

# Forest health monitoring in Krasnoyarsk krai, Russia, from 2013 to 2022

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**Abstract.** A comprehensive analysis was conducted to assess the impact of two primary groups of pests (defoliators and xylophagous insects) on forests in Krasnoyarsk Krai. The study spanned the period from 2013 to 2022, during which a total of 1.7 million hectares of damage were documented. Of this total, defoliators were responsible for 77.8%, amounting to 1.3 million hectares, while stem pests accounted for 22.2%, or 0.4 million hectares.

## 1 Introduction

Forest ecosystems represent a pivotal component of the biosphere. Green areas provide numerous ecosystem services, including the production of oxygen, the sequestration of carbon, the regulation of surface and groundwater flows, the maintenance of a favorable climate (mitigate the risk of wind damage, increase humidity, maintain stable temperatures), water purification, soil protection, self-defense against bacteria, fungi, and insects (phytoncides), and the preservation of biodiversity (forests provide habitat for most of the planet's terrestrial species) [1, 2, 3].

However, in the contemporary era, forests are subject to degradation due to various factors, including, but not limited to, pathogenic organisms (diseases and pests), anthropogenic influences, soil conditions, climate change, and forest fires [4].

In this context, one of the most notable regions is Krasnoyarsk Krai, which is regarded as one of the largest forest regions in Russia, with 105.0 million hectares designated as forest coverage [5].

According to data [6–15] compiled from the materials of the state forest pathology monitoring, over the last decade, more than 21.8 million hectares of forest have been listed as disturbed (Fig. 1). In recent years, the area of damaged forests has approached five million hectares per year. Projections based on simplified estimations, under the assumption of a stable forest health status, suggest a potential loss of all Russian forests within the next two decades.

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## 2 Materials and Methods

The most prevalent causes of forest decline over the decade (Fig. 2) are forest fires (28.7–78.8%) and insect damage (19.3–65.2%). From 2013 to 2017, the shares of these disturbances were equal to each other (30.0–40.0%), and showed a slight increase. However, from 2017 to 2021, there was a marked increase in the area of damage. Since 2021, forests have burned across more than 3.6 million hectares (67.1% of the total disturbed area), while 29.5% of forests have been damaged by pests. In 2022, the incidence of fires escalated by an additional 11.6%, while approximately 1.0 million hectares (19.3%) were damaged by insects.

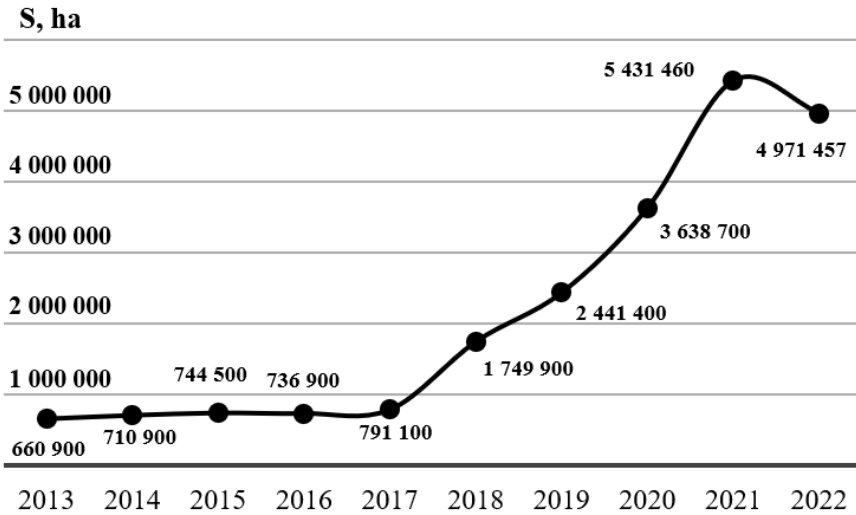


Fig. 1. Forest health dynamics in Krasnoyarsk Krai over the course of a decade.

