The impact of fire on plant biodiversity in the semideserts of Central Kazakhstan

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Abstract. The dynamics of species richness and diversity indices in pyrogenic successions of sagebrush and perennial saltwort communities in Central Kazakhstan were analyzed. The biodiversity of such communities during the initial years after fires was higher than that in unburnt phytocenoses. However, values of biodiversity parameters significantly decreased 27-31 years after fires.

1 Introduction

Fires that can occur due to both natural and man-made reasons are often considered as a key factor that have shaped the appearance of many woodless biomes of the Earth in temperate, tropical and subtropical climates. Periodical fires act as triggers for the development of pyrogenic successions of plant communities. To date a large volume of data on the role of fires in the dynamics of woodland communities has been accumulated, but much less attention has been given to pyrogenic successions in arid woodless biomes (e.g., steppes or semideserts), which are even more often affected by fires. For example, fires occur every 5-6 years in protected steppe ecosystems and every 10-12 years in agricultural lands of the Orenburg Region of Russia [1]. Fires tend to spread over large areas of arid plant communities due to the low degree of fragmentation and the high density of their vegetation cover [2].

There is a need for more systematic and detailed research on the pyrogenic dynamics of steppe and desert phytocenoses. A lack of attention to the role of the pyrogenic factor in the development of steppe communities has mainly arisen from the assertion that, in contrast to woodland fires, grassland fires do not lead to the fundamental restructuring of ecosystems and that pyrogenic fluctuations in steppe communities disappear over a period of less than 10 years [3]. Although this assertion can be true for communities of sod-forming grasses that are well adapted for surviving fires, its applicability to sagebrush-dominated steppes of drier climates is controversial. According to many studies [4], the post-fire regeneration of sagebrush (predominantly *Artemisia terrae-albae*) communities typical for Eurasian semideserts (also referred to as 'northern deserts' and 'desertified steppes') is only possible under conditions of grazing. As a consequence of the reduction of cattle numbers for economic reasons after the collapse of the USSR, post-fire successions in semidesert communities in the south of Russia and in Kazakhstan have been characterized by increased

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proportions of grasses, which in its turn leads to the further intensification of fires within those regions [5-7]. It is very unlikely that burnt sagebrush communities can rapidly regenerate under such conditions.

Successional dynamics (in particular, pyrogenic successions) of sagebrush communities of Eurasia are poorly studied and there is no systematic research on this subject. Similar communities, but dominated by different sagebrush species (e.g., *Artemisia tridentata*) are found within the Great Basin area of North America, where they have been studied in sufficient detail in terms of their sustainability and regeneration dynamics after different disturbances (e.g., [8-11]). However, the applicability of North American findings to Eurasian sagebrush communities is doubtful. According to the published data, communities of *A. tridentata* and similar species recover only very slowly from burning and their pyrogenic successions can last for 100-200 years and even longer, while the minimal interval between consecutive fires is estimated at more than 100 years [8, 9]. At the same time, fires in sagebrush communities of Kazakhstan occur with intervals of 10-20 years [12], therefore, it can be assumed that such phytocenoses recover from burning within shorter periods.

The aim of the present study was to assess the post-fire regeneration success over the last 35 years in sagebrush and sagebrush-saltwort communities typical for Central Kazakhstan on the basis of determinations of species richness (number of species per a unit of area) and α- and β-diversity (species diversity within a single plot and within different plots, respectively).

2 Materials and methods

A total of 106 geobotanical descriptions were carried out between 2014 – 2019 within the Ulytau District of the Karaganda Region, where sagebrush and perennial saltwort communities occupy flat interfluves and gentle slopes of the Kazakh Uplands, between the rivers of Sarysu and Baikonyr, to the southwest of the town of Zhezkazgan. Sagebrush species of the study region are represented by *Artemisia terrae-albae* that forms the most typical zonal communities on flat interfluves, with *A. pauciflora, A. semiarida* and *A. sublessingiana* communities being less common. The second most widespread type of zonal phytocenoses is dominated by perennial dwarf shrub *Salsola arbusculiformis*. There are also mixed communities co-dominated by *Artemisia* and *Salsola* species.

The geobotanical descriptions were performed within 10 x 10 m plots, where the projective cover, height and phenological phase of each plant species were recorded. We analyzed Landsat images since 1984 and identified the time of latest fires for each plot and, therefore, the durations of post-fire successions. Pyrogenic successions (1 to 31 years old) were observed in 64 of the 106 plots, while 42 plots represented unburnt phytocenoses (i.e., not burned over the analyzed term of 35 years).

