Pyrogenous transformations of steppe landscapes in the south-east of the Russian plain (natural parks in Volgograd region as a case study)

N O Ryabinina ORCID 0000-0003-2981-8845

Volgograd State University, Volgograd, Russia

E-mail: ryabinina@volsu.ru

Abstract. For a long time fires have been and still are one of the powerful factors for transforming steppe landscapes. The current condition and pyrogenous transformations of geosystems in the south-east of the Russian Plain were examined. The following methods of field complex landscape research were used, such as semi-portable methods of “key sites”, of crop (quadrat) areas and others. The article focuses on the conclusions about the pyrogenous transformations of geosystems drawn on the basis of long-term field observation on the territory of the Donskoy natural park and the Elton natural park of Volgograd Region. Monitoring has revealed that pyrogenous transformations of geosystems appear to pose a serious threat to biological and landscape diversity of steppe. Under the influence of fire, self-regulation processes in steppe geosystems slow down and resistance to external influence reduces. The structure simplifies, the homogeneity of vegetation cover increases, grass stand and overall projective cover decreases, wood-shrub vegetation dies out. The colourful aspects of the steppe are vaguely displayed. For the long term (up to 3-5 years) biological productivity of geosystems considerably reduces from 1.5 to 3 times. The upper layer of humus burns out, soil fertility decreases and aridization of local pyrogenous geosystems increases. Evaporation speeds up, soil humidity deficit goes up, underground water level goes down, springs run dry. Wind and water erosion processes are being activated. Fires destroy sites of reproduction, recreation and feeding for animals and also habitats of rare and endangered species. Pyrogenic transformation is the most serious real threat to the biological and landscape diversity of the steppes.

1. Introduction

Fires have been and still are one of the key factors behind transformations of steppe landscapes. According to the statistics, about 20% of Russian steppe territory is annually subjected to fire impact [1]. The analysis of domestic and foreign literature shows that the last decades have seen systematic studies of pyrogenous transformations of landscapes and ecosystems of meadow steppes in the forest-steppe zone of the Russian Plain, of steppes in Central Ciscaucasia, Ural, Siberia and Kazakhstan, also of ecosystems of low-grass and high-grass prairies of Northern America [1, 2, 3, 4, 5, 6, 7]. In Russia such researches have been carried out mainly in federal specially protected natural territories (SPNT). Landscapes of genuine and dry steppes in the south-east of the Russian Plain are not studied enough.

In Russian literature, separate and often one-time observations of pyrogenous changes of geosystems of Eastern-European steppes have been published. Data obtained by different authors about fire impact are very contradictory. Some researchers believe that fires have a positive influence
on productivity and dynamics of steppe phytocenosis while others note a negative impact on functioning and biodiversity of steppe and semi-desert landscapes [1, 3, 4, 8, 9, 10, 11].

For the first time the author of this article studies pyrogenous transformations of landscapes of dry and desertified steppes and post-pyrogenous successions on the south-eastern territory of the Russian Plain within Volgograd region. Key research sites are SPNT, primarily natural parks, where direct economic influence is reduced. The database of pyrogenous transformations of steppe landscapes has existed since 2002, when natural parks in Volgograd region were organized. To achieve the stated aim, the author has used a complex of laboratory, distant and field methods of geographical research. The results of long-term field landscape researches have been published in a number of articles [12, 13, 14].

