

# Fire frequency in the sagebrush deserts of Central Kazakhstan

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**Abstract.** The frequency of fire occurrence in sagebrush communities of Central Kazakhstan was studied on the example of model plots with a total area of about 4.3 thousand km<sup>2</sup> in the Ulytau region during the last 40 years. Data from Landsat satellite imagery 1984-2023 and geobotanical descriptions of communities made on different-aged burned areas in 2014-2023 were used to determine the combustibility of communities. It was revealed that for most of the territory the fire frequency is once in 20 years, the maximum (under intensive anthropogenic impact) is once in 8-13 years. Based on actual data, models for calculating fire probability were obtained for the whole territory and separately for communities of the most characteristic formation *Artemisieta terrae-albae*.

## 1 Introduction

The frequency of pyrogenic transformation of plant communities is an important factor influencing the structure of arid communities in different regions of the world (steppes, deserts, savannas, prairies, grasslands, etc.). Non-forested arid vegetation is better adapted to the effects of fire than forests because it has evolved under conditions of periodic burnouts for at least the last 6-8 million years [1, 2]. Therefore, fires are not considered as a catastrophic factor here triggering long-term regenerative succession. Many arid communities are characterised by regular fires that occur due to natural causes or more often due to anthropogenic activities. The frequency of fires can be affected by both changes in the type of economic activity and climate change, and the combination of these factors can lead to transformations in the vegetation cover of large areas. For example, in the Chernye Zemli nature reserve (Kalmykia, southwestern Russia), located in a zone of deserted steppes where large ungulates were almost completely exterminated, the introduction of a reserve regime in 1990 with limiting grazing completely transformed the vegetation of the region. Sagebrush communities were replaced by communities of annuals or turfgrasses dominated by *Stipa* and *Agropyron*; at the same time, the frequency of fires in the Reserve has increased over the years [3, 4], preventing the restoration of sagebrush communities.

Fires are rarely considered as a significant factor in community dynamics of true deserts, because in most cases they are characterised by low vegetation cover. Under these conditions, large plant individuals are separated from each other by patches of bare soil that prevent fire

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spread, and the development of a potentially large fire is stopped at the initial stage. However, this approach usually overlooks the fact that communities in the northernmost subzone of temperate deserts in contact with southern steppes, or the so-called northern deserts or steppe deserts [5], often have high enough projective cover of vegetation to allow the formation of large fires. For example, sagebrush communities of Central Kazakhstan, composed of such species as *Artemisia terrae-albae*, *A. semiarida*, *A. sublessingiana*, *A. pauciflora*, often have a total projective cover of up to 40-50% [5]. As a result, ignition in these communities can lead to large fires [6].

Pyrogenic dynamics of *Artemisia* communities occupying large areas of south-western Russia and northern and central Kazakhstan are insufficiently studied, including the timing of fires. For the steppe zone, this issue is slightly better studied; for example, it is known that in Volgograd region, from 1998 to 2018, more than 40% of natural zonal communities burned out, with individual sites burning out more than 10 times. In Astrakhan region, about 60% of zonal communities were subjected to fires during the same period [3]. In the steppes of the Orenburg region (Russia), fires in protected areas occur with a frequency of once in every 5-6 years, and once in every 10-12 years for lands involved in economic turnover [7]. Dara et al. [8] noted an increase in the frequency of fires and pyrogenically transformed areas in Northern Kazakhstan in the post-Soviet period and attributed the observed increase to the changed land use regime after the collapse of the USSR (reduction of areas in agriculture, transition of cattle breeding from government to private farmers, reduction of livestock and abandonment of some pastures). However, there is much less such information for the northern deserts subzone located to the south. V. Ivanov [9], who studied sagebrush communities in Western Kazakhstan in the middle of the 20th century, mentioned the frequency of fires for them in 10-20 years, which outlined the general term of the observed pyrogenic succession. However, changes in climate over the past decades, as well as changes in grazing intensity associated with the processes of the collapse of the USSR [8] and wild ungulates populations, may also have led to changes in fire frequency and pyrogenic dynamics of northern desert sagebrush communities in the region.

The aim of our study was to determine the frequency of fires in sagebrush deserts of Central Kazakhstan.

## 2 Materials and Methods

The study area is located in the southwestern part of the Kazakh uplands (Ulytau region of the Republic of Kazakhstan), 50-100 km southwest of the city of Zhezkazgan, in the interfluvium of the rivers Sarysu and Ashymuiyr. This area has been used in recent decades to receive first stages of 'Soyuz' and 'Proton' launch vehicles [6], whose impact sites have been regularly surveyed by the employees of the Lomonosov Moscow State University since 2014. The areas of the districts are 2725 km<sup>2</sup> and 1660 km<sup>2</sup>, respectively.