The α-diversity within each plot was assessed using the Shannon index calculated as follows:

$$H = - \Sigma \, (p_i \ln p_i) \tag{1}$$

where p_i is the proportion of the ith species in the biotope (the cover of the ith species in relation to the total cover of all species) and ln is the natural logarithm.

The β-diversity within different plots representing the same stage of pyrogenic succession was assessed using the Whittaker index, which was calculated as follows:

$$\beta_w = (S_M/a_M) - 1 \tag{2}$$

where S_M is the total number of plant species recorded within a community after performing M measurements and a_M is the mean number of species within the community. Both indices can be used to estimate α-diversity and β-diversity respectively in semiarid conditions (for example, [13]).

3 Results

The obtained dataset on plant communities burned at known times was divided into three age groups (N – the total number of plots in each group) as follows:
1) 'Early' – pyrogenic succession from 1 to 3 years old, N = 32;
2) 'Intermediate' – pyrogenic succession from 8 to 16 years old, N = 21;
3) 'Late' – pyrogenic succession from 27 to 31 years old, N = 11.

Between the specified time periods, there were no plots representing pyrogenic successions 4-7 and 17-26 years old.

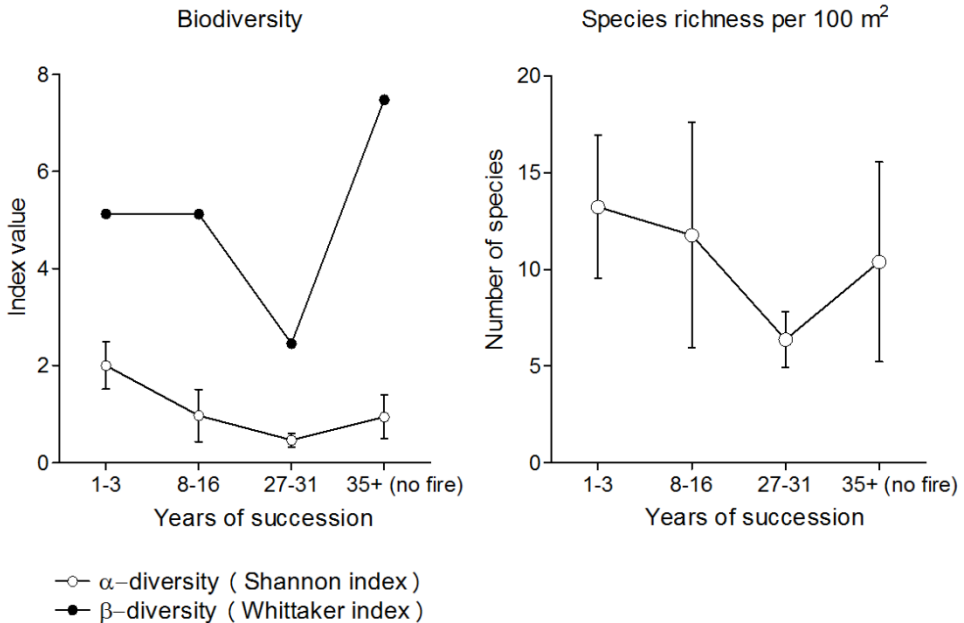The calculated values of mean species number and α- and β-diversity indices are presented in Figure 1.

Fig. 1. The dynamics of α- and β-diversity (on the left) and species richness (on the right) in the course of pyrogenic succession. Standard deviations are shown by error bars.

The pyrogenic successions that developed within formerly burnt sites were characterized by a decrease in all biodiversity parameter values over time, i.e., the negative dynamics of biodiversity. An obvious cause of the increased plant diversity in communities of 'Early' group (1-3 years old) was the removal of a closed canopy of sagebrush, which allowed for colonization by new species (e.g., *Ceratocarpus arenarius, Chorispora tenella, Descurainia sophia,* etc.) and activization of seed germination from the soil seed bank. Post-fire communities also retained some of their original species including fire-tolerant species of sod-forming grasses (*Stipa* sp.*, Agropyron desertorum, Festuca valesiaca*, etc.) as well as fire-sensitive species of sagebrush, single specimens of which were left unburnt. All these factors resulted in high mean values of species richness. Communities of 'Early'

group often lacked any conspicuous dominants and, therefore, had a very high α-diversity, i.e., much higher than that of unburnt phytocenoses.

