Some cenotic features of Scots pine blister rust and red ring rot in pine forests

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Abstract. Scots pine blister rust and red ring rot are common diseases on Scots pine throughout its entire range. Many specialists have studied these diseases in various aspects. Nevertheless, the cenotic patterns of incidence in pine forests, primarily for Scots pine blister rust, have been studied to a lesser extent. The study is aimed to establish the peculiarities of incidence of Scots pine blister rust and red ring rot in pine forests at the dendrocenosis-level in the context of forest conditions and the biology of pathogens. We studied the pine forests of the Dzerzhinskoe forestry located in the Krasnoyarsk Krai. Research methods included detailed forest pathological examination, macroscopic diagnostics of diseases, determination of indicators proving disease manifestation, and analysis of the series of diameter-related distribution of trees. Scots pine blister rust was proved to be of high injuriousness for trees and entire forest stand in case of hotspot emergency. Red ring rot does not play such a significant role in the plant community since trees with signs of rot retain their activity for a long time as part of the cenopopulation. Diameter-related distribution of the affected trees mainly corresponds to the general stand structure. Nevertheless, in red ring rot hotspots, there is a certain predominance of large specimens in the affected part of the stand, which is associated with a reduced immunity in such trees. Scots pine blister rust in herb-rich pine forests often damages trees with diameters below average. Scots pine blister rust pathogen completes different stages of its life cycle on different plants infecting intermediate host from various species of herbaceous growing in the ground cover of herb-rich pine forests.

1. Introduction

*Pinus sylvestris* L. (Scots pine) – is one of the most widespread conifers occurring in boreal forests in Europe and Asia [1]. Mixed-species pine stands are susceptible to pathogens that can have a significant (including negative) impact on forest biogeocenoses [2-4]. The dominant pathogens on Scots pine in the forests of Eurasia include micromycetes of the genus *Cronartium* (cause Scots pine blister rust) and the xylotrophic fungus *Porodaedalea pini* (Brot.) Murrill (causes red ring rot) [5-15]. In particular, Scots pine blister rust is ranked among the major diseases damaging coniferous forests in Sweden and Finland [16-21]. The diseases weaken trees, cause pathological litterfall accumulation (snag, rotten windbreak) and timber assortment reduction in commercial pine forests [22, 23]. Numerous studies of Scots pine blister rust and red ring rot in pine forests mainly contain general information about the incidence in different regions, data on the prevalence of diseases depending on forest conditions, forest inventory indicators, and their influence on forest health. The cenotic patterns of incidence in pine forests, primarily for Scots pine blister rust, have been studied to a lesser extent.
The purpose of our study is to establish the peculiarities of incidence of Scots pine blister rust and red ring rot in pine forests at the dendrocenosis-level in the context of forest conditions and the biology of pathogens.

2. Materials and methods of research

We studied the pine forests of the Dzerzhinskoe forestry located in the Krasnoyarsk Krai. According to the Korotkov forest community zoning scheme [24], the studied forest stands belong to the forest-steppe of the Kansk-Krasnoyarsk-Biryusinsky forest province. We used the materials of a detailed forest pathological examination of pine stands infected with Scots pine blister rust and red ring rot (the prevalence rate is ≥ 10%). Pine forests belong to the predominant forest types: lichen (includes forest community types: Lingonberry/Bearberry, Bearberry/Lichen); mossy (Lingonberry/Moss); herb-rich (Herbaceous, Blueberry/Herbaceous). Types of growing conditions: A1 (dry pine barrens); B1, B2 (dry, slightly moist pine forests growing on relatively nutrient-poor soils); C2 (slightly moist multi-storied mixed (coniferous/deciduous) forests dominated by *P. sylvestris* L. growing on relatively nutrient-rich soils). The survey covered forest stands of IV-XI age classes, II-IV bonitet classes, and a relative density of 0.4-0.6.

We conducted the detailed survey following generally accepted methods [25, 26] by a continuous enumeration of trees on sample plots (SP). Trees (150-200 pcs. on SP) were divided according to thickness steps (four-centimeter gradation) and condition classes: 1 – no signs of weakening; 2 – weakened; 3 – severely weakened; 4 – drying up; 5 – snag of the current year, 6 – snag of previous years. The value of the natural thickness step is expressed in tenths of the average diameter, taken as a unit. The condition class was indicated by a visual assessment of tree crowns. Tree diseases were diagnosed according to a set of direct symptoms. Symptoms of Scots pine blister rust include dark wounds with resin stains on stems and branches in different parts of the crown. Girdling of the stem may result in the death of the top or the entire tree. Symptoms of red ring rot in pine include basidioma and swollen knots produced by *P. pini*. Dormant stem rot (lack of apparent signs) in overmature pine stands was indicated by analyzing the state of heartwood in core samples taken with an auger at the height of 1.3 m for every tenth tree during counting.

