The impact of the intensity of selective sanitary cutting in oak forests on the defeat of the pedunculated oak (Quercus Robur L.) trees by powdery mildew

V Tsaralunga, A Tsaralunga, N Yakovenko* and Yu Gridnev

Department of Ecology, Forest Protection and Forest Hunting, Faculty of Forestry, Voronezh State University of Forestry and Technologies named after G F Morozov, 8 Timiryazev Street, 394087, Voronezh, Russian Federation

*E-mail: vglta@vglta.vrn.ru

Abstract. The article assesses the impact of the intensity of selective sanitary cutting in oak forests on the defeat of oak trees by powdery mildew. The research methodology included visual estimation and detailed inspection of oak plantations. On their basis, the species composition of pathogens was identified, the degree of crown desiccation from a complex of factors and leaf infestation with powdery mildew and necrotic spots was assessed. The dispersive analysis was applied for data processing. The analysis of the long-term survey of the plots passed by selective sanitary cutting shows that the degree of damage to oak trees by powdery mildew on permanent test areas practically does not depend directly from selective sanitary cutting, in general, and from their intensity, in particular. The dynamics of the damage degree of the oak trees by powdery mildew changed almost synchronously in all test areas and in the control area. The results can be used in the practice of the Voronezh region forestry enterprises when carrying out forest pathology surveys.

1. Introduction

Forest ecosystems of the Russian Federation, spread over a huge territory, make a significant contribution to the regional and global stability of the biosphere, conservation of forest genetic diversity, maintenance of global carbon balance, and perform global ecosystem functions such as climate and water-regulating, soil conservation, etc. Forests have many different functions that are an important component of the normal functioning of the biosphere. Green plantations soften the climate, strengthen the soil, contribute to optimal soil moisture, etc. In order to maintain an appropriate level of functioning, large tracts of forests, healthy stands free of pests and diseases are needed [1]. Plantations with the participation of pedunculated oak (Quercus robur L.) are of significant value in the European part of Russia as a whole [2,3].

These plantations are a source of timber and perform the most important ecological functions, among which it is particularly important to highlight such functions as water protection, water regulation, soil protection and sanitary-hygienic.

One of the most acute problems of Russian forestry is the progressive degradation of oak biocenoses. For more than 100 years, foresters have recorded an accelerated die-off of the main forest-forming species of oak forests in European Russia - the pedunculated oak. Against the background of an ever-increasing percentage of oak decline, there are periodic mass die-offs within the entire habitat. The repeated recurrence of these periods and their known rhythm indicate the inevitability of recurrences of...
oak depression and the corresponding aggravation of the oak problem. The main types of silvicultural measures in protective forest plantations are cleaning cutting carried out during specific age periods. They ensure improvement of the conditions for forest plantations formation, their growth and development, and forest reclamation properties.

The nature and intensity of cleaning cutting in different types of agroforestry plantations certainly differ. But all of them have two main aims: to improve the forest biological condition of the plantations and to increase their reclamation efficiency. Cleaning cutting has a positive impact on the growth parameters of forest plantations and leads to a significant increase in their productivity. In those forestries where plantations are mainly represented by oak forests of age class VI to XII, selective sanitary cuttings become the most common forest management measure and the main type of intermediate forest management.

The percentage of liquid wood yield in selective sanitary cuttings in oak forests is second only to clear-cutting. In terms of the volume of wood removed during selective sanitary cuttings in Russia as a whole, the maximum was in the mid-1970s, when it amounted to 121,101 thousand m³ over 5 years against 3,733 thousand m³ at the beginning of the 1960s. From 1961 to 1970 selective sanitary cuttings on the Voronezh Administration covered 78000 ha with selection of stock of 650000 m³, in the 70s – 101000 ha and 116000 m³, in the 80s – 85000 ha and 162000 m³, in the 90s – 56100 ha and 917000 m³. In the XXI century there was a reduction of the area of selective sanitary cutting by 36% compared to the previous decade. The current area of oak-dominated stands accounts for more than half of all forests in Voronezh region (56%). Foresters call this region the realm of the oak, although its total forest cover is now insignificant. Before the beginning of active economic activities (17th century), there were many more oak forests in the Voronezh region [4].

