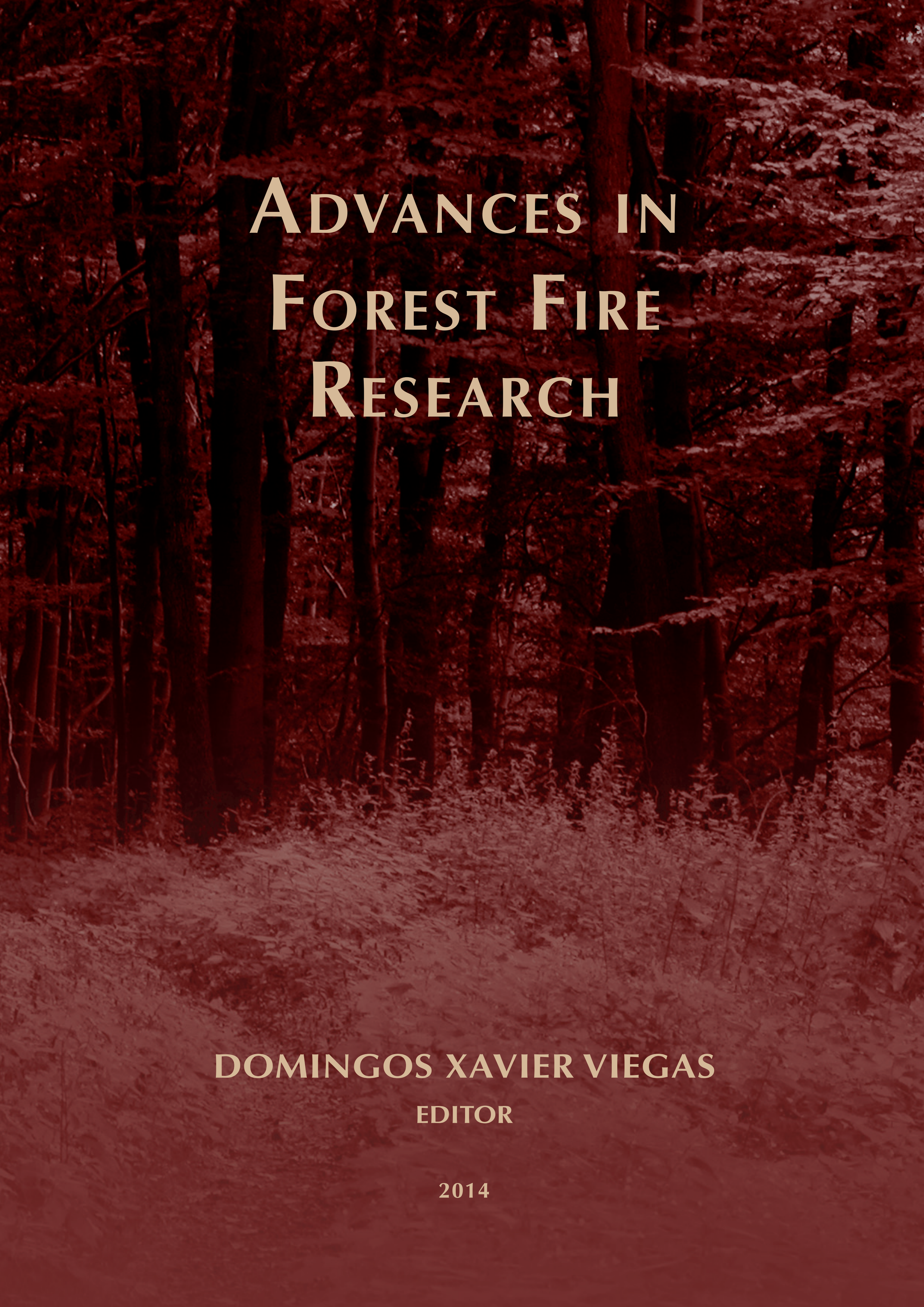

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Natural and anthropogenic fire regimes in boreal landscapes of Northwest Russia

