Effects of fire on production and destruction processes in steppe phytocenoses of Burtinskaya Steppe, Orenburg Nature Reserve

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Abstract. The paper deals with the production and destruction process in burned and unburned (control) steppe phytocenoses. The fire occurred in August 2014, after which a monitoring network consisting of 6 sites was laid out. During two vegetation seasons (2015–2016), we surveyed above-ground and below-ground phytomass stocks and on their basis production and destruction amounts in phytocenoses were calculated. Comparative analysis of control and burned communities revealed higher production and destruction of above-ground phytomass components in both years. With the general tendency for most phytocenoses to reduce above-ground production and increase litter in the second year of the survey, the first process was more intense in burned phytocenoses that were exposed to anthropogenic load in the past, and the second process occurred in almost all burned communities. In the below-ground sphere, mineralization processes were more intense during the entire survey period on control sites, and an increase in the mass of living and dead below-ground organs was more determined by the phytocenoses specifics, rather than their damage by fire.

1. Introduction
The urgency to study effects of fire on steppe vegetation cover is determined by the current tendency for increase in fire spread rate [1], deep transformation of steppe phytocenoses under influence of this factor, importance of steppe vegetation for agriculture, and the need to understand processes occurring in it when developing measures to preserve steppe ecosystems. In the Trans-Volga-Ural region, the beginning of fire intensification corresponds, in general, to the period 2002–2004, but some increased values were recorded in 1995 and 1998. In our study region, increased amount of fire events was observed across the entire area until 2010 [1]. High frequency of fires in steppe biome prevents vegetation from recovering and, therefore, resulting in dramatic rebuilt and destabilization of steppe communities.

To date, there are a significant volume of studies devoted to effects of fire on the vegetation cover of steppe. Pyrogenic factor was analyzed from the standpoint of changes in floral composition of phytocenoses [2–4], phytocenotic role of species [2, 5, 6], volume and dynamics of plant matter stocks [2, 7–15], production and destruction [3, 16]. Back in the second half of the twentieth century, many domestic and foreign ecologists repeatedly stressed the need to compare conditionally undisturbed and human-modified ecosystems using quantitative criteria, and, in particular, parameters of biological productivity [17]. The intensity and amount of production and destruction can be used as one of the
criteria for assessing effects of fires on vegetation cover. Understanding processes that occur in the steppe after a fire is necessary to develop approaches to conservation and restoration of steppe vegetation, especially in modern conditions, when the remaining virgin steppe is subject to protection and at the same time is in short supply.

2. Materials and Methods
The survey was carried out in Burtinskaya Steppe, Orenburg Federal Nature Reserve, in the Belyaevsky administrative district of the Orenburg region. The site with an area of 45 km² is located in the eastern part of the Pre-Ural Foredeep [18]. Botanically and geographically, this protected cluster is located in the Trans-Volga-Kazakhstan herb bunchgrass steppe [19, 20].

The survey years, based on weather conditions (Selyaninov’s hydrothermal coefficient values), were characterized as follows: 2014 was assumed as very dry, 2015 – as slightly dry and 2016 – as satisfactorily wet (table 1).

Table 1. Weather data for the Belyaevka meteostation during years of survey.

| Month | Years of Survey | 2014 | 2015 | 2016 |
|-------|----------------|------|------|------|
|       | Air Temperature, °C |      |      |      |
| May   |                | 18.8 | 15.7 | 16.2 |
| June  |                | 20.9 | 23.4 | 18.8 |
| July  |                | 19.9 | 21.5 | 21.6 |
| August|                | 24.5 | 19.5 | 26   |
| September |         | 14.8 | 17.2 | 14.6 |
|       | Precipitation, mm |      |      |      |
| May   |                | 41.5 | 90.3 | 77.2 |
| June  |                | 31.6 | 56.8 | 81.9 |
| July  |                | 26.4 | 28.9 | 71.3 |
| August|                | 16.6 | 25.3 | 8.3  |
| September |        | 12.9 | 14.5 | 62.2 |
| Selyaninov HTC for main vegetation season | | 0.4  | 0.7  | 1    |

