Original Research Article

Implications of tussock degradation for soil properties in Momoge wetland, Northeast China

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Abstract: Carex schmidtii wetland, as a unique landscape in the Momoge National Nature Reserve, has suffered from serious degradation due to climate change and anthropogenic disturbance before 2017 and soil properties of degraded tussock meadows have changed in last 30 years. In the present work, typical (TT), slightly degraded (SLT), severely degraded (SET) and completely degraded (CDT) tussock wetlands based on plant coverage was used to construct the degradation succession so as to study the effects of tussock degradation on soil properties. Soil physicochemical properties, stable isotopes of carbon ($\delta^{13}C$) in plants and soil organic carbon (SOC) were thoroughly investigated in field so as to predict the consequences of tussock degradation. Results showed that soil pH value was decreased with the degree of tussock degradation increased. The SOC, total nitrogen and total phosphorus of SLT had peak values among the four wetlands. The δ13C value in soil and plants demonstrated that the change of SOC during degradation process have no significant relevance with Carex schmidtii. Principal component analysis indicated that the clusters of TT and SLT are different from SET and CDT. Tussock degradation had a significant negative effect on soil properties. The findings can contribute to establishing the evidence for predicting the influences of tussock degradation on soil properties in Momoge wetland.

Keywords: Tussock, Soil properties, Degradation, Carex schmidtii, Momoge wetland

1. Introduction

Momoge Wetland is an international important wetland, but has suffered serious degradation due to climate change and anthropogenic disturbance[1-2]. As a dominant landscape along the Nen River, Carex tussock wetland appeals to a variety of rare bird species, including Ciconia boyciana, Accipiter gentilis, Falco *naumanni* and Grus vipio[3-4]. However, intensive human activities have severe effects on wetland structure and function. Pan et al.[3] reported that the area of Carex tussocks wetland decreased from 37,400 ha in 1,986 to 28,340 ha in 2002. Long-term drought and grazing contribute to poor permeability of soil, constraining the seeding, establishment and growth of Carex schmidtii tussocks. Moreover, the loss of wetlands seriously affects the survival of rare birds.

Carex tussock meadows was widespread in temperate freshwater marshes and streams, characterizing abundant root system and rich biodiversity[5-7]. Tussocks were comprised of hummock and Carex species. The hummocks were a mixture of plant roots, rhizomes, shoot bases and residue of sedge, and their heights are typically 10-40 cm above the soil surface and some even reach 1 m[8]. By increasing microtopography, Carex tussocks provided advantages for plant establishment and biodiversity promotion[9-10]. Tussock also had a capacity to sequester and accumulate carbon[6]. Recently, influenced by climate change and human activities, tussock wetlands are dying off and soil properties of degraded tussock meadows have changed[3, 7]. Therefore, the effect of tussock degradation on soil properties change deserves immediate attentions.

Scientific studies on the restoration of tussocks wetlands have achieved some successes, particularly the engineering restoration of Carex wetlands[11-14]. However, there are few studies addressing how soil properties in

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response to tussocks degradation. Soil plays an important role in nutrients cycle, which affects tussocks formation and community development[15]. It is pivotal to assess soil quality of degraded tussock meadows in characterizing the potential hazards of the degradation of tussock wetlands. As the fundamental indicators, soil physical and chemical properties can reflect the changes in soil quality[2]. For better protection of tussock wetlands, studies on the relationship between tussock degradation and soil properties are needed.

To the end, in combination with the measurement of soil physicochemical properties, stable isotopes of carbon in plant and soil in a degradation succession including four tussock sites were assessed. The purposes of this study were (1) to evaluate the effect of tussock degradation on soil properties, (2) attempt to establish the evidence for predicting the degradation of tussock wetlands. We hypothesized that the tussock degradation was the vital variable having a negative effect on soil properties.

