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Restoration of Species Diversity in Semi-arid Sandy Land Degraded by Overgrazing and Cultivation

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Abstract: The major challenges in biodiversity conservation in arid and semi-arid lands lie not so much in the biology of the species concerned, but in the social, economic, and political arenas within which people operate. We assessed the natural restoration of species diversity in a semi-arid region by examining the species richness, species dominance, diversity index (α diversity and β diversity), ecological dominance, community evenness, life form composition and family composition between six communities protected from grazing for 3, 6, 10, 18, 30 and 45 years. Species diversity and species richness were maximum in community with the longest protection time. Perennials and Gramineae plants played a more important role in communities with longer protection years. The results showed that protection from anthropogenic disturbances such as overgrazing, cultivation, etc. is relatively easy, low-cost and practical way for biodiversity conservation in seriously desertified regions.

Key words: Protection from grazing, land desertification, biodiversity conservation, anthropogenic disturbances, China.

Biodiversity and sustainable use are the words associated with human beings and very much related to the welfare of mankind. Most aspects of living systems are based on the variability and complexity of organisms that constitute the biodiversity of a given geographical region and, thus, in the world as a whole (Al-Eisawi, 2003). The planet's genes, species, and ecosystems are the product of over 3000 million years of evolution, and are the basis for the survival for our species (Abuzinada, 2003). Biological diversity, is valuable because (i) future practical uses and values are unpredictable, (ii) variability is inherently interesting and more attractive, and (iii) our understanding of ecosystems is insufficient to be certain of the impact of removing any single component (Abuzinada, 2003).

However, it is now generally accepted that biodiversity has been subjected to unprecedented damage and destruction, and that the world's biodiversity is being eroded at a faster rate than at any previous time in the Earth's history (Al-Eisawi, 2003; Grainger, 2003). Though a global issue, the world's attention has usually been focused on the loss of biodiversity from species-rich, humid, tropical ecosystems (Myers, 1993). The loss of biodiversity from the world's arid and semi-arid zones has been less widely considered (Grainger, 2003). With their modest rainfall, arid and

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semi-arid regions are characterized by relatively fewer species than the regions that receive better rainfall (McNeely, 2003). This makes it all the more important that the biodiversity available in arid and semi-arid environments be given even higher priority for protection and conservation; for each species lost from an arid and semi-arid region, the percentage of loss for the region's biodiversity is much higher than in more species-rich regions (McNeely, 2003; Batanouny, 1994).

Land degradation and desertification are menaces in many parts of the world, especially in arid and semi-arid regions (Dregne, 2002), with serious consequences for the natural vegetation, plant biodiversity and sustainable use of the natural environment (Brown, 2003). The direct causes of land degradation in arid areas stem from a drastic reduction of the perennial plant cover and simplification of the vegetation structure, water relations and microclimate (Le Houèrou, 1996). The indirect causes of land degradation are the same throughout the world, namely, ever-increasing pressure on the land from an expanding human and livestock population (Le Houèrou, 1996). Particularly in poorer regions, the collection of wood for fuel and construction purposes can have a significant impact on the vegetation (Warren *et al.*, 1996).

Horqin Sandy Land, characterized by wide spread sand dunes, once the most representative and typical steppe zone in north China, was still good pasture of royal in Qing Dynasty of China (1616-1884) (Liu *et al.*, 1996). Arid and windy climate, as well as loose sandy soil makes the eco-environment very fragile in Horqin Sandy Land (Zhao *et al.*, 1998). If soil cover is not adequate, loose sandy soil is easily eroded by frequently occurring strong winds. Because of rapid growth of population, leading to in overgrazing and cultivation, desertification has spread drastically in this region. Today, this region is a typical agro-pastoral transitional area, with pastoralism still accounting for certain part of local economy. Severe desertification has not only made this region prone to dust storms that so frequently occur in north China (Chen, 2002), but also led to land productivity destruction and biodiversity loss. Earliest endeavors of local governments to restore vegetation by providing protection from grazing were undertaken during 1950's. Those have been further strengthened in recent years, because the frequently occurring dust storms in north China have greatly influenced the environment of Beijing, the capital of China (Chen, 2002). The objectives of this study were mainly to assess recovery of species diversity during protection from grazing in a semi-arid sandy region, and to provide some strategies for biodiversity conservation and vegetation restoration.

Materials and Methods

Study area

This study was conducted at the Naiman Desertification Research Station, Chinese Academy of Sciences. The area lies at 42°54′ N and 120°41′E with an elevation of 300 m, and belongs to Naiman Banner of Inner Mongolia Autonomous Region, China. The study area is located at the central-southern part of a region called Horqin Sandy Land, which is characterized by extensively distributed sandy soil in north-eastern China.

