沙漠研究 11-2, 111-117 (2001)
Journal of Arid Land Studies

— Original Article —

Vegetation Indicators of Desertification in the Mu Us Desert and their Applicability to Remote Sensing

QIU Guo Yu[1, 2], SHI Peijun[1], SHIMIZU Hideyuki[2], TOBE Kazuo[2], GAO Yong[3] and OMASA Kenji[4]

For the development of remote sensing technologies, a sensitive, simple, and direct indicator for assessing the degree of desertification able to be applied by remote sensing technology is required. Vegetation can satisfy this requirement because changes in soil, water, and other micro-environmental factors can be sensitively reflected by changes in vegetation. The objectives of this study are to analyze the characteristics of vegetation at different stages of desertification and to discuss the possibility of applying these characteristics as indictors of desertification for use by remote sensing technology.

The field investigation was conducted in the Mu Us Desert, a typical sand desert in Inner Mongolia, northern China. We investigated 198 sampling areas, 179 of which were $1.5 \times 1.5\ m^2$ and 19 of which were $5 \times 5\ m^2$ in size. We recorded plant species, canopy coverage, number of individual plants, and height for every species.

Our results showed that as desertification proceeded, plant associations changed greatly. The type of association, minimum area of the association, canopy coverage, diversity, and evenness of vegetation changed significantly and could be used as indicators of desertification. Among these five parameters, minimum area, diversity, and evenness cannot be acquired from remotely sensed data. Coverage and type of association can potentially be detected by remote sensing technology. Yet, the degree of desertification could not be determined by coverage alone because it was not linearly related to the stage of desertification. Coverage + association type could be used to satisfactorily determine the stage of desertification. Recent progress has shown that, even though further improvements and field verification are required, it is possible to estimate vegetation coverage by remote sensing technology. However, the estimation of association type by remotely sensed data is still an unsolved issue. As sensor resolution and data analysis technologies are improved, a solution should be found in the near future.

Key Words: China, Desertification, Indicator, Remote sensing, Vegetation

1. Introduction

Vegetation is one of the most important ecosystem components. All environmental variations, such as weather, soil, sand activities, and water status, are sensitively reflected by changes in vegetation. Therefore, vegetation has the potential to be applied to assess the environmental changes. Zhu and Liu (1984) used vegetation characteristics to assess degree of desertification, which is a reverse succession of the plant community (Li, 1983). More recently, a sensitive, simple, and direct indicator applicable by remote sensing technology for assessing the degree of desertification has become necessary. The objectives of this study are to analyze the characteristics of vegetation at different stages of desertification and to discuss the possibility of applying these characteristics as indictors of desertification for use by remote sensing technology.

[1] Institute of Resources Science & China Center of Desert Research, Beijing Normal University. Beijing 100875, China.
[2] National Institute for Environmental Studies. 16-2, Onogawa, Tsukuba, Ibaraki 305-0053 Japan.
[3] Inner Mongolia Agricultural University. Huhhot, China.
[4] Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1, Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan.
(Received, August 30, 2000; Accepted, May 11, 2001)

2. Materials and Methods

The field investigation was conducted in the Mu Us Desert, a typical sand desert in northern China. The average accumulative temperature there for temperatures ≥ 10 ℃ is 3449 ℃ each year, and the region receives 2860 h of sunshine each year. The maximum monthly average temperature is 24 ℃, the minimum is -10 ℃, and the length of the frost-free period is 179 days. Annual precipitation is 468 mm. The topography is characterized by sand dunes, and the soil is sandy.

We investigated the vegetation by sampling. In all, 198 areas were sampled; 179 of the sampling areas were $1.5 \times 1.5\ m^2$ and 19 were $5 \times 5\ m^2$. In each sampling area, the species name, canopy coverage, number of individuals, canopy height, and other parameters were recorded for every plant species. In this study, relative canopy coverage (RC_i), which was used to represent the size of a population, was calculated as follows:

$$RC_i\ (\%) = \frac{C_i}{\sum C_i} \times 100 \qquad (1)$$

where C_i is the coverage of species i and $\sum C_i$ is the total coverage of association.