2. Materials and Methods

2.1 Study area

The study sites were located at Haernao (45°50′–46°18′N, 123°55′–124°4′E), situated in the eastern part of the Momoge Wetland Nature Reserve. This zone had a semiarid continental climate and experienced a mean annual temperature of 4.2℃ and a mean annual precipitation of 412 mm, concentrating in July and August. The dominant plants were C. schmidtii tussocks, Polygonum persicaria and Calamagrostis angustifolia in Haernao. Soils were classed as typical alluvial meadow soils with seasonal and temporary water logging[7, 16].

2.2 Soil sampling

Soil samples were collected using a metal auger to a depth of 10 cm at four sites in Momoge wetland, which are dominated by C. schmidtii tussocks. The four sites (Table 1) named typical tussock wetland (TT), slightly degraded tussock wetland (SLT), severely degraded tussock wetland (SET) and completely degraded tussock wetland (CDT), respectively. In each site, we randomly selected 4 sampling plots (5 m×5 m) as replicates. In each plot, we collected soil by five-spot-sampling method, brought samples to laboratory and adopted the method of coning and quartering to obtain samples to be determined.

Table 1 The waterlogging situation and vegetation of study sites.

Site	Waterlogging situation	Coverage of Carex tussock	Dominated vegetation
TT	Waterlogging depth 5–20 cm	65–75%	Carex schmidtii, Alisma orentale, Typha orientalis
SLT	Seasonal and temporary water logging depth 0–5 cm	35–63%	Carex schmidtii, Polygonum persicaria, Echinochloa caudata
SET	No water accumulation on the soil surface, the soil water content 40%~60%	15–21%	Carex schmidtii, Echinochloa caudata, Polygonum persicaria
CDT	Drought condition, soil water content < 40%	0–3%	Polygonum persicaria, Echinochloa caudata, Potentilla anserina

Note: *TT, typical tussock wetland; SLT, slightly degraded tussock wetland; SET, severely degraded tussock wetland; CDT, completely degraded tussock wetland.*

2.3 Samples determination

Soil bulk density were measured by drying method. Soil pH was determined by 1:10 soil/water solution with a Leici pH meter (Phs-3C, shanghai). Electric conductivity (EC) was determined by a wet sensor. Soil organic carbon (SOC) and total nitrogen (TN) was measured with a space-saving TON/TN analyzer (Multi N/C 2100, Jena, Germany). Total phosphorus (TP) was determined by Molybaenum-Antimony-Spectropho-Tometric Method with continuous flow analyzer (SKALAR San++, Netherlands). The C:N, C:P, N:P ratios for each site were calculated as mass ratios. The carbon isotope discrimination of plant and soil samples was analyzed by a mass spectrometer (MAT253, California, America).

2.4 Statistical analysis

Date analyses and draw graphs were conducted in the SPSS20.0 and OriginPro9.2. A Duncan's multiple range test was employed to determine the differences among the soil variables of different sites using the one-way analysis of variance (ANOVA). Significant difference was expressed by different letters at the $p = 0.05$ level. Principal component analysis (PCA) was performed using R.

3. Results

3.1 Soil bulk density, pH and EC

Tussock degradation has significant effects on soil pH and EC (Table 2). Soil pH decreased as the degradation degree of tussock intensified, and the values of soil pH in SET and CDT were significantly higher than TT and SLT ($F = 14.5$, $p < 0.001$). The greatest soil EC was 172.75 mS/m recorded in TT, whereas the smallest was 119.50 mS/m recorded in SET ($F = 12.1$, $p < 0.01$). Soil bulk density varied from 0.85 to 0.92 g/cm3 and there were no significant differences among the four sites ($F = 0.5$, $p > 0.05$).

Table 2 Soil bulk density, pH and EC in tussock wetlands.

