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Caragana Aboveground Biomass and Area Relationship in Semiarid Loess Plateau Region

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Abstract: This study aims to establish the relationship between biomass and area and then to determine minimum sample area for biomass investigation by building suitable model. The investigation of the effect of area size on biomass was carried out in the period from July to August, 2012 in Caragana brushland of Semiarid Hilly Region of Loess Plateau, China. The size of sample areas changed from 1×1 m to 10×10 m and a series of samples were selected in the nested way. The canopy area, basal diameter and height of Caragana plants were investigated. Arrhenius model, Logarithmic function, Michaelis-Menton model and Logistic model were used to fit the biomass-area data respectively. The results showed that the aboveground biomass reduced sharply and then gently with the increasing sample areas, which was the best fitted with Logistic model. The minimum sample area was got when the second derivative of the best fitted biomass-area equation was 0.

Key words: Semiarid region of loess hilly area, caragana plantation, nested plot, biomass-area curve, minimum area

INTRODUCTION

It is not necessary to sample the whole Caragana forest when investigating biomass of the field community for the limitation of human power, material, money and time because whole information with precision can get from a certain range and it was proved in plant study. However, it was not sure that how many number of the plots can representatively and suitably describe the whole forest biomass and how much sample area can we take basically to reflect the composition of the plant community. The minimum sample area is defined as the area that can reveal the real character and composition of a specific community. There are different minimum areas for different research objects and community types because they own a different characteristics.

There are many reports on the methods of determining the minimum area. Species-area relationship is often discussed on the law of species number with increasing sample area, it is an important basis for scale transformation of biodiversity (Tang *et al*., 2009). Because different minimum area is needed for investigation of biomass in different plant community (Cannone, 2004), proper sampling area should be determined accurately for community types (Ren *et al*., 2011). Important value, the sum of relative density and relative abundance or relative dominance and relative frequency, is not only a comprehensive quantitative indicator for community and has a good practicability in sampling and composition study for complex forest community (Curtis and McIntosh, 1951), but also a method of determining minimum sample area (You *et al*., 2002). Community coefficient-area curve also can determine the minimum area for investigation of important coefficient in a community, however it turned out that this method was not so good (You *et al*., 2002).

Now, there are many reports of species-area (Tong *et al*., 2008), important value-area (Huang and Wang, 2008), community coefficient-value to determine minimum area. Until now, there are a few reports on the relationship between biomass and area to determine the minimum area. The purpose of this research is to explore the relationship between biomass and area and then to determine the minimum sample area of the Caragana shrubland.

MATERIAL AND METHODS

Site description: This study was carried out at the Shanghuang Eco-experiment Station, the Institute of Soil

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and Water Conservation , Chinese Academy of Sciences, located in the semiarid region of the Loess Plateau (35°59'- 36°02'N, 106°26'- 106°30'E) in Guyuan, Ningxia Hui Autonomous Region. The altitude ranges from 1,534 to 1,824 m above the sea level. Precipitation is scarce in the period from January to March and the rainfall from June to September accounts for more than 70% of the annual precipitation. Mean rainfall measured between 1983 and 2001 was 415.6 mm with a maximum of 635 mm in 1984 and a minimum of 260 mm in 1991. The frost-free period is 152 days. The soil is mainly loamy loess,Calcaric Cambisol (FAO/UNESCO, 1988), which was developed directly from the loess parent materials. This soil is porous and widely distributed in the semiarid region of the Loess Plateau. There is a little change of soil texture with the depth in the soil profile (Yang and Shao, 2000). The experimental field was located in the caragana bushland in the middle of Heici Mountain with a slope gradient of 3°, facing southeast at the Shanghuang Eco-experiment Station. The study object is 26-year-old Caragana Plantation, under which the main plant species are Stipa bungeana Trip, Heteropappus altaicus (Willd.) Novopokr, Artemisia giraldii Pamp and Thymus mongolicus Ronn.

Sampling method: The field survey was carried out in the period from July to August, 2012 in Caragana korshinskii brushland. Because Caragana, the main afforestation species in the semiarid region of Loess plateau, China, was planted in the way of fish scale pit in experimental plot , we choose a series of sample plots from 1×1 m^{-2}, to 2×2 m^{-2}, to 3×3 m^{-2}, to 4×4 m^{-2}, ... and to 10×10 m^{-2} in the nested plot (Tang *et al*., 2009) in the homogeneous Caragana shrubland and then measured short diameter and long diameter, which is perpendicular to short diameter of canopy of every caragana brush and then measure height of every branch in a caragana brush with tape, basic diameter of every branch with vernier caliper and single biomass of every branch with electric scale in every sample. The nested plot can be seen in Fig. 1.