The interfluviums in study areas are represented by isolated residual uplands dissected by U-shaped gullies with gentle, occasionally terraced slopes. Soil cover is complex due to the influence of saline ground waters and the micro relief. Aridic Gypsisols, as well as the Gypsisols and Solonetz complexes occur in the watersheds and at the slopes of hummocks. Fluvisols and Calcisols are common in the higher lying floodplain river terraces and dry gully bottom. In botanic scope, the studied territory belongs to the North Turan province of the Iran-Turan subregion of the Sahara-Gobi desert region [5]. Zonal communities on interfluviums are represented by semishrub vegetation with a predominance of sagebrushes (the most common species is *Artemisia terrae-albae*). In the recently burned areas, communities of turfgrasses (*Stipa sareptana*, *Agropyron desertorum*) and annuals (especially *Ceratocarpus arenarius*) are widespread.

The present study uses 2 datasets:

1) Landsat satellite imagery dataset for the period since 1984, publicly available since 2008 [11], which allows us to determine for any point within the model area the years of fires, the location of fire contours, and the approximate area of pyrogenic impact for each fire [6].

2) Array of geobotanical descriptions of vegetation (N=208) on the surfaces of interfluves, gentle slopes of river valleys and river terraces, collected in the period from 2014 to 2023 by the employees of the Faculty of Geography of Lomonosov Moscow State University. Geobotanical descriptions were collected during the vegetation period (from the end of April to the end of September, most of them - from the end of April to the beginning of June, during the period of maximum detectable flora biodiversity). In the present study, only dominant species of communities were taken into account from the descriptions. The sites where descriptions were made were subjected to pyrogenic impact at different times (including a period more than 40 years ago, i.e. outside of the available remote sensing data). At the same time, only background communities that were not affected by the anthropogenic impact from the fall of launch vehicle stages were included in present array of geobotanical descriptions.

Based on satellite data, contours of pyrogenic impact zones within the Soyuz launch vehicle first stage impact area were identified [6]. Using these materials, the years of pyrogenic impact were established at the study points where geobotanical descriptions were made. Based on the composition of geobotanical descriptions, formations in the vegetation cover were identified in accordance with the most up-to-date summary of the vegetation of the region [5].

## 3 Results

### 3.1 Vegetation of the study areas

Two groups of formations typical for the zonal desert type of vegetation - *Artemisieta* and *Salsoleta* - and a less represented intrazonal shrub-steppe group of formations (*Aestifruticeti stepposa*) were identified among the plant communities of the study area. Formations are identified by indigenous communities that have not been subjected to pyrogenic and other impacts during the period of remote sensing data availability (i.e. 30-40 years for different descriptions), which are represented in 67 geobotanical descriptions. The remaining 141 descriptions correspond to communities that have been burned from 1 to 4 times since 1984. Among them, the overwhelming majority (110) were assigned to the *Artemisieta terrae-albae* formation. Communities of this formation are the most widespread in the study area, occurring on Gypsisols and Solonetz. The successional series of this formation represents a transition from annual communities (dominated by *Ceratocarpus arenarius*, *Descurainia sophia*, annual *Atriplex* species and others) and turfgrass communities (dominated by *Stipa* spp. and *Agropyron desertorum*) to communities dominated by *Artemisia terrae-albae* with the increasing in projective cover.

### 3.2 Probability of community burnout during pyrogenic succession

Taking into account regular local anthropogenic impact on the study area associated with the fall of launch vehicles, we do not consider it as a large-scale pyrogenic impact factor, since fires resulting from the first stage impact of launch vehicles most often occupy an area of tens and hundreds of m<sup>2</sup>, and the first km<sup>2</sup> as rare exceptions, which is orders less than 1% of the entire area in the study area [6]. In addition, the mechanical and chemical impact on the land cover specific to rocket and space activities occurs within a radius of up to 100 m from

the centre of the impact site. Any fire resulting from the fall of a stage and spreading to a distance greater than the radius of dispersal of its fragments is no different from other fires of anthropogenic origin. Thus, any fires of significant size in the study area can be regarded as single-type events, irrespective of the source of ignition.