Variable	TT	SLT	SET	CDT
Bulk density (g/cm$^{3)}$ (g/cm^3)	0.92 ± 0.02a	0.87 ± 0.04a	0.85 ± 0.05a	0.86 ± 0.05a
pH	7.39 ± 0.14a	7.31 ± 0.22a	6.45 ± 0.05b	6.37 ± 0.11b
EC (mS/m)	172.75 ± 3.17a	145.50 ± 6.74b	119.50 ± 5.38c	161.54 ± 4.50a

Note: *TT, typical tussock wetland; SLT, slightly degraded tussock wetland; SET, severely degraded tussock wetland; CDT, completely degraded tussock wetland.*

3.2 Soil organic carbon, total nitrogen and total phosphorus in tussock wetlands

Significant differences in SOC ($F = 10.2$, $p < 0.05$), TN ($F = 12.5$, $p < 0.05$), TP ($F = 4.7$, $p < 0.05$), the C:P ratio ($F = 5.7$, $p < 0.05$) and N:P ratio ($F = 8.6$, $p < 0.01$) were found among the four sites (Figure 1). The mean value of SOC, TN, N:P ratio and C:P ratio in the SLT were much greater than other three sites. The greatest TP was 0.54 g/kg recorded in SLT, whereas the smallest was 0.36 g/kg recorded in TT. The C:N ratio ranged from 9.38 to 11.22, and there were no significant differences among four tussock wetlands ($F = 0.2$, $p > 0.05$).

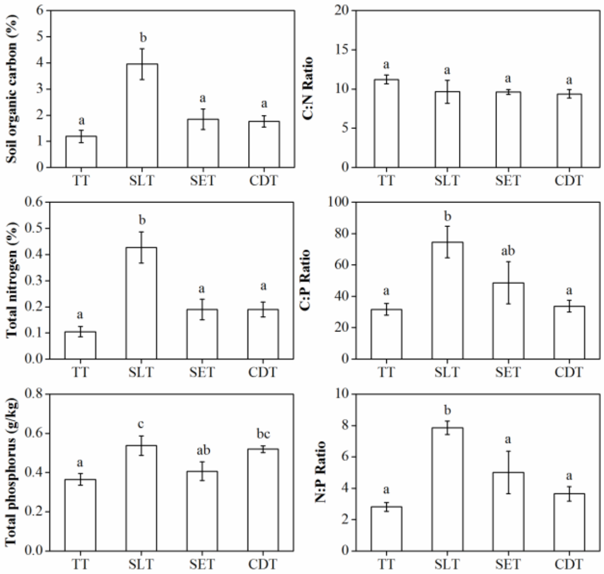

Figure 1 Soil organic carbon, total nitrogen, total phosphorus and their corresponding ratios in the four sites. TT, typical tussock wetland; SLT, slightly degraded tussock wetland; SET, severely degraded tussock wetland; CDT, completely degraded tussock wetland.

3.3 δ^{13}C in plant and soil in tussock wetlands

The δ^{13}C value in C. schmidtii was lower than soil (Figure 2). The δ13C value in plant ranged from −28.34‰ to −27.73‰ and there were no significant differences among TT, SLT and SET ($F = 2.2$, $p > 0.05$). The soil δ^{13}C values were consistent in TT, SET, CDT, and significantly higher than that in SLT ($F = 4.1$, $p < 0.05$). However, the peak values of δ^{13}C in plant and the valley values in soil were both presented in SLT.

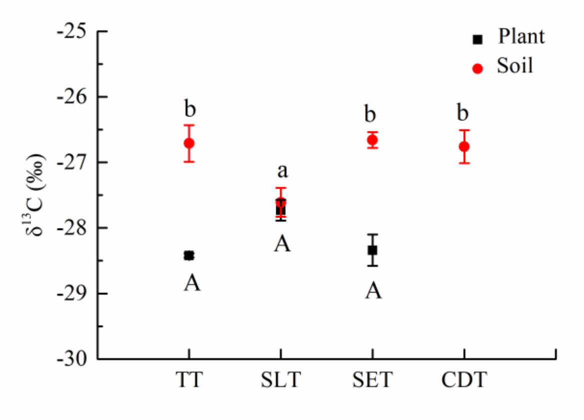

Figure 2 δ^{13}C in plant and soil. TT, typical tussock wetland; SLT, slightly degraded tussock wetland; SET, severely degraded tussock wetland; CDT, completely degraded tussock wetland. Lowercase letter indicated the differences in soil δ13C, and capital letters indicate differences in plant δ13C among all treatments.