For the reader's convenience, a few often-used concepts are explained below:

Dominant species is defined as the plant species that has the largest number of individuals or the largest coverage area, which can strongly affect the structure of the plant community.

Association: The association is the fundamental unit of vegetation classification. Plant assemblages having the same layer structure and the same dominant species can be put into the same association.

3. Results and Discussion

1) Determination of desertification stages

The experimental area was located in the eastern part of the Mu Us Desert, which was a typical grassland region in the past. Recently, however, because of overgrazing, woodcutting for fuel, and exploitation for farmland, desertification has widely occurred, and the natural vegetation has been seriously destroyed. As desertification has proceeded, a reverse succession of vegetation has occurred. Desertification stages were determinate by the following steps. Firstly, based on the analysis of the sampling data, the relationships among community types, individual plants, and environmental factors were analyzed. Then, samples were arranged according to environmental gradient and changes in plant species. Finally, the reverse succession series of vegetation was classified into 6 stages. The dominant species in each stage are shown in Table 1. A same reverse succession series has been reported in the same region (Li, 1983).

2) Plant associations at different stages of desertification

Figure 1 shows photographs of the associations for each of the 6 stages of desertification in the Mu Us Desert. The dominant plant species at each stage were *Sabina vulgaris* (stage 1, Fig. 1a); *Sabina vulgaris* + *Artemisia ordosica* (stage 2, Fig. 1b); *Artemisia ordosica* + *Caragana intermedia* (stage 3, Fig. 1c); *Artemisia ordosica* (stage 4, Fig. 1d); *Artemisia ordosica* + *Salix psammophila* (stage 5, Fig. 1e); and *Artemisia sphaerocephala* (stage 6, Fig. 1f). The list of plant species and their relative coverage in each the six stages of desertification are shown in Table 2. It is clear that dominant species and plant coverage change significantly from stages 1 to 6.

Table 1. Degree of desertification and corresponding plant association in the Mu Us sand desert (Mu Us Desert, Northern China).

Degree of Desertification	Type of Association
Stage 1 (No desertification)	*Sabina vulgaris*
Stage 2	*Sabina vulgaris* + *Artemsia ordosica*
Stage 3	*Artemsia ordosica* + *Caragana intermedio*
Stage 4	*Artemsia ordosica*
Stage 5	*Artemsia ordosica* + *Salix psammophila*
Stage 6 (Shifting dunes)	*Artemisia sphaerocephala*

Figure 1a

Figure 1b

Figure 1c

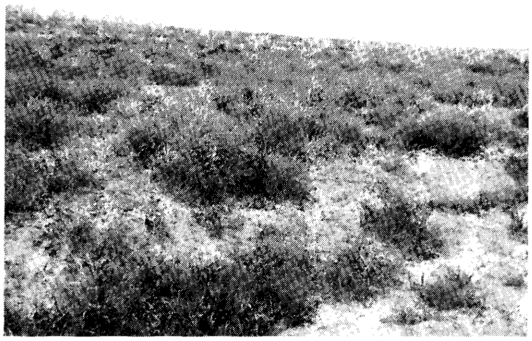

Figure 1d

Figure 1e

Figure 1f

Fig. 1. Photos of the plant association of each of the 6 stages of desertification in the Mu Us Desert. The dominant plant species for each stage are *Sabina vulgaris* (stage 1, Fig. 1a); *Sabina vulgaris* + *Artemisia ordosica* (stage 2, Fig. 1b); *Artemisia ordosica* + *Caragana intermedia* (stage 3, Fig. 1c); *Artemisia ordosica* (stage 4, Fig. 1d); *Artemisia ordosica* + *Salix psammophila* (stage 5, Fig. 1e); and *Artemisia sphaerocephala* (stage 6, Fig. 1f).

3) Minimum area of association

During the investigation of vegetation, numbers of species will increase with the increase of sampling area at the beginning period. After the sampling area increased to a certain value, all of the species will be included and number of species will not increase with the increase of sampling area. The area at which all of the plant species are included for the first time is defined as the minimum area of association. The minimum area is a parameter that can reflect the diversity of plant species in a given association. The larger the minimum area is, the greater the number of species includes in the association. Fig. 2

Table 2. A list of plant species and their relative coverage (%) at different desertification stages (Mu Us Desert, Northern China).

