Monitoring the development and forecasting of the mass reproduction (gradation) outbreaks of the *Dendrolimus sibiricus* Tschetv. in the Khabarovsk region

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**Abstract.** The article describes the probability of the *Dendrolimus sibiricus* outbreaks in the Khabarovsk region based on the methodology developed by ARRISMF (All-Russian Research Institute of Silviculture and Mechanization of Forestry). The history of outbreaks, their occurrence and intensity were analyzed. Results of field studies with direct census methods and reasonable forecast for 2019 are also described.

1. Introduction

Outbreaks of forest insect mass reproduction are considered as an important factor in the dynamics and evolution of forest ecosystems in several regions of Siberia and the Far East. The impact of insects significantly affects the forest-forming process, determines the composition, structure and productivity of forests [1]. Accurate and high-quality forecast of the development of the mass reproduction outbreak threat allows to register the growth of the pest abundance in a timely manner and to determine the measures for localization and suppression and subsequently allows preventing the death of forests.

*Dendrolimus sibiricus* is one of the most dangerous phytophag on the territory of Siberia and the Far East. Its outbreaks refer to catastrophic phenomena. Dried-out forests cause a high risk factor for natural fires, becoming impassable after the trees fall out. The reforestation takes a long time.

The northeastern part of the *Dendrolimus sibiricus* habitat borders passes around the 55th parallel of northern latitude: from the Udskaya Bay to the northwest; in the southern part bending around the Stanovoy Range and rises north along the lower reaches of the tributaries of the AldanRiver. In the Khabarovsk Territory, a serious increase of silkmoth abundance is recorded from time to time in the larch forests of the Lower part of the Amur River and cedar-broadleaved forests of the south of the region. The last outbreak of mass reproduction was recorded in 2001 over a large area of six forest districts (Kerbinskoe, Bystrinskoe, Nikolaevskoe, Ulchskoe, Kizinskoe, Taktinskoe) and partly in the Solnechnoe and Evoronskoe forest districts. Separated stands and spots of dried up larch stands were discovered on hills in the basin of the Amgun river and its tributaries, where previously large silkmoth outbreaks were not observed.
The history of outbreaks in the XX century can be traced to the discovery of mass reproduction in the basin of the Matay River. This outbreak was described by V.F. Ovsyannikov in the article “The destruction of forests at the headwaters of the Matay River”. Later it was reflected in the reports of entomologists who examined dried forest stands. The area of dead forest stands was indicated about 160 thousand hectares.

In 1952-1954 *Dendrolimus sibiricus* outbreaks were recorded in cedar-broadleaved forests in the basin of the Khor River - 60 thousand hectares, and in the basin of the Iman and Bikin Rivers – 301 thousand hectares, and in 1958 it was registered in the larch forests of Kerbinskoe forestry.

In 1969-1971 pest harborage areas were observed in larch woods of the Khabarovsk Territory in the Upper Bureinsky District (Urgalskoe forest district) (about 6000 hectares) [2]. They were formed on the southern slopes, which were well warmed by the sunlight, in thinned young, mature and overmature forests. Middle-aged and ripening forests were affected by *Dendrolimus sibiricus* in a smaller extent due to greater environmental plasticity.

Arid weather in 1996-1998 contributed to the decrease in stress resistance of forests, which resulted as a widespread development and mass reproduction of *Dendrolimus sibiricus* in 2001 on a total area over 750 thousand hectares in Nijneamurskoe forest protection district and in some little areas of Solnechnoe district (Amgunskoe, Solnechnoe, Evoronskoe forest districts).

In the upper part of the slopes, pest harborage areas appeared mostly in larch forests with dwarf Siberian pine on low-power dry soils, V growth class. Damaged larch forests of various ages (especially young ones) dried out here in the first instance. In the middle part of the slopes and on flat areas, pest harborage areas developed in the foxberry - Ledum rosewood, green moss - Ledum rosewood, reed-grass, rhododendron-forb-grass types of forest of III-IV growth class. Various types of larch forests on the terraces of large streams were also severely damaged and dried [3].

