Post-fire successions in protected mountain forests of Crimea

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Abstract. Forest fires are one of the most powerful factors, not only in Russia, but all over the world. It affects the structure of ecosystems and causes the landscape transformations in it. In Crimea, the ‘Krymskiy’ National Park, where research was conducted, is a major keeper of population natural forests. Post-pyrogenic changes in vegetation cover were studied in pine phytocenoses (Pinus sylvestris L., Pinus pallasiana D. Don.) and juniper phytocenoses (Juniperus communis subsp. hemisphaerica C. Presl., Juniperus sabina L.). The investigated areas were covered by fire different intensivity 2-37 years ago. It was found that the surface fires damages all elements of the forest phytocenosis. The juniper forests burn down completely and have not recovered in a period of up to 20 years. Forest fires cause secondary post-fire (pyrogenic) regressive succession in the mountain forests of Crimea. Herbaceous plants appear on the investigated sample areas where the forest is burnt: violent competitor plants (K-plants); stress-resistant plants (C-plants) and ruderal plants (P-plants), as well as – plants-pyrophytes. In the first years after a forest fire, the herbaceous plant community is more diverse and aligned. In subsequent years, the number of species decreases, and the index alpha plant diversity value also decreases.

1. Introduction

Forest fires are one of the most powerful factors, not only in Russia, but all over the world. It affects the structure of ecosystems and causes the landscape transformations in it [1-3].

During the period of 2009-2017, 583 forest fires occurred on the territory of the Republic of Crimea, of which 189 occurred on the territory of the ‘Yalta mountain forest nature reserve’. The total area of forest fires was 721.26 ha, including 6 ha of crown fires. During the same period, 13 forest fires occurred on the territory of the National Park ‘Krymskiy’ on an area of 123.2 ha.

The protected areas and objects are the basis of the ecological network and play the role of a ‘bank’ of the gene pool of the plant and animal world, since it is created primarily in territories that differ in the richness of fauna and flora and its diversity. On the territory of Crimea with the area of 2,700,000 ha created 8 specially protected natural territories (PNT) of Federal significance on the area of 129,697.7 ha. 107 specially protected natural territories of regional value in the area of 44,118.5 ha, which is 6.5% of the total area of the Peninsula. The total area of forests in Crimea is 290.3 thousand
ha or 11.17%, of which are forests, located on land specially protected natural area, constitute 51,897.3 ha or 17.9% of the Peninsula's forest area.

The Red Book of Crimea in 2015 includes Juniperus sabina L., Juniperus communis L. Meanwhile Juniperus communis L. quite changeable and plastic species, one of the ecological forms is Juniperus communis subsp. hemisphaerica C. Presl. (recommended for special protection). The Red Book of Russia includes the following species Pinus pallasiana D. Don., however, its Crimean population was excluded from the Red list of the Russian Federation in 2019 [4].

The study of the impact of fires on coniferous stands in the protected forests of the mountainous Crimea is carried out in order to reserve unique forests and to develop measures to prevent negative consequences.

In scientific research, post-fire (pyrogenic) succession is most often found in coniferous forests and is the research subject. The dynamics of plant species occurrence after a fire makes it possible to understand the essence of succession changes, the set of dominants and subdominants, and the transformation of forest landscapes [1, 5].

By area in the mountainous Crimea, Crimean pine plantations prevail. Scots pine natural stands form forests in dry conditions on relatively poorly fertile soils. [6]. The ‘Yalta mountain forest reserve’ with an area of 4.7 thousand ha or 55% is a major keeper of population natural pine forests, while the ‘Krymskiy’ National Park is represented by a share of 23.6% of the area, or 2 thousand ha [7, 8]. It is known that juniper Phytocenoses on the lower plateau of Chatyr-Dag are represented by two species Juniperus sabina L. and Juniperus communis subsp. hemisphaerica C. Presl, covering an area of 38.8 ha or 0.2% of forest land and 80.5 ha or 0.3% [8].

The aim of this research is to determine the direction and type of successional changes occurring under the influence of fires of different intensities in the coniferous forests of the Crimean mountains and to evaluate the possibility of restoring native forest phytocenoses.

2. Material and methods

After reconnaissance inspection of places passed by forest fires and analysis of forest descriptions, the sites were selected for made sample areas for studying pyrogenic successions [9].

In the course of the study, 6 sample areas were laid in pine phytocenoses and 3 sample areas in juniper stands. The taxational characteristics of sample areas in pine phytocenoses are presented in table 1.

