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Predicting development of harmful insects in agrobiocenoses as a promising area in plant protection

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Abstract

The problem of pests in ecosystems is systematic. Defoliation always leads to a lower quality of products [1, 2, 3].

Out of the many species of dendrophilous phytophages, the most dangerous are the following insects: gypsy moth, green oak leaf roller, brown-tail moth, lackey moth, winter moth. By destroying biomass, these insects lead to a sharp reduction in the number and deterioration of the quality of the products [4, 5, 6, 7].

In this regard, particularly urgent is the issue related to studying the peculiarities of the listed group of insects in specific conditions of their development for the purpose of predicting their mass reproduction.

Of particular importance is the issue of timely planning and assigning protective actions based on the forecast [8].

The success of plant protection depends on timely detection and removal of pests. However, there are many problems in the area of studying the peculiarities of pests' appearance, development and spreading [9].

According to data [9, 10], today the issue of regularities in formation of foci of main species of harmful insects and methods of accounting and forecasting remain poorly studied.

The methods of predicting leaf-eating insects still do not have variation-and-statistical substantiation. As a result, random and unreliable data are obtained. They cannot ensure high level of prediction accuracy [11, 12, 13]. According to the prediction results in plant protection, practicability, scope, and optimum deadlines of activities are established.

Solving the above tasks is required for improving plant protection as an aspect of increasing their productivity.

Keywords: pests, foci of injuriousness, plantings, phyllophage, defoliation, prediction, plant protection.

INTRODUCTION

In agrobiocenoses located on the territory of the Russian Federation, there are often outbreaks of various dangerous insects that cause weakening and withering of plants in large areas. Pests in agrobiocenoses that are capable of causing substantial ecological and economic damage reduce the environmental and ecological properties of plants.

MATERIALS AND METHODS:

The methodology was developed in accordance with the goals and objectives of the research. The location and time were chosen to provide comparative assessment of research results.

In the test areas, the following works were made:

- pathological examinations of agrobiocenoses for identifying insects' foci, their occurrence rate and harmfulness;
- establishing the reasons of harmful insects' mass reproduction outbreaks and peculiarities of their occurrence in time and space;
- studying special placement of this group of insects in the space of forest stands;
- analysis of various methods of prediction available at present; and
- development of a system for long-term and short-term prediction of harmful insects.

The issues related to the peculiarities of emergence and spreading of insects' mass reproduction outbreaks were studied in foci in the forest-steppe and steppe climatic zones of the Russian Federation. The production data for the period from 1994 to 2000 were used. The relationship between the abiotic environmental factors in the moments of outbreaks, contributing to the growth of insects, was studied.

The meteorological data included the average monthly temperature, the average monthly precipitation level, and their deviations from the many years average.

The influence of weather conditions during the period of development of larvae and butterflies' flight time (April through July, October), and the influence of low temperatures in January and February on the survival rate of wintering phases of insects have been analyzed.

To examine the extent of damage caused by insects, the state of agrobiocenoses was determined on the scale of physiological weakness:

Conventionally healthy (without external symptoms of weakening).

Weakened (with open crown, with drying branches not more than 1/2 part of the crown, started top drying).

Heavily weakened (with extremely open crown, with drying branches in more than 1/2 of the crown, with a lot of water sprouts).
Drying (with obvious symptoms of shrinking and presence of trunk insects, with pale green leaves).
Fresh dead wood – trees withered in the current year.
Old dead wood – trees withered in the past years [13].
The information about the population of leaf-eating insects in the trees was translated into the standardized accounting units by Formula 1: [14, 15]

$$y = 38.9d + 7.2d2 \qquad (1)$$

where y was the density of growing shoots (growth points on a tree);

d was the average diameter of the tree.

Larvae were accounted for by the method of selecting terminal branches in the tiers of model trees.

Accounting was done layer-by-layer from the top, middle and bottom parts of model trees.

To determine the average number of larvae per accounting unit, their average scores in the top, middle and bottom parts of the crown were multiplied, respectively, by 0.38, 0.42, and 0.20.

The accounting numbers of larvae were summed up. After accounting, the total number of larvae found in each part of the crown was divided by the total number of growth points in this part of the crown, and multiplied by 100. Thereby, the number of larvae per 100 growth points, or environmental density was determined.

