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Full Length Article

Effects of Clipping Frequency on the Relationships between Species Diversity and Productivity in Temperate Steppe

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Abstract

The relationships between the diversity of different species types (*i.e.*, total species, response species, effect species and common species), and the special function of ecosystems are not well understood. Our experiment was conducted on *Leymus chinensis* in a temperate steppe of northeast China from 2011 to 2013. We used a split-plot design with clipping treatment in the whole plot using two clipping frequency (clipping 1 time, clipping 2 times). Subplots were treated with fertilizer (urea 0, 3.26, 6.51 and 13.03 $g \cdot m^{-2} \cdot a^{-1}$). It was observed that the diversity of different species types affected ecosystem functioning differently. Aboveground net primary productivity (ANPP) was mainly affected by the diversity of response species and effect species. Clipping had enormous effects on the diversity of total species, whereas the changes in diversity of response species mainly correlated with resource availability. Our results suggest that ANPP is driven by the diversity of a few effect species because they have a great influence on ANPP. Moreover, the effects of diversity differ among different species.

Keywords: *Leymus chinensis*; Clipping frequency; Primary productivity; Species diversity

Introduction

The effect of species diversity on ecosystem function is a research issue in current ecology domain (Chen, 1997; Díaz and Cabido, 2001; Zhang and Zhang, 2002, 2003; Zhao, 2009). The ecosystem productivity is an important manifestation of function of ecosystem, and the productivity of plant community is the basis of ecosystem productivity (Tilman *et al.*, 1996; Jiang *et al.*, 2004). Therefore, studying the relation between species diversity of plant community and its productivity is of great significance in illustrating the effect of plant diversity on ecosystem function (Yang *et al.*, 2002).

Currently, there are two explanations about the relation between plant primary productivity and species diversity. Some people believe that plant community primary productivity is related with species diversity, as manifested by niche complementarity effect with characteristics of over production, asynchronism, and investment portfolio (Isbell *et al.*, 2009). The others believe that plant primary productivity is controlled by the dominant species, and accounted by sampling effect that is unrelated to species diversity (Grime, 1998; Sasaki and Lauenroth, 2011). Therefore, the opinions and explanations on the relation between species diversity and productivity are still controversial (Abrams, 1995). Whether the niche complementarity effect still plays an important role in natural ecosystem remains unknown (Grace *et al.*, 2007), and the natural background and mechanism accounting for the formation of such relation should be studied in a more extensive domain. Currently, Wang *et al.* (2013) made attempt to distinguish the identity of plant species (Díaz and Cabido, 2001; Hooper *et al.*, 2005), and defined the species which shows response to environment, so as to provide a new thought for studying species diversity and ecosystem function. In terms of the ecosystem of alpine meadow, such research clearly illustrated the relation between the diversity of species with different identities and the specific ecosystem function, and revealed the ecosystem functional effect and mechanism of species diversity.

Leymus chinensis meadow ecosystem plays an important role in developing animal husbandry, maintaining species diversity, conserving water and soil, and maintaining ecosystem balance (Liu, 2001). However, the acquired character of soil available nutrient resources of *Leymus chinensis* meadow tend to disappear with an increase in the degree of salinity-alkalinity, The primary productivity annually decreases, and grassland continuously degrades (Zhou *et al.*, 2011). As a result, by enhancing the acquired character of soil available nutrient resources and

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releasing nutrient limitation, grassland can have improved primary productivity, and stable production and sustainable utilization of grassland can be realized (Xi *et al*., 2010; Zhu *et al*., 2010; Li *et al*., 2011).

In this research, we conducted field control experiments with doubled clipping (frequency) and nitrogen fertilizer gradient for consecutive 3 years, so as to make a comparative analysis on the relation between the diversity of *L. chinensis* meadow species (including total species, response species, effect species and common species) and their aboveground net primary productivity, which provided theoretical basis for reasonable utilization of *L. chinensis* meadow and restoration of degraded grassland ecosystem.

