THE FIRE HISTORY IN PINE FORESTS OF THE PLAIN AREA IN THE PECHORA-ILYCH NATURE BIOSPHERE RESERVE (RUSSIA) BEFORE 1942: POSSIBLE ANTHROPOGENIC CAUSES AND LONG-TERM EFFECTS

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The assessment of the succession status and the forecast of the development of pine forests depend on their origin and need a detailed study of historical and modern fire regimes. This article summarises the information on the dynamics of fires in the forests of the plain area in the Pechora-Ilych Biosphere Reserve (Russia) before 1942. Current forest fires in the pine forests in the Pechora-Ilych Biosphere Reserve are a legacy of previous traditional land use on this territory. Thanks to the material analysis of the first forest inventory, the condition of the forests of the plain area was assessed for the first time 10 years after the foundation of the Pechora-Ilych Biosphere Reserve. It was shown that about 50% of the forests of the modern plain area (most of the lichen, green moss-lichen and green moss-shrub communities) at that time were already touched by ground and crown fires. The population got accustomed to the smoke along the tributaries of the Pechora and the Ilych rivers, so that they reflected it in the names. Perhaps, for several centuries, fires were initiated by the Mansi, who used this territory as winter pastures until the middle of the 19th century. Eventually, a small human population actively visited the forests having the purpose of logging, hunting, gathering of wild-growing plants and fishing. The interfluve of the Pechora and Ilych rivers was a mosaic of land, divided between the inhabitants of various villages. Careless handling of fire led to numerous uncontrolled fires that no one put out and as a result, vast territories of forests were burnt. After the formation of the Pechora-Ilych Biosphere Reserve, these pine forests continued to burn, but much less. Since the plain area adjoins the navigable River Pechora, the anthropogenic causes of these fires cannot be completely ruled out. At the same time, we do not exclude the possibility of fires from dry thunderstorms. However, when assessing the modern fire regime, it is important to remember that the high fire danger in these forests is a legacy of previous impacts, which requires further study.

Key words: boreal forests, ecosystem legacy, forest fires, land use, Northern Urals, pine forests, primary forests, succession

Introduction

One of the most powerful factors influencing the formation of boreal forests for thousands of years is forest fire. The fires had an effect on the structure, dynamics and biogeochemical cycles in forests (Goldammer & Furyaev, 1996; Randerson et al., 2006; Smirnova et al., 2017). At present there is an ongoing debate on causes of fires and the role of traditional land use (Bowman et al., 2011; Vanniиre et al., 2016; Kipfmueller et al., 2017; Kuosmanen et al., 2018; Dietze et al., 2018). The arguments are going on for a long time because the occurrence and spread of fires in different territories depended on a variety of both anthropogenic and natural causes, which vary on spatial and temporal scales (Whitlock et al., 2010). Recently, the importance of climatic conditions as a driving force of forest fires in European boreal forests for decades is already shown in the period of strong human influence on the occurrence of fires (Aakala et al., 2018). At the same time, an analysis of the history of fires and climatic characteristics in specific territories shows that even the increase in the number of fires cannot be connected only with the current climatic changes (Chibilev et al., 2016). The number of fires and the spread of fire can be directly related to anthropogenic factors, primarily to traditional land use (Wallenius, 2011). It should be admitted that in Russia, despite the ongoing evolution of forest pyrology, such publications are practically absent (Tikkanen & Chernyakova 2014; Burlakov & Drovnina, 2015).

At the same time, it is extremely important to consider the longevity of fire effects and their possible consequences while doing research of forest ecosystems. These effects constitute «ecosystem memory» and can manifest themselves for a long time (Jxgiste et al., 2017). They include changes in the species composition of the forest stand, age, morphological and spatial distribution, ontogenetic composition, horizontal structure, biodiversity and productivity (Evdokimenko, 2008; Lankia et al., 2012; Smirnova et al., 2017; Aleinikov et al., 2018; Mishko et al., 2018). The response of forest ecosystems to subsequent disorders is like the legacy of previous impacts (Rhemtulla & Mladenoff 2007), although it has been studied less. It is necessary to understand the role and mechanisms of this legacy not only to work out the methods of control that help sustain forests, but also to explain the current dynamic processes.

The pine (*Pinus sylvestris* L.) forests, widespread in the Russian North, are pyrogenic formations (Sambuk, 1932; Korchagin, 1954; Kolesnikov, 1985; Wallenius et al., 2007); moreover they are widely represented in protected areas. The assessment of the succession status and the forecast for the development of these forests directly depends on their origin, besides historical and modern fire regimes need to be studied thoroughly. However, the long history of fires can be reconstructed only with the help of focused research in model territories. Forests of specially protected areas, preserved in the first third of the 20th century, are extremely important subjects for such studies. All management interventions and natural disturbances are recorded there.

The Pechora-Ilych Biosphere Reserve (hereinafter – PIR) has been the subject of complex studies of forest ecosystems and the history of land use for many years (Smirnova et al. 2013; Aleinikov & Chagin, 2015; Aleinikov, 2017a; Ershov et al., 2017). The fire history in dark-coniferous (spruce – *Picea obovata* Ledeb., fir – *Abies sibirica* Ledeb., cedar – *Pinus sibirica* Du Tour) and light-coniferous (*Pinus sylvestris* L.) forests of the submontane area was studied (Aleinikov et al., 2015, 2017; Bobrovsky & Spai, 2017). The fire history on the plain area in the PIR has been studied less. Nevertheless, fires were reconstructed from 1434 to 1954, based on detailed dendrochronological research, as well as to attempt to separate fires determined by the climatic factors from those which were determined by anthropogenic factors (Drobyshev et al., 2004). The question on causes of previous wildfires remains open for discussion. In order to exclude or confirm the role of anthropogenic factor, it is necessary to have accurate data on ethnic makeup, human population of the territory in various periods, and time of forming settlements. It is important to know features of traditional land use and landscape development.

At present, pine forests on the plain area in the PIR are still an important object for studying their composition, structure, and productivity. The analysis of the age structure of a particular stand of trees on plots has shown that forest fires have affected these trees (Kutyavin, 2018). However, these results do not allow estimation of sizes of the previous fires and assessment of fires' long-term effects. At the same time, it is extremely important to reconstruct the history and spatial extremes of the previous forest fire sizes in order to estimate the succession state of these forests and possible realisation of ecosystem functions.

To evaluate the current succession processes in the pine forests of the plain area in the PIR and their succession status, it is necessary: (i) to analyse the state of the forests of the plain area in 1942; (ii) to generalise the data on fires on the territory of the plain area at different periods of time; (iii) to evaluate the possible role of previous traditional land use and forestry when forest fires occurred before the formation of the PIR.