Possible models: There are many possible models to simulate species-area curve. These models commonly used are as following(Zhang, 2011):

- Arrhenius model (Arrhenius ,1921): $S = kA^m$
- Connor and McCoy model (Connor and McCoy, 1979): $S = k+m^A$
- Logarithmic function (Napier,1614): S = klnA+m, Fig. 1 the nested plot
- Goodall model (Goodall, 1952): S = kln (A+1)
- Michaelis-Menton model (Michaelis and Menton, 1913): $S = k\text{-}me^{-gA}$

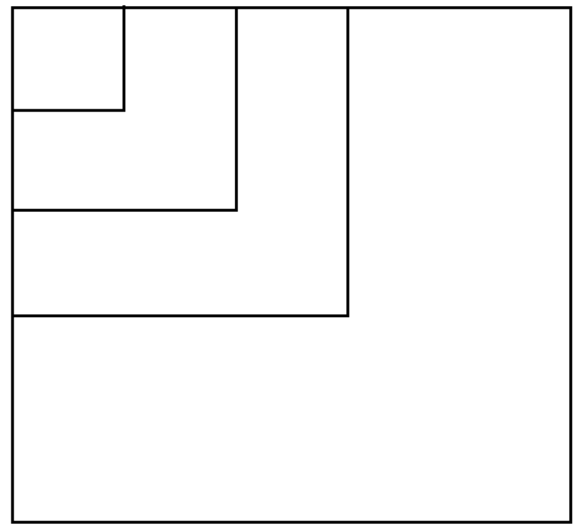

Fig. 1: The nested plot

- Logistic model (Verhulst, 1838): $S = k/(1+me^{-gA})$

where, S is species number appeared in the area. A, k, m and g are parameters. In order to fit biomass-area curve and then determine the minimum area, we select the possible model to fit biomass-area data and substitute B for S, in which B was biomass. Data were processed with Matlab Software.

RESULTS AND ANALYSES

The dynamics changes of biomass with area: The relationship between total biomass and quardrat area were showed in Table 1 and Fig. 2. It can be seen from Table 1 that total biomass increased with area from 3.1 to 144.9 kg, but the Caragana aboveground biomass per unit area reduced from 3.1 to 1.45 and the curve was sharply reduce and then to gently stable.

According to approach the law of biomass change with increasing area, we use the 6 models to fit the original data. we select model 1, 3, 5 and 6 to describe the biomass-area curve based on R^2 and the significance of models. The fitting effects of four models can be seen in Table 2.

Put the above parameters into the four models respectively and the equations of describing the biomass-area curve are as follows:

$$B = 2.922A^{-0.1809} \quad (1)$$

$$B = -0.32671nA+2.741 \quad (2)$$

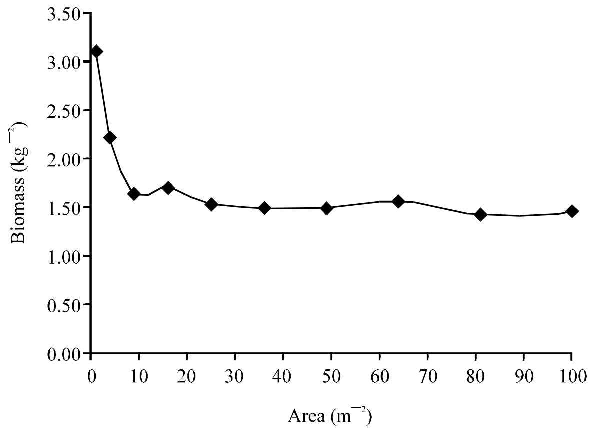

Fig. 2: Changing trends of the biomass

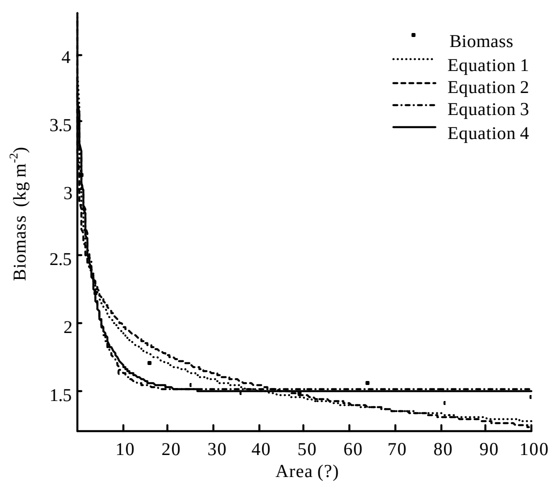

Fig. 3: Fitting curves of the four equations

$$B = 1.503+2.096e^{-0.2729A} \quad (3)$$

$$B = 1.49/(1-0.6118e^{-0.1633A}) \quad (4)$$

R^2 is the determinant coefficient and S is the residual standard deviation. The bigger of R^2 is , the better of the equation. At the same time, the smaller of S is, the better of the equation. Compared R^2 and S among the four biomass-area curves (Table 2 and Fig. 3), the results are as follow:

- With regards to R^2: Model (2)< Model (1)< Model (3)< Model (4)
- With regards to S: Model(2) >Model(1) >Model(3)>Model(4) , so the model (4) was proved to be the best model to fit the data

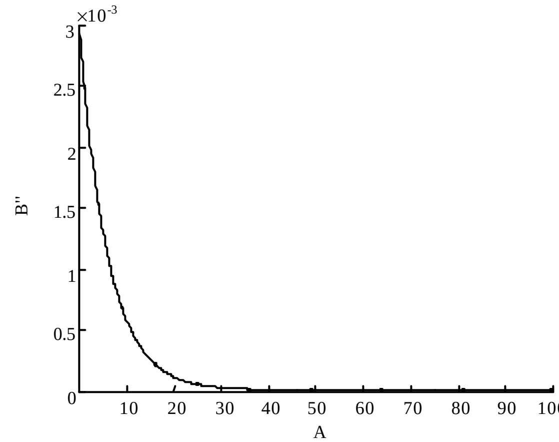

Fig. 4: Value of B'' change with increasing area

Table 1: Relationship between quadrat area and biomass

Sample area (m^{-2})	1	4	9	16	25	36	49	64	81	100
Weight (kg)	3.1	8.85	14.69	27.19	38.14	53.29	72.61	99.36	114.4	144.9
Biomass (kg m^{-2})	3.1	2.21	1.63	1.70	1.53	1.48	1.48	1.55	1.41	1.45

Table 2: Data fitting parameters of four models

Equation	k	m	g	R2	S
1	2.9220	-0.1809	-	0.9051	0.17190
2	-0.3267	2.7410	-	0.8289	0.23080
3	1.5030	-2.0960	0.2729	0.9811	0.08209
4	1.4900	-0.6118	0.1633	0.9826	0.07879

Determination of minimum area: Until now there are many methods for finding minimum area in the field biology. We define the area corresponding to the point at which the second derivative of the fitted biomass-area equation was 0 as the minimum area because the point was the bump changing point, since this point, the biomass per unit area does not change with increasing sample area. The second derivative of model 4 solved by Matlab Software was:

$$B'' = 0.0244/(\exp(0.1633A)*(0.6118/\exp(0.1633A)-1)^2)-0.02976/(\exp(0.3266A)*(0.1688/\exp(0.1633A)-1)^3)$$

and the relationship of B'' and A were showed in Fig. 4.

There was no inflection point in the curve of B'' and A, so the point that near to 0 was treated as inflection point. The value of 33.7?calculated by solving the equation when the value of 1×10^{-4} was equal to the limit point suggested that the suitable minimum area was 36 m^{-2} for that determining the minimum area should be larger than the calculated theoretical area.