2. Objectives and Methods

Donskoy natural park (square of 60,000 ha) is one of the key research territories. It occupies the north-east of the Lesser Meander of the Don River and sits in the heart of Volgograd region. It was organized in 2001 and now is one of the main nuclei of the regional network of SPNTs. The Lesser Meander of the Don River is characterized by high preservation and representation of natural complexes and can be seen as the core landscape and biological territory where practically all ecosystems and geosystems, typical of the sub-zone of dry steppes, can be found. According to the author, one can find virgin patches of feather grasses and herb-bunchgrass steppes on chestnut soils and of lightly-transformed ravine oak-linden groves, watershed steppe oak groves and within the landscape of “Donskie Ventsy”. The landscape occupies the high upper flat plateau of the Eastern-Donskoy Ridge (absolute height up to 252 m). In virgin herbages the following feather grasses prevail (Stipa lessingiana Trin. et Rupr., S. pennata L., S. dasiphilla Trautv., S. capillata L. and others) and also other grasses, like couch grass, June grass and other grasses, species of family Poaceae, mainly from genera Elytrigia and Koeleria. Motley grass is formed by such species as Salvia stepposa Host., Medicago falcata L., Galium ruthenicum Willd., Dianthus borbasi Vandas. and D. pallidiflorus Ser., Phlomis pungens Willd., Melampyrum arvense L., Crinitaria villosa L., by onions and others. In spring one can spot Iris pumila L., Tulipa schrenkii Regel and T. biberstieniana Schult. et Schult. fil., Adonis volgensis DC., Fritillaria ruthenica Wikstr., species of the genus Ornithogalums and other ephemerals. On virgin lands such nanophanerophytes grow, as Spirea hypericifolia L., Amygdalus nana L. and others [12, 15].

In Donskoy natural park, on the territory of Podgorsky chalky landscape, there are preserved vast areas of virgin chalky (calciphilous) and sandy steppes with endemic dwarf semishrub groups of hyssops (Hyssopus cretaceus) and thymes (Thymus cretaceus) on chalky outputs of Turonian age and on underlying Alb-Cenoman sands. Chalky steppes occupy the upper layer of the landscape, namely chalky plateaus and upper parts of slopes with absolute heights from 170-130 till 120-100 m. In the vegetation cover of chalky steppes the following endemic calciphilous species dominate: Stipa cretacea P. Smirn., Thymus cretaceus Klok. et Shost., Hyssopus cretaceus Dubj., Matthiola fragrans Bunge, Artemisia salсолoides Willd., Linum ucranicum (Griseb.ex Planch.,) Czern., Onosma tanaitica Klok., Genista tanaitica P. Smirn., Hedysarum cretaceum Fisch., Lepidium meyeri Claus, Crambe tataria Sebeök, Silene cretacea Fisch. ex Spreng. and S. hellmannii Claus, Linaria cretacea Fisch. ex Spreng., Jurinea ewrsmannii Bunge and J. cretacea Bunge, Scabiosa isetensis L., Astragalus albicaulis DC., A.dasyanthus Pall. and others. Sometimes bushes of Juniperus sabina L. can be seen [15, 16]. Sandy steppes occupy the lower layer of the landscape with absolute heights from 120-80 m up to the level of the right-hand bottomland of the Don River. In the vegetation cover the following psammophilous species prevail: Stipa pennata, Achillea gerberi Willd., Kochia Ianiflora (S.G. Gmel.) Borb., Euphorbia seguieriana Neck., Helichrysum arenarium (L.) Moench, Thymus marschallianus Willd. s.l., Astragalus longipetalus Chater, A.physodes L. and others. The park territory also includes the intrazonal landscapes of the Don valley with the eastern edge of the Archedino-Donskoy sandy area.
Systematic studies of structure, functioning and dynamics of geosystems on the territory of Donskoy natural park have been carried out by the author since early 1990s. Since 2002 monitoring researches have been made with the help of methods of landscape mapping and profiling and others. Also semi-portable methods of “key sites” and of crop (quadrat) areas were applied. These key sites were organized within watershed terrains of the protected steppe nucleus and the specially protected zone which encompasses landscapes of “Donskie Ventsy” and Podgorsky chalky landscape. There is the integrated program of studying components of geosystems, their interrelation and current processes on key sites. Also microclimate, geomorphological, hydrological and soil examinations are held. Annually, during the same period (1-9 of June, 16-26 of June, 4-10 of July, 12-20 of September, periodically in early and late April, in late October), observations are carried out: to record changes in species composition and structure of plant associations, to keep quantitative records of biological productivity of grass associations (i.e. resources of overground vegetable mass and overground mortmass, to manifest dependency of productivity on the regime of nature management (protected nucleus, agrolandscapes and others) and on natural features of the territory [12, 13, 14]. Before weighing, the crop masses were processed in laboratory settings to become absolutely dry. Location of key sites, points for observation and for complex description of landscape facies and quadrats are recorded with the help of GPS and are registered on large-scale maps. Observation materials are stored in standard forms for describing observation points and landscape facies [14].

