沙漠研究 11-1, 63-70 (2001)
Journal of Arid Land Studies

— Original Article —

Study on the Changes of Plant Diversity in the Established Communities for Rehabilitation of Desertified Land

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In arid and semi-arid regions, the best and inexpensive way to combat desertification is to establish vegetation without irrigation. After the establishment, the planted communities themselves will survive and further set up (succession). This process can be regarded as an opposite process of desertification. The objectives of this study are to investigate the change of plant diversity after the establishment of plant community and to analyze their relationships with some environmental parameters. The experiment was conducted in Tengeri Desert, the fourth largest sand desert in China. Vegetation has been continuously established in this area since 1956. A long-term research project has been conducted to analyze the variation of plant diversity in the established vegetation since 1982. Permanent sampling areas were set and vegetation related variables, soil water content, and meteorological parameters were continuously measured by using standard methods. Results showed that: (1) After more than 40 year's succession, the established shrub vegetation had evolved into shrub + herb + sporophyte community. Number of plant species increased from 3 to 6. These changes were determined by available water in the soil; (2) After the establishment, the coverage of plant canopy increased and gradually approached to the maximum value (about 30%) at the age of 7. Then the coverage decreased gradually. Finally, the coverage was stably around 15-20%; (3) Diversity index (Shannon-Wiener) increased from 0.3 to 0.7 and then decreased to 0.5, which was similar to the diversity index of natural vegetation in the same area. Meanwhile, dominant index decreased from 0.6 to 0.4 and then increased to 0.7. These results can provide knowledge not only for understanding the succession mechanism of established community in desertified area, but also for the rehabilitation of desertified land.

Key Words: Canopy coverage, Desertification, Established community, Plant diversity, Tengeri Desert

1. Introduction

Tengeri Desert is the fourth largest sand desert in China and occupies an area of 36,700 km^2. The encroachment of dunes causes problems for the oasis and railway on the fringe of the desert. Since 1956, extensive measures to combat desertification have been conducted and establishment of vegetation without irrigation is the best way to combat desertification (Qiu *et al.*, 1995). We call these vegetation as "established community" to distinguish from natural community. The established communities have not only protected the railway and oasis well for more than 40 years but also improved the environment greatly. However, during the same period, the established communities themselves have survived and further established, which causes the variation of plant diversity. The effects of established vegetation on environment and desertification have been widely reported (Qiu, 1988, 1991; Qiu and Shi, 1993; Qiu *et al.*, 1995). Researches on the changes of plant diversity in the established community are very few.

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(Received, October 11, 2000; Accepted, February 21, 2001)

In shifting sand dune area, due to low precipitation and movable ground surface, biodiversity is low. Only a few pioneer species of plant, animal, and insect can survive under this severe condition. The establishment of plant community in shifting dune area can improve not only the environment, but also the biodiversity of ecosystem. The objectives of this study are to investigate the changes of plant diversity after the establishment of plant community and to analyze their relationships with soil water status and other environmental parameters.

2. Material and Methods

1) Characteristics of site and weather

The experimental field is located in Shapotou area (37° 32′ N, 105°E), northeastern edges of Tengeri Desert, which is the fourth largest sand desert in China and occupies an area of 36,700 km^2. A standard meteorological station was set in this area and weather related parameters were measured by standard methods. More than 30 years (1956-1991) observation shows that the annual mean air temperature is 9.8℃. The mean air temperature in January and July are -6.9℃ and 24.3℃, respectively. Annual average precipitation is less than 200 mm and 80 % of them fall from May to September. Shifting sand dunes with sparse vegetation (2 or 3 species) is the natural landscape. Ground water table is deeper than 80 m.

2) Experimental field

Since 1950s, measures for desertification control have been taken in extensive area and these schemes have proved successful. Among the successful measures, the best and inexpensive way was to establish plant community without irrigation. To meet this requirement, plant community under non-irrigation condition (Non irrigation at the moment of transplant and later) had been established since 1956 in Shapotou area. After shifting dune being fixed by the established community, the communities themselves have survived and further established. Several herb species can naturally grow in the established community. Through more than 40 years efforts, established communities with different ages have been set up in a huge area (approximately 200 ha).