The number of eggs in egg-beds of each specie was determined indirectly by the weight of female nymphs based on the production data [16].

Arrangement of sampling points was random and systematic, according to the existing statistical methods [8, 17, 18, 19, 20, 21]. Statistical analysis of the obtained data was made according to the method of B. A. Dospekhov with the use of the Statistika software suite [17].

Development of a system for long-term and short-term prediction of leaf-eating insects was based on the analysis of their mass reproduction outbreaks, and the relationship between the population density and the area of foci. The nature of the physiological state of plants during the periods of development and reproduction of harmful insects (2006-2016.) was analyzed in order to supplement the data required for prediction.

The mass quantitative accounting for pests with simultaneous assessment of the degree of tree crowns' defoliation allowed revealing the statistical relationship between these indicators.

Results: Successful prediction of harmful insects and development of zonal systems of forest protection activities are only possible with good knowledge of the reasons for fluctuations in the number of harmful organisms and formation of mass reproduction outbreaks [12].

Studying the influence of trees' crown eating by insects on their mortality showed that the highest percentage of dead trees had been observed in the years of leaf-eating insects growth outbreaks [22, 23].

Analysis has shown that the sharp increase in the number of phyllophages and dissemination of foci area is mainly due to the climatic factors in the period of their occurrence (Table 1).

Thus, the sharp increase in the number of leaf-eating insects in the Volga region (from 4.1 thousand ha to 17.8 thousand ha) was caused by the existing weather situation. The highest defoliation rate was noted in 2009-2010, which was due to the sharp increase in the number of insects and to abnormally high temperatures in the summer of 2010.

Speaking about the influence of the factors of the abiotic environment [1, 14, 15, 24], it has been noted that the majority of the mass leaf-eating insects increase in their population due to the influence of modifying mainly meteorological factors that directly and indirectly influence the status of the population, violating the balanced bioeconomic relations.

An important role in outbreaks' development is also played by air temperature and precipitation during the butterflies' summer flight-time. The increase in the number of insects is also promoted by "mild" winters that do not cause freezing of their egg-beds [5, 25].

Using the most informative meteorological indicators in the period of outbreaks, a model has been developed that allows determining the start of population increase and its occurrence rate, which is the following:

$$y = -30.459 - 56.241x_1 + 135.18x_2 - 39.7x_3 + 3.126x_4 \quad (2)$$

where
y is the number of leaf-eating insects during recovery from depression and at the beginning of mass reproduction outbreaks;

x_1 is hydrothermal coefficient for May;

x_2 is hydrothermal coefficient for June;

x_3 is hydrothermal coefficient for July;

x_4 is absolute deviation of the minimum temperature of the coldest month from the norm.

The forecast error is m_y = 20.96%.

The practical importance of this model is in the fact that having indices of hydrothermal coefficient in these periods of main development of harmful insects, it is possible to establish the beginning of the growth of their foci in large areas.

In addition, studying the nature of changes in the foci areas and appropriate calculations provided forecast models for distribution of foci of leaf-eating insects. These models showed the relationship between the density of insects' population and the area of their foci. The dependence between these values had close relationship. The coefficients of correlation ranged between 0.72 and 0.93.

Table 1 - The nature of tree crowns' defoliation by harmful insects during outbreaks

No.	Type of insect	Years											Average
		Ecological density (pcs/100 gr. the green mass of leaves)											
		The degree of tree crowns' defoliation (%)											
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
1	Gypsy moth	10.6 30	23.2 40	27.6 40	37.6 50	62.5 70	12.5 30	11.4 20	0.0	0.0	11.6 20	31.6 50	27.6 40
2	Brown-tail moth	3.1 10	12.8 20	32.8 40	53.0 60	62.6 70	12.8 20	23.4 30	0.0	0.0	0.0	0.0	28.6 36
3	Winter moth	104.4 30	100.2 30	267.7 50	347.4 70	372.5 80	46.5 10	89.5 20	94.7 30	185.4 40	281.4 60	507.8 80	290.6 60
4	Green oak leaf roller	160.0 40	147.0 40	450.0 60	556.3 70	476.6 70	406.4 60	160.2 40	72.0 20	430.5 60	90.8 30	154.0 40	373.1 60
5	Lackey moth	17.2 30	24.3 40	26.1 40	37.0 50	32.6 50	30.8 50	12.8 20	2.1 10	0.0	0.0	0.0	22.8 40

