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# Influence of Different Mowing Systems on Community Characteristics and the Compensatory Growth of Important Species of the *Stipa grandis* Steppe in Inner Mongolia

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**Abstract:** The *Stipa grandis* steppe is a type of steppe in the Central Asian sub-region, and it is an important resource for livestock production in China. Mowing is one of the main management methods for this steppe. Verifying the response of the *Stipa grandis* steppe communities to different mowing frequencies is essential for the rational utilization of pastures and the protection and recovery of natural steppe. In this study, we investigated the community characteristics and compensatory growth of important species of the *Stipa grandis* steppe community under four mowing frequencies (TAY: twice a year; OAY: once a year; OTY: once every other year; NM: no mowing/enclosure), and found that different frequencies of mowing significantly influenced the community characteristics and the compensatory growth of dominant plant species. In the enclosure, species density was significantly lower, and height and biomass were significantly greater than in the mowing treatments. At the beginning of the growing season, mowing had a significant impact on the individual miniaturization of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides*. Mowing also had a significant impact on the diversity of the community. The Shannon diversity index, the Pielou evenness index, and the richness index were higher under OTY than other mowing frequencies. Under different mowing frequencies, growth rates were significantly different after the aboveground portions were cut, while the levels of biomass were not significantly different. *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* had less compensatory height growth under OAY compared to the other treatments; however, there were no significant differences in the relative growth rates of the three species under different treatments. *Stipa grandis* exhibited equivalent compensatory height growth; both *Leymus chinensis* and *Anemarrhena asphodeloides* exhibited over-compensatory growth. Based on the results of community characteristics and the compensatory growth of the dominant species, mowing every other year is currently the most practical mowing system.

**Keywords:** mowing frequency; community characteristics; diversity; individual miniaturization; compensatory growth

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## 1. Introduction

Mowing is a common and critical utilization of steppes, and it is one of the primary uses of high-yield natural steppes and artificial grasslands. Its purpose is to obtain fresh livestock fodder or to process mown herbage into silage, semi-hay, or hay that can be stored as livestock fodder. Some steppes are used entirely for mown herbage to feed livestock, thereby improving the utilization of grassland. For grassland ecosystems, mowing is an artificial interference mechanism affecting material circulation and other facets of the ecosystem. With regard to the impact of mowing on plant communities, studies in China and other countries have mostly focused on semi-natural grasslands [1–5]. Different methods of mowing can affect the community characteristics and biomass production by altering the height and density [6]. The results showed that mowing is necessary to maintain overall plant biodiversity in hay meadows through the removal of graminoid biomass and litter, but not all target forbs were favored by regular yearly mowing. Under excessive interference (mowing), the plants in steppes exhibit lower height, reduced leaf area, and individual miniaturization (plant height lower, individual biomass reduced), thus affecting the community structure [7]. However, plants can also alter their physiological or morphological properties, alleviating the adverse effects of external damage to achieve compensatory growth.

Mowing affects various aspects of steppes, and steppe plants also have feedback responses to mowing. *Stipa grandis*—a tufted type of xeric herbaceous perennial—is a unique Mongolian grass species in the steppes of the Central Asian sub-region. Mowing affects the community composition, community succession process, and aboveground biomass. Mowing conducted once or twice a year has a limited impact on the litter accumulation on the ground surface; however, when mowing is conducted more than three times a year, there is a dramatic reduction in ground surface litter [5]. Mowing also directly damages the aboveground portion of the plants in the community; different mowing frequencies have different levels of impact on the population structure, biomass, and yield of herbage, and structure and function of the steppe ecosystem [8–12]. In a 1991 study in China, Zhong et al. studied changes in the grassland under different mowing frequencies for 17 consecutive years on natural steppes [13], including responses of the grassland to different climatic conditions and found that mowing every other year was conducive to community biomass and communitydensity.