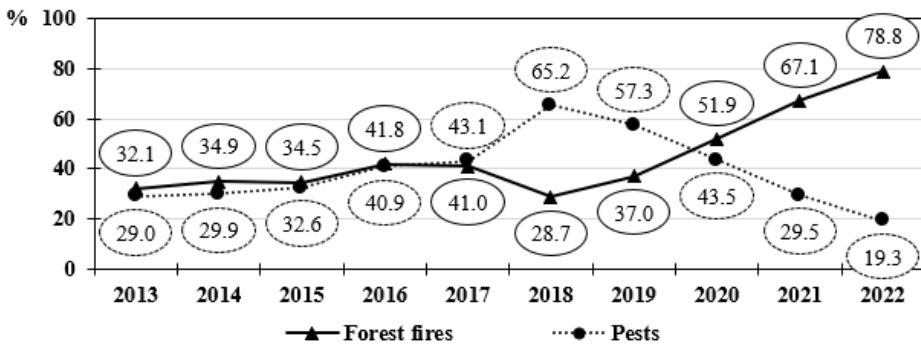


Fig. 2. Dynamics of damage to forests in Krasnoyarsk Krai from forest fires and pests.

The primary cause of this phenomenon is the Siberian moth (*Dendrolimus sibiricus* Tschetw.) outbreak in 2016, accompanied by a notable increase in the area of fir stands that have been damaged by the four-eyed fir bark beetle (*Polygraphus proximus* Blandford) from 2015 to 2018 [16, 17].

These species are classified as conifer pests and are divided into distinct groups. The Siberian moth (*D. sibiricus* Tschetw.) is a defoliator, while the four-eyed fir bark beetle

(*P. proximus* Blandford) is a xylophagous insect. These groups are responsible for the most significant damage to coniferous forests.

Two salient points merit emphasis: coniferous species lack resistance to defoliation, a trait that distinguishes them from deciduous species; and the four-eyed fir bark beetle (*P. proximus* Blandford) is an invasive species of Asian origin, with its primary range encompassing the Russian Far East, North-Eastern China, the Korean Peninsula, and Japan, where it inflicts damage on forests with less severity.

Coniferous forests of Krasnoyarsk Krai turned out to be not resistant to the four-eyed fir bark beetle (*P. proximus* Blandford). As a result, the pest began to damage healthy forest stands and displace native species of stem pests: *Monochamus Urussovi* Fisch., *M. Galloprovincialis* Oliv. and others.

Forests that have been damaged by pests are classified according to the first class of the natural fire danger (NFD) rating system, as delineated by the scale of Melekhov (2007). This classification is characterized by an exceptionally high fire hazard, with the potential for both ground and crown fires to occur throughout the entire fire season. Consequently, when considering the confluence of adverse climatic factors, a substantial escalation in flammability is to be anticipated for disturbed forests [3].

In relation to the aforementioned, the objective of the present research was to evaluate the extent of damage caused by groups of pests (xylophagous insects and defoliators) to forests in Krasnoyarsk Krai from 2013 to 2022, with a focus on regions where the potential for future forest fires exists.

### 3 Results and discussion

Krasnoyarsk Krai is located in Central and Eastern Siberia and is part of the Yenisei and Ob river basins. The region stretches for 3,000 km from south to north and 1,250 km from west to east, encompassing 60 forest management units in eight forest zones: Altai-Sayan mountain forest-steppe, Altai-Sayan mountain taiga, West Siberian middle taiga plain, West Siberian southern taiga plain, taiga in the lower reaches of the Angara river, Central Siberian plateau taiga, Central Siberian subtaiga forest-steppe, and Central Siberian subtaiga forests and low-density taiga.