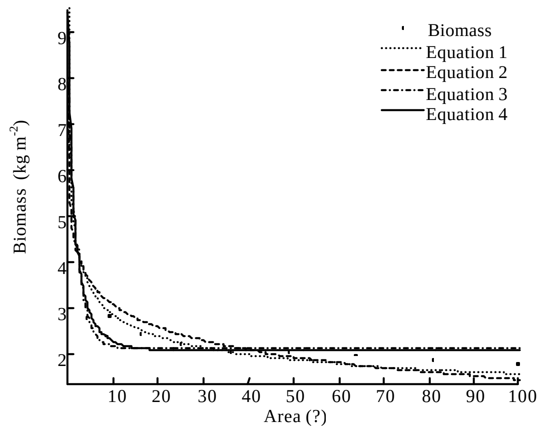

Fig. 5: Fitting curves of the four equations

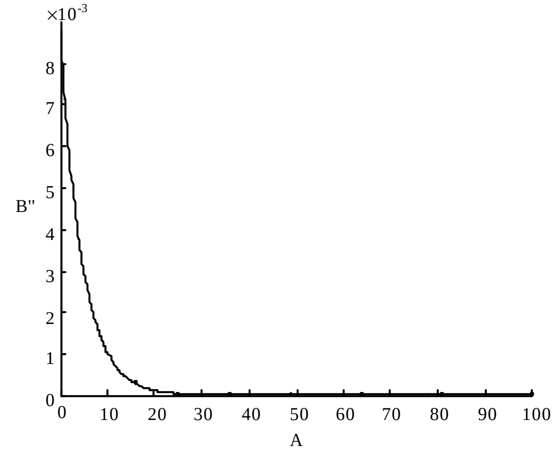

Fig. 6: Value of B'' change with increasing area

Table 3: Quadrat area and biomass

Sample area (m^{-2})	1	4	9	16	25	36	49	64	81	100
Weight (kg)	5.65	11.1	25.44	38.55	55.2	73.71	100.24	126.32	149.86	178.16
Biomss (kg m^{-2})	5.65	2.78	2.83	2.41	2.21	2.05	2.05	1.97	1.85	1.78

Table 4: Fitting results of four models

Equation	k	m	g	R2	S
1	5.2050	-0.2614	-	0.9072	0.3698
2	-0.7011	4.6760	-	0.8061	0.5346
3	2.1180	-5.7050	0.4859	0.9369	0.3260
4	2.0630	-0.7826	0.2127	0.9500	0.2900

Substantiation: In order to prove the applicability of the above result, the experiment was carried out again in August, 2012. Between July and August the Caragana aboveground biomass per unit area greatly changed because these days were at the fast growing season for Caragana and in this case the substantiation was necessary to be taken into consideration to test whether the above minimum area was proper in other plot.

The second data was in Table 3 and the four models also were used to fit the data, results were displayed in Table 4 and fitting effects in Fig. 5.

Put the above parameters into four models again and the models were to be:

$$B = 5.205A^{-0.2614} \quad (1)$$

$$B = -0.7011 \ln A+4.676 \quad (2)$$

$$B = 2.118+5.705w^{0.4859A} \quad (3)$$

$$B = 2.063/(1-0.782e^{-0.2127A}) \quad (4)$$

As 3.1 compared the biomass-area curves (Fig. 5) and R^2 and S (Table 4), the results are:

- With regards to R2: Model (2) <Model (1)<Model (3)<Model (4)
- With regards to S: Model (2) >Model (1) >Model (3) >Model (4)

so the model 4 was proved to be the best fitting equation. The second derivative of model 4 was:

$$B'' = 0.073/(\exp(0.2127A)*(0.7826/\exp(0.2127A)-1)^2)-0.11432/(\exp(0.4254A)*(0.7826/\exp(0.2127A)-1)^3)$$

and Fig. 6 displayed the curve of B'' and A.

In this case, the value of 31.02 m^{-2} calculated by using the method of solving second derivative was in the range of 36 m^{-2} determined before, which suggested that the method of determining the minimum area is right and proved that this minimum area can be widely used to the investigation of biomass in the loess hilly region.

DISCUSSION

Considering the trend biomass changes with the increasing area, Arrhenius model, Logarithmic function, Michaelis-Menton model and Logistic model were taken to fit the biomass-area curve. It turned out that the first investigation data and second data were fitted best with logistic function among four models. The minimum area was got by solving the second derivative of the fitted biomass-area curve. The first result was the value of

33.7 m^{-2}, so we determine that 36 m^{-2} was the minimal area for that determining the minimum area should be larger than the calculated theoretical area (Dietvorst *et al*., 1982). The second result A=31.02 m^{-2} was in the range of minimum area determined before, so A = 36 m^{-2} was proved to be the minimal area in the investigation of biomass in Caragana korshinskii shrubland of semiarid loess hilly region and it also comply with the scope of shrub sample area 10~50 m^{-2} which was empirical value, in other words, 36 m^{-2} can reflect the composition characteristics of all plantation.

With the determination of minimum area it will be more convenient to study Caragana korshinskii, such as forecasting the biomass of Caragana korshinskii shrubland and the bio-energy. The extension of the minimum area determined in this paper to other plants needed to be further substantiated.

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