Mowing twice a year can increase biomass in the short term, but this state is difficult to maintain in the long term. In addition, complete enclosure is unfavorable for the recovery of the pasture. The current primary mowing frequency for *Stipa grandis* steppe is once a year at the end of August. However, annual mowing in the long term led to lower productivity and degraded natural steppes, and reduced the compensatory growth of the plants, resulting in problems in the ecological environment and in sustainable production [8].

In this investigation, the object of study is a typical steppe with *Stipa grandis* as the constructive species, i.e., the dominant species that acts as a community creator and builder. Our aim was to identify the most desirable mowing frequency that had long-term productivity and sustainable utilization. The changes in community structure in the steppe and the variation in the compensatory growth of dominant plants within the community under different mowing frequencies were investigated. The most desirable mowing frequency was verified from the perspective of individuals and communities in terms of community recovery and sustainability in order to provide reliable references and feasible practices for reasonable mowing and steppe utilization.

## 2. Study Area

The study area was set in the grassland ecology experiment base of Inner Mongolia University, Xilinhaote City, Inner Mongolia, China. The region is located in the chestnut sub-region of the steppe within the temperate zone, with an altitude of 1101 m, and the soil type is primarily chestnut soil. The annual average temperature is −0.4 °C, with an accumulated temperature of approximately 24.12 °C. The average growing period of plants in the steppe is approximately 150 days. The average annual precipitation is approximately 350 mm, concentrated in June to September that account for approximately 80% of annual precipitation, and varies greatly between seasons and years. The annual evaporation is 1600–1800 mm. The constructive species of the area are *Stipa grandis* and

*Leymus chinensis*, and the dominant species are mainly *Anemarrhena asphodeloides*, *Cleistogenes squarrosa*, and *Carexkor shinskii.*

## 3. Materials and Methods

### 3.1. Experimental Setup

The sample study area was enclosed starting from May 2010, mowed every year from 1982 to 2010, the stubble height each time was 6 cm (the general stubble height in this region), and a total of four experimental treatments were performed (Table 1 and Figure 1).

**Table 1.** Fact sheet of research plots.

| | Label | Time of Mowing |
|---|---|---|
| Twice a year | TAY | June and August of 2011, 2012 |
| Once a year | OAY | End of August in 2010, 2011, 2012 |
| Once every other year | OTY | End of August of 2010 and 2012 |
| No mowing/Enclosure | NM | Starting from early 2010 |

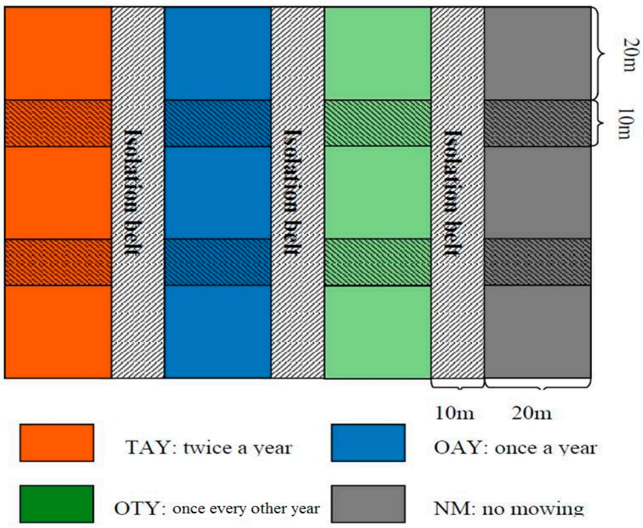



**Figure 1.** Plot arrangement design.

### 3.2. Investigation of Community Characteristics

Random sampling was conducted to investigate the community characteristics of treated fields in May–August of 2013. The quadrat area was 1 m × 1 m, with 5 quadrats selected within each treatment. In the quadrat, we measured the species numbers, the numbers of each species, the height of each species, and the biomass of each species (i.e., the weight of the dry plant after being dried at 65 °C). We counted the numbers and the biomass of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* from each treatment, and calculated individual biomass and the various relevant diversity indices. S is the number of species within the unit area; N is the number of present individuals of the species; and $P_i$ is the importance value of species i.

