Environmental problems of fighting fires in the permafrost zone

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Abstract. The impact of existing methods and technologies for extinguishing forest fires in the permafrost zone of the Krasnoyarsk Territory has been studied. Technologies to extinguish forest fires and the design of tools intended to carry them out environmentally safe for the nature of the North presented are. Methods for the delivery of technical equipment to the combustion centre and tactical extinguishing tactics that ensure the elimination of violations of forest ecology in permafrost are proposed.

1. Introduction

The history of the development of the Arctic accounts more than one century. But the Arctic remained unconquered, despite the wells, oil spills, ruined tundra and impoverished Aborigines by all-terrain vehicles.

The Arctic is not only ice, snow and boundless tundra. The area of permafrost on our planet reaches 35 million km², or 23% of the total land area, including 64% of the territory of the Russian Federation (11 million km²). 4.78 million km² of the area is covered with forests growing in the permafrost zone. This northern forest zone with a predominance of coniferous forests (boreal forests) is extremely environmentally sensitive and requires special approaches to their conservation in the face of increasing environmental pressures arising from the intervention of an unprepared person in natural processes [1, 2].

The boreal forests of cryolithozone in Russia have a stock of stem wood of more than 20 billion m³, but besides the source of raw materials, they are a natural biological regulator of the climate and natural environment, an ecological framework supporting the highly unstable ecological balance of the North of Eurasia. More than 80% of forest land on permafrost - monodominant larch stands, which stabilize the heat exchange between the atmosphere, soil and the frozen lithosphere, release oxygen and absorb carbon dioxide, maintain moisture circulation and deposit huge carbon reserves, which indicates their significant role in the carbon balance [1].

Forests in permafrost are distinguished by specific pyrological features caused by low rates of biological destruction of organic matter and, as a result, an increase in the amount of forest combustible materials by 3–5 times as compared with forests growing outside the permafrost zone.
The thinness of the tree canopy, although it contributes to the penetration of solar radiation to the soil surface, does not compensate for the effects of permafrost on the decomposition of forest combustible materials, and with a light day extended in summer and a small amount of precipitation (20-40 mm) contributes to the rapid fire maturation of the burning conductors, which creates an extremely high fire hazard in large areas [2, 3].

During fire emissions, that is, in the process of burning, salvo emissions of carbon occur, the process of post-fire emission, stretched for decades, occurs resulting from the destruction and decay of those who died from the fire, but not burnt large debris [4].

Throughout the entire historical period of their existence, boreal forests of cryolithozions were exposed to forest fires, which are the limiting and controlling factor in the formation of vegetation and habitat of wild animals. At the same time, the frequency of fire from the fifties of the twentieth century has increased significantly due to the implementation of the program of the Arctic. According to aero-visual surveys, fires occur near villages and geological sites. Previously, the local forests were burning very rarely. The cause of a forest fire should be a sufficiently intense source of heat, which is, for example, an extinguished fire [5].

Smoldering cigarette butts and sparks of different origin do not cause fiery burning, they only cause smoldering, which does not always turn into a fire. Lightning has a very high temperature, but due to exposure in thousandths of a second, they rarely generate fiery burning, especially since the vast majority of lightning is accompanied by precipitation. Therefore, the causes of forest fires are mostly man-made. As part of the sustainable development of the northern territories of Siberia and a socially oriented environmental management system, one of the priority tasks is to study the consequences of forest fires and their management strategies.

Territories with permafrost are currently, due to the development of human economic activity, one of the most burning, therefore the influence of forest fires in quantities many times higher than natural fires causes a violation of the existing natural balance. But forest fires occurred in the forests of the North before the start of economic development of the territory and did not destroy them.

2. Objects and methods of research

Forest fires occur for a number of reasons.

First, the cause of more than 90% of forest fires is man. In this case, the blame for the occurrence of forest fires rests mainly not on the indigenous population living in unity with the environment, but on visitors, mainly engaged in the search and mining of mineral resources, but not willing, and who do not care for their surroundings.

Secondly, the extinguishing of forest fires in the permafrost zone according to generally accepted technologies that do not take into account the specifics of a given region, is harmful to the environment, commensurate with the damage caused by the fire itself and often much better than it. Thus, the passage of heavy tracked bulldozers in the summer to the center of a forest fire, the laying of mineralized barrier strips with their help, or the performance of explosives with them, cause irreversible damage to the moss-lichen cover.