Material and Methods

Study area and characteristics of terrestrial ecosystems of the plain area in the Pechora-Ilych Nature Biosphere Reserve

Studies were conducted in the PIR (South-East of the Komi Republic, Russia) in the interfluve of the Pechora and Ilych rivers (Fig. 1). It forms one of the largest intact landscapes in Europe, widely known as UNESCO world heritage «Virgin forests of Komi Republic». In 1930, the PIR of 11 346 km^2 was established. In 1951, its area was reduced to 930 km^2. In 1959, it was expanded to 7213 km^2.

From 1959 to the present day, the PIR consists of two separate sections of different size. A small section (hereinafter the «plain area») with an area of 158 km^2 is located on a plain, on the right bank of the River Pechora in the southwest of the interfluve of Pechora and Ilych rivers (Fig. 1a). A large section (hereinafter the «foothill area») with an area of 7055 km^2 is located in the eastern, mountainous part of the Pechora-Ilych watershed (Fig. 1b).

The plain area is located in Pechora plain, which is a huge plain. Low altitudes distinguish it not more than 150–175 m a.s.l. and monotonous relief. The relief is undulating due to rare hills and ridges. The surface of the plain area is covered with thick quaternary sediments composed of fluvioglacial sands.

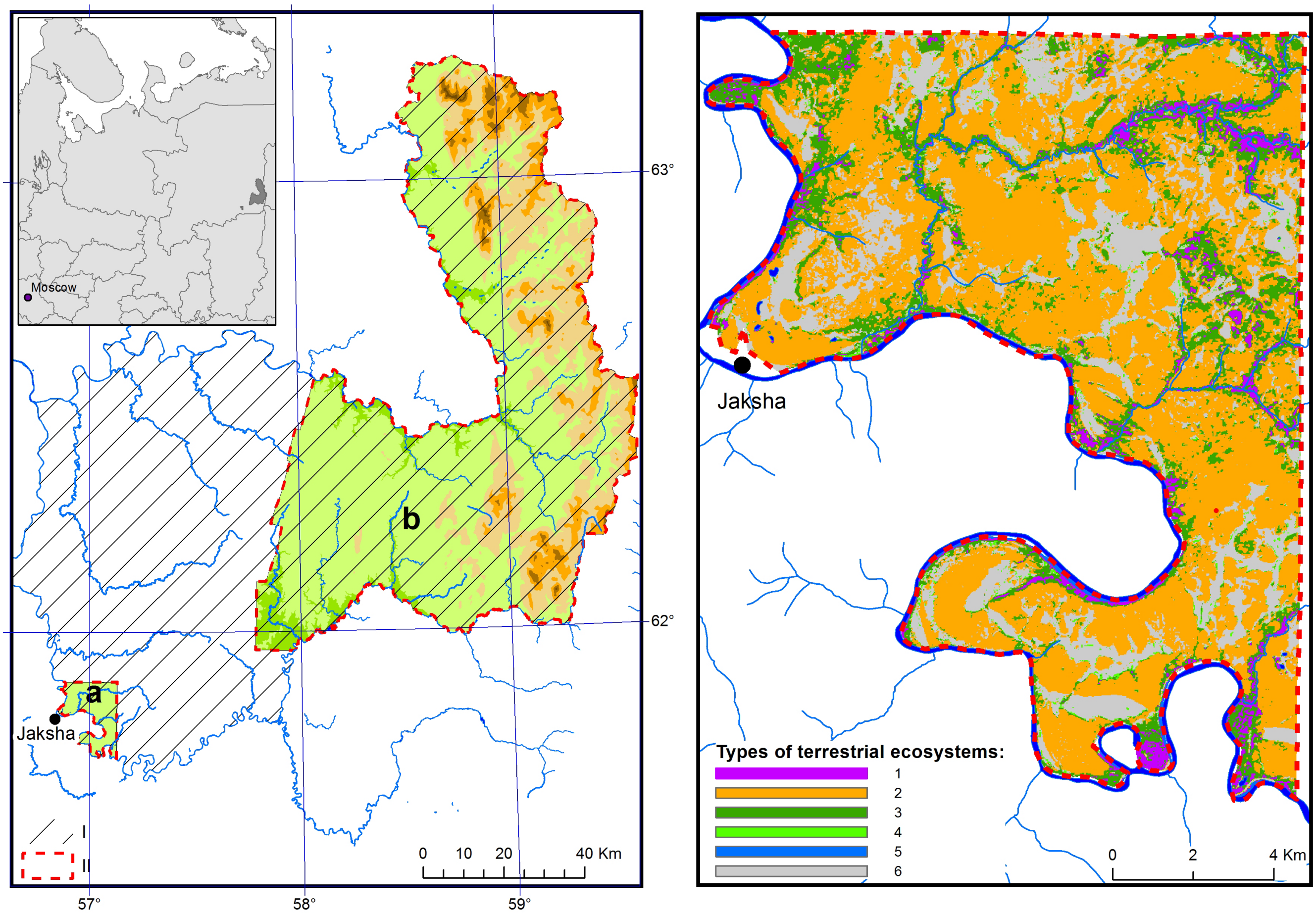

Fig. 1. Location of the Pechora-Ilych Nature Biosphere Reserve. Designations: a – plain area, b – foothill area; left map – interfluve of the Pechora and Ilych rivers; right map – modern boundaries for PIR. Types of terrestrial ecosystems of the plane area: 1 – dark coniferous forests, 2 – light coniferous forests, 3 – mixed forests, 4 – deciduous forests, 5 – rivers and lakes, 6 – swamps.

The climate is temperate continental and is under the influence of western air masses with frequent invasions of cold Arctic air along the ridges. The average annual air temperature is -0.4°C. The period with negative air temperatures lasts 175–185 days. The average temperature in January is -15.0 – -17.5°C, in July it is +15.5 – +16.5°C. The duration of the frost-free season is 80–110 days. The vegetation period lasts 140–150 days; the period of active plant growth goes on 90–100 days. The accumulated temperature above +5°C is 1600–1800, above +10°C is 1300–1420. The average annual precipitation is 500–800 mm. Snow cover is one of the main indicators of natural fire danger, it determines the duration of the fire hazard season. In the study area, it starts late October – early November, lasts for about 180–190 days and disappears late April – early May. Hydration is excessive; the hydrothermal moisture coefficient according to Selyaninov (1930) is 1.5–1.8.