We emphasize here that there are 3 common features for the planted communities series. First, all of the planted communities have been established on the same type of shifting sand dune. The dunes in this area are approximately 30 m in height with sparse vegetation. There are 3 plant species in the shifting dune area: *Artemisia sphaerocephala* (semi-shrub), *Agriophyllum squarrosum* (herb), and *Hedysarum scoparium* (shrub). All of them were destroyed when planted community was established. Therefore, established community was started from a field without natural vegetation.

Secondly, the plant species used to establish the planted communities are the same. The 3 plant species used are *Artemisia ordosica, Hedysarum scoparium*, and *Caragana korshinskii*. All of them are native species. The first species is semi-shrub. The other two are shrubs. Besides, the arrangements of these species in the established community are also the same. The arrangement of these three species is: one belt of *Artemisia ordosica*; one belt of *Hedysarum scoparium*; again one belt of *Artemisia ordosica*; one belt of *Caragana korshinskii*. The distance between belts is 2 m. Every belt is composed of two line, the distance between the line is 1 m and between the individual is also 1 m.

Thirdly, the procedures for establishing the community are the same. The moving dune is firstly fixed by straw checkerboard technique and then the three species are transplanted. By these efforts, it is guaranteed that, except the ages, the other conditions for the planted communities series are comparable with each other.

3) Soil water content

Soil water content was measured in the area of different aged community continuously since 1982. Gravimetric method was adopted to record the water content in 0-3 m sand layer at every 10 cm depth. The soil samples were taken every 10 days from April to November and every 15 days from December to March.

4) Vegetation Investigation

Permanent sampling areas were set in different aged communities. Since 1982, vegetation investigation has been conducted continuously every year. Besides, an extensive experiment was conducted in the areas of shifting dune, 2, 7, 25, and 33 years old communities and in a natural *Artemisia ordosica* community in 1989. The natural *Artemisia ordosica* community was located in the

nearby area. Totally 609 sampling areas were investigated. The size of quadrate in 87 sample areas was 10 m × 10 m and that of 522 sample areas was 1 m × 1 m. Species composition, size of plant canopy, age structure of population, and growing status were investigated in all of the sample areas. Measured data in the different sized quadrates were calculated into relative values according to the land surface area. For example, canopy coverage was calculated based on the size of plant canopy and land surface area. Therefore, its unit was percentage. The species composition and their coverage were shown in Table 1. It had to be noticed that it was difficult to distinguish the changes of artificial introduced plant species and naturally invaded species because the introduced species could naturally propagate by themselves. Therefore, the data shown in Table 1 were the mixed results of artificial introduced individuals and naturally propagate individuals.

3. Results and Discussion

1) Changes of species component

Three woody plant species were introduced to establish the vegetation. Therefore, in the 2 years old community, there were only 3 plant species. In the 7 years old community, several annual herbs naturally got into the community, such as *Agriophyllum squarrosum*, *Eragrostis poaoides*, *Bassia dasyphylla*, *Corispermum* spp., and *Salsola ruthenica*. *Eragrostis poaoides* is a species that widely distributed in the farmland of temperate zone. Its appearance in sand dune area showed that the dune surface was stable (Liu *et al.*, 1985). At this stage, the number of plant species increased to 9. Meanwhile, a layer of soil crust was formed on the dune surface, which stabilized the dunes and accelerated the changes of plant diversity more. Afterwards, the number of plant species varied between 6 and 7. Sporophyte species, such as *Barbula ditrichoides*, *Bryum argenteum*, and *Microcoleus vaginatus*, began to grow in the area of established community.

As shown in Material and Methods section, the differences of meteorological condition in the areas of different aged community were negligible. The reason that caused these changes was probably due to the changes of water status in the soil layer. The depth of soil crust increased with the age of community. The average depth of soil crust was 7.6 mm, 6.0 mm, and 2.3 mm for 33, 25, and 7 years old communities, respectively. Soil crust can not only increase the stability of dune surface but also intercept rainfall water, which prevents the infiltration of rainfall to the deeper soil layer. Figure 1 shows the relationship between the infiltration depth of rainfall water and the ages of established community. The infiltration

Table 1 Main plant species and their canopy coverage (%) in the shifting sand dune area, in the areas of different aged established communities (EC), and in the area of natural *Artemisia ordosica*.