Name of Species	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Artemisia ordosica	7.77	7.88	14.45	29.90	12.83	0
Cynanchum komorovii	0.23	0.59	0.08	1.13	0.06	0
Psammochloa villosa	0	0.03	0	0	0	0.29
Sabina vulgaris	13.95	8.60	0	0	0	0
Caragana intermedia	0	0.33	2.55	0	0	0
Coryspermum puberulum	0.02	0.03	0	0	0	0
Artemisia annua	0.53	0.17	0	0	0	0
Artemisia frigida	0	0.12	0	0	0	0
Cleistogenes squarrosa	0.01	0.05	0	0	0	0
Heteropapus altaicus	0.06	0.17	0	0	0	0
Eragrostis cilianensis	0.40	0.05	0.03	0.25	0.03	0
Setaria viridis	0.88	0.07	0.03	0	0.08	0
Pennisetum centrasiaticum	0.06	0.05	0.08	0.05	0.03	0
Allium mongolicum	0.10	0.01	0	0	0	0
Bassia dasyphylla	0.04	0.08	0	0	0	0
Silene repens var. *angustifolia*	0.11	0.07	0	0	0	0
Allium tenuissimum	0	0.01	0	0	0	0
Hedysrum fruticosum subspe. *laeve*	0	0.08	0	0	0	0
Agriophyllum squarrosum	0	0.01	0	0	0	0.09
Artemisia scoparia	0	0.02	0	0	0	0
Astragalus melilotoides	0	0.01	0	0.08	0	0
Salix psammophila	0	0	0	0	14.89	0
Artemisia sphaerocephala	0	0.10	0	0	0	9.00
Asparagus dauricus	0.02	0	0	0	0	0
Dontostemon eglandulosus	0.02	0	0	0	0	0
Carex stenophylloides	0.13	0	0	0	0.03	0
Chenopodium aristatum	0.03	0	0.03	0.13	0	0
Potentilla multifida var. *nubigena*	0.08	0	0	0	0	0
Artemisia sp.	0.03	0	0	0	0	0
Ixeris chinensis var. *graminifolia*	0.07	0	0	0.08	0.03	0
Euphorbia esula	0.01	0	0	0	0	0
Oxytropis psammocharis	0.01	0.01	0	0	0	0
Olgea leucophylla	0.01	0	0	0	0	0
Ferula bungeana	0.02	0	0	0	0	0
Phragmites communis	0	0	0	0	0.06	0
Chamaerhodes erecta	0.02	0	0	0	0	0
Euphorbia humifusa	0.02	0.01	0.03	0	0.03	0
Spiraea trilaba	0.01	0	0	0	0	0
Caryopteris mongolica	0.01	0.01	0	0	0	0
Orostachys fimbriatus	0.01	0	0	0	0	0
Prunus pedunculata	0.33	0	0	0	0	0
Moss (spp.)	4.73	1.25	0	9.15	0	0

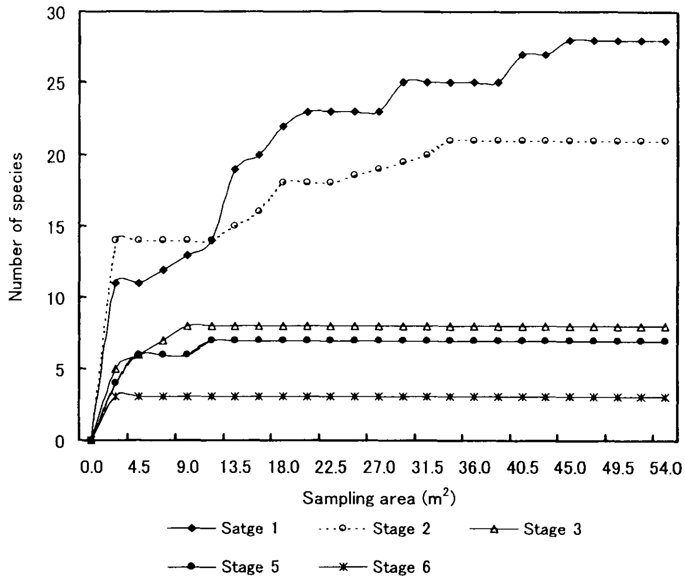

Fig. 2. Species area curves at different stages of desertification.