Under normal conditions in these areas the Dendrolimus sibiricus has two-years generation. In a two-year generation cycle, larvae can reach 7 or 8 age levels in warm seasons. During the period of population growth, a significant part of the population (up to 80-90%), switched to one-year generation. In this regard, the growth rate was very high and pest harborage areas with high density appeared within 1-2 years.

2. Material and methods

The studies were based on the ARRISMF method “Prediction the threat of mass reproduction outbreaks of economically dangerous forest insects” in order to test this algorithm [4]. Zones of pest harborage areas occurrence threat of were determined in the context of forest areas on the basis of indicators and their gradation shown in Table 1.

The most effective indicator for classification (zoning) is the frequency of mass reproduction of insects. Mass reproduction of insects in favorable conditions is observed on average every 10-11 years, in few favorable ones - once every 50 years, in adverse conditions no pest harborage areas appear.

The frequency of mass reproduction can be determined as the average duration of the time interval between the beginning of successive mass reproduction in the same area.

The frequency can also be defined as the ratio of the number of years in the observation period to the number of mass reproduction during this period. Information on observations was taken from 1967, since for earlier years it was not possible to find information about the area of damage caused by the *Dendrolimus sibiricus* during some outbreak.
Table 1. Scale of scoring indicators of the threat of insect mass reproduction.

| Indicators                                              | Distribution of scores on a five-point scale |
|---------------------------------------------------------|---------------------------------------------|
| Frequency of mass reproduction, years                   | over 50 26-50 21-25 12-20 up to 11           |
| The occurrence of pest harborage areas in the regions,%| up to 10 11-30 31-50 51-70 71-100             |
| Occurrence of pest harborage areas in forest districts,%| up to 3 4-10 11-20 21-40 over 40              |
| Maximum area of pest harborage areas, ha               | up to 102 102-103 103-104 104-105 over 105   |
| Relative area of pest harborage areas, %                | Less than 0.1 0.1-1.9 2.0-9.9 10-19.9 20 and over |
| The threat of mass reproduction                         | Very low Low Medium High Maximum              |

The occurrence (probability of formation) of mass reproduction outbreaks in a region or forestry is defined as the proportion of years with pest harborage areas in the region or forestry, respectively, of the total observation period (52 years), expressed as a percentage.

The intensity of mass reproduction is characterized by two indicators: the maximum (for the entire observation period) and the relative area of pest harborage areas.

The relative area of pest harborage areas is defined as the proportion of the average area of pest harborage areas of the forested area occupied by feed species.

The degree of mass reproduction threat can be used for estimation of insect harmfulness. Maximum harmfulness (5 points) - decay of forests due to the death of the main forest forming species. High severity - a chronic decrease in the productivity of forests due to spot drying of the trees of the first story, as well as mass drying of trees of the second story. Moderate pest damage is a chronic decrease in the productivity of forest stands associated with deep loss of wood growth. Weakness - a temporary decrease in the productivity of forests due to the loss of growth of wood and seed. Insignificant harmfulness (1 point) - economically imperceptible loss of wood growth.

3. Results and discussion

The most general results of the analysis for the Khabarovsk Territory are presented in Table 2. The average degree of threat of occurrence of pest harborage areas of the Dendrolimus sibiricus is stated in five forest districts of the Khabarovsk Territory [5].