Forests (90.1% of the total area) and swamps (8.4% of the total area) represent dominant terrestrial ecosystems of the PIR plain area (Table 1). The forest vegetation of the plain area is very monotonous: pine forests of various types dominate (Fig. 1). They cover about 68.1% of the total area. Mixed and deciduous forests are represented by 18.1% of the total area. They appeared after crown fire impacts and rare clear cuttings. A smaller area is covered by dark coniferous forests (4.3%), being located along the valleys of small rivers and streams. Frequent alternation of pine forests and swamps is a characteristic feature of the whole Pechora terrain.

History of peopling and occupation of the interfluve of the Pechora and the Ilych rivers

Based on exciting science, humans started inhabiting the River Pechora basin in the Upper Paleolithic (about 40 000 BC). Temporary hunting sites and sites on mammoth burial grounds (38 000–33 000 BC) were discovered (Pavlov, 2015). There are several caves along the Pechora and its tributaries that have been actively visited by humans for the past 2.5–3.0 thousand years (Fig. 2A) (Guslitser & Kanivets 1965).

Table 1. Characteristics of the terrestrial ecosystems of the modern plain area of Pechora-Ilych Nature Biosphere Reserve

Types of terrestrial ecosystems	Area, km^2	Share in the total area, %
Light coniferous forests	111.0	68.1
Dark coniferous forests	6.99	4.3
Deciduous forests	2.1	1.3
Mixed forests	27.3	16.8
Wetlands	13.7	8.4
Wastelands	0.9	0.6
Water	1.0	0.6

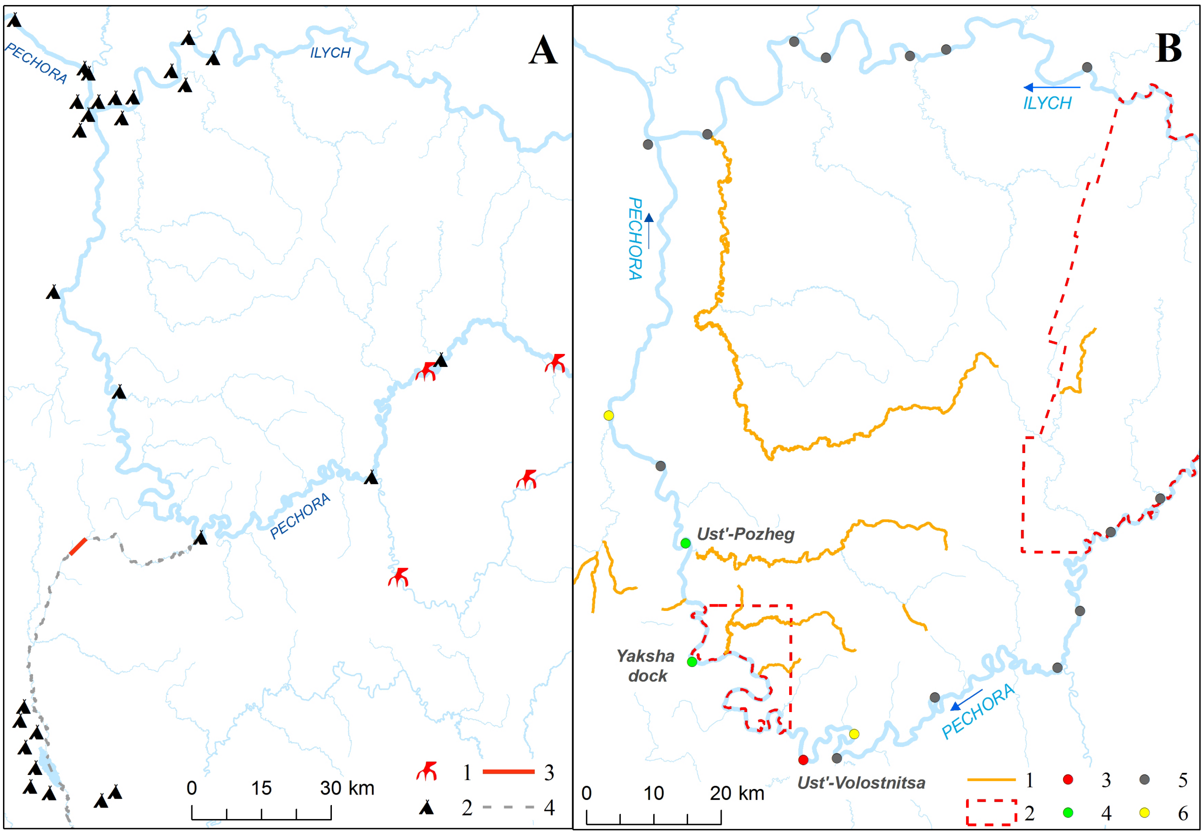

Fig. 2. Settlements in the interfluve of the Pechora and Ilych rivers at different times. A – in ancient times: 1 – archaeological sites; 2 – caves; 3 – portage between the River Volga basin and the River Pechora basin; 4 – fragment of the way from the River Volga basin to the River Pechora basin. B – in the Middle Ages and modern times. 1 – hydronyms (river names) associated with fires; 2 – modern boundaries of the Pechoro-Ilych State Nature Biosphere Reserve. Settlements established in 17th century (number 3, red dot), 18th century (number 4, green dot), 19th century (number 5, grey dot), 20th century (number 6, yellow dot).

In the past centuries the upper reaches of the River Pechora had an important geopolitical significance, since several portage routes passed along them: 1) from the Northern Dvina basin to the River Pechora basin; 2) from the River Pechora basin to the River Ob' basin. The most significant was the path from the River Volga basin (Caspian Sea) to the River Pechora basin (Arctic Ocean). (Fig. 2A). Along this path, there were many archaeological sites discovered (Chagin, 2017).

From about the 10th to the 18th century, this territory belonged to the Mansi (Voguls) and their ancestors – the indigenous Finno-Ugric population of the Northern Urals. Their ethnic-specific area at that time was much wider than the modern one. Mansi led a nomadic life, were hunter-gatherers and fishing (Sokolova, 2009; Chagin, 2012; Aleinikov, 2017a). Mansi's seasonal settlements existed near modern Yaksha village (Varsanofieva, 1929). Since the 18th century, the Russians gradually supplanted the Mansi, moving upstream Pechora and establishing new villages.