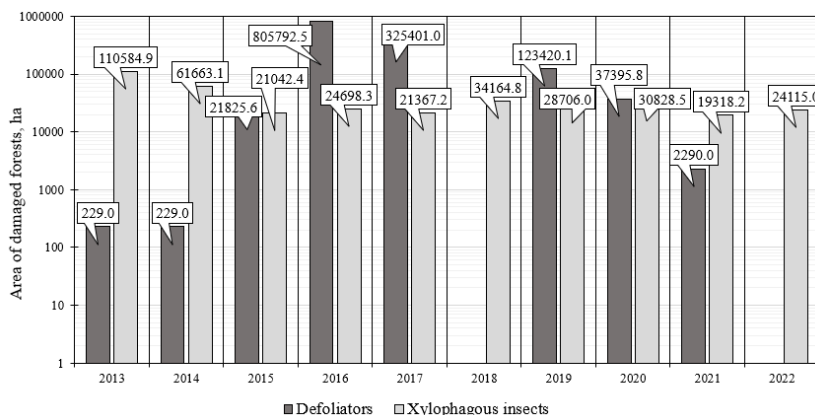
Over the course of a decade (2013–2022), insects damaged approximately 1.7 million hectares (Fig. 3) of forests in Krasnoyarsk Krai, according to the State Reports "On the state and protection of the environment in Krasnoyarsk Krai" for the study period [6–15]. Of these, defoliators were responsible for 77.8% or more than 1.3 million hectares, while xylophagous insects accounted for 22.2% (0.4 million hectares).

In the year 2016, the most extensive area of damaged forests was identified, amounting to 830.5 thousand hectares, coinciding with the outbreak of the Siberian moth (*D. sibiricus* Tschetw.). According to the state report [9], 99.75% of the forests that experienced defoliation in this year can be attributed to this pest. The distribution of the affected area across different forest management units is as follows: Yeniseyskoye (606.1 thousand hectares), Nizhne-Yeniseyskoye (197.5 thousand hectares), and Severo-Yeniseyskoye (205.1 hectares). An area of 1961.0 hectares was damaged by the gypsy moth (*Phalaena dispar* Linnaeus), which was concentrated in the Usinskoye forest management unit.

Since 2019, the outbreak of the Siberian moth (*D. sibiricus* Tschetw.) has been documented in the Irbeyskoye forest management unit, encompassing an area of 108.2 thousand hectares. However, by 2022, the outbreak had ceased.

In the years 2013 and 2014, a substantial area of forests suffered damage from defoliators, amounting to 229.0 hectares. This phenomenon was particularly notable in the

Ermakovskoye and Kizirskoye forest management units, where outbreaks of the moth *Phyllocnistis labyrinthella* Bjerk. were observed [6–15].



**Fig. 3.** Dynamics of the area of forests in Krasnoyarsk Krai that have been damaged by two primary groups of pests.

In 2013, the maximum recorded area of forest damage due to stem pests in the region was documented at 110.6 thousand hectares, with various insect families being documented in the records, including bark beetles, longhorn beetles, jewel beetles, weevils, horntails, wood borers, and clearwing moths. Significant areas of damaged forests were identified in the Irbeyskoye (26.7 thousand hectares) and Motyginskoye (36.7 thousand hectares) forest management units, where the primary pest was the longhorn beetle (*M. Urussovi* Fisch.). This pest accounted for 57.3% of all damage by xylophagous insects in the region during that year.

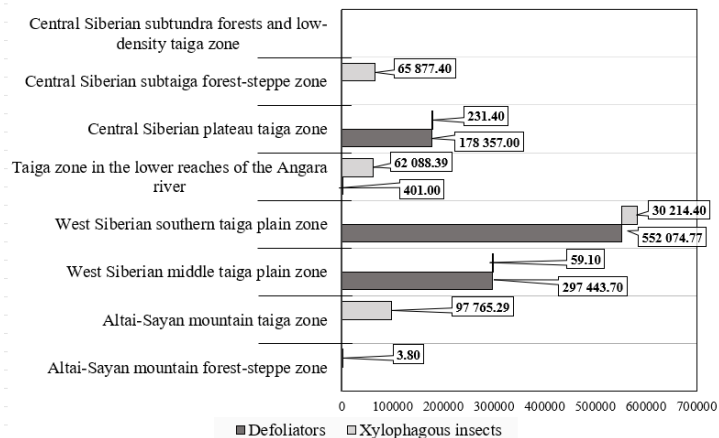
In 2021, the minimum area of forests damaged by stem pests was documented to be 19.3 thousand hectares. The four-eyed fir bark beetle was responsible for 83.9% of the observed damage, thereby substantiating the aforementioned thesis that this species displaces the native species of pests. For instance, in 2016, the four-eyed fir bark beetle accounted for 47.8% of the damage.

