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Full Length Article

Mowing Frequency Changed Community Characteristics of *Carex argyi* Grassland and Soil Properties in Tian-E Island National Nature Reserve

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Abstract

The Tian-E Island National Nature Reserve, located in Shishou, Hubei, is a typical wetland habitat with abundant animal and plant resources. In recent years, due to the increase of the elk population, the wetlands in protected area have deteriorated significantly. The favourite species of elk and a constructive species in the reserve, *Carex argyi* grassland is mainly managed by mowing. To assess the effects of different mowing frequencies on community characteristics and surface soil properties of the *C. argyi* grassland, four field trials were conducted in the reserve during the growth period of *C. argyi* from March to June, which involved four mowing frequencies from one to four times and without mowing treatment taken as control. Results showed that with the increased mowing frequency, the aboveground biomass and density of the *C. argyi* grassland community decreased, while the community diversity increased significantly. The increase of mowing frequency increased the sand proportion of each soil layer and reduced the clay proportion, and had no significant effect on the content of soil organic matter. Mowing reduced the contents of available nitrogen, available phosphorus, and available potassium in each soil layer. In crux, mowing once during the growth period can maintain the above-ground biomass and community diversity of the *C. argyi* grassland in the wetland habitat in a good state and improve soil nutritional status, which is beneficial to *C. argyi* as the forage of elk.

Keywords: Mowing frequency; *Carex argyi*; Community characteristics; Soil particle proportion; Soil nutrient elements

Introduction

Grassland is an important part of the terrestrial ecosystem, and it is a comprehensive natural body composed of grass and its living land (Jiang *et al.* 2016). The total area of grassland in China is 3.9×10^8 ha, accounting for 13% of the world's grassland area and about 41% of the national land area. It is the largest ecosystem in China's land area. It is not only an important animal husbandry production base, but also an important ecological barrier, which plays an important role in the global ecosystem balance. In recent years, destructive activities such as artificial reclamation of grasslands have been increasingly intensified because of the one-sided pursuit of economic benefits. The grassland ecosystem in China, whether in southern or northern, has experienced extensive widespread grassland degradation, desertification, and even ecosystem imbalances (Xiang *et al.* 2019; Yang *et al*. 2019).

At present, as an artificial alternative to grazing, mowing is the most common and extensive way of grassland utilization. A large number of studies on the effects of mowing on grassland have been carried out at home and abroad (Dyke *et al.* 2004; Field *et al.* 2008; Valliere *et al.* 2019). It can affect the interception of light by species with a higher spatial position, change the growth response of inherent plants to existing resources and the intensity of interspecific competition and then modify the community structure and species composition (Staalduinen *et al*. 2010a; Bernhardt-Römermann *et al*. 2011; Wan 2014). Moderate mowing can increase species diversity and maximize the use of resources (Ljubicic *et al*. 2014), which helps to increase species diversity and productivity, but the effects of mowing to varying degrees on productivity and diversity are different (Yamauchi and Yamamura 2004; Hooper *et al*. 2005). Grasslands in different habitats have different responses to mowing due to the influence of community types, climatic conditions and soil properties. Compared with typical steppe, meadow steppe and desert steppe, there are few studies on the effect of mowing on grassland in a wetland habitat.

The Tian-E Island Elk Reserve is a national nature reserve with the main purpose of *ex situ* protection of elk, which has a typical wetland habitat. Its unique geographical, hydrological, and climatic conditions make it a paradise for many endangered animals (Peng and Zhao 2004). In recent years, due to the increase of the elk population, the opening of wetlands and climate change, the wetlands in the reserve

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have been significantly degraded (Wen *et al*. 2012). As a favourite species of elk and a constructive species in the reserve, *C. argyi* grassland is mainly managed by mowing; however, information about the effects of mowing on *C. argyi* grassland community structure and soil characteristics is lacking. Therefore, this study was conducted to evaluate the role of mowing frequency on community characteristics and soil properties of *C. argyi* grassland to find the appropriate mowing frequency to maintain the sustainable utilization of grassland and provide natural forage for elk better in the reserve.

Materials and Methods

Research area

The study area is located in the Tian-E Island Elk National Nature Reserve in Shishou city, Hubei Province, China (E112°33', N29°49'), which covers an area of 1567 ha, and the core area is about 1167 ha. The average altitude is 35 m, of which the highest point is 38.44 m, the lowest point is 32.91 m, and the relative height difference is not obvious. It is a subtropical monsoon climate area, with hot summer, dry and cold winter climate, distinct seasons and abundant rainfall. On the other hand, the annual average temperature in those areas is 16.5°C, with 28.5°C in the hottest month (July) and 3.5°C in the coldest month (January). The annual precipitation is more than 1200 mm, rainy in spring, early summer and late autumn. The average annual relative humidity is 80%. The frost-free period lasted for 261 days. The main trees and herbaceous plants in this region are *Populus nigra*, *Salix matsudana*, *Melia azedarace*, *Phragmites communis*, *Miscanthus sacchariflorus*, *Carex argyi*, and *Roegneria kamoji*.