- Individual biomass = $\text{biomass}_i/\text{number}_i$
- Importance value index ($P_i$) = (Relative height + Relative density + Relative biomass)/3
- Shannon–Wiener index (H′) = $-\sum P_i \ln P_i$
- Pielou's evenness index (Jsw) = $H'/\ln S$
- Richness index = $(S - 1)\log N$

### 3.3. Assessment of Compensatory Growth of Dominant Species in the Community

The required data of compensatory growth of dominant species was selected from the data of the community characteristics measured in the quadrats. Plant compensatory height (CH) = plant height in August + plant height in May. Relative growth rate (RGR, $cm \cdot d^{-1} \cdot cm^{-1}$) = plant height in August/(stubble height in May × days of growth); in this study, the days of growth was defined as the days between the measured date in August and the measured date in May.

### 3.4. Calculation of Compensatory Growth Index of Biomass (G/C)

The compensatory growth patterns were represented by the compensatory growth index (G/C) proposed by Belsky. If G/C > l, this is over-compensation; if G/C = l, this is equivalent compensation; if G/C < 1, this is low compensation. In this study, G is the sum of the aboveground biomass in August 2013 and in August 2012 under the three mowing frequencies, and C is the sum of the aboveground biomass in August 2012 and August 2013 under enclosure.

### 3.5. Statistical Analyses

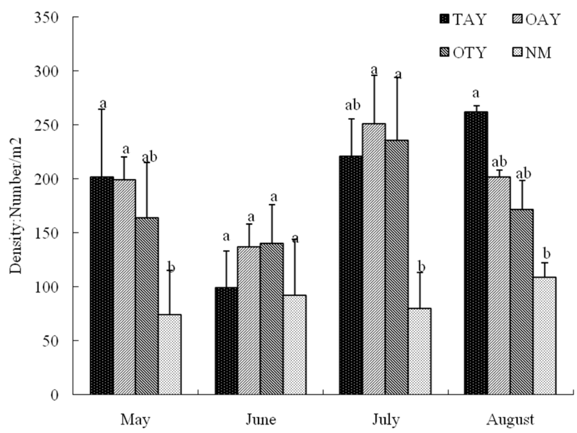
We used Excel 2007 to calculate the average of the repeats, and SPSS19.0 to make the ANOVA analysis on the difference between the treatments.

## 4. Results

### 4.1. Community Characteristics

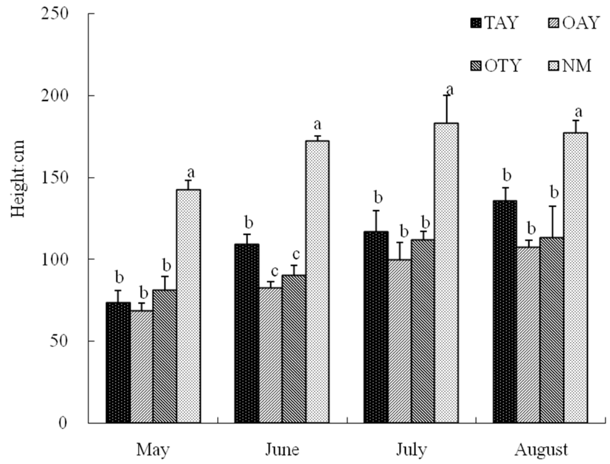
First, species density was significantly higher under mowed than enclosed treatments ($p < 0.05$) in May, July and August (Figure 2a). Second, however, plant height was significantly higher under enclosed than mowed treatments ($p < 0.05$) from May to August (Figure 2b). Also, third, the biomass was significantly heavier under enclosed than mowed treatments ($p < 0.05$) (Figure 2c). The biomass under OTY (mowed once every other year) was only lower than NM (no mowing/enclosure), and was significantly higher than TAY (twice a year) and OAY (once a year) in May, June, and August.