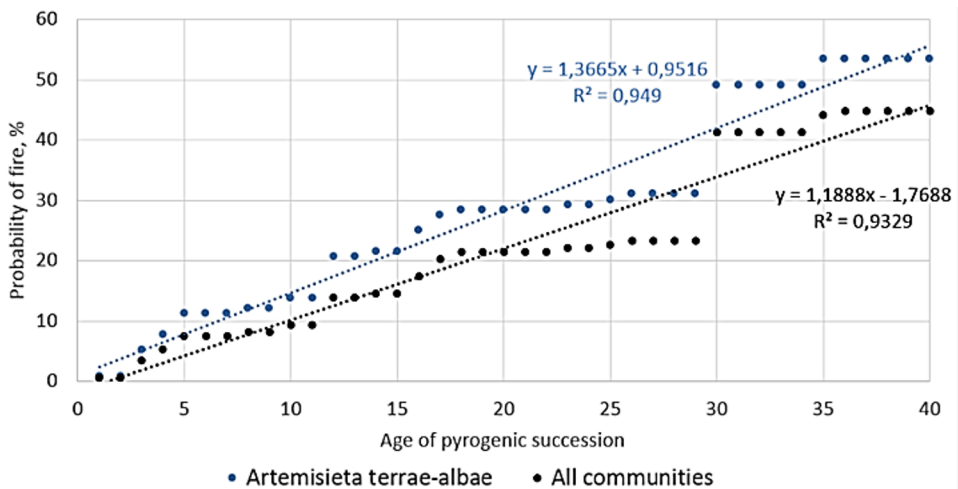
By determining from remote sensing data the age of the last fire that led to the formation of the currently observed community, as well as the time interval between the last and penultimate fire, we can construct a model of changes in the probability of community burnout during pyrogenic succession. In this construction, we also make the following considerations:

Pyrogenic dynamics of sagebrush communities in Kazakhstan with periodic fires can be considered as a self-generated repeating succession described by the example of other arid communities [11]. During such succession, the probability of fire increases due to the accumulation of mortmass in communities, increase in plant cover and biomass growth of the edifier species *Artemisia terrae-albae*, which has a high content of essential oils and other combustible substances [12].

The locations of the points selected to describe the communities associated with the impact sites of falling rocket parts are stochastic, since it is impossible to predict the impact site location inside the borders of falling region. At the same time, the descriptions made at a small distance from each other (up to 100-200 m) and thus violating the principle of random selection make up an insignificant volume in the data set (no more than 10% in total).

*Artemisia* communities that have not burned during the period of remote sensing data availability (40 years) may be subject to pyrogenic impact in the future.

The model of fire probability growth during succession constructed from actual data is shown in Fig. 1. The whole array of burning and non-burning descriptions (A) is here estimated as 100%; a fire occurring in a certain succession year corresponds to an increase in the probability of fire occurrence in that year by  $(1/A) \times 100\%$ . An averaged trend of probability growth with an approximation probability  $R^2 > 90\%$  is plotted from the actual points.



**Fig. 1.** Change in fire probability during pyrogenic succession separately for *Artemisieta terrae-albae* formation and for all communities in the areas of stage falling. Dots are plotted according to actual data of the descriptions; dotted lines are trends corresponding to these data (trend and  $R^2$  formulas are shown in the figure in their respective colors).

The model shows that the increase in the probability of fire occurrence generally follows a linear trend well. Sharp jumps in the probability (e.g., at the age of 30 years) are associated

with individual large fires leading to the burnout of significant areas (in our actual data, these are the fires of 1987 and 2017, which affected both impact areas; for example, in 2017, 74% of the 'Proton' stage falling area and 22% of the 'Soyuz' falling area burned out). However, within the trend, such spikes are 'balanced' by the absence of fires in study area in subsequent years, as the state of vegetation cover in the first years after a fire is not favourable to re-burn.