The records of vegetation cover were carried out during two vegetation seasons of 2015–2016. For our survey we laid out 6 permanent sites throughout Burtinskaya Steppe and its protection zone. Each site consisted of two sections: burned (A) and unburned (B), and included 3 sample plots for burned and 3 sample plots for control communities, i.e. 6 sample plots in total for each site. Permanent survey sites were selected based on their availability, diversity (position in the terrain, vegetation cover, etc.) and the possibility to compare pairs of sample plots (burned and unburned). The survey sites were located along the contour of the 2014 burned area, and unburned (control) areas were selected in the closest possible proximity and similar conditions to the burned ones (figure 1).

Phytocenoses on the sites belonged to different associations of two formations – *Stipeta zalesskii* and *Stipeta lessingiana*. These formations are most common in the studied reserve cluster [21, 22]. Sites ## 1 and 3 were most affected by overgrazing in the previous unprotected period, and plot # 4, located in the reserve protective zone, was an old-aged fallow land. Geobotanical descriptions were performed using standard geobotanical techniques [23–27] on sample plots with a size of 10×10 m. Above-ground plant substance was recorded using the method proposed by N Bazilevich and co-authors (1978)[28]. The cuts were performed in each community during vegetation season: in spring (May), summer (June), late summer (August) and fall (September) periods. The plants were cut at ground level, on areas of 0.25 m² with 3 replicates. Plant substance stocks were described by the
following symbols: G – Living phytomass, L – Litter, D – Above-ground dead phytomass, R – Living below-ground organs, V – Dead below-ground organs.

Below-ground organs were counted on 2 sites (## 4, 5) using the monolith method [29, 30], on plots laid out for counting above-ground phytomass. After completing the cuts and collecting the litter, a 0.25 m² monolith was removed every 10 cm to a depth of 50 cm with 3 replicates on each site. Selected samples were washed in water using nets and sieves with small holes. Separation of below-ground phytomass into living and dead was carried out using S A Aliyev’s method (1966) [31]. In the laboratory, living and dead roots were dried out at 105° C to a completely dry state in a drying cabinet (SHS-40PZ). The processed samples, corresponding to a certain part of the vegetation cover, collected in one period and from one site, were summed up and recalculated in g/m².

Production and destruction processes were described using balance equations [28, 32]. In our study, we used common terminology and symbol system. The symbols ΔG, ΔD, ΔL, ΔR, and ΔV denoted growth in corresponding blocks. Decomposition of the litter was indicated by the symbol ΔM and below-ground plant residues by the symbol ΔW [33]. The intensity of processes was indicated by the following symbols: ANP – above-ground net primary production, BNP – below-ground net primary production, primary production NPP = ANP + BNP. For measuring stocks we used the unit g/m², and for measuring growth rate – g/m² per year.

Data analysis was performed using Statistica 6.1 software. To assess statistical significance of differences in the stocks of phytomass and its components on burned and control sites we used Mann-Whitney U-test (α=0.05).

3. Results and Discussion
Above-ground phytomass production and destruction growth rates are shown in table 2. Above-ground net primary production of control steppe communities varied significantly on different sites, depending on plant community type, its floral composition and economic development rates in the

![Figure 1](image-url)
previous unprotected period. In burned communities, despite the differences described above, production amounts were similar, which suggests that some features of phytocenoses were smoothed out in the first two years after the fire. In the first year after the fire, the production of control communities exceeded the production of burned communities by 1.2–5 times (with the exception of site # 4, where these amounts were almost equal), in the second year by 1.5–8 times (with the exception of site # 6, for the same reason).

The data obtained (table 2) indicated that in the second year above-ground production decreased on burned and almost on all unburned sites. At the same time, above-ground living phytomass stocks in burned communities increased in 2016, compared to 2015 (statistically significant differences were confirmed by the Mann-Whitney U-test, α <0.05). No such differences were found in the stocks of control communities. In 2016, net primary production of burned communities was 1.1–4 times less than in the previous year, and that of unburned communities was 1.3–2 times less (except for plots #4B, 5B, where the production in 2016 exceeded the production in 2015 by 1.4–2 times). The decrease in production along with an increase in stocks in burned phytocenoses was associated with an increase in stocks of above-ground dead phytomass and litter, which accumulated over two years, and intensification of destruction processes.