As can be concluded from Table 2, under a high frequency of mowing (TAY), there was a reduction in semi-xeric and xeric forbs in the community; but an increase in forbs and the number of species at OTY. The importance value index of *Stipa grandis* increased in the enclosure at OTY. The importance value index of *Anemarrhena asphodeloides* increased under TAY. The importance value index of *Leymus chinensis* decreased under NM.

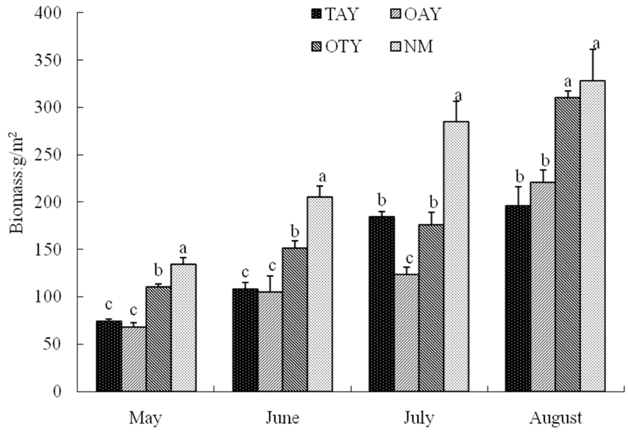



(**a**)

**Figure 2.** *Cont.*




(**b**)




(**c**)

**Figure 2.** (**a**) Seasonal variation in the species density (number of all species inside the quadrat) under different mowing frequencies; (**b**) Seasonal variation in the community height (height of all species inside the quadrat) under different mowing frequencies; (**c**) Seasonal variation in aboveground biomass per unit area (biomass of all species inside the quadrat) of the community under different mowing frequencies.

**Table 2.** The importance values of specie of *Stipa grandis* steppe under different mowing frequencies.

| **Species Name** | **Water Ecotype** | **Importance Values** | | | |
|---|---|---|---|---|---|
| | | **TAY** | **OAY** | **OTY** | **NM** |
| *Stipa grandis* | Xerophyte | 0.35 | 0.36 | 0.4 | 0.41 |
| *Anemarrhena asphodeloides* | Mid-Xerophyte | 0.34 | 0.17 | 0.21 | 0.23 |
| *Leymus chinensis* | Mid-Xerophyte | 0.26 | 0.31 | 0.26 | 0.13 |
| *Cleistogenes squarrosa* | Xerophyte | 0.015 | | | 0.025 |
| *Allium bidentatum* | Xerophyte | 0.014 | 0.029 | 0.018 | 0.065 |
| *Allium plurifoliatum* | Xerophyte | | 0.047 | 0.023 | |
| *Carex korshinskii* | Mid-Xerophyte | | | 0.055 | 0.085 |
| *Allium tuberosum* | Mid-Xerophyte | | 0.018 | 0.021 | |
| *Allium condensatum* | Mid-Xerophyte | | 0.056 | | |
| *Artemisia frigida* | Xerophyte | | | | 0.058 |
| *Oxytropis myriophylla* | Mid-Xerophyte | 0.014 | | 0.018 | |
| summation | | 6 | 7 | 8 | 7 |

TAY: Twice a year; OAY: Once a year; OTY: Once every other year; NM: No Mowing, Enclosure.

As can be concluded from Table 3, the Shannon diversity index was higher under enclosure than mowing. In the early growing season, the richness index of communities under enclosure was significantly lower than mowing. However, in the late growing season, the richness index of the community under enclosure was significantly higher than mowing. As can be seen from Table 4, in the early growing season (May and June), the individual biomasses of *Stipa grandis* and *Anemarrhena asphodeloides* under OAY were significantly lower than other treatments ($p < 0.05$). In the growing season, the individual biomass of *Leymus chinensis* under OAY was significantly lower than other treatments ($p < 0.05$).