The first village on the banks of the River Pechora (Ust'-Volosnisa) (Fig. 2B) was founded only at the end of the 17th century, the second village (Ust'-Pozheg) (Fig. 2B) – in the mid-18th century. These villages consisted of several courtyards. Several dozen residents served the trade route from the River Kama basin. The local people traded and constructed barges. Late 18th century, between these villages the Yaksha dock was established, where warehouses for goods were located (Aleinikov & Chagin, 2015; Chagin, 2017).

The active peopling of the territories along the River Pechora and the River Ilych began in the early 19th century. At this time, the Komi-Zyrians founded the first settlements on the River Ilych. In 1843, there were three villages along the River Ilych (Chuvyurov, 2010). In the same period, the Russians had begun to develop the River Pechora. Several villages were founded at once. In 1897, 146 people lived along the River Ilych, 530 people lived along the River Pechora to its inflow the River Unya (Chuvyurov, 2010; Aleinikov & Chagin, 2015). In 1929, at the eve of the PIR' establishment, 29 settlements with 269 courtyards existed along the banks of the River Pechora and the River Ilych. The population of the interfluve in 1929 was about 1600 people (Schillinger, 1929). The population density was about 0.1 person per km^2. The settled population was engaged in hunting, fishing, carting, barge building, agriculture, and logging.

Methods

We obtained important information on the forest state at the time of the PIR establishment using the material of the first inventory conducted in 1941–1942. When we analysed the inventory material, we considered the following parameters: the site area, the forest stand composition, the average age of the stand, damaged/undamaged by wildfire, site class (indicator of the forest stand productivity).

In order to geo-referencing the previous fires and analyse the forestry management material of different years, 1915–1961, a net of rides in the Pechora-Ilych interfluve was reconstructed. (Fig. 3). In 1942, the interfluve area was divided into new forest quarters with an area of about 30–40 km^2. Their boundaries coincide with the boundaries of the current quarters of the plain area in the PIR (Fig. 3B). By 1942, only 90% of the modern plain area in the PIR was studied. A part of quarter 176 remained unexplored.

The forest inventory map (1942) was used to reconstruct the transformation of the forests by 1942. The map, that depicted age and cover type classes were digitised in vector format and georeferenced using QGIS software (QGIS Development Team, 2019). The composition of the forest cover was classified into five types: 1 – «pine forests» (> 75% of the cover dominated by *Pinus sylvestris*), 2 – «spruce forests» (> 75% of the cover dominated by *Picea obovata*); 3 – «birch forests» (> 75% of the cover dominated by birch *Betula pubescens* Ehrh.); 4 – «mixed» (< 75% of the cover dominated by conifers and > 25% by deciduous species), 5 – «swamp»; 6 – «burnt area» (stand under the age of 20 years).

The composition of forest types was classified into five types: 1 – lichen (*Cladinosa*) forests; 2 – green moss – lichen (*Hylocomioso-cladinosa*) forests; 3 – green moss – dwarf shrub (*Fruticuloso-hylocomiosa*) forests; 4 – *Polytrichum*-*Sphagnum* (*Polytrichoso-sphagnosa*) forests; 5 – green moss – small boreal herb (*Parviherboso-hylocomiosa*) forests in accordance with the prodromus of the vegetation and forest distribution in the boreal forests (Smirnova et al., 2017). The map from 1942 included forest age classes with steps in 20 years. We added a 0–20 year age class to those areas designated as «recently burnt».

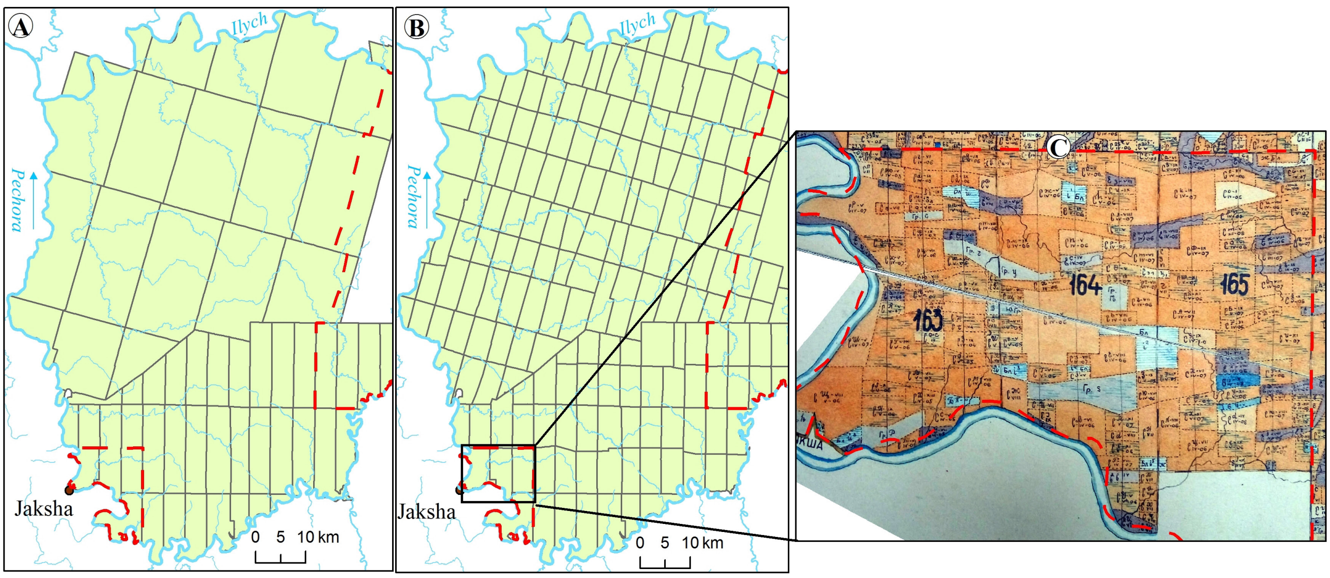

Fig. 3. A net of rides on a plain area in the Pechora-Ilych State Nature Biosphere Reserve over different time periods: A – 1915–1941, B – 1941–1961. C – fragment of the forest inventory map from 1942. Red dotted line outlines the modern plain area of the Pechora-Ilych State Nature Biosphere Reserve.

The fire history on the plain area in 1936–1942 was restored with the help of the Chronicles of Nature of the PIR and different remaining fire reports in the archives. Unfortunately, the reported data give us information only about the number of fires, the dates of fire occurrence and their causes. It is impossible to calculate the important indicators such as the average fire area and fire rotation, since the reports show approximate territories that need to be clarified in open areas. The reason is that GPS has been introduced only recently. While analysing the data of this period, it is important to take into account the features of the reserve establishment initial stage: there was no formed staff, radio communication and means of transportation. Perhaps not all fires could be detected in that period.

