Opportunities for assessing the risk of an outbreak of Siberian silkworm (Dendrolimus superans sibiricus Tschetv.) in taiga forests

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Abstract. The problem of damage and infestation of forests by pests and diseases takes a significant place in forestry. The combination of these factors, taking into account cutting and harm to forests from fires and other human activities, as a result leads to tremendous degradation of forest ecosystems. In modern conditions, the forest pathological stands condition in Russia is determined on the basis of data from forest pathological surveys and state forest pathological monitoring. For the current period (2020), disappointing statistics remain on the reproduction of the Siberian silkworm population (Dendrolimus superans sibiricus Tschetv.) nd the negative consequences for taiga forests. Modern climatic changes on a planetary scale have a significant impact on mass outbreaks of dangerous phytophage. In the near future, adaptation measures in the field of forest pathological monitoring should be based on risk factors when planning forest protection measures, a diverse selection of adaptation options and adopting a flexible forest management system at the regional level. In this paper, we consider one of the methods for improving forest pathological monitoring, based on the principles of covering as large a territory as possible with remote sensing data (ERS) combined with predictive models based on GIS that allow predicting the risk of mass reproduction of the Siberian silkworm based on the previously studied factorial dependence.

Damage and infestation of forests by pests and diseases causes great environmental and economic harm to the forestry of this country. The combination of these factors leads to a loss of the current growth of wood, drying out and degradation of forest stands, a decrease in their environmental, water protection, and agroforestry functions. Taking into account deforestation and harm to forests from fires and other human economic activities, a colossal degradation process occurs as a result [1, 2, 3, 4, 5].

The deterioration of the sanitary condition of the forests of the boreal zone is attracting increasing attention of researchers and the public. Adverse climate change, intensification of anthropogenic impact, inter-regional movement of diseases and pests are the main causes of modern forest degradation [1, 6, 7, 8, 9].
In modern conditions, the forest pathological condition of stands in Russia is determined on the basis of data from forest pathological surveys and state forest pathological monitoring carried out by the Russian Center for Forest Protection (Roslesozashchita).

State forest pathological monitoring (hereinafter - SFPM) is part of state ecological monitoring (state environment monitoring) and is carried out on the basis of Article 56 of the Forest Code of the Russian Federation and Order of the Ministry of Natural Resources and Ecology of the Russian Federation dated 04.08.2015 No. 340 “On approval of the Organization and implementation of state forest pathological monitoring.” State forest pathological monitoring is carried out throughout the forest fund of the Russian Federation [10].

The purpose of SFPM is the timely detection, assessment and forecast of changes in the forest pathological condition for management in the field of forest protection and sanitary safety in forests [10].

Currently, SFPM is based on various methods of its implementation [11]:

- regular ground-based observations of the sanitary and forest pathological of forests condition;
- selective monitoring of pest populations;
- selective ground-based observations of the sanitary and forest pathological of forests condition;
- inventory of pests centers;
- assessment of the sanitary and forest pathological condition of forests;
- remote monitoring of forests condition;
- expeditionary examinations.

According to the latest official data of Roslesozashchita, the forest pathological condition of the forests (01.01.2018) in the Russian Federation was not developing for the better, centers of pests acted on an area of 3,638.9 thousand ha, which is 8.9% higher than their average long-term indicator, since 1962 [12]. According to the situation for period 2018-2019, currently, statistics are not available, therefore, the work provides information limited to 2017.

A significant share of taiga forests is geographically concentrated in the Siberian Federal District (SFD). In the last decade, the chronology of damage to forests by coniferous pests based on SFPM statistics (figure 1) proves the negative dynamics of conservation of taiga forest ecosystems, and, consequently, their time stability.

Among coniferous pests, the most dangerous for the country's coniferous forests is the Siberian silkworm (Latin Dendrolimus sibiricus), outbreaks of mass reproduction of which regularly occur in various parts of its range and invariably lead to the drying up of forests. In some years, the areas of the sites of dead stands reached hundreds of thousands of hectares [1, 2, 4, 10, 11, 12]. Concomitant mass reproduction of stem pests or the additional impact of other negative natural and man-made factors make harm to forests especially significant. Also, outbreaks of the Siberian silkworm exert selective pressure on taiga biogeocenoses, contributing to the wide distribution of birch and aspen because of the decrease in the area of dark coniferous stands.

![Figure 1. Dynamics of areas of centers of coniferous pests in the Siberian Federal District according to SFPM.](image-url)
Siberian silkworm is one of the most studied phytophage species [1, 2, 3, 4, 13, 14]. Regular observations and surveys of pest centers have been carried out since 1962. Over 55 years of observations, silkworm centers, varying in area from 4.2 to 6,934.2 thousand ha, were recorded annually and acted simultaneously in the stands of 3 to 13 entities of the country. The average area of pest centers for this period is 563.4 thousand ha [12].