**Table 3.** The Shannon–Wiener index, Pielou's evenness index, and richness index under different mowing frequencies.

| | Diversity Index | TAY | OAY | OTY | NM |
|---|---|---|---|---|---|
| May | Shannon-Wiener | 1.33 ± 0.28 b | 1.30 ± 0.26 b | 1.36 ± 0.13 b | 1.62 ± 0.11 a |
| | Pielou | 0.80 ± 0.11 a | 0.84 ± 0.31 a | 0.80 ± 0.12 a | 0.83 ± 0.05 a |
| | Richness | 16.13 ± 1.97 ab | 13.80 ± 1.67 b | 18.50 ± 1.21 a | 11.23 ± 1.22 c |
| June | Shannon-Wiener | 1.41 ± 0.15 a | 1.32 ± 0.38 b | 1.44 ± 0.07 a | 1.47 ± 0.06 a |
| | Pielou | 0.79 ± 0.14 ab | 0.82 ± 0.19 ab | 0.94 ± 0.11 a | 0.75 ± 0.09 ab |
| | Richness | 15.97 ± 1.68 b | 10.69 ± 1.05 c | 24.29 ± 0.57 a | 25.55 ± 3.32 a |
| July | Shannon-Wiener | 1.42 ± 0.22 ab | 1.29 ± 0.22 b | 1.56 ± 0.15 ab | 1.64 ± 0.18 a |
| | Pielou | 0.86 ± 0.16 a | 0.85 ± 0.17 a | 0.92 ± 0.10 a | 0.81 ± 0.07 a |
| | Richness | 19.41 ± 3.65 a | 14.20 ± 1.65 b | 21.81 ± 0.65 a | 15.80 ± 1.78 b |
| August | Shannon-Wiener | 1.52 ± 0.34 ab | 1.36 ± 0.11 b | 1.78 ± 0.22 a | 1.63 ± 0.15 a |
| | Pielou | 0.8 ± 0.18 a | 0.79 ± 0.09 ab | 0.88 ± 0.09 a | 0.81 ± 0.07 a |
| | Richness | 20.5 ± 3.62 c | 12.32 ± 1.03 d | 24.26 ± 0.33 b | 30.63 ± 3.36 a |

Note: Entries in the same column and suffixed by the same letter are not significantly different from each other ($p > 0.05$).

**Table 4.** The average monthly values in the individual biomass of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* under different mowing frequencies.

| | Date | The Individual Biomass (g/Plant) | | | |
|---|---|---|---|---|---|
| | | TAY | OAY | OTY | NM |
| *S. grandis* | May 2013 | 2.82 ± 0.70 b | 2.26 ± 0.34 b | 6.29 ± 0.44 a | 6.70 ± 0.67 a |
| | June 2013 | 5.71 ± 0.47 ab | 3.52 ± 0.41 b | 8.23 ± 0.80 a | 7.77 ± 2.04 a |
| | July 2013 | 5.27 ± 0.63 ab | 3.27 ± 0.39 ab | 5.44 ± 0.46 ab | 13.83 ± 1.07 a |
| | August 2013 | 6.88 ± 1.20 a | 9.06 ± 1.25 a | 12.13 ± 0.92 a | 9.96 ± 2.82 a |
| *L. chinensis* | May 2013 | 0.19 ± 0.022 bc | 0.11 ± 0.003 c | 0.21 ± 0.041 b | 0.35 ± 0.009 a |
| | June 2013 | 0.31 ± 0.030 a | 0.15 ± 0.017 a | 0.31 ± 0.104 a | 0.48 ± 0.23 a |
| | July 2013 | 0.40 ± 0.062 a | 0.20 ± 0.018 a | 0.30 ± 0.15 a | 0.24 ± 0.017 a |
| | August 2013 | 0.39 ± 0.046 bc | 0.29 ± 0.023 c | 0.48 ± 0.048 b | 0.81 ± 0.022 a |
| *A. asphodeloides* | May 2013 | 0.15 ± 0.006 b | 0.10 ± 0.009 c | 0.12 ± 0.012 bc | 0.33 ± 0.017 a |
| | June 2013 | 0.25 ± 0.030 ab | 0.14 ± 0.025 b | 0.19 ± 0.014 ab | 0.30 ± 0.056 a |
| | July 2013 | 0.34 ± 0.038 a | 0.17 ± 0.020 b | 0.23 ± 0.046 ab | 0.28 ± 0.047 ab |
| | August 2013 | 0.27 ± 0.050 a | 0.22 ± 0.007 a | 0.24 ± 0.083 a | 0.28 ± 0.12 a |

Note: Entries in the same column and suffixed by the same letter are not significantly different from each other ($p > 0.05$).