This is a typical semi-arid and agro-pastoral transition zone, with mean annual precipitation of 366 mm, falling predominantly between June and August. Average temperature is 23.7ºC in July and in January it is -12.7ºC. Average annual wind speed is 3.5 m s^{-1}, with most windy days and wind storms occurring between March and May. Wind speed exceeds 5 m s^{-1} on more than 200 days in a year, causing soil erosion. Because of irrational cultivation and over-grazing, as well as windy climate and loose sandy soil, land desertification in this region has spread rapidly. Topography is characterized by mobile sand dune, semi-fixed sand dune, stabilized sand dune and lowland meadow (Zhao *et al*., 2000). The predominant plants are grasses and forbs such as *Cleistogenes squarrosa* (Trin.) Keng, *Setaria viridis* (L.) Beauv., *Salsola collina* Pall., *Corispermum elongatum* (Bge. ex Maxim.), *Bassya dasyphylla* (Fisch. et Mey.), *Artemisia halondendron* (Turcz. ex Bess) and *Chenopodium glaucum* L.

Site description

Six sites selected for the study had been protected from grazing for vegetation restoration for 3, 6, 10, 18, 30 and 45 years. These sites had similar topography and soil type, and had not been grazed. At the start of study these sites had mobile sand dunes with a gentle slope. The areas of these sites ranged from 10.2 ha to 21.6 ha, and distances between these sites ranged from 0.5 km to 7.2 km. By comparing these sites, we could make some conclusions on ecological processes of biodiversity recovery and vegetation rehabilitation by providing protection from grazing.

Sampling and data collection

In each of the 6 sites, 60 quadrates of 1 m^2 were investigated. Abundance, height and cover of every species in each quadrate was monitored. Biomass would have been suitable and ideal variable for community research, however, because of the biomass harvesting and considerations that, in this arid windy and sandy region, every piece of unvegetated land is prone to erosion, biomass was not disturbed and measured.

Calculation and measurement of species diversity index

Dominance and importance value of each species was calculated as:

$$IV = RA + RH + RC$$

where, IV is the importance value, RA the relative abundance, RH the relative height and RC the relative cover of species. RA, RH, and RC were all represented as per cent values.

Species dominance was calculated as:

$$DV = IV/3.$$

Species diversity was measured by three α-diversity indices such as the Shannon-Wiener index (SW), ecological dominance index (SN, the Simpson index) and evenness index (PW, the Peng-Wang index) (Peng, 1983), and by β-diversity index which is calculated as Sørensen index:

$$C = \sum Z_j/(aN+bN)$$

where Z_j is the sum of importance value of species j which is common in plot A and B, aN and bN are sum of importance values of all species in plot A and B, respectively.

Table 1. Species composition and species dominance (%) in communities protected from grazing

Species	Period of protection (years)					
	3	6	10	18	30	45
Agriophyllum squarrosum	68.08	28.02	0.69	0	0	0
Setaria viridis	16.91	30.81	12.92	3.72	10.50	8.24
Bassia dasyphylla	9.06	18.31	32.91	4.83	6.26	0.96
Salsola collina	3.39	5.55	16.42	4.09	21.01	6.39
Corispermum elongatum	0.19	1.23	4.45	3.19	4.83	2.98
Cynanchum thesioides	1.43	0	5.07	1.39	3.41	0.15
Artemisia halodendron	0.94	3.76	7.54	73.60	13.41	0
Digitaria ciliaris	0	2.42	4.12	0.49	0.61	0.49
Ixeris chinensis	0	3.42	2.69	1.44	2.65	0
Eragrostis pilosa	0	0	0.39	0.26	3.41	10.42
Aristida adscensionis	0	0	1.13	0.98	11.74	9.68
Chloris virgata	0	0	0	0	0.71	12.96
Cenchrus calyculatus	0	0	2.11	0	0	0
Lespedeza davurica	0	0.80	2.17	1.94	0.78	2.90
Melissitus ruthenicus	0	0	1.68	0	2.64	0.43
Messerschmidia rosmarinifolia	0	4.08	1.83	0	0	0
Euphorbia humifusa	0	0	1.89	0.46	6.47	0.22
Pennisetum centrasiaticum	0	0	0	0.40	1.29	1.26
Leymus secalinus	0	0	0	3.20	0.42	0.04
Euphorbia esula	0	0	0	0	0.23	0.11
Artemisia frigida	0	0	0	0	1.96	1.64
Gueldenstaedtia stenophylla	0	0	0	0	0.07	0
Phragmites australis	0	0	0	0	0.92	0.46
Thalictrum squarrosum	0	0	0	0	0.59	0.36
Kummerowia striata	0	0	0	0	0	0.06
Allium senescens	0	0	0	0	0.25	0.9.
Carex durinscula	0	0	0	0	0	0.26
Lappula myosotis	0	0	0	00	0	0.64
Olgaea leucophylla	0	0	0	0	0.05	0.02
Cthinops gmelini	0	0	0	0	0	0.02
Saposhnikovia divaricata	0	0	0	0	0.14	0.66
Potentilla bifurca	0	0	0	0	0	0.75
Tribulus terrestris	0	1.67	0	0	0.06	3.99
Chenopodium glaucum	0	0	0	0	0.69	6.85
Artemisia scoparia	0	0	1.97	0	0.88	2.85
Cleistogenes squarrosa	0	0	0	0	4.03	24.03
Total of species	7	11	17	14	28	30