According to several authors [5-7], there are several causes of oak forest desiccation: changes in the hydrological regime of the territory, resulting from plowing of sloping lands, natural reduction of runoff and reduction of spring-summer floods or artificial regulation of river runoff, along the floodplains of which there are large forests, including oak forests; damage to the root systems of oak forests in snowless frosty winters; termination of chemical protection of floodplain oaks against insect pests in conditions of sharp depletion of forest biocenosis entomophages; disturbance of the ecological balance of forest biogeocenoses as a result of unregulated fodder stocking and animal grazing; high recreational loads on oak forests.

It should be noted that there is no clear understanding of the reasons for the degradation of oak forests in the modern scientific literature. At the same time, many researchers [8-11] emphasise the uneven impact of individual ecological factors on their condition. In general, the available conclusions on this issue are insufficient to justify a set of measures to improve the condition of oak plantations, in particular by sanitary cutting in middle-aged and low-growing stands and foci of infection. In this connection, the question of assessing the impact of selective sanitary cuttings in oak forests on oak powdery mildew defeat becomes relevant.

Powdery mildew can cause serious damage to the plant in some cases. It is manifested by a 3.5-fold decrease in assimilation, a 1.6-fold increase in stomatal conductance in leaves with a high degree of damage (over 60%) up to the death of the plant [12]. The negative effects are particularly pronounced in weakened individuals in urban and old-age stands. The harmfulness of oak powdery mildew increases with increasing development of the disease, especially when the leaves are affected.

The increase of leaf blade coverage by fungus mycelium leads to 1.2-2 times lower seedling height and 1.1-1.8 times lower lateral shoots. Oak leaf powdery mildew causes weakening of biosynthesis and accumulation of pigments in affected leaves. With increasing degree of infestation of the leaf lamina by the fungus, chlorophyll ‘a’ content decreases by 14-40%, chlorophyll ‘b’ by 17-50% and carotenoids by 1.3-1.7 times. Visible photosynthesis in diseased leaves is reduced by 43% compared with healthy leaves and true photosynthesis by 50%. Transpiration intensity in diseased leaves is 15% lower than in healthy leaves.

Disease causes significant changes in the content of mineral elements in oak leaves. The amount of total nitrogen is increased by a factor of 1.2 times in the case of severe to moderate damage to the leaf
lamina by the pathogen at the start of fungal development, and by a factor of 1.1 times in the case of further development. When the leaf is weakly affected by the disease, the content of total nitrogen does not differ significantly from the control. Phosphorus content increases by 1.2 times with increasing degree of leaf blade damage. Potassium content increases 1.1-1.5 times with increasing degree of leaf damage. The aim of the research is to determine the impact of the intensity of selective sanitary cutting in oak forests on the infestation of pedunculated oak (*Quercus robur* L.) trees by powdery mildew.

2. Methods and materials

The objects of the research were 70-90-year-old stands of oak trees in the right-bank part of Voronezh, on the area of the educational and experimental forestry of Voronezh State University of Forestry and Technologies named after G F Morozov. Pedunculated oak (*Quercus robur* L.) is one of the main forest forming species, planting material of oak is grown everywhere in forest nurseries of the country. The model object, an oak powdery mildew pathogen *Microsphaera alphitoides* Grif. et Maubl., is invasive in the studied region, widespread and economically important. It causes physiological weakening and premature death of stands. The studies were carried out by the detailed method in permanent plots and by reconnaissance method.

The observation period covered 1981-2019. The study was carried out in May and early June. The reason for this is that, in early summer, a poorly visible, whitish, spider-like mycelial plaque forms on the affected leaves. As the conidial stage begins to develop, it becomes powdery, and later it becomes felted. The mycelial plaque can develop on both the upper and lower sides of the leaves. In late summer, the marsupial stage of the cleistothecium fungus develops on the mycelium. It has the appearance of initially brown, later black numerous dots located along the veins of the leaf. The cleistothecia have colourless appendages, many times branched dichotomously at the ends. The sacs are wide-bulb-shaped, 43-83×26-55 μm in size.

Ascospores are ovoid or ellipsoidal, colorless, unicellular, 18-32×9-18 μm in size. Plaque is also formed on young shoots. Cleistothecia overwinter on fallen leaves. In the following year, when the average daily air temperature reaches 16 °C, ascospores mature in the sacs. They carry out the primary infestation of young leaves. Conidia formation and proliferation occur between 18 and 25 °C. The optimum temperature for conidia germination is 20-22 °C. Conidia germinate better in good light. The formation of cleistothecia is more active in dry weather. For their maturation, wet and warm weather in May/early June is required.