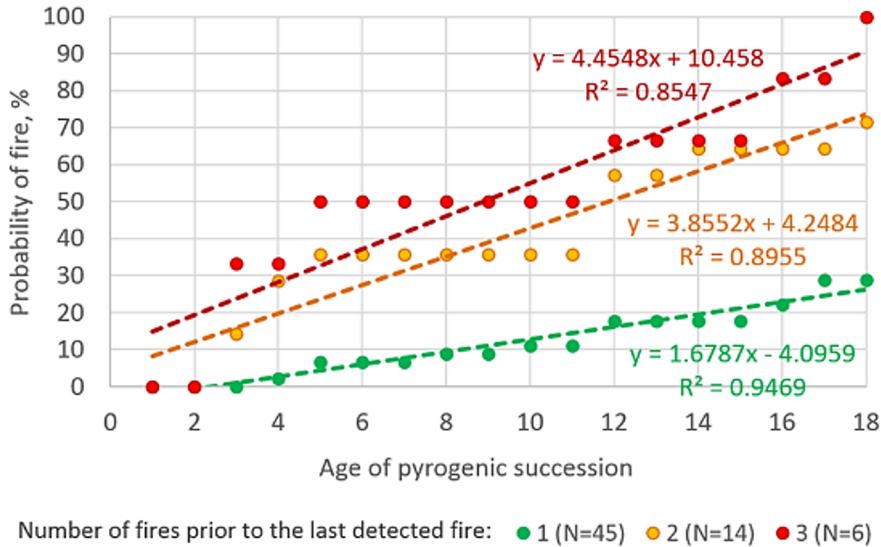
The graph indicates that the probability of burnout of sagebrush community during 40 years exceeds 50%. For the period of fire turnover of sagebrush in Kazakhstan in 10-15 years [9] indicated in the literature, the probability of fire changes from 13% to 22% according to our actual data for this interval and from 15% to 21% according to the calculated trend. For 5 selected years, the sum of fire probability is close to 100%. According to our observations, in the period of 10-15 years sagebrush most often takes the positions of co-dominant and dominant in communities of the *Artemisieta terrae-albae* formation, while quite a lot of turfgrasses (e.g., *Stipa sareptana*, *Agropyron desertorum*) or annuals (*Ceratocarpus arenarius*) are still present in the communities. In later periods of pyrogenic succession, communities are mostly represented by monodominant sagebrush vegetation.

In a similar analysis of the array of all plant communities, the model is characterized by a slower increase in the probability of fire occurrence, which is approximately 10% over 10 years (for sagebrush communities, the increase over the same period is almost 14%). The similarity of the plots is due to the fact that sagebrush communities are the most common communities in the region, making up the majority of the array, and sagebrush often occur as subdominants for other formations (e.g., *Atripliceta canae*). At the same time, the slower increase in fire frequency is due to the fact that the full dataset contains communities that are rarely affected by fires due to sparsity (total projective cover is 10-20%) and low stocks of combustible phytomass - for example, communities of *Anabaseta salsae* and *Nanophytoneta erinacei* formations, typical for highly saline soils and rubbly hillsides, respectively. It should be noted that, in fact, in the first years after the fire, burned areas most often cannot be subjected to repeated pyrogenic impact due to the lack of combustible biomass and low cover; cases of repeated fires are observed not earlier than 3 years after the initial burnout. Otherwise, it follows from the linear trend that, in fact, the probability of fire does not depend on the age of the community: the number of fires recorded in communities with the age of 10, 20, 30 and more years of pyrogenic succession does not significantly differ from each other. That is, their burnout is due to randomness: fire occurrence and its arrival at a particular site. It should also be taken into account that actual large fires affecting large areas obviously occur more often in years with unfavorable weather conditions (early spring with low precipitation, long summer drought, high temperatures). Thus, the present trend cannot be used as an accurate predictor of a pyrogenic event, but can be taken into account in theoretical calculations of burnability and fire hazard of communities.

The available dataset also allows us to assess the correlation between the probability of community burnout and the frequency of pyrogenic impacts observed in the same area in the past. We compared data for communities that burned from 2 to 4 times during the period of remote sensing data availability; the duration of the last inter-fire period (between the last fire that led to the formation of the current community and the preceding fire) was used as the successional period. The resulting model (Fig. 2) was constructed for the entire array of geobotanical descriptions, but 93% of descriptions belong to the *Artemisieta terrae-albae* formation.

As can be seen in Fig. 2, the probability of fire occurrence in a community increases with the number of previous fires. On the one hand, this pattern can be explained mathematically: since we have a limited period of remote sensing data availability (40 years), the more fires recorded in an area during this time, the smaller the inter-fire intervals between them. On the other hand, a biological explanation for this increase is also suggested: it is known that regular fires lead to the growth of turf grasses, which are well tolerant to fire, and to the

‘steppification’ of desert vegetation [13]. Increased grasses cover, in turn, may lead to more frequent fires, as grasses form large amounts of flammable dead litter. This is probably the reason why the data set for communities with 2 and 3 previous fires in the pyrogenic history shows a rapid increase in the number of repeated fires at the age of 3-6 years of succession, which is not observed in communities that burned only once before the last fire.