Results

Species composition and species dominance

Table 1 shows species composition of communities during different protection periods. Minimum number of species was 7 in the late established community on mobile sand dune. Maximum of 30 species were recorded at site with longest protection of 45 years.

A common characteristic was shared by all communities in species dominance. A prominent dominant species accounted for most part of the community function in each of the communities protected from grazing for different durations.

In the late established community (3 year) on mobile sand dune, *Agriophyllum squarrosum,* as a pioneer plant, was the species at absolute prevalence accounting for nearly 70% of the total dominance. In contrast, its dominance shrinked dramatically to about 28% and again to 0.69% in 6 year and 10 year communities. *Setaria viridis* and *Agriophyllum squarrosum* were the co-dominants with about 30% and 28% dominance, respectively, in 6 year community.

Bassia dasyphylla was the dominant in 10 year community with about 33% dominance, *Artemisia halodendron* in 18 year community with 73% dominance, the highest in all communities, *Salsola collina* in 30 year community with 21% dominance, the lowest in the whole sequence, and *Cleistogenes squarrosa* in 45 year community with 24% dominance, respectively.

Table 2. Species diversity in the communities protected from grazing (mean±S.E)

Community number	Protection time (year)	Species richness (species m^{-2})		α-diversity (species m^{-2})		Ecological dominance	Community evenness
		Quadrate scale	Community scale	Quadrate scale	Community scale		
6	45	12.24±0.31	30	1.47±0.08	2.5265	0.1046	0.7439
5	30	8.02±0.26	28	1.43±0.06	2.5951	0.0947	0.7800
4	18	5.44±0.58	14	0.94±0.16	1.1761	0.5456	0.4459
3	10	5.86±0.35	17	1.36±0.08	2.1572	0.1691	0.7609
2	6	5.00±0.30	11	0.94±0.08	1.8092	0.2074	0.7546
1	3	2.93±0.32	7	0.47±0.10	1.0112	0.4966	0.5198

Species diversity index

Species richness increased significantly both at quadrate scale and site scale with increasing duration of protection from grazing (Table 2). Shannon-Wiener index (SW) was higher in communities with longer protection time than in communities with shorter protection time. With increasing duration from grazing this ecological dominance decreased protection and community evenness increased suggesting that community spatial structure was improved in community with a longer protection period.

Table 3. The similarity between communities protected from grazing for different years

Number of community	1	2	3	4	5	6
1	1	0.9313	0.9000	0.6092	0.4567	0.1549
2		1	0.9204	0.7977	0.6400	0.4257
3			1	0.9405	0.08981	0.6742
4				1	0.9204	0.3434
5					1	0.9107
6						1

Sørensen index was higher between communities with a smaller difference in duration of protection from grazing indicating that communities were similar in species composition along with increasing protection time.

Life-form composition

Plants were grouped according to two life forms: therophytes (annuals and biennials, because biennials were much fewer, and were grouped with annuals as therophytes) and perennials. The number of therophyte and perennial species increased with increasing duration of protection (Table 4). Dominance of therophytes decreased slowly, while that of perennials increased with increasing period of protection. Dominance of perennials obviously surpassed that of therophytes in 18-year community, which should be attributed to the profuse growth of *Artemisia halodendron*. *A. halodendron*, a native semi-shrubby perennial plant species of this region with strong sand-stabilizing ability, was of great importance in natural restoration of vegetation. Because of the exclusive dominance of *A. halodendron*, resulting in competitive exclusion, species richness and species diversity was lower in 18-year community than that of 10-year community.