Production process in steppe burned and unburned communities was mainly characterized by the most intensive growth rate of the living phytomass in spring-summer period, namely from May to June, later growth rate declined. This period was characterized by development and flowering of the main dominants – firm-bunch grasses Stipa zalesskii Wilensky, S. lessingiana Trin. & Rupr., Festuca valesiaca Gaudin, Helicotrichon desertorum (Less.) Nevski. The largest portion of various forbs also produced living phytomass in spring and summer period. Net primary production in dwarf semishrubs, depending on the phenological characteristics, increased at the beginning or at the end of vegetation season. Forbs recovered faster in plant communities after firing, because their stocks in both the first and second years were very close to the stocks of the control communities. No statistical differences were found between the living forbs stocks on burned and control plots for two years according to the nonparametric Mann-Whitney U-test (at α<0.05).

**Table 2.** Above-ground phytomass production and destruction growth rates, g/m² per year.

| Year | 2015 | 2016 |
|------|------|------|
|      | ANP  |      |
| 1A   | 88   | 42   |
| 1B   | 192  | 103  |
| 2A   | 115  | 67   |
| 2B   | 175  | 103  |
| 3A   | 107  | 62   |
| 3B   | 520  | 398  |
| 4A   | 110  | 26   |
| 4B   | 112  | 218  |
| 5A   | 111  | 95   |
| 5B   | 141  | 196  |
| 6A   | 113  | 93   |
| 6B   | 216  | 101  |
|      |      |      |
| ΔD   | 99   | 117  |
|      | 168  | 151  |
|      | 81   | 121  |
|      | 197  | 205  |
|      | 124  | 200  |
|      | 508  | 178  |
|      | 56   | 266  |
|      | 103  | 115  |
|      | 104  | 146  |
|      | 164  |      |
|      | 133  |      |
|      | 197  |      |
|      | 40   |      |
|      | 143  |      |
|      | 69   |      |
|      | 125  |      |
| ΔL   | 69   | 107  |
|      | 134  | 211  |
|      | 12  | 79   |
|      | 130  | 215  |
|      | 83  | 38   |
|      | 329  | 260  |
|      | 36   | 74   |
|      | 160  | 79   |
|      | 40   | 137  |
|      | 143  | 131  |
|      | 69   | 69   |
| ΔM   | 61   | 107  |
|      | 0   | 211  |
|      | 6   | 79   |
|      | 130  | 215  |
|      | 56  | 38   |
|      | 321  | 260  |
|      | 27   | 74   |
|      | 169  | 79   |
|      | 30   | 137  |
|      | 74   | 131  |
|      | 42   | 69   |

*The intensity is assumed to be zero according to the minimum estimation method for intensity of formation and decomposition of plant organic mass (Bazilevich, 1978). 

Death of plant organs occurred (above-ground dead phytomass growth ΔD) during the entire vegetation season. In the first year after the fire, due to small amount of living phytomass in burned areas, compared to control communities, a smaller amount of above-ground dead phytomass was formed (table 2). In control phytocenoses, above-ground dead phytomass growth was 1.5–4 times in
2015, and 1.3–3.5 times in 2016 higher than those on burned plots. Between 2015 and 2016, the growth in burned and control phytocenoses was small, and in some control sites it declined. Growth of above-ground dead phytomass varied depending on phenological characteristics of various steppe plant species, was recorded in all periods, but increased in the late summer and fall, which was associated with transition of main parts of plants to the stage of dormancy and death of above-ground organs.