When discussing the history of forest fires and the possible role of population and traditional land use, documentary archives (written and cartographic sources of the 19–20 centuries, archival data) are used. The analysis of the available archival materials made it possible to reconstruct quite accurately the time of settlement, human population density, and main crafts at the upper part of the River Pechora (Aleinikov & Chagin, 2015; Aleinikov, 2017a).

We conducted a systematic review of ethnographic and historical literature of 18–19 century, searching for documentation of fire use of the indigenous and colonisation people. Additionally, the toponymic data of the interfluve was analysed, because the names of geographical objects reflect the various aspects of the human society. Some toponyms could point to different realities of economic and commercial significance, including the characteristics of the surrounding forest (Zhitnikov, 1965; Rudnykh, 1966; Conedera et al., 2007; Cogos et al., 2019).

Results

The documentary archives about fires in the Pechora and Ilych interfluve until 1930

The dendrochronological (Drobyshev et al., 2004) and toponymic data collected in the Pechora and Ilych interfluve area showed a long fire history of the forests in the interfluve area. It often occurred that fires found their use in numerous local toponyms (Fig. 3B). Similar place names, denoting the effects of fire, are found throughout the Russian North. Associated with fire hydronyms confirm, that a river originates in a burning place or flows through the burnt forest (Verkhoturova, 2007).

In addition to toponymic data, there is fragmentary historical and archival evidence on wildfire impacts in the late 19th – early 20th centuries. During expedition aimed to explore forests in the Pechora region in 1900, researchers analysed the age structure of the pine forests in the River Pechora basin. They suggested that fires occurred in 1732, 1740, 1761, 1775, 1778, 1802, and devastating fires were in 1775 and 1802 (Anonymous, 1912). Nat (1915a,b) and Milovanovich (1926) worked in the pine forests of the interfluve at that time. They also noticed multiple traces of the past fires and their effects. There has been known a large fire on the right bank of the River Chelach, at the mouth of the River Ilych in 1888. The burnt area was more than 135 km^2. In 1890–1900, there were a series of expeditions aimed to explore forests in the basin of the River Pechora. We discovered near Yaksha dock on the left bank of the River Pechora, there was a large old burnt area of more than 77 km^2 in 1899. It was covered with 10–30-year-old pine young forest. In 1926, there was a large wildfire in the River Pal'-Yu basin. Therefore, by the establishment of the PIR in the modern borders, the forests on the plain area represented mosaics of burnt areas.

Fires and the state forest on the plain area PIR in 1930–1942

The formation of the PIR in 1930 was an important activity for reservation and functioning of the forests of the interfluve area. Actually, the PIR acts only since 1935. The first record of wildfire evidence was noted in 1936. The period of 1930–1936 is still poorly studied, although large fires occurred on foothill areas (Aleinikov et al., 2015) in those years on the plain area in the PIR (Korchagin, 1940).

From 1936 to 1942, 17 fires covering more than 12.7 km^2 were observed in the pine forests of the interfluve area. During this period, fires occurred annually. Most of the fires occurred in the areas, adjacent to the floating rivers: Pechora, Ilych and Pal-Yu. Unfortunately, we cannot determine the location of these fires on the modern plain area in the PIR, because the rides net, used at that time, did not coincide with the modern one (Fig. 2).

During this period, most of the fires occurred in July (47.0% of the total records), less in August (41.2%), and separately fire records in June and September. Such seasonal distribution corresponds to the peculiarities of the fire season in the plain area in the PIR: late May the snow cover goes down, and the average daily temperature increases gradually. This contributes to the drying of forest flammable material. In addition, in June – July there are often thunderstorms that can cause fires. On the other hand, it is during this period that the forests begin to be actively visited by the local population.

The vast majority of fires (88.2%) are surface fires, which destroyed the undergrowth and ground cover in pine forests. In nine cases a thunderstorm was thought to be the cause of the fire. In six cases it was suggested to be careless handling of fire. And in two cases the reasons were unknown.

The material of forests' inventory of 1941–1942 are of high significance for reconstruction of historical fire regime and assessment of the past forest fire frequency on the modern plain area. It has been noted that «it was rare indeed to see the areas without traces of fires over the period passed». Moreover, the engineers used a new net of rides according to which a plain area in the PIR was divided into four quarters: 163, 164, 165, 176 (Fig. 2B).

The map analysis showed that in 1942, pine forests covered 81.8% of the plain area in the PIR, spruce forests – 9.5%, birch forests – 0.5%, mixed forests – 0.7%, burnt areas (stand under the age 20 years) – 6.4%.

An analysis of the age structure showed that in 1942 forests of all ages were represented on a plain area. Most of the forests are concentrated in two age classes – from 120 to 200 years. Old forests (200+ years) covered less than 8% of the total area. Pine forests were represented by all ages – from 20 to 250 years. Spruce forests were represented by three classes of stands: from 40 to 160 years. Birch forests were from 40 to 80 years old, mixed – from 80 to 120 (Fig. 4).

The analysis of inventory material showed that a significant part of the forests was affected by fires (Table 2).

Table 2 shows that by 1942, 17.2% of the forest area was covered by young and middle-aged to 60-year-old forests. These forests have recovered after crown fire influence. Most of these burnt areas were replaced by *Betula* spp., *Populus tremula* L. (aspen) and *Pinus sylvestris*. Currently, these are deciduous and mixed forests (Fig. 1). The age of the forest stand destroyed by fires ranged from 60 to 250 years. Of the fire-damaged forests, the forest stands of the IV site class dominate. Such a low site class indicates a long-term degradation of pine forests induced by multiple wildfire impacts.

The analysis of the typological structure of the burnt and unburnt forest areas shows that 49.8% of the total area pine forest (including 50% of *Cladinosa* forests, 72% of *Hylocomioso-cladinosa* and 72% of *Fruticuloso-hylocomiosa* forests) were affected by fires. *Polytrichoso-sphagnosa* forests were considerably less damaged by wildfire (11%). *Parviherboso-hylocomiosa* (*Piceeta obovata*) forests have not been damaged (Fig. 5).