Sample plots were established in the 33rd quarter of the right bank district forestry of the Voronezh State Forestry University's experimental forestry in 1981. According to the forest inventory of 1972, all sample plots were within one compartment (15.3 ha). Each sample plot was rectangular in shape and covered 3 ha. The control plot was on an area of 3.3 ha.

Powdery mildew most often affects young coppice (figure 1) or non-timbered annual shoots (figure 2), but occasionally powdery mildew can be observed on leaves throughout the crown with a decrease in intensity from the lower to the upper part of the crown. On this basis, in the course of long-term monitoring of the ecological and forestry effects of experimental selective sanitary cutting in order to determine its impact on the condition of coppice oak trees, we also traced the dynamics of powdery mildew infestation in oak trees over a 38-year period.

On the test plots (figure 2) in May-August 1981 selective sanitary cutting of different intensity was carried out. The intensity of stand felling increased from the first to the fourth test area. Thus in the first test area 1 only deadwood (trees of categories 5-11 according to the Russian Forest Health Regulations 2017) was removed, in the second test area-deadwood, non-viable trees (categories 4-11), in the third test area-deadwood, non-viable and seriously weakened trees (categories 3-11) and in the fourth test area all oak trees were removed, except for healthy ones (categories 2-11).

No cutting or silvicultural activities were carried out in the control area. The representativeness of the sample data was set to within standard error, which corresponds to 70% of their probability. This is sufficient for visual field studies.
Figure 1. Powdery mildew on annual oak annual coppice.

Figure 2. Appearance of the permanent test area.

The degree of damage was assessed using a 5-point scale: 0 – healthy tree; 1 – affected up to 10% of the crown; 2 – affected from 10 to 25% of the crown; 3 – 25 to 50%; 4 – more than 50%; 5 – complete death of the tree. Figure 3 illustrates demonstrate the degree of damage to oak leaves by powdery mildew. To determine the overall disease resistance of oak stands, a scale of resistance scores was applied: 1 – highly susceptible; 2 – susceptible; 3 – susceptible to a weak degree; 4 – resistant; 5 – highly resistant.

Figure 3. The degree of damage to oak leaves by powdery mildew: on the left 0%, on the right-up to 25%.

Determining the species composition of the assortment and bio-ecological characteristics of promising species and forms of the genus Quercus involved visual inspection of plantations, collecting herbarium, taking samples to determine pathogens, working with literature, and studying design and report documentation on their establishment. The development of the disease was determined according to the formula:

\[ R = \frac{\sum (a \times b)}{N} \]

where \( R \) – the intensity of the disease (score or %); \( \sum (a \times b) \) – the sum of the products of the number of plants and their corresponding percentage of infestation; \( N \) – the total number of plants counted.

Different types and varieties of oak show different resistance to diseases. Thus, early trees (Quercus Robur Var. Praecox) are more strongly affected by powdery mildew, weaker-fluffy oak, red oak (northern), Mongolian, eastern and cork are considered relatively stable. The susceptibility of the leaves to powdery mildew also depends on their age and condition. Young leaves are more susceptible to the pathogen, while leaves older than one month are almost not affected by the pathogen [13]. In the early-blooming form of the late oak (Quercus Robur Var. Tardiflora), late spring frosts, in addition to the leaves, often damage the female inflorescences located on the upper parts of the shoots. This is one of
the main reasons for the weak fruiting of oak in some years. Late frosts damage not only the leaves but also the young shoots and, as a consequence, they stop developing, turn black and wither.

A total of 4,484 (2000) to 2,289 (2019) trees in 4 test areas and one control area were studied by random sampling.

3. Results and discussion

In the oak forests of the G F Morozov Voronezh State University of Forestry and Technologies Experimental Forestry, the pedunculated oak is the dominant species. This species includes phenological forms (early- and late-blooming), as well as different morphoforms – spreading and pyramidal. We considered early- and late-blooming forms with a spreading crown. They differ in the timing of flowering of the leaves.