3.4 The PCA of soil properties

The PCA results of soil properties revealed two Dims explaining 64.8% of the total variation (Figure 3(a)). The Dim1 explained 46% of the variation for soil properties, which was strongly correlated with TP, TN, SOC, δ^{13}C, N:P ratio and C:P ratio. The Dim2 explained 18.8% of the variation for soil properties, being strongly correlated with pH and C:N ratio. The clusters of TT and SLT recorded significant differences along Dim1 and Dim2 due to their unique positions (Figure 3(b)). The soil properties of SET are similar to CDT.

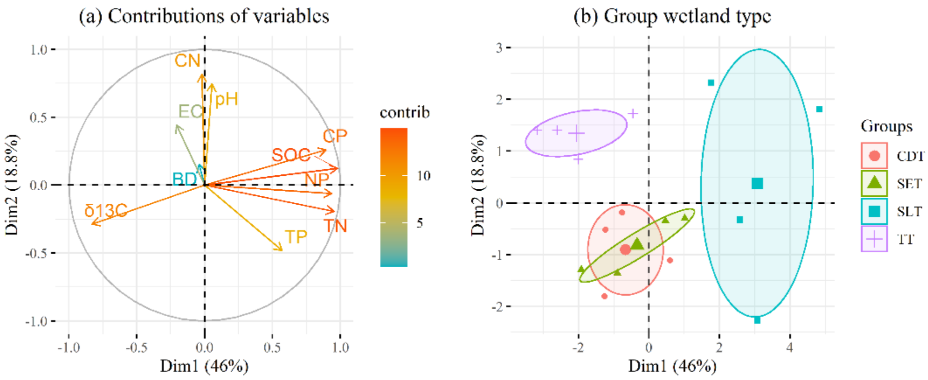

Figure 3 Principal component analysis of soil properties in four sites. BD, Bulk density; EC, electric conductivity; SOC, Soil organic carbon; TN, total nitrogen; TP, total phosphorus; CN, C:N ratio; CP, C:P ratio; NP, N:P ratio. TT, typical tussock wetland; SLT, slightly degraded tussock wetland; SET, severely degraded tussock wetland; CDT, completely degraded tussock wetland.

4. Discussion

4.1 Long-term change of soil properties at Haernao Zone in Momoge wetland

Climate change and anthropogenic disturbance have brought profound positive or negative effects on wetland ecosystem[2, 7, 17]. Soil properties in C. schmidtii-dominated tussock wetland have changed in the last 30 years (Table 3). Soil in tussock wetlands with a moderate pH and a high EC. The soil pH values ranged from 6.37 to 7.39 in our study, which were consistent with the finding of Zhang[18], but significantly lower than the results in common[19-20]. Wang et al.[16] reported that the average EC was 43.63 mS/m (1:1 soil /water solution) in an undisturbed wetland, while our results was 172.75 mS/m. Both of them were not more than 400 mS/m that was considered as the minimum threshold for saline[21]. Soil bulk density had no difference with Jiang et al.[22], who reported that the average bulk density ranged from 0.75 g/cm^3 to 0.95 g/cm^3 at Haernao. The low bulk density means a low benefit associated with flood mitigation[22]. All these indicated that soil pH, EC and bulk density have almost no change compared to previous studies.

Table 3 Soil properties at Haernao in Momoge Wetland[2].

Year	SOC (%)	TN (%)	TP (g/kg)	C/N	C/P	N/P	Reference
2016*	2.19	0.22	0.46	9.96	47.17	4.82	this study
2010	2.13	0.13	0.36	13.74	46.03	3.35	[16]
2010	2.11	0.18	--	11.72	--	--	[18]
2005	2.01	0.18	1.4	11.17	14.35	1.29	[23]
1985	5.35	0.47	0.90	11.38	59.44	5.22	[24]

Note: *"--" represents that the value was missing. "*" means the date was average.*