Most often, pest centers are formed and act in coniferous stands of five constituent entities of the Russian Federation in the territory of the Siberian Federal District: the Republic of Tyva, Altai and Krasnoyarsk Territories, as well as in the Irkutsk and Tomsk Regions. In other regions, an increase in the number of pest populations to a focal level occurs regularly with varying frequency [10, 11, 12].

In 2016, an avalanche-like growth in numbers and the formation of large centers of this pest in the forests of the Asian part of Russia were observed (figure 2). During 2016, the area of the pest centers of this pest in Russia increased by more than 21 times (by 1,281.9 thousand ha), which is 145.1% higher than its average long-term indicator [11].

Figure 2. Dynamics of the centers of the Siberian silkworm in the Siberian Federal District in 2015 - 2017.

More than 96% of the area of the centers of Siberian silkworm identified in 2016 were in forests of the Krasnoyarsk Territory, Tomsk, Kemerovo and Irkutsk Regions [10, 11].

According to accumulated knowledge, such a rapid development of populations was due to several reasons [12]:

- gradational 10-year cycle (the last centers acted 10-12 years ago);
- favorable weather conditions for the pest during 2014-2016. (significant moisture deficit and high air temperatures during vegetation periods, warm autumn periods and high snow cover), which contributed to the high survival rate of the Siberian silkworm at all developmental phases (egg, caterpillar, pupa, imago) and high fecundity of its females;
- general climate warming, which allowed the pest to settle outside the northern border of its range;
- the transition of the population from a two-year to a one-year development cycle, which allowed it to increase its number in a shorter time;
- low number of entomophages;
- insufficient volumes of measures to eliminate centers of the Siberian silkworm in 2015-2016. [10, 11].
It should be noted that the above listed reasons for the mass reproduction of a dangerous phytophage are well known and are not sudden in nature.

For the current period, unfavorable statistics on the reproduction of the Siberian silkworm population and negative consequences for taiga forests are preserved, as evidenced by official data of the Federal Forestry Agency of the Russian Federation [4]. In most regions of Russia, there has been a negative trend in the accumulation of dead forest stands that have remained standing, which is caused by insufficient volumes of sanitation cutting and other forestry activities aimed at developing dead forest stands [10, 11, 12].

For the timely implementation of effective protective and preventive measures it is necessary to predict, at an early stage, the threat (risk, probability) of mass reproduction of the Siberian silkworm and damage to the stands. The importance of forest pathological forecasts and their necessity is not in doubt, and they are present as part of any forest system [1]. Obviously, preventive measures to protect forests prevent both environmental and economic harm. Bearing in mind, the large scale of Russian forest spaces, one of the methods for improving forest pathological monitoring should be a method based on the principles of covering as large a territory as possible with remote sensing data (RSD) combined with forecast models that predict the risk of mass reproduction of the Siberian silkworm based on the previously studied factorial dependence.

For more than half a century of studying this dangerous pest, the scientific community has established that reserves and primary centers of silkworms are more often confined to dark coniferous plants growing on more heated and aerated areas, with drier growth conditions or with well-drained soils, of medium density (0.4-0.7) or to their outskirts, edges, lowlands, more often to pure stands, of older classes, belonging to groups of drier or fresher types of forest (green-moss, herbaceous, etc.) [1, 2, 4, 10, 11, 12]. Everywhere in the area of the silkworm in Russia, 2-year generation was recorded, exceptions may be warm years, when the pest develops along an annual cycle [1, 2, 4, 11].

Outbreaks of this phytophage are evolutionarily determined and cyclically repeated in time [1, 4, 7, 12, 13]. The weather conditions have significant impact on the dynamics of the numbers. Relation of breeding outbreaks to periods of dry years and an increase in numbers after droughts have been noted long ago [1, 3, 4, 7]. Another evidence is the period 2015-2016. According to all available data from world climate centers, 2015 was the warmest year on a global scale for the entire time of observations [10, 11]. It was exceptionally warm in the winter season of 2014–15; in Russia as a whole, the deviation from the norm was ±3.56 °C. It was especially warm in the Asian part of Russia (anomaly of 3.65 °C). In the center of Siberia, maximum seasonal anomalies were noted, which reached 8 °C. A change in the temperature regime in the positive direction contributed to a sharp increase in the populations of Siberian silkworms in the Krasnoyarsk Territory, Irkutsk and Tomsk Regions, and other entities of the Russian Federation [11].

Given the uncertainty associated with ecosystem responses to climate change, building an effective territorial observing system taking into account the specifics of the ecology and biology of the pest is extremely important. At the same time, the adoption of optimal decisions on protecting the forest from pests, requires, first of all, a comprehensive risk analysis so that it might be possible to better assess and compare the likely results of a number of measures. For example, attempts to eradicate some outbreaks can be very costly and unsuccessful at the same time, or in the worst case lead to unintended results that will lead to new problems.