### *4.2. Compensatory Growth*

As can be seen in Figure 3, the compensatory growth height of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* under enclosure was significantly higher than mowing treatments ($p < 0.05$), with the lowest height under OAY. OAY produced lower compensatory growth height than the other treatments, indicating that it caused the greatest damage to plants.

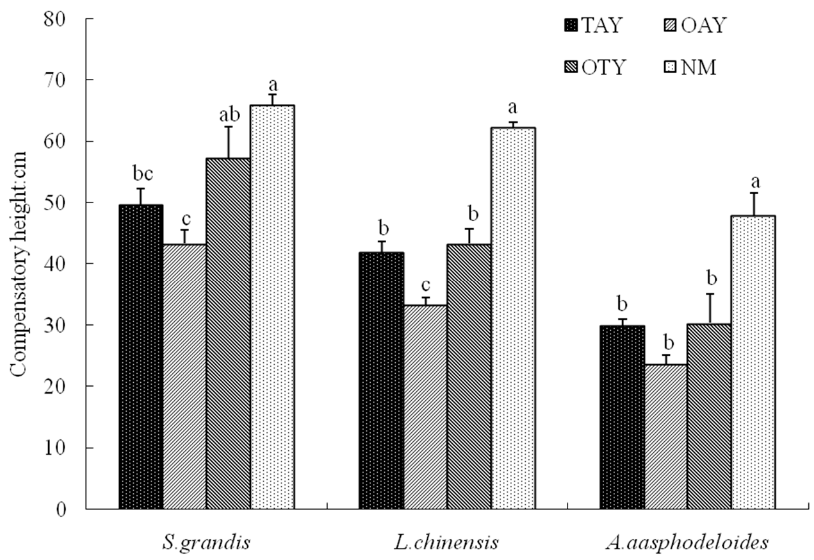



**Figure 3.** The compensatory height of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* under different mowing frequencies.

As can be seen in Figure 4, under different mowing frequencies, the relative growth rates of *Stipa grandis* and *Leymus chinensis* showed no significant differences, while the relative growth rate of *Anemarrhena asphodeloides* was lowest under OAY ($p < 0.05$).

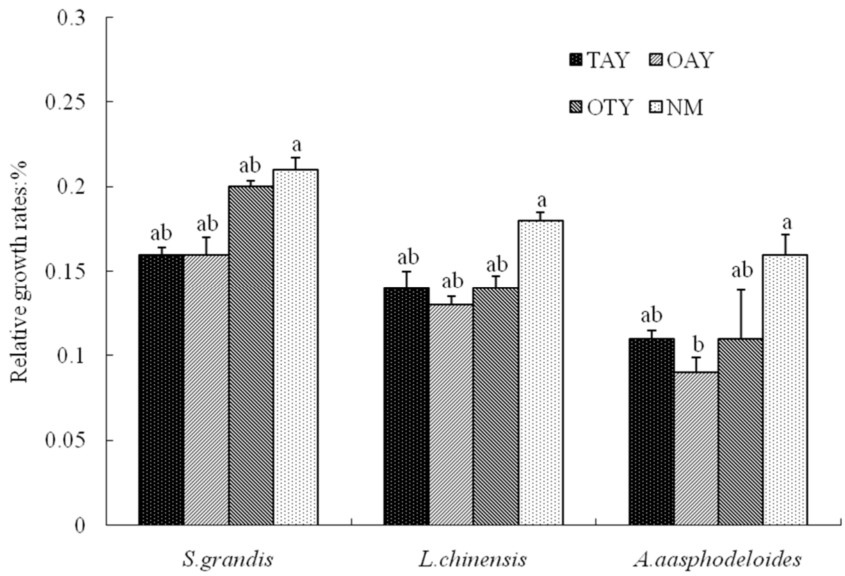



**Figure 4.** The relative growth rates of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* under different mowing frequencies.

