpose of exploring whether hydrologic mediation can promote restoration of the original vegetation and improve soil properties; whether planting *C. schmidtii* can restore dominant peatland species; and whether better results can be achieved when the two measures are employed in combination.

2. Methods

2.1. Study site

The study site is located at the Jilin Longwan National Nature Reserve, with an elevation of 617 m and at a distance of 1 km west of Jinchuan town, Jilin province, China (42°20′35″N, 126°21′58″E; Fig. 1A). This area is characterized by a semi-arid and temperate continental monsoon climate with a mean annual temperature of 4.1 °C, mean annual precipitation of 704.2 mm (with 61% of precipitation occurring from June to August), and mean annual evaporation of 1276.1 mm. There are approximately 110–120 frost-free days and the weather is usually cold and damp. The precipitation varied during the three experimental years. In 2012, the annual total precipitation was 631.8 mm, whereas the year 2013 saw a higher total precipitation of 1139.4 mm, while in 2014, the precipitation amounted to 841.6 mm. Air temperature in these three years showed a similar dynamic, with the maximum and minimum mean monthly air temperature at 21 °C and −18 °C, respectively (Supplemental Fig. S1). The peatland area covered about 98.6 ha in this region in the 1980s. In recent decades, about 23.8 ha of peatland have been reclaimed to paddy field, dry cropland, or fishpond.

2.2. Experimental design

The study area is separated from the natural peatland by the North River (Fig. 1B). In earlier days, it was also part of a natural peatland formed by barrier lake succession, but nearly twenty years ago, it was cultivated and became paddy fields. A total area of about 2000 m^2 paddy fields was divided into four testing plots, each with an area of about 500 m^2 and with the same original water and tillage conditions. Different treatments were implemented in the four plots, namely: (1) natural restoration (N), (2) hydrologic mediation (W), (3) plantation of *C. schmidtii* (T), and (4) plantation of *C. schmidtii* with hydrologic mediation (WT) (Fig. 1C). For the plots of W and WT, hydrologic mediation was carried out in the months of May, June, and July of each year from 2012 to 2014 by diverting water through a dam constructed in the river, and with the water level kept at about 0–10 cm through observation of the water-level scales and artificial control of the water gap through opening or closing. When the water level reached about 10 cm, we closed the water gap; when it dropped to 0 cm, we opened the water gap and continued irrigation. Because the T plot area is slightly larger than the WT plot, in order to obtain similar plantations, 339 clusters and 280 clusters of *C. schmidtii* were planted into the T and WT plots, respectively, from the natural peatland in early June of 2012. The planting density in both plots was 1 cluster per square meter. The heights of the planting plants in both plots were 30–50 cm, and their basal widths were 6–10 cm. To ensure effective implementation of each treatment, the four plots were separated from each other by ridges.

2.3. Sampling method

2.3.1. Plant community investigation

Ten random quadrats (1 m × 1 m) were established in each plot, and the vegetation was surveyed each year from 2012 to 2014 in early August when biomass is at its highest. Community coverage was measured by the projection method. Plant species and coverage of each quadrat were recorded before plants were clipped. Individual quantities of each species were recorded before being oven-dried at 65 °C to a constant weight, and aboveground biomass of each species was measured in each sampling quadrat. Then, species diversity and richness were calculated for each quadrat. In 2013, three samples were collected in each quadrat from 0 to 60 cm depth by using a stainless steel auger, 8 cm in internal diameter. Roots were separated from the soil samples, cleaned, and oven-dried at 65 °C to a constant weight. Additionally, the *C. schmidtii* planted in the T and WT plots was surveyed in mid-June of each year from 2012 to 2014, specifically for indices such as height and basal width, which were measured by tape. The number of survival