Plant family composition

Number of plant families was progressively increasing (Table 5), and the most important four families were

Table 4. Plant life-form composition in communities protected from grazing (Life-form composition)

Protection time (year)	Total species	Therophytes			Perennials		
		Species No.	Per cent	Dominance (%)	Species No.	Per cent	Dominance (%)
3	7	6	85.71	99.06±2.9	1	14.29	0.94±2.9
6	11	8	72.73	95.44±16.1	3	27.27	4.56±16.1
10	17	13	76.47	85.92±13.07	4	23.53	14.09±13.07
18	14	9	64.29	19.43±25.87	5	35.71	80.57±25.87
30	28	18	64.29	19.43±25.87	5	35.71	80.57±25.87
45	28	21	70.00	68.09±16.82	9	30.00	31.91±16.10

Table 5. Plants family composition in communities protected from grazing

Protection time (year)	Total species	Family number	Chenopodiaceae		Compositae		Gramineae		Leguminosae	
			Nos.	Ds (%)	Nos.	Ds (%)	Nos.	Ds (%)	Nos.	Ds (%)
3	7	4	4	80.71± 16.4	1	0.94± 2.9	1	16.91± 14.60	–	–
6	11	6	4	53.12± 16.6	2	7.09± 13.4	2	33.24± 16.20	1	0.80± 2.29
10	17	7	4	54.47± 7.95	3	9.51± 11.03	5	20.29± 9.1	2	3.85± 5.77
18	14	6	3	12.12± 5.15	2	75.04± 75.67	5	8.56± 7.88	1	1.94± 3.21
30	28	10	4	32.79± 15.22	4	18.90± 16.17	8	33.02± 20.71	3	3.48± 8.25
45	30	12	4	17.19± 8.78	3	4.50± 6.12	9	66.38± 12.71	2	3.37± 4.04

Nos. Number of species, Ds: dominance of species of the family.

Chenopodiaceae, Compositae, Gramineae and Leguminoseae. Number of Chenopodiaceae species was stable among communities, while those of Compositae and Leguminosae fluctuated slightly, and those of Gramineae revealed steadily increasing trend. Both species number and species dominance of Chenopodiaceae were at a prevalence in community with shorter protection time (3-year community and 10-year community), and that of Gramineae had an increasing trend. Thus plants of Gramineae accounted for most part of the community function in 45-year community with longest protection time. Dominance of Compositae reached a very predominant position in 18-year community.

Discussion

We see from above that a different species was the dominant which accounted for most part of the community, in each of the 6 communities studied. There is a general trend in vegetation development in this region. *Agriophyllum squarrosum* always monopolizes on mobile sand dune, while *Artemisia halodendron* is dominant on semi-fixed sand dune, and *Cleistogenes squarrosa* predominates on stabilized sand dune (Li *et al.*, 1997). Patterns observed in our study are consistent with this general trend. The underlying reason is that ecological traits of dominant species fit to certain community habitat, and this makes the species competitive with a higher fitness in that habitat. Our results showed that, various species with diverse traits make it possible that one or another of these species may be well adapted to specific habitat and be the dominant in that habitat, making considerable contribution to community function and vegetation restoration. This is one of the many treasurable values of biodiversity. Biodiversity provides some indigenous genetic resources to control desertification. These genetical resources are necessary to support the sustainable use of natural resources and are of importance for sustaining the dry ecosystem. Sufficient biodiversity and genetical resources exist to support natural vegetation, to ensure the control of degradation and desertification and fix sands if used sustainably.

Vegetation is the shelter and medium for biodiversity. Vegetation destruction resulting from overgrazing and cultivation, etc., is among the most drastic menaces causing loss of biodiversity. So, vegetation restoration is one of the most effective ways for biodiversity conservation. From our research results we see that, by providing protection from grazing, species richness and species diversity increased significantly. Methods of conservation have been listed by many researchers (IUCN, 1986; Groombrige, 1992). Such conservation methods are general and do not deal with specific regions or specific issues. In this semi-arid sandy region we observed, protection from grazing is beneficial for biodiversity conservation, as well as for vegetation restoration. It should be stressed that it may not be possible to re-establish the natural vegetation entirely, especially in the short term. However, it is still the most fruitful and practical way for biodiversity conservation and vegetation restoration.

The major challenges in biodiversity conservation in arid and semi-arid lands lie not so much in the biology of the species concerned, but rather in the social, economic, and political arenas within which people operate (McNeely, 2003). We need to build a broader constituency for conserving biodiversity, extend the responsibility for conserving biodiversity far beyond government agencies, bring local people into the conservation movement, ensure that sufficient information is available to those who need it, restore degraded ecosystems, and motivate far greater public support for biodiversity. A balance must be sought between the interests of landscape conservation and sustainable livestock or/and agricultural economy. It is possible to develop grazing and/or agricultural programs that enhance the productivity of agricultural produce from the region.

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