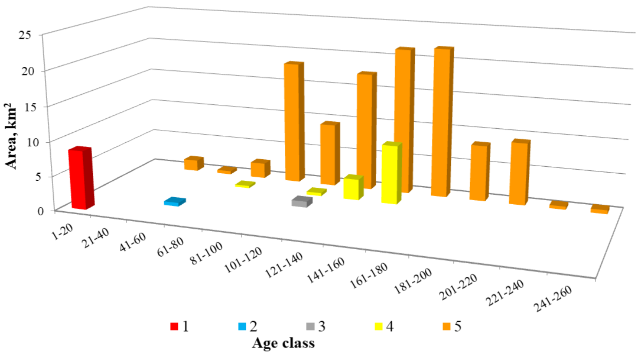

Fig. 4. Stand age distribution of forest in the modern plain area in the Pechora-Ilych State Nature Biosphere Reserve in 1942.

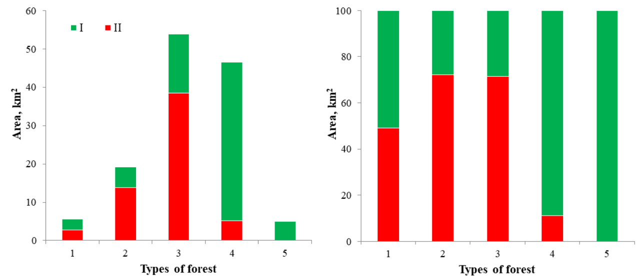

Fig. 5. Proportions of vegetation types in the burnt and unburnt areas of the 1942. Designations: I – unburnt forest; II –burnt forest. Forest types: 1 – *Cladinosa*; 2 – *Hylocomioso-cladinosa*; 3 – *Fruticuloso-hylocomiosa*; 4 – *Polytrichoso-sphagnosa*; 5 – *Parviherboso-hylocomiosa.*

Table 2. Different-year-old area burnt in the forests on the territory of the modern plain area in the Pechora-Ilych State Nature Biosphere Reserve, found in 1941–1942

Quarters number over 1941–1961	Forest area, km²	Area burnt over 1941–1942 years, km²					A ratio of different year-old burnt area to the total forest area, %
		1–20-year-old area burnt	21–40-year-old area burnt	41–60-year-old area burnt	> 60-year-old forests, destroyed by fire	Total	
163	33.5	2.6	0	0.3	15.5	18.5	55.1
164	34.6	4.2	0	0	19.5	23.7	68.6
165	37.0	1.3	0	0.6	10.4	12.3	33.3
176 (part)	26.9	0.5	1.5	0.3	8.0	10.3	38.5
Total	132.0	8.6	1.5	1.2	53.5	64.8	49.1

In 1943, in 176 quarters two more fire evidences occurred with an area of more than 13 km^2. There were no wildfire evidences in 1946–1951 in the Chronicles of Nature of the PIR. And probably it is possible to find more information in archives about whether forest fires occurred or not.

As a result of past fires, by the time the PIR was created, the pine forests of the interfluve of the Pechora and Ilych rivers were already highly flammable pyrogenic communities, prone to fire, even from thunderstorms.

Discussion

Long-term effect of previous fires

In boreal forests, fires are of crucial importance in relationship to early and late successional tree species, and the formation of typological structure of forests (Korchagin, 1940; Vasilevich, 1980; Heinselman, 1981; Wallenius et al., 2010). Based on the analysis of the first inventory of forests, an assessment of the state of the forests of the plain area 10 years after the establishment of the PIR was made for the first time, in a remote area with a low population density and dominant old-aged pine forests on the hills, summits and swamps, as well as spruce forests on the lowlands.

Information concerning fire-damaged forest in 1942 allowed the fire dynamics that prevailed before the establishment of the PIR. We showed that more than 50% of lichen and 70% of green moss-lichen and green moss-dwarf shrub pine forests of the modern plain area in the PIR was affected by surface and crown fires. Fires in this area occurred repeatedly. So, of the 33.5 km^2 that was burnt in 1936–1945, more than 16.0 km^2 burnt more than once. However, young age spruce forests in 1942 (Fig. 4) demonstrated by possible stand-replacing fires, because in the natural spruce forests the age should be higher (Wallenius, 2002; Smirnova et al., 2017).

Frequently repeated fires in the Pechora and Ilych interfluve had long-term effects. Firstly, the fires stopped autogenous successions, prevented regeneration of species vulnerable to fire (spruce, fir, cedar), while contributing to regeneration of fire adapted species (pine, birch, aspen, rarely – larch (*Larix sibirica* Ledeb.) and cedar) (Nat, 1915a,b; Korchagin, 1940; Kutyavin & Torlopova, 2016). In the ground cover, fires displaced green mosses and shrubs, favouring the lichen growth (Vasilevich, 1980). Secondly, multiple fires disrupted the natural process of aging and death of the trees, thereby inhibiting formation of heterogeneous structure with pits, mounds, coarse woody debris (Harper et al., 2005; Smirnova et al., 2008).

Currently pine lichen forests – 24.03 km^2 (21.7% of the total area of all pine forests) and pine green moss forests – 66.74 km^2 (60.2% of the total area of all pine forests) dominate on the plain area in the PIR . If the future is fire-free, it is likely that the pine forest stands will gradually become spruce forests. (Wallenius et al., 2005). This is confirmed by successful regeneration of *Picea obovata* in some types of forests (Kutyavin & Torlopova, 2016). However, a large amount of flammable foliage, a simplified horizontal structure and thin bark are highly flammable. This can be easily burnt as a result of natural causes, e.g., dry thunderstorms. Spruce forests along rivers should be considered as the least burnt forests on the plain area in the PIR.

Possible causes of previous fires

The main types of past land use in boreal forests include clear cutting, forest clearance for agricultural land, slash-and-burn agriculture (Pyne, 1998; Smirnova et al., 2017). The intensity and duration of human impact on forests, however, has varied considerably from place-to-place and from region-to-region. In the north Urals, agriculture did not spread for a long time due to poor soils, unfavourable climatic conditions and a low population density. Forest fires were the principal disturbance agent. Fires can be caused by human activities, including slash-and-burn agriculture, measures to improve conditions of domestic animals grazing and hunting (Groven & Niklasson, 2005).

Vast areas of the pine forests older than 160–200 years on the plain area in the PIR indicate that there were significant incidents of fires before the PIR was established. Pine forests are prone to lightning-triggered fires (Heinselman, 1981), but even in such forests humans-ignited fires occur more often (Wallenius et al., 2010). The local weather can increase the scale of these fires. For example, in the drought of 1934 year, a slash-and-burn cultivation on the foothill area of the PIR led to a fire on an area of more than 95 km^2 (Aleinikov et al., 2015, 2018). Nevertheless, assuming that the cause of most fires was human means that the non-random occurrence of fires still needs an explanation. Reasonable explanations for the spatially and temporally non-random pattern of fire events might be found from local history. An attempt to assess the relationship of fires over 600 years with the distance up to modern villages has been already made by Drobyshev et al. (2004). However, the authors did not take into account the periods of villages' formation and specific character of ethnic-cultural landscape in different periods.