The early form blossoms and turns green 2-4 weeks earlier than the late form. Trees in the late-blooming form usually have better physical and mechanical wood quality and are more straight trunked than those in the early-blooming form. There are coppice and seed, pure and mixed oak forests, simple and complex in form, usually of the same age.

In well-preserved oak forests, the 1st tier is formed by pedunculated oak with an admixture of European ash, the 2nd tier includes Bosnian maple, elm family, small-leaved linden, and in the 3rd tier, common hazel and English field maple dominate in the undergrowth. Visual assessment of oak cultivars showed that almost all foliage on small category plants and more than half of the foliage on medium- and large-sized specimens was also noted. The reason for this is human factor.

And only plants over 3.5 m in height are free of powdery mildew and have no significant damage. They are well developed and can take part in the stand in the future. Based on an analysis of long-term research material, we can say that powdery mildew was completely absent from the crowns of mature trees in 1992, 2006 and 2010. Statistical data on the number and degree of damage to the leaf surface of pedunculated oak trees by powdery mildew on the PTA of the SSC passed of different intensity and the control area are shown in table 1.

| Degree of defeat, % | Survey year | Trees were examined for PTA units / % (from the registered trees on the sample in the year of the survey) | Total units / % (of the surveyed for the year) |
|---------------------|-------------|-------------------------------------------------------------------------------------------------|---------------------------------------------|
|                     |             | 1 | 2 | 3 | 4 | Control |
|---------------------|-------------|-----------------|----------------|----------------|----------------|-----------------|----------------|----------------|
| 0                   | 1982        | 9/1.2 | 17/2.2 | 4/0.6 | 46/6.7 | 27/3.2 | 105 / 2.8 |
|                     | 1987        | 249/31.2 | 315/35.1 | 210/27.8 | 284/34.8 | 302/31.5 | 1360 / 32.2 |
|                     | 1995        | 306/58.6 | 287/59.1 | 328/55.2 | 231/48.3 | 402/52.8 | 1554 / 54.7 |
|                     | 2000        | 84/10.7 | 201/22.6 | 96/10.9 | 48/4.8 | 133/14.4 | 562 / 12.5 |
|                     | 2013        | 212/50.2 | 305/56.7 | 214/50.0 | 244/42.8 | 293/41.8 | 1268 / 47.7 |
|                     | 2019        | 162/37.8 | 218/47.3 | 178/43.0 | 173/39.7 | 217/38.5 | 948 / 41.4 |
|                     | 1982        | 189/24.5 | 142/18.0 | 214/31.0 | 111/16.3 | 245/29.3 | 901 / 23.9 |
|                     | 1995        | 246/31.3 | 312/35.1 | 261/29.6 | 285/28.4 | 278/36.5 | 1382 / 30.8 |
|                     | 2000        | 158/37.4 | 156/29.0 | 121/28.2 | 187/32.8 | 222/31.7 | 844 / 31.7 |
|                     | 2013        | 248/57.9 | 205/44.5 | 218/52.7 | 236/54.1 | 267/48.5 | 1174 / 51.3 |
|                     | 1982        | 451/58.3 | 476/60.4 | 284/41.1 | 399/58.4 | 423/50.7 | 2033 / 53.9 |
|                     | 1987        | 326/40.8 | 298/33.2 | 271/36.0 | 286/35.0 | 313/32.4 | 1494 / 35.3 |
| Up to 25            | 1995        | 92/17.6 | 74/15.2 | 105/17.7 | 120/25.1 | 146/19.2 | 537 / 18.9 |
|                     | 2000        | 339/43.1 | 264/29.7 | 303/34.4 | 212/21.1 | 294/31.9 | 1412 / 31.5 |
Analyzing the data in the table, it can be observed that the degree of oak leaf defeat by powdery mildew varied considerably depending on the year of observation. Thus, while in 1982, 1987 and 2000, most oaks had a leaf surface infestation of 25-50%, in 2013 and 2019 it was less than 25%.

Significant differences in this indicator were observed only once in 2000, when the average leaf infestation on PTA4, with the highest intensity, was 20% higher than on other PTAs and in the control area. However, this probably should not be attributed to cutting intensity, as, firstly, it did not appear in the previous or subsequent years of observations, and secondly, the percentage of infested trees was not significantly different in the other test plots and the control area. The data obtained from the averaged data can be presented more clearly (table 2).