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Abstract
Patterns in the natural fire regime in different types of geographical landscape and its present-day transformations are considered. Surveys were carried out in the north-west of the Russian boreal zone at the junction of two North-European physiographic domains – Fennoscandian Shield (Fennoscandia) and East-European (Russian) Plain. The resultant data disclose the history of fires and their landscape-related characteristics over the past millennium. The frequency and intensity of wildlife fires may differ drastically among landscapes – from 1-2 in a century to 1-2 in a millennium. Multiple intermediate variants fill the range between these two poles. It is demonstrated that conservation of pristine forests with their spontaneous dynamics in protected areas is possible only under a natural fire regime. The total and average size of fires has been gradually decreasing. In the study area, e.g. the indices have over the past half a century ranged within 100-10 000 ha, and 5-20 ha a year, respectively. Humans have significantly increased the frequency of forest fires. The patterns identified can be quite confidently extrapolated to the whole boreal zone of European Russia. The characteristics of geographical landscapes (the range, ratio and spatial arrangement of their types) and land use history must however be taken into account.

***Keywords**: boreal landscapes, natural fire regimes, current situation*

1. Introduction

Various aspects of the natural development of European boreal forests as related to fires are discussed in a great number of publications, including the authors' own (Gromtsev 1996, 2002, 2008, etc.). It is obvious the topic is of high interest to researchers. Fires (lightning-ignited) used to be the weightiest ecological factor shaping the structure and dynamics of pristine forests. Man-induced fires are now an equally important factor.

In an overwhelming majority of cases systematized data on natural fire regimes in Russia were obtained either by dating fire scars on trees or from archives. In the first case retrospective analysis is limited to 250-350 years (maximum age of the oldest tree generation). In the second case only very strong fires were recorded, but were not referenced to specific locations and ecotopes. Furthermore, averaged data for a region or habitat with no connection to the landscape features of boreal areas are usually given. They however also focus on individual sites without linking the situation to specific characteristics of boreal landscapes. Let us analyze the successions of spontaneous boreal forests in different types of geographical landscape in the second half of the Holocene and follow the major trends in them.

2. Study area, methodological background, and methods

Surveys were carried out in the north-west of the Russian boreal zone in the drainage basins of Lakes Ladoga and Onega, and west of the White Sea. Administratively, the central position in this region is occupied by the Republic of Karelia (total area ca. 15 mln ha excluding the water area of the named waterbodies). The area lies at the junction of two North-European physiographic domains – Fennoscandian Shield (Fennoscandia) and East-European (Russian) Plain (Fig.1). Hence, the study area features a high diversity of geographical landscapes, even in terms of the relief (from flat marine plains to crystalline uplands rising higher than 1000 m above sea level).

Different types of geographical landscape were surveyed using the classification and map prepared in advance (Tab.1). The landscapes were distinguished by genetic types of relief, degree of paludification, and prevalent forest vegetation (prior to human impact on the forest cover). The classification was based on the zonal and the typological principles. The former differentiated the territory into the northern, middle and southern taiga subzones. The latter implied that contours similar in all landscape-forming traits but spatially discontinuous were combined into one 'type'. An average area of a landscape contour was ca. 100,000-150,000 ha. Over 30 landscape types have been identified and comprehensively studied (forests, wetlands, flora and fauna, land use history, etc.). Both the natural and the human-induced change of the landscape biotic components was studied. As applied to fires the main methods were: 1) stratigraphic analysis of peat deposits with dating of fire layers according to the peat deposition rate (ca. 1000 cores were treated); 2) recording of charcoal underneath the forest floor and the remains of burnt tree trunks with simultaneous analysis of the forest cover composition and age structure (ca. 5 000 pits); 3) dating of fire scars on trees (several hundreds records); 4) analysis of various archival materials (since mid-19th century) and modern fire statistics (covering the past 60 years).