Field and laboratory studies

In 2018, research was started in the wetland environment of Tian-E island natural reserve located in Shishou, Jingzhou, and found that: as a favourite species of elk and a constructive species in the reserve, some *C. argyi* lawns in the reserve are growing well, while some are stunted. After asking the staff of the reserve, we learned that there is no other management except mowing in routine maintenance. A preliminary experiment was conducted from April to May. At that time, control group without mowing was set up, and the other two treatments were mowing once and two times, respectively. The results showed that mowing decreased the aboveground biomass, density, sand proportion, as well as the contents of soil organic matter and soil nutrients.

In 2019, the mowing frequency was increased and the experimental design was improved by adopting a randomized complete block design and replicated three times. For that randomly selected 15 plots of grassland with net plot size of 2 m × 3 m were used, and borders were defined by natural barriers. Four different mowing treatments with mowing once (M_1), mowing 2 times (M_2), mowing 3 times (M_3), mowing 4 times (M_4), and the control without mowing (M_0) were used. By artificial cutting, all the aboveground parts of the plants in the plot that needed to be mowed were processed and removed from the base at a time. The mowing treatment was begun on March 6th, and completed on June 6th, with a one-month interval of each mowing.

On October 6th, 2019, the community characteristics of each treatment plot were investigated in the field, and soil samples were also collected for further analysis. Three sample plots with an area of 50 cm × 50 cm were randomly selected in each treatment plot to determine the plant species composition, plant height, plant number, and coverage. Plants of all three sample plots in each treatment plot were mowed from the base and collected into marked plastic sealed bags, and then they were taken back to the laboratory of the Yangtze University to weigh fresh, and dried at 85°C for 48 h to the constant weight to weigh the dry weight.

The soil texture was determined by American soil particle size rapid method (Zhang and Wang 2002), soil organic matter was determined by potassium dichromate volumetric method-dilution thermal method, the available nitrogen was determined by alkali hydrolysis diffusion method, the available phosphorus was determined by ammonium carbonate soaking-molybdenum antimony sulfate colorimetric method, available potassium was determined by Flame Spectrophotometry (Bao 2008).

Statistical analysis

All collected data were analysed using one-way ANOVA to check the overall significance of data while Duncan's new multiple range test were performed using SAS 9.0 software to separate treatments means at $P \leq 0.05$, and the graphs were prepared using Microsoft Excel program 2003.

Results

The variation of community characteristics

With the increase of mowing frequency, both fresh weight and dry weight of the aboveground biomass decreased significantly ($P < 0.05$). Compared with the control treatment, the fresh weight and dry weight of aboveground biomass decreased by a minimum of 1.4 and 10.2% under M_1, and by a maximum of 60.5 and 74.7% under M_4 (Fig. 1).

With increase in mowing frequency, the community density decreased significantly ($P < 0.05$). Compared with the control treatment, the community density decreased by a minimum of 19.1% under M_3, and by a maximum of 31.9% under M_2, but there was no significant difference among different mowing treatments except M_3 (Fig. 2).

The variation of community diversity

With the increase of mowing frequency, the community

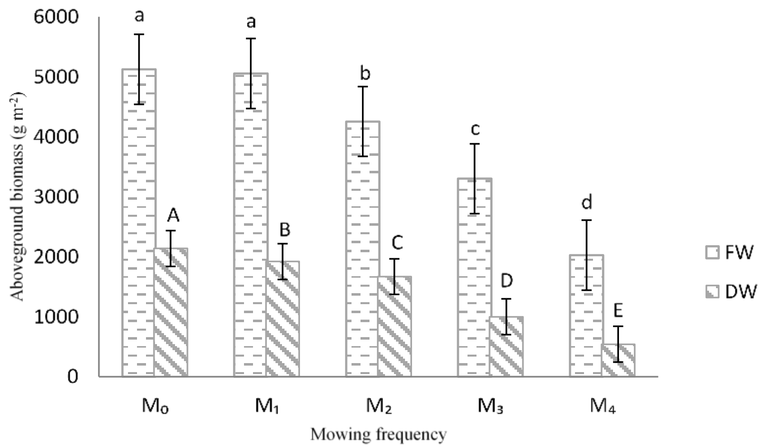

Fig. 1: Effect of different mowing frequency on the aboveground biomass of *C. argyi* grassland
M_0 represents the treatment without mowing. M_1, M_2, M_3 and M_4 represent the treatment with mowing one, two, three, four times, respectively. FW and DW represent the fresh weight and dry weight, respectively. Different capital letters denote significant differences in fresh weight, while different lowercase letters denote significant differences in dry weight ($P < 0.05$)