Growth of litter (ΔL) in burned communities in the first year after the fire was very small and varied between 12 and 83 g/m² per year. In 2015, as communities recovered, the stock of living phytomass increased, which turned into above-ground dead phytomass during vegetation season and contributed to growth of litter. In 2016, transition of above-ground dead phytomass to litter increased by 1.1–10 times and varied in different communities between 88 and 148 g/m² per year. In control communities, the litter growth varied between 125 and 329 g/m² per year in 2015, and between 184 and 339 g/m² per year in 2016 (table 2). In 2016, it increased in all phytocenoses by 1.1–2 times, but when comparing pairs of plots (burned – unburned), it was clear that in each of them this increase was more pronounced in burned phytocenoses than in unburned ones.

Steppe mat thickness was highly susceptible to seasonal variability due to different rates of litter fall accumulation and decomposition. The greatest increase in litter was observed in the late summer, fall and spring periods. In control communities, the growth of litter was 2–10 times higher than that of in burned areas in 2015, and 1.5–3 times higher in 2016.

In burned communities mineralization (ΔM) varied between 6 and 61 g/m² per year in 2015, and between 38 and 137 g/m² per year in 2016. Mineralization of litter in burned phytocenoses was small, which was primarily due to its small stocks. In control communities, mineralization in different phytocenoses varied between 69 and 321 g/m² per year in 2015, and between 79 and 260 g/m² per year in 2016 (table 2).

The most intensive destruction of litter (ΔM) was observed in 2015 in spring and early summer periods, when an increase in precipitation (see table 1) led to activation of mineralization processes in communities. In 2016, mineralization of plant residues occurred during the entire vegetation season, but in the late summer and fall period it was more intense, due to an increase in precipitation and replenishment of litters. In most of surveyed phytocenoses, mineralization process was more intense in wet 2016 than in dry 2015, with the exception of unburned plots #3, 4 and burned plot #3, where mineralization was more intense in 2015. In 2015, mineralization was 1.5–22 times higher in control communities compared to the burned ones, with the exception of unburned plot #1, where mineralization was minimal. In 2016, mineralization increased both in control and in burned plots, the former exceeding the latter by 2–7 times.

The above analysis indicates that deviations from general trends in the mineralization dynamics occur in areas anthropogenically disturbed in the past (## 1, 3, 4).

Below-ground phytomass stocks were determined only on plots #4, 5 in spring, summer and fall periods, so the production was calculated in two periods: from May until June and from June until September.

In 2015, below-ground phytomass production ranged from 525 to 1,100 g/m² per year on control plots, and from 562 to 596 g/m² per year on burned plots. The following year, it varied between 177 and 380 g/m² per year in control phytocenoses, and reached 232 g/m² per year in burned communities (table 3).

Intensity of production process in the below-ground phytomass block differed on two burned plots: production was higher in control communities for two years on plot #4, and it was lower on plot #5. This may have been due to phytocenotic structure of burned and control communities of plot #4 in 2015. In burned phytocenoses, the projective cover of various forbs during this period played a more significant role in formation of above-ground phytomass, compared with control phytocenoses (due to the increased abundance of Galium octonarium (Klokov) Soó, Hedysarum argyrophyllum Ledeb., Potentilla glaucescens Schldl. и др.), which influenced the increase in below-ground production. In 2015, projective cover values of the remaining groups on burned plots were less than
those on control plots. However, in the second year of our survey, the projective cover of all living forms on control area was higher than on burned area, although the intensity of production was still higher in burned area.

On plot # 5, for two years, below-ground production of unburned phytocenosis was greater than production of burned one, and that was also true for the total values of the projective cover of various phytocenosis fractions.

Differences in production on various survey sites can be attributed to relief patterns (plot # 4 was a gently sloping plain, and # 5 was a hill top); economic use in the past (plot # 4 was old-aged fallow land and plot # 5 was virgin steppe); differences in vegetation cover structure (plot # 4 Stipeta lessingiana formation, and plot # 5 was Stipeta zalesskii formation).

In 2015, production of below-ground phytomass recorded in burned community on plot # 4 slightly exceeded production on control plot, which might be due to the death of some of living below-ground organs after the fire and the need to compensate them in spring. On plot #5, production of control community was almost twice as large as production recorded in burned phytocenosis. Growth of living roots was most intense in spring-summer period, when above-ground phytomass of cereals had already formed, after which below-ground phytomass actively started. Above-ground and below-ground phytomass of various forbs is produced simultaneously in the same period [33, 34].