Soil organic carbon (SOC) is an important source or sink of atmospheric CO2[25-26]. In our study, SOC was 1.19%~3.95% in the four tussock wetlands, which was less than the SOC values (up to 5.35%) in history[23]. Recent studies reported that the SOC in Momoge wetland was approximately 2.13%[16, 18, 22], being closed to the results in this study. Nitrogen and phosphorus influenced plant growth and soil carbon storage[27-28]. The TN had a slight change in recent findings, but all of them were less than the result reported in Chinese Marsh[23]. Comparing to the finding in 1985[23], the TP decreased over time. The C:N ratio was 9.96, being significantly lower than the previous findings[2]. The C:P and N:P ratios are consistent with the studies mentioned in **Table 3** except[23]. Our results showed that the soil's C:N:P ratio was 48:5:1 at Haernao, which was higher than those (52:5:1) in China's soil[29]. However, the soil C:N:P ratio in tussock wetlands decreased, when compared to those in 1985 (59:5:1).

4.2 Effect of tussock degradation on soil properties

Wetland degradation significantly affected the soil properties[30-31]. The soil pH decreased with the degree of tussock degradation intensifying. This was consistent with Huang et al.[32], who reported that soil pH significantly decreased after wetland degradation. Moreover, soil EC of TT was similar to CDT, but not other two sites, referring to that EC is not the vital variable leading to the degradation of tussock. In previous studies, soil bulk density increased with wetland degradation[33], but we found that soil bulk density had no differences among the four sites.

In our study, SOC, TN, C:P and N:P ratios had similar response to tussock degradation. As the degree of tussock degradation intensified, SOC, TN decreased. Similar change of SOC and TN with vegetation degradation were observed by Huang et al.[32], Pan et al.[31]. With soil water content decreasing, organic matter decomposition and N mineralization rate increased leading to the loss of SOC, nitrogen and phosphorus[30]. Moreover, we observed that the minimum of SOC and TN were found in TT. This maybe closely with flooding depth and high EC. Flooding depth was considered as the vital variable limiting plant production, turnover of organic matter and accumulation of SOC in wetlands[34]. In fact, flooding depth decreased the SOC, TN and TP in wetlands[35-36]. The anaerobic environment induced by high flooding depth slow the decomposition of plant residues and limit the turnover of organic matter. An anaerobic environment led to release of SOC, nitrogen and phosphorus from surficial soil and some soluble substance in wetland flowed away[37-38]. Furthermore, the EC was also a critical variable influencing SOC. Zhao et al.[34] found that high EC induced by salinity could inhibit accumulation of SOC. Additionally, a low SOC content indicated that the sorption capacity for nitrogen and phosphorus decrease[39-40], plausibly explaining why the nitrogen and phosphorus in TT was lower than other three degraded tussock sites in Momoge wetland.

Soil and plant δ13C had been wildly used to investigate C cycling in soil-plant system[41-42]. The δ13C values in C. schmidtii were similar among the four sites, indicating C. schmidtii had no significant change of carbon. Moreover, the nadir value of soil δ13C was found in SLT, though it had a δ13C peak value in plant. This may be related to the carbon absorption and fixation of C. schmidtii. Plants affected the formation SOC in restored wetlands[43]. Feng et al.[44] also suggested that the decrease of soil δ13C was closed to the aboveground residues. Soil properties of TT and SLT was significantly different from SET and CDT.

5. Conclusion

Soil properties in tussock wetlands have changed in last 30 years and SOC, TN and TP decreased over time. Tussock degradation had a negative effect on soil properties in Momoge wetland, and the effect increased as the degree of tussock degradation intensified. Soil properties of TT and SLT recorded significant differences with SET and CDT. The results provide evidence for tell the influences of tussock degradation on soil properties in Momoge wetland. However, it should be noted that the mechanism that the effect of tussock degradation on soil properties was complex. Further research about microbial community and enzyme activity in soil may be needed to explain the relationship between soil properties and tussock degradation.

Author contributions

Conceptualization, Dongjie Zhang; methodology, Shiya Gao and Wenjun He; software, Xuepeng Liu and Wenjun He; investigation, Junping Tian, Hui Wang and Xiaoxuan Shi; writing—original draft preparation, Dongjie Zhang and Xuepeng Liu, and Yongxin Wei; writing—review and editing, Dongjie Zhang, Shiya Gao and Wenjun He. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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