In the 'Intermediate' group of communities (8-16 years old), sagebrush generally restored its status as a dominant species, which led to a decrease in α-diversity to the same level as in unburnt phytocenoses. However, β-diversity decreased only insignificantly, which implies that the diversity within the group of plots was comparable to that of 'Early' group. The mean number of species per a 100 m^2 in 'Intermediate' group was slightly higher than that in unburnt phytocenoses.

All the communities of 'Late' group (27-31 years) were characterized by the lowest values of species richness (from 4 to 7 species per 100 $м^2$) and biodiversity indices (e.g., Shannon index of 0.47±0.14), which corresponded to the lower ends of these parameter ranges observed in unburnt communities.

The group of unburnt phytocenoses (35+ years with no fire) had a very high β-diversity, which exceeded that in all pyrogenic communities. This can be explained by the high heterogeneity of this group, i.e., apart from sites that burned several decades ago it included sites that hardly ever burned because of very low vegetation densities predetermined by edaphic factors (e.g., outcrops of rock debris and highly saline areas). In addition, this group included communities of *Salsola arbusculiformis*, which did not restore its dominant status in communities of different ages (where this species had a total cover of no more than 1%). Such a slow post-fire recovery of perennial saltwort communities probably implies that the natural regeneration of *Salsola arbusculiforms* is controlled by different factors as compared to those of *Artemisia* sp. regeneration.

4 Discussion

The observed pattern of biodiversity dynamics agrees with generally known facts about the post-fire dynamics of arid plant communities. For example, 2-year-old pyrogenic communities of semi-steppe rangelands in Iran [14] are characterized by a statistically significant increase in Shannon index values up to the level comparable with that (1.98) observed by us in the 'Early' group. At the same time, significant decreases in both α- and β-diversity occur in older cenoses (on average, 17 years old) in the aforementioned North American communities of *A. tridentata* [11].

The ranges of species richness and Shannon index values determined by us in the 'Early' and, especially, 'Intermediate' group were wider than those in 'Late' group probably due to differences in fire frequencies. Over the past 35 years, many of the communities in 'Early' and 'Intermediate' group had been burned several (2-4) times, while the communities in 'Late' group burned only once over the analyzed period. According to [11], a single fire has resulted in a decreased α-diversity in 17-year-old sagebrush communities of North America, however, β-diversity decreased in similar communities only after three consecutive fires. It is likely that the similarity between Whittaker index values for the communities in 'Early' and 'Intermediate' group can be connected with the frequent fires over the study period.

The severity of fires can have ambiguous impacts on biodiversity. For example, α-diversity and the severity of fires in semiarid forests of North America have a non-linear relationship that is represented by a hump-shaped curve [15]. Therefore, high-severity fires lead to a decrease in α-diversity and medium-severity fires lead to an increase in α-diversity in pyrogenic successions. The same factor can probably account for the wide ranges of α-diversity and species richness detected in the 'Early' group, where several fires of different severities could had occurred over the study period.

The low values of biodiversity indices and species richness observed in the 'Late' group (27-31 years old) compared to those in unburnt phytocenoses probably indicate that the

post-fire restoration of biodiversity up to its original levels can take much longer than 30 years. However, this suggestion is probably more applicable to *Salsola arbusculiformis* communities, which regenerated very slowly in the studied plots. In communities of *Artemisia* species their dominant status was generally restored within 8-16 years after fires, which corresponds to the estimated fire reoccurrence periods of 10 to 20 years [12]. Nevertheless, further research on pyrogenic dynamics of sagebrush and saltwort communities is required in order to more accurately establish their post-fire regeneration periods. Such research will be highly relevant in light of the significant intensification of fires observed in Kazakhstan over the recent decades [6].

5 Conclusion

Fires in sagebrush and perennial saltwort communities of Central Kazakhstan resulted in an increase in plant biodiversity during the initial years after burning. In 8-16 years after fires the total number of species and α-diversity of communities reached values comparable with those in unburnt phytocenoses. Subsequent successional dynamics in the absence of further fires resulted in a decrease in diversity parameters, but still within the range of values observed in unburnt communities. Correspondence between the biodiversity restoration period and the fire frequency was indicative of the resistibility of sagebrush communities to such fires. However, a disruption of this historically created balance can be expected due to the recent intensification of fires within the study region.

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