Table 1. Classification of landscapes (example of the Republic of Karelia)

Predominant habitats	Degree of paludification		
	heavy >50%	moderate 20-50%	low <20%
I. Lacustrine, glacio-lacustrine and marine (m) plains			
Spruce	1/1,5[A]	2/4,0	-
Pine	3/8,5	4/2,0	5/+[B]
II. Glacial (g) and fluvioglacial (fl) hilly-ridge plains			
Spruce	-	6/4	-
Pine	7/5,0	8/4,5	9/1,0
III. Glacial accumulation plains with rugged topography			
Spruce	-	10/2,5	-
Pine	-	11/2,0	-
IV. Tectonic denudation hilly-ridge plains with a complex of glacial deposits (g) and low mountain topography (lm)			
Spruce	-	2/12,5	-
Pine	13/8,0	14/37,5	-
V. Tectonic denudation ridge (selga)			
Spruce	-	15/+	16/1,0
Pine	-	17/2,5	18/1,5
VI. Rock			
Pine	-	19/1,0	20/0,5

[A] - number of the landscape type/percent of the region's area;
[B] - less than 0,5%

3. Results

The resultant data disclose the history of fires and their landscape-related characteristics over the past millennium. Distinct fire layers (FL) were detected in deposits at different depths. The deepest-lying FL was at 2.85 m, and a charred organic-mineral layer – at 3.7 m. The layers are roughly dated to 5.5-7.5 Ka B.P. Searching for older FL involves sampling from deeper peat deposits (down to 10 m), few of which have been found in our landscape profiles. Thus, fires were a common ecological factor influencing the forest cover in the Holocene. Note here that only the fires reaching into peatland habitats are considered. Their traces can be clearly identified in the field. Fires confined to dry areas were identified separately by fire scars on trees and stags, or by charcoal underneath the forest floor.