Materials and Methods

Profile of Research Area

Research was conducted in *L. chinensis* meadow of Suihua Experiment Station of National Grass Industry from 2010 to 2013. The research area was located at Yuanda Village, Lanxi County of Heilongjiang Province (E125°28′24″，N 46°32′17″), with continental monsoon climate, annual rainfall of 469.7 mm and annual mean temperature of 2.9^{o}C; The annual accumulated temperature of such research area ≥10^{o}C，the active accumulated temperature is 2760^{o}C; The soil of the research area was had three levels of salinization (low, medium, and high salinization), with total salt content varying within 0.157%~0.318%, and pH value varying from 8.12 to 10.08. The community was mainly meadow steppe where species were abundant including *L. chinensis* (constructive species), *L. quinquenervius*, *Hemarthria sibirica*, *Carex duriuscula*, *Phragmites communis*, etc. The research communities were all set in clipping pasture, which was free from the grazing pressure.

Research Method

Main-plot was for clipping frequency, with arrangement of 2 levels, *i.e*., clipping once per year (C1) and clipping twice per year (C2). Split-plot treatment was application of nitrogen fertilizer (urea), with four levels including N0 (0 $g·m^{-2}·a^{-1}$), N1 (3.26 $g·m^{-2}·a^{-1}$), N2 (6.51 $g·m^{-2}·a^{-1}$) and N3 (13.032 $g·m^{-2}·a^{-1}$). The test layout is shown in Table 1. In 2011, the medium-degraded *L. chinensis* grassland (mean number of branches of *L. chinensis* were 50–80 m^{-2}) was set as test sample field. After greening back, nitrogen fertilizer was applied when the mean temperature of 10 cm-deep soil within 5 d was maintained over 5^{o}C. The first clipping was done when *L. chinensis* entered in heading period or plant height reached 40 cm; The second clipping was done one month before frost, with remaining stubble being 5 cm high. The main plot was in arrangement of 10 × 10 m, subplot was in 5 × 5 m arrangement. Each subplot was divided into four observation quadrats in 1 × 1 m, including 1 permanent quadrat for long-term observation of species composition variation, and remaining 3 quadrats for plant traits determination. Before each clipping from 2011 to 2013, we measured the number of species, cover degree (visual inspection), density (regarding dicotyledon as individual number, monocotyledon as ramets amount), plant height, total aboveground biomass (drying at 60^{o}C for 72 h) in totaling 96 permanent quadrats. The sum of 2 clipping biomasses were regarded as estimated value of aboveground net primary productivity (ANPP, $kg·m^{-2}·a^{-1}$). The data collected in 2012 was used for data analysis in this paper.

Statistical Analysis

The formula for calculation of important value (IV) was V = (relative density + relative cover degree + relative height)/3 (Ren, 1998). Species diversity was calculated by the formula of Simpson diversity index $D=1-\sum Pi^2$, where Pi is the relative density of the *i* th species in quadrat, *s* is the number of species (Ma and Liu, 1994). Ecosystem function was characterized by plant community ANPP. All data were subjected to variance analysis using General Linear Model (GLM) of SPSS 17.0.

Results

Type of Response Species

There were totally 54 types of plants (in 18 families and 37 categories) in *L. chinensis* meadow. The numbers of RS, ES and CS are 18, 7, 36, accounting for 34, 13 and 67% of total species, respectively. The ES accounts for 39% of RS. RS and ES, respectively account for 50 and 20% of CS. Under frequency, nitrogen fertilization, and clipping × nitrogen fertilization, the number of RS accounts for 15, 23 and 12% of total species, respectively (Table 1).