In the current context, one of the options for timely timely detection of the forest condition is the use of remote sensing data combined on the basis of GIS with “layer-by-layer” information on the natural characteristics of forests and factors that accurately identify and predict the propagation of a dangerous pest at the regional level. Similar to forest pathological monitoring systems, BioSIM is successfully used in Canadian forests [9].

The effective use of spacer photography to detect insect pest outbreaks can be based on NOAA / AVHRR and TERRA / MODIS satellite survey data. Moreover, the generation of “survey” spectroradiometers TERRA / MODIS, SPOT-Vegetation, have improved radiometric characteristics and are designed (in contrast to NOAA / AVHRR) for solving environmental problems. High-resolution
surveying (Landsat) allows you to detail the dynamics of damage to forest stands [15, 16]. Previously conducted researches by V.I. Kharuk, E.V. Fedotova and others proved that regular surveys of the territory of taiga forests from space, even on a small scale (NOAA / AVHRR, TERRA / MODIS), make it possible to successfully monitor the state of stands in the outbreak of mass reproduction of the Siberian silkworm. In addition, the authors identified landscape confinement of stands damage at an early stage of an outbreak. Using a digital elevation model and data on the position of the primary pest centers allows to concentrate monitoring in limited areas with the highest probability of an outbreak of mass reproduction [15, 16, 17, 18].

When creating a database in the GIS, it is recommended to use the available forest inventory materials (forestry-mensurational description and cartographic material of forestries) as the main characteristic of stands at the regional level. In addition, in order to make optimal decisions on control measures in case of an outbreak of an insect phytophage, it is necessary to zone the territory and fill the geographic information system with information on the purpose of forests, available forest infrastructure, the presence of nearby settlements, aviation, ground accessibility of forest areas, and other additional data.

To identify the location of the dangerous phytophage, it is sufficient to use the accumulated information on the ecological and biological characteristics of the pest and data on outbreaks of the Siberian silkworm of previous years, which will allow us to allocate reserves and outline close monitoring points at the initial stage. Since the mensurational characteristics of the stands for various reasons do not always coincide with the “nature”, it is advisable to use the vegetation index of the normalized difference NDVI and the improved vegetation index EVI to verify the current state of stands and the dynamics of distribution of the insect phytophage [15, 17].

NDVI - (Normalized Difference Vegetation Index) - normalized relative vegetation index - a quantitative indicator of photosynthetically active biomass, is one of the most common and used indices for solving problems using quantitative estimates of vegetation cover. EVI - (Enhanced vegetation index) - an advanced vegetation index - designed to enhance the signal in regions with high biomass. The two vegetation indices complement each other in global vegetation studies and improve the detection of vegetation changes and the extraction of biophysical parameters of the crown. Sites with a low index value indicate a small amount of biomass, and, consequently, damage to stands by the phytophage [15]. Vegetation indices in the form of ready-made images are available on the LP DAAC website (The Land Processes Distributed Active Archive Center): https://lpdaac.usgs.gov/.

During monitoring, the synchronization of processes occurring in the stands with changes in climatic parameters by season and year can be provided automatically using the information available on the NASA Prediction of Worldwide Energy Resources official website: https://power.larc.nasa.gov/. The indicators for predicting the outbreak of the pest should be taken as the amount of precipitation for the year and the sum for days with a stable temperature above 10 0C [1, 2, 4, 7, 10, 11, 12, 13].

Long-term mathematical prediction of the occurrence and development of outbreaks of the Siberian silkworm has been undertaken repeatedly by various scientists [1, 4, 7, 13]. However, to date, none of them can be put into practice for various reasons. In our opinion, the most acceptable for forecasting purposes is a variant of the empirical-statistical model developed by V. Yu. Nikitina. The model is based on spatio-temporal series of population dynamics. The population leaves the stability zone mainly due to such a factor as drought for two or more years [7]. In addition, V. Yu. Nikitina and V.N. Nikitin expanded point simulation model due to the migration interaction of individual micropopulations of insects with each other. In this case, the model acquired a spatially distributed character. When creating the model, the territory was divided into cells with its point discrete models of pest populations [7].

In further work, it is expected that the authors’ ideas with the elements of improving this model will be taken as a basis by combining it with the above-mentioned outbreak indicators, which will make it possible to increase the accuracy of the forecast for the mass reproduction of the dangerous pest. The complex application of this model, cartographic materials, and Earth remote sensing data will give an
opportunity to carry out short-term forecasting of the dynamics of the number of pests, as well as to study in detail the nature of migration processes in various phases of the outbreak.

The proposed option for assessing the risks of outbreaks of Siberian silkworms is preliminary and requires verification at the pilot project level within a small area, for example, forestry. And only in case of a positive effect worked out in time it can be spread to other territories.

Obviously, measures in the field of the forest pathological monitoring for the operational detection of the state of the forest environment are currently not fully improved and require further research. The creation of simulation models of mass reproduction of pests at the regional level makes it possible to optimize the processes of planning forest protection measures, using pest control and assessing changes in the potential spectrum of organisms in a particular forest territory.

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