Plant Species	Shifting dune	2 years old EC	7 years old EC	25 years old EC	33 years old EC	Natural *Artemisia ordosica*
Artemisia sphaerocephala	0.22		0.99			
Agriophyllum squarrosum	0.26		0.01			
Hedysarum scoparium	3.53	1.80	2.94	2.84	3.03	
Artemisia ordosica		2.80	12.40	7.50	13.36	21.14
Caragana korshinskii		0.20	5.67	2.48	0.09	6.66
Eragrostis poaeoides			1.17	1.42	1.06	
Bassia dasyphylla			1.34	0.68	1.03	0.55
Corispermum spp.			0.05	0.13	0.02	0.67
Salsola ruthenica			5.52	0.01		12.22
Oxytropis aciphylla						0.16
Penisetum centrasiaticum						0.20
Total coverage (%)	4.01	4.80	30.09	15.06	18.59	41.60
Coverage of shrub (%)	3.75	4.80	22.00	12.82	16.48	27.96
Coverage of herb (%)	0.26	0	8.09	2.24	2.11	13.64

depth decreased linearly with the age of community. Therefore, in the old established community transpiration caused decrease of water storage could not be recovered. As reported by Qiu *et al.* (1995), in shifting dune area, the amount of water storage was 150 mm in 0-3 m soil layer and 50 mm in 0-1 m soil layer. The amount of water storage was 100 mm, 80 mm, 60 mm, and 60 mm for 2, 7, 25, and 33 years old communities, respectively. The amount of water storage in 0-1 m soil layer was 30 mm, 25 mm, 20 mm, and 20 mm for 2, 7, 25, and 33 years old communities, respectively. The amount of water storage decreased with the age of community.

In the area of natural *Artemisia ordosica* community, due to grazing and other human activities, soil crust was damaged and rainfall water could infiltrate to the deep layer. Therefore, water status was better than established area. Table 2 shows a comparison of soil water content between natural *Artemisia ordosica* community and 23 years old established community. Generally, soil water content in the established area was lower than that of natural vegetation area. Sometimes, water content in established area could be lower than wilting point (0.7%). Consequently, the growth of those woody species with a deeper root system (*Hedysarum scoparium* and *Caragana korshinskii*) was limited. The concentrating of rainfall water to the soil surface layer provided a better environment for the growth of those species with shallow root system (*Artemisia ordosica*, annual herb and sporophyte).

2) Canopy coverage

Canopy coverage is one of the most important factors that can reflect the feature of plant community in arid, semi-arid area. This is because the ground surface is seldom fully covered by vegetation canopy. The coverage is not only a parameter that can reflect the characteristics of plant community, but also a parameter that can reflect the characteristics of environment (Qiu *et al.*, in printing). According to the canopy coverage of vegetation, sand dunes were divided into shifting dune, semi-shifting dune, and fixed dune (Zhu *et al.*, 1974). Canopy coverage was also applied as an indicator of desertification (Zhu and Liu, 1984; Qiu *et al.*, in printing).

Figure 2 shows the variation of canopy coverage with the age of established community. In 2 years old communities, the coverage was around 5%. Subsequently, the coverage increased and approached to the maximum value (about 30%) at the age of 7. Then the coverage decreased gradually. Finally, the coverage was stably around 15-20%. The coverage of shrub and herb showed a similar variation trend. These results showed that the coverage

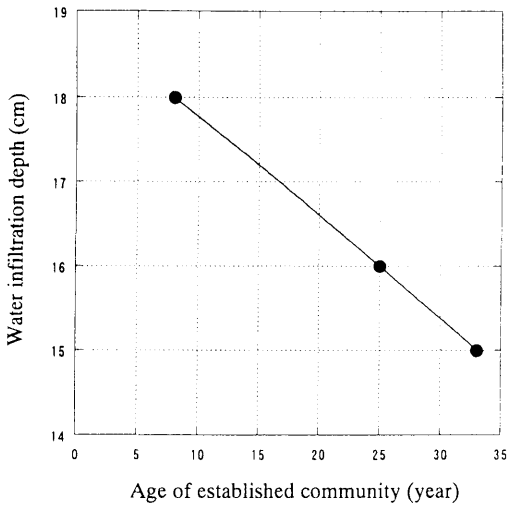

Fig. 1. Relationship between the age of established community and the rainfall water infiltration depth.
Measured on April 19, 1989; precipitation: 11.7 mm.
Measurement was repeated 10 times in every area.