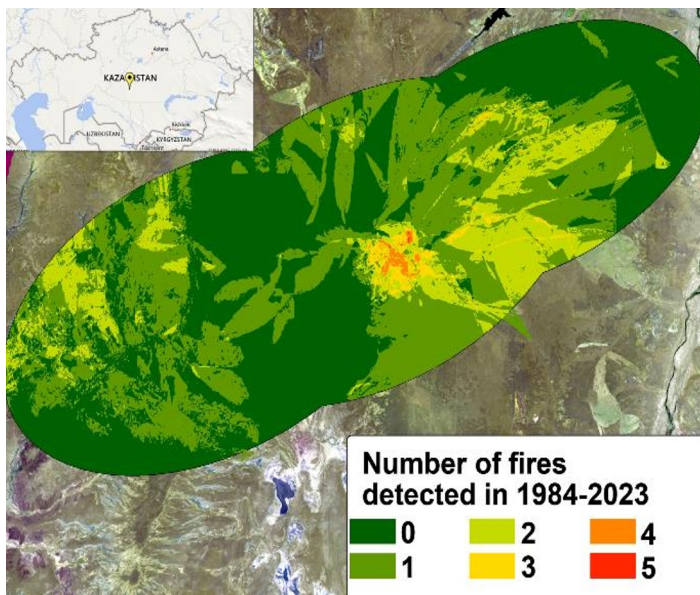


**Fig. 2.** Change in the probability of fire occurrence depending on the number of previous fires. Dots are plotted using actual data on the burnability of the surveyed areas; dotted lines are trends corresponding to these data. Trends and  $R^2$  formulas are coloured according to the data for which they are plotted.

At the frequency of burning 2 times in 40 years (1 previous fire), the rate of increase in the probability of re-fire generally corresponds to the calculations given in Fig. 1 (13% in 10 years), taking into account only regularly burning communities. At the same time, more frequent fire events in the past lead to a significant increase in the probability of fire recurrence (by a factor of 4-5 according to Fig. 2, but the previously described limitations of the period of remote sensing data availability should be taken into account). Thus, the 20-year fire turnover observed in most of the studied model area can actually be considered as natural for it in the current historical period and not leading to significant changes in the course of succession. According to our observations, during the 20-year succession period in the overwhelming majority of communities sagebrush becomes the dominant species of the community; at the same time, the formation of sagebrush-dominated communities is possible even 8-10 years after the fire, since the survival of *A. terrae-albae* seedlings depends to a large extent on weather conditions in spring [14]. These features are likely to account for the fire intervals of 10-15 years described in earlier sources [9]. At the same time, more frequent pyrogenic events may shift the ecological equilibrium towards the dominance of turfgrasses. This is especially important under conditions of intensive anthropogenic pressure on desert communities near populated areas, as well as under conditions of global climate change, which may affect the conditions of sagebrush regeneration and the frequency of fires in Central Kazakhstan.

### 3.3 Frequency of community burning according to remote sensing data

Based on the results of Landsat data processing for the area of the ‘Soyuz’ launch vehicle first stage impact (Fig. 3) for the period 1984-2023, it was revealed that 40% of the territory has not been subjected to fires in the last 40 or more years, which suggests the presence of indigenous communities. These areas include both areas that are not subject to fire due to the low burnability of their characteristic communities (e.g., sparse halophyte vegetation) and potentially flammable communities of wormwood and perennial saltwort that are not subject to fire due to the presence of natural barriers (primarily river valleys and areas of low burnability of vegetation discussed earlier) in their vicinity. Most of the study area (59% in total) is characterised by 1-2 fires over 40 years of observations, more often occurring outside the area borders. Thus, on 98.5 percent of fires in the fall area are observed not more often than once in 20 years.



**Fig. 3.** Frequency of pyrogenic impact in the area of the fall of the first stages of ‘Soyuz’ launch vehicles.

The remaining 1.5% of the territory is characterised by the frequency of fires 3-5 times in 40 years, which corresponds to the average frequency of once in 8-13 years, more consistent with the data of V. Ivanov (Ivanov, 1958). It is characteristic that the area with the highest fire frequency, firstly, is located in the centre of the fall area (where the probability of the rocket stage fall is higher than in the periphery of the area); secondly, until the early 1990s, there was a settlement in this area, apparently serving as a source of a number of fires.

## 4 Conclusion

Based on remote sensing data for the model sites, it can be concluded that the majority of communities in the region burn with a frequency of no more than once in 20 years, with the maximum frequency of fire observed by remote sensing being once in 8-13 years.

The increase in the timing of fire intervals obeys a linear trend, and in fact fire susceptibility seems independent of successional age. Each year the probability of re-fire increases by approximately 1% for the total array of the studied communities and by almost

1.5% for sagebrush communities with pronounced pyrogenic cyclicality. For areas burned more than 2 times in 40 years, the probability of fire development is 4-5 times higher than for communities with a fire frequency of once in 20 years.

The obtained formulas and probabilities can be used for calculations of fire susceptibility of arid territories of Eurasia sagebrush deserts depending on pyrogenic history in the previous period, which can be reconstructed from remote sensing data.

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