As can be seen from Table 5, the compensatory biomass growth of *Stipa grandis* under OTY was 0.99, thus equivalent to compensatory growth. The compensatory growth indices of *Leymus chinensis* and *Anemarrhena asphodeloides* were both greater than 1 (over-compensatory growth). *Anemarrhena asphodeloides* exhibited over-compensatory growth under any mowing frequencies.

**Table 5.** The compensation index of biomass of *Stipa grandis*, *Leymus chinensis*, and *Anemarrhena asphodeloides* under different mowing frequencies.

| Compensation Index | TAY | OAY | OTY |
|---|---|---|---|
| *Stipa grandis* | 0.46 c | 0.68 b | 0.99 a |
| *Leymus chinensis* | 0.88 b | 0.66 c | 1.10 a |
| *Anemarrhena asphodeloides* | 1.92 b | 1.34 c | 2.69 a |

## 5. Discussion

As an artificial alternative to grazing, mowing can change the inter-specific and intra-specific competition intensity, thus altering the community structure and species composition [14,15]. With regard to diversity, moderate mowing can increase the diversity of species and maximize the utilization of limited resources [16]. Mowing improves spatial heterogeneity and reduces the intensity of competition among species; however, varying degrees of mowing has different effects on productivity and diversity [17,18]. Therefore, mowing can produce different effects on plant community productivity and species diversity, respectively, by directly influencing the growth of plants or affecting the habitat resources that plants depend on for survival [14,19,20]. This study revealed that mowing decreases the Shannon's diversity index and the richness index, whereas the evenness index is not significantly affected by mowing (Table 3).

The main effects of mowing on plant communities are the changes of species composition, the population density and biomass of the community [6]. Under excessive interference, the plants in the steppes had shorter growth, reduced leaf area, and individual plant miniaturization occurred. In this study, individuals of the constructive and dominant species were smaller under mowing treatments than under enclosure, but following the growth during the growing season, the differences among individuals decreased gradually, whereas variation appeared more at the community level, including in species density, height, and biomass. Enclosure increased the height and biomass of the community, but reduced species density. The reason could be that long-term enclosure leads to the accumulation of standing dead vegetation and litter, which hinders the horizontal expansion of growing plants, the germination of seeds on the ground surface, and the asexual reproduction of roots and stems.

The compensatory growth theory proposed by Belsky, et al. [11] states that plants reduce their external damage via the regulation of energy distribution patterns and changes in their morphological or physiological characteristics [12]. Some studies have shown that mowing can stimulate and change the photosynthetic process in plants [21], produce more tillers, and alter the material cycling pathway to induce plant growth [22]. The compensatory regeneration of plants after mowing is related to the physiological characteristics of the plant itself and to the mowing time, stubble height, mowing system, environmental impact factors, and so on [23,24]. Mowing frequency has a prominent impact on the compensatory growth of plants: high-frequency mowing reduced the compensatory growth of plants but cannot offset the external damage. Therefore, long-term high-frequency mowing hinders the recovery and growth of constructive species and dominant species, affecting the community structure, and leading to degradation of the steppes (Figure 3).

Mown plants compensate for the missing tissue by increasing their relative growth rate [25,26]. For plants with a low growth rate or a small amount of missing tissues, only a small increase in the growth rate is needed to compensate for the lack of tissues after mowing, thus it is easier to achieve over-compensation [25]. Our results show that the relative growth rate has a delayed response to mowing, and that short-term mowing treatments do not have a significant impact on the relative growth rates of the three species (Figure 2). This study confirms that a moderate frequency of mowing is beneficial to the compensatory growth of constructive species and dominant species within a community. Under the high frequency of mowing treatment, *Stipa grandis* exhibits low level of compensatory growth, and long-term high frequency mowing will inevitably lead to the degradation of the constructive species and a decrease in the niche occupation, causing it to be easily replaced by other species, thusly changing the community structure. However, under the moderate frequency of mowing treatment, the compensatory growth of the constructive species and dominant species helps to maintain the stability and functionality of the community, which is consistent with the intermediate disturbance hypothesis [27].