The principal object of investigation is zonal geosystems of fescue-feather grass steppes. In the protected nucleus of the park, three key sites (“Tselina 1, 2, 3”) are located within watershed terrains in “Donskie Ventsy” with virgin associations of feather grasses on light-loamy chestnut soils. The key sites “Tselina 1” and “Tselina 3” are excluded from economic usage, “Tselina 2” is periodically used as hayfield. “Tselina 1” saw fires in August of 2006 and July of 2009, “Tselina 2” was partly on fire in 2006. The fire did not touch “Tselina 3” which was surrounded by fireguards. The fourth “Verchno-Filimonovsky” site was organized on the watershed glacis at the upper reaches of Filimonovskaya balka where motley grass-feather grass associations dominated (Stipa lessingiana+Stipa pennata+Elytrigia repens+Medicago falcate+Vicia cracca). This area greatly suffered from fires in August of 2006 and in late October of 2011. Also in 2002-2003 monitoring key sites were organized on areas of middle-aged fallow lands (secondary steppes) which met fire in 2006. There are another three key sites within Podgorsky chalky landscape.

A similar survey is being carried out on the territory of Elton natural park. This park is situated in the south-east of Volgograd region, within Elton region of the Caspian Lowland semi-desert landscape province [15]. The distinctive feature of the Eastern-European semi-desert is the youth of its zonal landscapes linked with geological youth of this part of the Russian Plain. Salinity of soil-forming species (loamy sea Khvalyn deposits) and shallow occurring mineralized underground waters determine the primary enrichment of soils with salts and development of halophilous vegetation on them and also the wide spreading of saline lands. The dominant zonal type of vegetation in the semi-desert landscape zone is desertified wormwood-bunchgrass steppes on light chestnut soils accompanied by dwarf semi-shrub associations with domineering Artemisia pauciflora Web. and A. lerchiana Web. ex Stechm., Kochia prostrata (L.) Schrad., Pyrethrum achilleifolium Bieb. and Festuca valesiaca on saline lands. Grasses and motley grass-grasses associations, occasionally with bushes of Spirea, are formed in microhollows, limans, depressions with meadow-chestnut soils.

On saline soils and saline lands around Lake Elton, the following associations can be found containing such hyperhalophiles as Anabasis salsa C.A. Mey., Halocnemum strobilaceum (Pall.) M.Bieb., Salicornia europaea Willd., Atriplex cana C.A. Mey., of annual glass worth, of halophilous wormwood, and Suaeda physophora Pall. and others, Nitraria schoberi L., Limonium suffruticosum (L.) Kuntze, Petrosemionia brachiata (Pall.) and others [17,18].

3. Results of research
Traditions of “melioration” for pasture vegetation via fires have a thousand-year old history. It is widely assumed that destroying of overground mortmass improves the quality of pastures as mortmass
prevents steppe plants from development and seed sprouting. It is recommended to use fires in steppe SPNTs to regulate steppe ecosystems, to raise productivity of grasslands and to exterminate weeds and poisonous plants [1, C. 114-130]. Nevertheless, long-term researches, undertaken by the author on the territories of Donskoy and Elton natural parks, show that fires have an extremely negative influence on landscapes of steppes and semi-deserts.