The first sample areas are laid in native forests Pinus sylvestris L., passed by a surface sustainable fire, 4 sample areas (number 2-5) in native forests Pinus pallasiana D. Don. where the surface fire was runaway and steady, the pine forests were saved. The sample areas №6 were laid in a deciduous young forest, formed 37 years after the forest fire. The layout of the sample areas and surveyed areas is shown in figure 1. All work types provided by standard methods were performed on sample areas, size of 0.25 ha [9]. For each sample area, the following are defined: slope exposure, slope °, altitude above sea level, m; forest site type; species of tree; forest age; projective covering of tree crowns (completeness); set age after fire; site quality in points; standing volume; number of dead trees. Based on the studies of the components of the phytocenosis in the areas, it was established succession direction and stage [9]. Table 2 shows the characteristics on burnt areas juniper shrubs.

In the studied trial areas, regressive exoecogenetic successional changes are observed in low-growing juniper plantations, which pass through the initial stage (3 years after the fire) and the meadow stage (13 and 20 years after the fire). After a forest fire, the number of plant species increases. The list of plants is changing where junipers grew, after the fire, their place was taken by grasses, mosses and lichens.
### Table 1. Characteristics of the sample areas in burnt pine forests of varying intensity of fire.

| Taxation index | No. Sample areas |
|----------------|------------------|
| Division, site | 1 2 3 4 5 6      |
| Slope exposure, |                  |
| slope°, altitude |                  |
| above sea level, m |                  |
| Forest site types | moderately moist fertile soil | dry fertile soil | dry fertile soil | dry fertile soil | dry fertile soil | moderately moist fertile soil |
| Species of tree | Pinus sylvestris | Pinus pallasiana | Pinus pallasiana | Pinus pallasiana | Pinus pallasiana | Fagus orientalis |
| Forest age, years | 25 55 | 200 | 200 | 199 | 119 | 259 | 139 | 5-30 |
| Area age after fire, years | 2 | 3 | 8 | 8 | 12 | 12 | 37 |
| Forest height, m | 6 | 25 | 26 | 25 | 21 | 27 | 22 | 8 |
| Average diameter, cm | 16 | 28 | 44 | 48 | 28 | 52 | 28 | 6 |
| Completeness | 0,6 | 0,7 | 0,8 | 0,6 | 0,6 | 0,6 | 1,0 |
| Site quality | 5 | 3 | 3 | 3 | 2 | 2 | 2 |
| Tree trunk height after fire, m <6 | >5 | <3 | 0,5-14,5 | 0,5-8 | До 8 |
| Standing volume, m³/ha | 570 | 560 | 710 | 530 |
| Number of dead trees | 198 | 110 | 15 | 19 | 4 |
| Succession direction | regressive |
| Succession stage | initial |

### Table 2. Characteristics of sample areas on burnt areas of juniper shrubs form creeping.

| No. | Fire year, fire place age, fire type | Division/site | Composition of tree species before fire | Succession direction | Succession stage |
|-----|-------------------------------------|---------------|----------------------------------------|----------------------|-----------------|
| 1.  | 2015, 3 years, surface fire, sustainable | 334/41       | Juniperus communis, form creeping       | Regressive ekzoecogenetic | initial |
| 2.  | 2005, 13 years, surface fire, runaway  | 334/10       | Juniperus communis, form creeping (80%), Juniperus sabina (20%) | Regressive ekzoecogenetic | meadow |
| 3.  | 1998, 20 years, surface fire, sustainable | 7/1          | Juniperus communis, form creeping (90%), Juniperus sabina (10%) | Regressive ekzoecogenetic | meadow |
One of the main indicators of the abundance of plant species is the projective cover of certain species. Determination of the projective cover of species for the determination of dominants and subdominants based on the presence of living species of vegetation was carried out on the sample plots we laid (table 1-2, figure 1).

![Figure 1](image-url)  
**Figure 1.** Schematic location map of quarter passed by forest fires and sample areas.

We determined the projective cover of each species on sites measuring $2 \times 2$ meters as a percentage of the site area. The total coverage does not equal the sum of the species coverage as the terrestrial parts of the plants overlap. At each sample area, 10 plots were laid 5 meters diagonally across the site.

The height of fire damage on a tree trunk after a fire was determined by the method of Edeny, Usenay and al. [10]. The alpha diversity was assessed using Shannon indices, alignment of Shannon, Simpson, and Margalef to determine the state of vegetation after wildfires.
3. Results and discussion
In figure 1 indicates the Federal territory of the National Park ‘Krymskiy’ area of 34.5 thousand ha, and specially protected natural territories of regional value of ‘Chatyr-Dag’ with an area of 0.9 ha. The map-schematic shows the division after the forest fires. Fires mainly arise in the most valuable coniferous forests. Each forest division has its own colour depending on how many times there were fires in them. The mapping makes it possible to determine the most fire-danger areas in which scientific research and preventive work should be carried out. The recent large fires have highlighted the importance of understanding post-fire processes in forest ecosystems, in order to implement ecologically sound post-fire forest restoration practices [11].