shows the species and area curves at different stages of desertification. Distribution of all of the 5 curves shows that the number of species first increases with the increase of sampling area and then keeps constant. The sampling area at which the number of species starts to keep constant is equal to the minimum area. Therefore, it was found that the minimum area for stages 1 to 6 (omitting stage 4) was 45, 29, 25, 9, and 2 m^2, respectively (Fig. 2). As desertification proceeded, the minimum area of each association obviously decreased. The minimum area in the region with no desertification (stage 1) was approximately 20 times as large as the minimum area in the region of shifting dunes (stage 6). Thus, the minimum area sensitively reflected the degree of desertification.

4) Variation in association coverage during desertification

Canopy coverage is one of the most important factors that can reflect the features of a plant community because the ground surface is seldom fully covered by the vegetation canopy in arid, semi-arid, and sub humid areas. The coverage can reflect not only the characteristics of the plant community, but also the characteristics of the environment. Therefore, coverage is closely related to desertification.

Figure 3 shows the variation in association coverage at different desertification stages. At stage 1, relative coverage was 25%. As desertification proceeded, coverage decreased to 19% at stage 2 and to 17% at stage 3. At stage 4, however, coverage increased to 32%, the maximum value in the reverse succession series. Afterwards, coverage decreased to 28% at stage 5 and finally to 9% at stage 6. The maximum canopy coverage occurred at stage 4, not at stage 1. These results show that the variation in relative

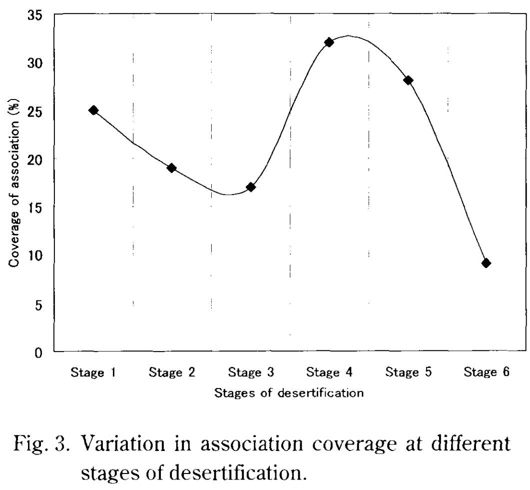

Fig. 3. Variation in association coverage at different stages of desertification.

canopy coverage during desertification was nonlinear.

The variation in coverage in the Shapotou area showed a similar pattern (Qiu and Shi, 1991). Shapotou is located at the southeastern edge of the Tengeri Desert, the fourth largest sand desert in China. Since 1956, a long-term study has been conducted to analyze the variation in plant diversity in the established vegetation and to see whether the planted communities could stably survive in Tengeri Desert. Results showed that at the early succession stage, the relative coverage of the plant canopy increased and gradually approached a maximum value (about 30%) after 7 years. Then the coverage gradually decreased to 15% to 20% (Qiu and Shi, 1991). Thus, the studies both in the Mu Us Desert and that in the Tengeri Desert showed a non-linear variation in relative coverage during desertification.

This nonlinear variation in coverage was related to the availability of soil water and the stability of the soil surface. At stages 1, 2, and 3, there was a layer of soil on the dune surface and the sand dune was stable, and the dominant species were *Sabina vulgaris* and *Artemisia ordosica*. The soil layer intercepted water from precipitation, and only small amount of the rainfall could infiltrate through it. The other part evaporated from the soil surface directly to the atmosphere. The water use efficiency from stages 1 to 3 was not very high. Consequently, canopy coverage was also not very high. At stage 4, the dominant species was *Artemisia ordosica*. At this stage, the sand surface was stable, but no soil layer was formed on the surface because of grazing or woodcutting. Therefore, water from precipitation could easily infiltrate to the plant root zone. The portion of rainfall lost during evaporation process decreased and that lost from transpiration increased. Because water use efficiency was high, relative canopy coverage was also high. At stages 5 and 6, although rainfall could easily infiltrate to the plant root zone, the movable soil surface limited plant growth. Therefore, relative coverage again became low.