We analyzed data from 15 sample plots. Scots pine blister rust was studied on 12 sample plots, red ring rot – on four ones. According to the forest pathological inventory at the sample plots, two indicators of disease manifestation were established: prevalence and injuriousness. The prevalence was determined as the proportion (%) of affected trees from the total sample size. The injuriousness was assessed the weighted average condition index ($K_{av}$) of the affected part of the stand, which was calculated by the formula:

$$K_{av} = \frac{(P_1 \times K_1 + P_2 \times K_2 + P_3 \times K_3 + P_4 \times K_4 + P_5 \times K_5)}{100},$$

where $P_i$ is the proportion of stem stock of each condition class of the affected trees, %; $K_i$ is the index of trees condition class (1 – no signs of weakening, 2 – weakened, 3 – severely weakened, 4 – drying up, 5 – all-years snag). At $K_{av} \leq 1.5$, the aggregate of affected trees, on average, has no visible signs of weakening; $1.5 < K_{av} \leq 2.5$ – affected trees are weakened on average; $2.5 < K_{av} \leq 3.5$ – severely weakened; $3.5 < K_{av} \leq 4.5$ – drying up; $K_{av} > 4.5$ – died.

The central aspect in the study of incidence in pine forests at the dendrocenotic level was the analysis of the distribution of affected trees by the stem diameters (thickness steps) at the height of 1.3 m in the general structure of the stand. Comparative analysis of the series of distribution of trees by thickness steps in stands infected with red ring rot was performed using the $\lambda$ criterion (Kolmogorov-Smirnov) [27].

3. Results and discussion

Scots pine blister rust is ubiquitous in the pine forests of the study area [22]. However, hotspots (prevalence over 10%) were identified in less than half of the cases. The degree of damage to forest stands in Scots pine blister rust hotspots was weak (11-20%), less often - moderate (21-30%) (table 1). The chronic disease on trees leads to their weakening and drying up. According to our data (table 1), the
weighted average condition index of the affected trees was from 2.6 (severely weakened) to 4.4 (dying up). Thus, Scots pine blister rust is highly injurious, and its hotspots are a factor disturbing pine forests' sustainability.

Table 1. Pine forests damage indicators in Scots pine blister rust hotspots.

| SP | Pine forest type       | P, %<sup>1</sup> | K<sub>av</sub><sup>2</sup> infected trees | Average diameter, cm stand affected trees |
|----|------------------------|-----------------|-----------------------------------------|------------------------------------------|
| 1  | Lingonberry/Moss       | 10.5            | 4.3                                     | 22.8                                     | 22.4                                     |
| 2  | Lingonberry/Bearberry  | 13.5            | 3.8                                     | 23.8                                     | 24.3                                     |
| 3  | Lingonberry/Lichen     | 21.2            | 3.3                                     | 30.7                                     | 31.3                                     |
| 4  | Lingonberry/Lichen     | 28.2            | 2.9                                     | 32.0                                     | 32.6                                     |
| 5  | Lingonberry/Moss       | 12.7            | 3.0                                     | 31.8                                     | 31.1                                     |
| 6  | Lingonberry/Herbaceous | 10.0            | 4.1                                     | 19.4                                     | 16.1                                     |
| 7  | Lingonberry/Lichen     | 11.4            | 4.4                                     | 38.7                                     | 40.4                                     |
| 8  | Lingonberry/Herbaceous | 15.8            | 2.7                                     | 29.9                                     | 29.8                                     |
| 9  | Lingonberry/Lichen     | 14.4            | 2.6                                     | 30.2                                     | 29.6                                     |
| 10 | Lingonberry/Herbaceous | 16.5            | 3.3                                     | 43.2                                     | 36.8                                     |
| 11 | Herbaceous             | 13.7            | 3.9                                     | 49.5                                     | 38.4                                     |
| 12 | Lingonberry/Lichen     | 17.0            | 2.8                                     | 35.2                                     | 34.6                                     |

<sup>1</sup> prevalence rate.  
<sup>2</sup> weighted average condition index.

Scots pine blister rust pathogens are obligate parasites with anemochorous spores that enable them to affect more or less viable trees. The representation of trees with different morphometric parameters in the affected part of the cenopopulation mostly corresponds to the general structure of the stand. Figure 1 confirms this pattern showing the diagrams of the distribution of trees by diameter in hotspots pine forests. Nevertheless, in the stands of the herb-rich group (SP 6, 10, 11), there is a shift in the number of infected trees towards diameters below the average, meaning the average diameter of the aggregate of affected trees is less than the average for the stand (Table 1). We explain this by the presence of a heteroecious rust fungus *Cronartium flaccidum* [Alb. & Schwein.] G. Winter, acting as a major Scots pine blister rust pathogen. *C. flaccidum* is characterized by a vertical transfer of infection (basidiospores) from intermediate hosts (herbaceous plants) to pine crowns. As a result, smaller trees become infected first. In pine forests of mossy and even more so lichen group, with a lack or absence of herbs in the ground cover, the dominant pathogen is autoecious *C. pini* [Willd.] Jørst. This micromycete completes the entire life cycle on a single host (pine in our case). Therefore, the presence of a significant number of aeciospores in the crown determines the infection of trees of different sizes (diameters).