Fires happen annually and in any season in various areas of Donskoy natural park. It may be conditioned by winter with little snow, by hot and dry summer and by dominant windy weather all year round. The period of observation provides the following data: 2011, 2012 and 2013 saw droughts, the years of 2003-2006, 2014 and 2016 were humid; in 2002, 2007-2010, 2015 annual precipitation was corresponding to average perennial figure of 35 mm. The main cause of fires is breached safety requirements during haying and other works. This led to biggest fires in August of 2006 and July of 2009 when more than one third of the park territory and Kachalinskaya village was destroyed by fire. In autumn, winter with little snow and spring fires happen after burning out of stubbles and pastures. They move from adjoining agrolandscapes onto the park territory though mortmass stocks in dry steppe geosystems are minor and average 4.2-7.6 cm center per hectare on virgin lands. Podgorsky chalky landscape almost completely burned down in 2009 and partly in 2006 and in May of 2008. Fires happen in spring and summer every 2-3 years on some areas of “Donskie Ventsy” landscape and on slopes of Dry balka.

According to the author’s data, a single fire in virgin associations of feather grasses (Stipa lessingiana) leads to reduction of productivity of surface phytomass, in average to 40-50% (table 1). Legumes and mesophyllous motley grass practically disappear from the herbage for 2-4 years. Moss and lichen cover and surface algae (Nostoc and others) die out completely. The upper layer (up to 2-4 cm) of the humus horizon burns out. Before fires, mortmass stocks average about 6.5-7 centners per hectare, after fires they burn down completely and recover only in the 2d -3d year under favourable conditions. Under long-term drought (2011-2014) they recover in the 5th year. As a result, the amount of humus in the upper soil layer is reduced up to 20-25%. If fires take place every 3-4 years, virgin feather grasses associations see a structure change of phytocenosis and Festuca valesiaca dominates instead of feather grass (Stipa lessingiana, S. pennata, S. capillata and others). The overall projective coverage is reduced to 50% (table 1). Singular species of motley grass from genera Medicago, Galium, Dianthus tend to disappear from the herbage or be scarcely represented. The number of Iris pumila is reduced to 30%. Adonis wolgensis and species of the genus Allium – up to 50-60%. Most of them break in bloom only 2-3 years after the fire. Species of the genus Tulipa have better fire-surviving skills; adult plants keep their numbers while young plants and seedlings tend to die out. Shrubs of Spirea and Chamaecytisus ruthenicus die up to 20-30%, Amygdalus nana – up to 80-90%; the survived plants grow very slowly.

**Table 1.** Average biological productivity of the aerial part of the phytomass in key sites of the Donskoy Nature Park in 2002-2016.

| Key site           | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Verchne-Filimonovsky | -    | -    | 63.03| 43.1 | 39.5 | 35.8*| 22.87| 37   | 61.85| 35.2 | 29.4*| 28.85| 57.86| 63.19| 52   |
| Tselina 1          | 16.80| 15.90| 28.80| 31.52| 26.30| 11.57*| 20.34| 13.71| 17.5* | 15.74| 13   | 18.35| 27.81| 21.72| 27.57|
| Tselina 2          | -    | 21.93| 25.22| 72.8 | 36.9 | 23.07*| 29.47| 30.81| 40.42| 25.36| 20.91| 27.32| 55.1 | 39.5 | 54.5 |
| Tselina 3          | -    | 27.74| 26.16| 27.50| 19.94| 26.80| 19.33| 29.74| 19   | 19.13| 28.46| 38.1 | 27   | 34.1 |

*hay cuts made the following year after the fire

After fires in 2009, feather grasses and motley grass were depressed and almost did not bloom in 2010-2012. Flowery aspects of steppe revealed weakly. Due to absence of mortmass, moss and lichen, washing-out and blowing of fine earth from the upper layer of the soil become more prominent. Microhollows tend to form up to 5-7 cm between sods of feather grasses (Stipa lessingiana, S. pennata, S. capillata and others) and Festuca valesiaca. Frequent fires lead to deepening of deflation.
hollows and to forming tussocks of bunchgrass among them. Seed reproduction of grasses and motley grass is obstructed for the next 2-3 years after the fire. The overall projective coverage is reduced up to 35-40%. Productivity of virgin zonal phytocenosis drops about 1.5-2 times.