The frequency and area of forest fire propagation are characterized in connection with the dynamics of climatic factors. The temperature regime is shown to exert the most noticeable influence on the implementation of pyrogenic factors under the conditions of the southern macroscope of the Main Ridge of the Crimean Mountains [12].

In recent decades, the frequency of catastrophic forest fires has increased pine forest on the southern macroslope of the Main ridge of the Crimean mountains. At the same time, as the most severe consequences of major fires of the last however, it is necessary to highlight unsatisfactory natural renewal, deep transformation of the species and ecological structure of forest biocenoses. [13].

The number of fires or area burned has increased recently in parts of the northern temperate zone, but is climatic change responsible. The landscape may shape potential responses to climatic change, leading to disequilibrium between climate and fires.

To assess successional changes in burnt areas, the study of the species composition of the ground cover is often used. Stančič L and Repe B are found that the plant species composition of burned areas is similar to that of areas unaffected by wildfire. The settlement of the plant species by the pioneers took place 5 years after the fire [14].

It was noted that Scots pine is more resistant to fire than spruce. Stabilization of the ground cover and shrubs occurs 150 years after the fire [15].

Rainsford and all are note that not only the amount of elapsed time is important for plant regeneration after fires, but also the characteristics of the forest before the fire, as well as the type and severity of the fire [16].

On sample areas number 1-4 in pine forests, it was found that a surface fire damage all elements of the forest phytocenosis. The degree of damage depends on the nature of the forest fire (runaway or steady). In case of sustained surface fires, the undergrowth, scrub, and living ground cover are destroyed. The percentage of trees falling off according to the method is not uniform, it depends on the average diameter of the trunk and the height of a tree trunk after the fire. The undergrowth after a forest fire is restored vegetative and it is represented by the following species: *Quercus petraea* (Matt.), *Acer stevenii* Pojark., *Fagus sylvatica* L., *Fraxinus excelsior* L., *Cornus mas* L. During the survey of experimental areas there are single annual seedlings *Pinus pallasiana* D. Don. and *Pinus silvestris* L. There are types of non-tiered vegetation: *Hedera helix* L., *Clematis vitalba* L., *Rubus caesius* L., who are actively trying to develop the liberated territory. The ecological conditions of the burned sites were generally hospitable for natural forest regeneration [17].

On trial area 6, after 37 years after the fire, the coniferous forests were replaced by dense undergrowth of deciduous trees.(table 1) The age of 5-25 years: *Fagus sylvatica* L. (80%), *Fraxinus excelsior* L. (10%), *Acer stevenii* Pojark (10%), *Pinus sylvestris* L. (>10%), *Pinus pallasiana* D. Don (>10%). The pine staddle appeared a few years after the fire, then hardwood undergrowth began to prevail, which overtook conifers in growth, they fell behind and shrank. No other elements of forest phytocenosis were found. The natural restoration after large fires depends on regeneration (e.g., from seeds and sprouts) of the remaining trees that have sustained less damage, until secondary forests are established [11].

One of the founded indicators post fire succession is a change in species compositions of ground cover. On surveyed us sample areas in figure 1. Types of dominant ground cover of pine phytocenose sare shown in figure 2.
Figure 2. Histogram of dominant species of herbaceous plants on burning in pine forest.

On the plateau of Chatyr-Dag mountain, the low-level forest fires destroy all elements of the phytocenosis: living ground cover, litter, and a stand of low-growing juniper stalks. After the fires of 1998, 2005, and 2015, the juniper elms are not restored and the ecosystem is transformed (plants, the fertile layer are burned, and rock outcrops are exposed), as can be seen in figure 3.

Figure 3. Landscape of the territory after a low-level forest fire in 2005 on the plateau of Chatyr-Dag.

The transformation degree of the living ground cover under the action of the pyrogenic factor is determined by both the pre-fire type of forest and the strength of the pyrogenic effect. In the first years after fires, regardless of the intensity, there is a decrease in the projection coverage and phytomass of the living ground cover [18].

In the first years, the place freed from vegetation is occupied by pioneer plants (Poacea and Cyperaceae, Teucrium Chamaedrys L.). 13 years after the fire, the pioneer vegetation is replaced by meadow vegetation, and small shrubs begin to appear (Rubus caesius, Rosa spinosissima). After 20 years, the meadow stage continues, single shrubs, coniferous and deciduous trees appear in the phytocenosis. The percentage of species of herbaceous plants participation is shown in figure 2.