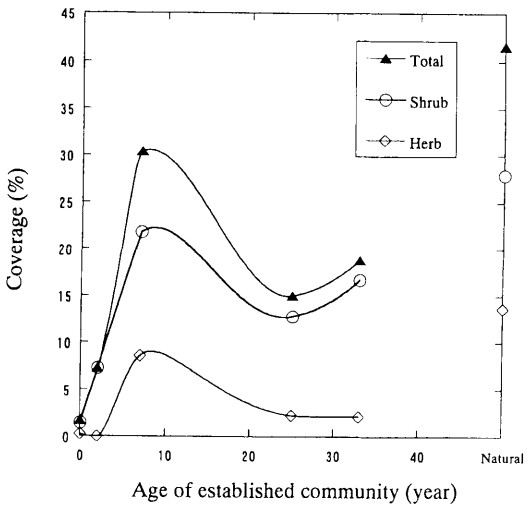

Fig. 2. Variation of coverage with the age of established community.
The numbers on X-axis is the age and the word "natural" means the natural *Artemisia ordosica* community.

Table 2 Monthly variation of the water content (%) in 0-3 m soil layer in natural *Artemisia ordosica* community and 23 years old established community (Measured in 1987).
Soil water content during April to November was the average value of every 10 days measurement. While soil water content during January to March and December was the average value of every 15 days measurement. Measurements was made at every 10 cm depth and their average values for every 20 cm depth were shown in this table.