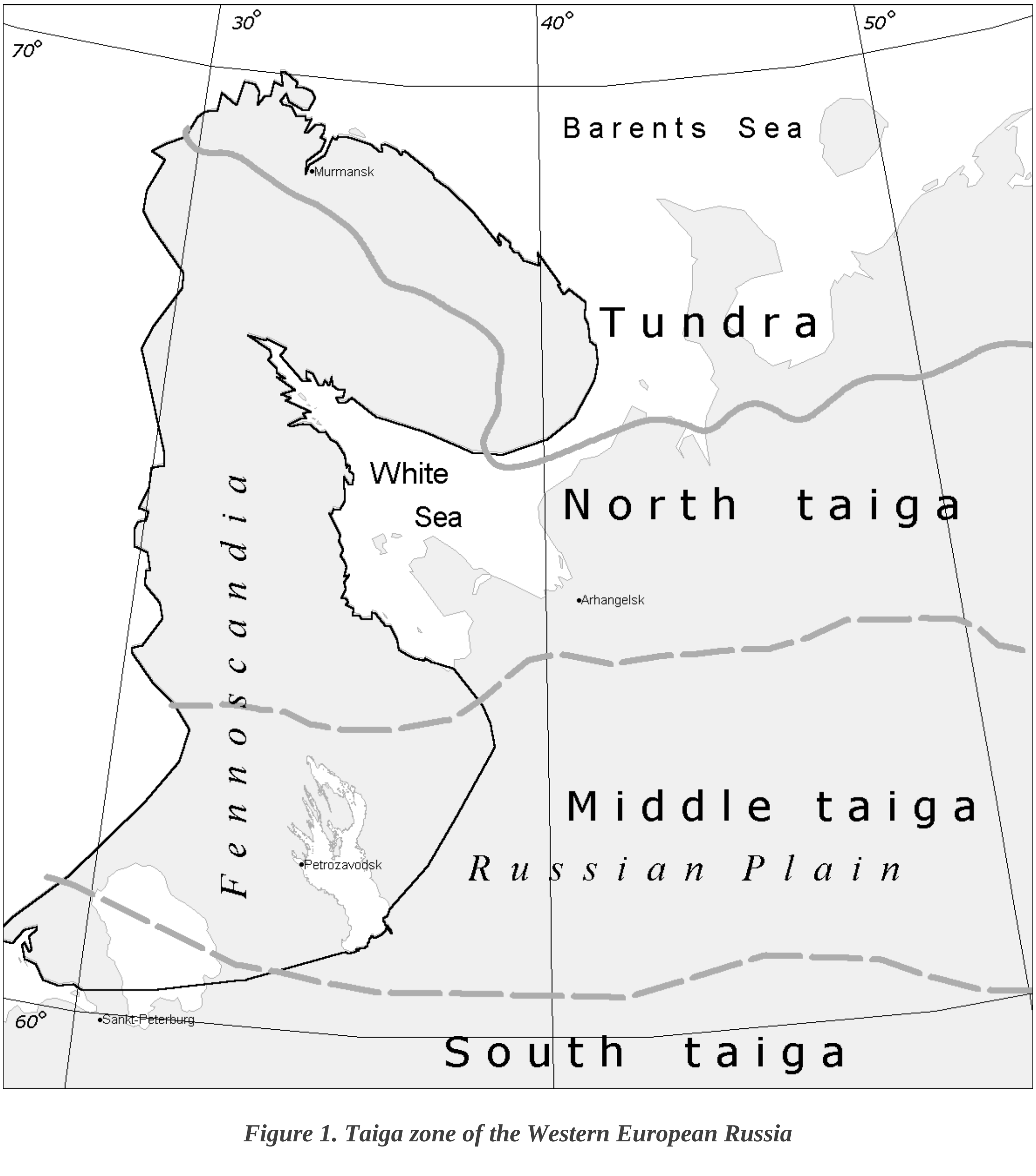

Figure 1. Taiga zone of the Western European Russia

Landscape-related patterns of the fire regime are quite vivid. The fire regime is more or less specific to each landscape type. The overall situation is however quite predictable – the number of FL was the lowest in landscapes of different genesis and paludification clearly dominated by spruce forests. Landscapes of different genesis and paludification dominated by pine forests were the most susceptible to fires (Tab.2).

Table 2. Frequency of forest fires in different types of geographical landscapes (data from the stratigraphic analysis of peat deposits, only the most illustrative types of landscapes are included)

Max number of fires (according to data for an individual drill hole, years ago)	Fire frequencies in different types of geographical landscape (the names of landscape types are abridged)					
	North taiga subzone			Middle taiga subsone		
	Low mountain spruce	Rocky pine	Fluvioglacial hilly-ridge pine	Tectonic denudation hilly ridge spruce	Tectonic denudation hilly ridge pine	Fluvioglacial hilly-ridge pine
<300	0	0	0	0	1	1
300-750	0	2	0	0	4	7
751-1500	0	3	4	2	5	11
1501-2200	0	-[A]	4	0	0	-
Total	0	5	8	2	10	19

[A] - the age of the peat deposit with the max number of layers is below 1500 years

Thus, some ‘spruce’ landscapes were affected by fires approximately once or twice in a thousand years. They were apparently catastrophic events induced by abnormal weather (droughts). Such stand-replacing fires destroyed nearly totally large spruce forests on mineral land. The only refugia were wet sites with flowing water, swamps, etc., from where the surviving spruce dispersed to the surrounding areas. These landscapes are a kind of a model of top fire resistance. The conditions there are least favorable for fire emergence and spread. The landscape biotic components have been affected by fires only sporadically, but with all-embracing effect.

Some ‘pine’ landscapes experienced stand-replacing fires (when even part of wetland habitats burnt down) 1-3 times every 300 years. Running understory fires in pine forests on dry sandy soils were even more frequent (sometimes twice a century). These habitats are a showcase of fire vulnerability. The conditions there are the most favorable for fire emergence and spread. The biotic components of these landscapes have grown adapted to frequent fire impact. Their structure and spontaneous dynamics have been controlled by fires for millennia.

Multiple intermediate variants filled the range between these two poles of the natural fire regime.

Fires as an ecological factor. Primary taiga forests in the Russian taiga zone represent, with very few exceptions, different stages and patterns of pyrogenic succession series. Prior to the commencement of human activities boreal forests had represented different stages of secondary successions – from pioneer vegetation groupings on naturally emerging burnt areas or areas of wind-fallen forest to climax forest communities. A whole spectrum of phytocenoses at different stages of the secondary succession lay between these two extreme variants. The boreal territory in general was however dominated by coniferous communities approaching their climax. The situation changed abruptly only after stand-replacing fires, which were real natural catastrophes. Leaving alone the modifications in the forest cover induced by the global climate change in the late Holocene one can claim that changes in primary boreal ecosystems were of a cyclic nature. They followed the pattern: pre-climax – catastrophe (fire or windstorm) – series of regeneration stages – pre-climax.