It was established that the drastic reduction of bioproductivity (key site “Tselina 1”) in 2007, 2009-2010 was caused by fires in August of 2006 and on the 10th of July in 2009 (table 1). The complex and intense drought lasted from late March till October in 2012 and caused the sharp reduction of bioproductivity and mortmass stocks on all key sites of 2012-2014.

Landszapes of chalky steppes suffer the most from fires. Even single fires can lead to complete extinction or sharp (up to 70-90%) decrease of endemic plants. For example, after fires in 2006 and 2009, the population of Calophaca wolgarica (L. fil.) DC perished on the territory of Podgorky chalky landscape. Juniperus sabina L. was reduced to 90% (only some rooted branches were left). Moss, lichen and algae practically disappeared for 3-4 years, the number of Artemisia salsoloides, Thymus cretaceus, Matthiola fragrans, species from genera Jurinea and Astragalus was reduced up to 30-40%.

Many plants never bloomed in the first year after the fire. In the result of pyrogenous changes, erosion processes activated on chalky cliffs and steep slopes of the southern exposition. During one autumn-spring period, slope ravines and canyons deepened up to 10-30 cm, also slope edges shifted and chalky talus moved.

In the result of a single fire in 2006, about 30% Quercus robur, about 50% Tilia cordata and up to 90% Malus sylvestris and Pyrus communis perished in ravine oak groves of “Donskie Ventsy”. At edges of forests Amygdalus nana, Cerasus frutiosa, Acer tataricum and others recovered only in 5 years by 2011. The fire of 2009 destroyed more than ¾ of the unique watershed oak grove of Ilovlya. Not only trees and bushes burned down but also grass cover and the upper soil layer did. Only in 2011 the grass cover was partly restored. The maximum harm is done by autumn fires because by that time tree waste has been significantly accumulated on the surface soil. In late October of 2011 the fire almost completely destroyed the watershed oak grove of Belousova and the considerable area of ravine forests on the north-eastern slope of “Donskie Ventsy” and in the upper reaches of Filimonova balka. The grass cover and upper soil layer burned down in these ecosystems.

After fires in 2012-2014 the Verchne-Filimonovskiy patch saw severe changes in phytocenosis structure as pyrogenous transformations superimposed with changes caused by drought of many years. Feather grasses (Stipa pennata, S. dasiphilla and others), Elytrigia repens and motley crew almost completely vanished from motley grass-grasses associations, here Festuca valesiaca became dominant. The projective coverage was reduced from 90% till 50%. Many invertebrates die in steppe fires, sites of reproduction of birds and animals disappear. On fallow lands (secondary steppes) areas the succession status degrades, the proportion of wormwood and weeds enlarges, the quality of pastures and haymaking regions worsens. Due to exhaustion of vegetative cover, the local climate is subjected to aridization. In summer temperature on soil surfaces reaches 65°C, evaporation increases, deficit of moisture in soils increases, underground water level goes down, springs run dry. In 2002-2006 the flow rate of Verchn-Filimonovskiy spring in the same balka was 0.6-0.7 l/s, in 2013-2016 – 0.05 l/s, in 2007-2010 three springs in Ilovlya oak grove perished (in 2002 their flow rate was 0.3-1.0 l/s).

Every year the landscapes of Elton natural park suffer from more intense anthropogenic factors (pascual, recreational and others). Annually fires envelop vast territories during spring and summer. The aim was to provide a landscape monitoring of Kharo-Elton landscape which was formed on the territory of Caspian Mid-Khvalyn sea accumulative lowland with absolute heights below 25 m. To do so, 5 key sites were organized with hay-making areas in ecosystems with different levels of anthropogenic changes [14]. Two sites are situated on borders of the zones which suffered from fires. On site “South 1”, located southward Lake Elton, associations of Stipa lessingiana+Agropyron cristatum+A.desertorum dominate. Quadrats were organized on the 1st of June in 2015 on areas of facies with different levels of changes (burnt and untouched) and on borders of the burnt zone: 1) lightly-changed (seeing no fires for the last 5 years); 2) shattered geosystem, pyrogenous digression (having seen fires in spring of 2011, 2013 and in summer of 2014) (table 2). On another key site,
located northward Lake Elton, zonal associations of *Stipa capillata*+*Stipa zalesskii*+*Festuca valesiáca*+*Artemisia lerchian* prevail and signs of summer fires in 2011 are well observed.