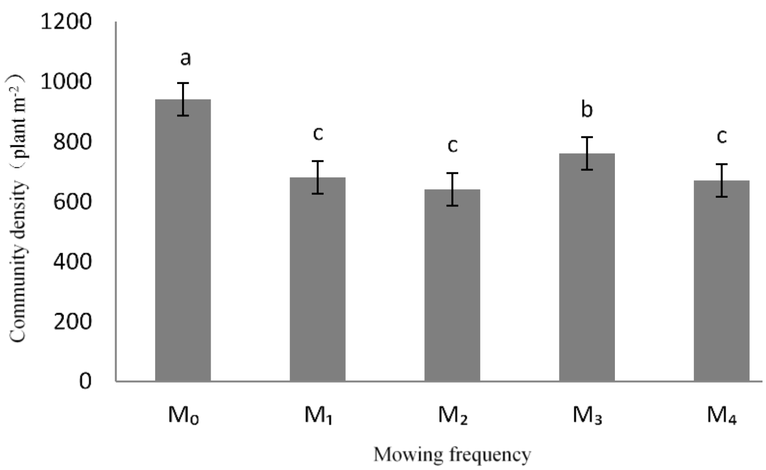

Fig. 2: Effect of different mowing frequency on the community density of *C. argyi* grassland
M_0 represents the treatment without mowing. M_1, M_2, M_3 and M_4 represent the treatment with mowing one, two, three, four times, respectively. Different lowercase letters denote significant differences among treatments ($P < 0.05$)

diversity indices all increased significantly ($P < 0.05$). Compared with control treatment, the Margarlef, Simpson, Shannon-Wiener and Pielou indices were increased by a maximum of 88.8, 24.1, 58.8 and 26.2% under M_4, respectively. Among the different mowing frequencies, the Shannon-Wiener index of M_2 was significantly lower than that of the other treatments, and the other indexes were not significantly different (Table 1).

The variation of soil particle proportion

With increase of mowing frequency, the sand proportion in each soil layer of 0–30 cm increased significantly ($P < 0.05$), except the sand proportion under M_1 and M_4 were lower than that under M_0 in the 0–10 cm soil layer. Compared with the control treatment, the sand proportion increased by a maximum of 26.0% under M_3, and decreased by a maximum of 9.2% under M_4 in the 0–10 cm soil layer (Table 2).

With the increase of mowing frequency, it has no significant effect on the silt proportion in the 0–30 cm soil layer (Table 2). With the increase of mowing frequency, the clay proportion in each soil layer decreased significantly ($P < 0.05$). Compared with control, the clay proportion was decreased by a minimum of 16.1% under M_4, and by a maximum of 52.3% under M_2 in the 0–10 cm soil layer. The changing trend of clay proportion was consistent in each soil layer of 0–30 cm (Table 2).

The variation of soil nutrient element content

With the increase of mowing frequency, the soil organic matter decreased insignificantly in the 0–20 cm soil layer (Table 3). Compared with control, the soil organic matter

Table 1: Effect of different mowing frequency on the diversity index of *C. argyi* grassland

Mowing events	Margarlef index	Simpson index	Shannon-Wiener index	Pielou index
M_0	0.98 ± 0.09b	0.58±0.03b	1.31 ± 0.12d	0.65 ±0.03b
M_1	1.75 ± 0.05a	0.77±0.03a	1.93 ± 0.05ab	0.78 ±0.07a
M_2	1.40 ± 0.07ab	0.72±0.05a	1.72 ± 0.09c	0.75 ±0.02a
M_3	1.81 ± 0.04a	0.72±0.06a	1.85 ± 0.12bc	0.72±0.03ab
M_4	1.85 ± 0.18a	0.80±0.04a	2.08 ± 0.05a	0.82 ±0.08a

M_0 represents the treatment without mowing. M_1, M_2, M_3 and M_4 represent the treatment with mowing one, two, three, four times, respectively. Within each column, different lowercase letters denote significant differences among treatments ($P < 0.05$)