Table 2. The threat of mass reproduction outbreak of Dendrolimus sibiricus in forest districts in the Khabarovsk Territory.

| Forestry          | Threat | Intensity | Occurrence | Level of threat |
|-------------------|--------|-----------|------------|-----------------|
| Avanskoe         | low    | low       | low        | low             |
| Amgunskoe        | low    | low       | low        | low             |
| Ayanskoe         | low    | low       | low        | low             |
| Badjalskoe       | low    | low       | low        | low             |
| Bikinskoe        | low    | low       | low        | low             |
| Bolonskoe        | low    | low       | low        | low             |
| Bistrinskoe      | low    | high      | low        | medium          |
| Visokogornoe     | low    | low       | low        | low             |
| Gorinskoe        | low    | low       | low        | low             |
| Gurske           | low    | low       | low        | low             |
| De-Kastrinskoe   | low    | low       | low        | low             |
| Location            | High  | Low  | Low  | Medium |
|---------------------|-------|------|------|--------|
| Innokentievskoe     | low   | low  | low  | low    |
| Kerbinskoe          | low   | high | low  | medium |
| Kizinskoe           | low   | low  | low  | low    |
| Komsomolskoe        | low   | low  | low  | low    |
| Kur-Urmiyskoe       | low   | low  | low  | low    |
| Lazarevskoe         | low   | low  | low  | low    |
| Litovskoe           | low   | low  | low  | low    |
| Muhenskoe           | low   | low  | low  | low    |
| Nanayskoe           | low   | low  | low  | low    |
| Nijnetambovskoe     | low   | high | low  | medium |
| Nikolaevskoe        | low   | low  | low  | medium |
| Oborskoe            | low   | low  | low  | low    |
| Okhotskoe           | low   | low  | low  | low    |
| Padalinskoe         | low   | low  | low  | low    |
| Severnoe            | low   | low  | low  | low    |
| Sovetskoe           | low   | low  | low  | low    |
| Solnechnoe          | low   | low  | low  | low    |
| Sukpaikskoe         | low   | low  | low  | low    |
| Tuminskoe           | low   | low  | low  | low    |
| Tyrminske           | low   | low  | low  | low    |
| Ukturskoe           | low   | low  | low  | low    |
| Ulikanskoe          | low   | low  | low  | low    |
| Uleskoe             | low   | high | low  | medium |
| Urgalskoe           | low   | medium | low | medium |
| Khabarovskoe        | low   | low  | low  | low    |
| Khekhtsirskoe       | low   | low  | low  | low    |
| Khorskoe            | low   | low  | low  | low    |
| Chumikanskoe        | low   | low  | low  | low    |
| Evoronskoe          | low   | low  | low  | low    |

In the larch forests of the Upper Bureinsky district (Urgalskoe forest district, 1969), Nikolaevsky, Ulchsky and Polina Osipenko districts (Nikolaevskoe, Bystrinskoe, Ulchskoye, Kerbinskoe forest districts, 2001-2003), when outbreak was detected, the degree of threat was defined as the average. Outbreaks in these areas are associated with the previous dry periods during 2-3 years, high solar activity and transition of the main part of the silkworm population in these areas in a one-year development cycle.

It should be noted that there are no forest areas where over the 50-year observation period large outbreaks would occur twice. This suggests that from 1967 cycles between outbreaks separately for each forestry of the Khabarovsk Territory were not yet fully completed. During this period, some of the damaged stands were restored becoming reservations for the silkworm, and under favorable weather conditions, larger mass reproduction of the Siberian silkworm is possible than if the frequency of outbreaks were several times shorter. This is confirmed by the estimations, where the intensity of the outbreak in Nikolaevsky district (Nikolaevskoye forest district), Ulchskoe district (Bystrinskoe, Ulchskoe forest districts), and Poliny Osipenko district (Kerbinskoe forest district) proved to be strong.

The above calculated threat rates do not fully take into account the condition of the food base of the *Dendrolimus sibiricus*. Therefore, in the last outbreak of 2001-2003 after damage by a pest the larch stands, which until 2000 had already been weakened by drought, dried up [6]. This, respectively, resulted in a reduction in the area of potential for breeding of the *Dendrolimus sibiricus*. Anyway, as the dead plantings overgrow with conifers, the risk of outbreaks remains and increases again.
Also, the methodology does not take into account the qualitative characteristics of the population. These indicators are replaced by calculations of population density (absolute population) and the multiplication factor. Based on them, the phase description is calculated, and the long-term data present the phase trajectory of a consistent (year-by-year) population change. Because there are no forest districts in the Khabarovsk Territory where an outbreak occurred more than once, it is not possible to construct and statistically estimate threshold values of population density by average values.