Interpreting data on fires occurred in the 15–19 century, it is necessary to remember about Mansi (Voguls). This is an indigenous population of the Urals, the area of settlement of which was much wider than today (Chagin, 2012; Aleinikov, 2017a). It must be recognised that influence of the Mansi and their traditional economy on natural landscapes has not yet been studied. In addition to hunting and fishing, the Mansi were engaged in reindeer herding (Golovnev, 1993; Slezkine, 1994; Abramov, 2017). Pine lichen forests were very important for that (Klein, 1982; Berg et al., 2011; Rautio et al., 2015). Currently, only a few data show that the Mansi used pine forests in the Pechora and Ilych interfluve as winter pastures (Milovanovich, 1926; Varsanofieva, 1929)

The Mansi people actively used fire. The Mansi used a fire to burn old-growth dark coniferous forests and recovered young deciduous forests with rich grass cover. These forests are a favourite habitat for the elk *Alces alces* (Linnaeus, 1758), the main object of hunting (Aleinikov, 2017b).

Could the Mansi use fire in pine forests? Unfortunately, there is no direct information about it yet. Until recently, it was considered that reindeer herders to be relatively careful in the handling of fires, because fires destroyed reindeer lichens, the most important winter forage of reindeer (Wallenius et al., 2005; Collins et al., 2011). However, recent studies have shown that this activity was common among another ethnic group of the Sami people in Sweden. They burnt pine forests to maintain a lichen cover in winter reindeer pastures (Hцrnberg et al., 2018). Whether burning was used in the Pechora-Ilych interfluve area or not it is an open question, which required additional paleoenvironmental studies. If it was used, then it will imply that for five centuries the Mansi controlled burning in these forests.

The increased demand for pine wood quality, late 19th century, enhanced the anthropogenic effect on forests in the interfluve area. Until the 1930s, timber was actively harvested along the large tributaries of the River Pechora and River Ilych. These are River Pozheg, River Chelach, River Pal'-Yu, and River Mort-Yu. Nat (1915a,b) wrote that forestry management (e.g. selective logging of sawlog) led to forest littering. And the carelessness of local population in fire handling was a cause of fire occurrence. Later, a role of forest littering and untreated felling sites in fire distribution was confirmed on the other areas (Molchanov, 1934; Korchagin, 1954). In Scandinavian countries an increasing demand for wood conversely stimulated saving of forests and reduced the number of fires (Groven & Niklasson, 2005; Storaunet et al., 2013).

Along with harvesting, hunting and fishing, active forest visits formed another cause. Hunting for local people was the main activity (Chagin, 2015). The Pechora and Ilych interfluve represented a mosaic of hunting grounds of the Russian, Komi-Zyryan and Mansi people. In 1929, there were about 800 hunters in this area (Schillinger, 1929). Despite an extremely low population density, the local inhabitants visited actively the surrounding forests at a considerable distance (tens of km) from the villages. Hunters made hunting cabins, barns, baths, cleared hay meadows. During the visits in their areas, local people used fire for cooking, smoky fires, and others. Then every hunting cabin should be considered as a potential fire seat. Hunting trails deviated for 10 km into the forest from the hunting cabins, along which all trap types were placed. Unfortunately, accurate data on location of all hunting cabins are absent. However, it is known that they were placed every 5–10 km on most of the rivers. Local hunters chose primarily the navigable tributaries of the River Pechora and River Ilych. Hunting grounds along the River Pal'-Yu and River Chelach were of special demand among the local population (Fig. 6B), because these rivers were navigable up to the riverheads.

Any anthropogenic activity along the navigable rivers in the plain area between the rivers could be accompanied by accidental uncontrolled wildfires. For example, Aleynikov et al. (2017) showed similar dependence of burnt sites location on the distance to navigable rivers using dark coniferous forests in the foothills area of the PIR.

Thus, despite a low density of human population, people have actively visited these forests in different periods. The earliest period, 15–18 century, remains the least studied. During this time, the Mansi people used the wildfire to increase the productivity of winter pastures for reindeer.