Variation of Productivity

Clipping, nitrogen fertilization and interaction of clipping and nitrogen fertilization had significant effect on community ANPP (clipping: $F(1,2) = 5.536$, $p < 0.05$; nitrogen fertilization: $F(3,13) = 71.335$, $p < 0.001$; clipping × nitrogen fertilization: $F(3,12) = 5.054$; $p < 0.05$). When nitrogen fertilization was not given, the primary productivity with two clippings was decreased by 26.7% as compared with primary productivity with one clipping. After nitrogen fertilization, the mean primary productivity with one and two clippings ware respectively increased by 35.6 and 43.9%, making the difference between primary productivity with one clipping and primary productivity with two clippings disappear (Fig. 1).

Relation between Species Diversity and Community Primary Productivity

Only the RS diversity was negatively correlated with community net primary productivity ($p < 0.05$) after nitrogen fertilization (Table 2). The regression slope was also

Table 1: ANOVA for important value (IV) of species and regression analysis for the IV with aboveground net primary productivity

Plant species	B (2,2)	C (1,2)	N (3,12)	C×N (3,12)	R^2 (n=24)	Species type
Leymus chinensis	0.926*	1.455**	7.318**	0.908*	0.325**	RS,ES
Lathyrus quinquenervius	1.267**	1.760**	8.951*	1.452**	0.512**	RS,ES
Carex duriuscula	0.507	0.704**	3.580*	0.581*	0.426**	RS,ES
Scirpus tabernaemontani	0.169	0.235*	1.193*	0.194	0.004	RS
Sanguisorba officinalis	0.127	0.176	0.895	0.145	0.007	RS
P.flagellalis	0.121	0.168	0.852	0.138	0.011	RS
Hemerocallis minor	0.101	0.141	0.716*	0.116	0.019	RS
Stachys chinensis	0.169	0.235**	1.193**	0.194	0.225**	RS,ES
Saposhnikovia divaricata	0.422	0.587	2.984**	0.484*	0.036	RS
I.dichotoma	0.091	0.126	0.639	0.104	0.021	RS
Cynanchum amplexicaule	0.091	0.126	0.639	0.104	0.008	RS
Lythrum salicaria	0.106	0.147*	0.746	0.121	0.004	RS
Linum stelleroides	0.133	0.185	0.942*	0.153	0.032	RS
S.ambraceus	0.149	0.207	1.053**	0.171	0.164**	RS,ES
Aster tataricus	0.115	0.160	0.814	0.132	0.015	RS
Phragmites communis	0.253	0.352*	1.790**	0.290	0.145**	RS,ES
Hemarthria sibirica	0.507	0.704**	3.580**	0.581*	0.135**	RS,ES
Arundinella hirta	0.845*	1.173**	5.967**	0.968**	0.046	RS
No. of response species (%)	3 (6%)	8 (15%)	12 (23%)	6 (12%)	7 (13%)	

Note: B, block; C, clipping; N, fertilizing; ×, interaction; RS, response species; ES, effect species; *, $p < 0.05$; **, $p < 0.01$

Table 2: Regression analysis for the diversity with aboveground net primary productivity

Plant species	Fertility gradient												Clipping frequency					
	N0			N1			N2			N3			One time			Two times		
	a	*F*	R^2	*a*	*F*	R^2	*a*	*F*	R^2	*a*	*F*	R^2	*a*	*F*	R^2	*a*	*F*	R^2
No. of total species	2.50	2.1	0.08	-2.5	2.12	0.05	-3.0	2.2	0.07	-3.5	2.62	0.06	-0.65	2.32	0.06	0.53	2.32	0.01
Response species (%)	1.51	1.32	0.06	-1.63	1.21*	0.09	-1.96	1.76*	0.11	2.63	2.16*	0.14	-1.5	8.52**	0.20	0.73	2.02	0.08
Effect species (%)	0.06	0.01	0	-0.06	0.01	0	-0.58	0.01	0	-0.96	0.08	0	-0.66	0.33*	0.12	-0.06	0.01	0
Common species (%)	2.56	2.3	0.03	-3.12	2.6	0.03	-3.42	2.26	0.06	-3.62	2.71	-3.12	2.6	0.03	-3.42	2.26	0.06	-3.62