Depth (cm)	23 years old established community											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 – 10	1.44	1.21	0.64	0.30	0.29	2.72	0.28	0.28	2.00	1.89	0.68	0.59
10 – 20	1.00	0.83	0.72	0.42	0.32	1.94	0.46	0.30	1.94	0.87	1.83	0.83
20 – 40	0.96	0.89	0.83	0.60	0.77	0.45	0.94	0.54	0.57	0.60	1.19	2.05
40 – 60	1.11	0.75	0.89	0.69	0.92	0.63	1.29	0.79	0.47	0.54	0.77	1.36
60 – 80	1.26	1.25	1.07	0.94	0.71	0.46	1.28	0.62	0.61	0.67	0.86	1.53
80 – 100	1.42	1.26	1.16	0.97	0.70	0.82	0.77	0.58	0.73	0.89	1.05	1.21
100 – 120	1.81	1.24	1.37	0.95	0.95	0.60	0.68	0.59	0.74	0.94	0.68	1.06
120 – 140	1.23	1.11	1.25	0.66	0.78	0.93	0.63	0.70	0.72	0.87	0.57	1.13
140 – 160	1.82	1.23	1.18	0.75	0.68	0.71	0.84	0.93	0.77	0.81	0.69	0.95
160 – 180	1.74	1.45	1.64	0.74	0.74	0.96	0.90	0.95	0.82	0.71	0.80	0.98
180 – 200	1.57	1.76	1.43	0.65	0.66	1.06	1.00	0.78	0.79	0.79	0.81	1.01
200 – 220	1.34	1.40	1.27	0.79	0.87	0.95	1.07	0.75	0.93	0.86	0.82	0.98
220 – 240	1.23	1.35	1.57	1.05	1.03	0.90	0.89	0.96	1.00	1.08	0.77	0.86
240 – 260	1.23	1.08	1.50	1.97	1.07	1.31	0.91	0.96	1.03	1.33	1.10	1.17
260 – 280	1.36	1.18	1.35	1.16	1.03	0.87	0.94	1.09	1.12	1.38	1.23	1.25
280 – 300	1.47	1.10	1.18	1.29	1.19	0.98	1.02	1.12	0.97	1.47	1.09	1.58
Average	1.37	1.19	1.19	0.81	0.79	1.02	0.87	0.75	0.95	0.98	0.93	1.16
Total average	1.00											
Depth (cm)	Natural *Artemisia ordosica*											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 – 10	0.75	0.60	0.64	0.36	0.43	0.50	1.68	2.95	6.89	1.53	1.08	0.85
10 – 20	0.76	0.41	0.82	0.52	0.14	0.55	2.47	0.65	5.29	1.98	1.67	0.85
20 – 40	1.03	1.14	0.94	0.54	0.42	0.85	1.66	0.87	0.85	1.05	1.02	1.10
40 – 60	1.38	1.65	1.34	0.90	0.54	1.10	1.20	0.63	1.19	1.23	1.15	1.03
60 – 80	1.27	1.69	0.95	098	0.91	0.97	1.39	1.17	1.45	1.20	1.31	1.18
80 – 100	1.05	1.51	1.18	1.20	0.74	1.28	1.10	1.39	1.33	1.49	1.31	1.57
100 – 120	1.44	1.65	1.06	0.89	0.75	1.10	1.25	1.14	1.22	1.29	1.48	1.45
120 – 140	1.40	1.09	1.35	0.88	1.11	1.33	1.52	1.13	1.23	1.07	1.14	1.67
140 – 160	0.95	1.18	1.30	1.11	1.19	1.76	1.58	1.60	2.33	1.65	1.39	2.25
160 – 180	1.30	1.20	1.11	1.07	0.76	1.33	2.03	1.53	1.43	1.29	1.01	1.45
180 – 200	1.18	1.21	1.19	1.05	1.04	1.03	0.80	0.87	1.28	1.46	1.01	1.33
200 – 220	2.82	2.63	1.56	1.04	2.10	1.40	1.22	1.32	1.38	1.07	1.12	2.47
220 – 240	3.39	4.58	2.79	2.77	3.32	2.60	2.91	2.96	2.74	0.97	2.58	2.62
240 – 260	3.08	2.70	2.82	3.63	2.49	5.57	4.45	3.57	3.31	2.74	3.13	3.03
260 – 280	4.59	3.76	3.20	2.89	3.47	3.82	3.36	3.07	3.50	3.27	3.47	3.80
280 – 300	6.04	5.64	5.10	3.60	2.94	3.45	3.24	3.23	3.80	3.88	3.04	4.16
Average	2.03	2.04	1.71	1.46	1.40	1.79	1.99	1.76	2.45	1.70	1.73	1.93
Total average	1.83											

was not linearly changed with the age of estab-lished community.

The reason that had caused the non-linear variation of coverage was related to the availability of soil water and the stability of soil surface. In shifting dune area and young (2 year old) communities, though rainfall could easily infiltrate to plant root zone, the movable soil surface limited the growth of plant. As a result, canopy coverage was relative low. In 7 years old community, despite the stable dune and a thin soil crust layer, water from precipitation can easily infiltrate to plant root zone. Plant grew well in this stage. In the 25 and 33 years old communities, soil crust intercepted water from precipitation and only part of the rainfall could infiltrate through the soil layer. Other part was evaporated from soil surface directly to ambient atmosphere. Subsequently, canopy coverage was low.

The process of establishment of vegetation is actually a converse process of desertification. Based on the data of field investigation, Qiu *et al.* (in printing) showed coverage was not linearly related with the progress of desertification in Mu Us Desert area. This result was again confirmed in this study.

3) Indices of diversity and dominance

Diversity is a parameter that indicates the richness of plant species in given vegetation, which is mainly affected by the environmental parameters and the interaction of plant population. Simpson's index and Shannon-Wiener's index are widely applied as diversity index (Thomas, 1981). Simpson's diversity index can be expressed as:

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

where D is the diversity index, s is the number of species in vegetation, and p_i is the relative size of species i (p_i is expressed by relative coverage in this study, Table 3). One feature of Simpson's diversity index is that it gives a relative small weight to the species with a small p_i. However, in arid and semi arid regions, only a few dominant species have a large p_i and most of the other species have a relatively small p_i (Table 3). Simpson's diversity index loses information under these conditions. Therefore, Shannon-Wiener's diversity index is applied in this study, which can be expressed as:

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

There are several ways to express the dominant index. Berger and Barker (Robert, 1979) suggested a simple dominant index as:

$$d = N_{\max}/N_T \qquad (3)$$

where d is the dominant index, $N_{\max}$ is the individual numbers of the maximum population and N_T is the total individual number in the vegetation. Under the conditions of arid and semi-arid environments, we used coverage to

Table 3 Relative coverage (%) in the shifting sand dune area, in the areas of different aged established communities (EC), and in the area of natural *Artemisia ordosica*.