In fact, population rises occur every 10-12 years and correspond to peaks of solar activity. However, not every rise leads to the emergence of pest harborage areas [7]. Therefore, in the result of census in coniferous plantations, 11 forest districts (Bystrinskoe, Nijnetambovskoe, Nikolaevskoe, Nanaiskoe, Mukhenskoye, Padalinskoe, Tumininskoe, Khekhtsirskoe, Khabarovskoe, Khorskoe and Urgalskoe) showed a significant increase in the number of Dendrolimus sibiricus in comparison with the past years. In 2017, the occurrence of the pest in Bystrinskoe, Nikolaevskoe, Ulchskoe forest districts ranged from 10% to 60%, and in some places up to 80% [8]. In the southern districts of the region, the occurrence of silkmoth in cedar-broad-leaved forests ranged from 4 to 22% (Avanskoe, Bikinskoe, Khekhtsirskoye forest districts). The pest development was found on a total area of 1565 hectares, most larvae of the two-year generation. In 2016, the results of surveys conducted in June, August and September showed a low number of larva peer tree in Bystrinskoe, Nikolaevskoe, Kizinskoe, Ulchskoe, Khabarovskoe and Khekhtsirskoe forest districts, ranged from 0.1 to 0.7 larvae, maximum 3 larvae with a relative population 10 to 40%, also a two-year generation larvae [9-11].

In 2016-2017, no laboratory studies have been conducted due to the low occurrence of the Dendrolimus sibiricus.

According to the results of laboratory studies in 2018, the larvae developing in a two-year development cycle (60%), with a dark color, active feeding and molting prevailed. The maximum mass of the last age larva collected before their pupation was 4.802 mg, the average was 3.769 mg, and the minimum was 2.815 mg. The maximum weight of cocoons from larvae cuddled under laboratory conditions was 3.110 mg, the average was 1.572 mg, and the minimum was 1.141 mg. The average sex ratio of the butterflies that emerged from the cocoons: 45% of females and 55% of males. These indicators are in the long-term annual average range of values.

Qualitative indicators that indicate a further increase in numbers are a low infection rate and a high survival rate of pests. The infection rate of larvae collected in May and June averaged 19.2%, including 12.7% of infestations with parasitic insects (Takhin's fly, ichneumon) and diseases was about 6.5%. Larvae survival rate was 80.8%. This is much higher than usual in values in the period between outbreaks.

In May and June, 2018, in some areas of coniferous forests in the territory of Khekhtsirskoe and Khabarovskoe forest districts, according to the results of examinations of paper trapping belts and tree trunks, the number of silk moth larvae in larch forests, with two-year generation was from 5 to 8 per tree; in cedar-broadleaved forests – from 1 to 3 larvae per fir or cedar tree. In the autumn, the number of larvae of a new generation in different parts of these forest districts ranged from 0.1 to 8 per tree, up to a maximum of 17. In the larch forests of the Lower Amur area, no further increase of silkworm abundance was registered in June and July because of bad weather conditions (frost, fog, rain).

4. Conclusion
The research results confirm the conclusion about the end of the period between outbreaks for the Siberian silk moth and the population’s release from depression. In 2019, the growth rates of the Siberian silk moth population will be more likely to increase, but the intensity will depend on favorable conditions for pests reproduction. Partly in areas of the southern slopes of mixed larch forests and middle-aged larch forest crops, the pest can turn to a one-year development cycle in the central and southern regions (Lazo, Nanayskoe, Khabarovskoe, Urgalskoe, Solnechnoe and Komsomolskoe districts). The influence of the winter period of 2019 (anomalously winter with low snowfall) on the condition of the silkmoth wintering larvae will be studied in spring and summer abundance surveys.
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