The models had the following form:

1. The model for predicting the spread of green oak leaf roller foci

$$y = 2.633 + 0.735x - 0.160x^2 \qquad (3)$$

2. The model for predicting the spread of gypsy moth foci

$$y = 3.114 - 0.862x - 2.073x_2 \qquad (4)$$

3. The model for predicting the spread of brown-tail moth foci

$$y = 2.790 + 1.529x - 1.137x^2 \qquad (5)$$

4. The model for predicting the spread of lackey moth foci

$$y = 1.718 + 6.109x - 7.423x^2 \qquad (6)$$

5. The model for predicting the spread of winter moth foci

$$y = 2.457 + 1.119x - 0.325x^2 \qquad (7)$$

where

u was the area of expected distribution of foci of the leaf-eating insects;

x was the number of larvae of insects per 100 growth points.

Errors in the models for predicting the foci area were the following:

for green oak leaf roller, m_y = 22.14 %;

for gypsy moth, m_y = 7.7 %;

for lackey moth, m_y = 19.04 %;

for brown-tail moth, m_y = 24.02 %;

for winter moth, m_y = 11.22 %.

Using the obtained models, one can predict the probable area of pests' spreading in specific forest conditions of the Volga region.

The next stage of prediction is establishing the extent of expected crown defoliation from the leaf-eating insects.

This prediction is the most important for making the decision about appropriateness of protective measures to be taken.

According to some authors, the criterion for fighting insects is not density of their populations, but the degree of plants' defoliation and consequent weakening or withering of plants [2, 11, 12, 22, 26].

Mass surveys of pests with simultaneous assessment of the plants' defoliation degree revealed a correlation between the degree of trees' defoliation and the ecological density of leaf-eating insects.

These interdependencies were expressed by regression models that allowed predicting the expected degree of damage to the plantings.

These models had the following form:

1. The model for predicting the degree of damage to plants by green oak leaf roller

$$y = 21.803 + 0.087x \qquad (8)$$

2. The model for predicting the degree of damage to plants by gypsy moth

$$y = 21.996 + 0.762x \qquad (9)$$

3. The model for predicting the degree of damage to plants by brown-tail moth

$$y = 7.4 + 0.987x \quad (10)$$

4. The model for predicting the degree of damage to plants by lackey moth

$$y = 14.566 + 0.875x \qquad (11)$$

5. The model for predicting the degree of damage to plants by winter moth

$$y = 17.148 + 0.124x \qquad (12),$$

where y was the degree of expected damage to plants from leaf-eating insects;

x was the number of eggs per 100 points of growth.

Errors of the models for predicting the expected degree of damage to plants were the following:

for green oak leaf roller, m_y = 10.2 %;

for gypsy moth, m_y = 8.7 %;

for brown-tail moth m_y = 7.7 %;

for lackey moth, m_y = 11.8 %;

for winter moth, m_y = 9.2 %.

Based on these models, a matrix for short-term predicting expected threat of plants defoliation by leaf-eating insects (Table 2) has been developed.

The procedure of using this table is as follows. First, the number of growth shoots, or growing points on the model tree of the spot is determined using the formula of converting the accounting data into the ecological density:

$$y = 38.9\acute{x} + 7.2\acute{x}^2 (13)$$

Next, the number of eggs of leaf-eating insects on an average tree plot area, or the density of the wintering stock should be determined.

After that, the reserve of eggs per average tree in the plot is divided by the number of growth shoots (growth points) on the tree, and multiplied by 100.

Thus, the number of eggs per 100 growth shoots or growth points is determined for a specific pest.

To predict the degree of expected plants' defoliation using Table 2, it is also necessary to take into account the eggs' survival rate during their wintering period. Eggs' survival rate can be easily determined in the laboratory conditions by the difference between the total number of eggs in the experiment and the number of hatched larvae. According to our data, eggs' survival rate on the average may be for gypsy moth 0.85, for the green oak leaf roller – 0.91, for brown-tail moth - 0.76, for lackey moth - 0.72, and for winter moth - 0.84.

After that, using Table 2, the appropriate degree of expected plants' defoliation by specific insect is found.

Reaching high insect population, when the threat of plants' defoliation reaches 50% and more, may be the criterion of appropriateness of protective measures.