different from that without nitrogen fertilization (p=0.033), however the diversity of RS only accounted for 9, 11 and 14% of productivity change. The diversities of other species are neither correlated with community net primary productivity, nor affected by clipping. The diversities of total species and CS were not correlated with net primary productivity with or without clipping; The diversities of RS and ES were negatively correlated with net primary productivity with one clipping, accounting for 20 and 12% of productivity change (Table 2). The regression slope K value of ES with one clipping was significantly different from that with two clippings (p = 0.003), while the regression slope K value of RS was not affected by clipping frequency (Fig. 1).

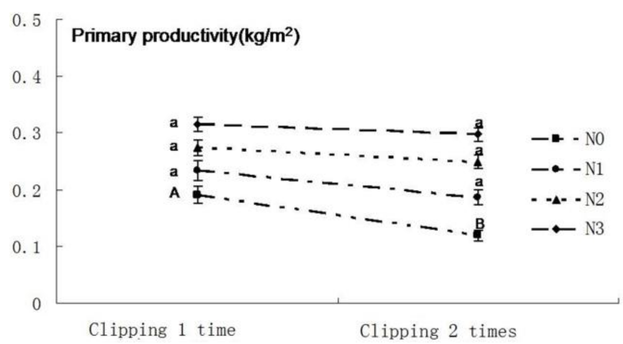

Fig. 1: Effects of clipping and fertilizing on primary productivity (mean ± SE, n = 24). Same small letters indicate no significant difference among clipping times treatments (p > 0.05). Different capital letters indicate significant difference among fertilizing treatments in quadrat (p < 0.001)

Discussion

According to the response of species IV upon clipping, community species were categorized into four types (Response Species, Effect Species, Common Species, and Total Species). Results showed that the diversities of different types of species had different effects on ecosystem net primary productivity. The diversities of RS and ES (minority species) were negatively correlated with net primary productivity (Hooper *et al.*, 2005). The diversities of total species and common species (accounting for 67% of total quantity) were not correlated with net primary productivity, while that of RS and ES (accounting for 34 and 13%, respectively) were negatively correlated with productivity, whereas a highest accountability was only 20% (RS with nitrogen fertilization and one clipping). However, the common species density had significant negative effect on aboveground net primary productivity. The "identity" of species may be more important than its diversity.

Results showed that clipping for consecutive three years significantly increased the diversities of total species and response species as well as decrease the community primary productivity. In this research, effect of clipping and nitrogen fertilization on species diversity and that on net primary productivity are opposite, which was consistent with moderate disturbance hypothesis and Tilman's research (Tilman, 1987, 1999; Tilman *et al.*, 2006). Above effects were correlated with the response difference of four types of species, which indicated that the diversity of minority species which directly affect net primary productivity is more affected by nitrogen fertilization, while the diversities of other species is more affected by clipping. Many researchers showed that nitrogen fertilization can increase net primary productivity (Tilman, 1982) and decrease species diversity as well (Lepš, 2004; Grman *et al.*, 2010). However, this research shows that although the productivity of community with two clipping increased more significantly after nitrogen fertilization, the productivity of community with two clippings was still slightly lower than that with one clipping. This indicated that after nitrogen fertilization, the compensatory growth capacity of *L. chinensis* meadow could not cover the negative effect by long-term two clippings, which is consistent with research on compensatory growth (Zhou *et al.*, 2011). According to the variation of species diversity and net primary productivity with double clipping and nitrogen fertilization in this research, we believe that the most important premise for maintaining high level of net primary productivity and species diversity and long term stable grow of *L. chinensis* meadow was clipping twice a year with nitrogen fertilization at N3.

Conclusion

Species diversity has positive effect on ecosystem function in short-term diversity experiment. The "identity" of species may be more important than species diversity, therefore the differentiation of species diversity effect can be manifested.

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