5) The diversity and evenness at different desertification stages

Diversity is a parameter that reflects the richness of plant species in a given association, which is mainly affected by environmental parameters and the interaction of plant populations. Diversity index (D) can be expressed as

$$D = 1 \Big/ \sum_{i=1}^{s} p_i^2 \qquad (2)$$

where s is the number of species in the association and p_i (unit less) is the relative size of the population of species i. As mentioned in the Materials and Methods section, relative size of population is expressed as relative coverage.

Evenness (E) indicates the uniformity of plant species in a given association and is calculated by the following equation:

$$E = 1 \Big/ (s \cdot \sum_{i=1}^{s} p_i^2) \qquad (3)$$

The diversity and evenness of the associations at each of the desertification stages are shown in Table 3. Generally, diversity decreases as reverse succession proceeds. Our results agree with this observation. Compared with

Table 3. Diversity and evenness of associations at different desertification stages.

Stages of Desertification	Dominant Species	Number of Species	Total Coverage	Diversity (D)	Evenness (E)
Stage 1 (non Desertification)	*S. vulgaris*	30	25	1.20	0.40
Stage 2	*S. vulgaris* *A. ordosica*	25	19	1.25	0.56
Stage 3	*A. ordosica* *C. intermedia*	8	17	1.05	0.74
Stage 4	*A. ordosica*	7	32	1.01	0.52
Stage 5	*A. ordosica* *S. psammophila*	10	28	1.13	0.74
Stage 6 (Shifting dunes)	*A. sphaerocephala*	3	9	1.07	0.90

forest and rangeland vegetation, diversity in a desert is much smaller because the number of species is fewer and the difference in relative coverage between the dominant species and other species is very large. For example, there were 9 species in sampling area number 99. In this case, the relative coverage of the dominant species, *Sabina vulgaris*, was 80%, while the relative coverage of the other 8 species was only 4%.

Table 3 shows that evenness increased as desertification (reverse succession) proceeded. Evenness increased from 0.40 in the region of non desertification to 0.90 in the shifting dune region. Usually, evenness increases with succession of the plant community. It is not clear why evenness decreased with succession in the desert, but it may be related to the low coverage. During the six stages, non of the ground was fully covered, and competition between individual plants was relatively weak. However, because evenness increased with the degree of desertification, it can be used as an indicator of desertification.

4. Conclusion

The results of our field investigation and data analysis showed that as desertification proceeded, the plant association changed greatly. From the point of view of vegetation science, the following parameters changed significantly and can be used as indicators of desertification: type of association, minimum area, coverage, diversity, and evenness. Among these five parameters, data on minimum area, diversity, and evenness cannot be acquired by remote sensing technology. Coverage and type of association can potentially be detected by remote sensing. However, as discussed above, coverage did not vary linearly with desertification. In other words, the degree of desertification cannot be determined by coverage data alone. Therefore, coverage + type of association is a more satisfactory indicator of desertification.

Using Landsat data, Imagawa (1996) reported that it is possible to verify rangeland, farmland, forest, wetland, villages, and water bodies. More recently, researchers have tried to calculate the vegetation index using remotely sensed data. Furthermore, the estimation of vegetation coverage and vigor has been challenged (Oki, 2000, unpublished research report). These efforts show that, even though further improvement and field verification are required, estimation of vegetation coverage by remote sensing technology is possible. However, the estimation of association type using remotely sensed data is still an unsolved issue. As sensor resolution and data analysis technologies are improved, we expect a solution in the near future.

References

Imagawa, T. (1996): Desertification in eastern China viewed from space. *Soil Phys. Cond. Plant Growth, Japan*, **74**: 29-37.

Li, X.F. ed. (1983): *The Natural Conditions and its Improvement and Utilization in Mu Us Desert.* Science Press, Beijing.

Qiu, G.Y. and Shi, Q.H. (1991): Analysis of community composition in the succession of artificial vegetation in Shapotou area. *J. Arid Land Resources and Environment*, **5** (1): 22-32.

Zhu, Z.D. and Liu, S. (1984): The definition of desertification and the determination of desertification degree. *J. Desert Research*, **4** (3): 2-8.