Table 2. The number of eggs per 100 growth shoots or growth points that corresponds to various degrees of leaves' eating by insects

Types of leaf-eating insects	The degree of expected damage to plants, %									
	10	20	30	40	50	60	70	80	90	100
Gypsy moth Ocneria dispar L.	□	1.0	10.6	23.2	37.6	49.2	62.5	76.5	89.6	103.1
Green oak leaf roller Tortrix viridana L.	□	10.0	90.0	160.0	300.0	450.0	556.0	660.0	790.0	900.0
Brown-tail moth Euproctis chrysorrhoea L.	3.1	12.8	23.4	32.8	42.7	53.0	62.6	74.1	83.0	93.4
Lackey moth Malacosoma neustria L.	2.1	8.0	17.2	26.1	37.0	47.9	60.0	73.0	87.7	103.0
Winter moth Operophthera brumata L.	□	9.5	104.4	185.4	267.7	347.4	428.2	507.8	592.3	674.5

DISCUSSION

Predictions should ensure timely detection of insects' mass reproduction outbreaks, formation of their foci, correct choice and assignment of measures for protecting trees. Prediction is a research process where probabilistic information is obtained about the future state of predicted population [12].

In the practice of trees' protection in forestry, the main prediction method is currently short-term prediction with the use of the critical numbers developed by A. I. Ilyinsky [22].

As pointed out by [11, 28], the value of critical numbers, or the threat indicator was determined by the number of insects that cause complete defoliation of tree crowns.

In order to calculate the critical number, it is necessary to collect a lot of data about population in the plantings before the period of larvae feeding, and foliage or pine needles' loss after feeding. Then the minimum population density is determined, which ensures eating of 75%; in this case, the value is taken as the critical number. Tables of critical numbers for all most important fir- and leaf-eating insects have also been created.

As eminent entomologist [11] pointed out in his monograph, European entomologists have perfected these calculations. Works [29, 30, 31] are of great interest. He proposed direct calculation of population density per weight of foliage (needles), and made calculations that can provide an indirect estimate of the weight of foliage (fir) by diameter, height and growth class.

Natural mortality from the moment of accounting until the moment of eating was usually not considered, or taken conventionally equal to about 50%, which increased the prediction error.

In the early 70s, several Russian authors followed the way of improving the methods of short-term prediction.

Thus, [26] developed a prediction method based on using the information about specified feed rate of the pests in their natural population.

The real feed rate was expressed in grams of green weight, which might be eaten up by larvae in the natural habitat.

Knowing the number of insects on a branch, and the amount of green mass on it, the population density per 100 g was calculated.

Therefore, there is a need to determine the amount of green mass in the tree or the plant.

Direct determination is usually impossible, as at the moment of prediction the leaves and needles of the current year may be absent.

Therefore, indirect assessment via the diameter of the branch was used. The essence of this method is in the fact that there is the dependence between branch diameter and the weight of the green mass on it.

The disadvantage of this prediction method [26] is a significant error in case of low and high population density.

During that period, the method of short-term prediction via determination of the feed rate of pests in natural populations and the expected damage to the foliage (needles) [32] was developed. The author proposed a formula for calculating the feed rate (r_0) for the pest in the natural habitat:

$$f = 1.35 t_{avg} N_0 (r_k w + r_0) \quad (14)$$

where f was the expected damage to plants (%);

t_{avg} was half the period of larvae development;

N_0 was the initial first age larvae density per 100 g of green mass;

r_k was the pests' feed rate;

w was the larvae survival rate in the following year, in fractions of unity;

r_0 was the initial weight of hatched larvae.

Prediction using formula [32] is associated with a number of difficulties.

First, the need to establish feed rate of the pest is invoked.

In specific conditions of population development, insects' feed rate may change, therefore careful research in the area of its definition is required.

As shown by the analysis of harmful insects' prediction in agriculture, there are many problems.

In particular, the methods of long-term prediction for most agricultural pests have not been developed enough. There are no clear criteria for the existing harmfulness thresholds in the context of specific conditions of pest development. However, the use of the scientific material from this article might be the basis for removing the detected disadvantages.

CONCLUSION

Thus, the proposed prediction method will provide identification of the start of leaf-eating insects' mass reproduction, formation of foci, determining the threat of plants' defoliation, and taking prompt protective measures, which is of great economic importance in the conditions of the Volga region.

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