The pyrogenic factor has for millennia controlled the forest formation process. Fires destroyed dead organic matter, affected the forest vegetation properties of habitats, enhanced the formation of specific faunistic complexes, etc. In the absence of fires the structure of primary taiga forests underwent transformation in which the forest-forming tree species ratio changed towards shade-tolerant species. Coarse non-decayed litter deteriorating the soil suitability for forest vegetation was accumulated. The productivity of forest areas decreased, and their structure was simplified, including the less mosaic pattern of the landscape forest cover, etc. Corresponding modifications occurred in the biota in general.

Fires are a powerful natural factor that has ensured renewal and homeostasis in spontaneous forest ecosystems for at least several millennia. Preservation of primary boreal forests in protected areas in their primeval state can only be achieved if a certain fire regime that has established in the boreal landscape in the post-glacial period is maintained.

Human-induced modification of natural fire regimes. Natural fire regimes have been profoundly modified by humans. In the boreal zone of Europe this process commenced at different times and in different scope. Formally, human impact on natural fire regimes in the European part of Russia's boreal zone began some 5-10 Ka B.P., as people colonized the territory after glacial retreat. Obviously, with the arrival of ancient hunters and fishermen lightning was no longer the only cause of ignition. The number of fire outbreaks grew sharply over the past centuries due to the wide use of slash-and-burn agriculture and widespread selective forest felling. Thus, 19th century sources already state that at least 90 of 100 fires were caused by slash-and-burn (fire spreading beyond the sites). Generally speaking, humans significantly increased the frequency of forest fires. Until the last century they had spread spontaneously, restrained only by natural firebreaks (hydrographic network), or stopped due to weather (rainfall).

The total and average size of fires has lately been gradually decreasing. E.g., in the Republic of Karelia (area almost 15 mln. ha of area in total) the indices have over the past half a century ranged within 100-100 000 ha (Fig.2), and 50-2500 fires per year (Fig.3). Some large fires affected an area of several thousands hectares (one ignition is 2013 burnt over 6,000 ha). These cases are however exceptional. An average fire in the past decades rarely exceeds 10 ha due to timely detection and quick localization by modern technology.