A comprehensive analysis of forestry regulations across all forest management units in Krasnoyarsk Krai was conducted to identify regions most vulnerable to invasive disturbances (Fig. 4).

The analysis revealed that no pest outbreaks were identified in the Central Siberian subtaiga forests and low-density taiga zone, a phenomenon attributed to the region's harsh climate.

The West Siberian southern taiga plain zone has the largest area of damaged forests, with a total of 582.2 thousand hectares. In this zone, the share of defoliators is 94.8%, and the outbreak of the Siberian moth (*D. sibiricus* Tschetw.) in the Yeniseyskoye forest management unit is the primary cause. The xylophagous insect component, accounting for 5.2% of the total, is predominantly attributed to the outbreak of the four-eyed fir bark beetle (*P. proximus* Blandford), which accounts for 79.4% of the recorded damage.

In the Central Siberian subtaiga forest-steppe, Altai-Sayan mountain taiga, and Altai-Sayan mountain forest-steppe zones, no defoliator outbreaks were identified. However, the first two forest zones exhibited the most extensive areas of damage caused by xylophagous insects (Fig. 4). In contrast, the Altai-Sayan mountain forest-steppe, West Siberian middle taiga plain, and Central Siberian plateau taiga forests exhibited minimal damage from stem pests.



**Fig. 4.** Area of forests disturbed by the two primary pest groups in forest zones of Krasnoyarsk Krai.

Furthermore, the percentage of damage caused by pests was calculated based on the area occupied by each forest zone. According to these calculations, the West Siberian southern taiga plain (9.2%) and the West Siberian middle taiga plain (5.8%) zones were the most damaged. The latter is represented by a single forest management unit, Nizhne-Yeniseiskoye, where the primary pest is the Siberian moth (*D. sibiricus* Tschetw.), which accounts for 99.9% of the damage.

## 4 Conclusion

A comprehensive evaluation of the damage to forests by pests in Krasnoyarsk Krai over the span of a decade (2013–2022) has yielded several key conclusions:

- during the study period, approximately 1.7 million hectares of forests were documented as damaged by insect pests, with the most perilous species identified as *P. proximus* Blandford and *D. sibiricus* Tschetw.;
- the preponderance of damage is attributed to defoliators, comprising 77.8% of the observed cases, with *D. sibiricus* Tschetw. constituting the predominant species;
- the proportion of damage caused by xylophagous insects is 3.5 times lower and relates mostly to damage caused by the invasive species *P. Proximus* Blandford, which accounts for an average of 72.4% over the period of its appearance (2016–2022);
- a rise in the occurrence of fires was observed in Krasnoyarsk Krai as a whole following the outbreaks of insect pests;
- *P. proximus* Blandford has been observed to displace native species of stem pests (2016 – 47.8%; 2017 – 47.5%; 2018 – 66.6%; 2019 – 88.5%; 2020 – 84.9%; 2021 – 83.9%; 2022 – 87.9%);
- the highest recorded area of forests disturbed by pests occurred in 2016, measuring 830.5 thousand hectares, whereas the lowest recorded disturbance was observed in 2021, with an area of 21.6 thousand hectares;
- the following forest management units have been particularly damaged by defoliators: Yeniseyskoye, Nizhne-Yeniseyskoye, Severo-Yeniseyskoye, and Irbeyskoye;
- the stem pests demonstrated a higher level of aggression in the Gremuchinskoye, Pirovsky, Yeniseyskoye, Tayozhinskoye, Uyarskoye, Kozulskoye, and Bolshemurtinskoye forest management units;
- the forest zones that experienced the most significant damage were the West Siberian southern taiga plain (9.2%) and the West Siberian middle taiga plain (5.8%).

## Acknowledgements

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