The most direct consequence of the succession of pasture degradation is reduced productivity. Steppe utilization efficiency decreases as a result of over-exploitation and degradation of the pasture, which negatively affects its sustainable use. Enclosure is beneficial for the recovery of the constructive species and dominant species within a community, but long-term enclosure can easily lead to enhanced competitiveness of constructive species and decreased living space for species other than the constructive species. This will cause uniformity in community species, reduce species diversity, decrease the ecological amplitude of the species, and reduce the use of resources, which is detrimental to the stability of the steppe ecosystem and the comprehensive utilization of energy. However, a high frequency of mowing can result in serious damage to grasslands, and long-term use can lead to grassland degradation.

According to the intermediate disturbance hypothesis [27], external disturbance reduces inter-specific exclusion processes, particularly the exclusion of other dominant species within the community; thus, there are better opportunities for species from outside and within the community to migrate and grow. Therefore, an intermediate level of disturbance will ensure a maximum level of species richness and diversity. This is inconsistent with the results of this study, perhaps because the study area was recovering from degradation, so enclosure was more effective for community recovery, leading to higher diversity and evenness of the community under enclosure than under mowing treatments. The community biomass and the community density was higher in the OTY compared to the other mowing treatments, but the lower accumulated biomass over multiple years was its shortcoming. However, from a long-term point of view, it has the advantages of fully compensating for its shortcomings. Mowing every year and mowing twice every year had the effect of promoting degradation. Enclosure for years will gather too much *Bacillus subtilis*, affecting plant growth and community succession. From the perspective of ecological protection and the long-term sustainable use of resources, mowing every other year is the most reasonable mowing frequency. This is similar to the results showing that while yearly mowing cannot be considered to be enough to recover target vegetation composition [28] and decreased mowing frequency (mowing in every second or third year) on the entire meadow or temporarily changing mosaics of mown and unmown stripes might be the most suitable management option for maintaining the highest biodiversity of forbs [29].

## 6. Conclusions

The main conclusions of this study are that mowing increases species density but reduces height and biomass growth, and that the constructive species *Stipa grandis* and dominant species *Leymus chinensis* and *Anemarrhena asphodeloides* had a trend toward individual miniaturization. Mowing twice a year reduced the forbs and the overall number of species within the community, and decreased the importance values of *Stipa grandis* and *Anemarrhena asphodeloides*. Under enclosure, the importance value index of *Leymus chinensis* decreased. Mowing every other year led to higher diversity, evenness, and richness indices of the community compared to other mowing frequencies. The relative height growth and growth rate were lower when mowing occurred once or twice a year compared to mowing every other year. The constructive species *Stipa grandis* exhibited equivalent compensatory growth when mowing occurred every other year (biomass compensatory growth index = 0.99), while *Leymus chinensis* exhibited over-compensatory growth (biomass compensatory growth index = 1.10). *Anemarrhena asphodeloides* exhibited over-compensatory growth under all three frequencies of mowing—biomass compensatory growth index = 1.92 (TAY), 1.34 (OAY), and 2.69 (OTY), respectively. Mowing every other year was found to be the most reasonable mowing frequency in practice.

Combining the results, we can know that mowing every other year could keep or even recover the productivity and biodiversity of degraded grassland. However, the experiment was short, the different mowing treatments had few cycles, and could not explain the effect of mowing long-term on the grassland ecosystem; and the indexes measured could not explain the detailed reasons for changes in community characteristics and biodiversity. In future experiments, we should observe the effects of long-term mowing and measure more indexes.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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