Red ring rot is widespread in mature and overmature pine stands within the study area, forming hotspots. The damage to forest stands reaches a strong degree (on average 38.0 ± 2.1%) [23]. Damage and decay of heartwood caused by *P. pini* are ecologically reasoned, but it significantly reduces the quality of trees as the primary forest resource. The fungus does not disturb physiologically active peripheral elements of the tree stem. Therefore, trees affected by red ring rot are in a satisfactory condition: the weighted average condition index for such trees in the analyzed samples does not exceed 1.7.
Figure 1. Distribution by thickness steps (cm) of all trees (white) and those affected by Scots pine blister rust (black) (pcs.).
The spread of red ring rot in pine stands also follows a particular pattern associated with the stem diameter. We have analyzed the series of diameter-related distribution of trees in red ring rot hotspots according to the enumeration data on four sample plots laid out in mature and overmature pine stands of the predominant forest types (figure 2). Diagrams prove that the part of the stand affected by red ring rot mainly retains the diameter characteristic typical of forest stands. The obtained results are consistent with those from other studies [28-30]. We also conducted an additional comparative analysis of the considered distribution series basing on calculating the statistical criterion $\lambda$ (Kolmogorov-Smirnov) and comparing average diameters (table 2). For three sample plots (SP 7, 13, 15), no significant differences were found between the compared series of tree distribution by thickness steps within the entire stand and its part affected by red ring rot: design values of the criterion $\lambda \leq$ its critical value for confidence level 0.95. On SP 14, a significant difference was recorded between the compared samples because there were no affected small-diameter trees. Thus, in pine forests, red ring rot usually affects trees of different thicknesses respectively to their share in the cenopopulation. Nevertheless, there is a certain tendency towards the predominance of large-sized specimens among infected trees. The increased susceptibility to red ring rot of large trees is due to their anatomical and morphological structure. In particular, a large proportion of heartwood [31] and insufficient cleansing of the stem from branches which act as the “gates” to infection.

Table 2. Results of a comparative analysis of the thickness-related distribution of trees affected by red ring rot.

| SP | Average diameter, cm | Comparative analysis of the series of trees distribution (see figure 2) by the criterion $\lambda$ |
|----|----------------------|-------------------------------------------------------------------------------------------------|
|    | stand                | affected trees                                     | $\lambda_c$ (calculated value) = $\lambda_{0.05}$ (critical value for confidence level 0.95) |
| 7  | 38.7                 | 41.8                                               | $\lambda_c(1.36) = \lambda_{0.05}(1.36)$ |
| 13 | 33.3                 | 37.0                                               | $\lambda_c(1.26) < \lambda_{0.05}(1.36)$ |
| 14 | 35.1                 | 42.9                                               | $\lambda_c(2.93) > \lambda_{0.05}(1.36)$ |
| 15 | 38.7                 | 39.8                                               | $\lambda_c(0.59) < \lambda_{0.05}(1.36)$ |

$^1$ calculated value.
$^2$ critical value for confidence level 0.95.

4. Conclusion

The incidence of Scots pine blister rust and red ring rot in mature and overmature pine forests reaches the hotspots extent: weak and moderate damage to stands by Scots pine blister rust, severe damage by red ring rot.

Within the forest stands, diseases affect trees of different morphometric parameters. The distribution of the affected trees by thickness steps mostly corresponds to the general diameter structure of the stands. Nevertheless, in red ring rot hotspots, there is a certain predominance of large specimens in the affected part of the stand, which is associated with a reduced immunity in such trees. Scots pine blister rust in herb-rich pine forests often damages trees with diameters below average. This is probably due to the bioecological characteristics of the pathogen, which complete different stages of its life cycle on different plants infecting various species of herbaceous. So the ground cover of herb-rich pine forests provides intermediate hosts for $C. flaccidum$ development. This thesis requires additional experimental study.

Trees affected by Scots pine blister are fatally weakened and gradually turn into pathological litterfall. The coenotic role of red ring rot is insignificant; trees with signs of rot maintain a satisfactory condition and remain in the cenopopulation for a long time.

The presented results supplement the available information on the biocenotic features of Scots pine blister rust and red ring rot in pine forests and can help assess the resource potential of commercial forest stands.
Figure 2. Distribution by thickness steps (cm) of all trees (white) and those affected by red ring rot (black) (pcs.).
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