The result is a violation of the thermal regime under the living ground cover and forest litter of soils, their thawing with the formation of subsidence and failing landforms, accompanied by waterlogging of the territory. In the foreign Arctic, the use of vegetative cover transport in the permafrost zone has long been banned in the summer. It is easy to calculate that in the case of significant (sometimes tens of kilometers) remoteness of the centers of occurrence of forest fires from the locations of forest fire equipment, even with its timely arrival and operational extinguishing, the size of the area damaged by thermokarst on the way to the fire can be only in the initial stage of development more than 10 - 15 ha. During fires and the passage of heavy tracked vehicles to them, the superficial root system, which forms in permafrost trees, is damaged, which, after contact with the injured parts of the fungal infection, causes an irreversible process [6].
3. Results and discussion

The laying of mineralized barriers by tillage or digging tools (plows or dozer blades on heavy tracked tractors) inevitably causes a steady development of thermokarst around the extinguished conflagration, and when it is located on a site with a slope of more than 8-15°, a viscous-plastic flow of the forest soil occurs down the slopes in the boundaries barrier line (solifluction) [5, 7].

This phenomenon is accompanied by a massive tree fallout, thawing of exposed mineral soil and water soil erosion as a result of the rapid melting of conserved moisture previously contained in the frozen soil, enhanced by its runoff into water bodies, which leads to contamination of spawning grounds of valuable fish species. The developmental scheme of thermokarst and solifluction is shown in Figure 1.

![Figure 1](image)

**Figure 1.** The development scheme of thermokarst and solifluction in violation of the thermal regime of permafrost when performing forest fire work on generally accepted technologies.

At the same time, forest fires destroy the developing forests of the North, oxygen is consumed in their fires, carbon dioxide and carbon monoxide gases, as well as pyrolysis products are released into the Earth’s atmosphere. For example, in Evenkia, in recent years, more than 7 million hectares of forest have died in forest fires, 130.2 million tons of oxygen were consumed and 52.5 million tons of carbon dioxide and greenhouse gas pyrolysis products released into the Earth’s atmosphere. effect and causing undesirable climate warming of the entire planet. Direct damage only from the loss of timber amounted to approximately 1.5 billion rubles. Figure 2 presents a map of forest fires in the Krasnoyarsk Territory for 2016, from which the scale of fire damage in the Northern forests is visible.

But the price of wood grown in the temperate zone and the north of Russia cannot be the same. Now it averages at least 40 cents per cubic meter. And if after a fire in a temperate zone, the forest is restored within 80 - 100 years, then in conditions of cryolithozone under favorable conditions of self-seeding only tree growth takes at least 500 years. And when a lake of thermokarst origin or a piece of forest passed by fire crawled down the mountain slope on the place of the dead plantings, revealing the stony rocks underlying it, many years are needed for the overgrowing of the lake, for the passage of weathering processes of the parent rocks and the formation of a new soil layer.

However, none of the guidelines for extinguishing forest fires paid attention to the specifics of forest fire work in permafrost. There are no restrictions on the use of means of mechanization by the nature of the permissible pressures on the bearing surface, preventing its damage.
Figure 2. Map of forest fires in the Krasnoyarsk Territory for 2016. (Space monitoring center data) 210 thousand hectares burned out (including 207,689 hectares of forest land and 2,108 hectares of non-forest land).

The need to isolate permafrost from the penetration of heat into it when extinguishing forest fires, preventing irreversible phenomena of thermokarst and solifluction is not noted. At the same time, theoretical studies [5] speak of the need to restore the integrity of the moss cover along the track of the support strip after extinguishing a fire, although this is difficult or impossible in the framework of existing technologies and means of mechanization.

A way out of this situation can only be in the development of new technologies for extinguishing forest fires in permafrost conditions, the development of special machines and tools for their implementation, taking into account the proposed restrictions. Such restrictions are: exclusion of damage to the ground cover on the way to the place of a forest fire; immediate thermal insulation of the open mineral soil after removing the moss cover from its surface; the use of environmentally friendly methods of extinguishing, ensuring minimal damage to the ground cover during the work; reducing the negative effects of fire on the forest (thermokarst, solifluction, water erosion) in fire extinguishing technologies.
It is a way to make it a little bit more than that. There are no restrictions on the area of forest fire; moss cover from its surface; the use of environmentally friendly methods of protection during the work; reducing fires on the forest (thermokarst, solifluction, water erosion) in fire extinguishing technologies.

The economic evaluation of extinguishing technologies needs substantial revision. If in non-permafrost areas the delivery of vehicles under their own power and transportation of workers to a forest fire on off-road vehicles to a distance of 50–70 km is expedient and its movement by 80–90% is carried out on roads, in the North, with almost no roads and delivery of people by tracked all-terrain vehicles do not fit into the restrictions. It is necessary to use wheeled all-terrain vehicles on ultra-low pressure tires.