Table 2: Effect of different mowing frequency on soil particle content

Soil particle types	Mowing events	Depth of soil		
		0–10 cm	10–20 cm	20–30 cm
Sand (%)	M_0	30.49±1.90bc	9.43±0.45c	7.35±0.42d
	M_1	27.96±0.79c	11.70±0.02b	8.31±0.23cd
	M_2	32.71±1.86b	12.93±0.96b	9.86±0.77b
	M_3	38.41±1.08a	19.65±1.90a	10.42±0.79a
	M_4	27.68±2.05c	11.61±0.97b	9.15±1.03bc
Silt (%)	M_0	59.79±4.32ab	82.71±7.15a	86.09±2.68a
	M_1	64.86±3.05a	82.62±6.18a	87.81±1.92a
	M_2	62.65±4.11ab	84.03±5.34a	86.86±5.63a
	M_3	56.84±1.45b	76.35±1.08a	86.43±1.48a
	M_4	64.15±5.69a	81.94±1.35a	85.10±3.13a
Clay (%)	M_0	9.72±0.86a	7.85±0.53a	6.57±0.46a
	M_1	7.18±0.12c	5.68±0.38c	3.88±0.32c
	M_2	4.64±0.21d	3.04±0.04e	3.29±0.18d
	M_3	4.75±0.18d	4.01±0.38d	3.15±0.11d
	M_4	8.16±0.70b	6.46±0.43b	5.75±0.13b

M_0 represents the treatment without mowing. M_1, M_2, M_3 and M_4 represent the treatment with mowing one, two, three, four times, respectively
Within each column, different lowercase letters denote significant differences among treatments ($P < 0.05$)

Table 3: Effect of different mowing frequency on soil nutrient element content

Nutrient types	Mowing Events	Depth of soil		
		0–10 cm	10–20 cm	20–30 cm
Organic matter (g kg^{-1})	M_0	79.18 ± 4.47a	24.42 ± 1.60a	12.96 ± 0.99b
	M_1	77.20 ± 7.53a	21.92 ± 1.47a	16.94 ± 0.56a
	M_2	73.52 ± 2.65a	22.58 ± 2.24a	18.73 ± 1.68a
	M_3	75.00 ± 4.69a	23.58 ± 1.45a	13.50 ± 0.68b
	M_4	73.09 ± 3.40a	22.34 ± 0.77a	12.72 ± 1.68b
Available nitrogen (mg kg^{-1})	M_0	182.66±10.97a	70.74 ± 5.49ab	40.46 ± 2.62cd
	M_1	167.75 ± 8.17a	62.23 ± 3.14c	48.03 ± 4.10b
	M_2	180.53 ± 4.02a	63.88 ± 3.49bc	54.89 ± 1.72a
	M_3	182.18 ± 9.99a	73.11 ± 2.48a	42.35 ± 1.54c
	M_4	170.12 ± 7.94a	67.55±4.63a-c	36.29 ± 2.80d
Available phosphorus (mg kg^{-1})	M_0	2.74 ± 0.18a	1.46 ± 0.05a	1.07 ± 0.03c
	M_1	2.70 ± 0.18a	1.22 ± 0.06b	0.99 ± 0.08c
	M_2	1.71 ± 0.10b	1.22 ± 0.09b	1.08 ± 0.02c
	M_3	1.75 ± 0.11b	1.19 ± 0.11b	1.38 ± 0.19b
	M_4	1.33 ± 0.16c	1.08 ± 0.03b	2.40 ± 0.22a
Available potassium (mg kg^{-1})	M_0	296.07±26.71a	276.86±10.19a	224.42±16.62a
	M_1	200.78±17.96c	189.70±9.98c	157.94±11.67b
	M_2	217.03±5.52bc	193.39±7.68c	174.19±11.30b
	M_3	232.54±14.07b	225.15±12.98b	187.43±10.47b
	M_4	227.37±6.37bc	203.73 ± 5.17c	148.33 ± 8.39b

M_0 represents the treatment without mowing. M_1, M_2, M_3 and M_4 represent the treatment with mowing one, two, three, four times, respectively
Within each column, different lowercase letters denote significant differences among treatments ($P < 0.05$)

was decreased by a maximum of 7.7% under M_4 in the 0–10 cm soil layer. With the increase of mowing frequency and soil depth, the content of available nitrogen, available phosphorus and available potassium all had a significant decreasing trend ($P < 0.05$), except the available nitrogen decreases insignificantly in the 0–10 cm (Table 3). Compared with control, the available nitrogen content were decreased by a maximum of 8.2% under M_1, but the difference among different mowing frequencies was not significant in 0–10 cm soil layer. However, the available phosphorus contents were decreased by a minimum of 1.5% under M_1, and by a maximum of 51.5% under M_4. Likewise, available potassium contents were also decreased by a minimum of 21.5% under M_3, and by a maximum of 32.2% under M_1 in 0–10 cm soil layer (Table 3).