The species richness of the burned stands was significantly higher than in the neighboring forests, which were not affected by any recent fire. But maximum species diversity was reached 3 years after the fire. A management regime that supported bare sand and heath areas, as well as the removal of all
but single pines, was found insufficient to support the full range of species dependent on forest fires [19].

The detailed studies of living ground cover in places where the fire destroyed the entire phytocenosis were carried out. The vegetation types that occur in the burning areas are shown in figure 4.

![Figure 4](image-url)

**Figure 4.** Histogram of dominant species of herbaceous plants on burning in juniper plantation.

On the histogram (figure 2) the dominant species at different stages of secondary pyrogenic succession are indicated, the occurrence of which was less than 10% is excluded. Most species are perennial plants that emerge from underground parts that have survived forest fires. The dominants and subdominants of the harem vegetation cover replace each other at different stages of secondary succession [1]. At the initial stage, the pioneer group of plants is dominated by: *Helianthemum grandiflorum* (Scop.) DC., *Teucrium chamaedrys* L., *Capsella bursa-pastoris* (L.), *Fragaria vesca* L., *Achillea setacea* Waldst. & Kit., *Poa cespitosa* and *Cypripedium*.

At the meadow stage: *Thymus tauricus* Klokov & Des.-Shost., *Achillea setacea* Waldst., *Plantago lanceolata* L., *Cruciata taurica* (Pall. ex Willd.)

At the control research area: *Helianthemum grandiflorum* (Scop.) DC., *Thymus tauricus* Klokov & Des.-Shost., *Fragaria vesca* L., *Achillea setacea* Waldst. & Kit., *Poaceae and Cypripedium*, *Stellaria media* (L.) Vill. *Carduus arborescens* Jacq.

At the same time, a significant area of 60% is occupied by *Juniperus sabina* L., *Juniperus communis* subsp. *hemisphaerica* C. Presl.

In the main native phytocenoses of the mountainous Crimea, the plants are distinguished by the ability of the species to grow together in phytocenosis: violent plants, competitors (K-plants); stress-tolerators plants (S-plants) and ruderals plants (R-plants), but also – plants-pyrophytes that emerge from underground parts that have survived forest fires.

To assess the alpha-diversity in the burning juniperlow-grow, we calculated Shannon index, the Shannon equalization index, Simpson index and Margalef index. These calculations are shown in table 3.
Table 3. Alpha-diversity indices of ground cover on burning areas in juniper communis (shrubs form creepy), juniper sabina.

| Number of years after a forest fire | 20  | 13  | 3   |
|-------------------------------|-----|-----|-----|
| Number of species             | 20  | 25  | 29  |
| Shannon index                 | 2.51| 2.50| 2.89|
| Shannon qualization index     | 0.84| 0.78| 0.86|
| Simpson index                 | 0.85| 0.91| 0.93|
| Margalef index                | 3.24| 3.73| 4.35|

The Shannon, Simpson, and Margalef indices show that in the first years after a wildfire, the herbaceous plant community is more diverse and aligned. In subsequent years, the number of species decreases, and the index value also decreases. In all communities there are dominant species with a large number of individuals, subdominant and random species, the number of which is very large, also plant species whose numbers are extremely low. In addition the structure of dominance undergoes seasonal spatial changes.

The dendroecological reconstructions of historical fire frequency, severity, spatial variability, and extent, supported by other evidence, are important in addressing these issues. Collectively it demonstrates the importance of ecosystem-specific research that can guide management aiming to safeguard human, cultural and biological values in fire-prone forests and enhance forest resilience to the cumulative effects of global environmental change [19].

4. Conclusion
As a result of this research, the set aim was achieved: the direction and type of successional changes occurring in forest phytocenoses were determined, changes in vegetation at different stages of post-fire succession were shown.

The fires in the mountain forests of Crimea cause pyrogenic secondary succession, regressive orientation. During which forest landscapes are transformed. What is observed in the change of dominant plant species in the forest phytocenosis at different stages of secondary pyrogenic succession. In valuable low-growth juniper plantations, it is irreversible. In indigenous pine forests, they depend on the degree of fire impact on the forest phytocenosis, forest types, and the frequency of fires in forest ecosystems. Post-fire sucessions have a long succession series. In the main native phytocenoses of the mountainous Crimea, plants are distinguished by the ability of the species to grow together in the phytocenosis: competitors (K-plants); stress-tolerators plants (S-plants) and ruderals plants (R-plants), but also – plants-pyrophytes. Our researches in mountain forests Crimea confirmed the conclusion that indicators of alpha plant diversity show that in the first years after a forest fire, the herbaceous plant community is more diverse and aligned. In subsequent years, the number of species decreases, and the index value also decreases.

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