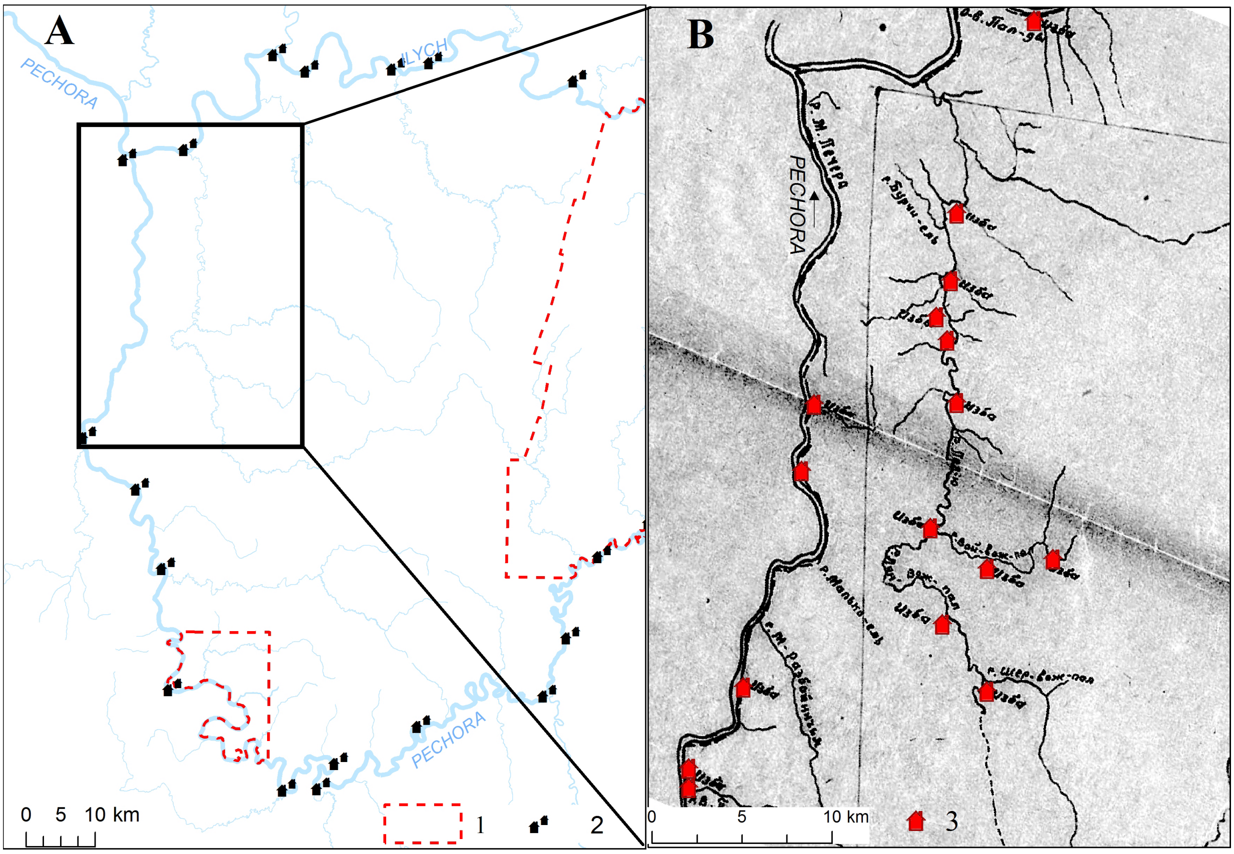

Fig. 6. A – settlements in the interfluve of the Pechora and Ilych rivers in 1930; B – fragment of the map of the Pechoro-Ilych State Nature Biosphere Reserve of 1935. Designations: 1 – modern boundaries of the PIR, 2 – settlements in 1930, 3 – hunting cabins along the river Pal'-Yu in 1935.

Conclusions

The forests of the interfluve of the Pechora and the Ilych river are unique. This is a valuable object for studying the modern forest ecosystems and the long-term consequences of the traditional land use of several ethnocultural groups (Russians, Mansi, Komi) who had been using this territory for a long time. So far, the traces of previous impacts have been preserved thanks to the creation of the PIR in 1930 and the termination of anthropogenic activity. Therefore, many characteristics of forests are an ecosystem memory that requires further investigation. In the study, we attempted to characterise the economic use peculiarities of forests between the Pechora and the Ilych river in different periods. Detailed comprehensive investigations are needed being based on historical, archival, dendrochronological and palynological data.

Due to the analysis of historical and archival materials, we showed the forest conditions in the modern plain area in the PIR 10 years after the PIR foundation. According to preliminary estimates, pine forests were formed and maintained by frequent low-intensity fires by 1942. By this time, the PIR was established. About 50% of the forests had been affected by wildfire. Most of all, green moss-lichen pine and green moss – dwarf shrub pine forests (72% of the area of these communities) were damaged by fires. Burnt areas along the tributaries of the River Pechora and the River Ilych were so routinely for local people, that they reflected them in the local place names. Perhaps, the Mansi people initiated wildfires for several centuries. They used this area as winter pastures for reindeer until the mid-19th century. Eventually, the small Russian population actively visited the forests with the purpose of logging, hunting, fishing, and gathering of wild-growing plants. The interfluve was a land mosaic, divided between the inhabitants of various villages. Careless fire handling led to numerous uncontrolled fire evidences, which have not been put out. And, as a result, vast forest areas were burnt.

Fires on the same area occurred many times. For example, out of 33.5 km^2 burnt in 1936–1945, more than 16 km^2 of forests were fire-damaged sites of various ages. Frequently recurring fires interrupted the natural succession development of these plant communities. These wildfires hindered the spruce restocking by contributing to the reproduction of *Pinus sylvestris*, *Betula* spp., *Populus tremula*, rare – *Larix sibirica* and *Pinus sibirica*. As a result, modern low-productive pine forests with a large amount of highly flammable forest fuel were formed. After the PIR establishment, these pine forests continued to burn, but with less frequency.

Since the plain area adjoins the navigable River Pechora, the anthropogenic causes of these fires cannot be completely excluded. At the same time, we do not exclude the possibility of fire appearing from dry thunderstorms. However, to assess the modern wildfire regime, we should remember that in the pine forests the high fire danger is a legacy of previous fire impacts. This requires further study of the fire status of forest ecosystems.

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ИСТОРИЯ ПОЖАРОВ В СОСНОВЫХ ЛЕСАХ РАВНИННОГО УЧАСТКА ПЕЧОРО-ИЛЫЧСКОГО ПРИРОДНОГО БИОСФЕРНОГО ЗАПОВЕДНИКА (РОССИЯ) ДО 1942 ГОДА: ВОЗМОЖНЫЕ АНТРОПОГЕННЫЕ ПРИЧИНЫ И ДОЛГОВРЕМЕННЫЕ ПОСЛЕДСТВИЯ

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Оценка сукцессионного статуса и прогноз развития сосновых лесов зависят от их происхождения и нуждаются в детальном исследовании исторических и современных пожарных режимов. В статье обобщены сведения о динамике пожаров в лесах равнинного участка Печоро-Илычского государственного природного биосферного заповедника (Россия). Современные лесные пожары в сосновых лесах заповедника – наследие предшествующего традиционного природопользования на этой территории. Благодаря анализу материалов первой инвентаризации лесов впервые оценено состояние лесов равнинного участка спустя 10 лет после организации заповедника. Показано, что около 50% лесов современного равнинного участка заповедника (большая часть лишайниковых, зеленомошно-лишайниковых и зеленомошно-кустарничковых сообществ) на тот момент уже были пройдены низовыми и верховыми пожарами. Гари вдоль притоков Печоры и Илыча были настолько обычны для населения, что нашли отражение в их названиях. Возможно, на протяжении нескольких веков пожары инициировали манси, которые использовали эту территорию в качестве зимних пастбищ вплоть до середины XIX в. В последствии, немногочисленное русское население активно посещало леса с целью лесозаготовок, охоты, сбора дикоросов и рыбной ловли. Междуречье представляло собой мозаику угодий, поделённых между жителями различных деревень. Неосторожное обращение с огнём приводило к многочисленным неконтролируемым пожарам, которые никто не тушил и поэтому сгорали огромные площади лесов. После образования заповедника эти сосновые леса продолжили гореть, но уже значительно меньше. Поскольку равнинный участок примыкает к судоходной реке Печоре полностью исключать антропогенные причины этих пожаров нельзя. Мы не исключаем возгорания от сухих гроз. Однако, при оценке современного пожарного режима важно помнить о том, что высокая горимость этих лесов – наследие предшествующих воздействий, требующее дальнейшего изучения.

Ключевые слова: бореальные леса, история пожаров, первичные леса, Северный Урал, сукцессии, традиционное природопользование, экосистемное наследие