**Table 2.** Pyrogenous transformations at the key site “South 1” of Elton natural park.

| №  | Plant species          | № 1 - untouched | № 2 - burnt untouched |
|----|------------------------|----------------|------------------------|
|    | abundance | pheno phase | height, cm | abundance | pheno phase | height, cm |
| 1  | *Stipa lessingiana*    | cop1 | drying | 20 | un | drying | 10 |
| 2  | *Agropyron cristatum*  | cop1 | fruiting | 40 | sol | fruiting | 30 |
| 3  | *Agropyron desertorum* | cop1 | fruiting | 40 | sol | fruiting | 30 |
| 4  | *Festuca valesiáca*    | sp | drying | 20 | sol | drying | 10 |
| 5  | *Artemisia lerchiana*  | sp | budding | 30 | sp | budding | 30 |
| 6  | *Medicago romanica*    | sol | flowering | 20 | - |
| 7  | *Euphorbia undulata*   | sol | flowering | 30 | - |
| 8  | *Artemisia austriaca*  | sol | vegetation | 15 | - |
| 9  | *Melilotus officinalis* | un | drying | 50 | - |
| 10 | *Onopordum acanthium*  | un | drying | 50 | - |
| 11 | *Euphorbia virgata*    | un | flowering | 40 | - |
| 12 | *Stipa capillata*      | un | flowering | 50 | - |
| 13 | *Poa bulbosa*          | cop1 | withered | 5-6 |
| 14 | *Bromus squarosus*     | cop1 | withered | 5-10 |
| 15 | *Ceratocephala testiculata* | cop1 | withered | 5-10 |
| 16 | *Lepidium ruderale*    | cop1 | withered | 5-10 |
|    | Total projective cover of plant (%) | 55-60% | 25-30% |
|    | Average height of herbage ( in cm) | 40 cm | 10 cm |
|    | Moss and lichen cover, projective cover | 10% | 0% |
|    | Average bioprodutivity of surface phytomass (dry), centner / hectare | 12-18 centner / hectare | 2-5 centner / hectare |

For comparative purposes, key sites were established on various areas of facies with different levels of changes: 1) light changes, 2) heavy changes. The overall projective coverage with grasses and dwarf semi-shrubs on site №1 is 40-50 %, average height of herbage is 35 cm; site №2 - 30% and 25 cm accordingly. The projective coverage with moss and lichen on site №1 is 10 %; site №2 - 5% accordingly. The productivity of ground phytomass on site №1 is 22.4 ha; site №2 - 5-7 centner per hectare accordingly. Due to frequent fires exhaustion increases in 1.5-2 times, height and species diversity of the vegetation cover goes down, forage herbs become rare. The proportion of large bunchgrasses and motley grass sharply declines, the amount of wormwood, *Poa bulbosa*, ephemers and weeds increases in 2-3 times. Steppe shrubs perish. Productivity of ground phytomass of zonal grass associations decreases in 3-4 times (table 2). These areas are simultaneously used as hay making areas and pastures which prevents self-restoration of grass cover, reduces species diversity, productivity and sustainability.