Efficiency of fire detection due to the infinite size of the territories and their extremely low population, excluding the presence of observation fire stations (towers) with the service personnel in these conditions should be provided with satellite, airborne and automatic ground monitoring systems. Fire extinguishing at an early stage of development during operational arrival at a fire center can be performed by one brigade of forest firemen of 5-6 people delivered by air or on all-terrain vehicles mentioned above.

But in order to cope with a forest fire by small forces, we need high efficiency of this brigade, which can only be achieved by using highly efficient technical means that provide at least three to five times the localization rate of the forest fire perimeter over the rate of its increase.

To overcome the current situation is possible only through the development of new vehicles and forest fire equipment [2]. When extinguishing water and fire extinguishing compositions - the creation of forest fire units on the basis of wheeled all-terrain vehicles, supplying water directly to the fire or wetting support and barrier lines before the edge of a forest fire. To bring down the flame of a high-speed air-liquid jet, testing of already existing forest fire blowers is necessary for extinguishing fires in p In the presence of water sources it is realistic to use existing motor pumps. It seems promising to install barrier lines by wetting a high-speed jet of liquid from a helicopter, but the cost of this technology may be too high, and a new solution of this technological process using an AH-2P amphibian is desirable. Experiments in this direction were conducted as early as the beginning of the 50s by N.P. Kurbatsky, but they were forgotten due to the lack of necessary economic incentives.

In reality, the use of barrier or support strips of quick-hardening flame-retardant polymer foam, laid on the ground after removing the moss-lichen cover and litter, but such technologies and means for their implementation have yet to be created. Foam is an excellent heat insulator, durable, has a sufficiently high strength and does not have a negative impact on the environment. Ground wetting of the support bands with retardant solutions requires the use of compact lightweight aggregates capable of working in the forest without damage to the living ground cover.

All means of mechanization for their implementation must be delivered to the hearth of a forest fire when it is significantly removed from its location by a MI-8 type helicopter with a payload of 3–4 tons. A team of forest firefighters, supplies and equipment are also delivered by the same helicopter.

Such technologies for extinguishing fires in the permafrost subject to their timely detection and rapid deployment of forces will help reduce the harm caused by man to the nature of the North. The cost of protecting the northern forests from fires should not stop us, since the destruction of unique forests of the North in fires entails the exacerbation of the most important problems inherent in the whole circumpolar region, namely, the global warming of the climate as a result of emissions of large amounts of carbon dioxide. gas and pyrolysis products; pollution of the natural environment, destruction of spawning grounds for valuable fish species, destruction of unique landscapes that have developed over a long period as a result of the development of thermokarst, solifluction and water erosion of the soot areas; the destruction in the fire of fires of flora and fauna of forests as habitats and livelihoods of indigenous population of the North.

Simultaneously with the solution of the problem of protecting the forests of permafrost zones from fires, the following issues should be considered: reforestation on the burns, taking into account the
reclamation of land disturbed by forest fires and the aftermath of their extinguishing technologies, which have a negative impact on the environment; the participation of the indigenous peoples of the Russian North in the implementation of work on the protection and restoration of forest plantations in the territories covered by fire, as well as extinguishing forest fires, which will partially solve the problems of employment and improve their living standards; the creation of natural reserves and national parks to preserve the unique creations of the nature of the North, to solve the problem of recreational use of Evenkia natural reserve (natural reserve) and other areas of the Arctic.

Currently, the problems of the Russian Arctic are not resolved. Although the first steps of the state in this direction in the legislative plan have been made, there is still no mechanism for the implementation of laws, the budget does not support environmental protection and sustainable development, since this has never been a priority of Russian state policy, and it is difficult to reverse the stereotypes that have been formed.

4. Conclusion
The International Union for Conservation of Nature (IUCN) can help solve the above problems in terms of:

1) financing of work on monitoring of forest disturbance of cryolithozone by fires and forecasting the probable loss of forest resources under the influence of forest fires;

2) supporting research of combustible forest materials in permafrost and the development of methods for the rapid assessment of their fire status and the forecast of forest burning;

3) financing the development and implementation of environmentally friendly technologies and technical means for extinguishing forest fires in permafrost;

4) supporting the creation of centers for training indigenous people in extinguishing forest fires using new technologies;

5) participation in the creation of biosphere reserves and national parks in the Northern Territories.

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