In 2015, growth rate of dead below-ground phytomass (ΔV) varied between 142–618 g/m² per year on control sites, and between 240 and 426 g/m² per year on burned sites. The data obtained (table 4) indicated that burned phytocenoses were characterized by high values of the indicator describing transition of living roots to dead ones. In the following year, ΔV in burned communities was 199–299 g/m² per year, in control phytocenoses it varied between 160 and 290 g/m² per year. In this year, on site # 5, ΔV was almost equal in control and burned communities, and on site # 4, in burned phytocenoses, it was 1.2 times more than on unburned ones. The area specifics seemed to be important in reaching balance between ΔV values in fire-affected and control phytocenoses: site # 4 was old-aged fallow land, and site # 5 was virgin steppe area. At the latter site, ΔV reached the values of control phytocenosis faster. At the same time, control sites demonstrated ΔV increase in the second half of vegetation season, and burned sites did so in the first half of the season.

In above-ground sphere, production and growth of dead roots was more intense on site # 4 in burned phytocenosis, and on site # 5 in unburned one.

Mineralization (ΔW) of below-ground phytomass in burned communities in the first year after the fire reached 303 g/m² per year, in the second year – 319 g/m² per year, in the control it varied between 70 and 518 g/m² per year and between 100 and 340 g/m² per year, respectively. In both years of the survey, mineralization in control communities was higher than in burned ones. Mineralization process proceeded evenly throughout vegetation season and we found no clear predominance by month.

In 2015, the total production (NPP) in control communities varied between 637 and 1,241 g/m² per year, in 2016 between 395 and 576 g/m² per year. By 2016, it decreased by 1.5–2 times. In burned

| Year | 2015 | 2016 |
|------|------|------|
| Plots | 4A  | 4B  | 5A  | 5B  | 4A  | 4B  | 5A  | 5B  |
| ΔR (BNP) | 562 | 525 | 596 | 1100 | 232 | 177 | 0   | 380 |
| ΔV     | 240 | 142 | 426 | 618  | 199 | 160 | 299 | 290 |
| ΔW     | 0** | 70  | 303 | 581  | 0   | 100 | 319 | 340 |

*The intensity is assumed to be zero according to the minimum estimation method for intensity of formation and decomposition of plant organic mass (Bazilevich, 1978).
communities, net primary production varied between 672 and 707 g/m² per year in 2015, and between 95 and 258 g/m² per year in the second year. From 2015 to 2016, production of burned phytocenoses decreased by 2.5–7 times. The total net primary production of control communities within two years was naturally higher than production of burned phytocenoses. Plot # 4 was an exception due to a small difference in BNP with almost the same ANP as control community (table 4).

| Year | 2015 | 2016 |
|------|------|------|
|      | Plots |      |
|      | 4A    | 4B   | 5A   | 5B   | 4A    | 4B   | 5A   | 5B   |
| ANP  | 110   | 112  | 111  | 141  | 26    | 218  | 95   | 196  |
| BNP  | 562   | 525  | 596  | 1100 | 232   | 177  | 0    | 380  |
| NPP  | 672   | 637  | 707  | 1241 | 258   | 395  | 95   | 576  |

4. Conclusion

Production, growth and decline of above-ground phytomass components after the fire were higher in control phytocenoses in both years. With the general tendency for most phytocenoses in the second year of the survey to reduce above-ground production and accumulation of litter, the first process was more intense in burned phytocenoses that were exposed to anthropogenic influence in the past, and the second process occurred in almost all burned communities. In below-ground sphere, on burned plot # 4 and control plot # 5, production processes were more intense and an increase in dead roots was recorded. Mineralization processes in below-ground layer were more intense in control sites during the entire survey period. In this paper, we considered the changes in production-destruction process in burned and control steppe ecosystems. The pyrogenic factor significantly affected production and destruction patterns, while the phenological features of species and weather conditions in the study area actively contributed to this process.

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