The results of our researches demonstrate that presently the bigger part of geosystems in Elton natural park are pyrogenous and pascual digressions. The main cause for the current critical geocological situation is fires on pastures which leads to progressive degradation of soil-vegetation cover and desertification. Elton region is the key ornithological area which draws the main line of one of the largest migration routes of Eurasia. Preservation of natural grass and shrub vegetation creates sheltering, nesting, resting, roosting and feeding places for many species, especially for little forest birds during spring and autumn migration flights.
Conclusions
In the result of long-term field landscape researches in Donskoy and Elton natural parks, the author has come to the conclusion that fires have an exclusively negative impact on landscapes of dry steppes and semi-deserts. For the long time biological productivity of geosystems considerably reduces (from 1.5 to 3 times in dry steppes, in 3-4 times in semi-deserts). Height and projective cover reduces, structure simplifies, homogeneity of vegetation cover increases. Wood-shrub vegetation dies out while soil fertility decreases. Wind and water erosion processes are being activated. Underground water level goes down and springs run dry. Steppe fires destroy sites of animal reproduction and habitats of rare and endangered species. Pyrogenous transformations of natural geosystems are the most threatening and real factor for biological and landscape diversity of steppes.

References
1. Steppe fires and management of the fire situation in the steppe PAs: ecological and nature conservation aspect. Analytical review 2015 (Moscow: Publishing house of the Center for Wildlife Conservation) p 144
2. Semenova-Tyan-Shanskaya A M 1966 Dynamics of steppe vegetation (Moscow-Leningrad: Nauka) p 172
3. Isakov Yu A, Kazanskaya N S and Tishkov A A 1986 Zonal features of ecosystem dynamics (Moscow: Nauka) p 309
4. Oparin M L and Oparina O S 2003 The influence of burns on the dynamics of steppe vegetation Povolzhskiy ecological journal 2 pp 158-171
5. Tishkov A A 2000 Fires in the steppes and savannas Questions of steppe studies 2 pp 9-22
6. Coffin D P, and Lauenroth W K 1989 Spatial and temporal variation in the seed bank of a semiarid grassland American J. of Botany 76 pp 53-58
7. Fire in North American tallgrass prairies 1990 ed S L Collins and L L Wallace (Norman, Oklahoma: Oklahoma University Press) p 238
8. Lavrenko E M 1950 Some observations on the effect of fire on the vegetation of the northern steppe (Poperechenskaya steppe of the Penza region) Botanical journal vol 35 2(42) pp 905-908
9. Rabotnov T A 1978 On the significance of the pyrogenic factor for the formation of vegetation cover Botanical Journal vol 63 11 pp 1605-1611
10. Rodin L E 1981 Pyrogenic factor and vegetation of the arid zone Botanical journal vol 66 12 pp 1673-1684
11. Malysheva G S and Malakhovsky P D 2000 Fires and their influence on vegetation of dry steppes Botanical journal vol 85 1 pp 96-103
12. Ryabinina N O 2012 Influence of fires on geosystems of dry steppes of the Donskoy Nature Park of the Volgograd Region Regimes of steppe specially protected natural areas (Kursk) pp 218-222
13. Ryabinina N O 2013 Natural and anthropogenic factors of variable dynamics of biological productivity of virgin geosystems of stipa and festuca steppes of the Eastern Don ridge Vestnik Volgogr. gos. un-ta Ser. 11: Estestvennye nauki 2(6) pp 62-68
14. Ryabinina N O 2018 The influence of fires on the steppe and semi-desert landscapes of the southeast of the Russian Plain (on the example of natural parks in the Volgograd region) Geography and natural resources 4 pp 38-46
15. Ryabinina N O 2015 Nature and landscapes of the Volgograd region (Volgograd, Volgu Publ.) p 370
16. Ryabinina N O and Shilova N V 2013 Research and prospects preservation of steppe calciphilous landscapes in the Volgograd region Vestn. Volgogr. gos. un-ta Ser 3: Ekonomika Ekologiya 1(22) pp 236-242
17. Levina F Ya 1971 Semi-desert zone South-east of the European part of the USSR (Moscow: Nauka) pp 230-240
18. Safronova I N 2005 The Desert Steppes of the Lower Volga Region Povolzhskiy Ekologicheskiy Zhurnal 3 pp 262-268