Plant Species	Shifting dune	2 years old EC	7 years old EC	25 years old EC	33 years old EC	Natural *Artemisia ordosica*
Artemisia sphaerocephala	5.49		3.29			
Agriophyllum squarrosum	6.48		0.03			
Hedysarum scoparium	88.03	37.50	9.77	18.86	16.30	
Artemisia ordosica		58.33	41.21	49.80	71.87	50.82
Caragana korshinskii		4.17	18.84	16.47	0.48	16.01
Eragrostis poaeoides			3.89	9.43	5.70	
Bassia dasyphylla			4.45	4.52	5.54	1.32
Corispermum spp.			0.17	0.86	0.11	1.61
Salsola ruthenica			18.34	0.07		29.38
Oxytropis aciphylla						0.38
Penisetum centrasiaticum						0.48

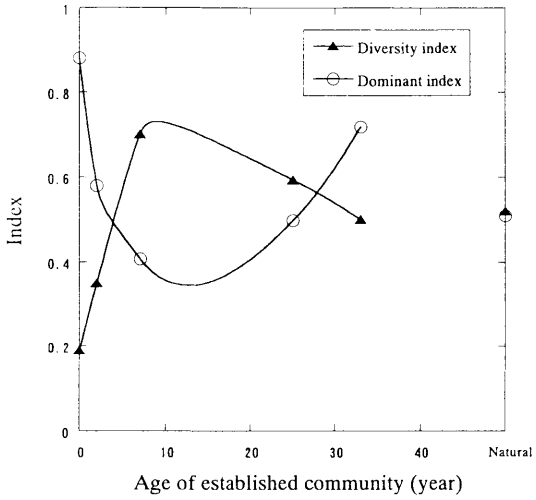

Fig. 3. Variation of plant diversity index and dominant index with the age of established community. The numbers on X-axis are the age and the word "natural" means the natural *Artemisia ordosica* community.

replace the individual number. Hence, Eq. (3) can be expressed as:

$$d = C_{max}/C_T \quad (4)$$

where C_{max} is the coverage of the maximum population and C_T is the total coverage of the vegetation.

Figure 3 shows the variation of diversity index and dominant index in the established communities. In the 2 years old community, D was 0.35. As the increase of the age, D increased to 0.7 in the 7 years old vegetation. Afterward, D decreased to 0.6 in 25 years old vegetation and 0.5 in 33 years old vegetation. D was 0.5 in natural *Artemisia ordosica* community. Conversely with diversity index, dominant index d was 0.6 in the 2 years old community and gradually decreased to 0.4 in the 7 years old community. After that, d increased gradually. In natural *Artemisia ordosica* community, d was 0.5. These results show that diversity index and dominant index were also not linearly varied with the progress of desertification.

4. Summary

Succession of established community is an opposite process of desertification. The results of a long term field experiment show that: (1) After more than 40 year's succession, the established shrub community had evolved into shrub + herb + sporophyte community. The number of plant species increased from 3 to 6. These changes were determined by available water in the soil; (2) At the early stage, the coverage of plant canopy increased and gradually approached to the maximum value (about 30%) at the age of 7. Then the coverage decreased gradually. Finally, the coverage was stably around 15-20%. Coverage does not linearly relate with the succession of community. (3) After the establishment, diversity index (Shannon-Wiener) increased gradually from 0.3 to 0.7 and then decreased to 0.5. Meanwhile, dominant index decreased from 0.6 to 0.4 and then increased to 0.7. These results show that established community is considerably changed during the succession of vegetation. However, these changes are not linearly related with age of planted community. In other words, canopy coverage, diversity index, and dominant index are not linearly related with the degree of desertification. These results can provide knowledge not only for understanding the mechanism of succession of community, but also for rehabilitation of desertified land.

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