Discussion

The results of this study showed that the aboveground biomass of the grassland community was decreased by increasing mowing frequency, and the community density of *C. argyi* as a constructive species was also decreased (Fig. 1–2). As one of the main ways of grassland utilization, mowing can have different effects on plant community productivity and species diversity by affecting the habitat resource status of plants or directly affecting plant growth, respectively (Rajaniemi 2002; Staalduinen *et al.* 2010b). Long-term non-mowing will increase the accumulation of litter, a large amount of ground cover will cause plant seeds unable to touch the soil and cannot germinate, and lead to a decline in grassland species and productivity ultimately (Wang *et al*. 2014). However, with the increase of mowing frequency, the destruction of grassland vegetation by humans will exceed the threshold of ecosystem restoration, resulting in a sudden decrease in aboveground biomass (Ritchie *et al.* 1998). Community plants respond to mowing in varying degrees, mowing often causes greater damage to the growth of dominant species, and increases the available resources and space in the community, which is conducive to the expansion of less damaged non-dominant species populations, thereby reducing the population density of dominant species (Han *et al.* 2010; Sun 2012).

The diversity of grassland communities largely maintains the sustainability of grassland ecosystems and the stability of grassland productivity (Tilman *et al*. 1996). However, the academic community has not formed a unified consensus on the response of grassland community diversity to mowing. Grime *et al*. (1987) and Wang *et al*. (2012) believed that mowing enhanced grassland species richness to a certain extent, while Huhta *et al*. (2001) believed that long-term mowing had no significant effect on species richness. Community diversity is affected by a combination of biological factors, environmental factors, community succession, natural disturbances, and human disturbances. In this study, the increase of mowing frequency inhibited the competitive production of dominant species of *C. argyi* in its growth period, and provided breeding opportunities for other species with poor competitiveness (Miguel *et al.* 2005). The competition caused by mowing is conducive to species occupying different niche to maximize the utilization of limited light resources, and the dominant species and functional groups of the grassland community will change accordingly (Hooper 1998). Thus, the community diversity of *C. argy*i grassland was increased.

The plant-soil system is an organic whole that interacts and influences each other. When the ground part of the plant changes due to human disturbance such as mowing, it will inevitably affect the physical and chemical properties of the soil (Greene *et al.* 1994). Soil bulk density is an important physical property of soil, which reflects the degree of soil degradation to a certain extent. The increase in sand proportion means the increase in soil bulk density, the larger the bulk density value, the more serious the soil degradation (Wheeler *et al*. 2002; Keller and Håkansson 2010; Suuster *et al.* 2011). In this study, mowing increased the sand proportion and decreased the clay proportion in each soil layer, which was the most significant when mowing three times. As the main material and energy source to regulate soil biological ecological dynamics, Soil organic matter has the properties of improving soil structure and maintaining soil moisture, and is an important indicator of soil properties (Zhang *et al*. 2005).

Excessive mowing can cause the damages and degradation of the aboveground parts of the community, leading to a loss of soil resources and not being well replenished (Sun *et al*. 2016). It can also change the cycle and behaviour characteristics of chemical elements in the grassland ecosystem. Continuous mowing makes the output of nutrients greater than the input of the grassland, breaking the dynamic balance of soil nutrients, and has negligible effect on the chemical properties of soil (Liu *et al.* 2016). In this study, mowing reduced the content of soil organic matter. Because the decomposition of the litter in the control took a long time (Wang *et al*. 2003), the difference between the treatments and the control was not obvious in the short term. However, with the increase of mowing frequency, the removed plants took away more N, P and K, but less returned to the soil (Curtin *et al*. 1998), which reduced the content of available nitrogen, available phosphorus, and available potassium in the soil.

Conclusion

Results of this study unveiled that mowing frequency had considerable effects on *C. argyi* community structure and soil characteristics. Moreover, mowing once during growth period is more appropriate to maintain above-ground biomass and community diversity of *C. argyi* grassland in the wetland habitat in a good state and to improve soil particle structure and nutritional status, which is beneficial to *C. argyi* as the forage of elk.

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Author Contributions

LYY designed the experiments, HBY wrote the manuscript, PF and YQL performed the experiments, HBY, PF and LL statistically analyzed the data and made illustrations.

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