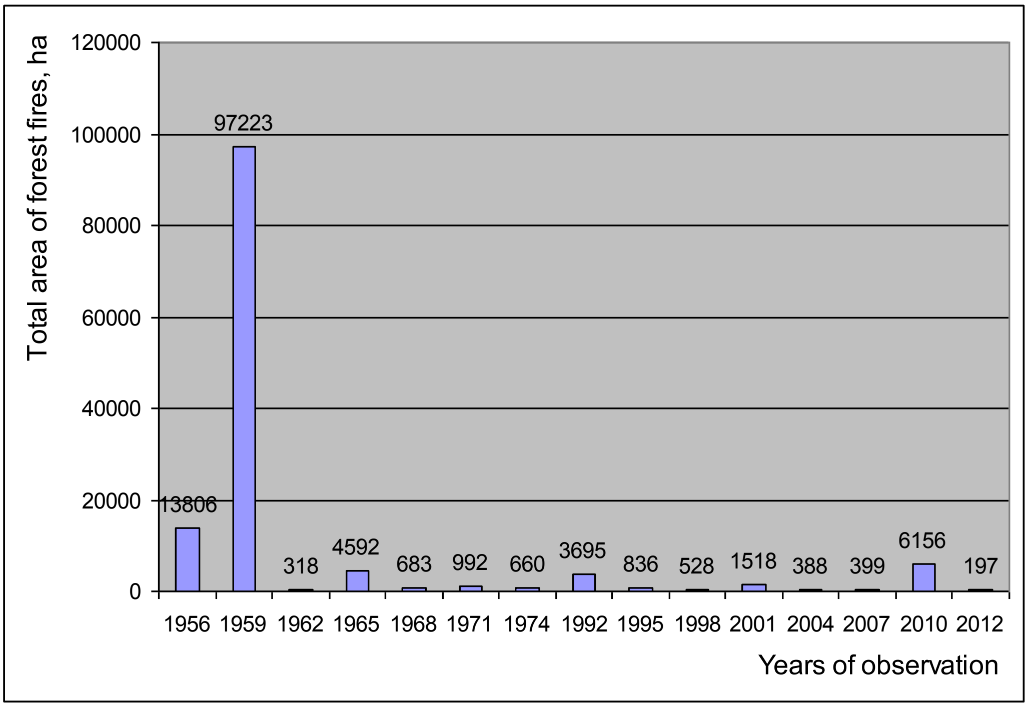

Figure 2. Total area affected by fires in the Republic of Karelia (selected data are presented)

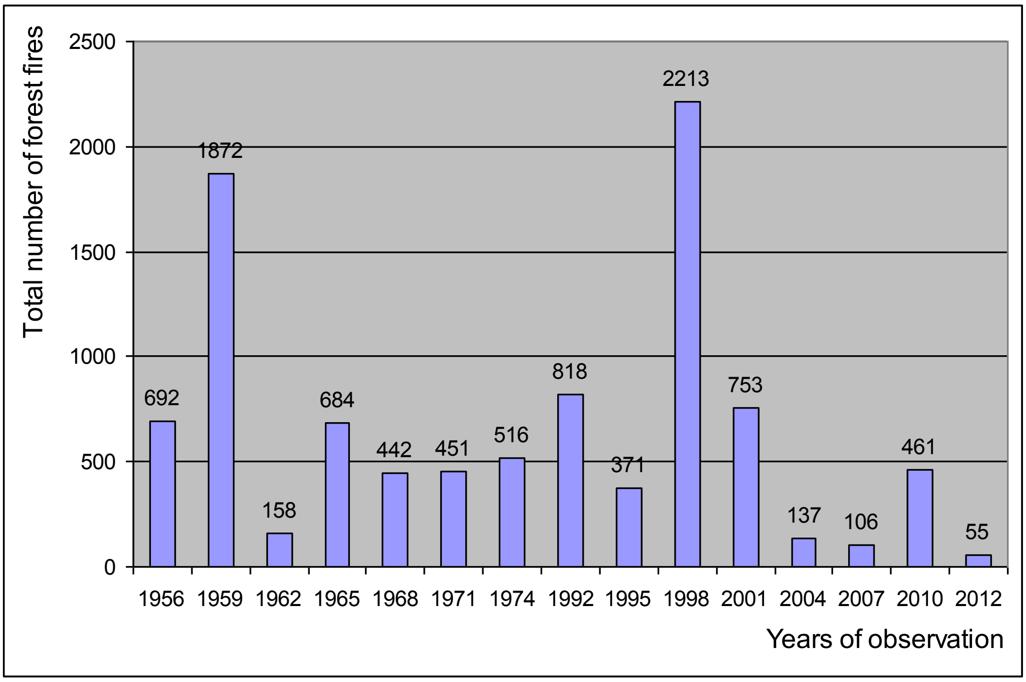

Figure 3. Total number of fires in the Republic of Karelia (selected data are presented)

Variation of the total area, number and average size of fires is due to the summer weather alone. Fires are expressly taken under control and eliminated by specialized agencies, using aircraft where needed. Thus, natural fire regimes have been fundamentally changed, mainly through a reduction in the size of a fire – from tens and hundreds of thousands hectares in primeval landscapes to some tens of hectares now. Human impact has dramatically increased the frequency of outbreaks. As mentioned above, it ranged from 1-2 in a century to 1-2 in a millennium depending on the landscape. The number has now grown to a total of several thousands a year. Yet, all the indices still correlate quite clearly with the landscape characteristics, and can vary by a factor of tens of times. Conservation of pristine forests with their spontaneous dynamics in protected areas is possible only under a natural fire regime.

4. Conclusions

The patterns identified can be quite confidently extrapolated to the whole European part of boreal forests in Russia. The characteristics of geographical landscapes (the range, ratio and spatial arrangement of their types) and land use history must however be taken into account.

5. References

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