Table 2. Weighted average percentage of powdery mildew defeat of oak trees on the permanent test area and control area.

| Survey year | Weighted average % of powdery mildew defeat of the pedunculated oak on the PTA and control area | Average % for the year |
|-------------|--------------------------------------------------------------------------------------------------|-----------------------|
|             | 1 2 3 4  | Control |
| 1982        | 37.7 | 37.7 | 33.7 | 36.6 |
| 1987        | 24.3 | 24.3 | 25.4 | 24.5 |
| 1995        | 18.7 | 18.7 | 19.4 | 17.1 |
| 2000        | 43.5 | 43.5 | 32.7 | 32.3 |
| 2013        | 16.5 | 16.5 | 15.3 | 12.3 |
| 2019        | 11.5 | 11.5 | 10.2 | 9.6 |

Long-term observations of the plots subjected to selective sanitary cutting revealed no marked changes in the spread of powdery mildew, either in time or space, or in the degree of defeat. However, it is known that the nature of powdery mildew mycelial development depends significantly on the stage of leaf development itself [14]. Secondary foliage that appears after defoliation of the crown by leaf-eating insects (green oak leafworm, gypsy moth, oak crested moth, etc.) is much more strongly affected by powdery mildew [15].

Consequently, selective sanitary cutting can theoretically indirectly affect the nature and intensity of the oak crown damage by powdery mildew. In our studies, this pattern did not appear even in the second...
year after cutting and during the mass reproduction of the green oak leaf beetle (1982). Conversely, in 2000, the area least affected by green oak leaf beetle (PTA 4) had the highest degree of powdery mildew defeat. Most likely, this is due to the fact that, despite the different intensity of selective cutting, the remaining fullness of the plantings was comparable (the difference was within 0.1) and, accordingly, all the plots had comparable microclimatic conditions. Nevertheless, this issue is of fundamental importance for the environmental optimisation of HRV and requires further in-depth scientific research.

4. Conclusion

The following generalizations can be made on the basis of the study. Infection of oak plantations with powdery mildew was not recorded in some years (1992, 2006, 2010) on the experimental areas, while in the years of detailed survey (1982, 1987, 1995, 2000, 2013, 2019) the weighted average spread of this pathogen ranged from 36.6% (1982) to 9.9% (2019).

There was no significant dependence of the degree of damage to the oak stands by powdery mildew on the intensity of the selective cutting. The differences in the degree of leaf infestation of oak trees in some years (for example, 2000) in the test areas should not be associated with the intensity of cutting. This is due to the fact that this trend did not occur in previous or subsequent years of observation, and the percentage of affected trees in the test areas was comparable to the same indicator in the control area.

In order for selective sanitary cutting in oak forests to be ecologically justified and to produce a positive forest protection effect, the concept of sanitary cutting must be changed. It is necessary to shift the cutting priorities from dead standing trees and dying trees to weakened and severely weakened trees. The decision to carry out sanitary cutting should be based on an integrated silvicultural and forest pathology assessment of the plantation, and not on the stock of a certain category of stands, as is done in practice. Selective sanitary cutting in oak forests should not primarily focus on cutting dead wood and clearing dead wood, but on removing trees that are a breeding ground for pests and diseases from the plantation.

References

[1] Gea-Izquierdo G and Cañellas I 2014 Local Climate Forces Instability in Long-Term Productivity of a Mediterranean Oak Along Climatic Gradients. Ecosystems 17 228 doi: 10.1007/s10021-013-9719-3

[2] Pyzhev A, Sharafutdinov A. and I V Borisova 2020 Ecological and Economic Modelling of the Forestry Problems of Russia. IOP Conf. Ser.: Mater. Sci. Eng. 753 082004 doi: 10.1088/1757-899x/753/8/082004

[3] Shvidenko A and Shvidenko D 2013 Climate Change and Wildfires in Russia. Contemporary Problems of Ecology 6(7) 683 doi: 10.1134/S199542551307010X

[4] Shorohova T V, Sinevich S, Kryshen A and Vanha-Majamaa I 2019 Variable retention forestry in European boreal forests in Russia. Ecol. Process. 8 34 doi: 10.1186/s13717-019-0183-7

[5] Saharan G S, Mehta N K and Meena P D 2019 Powdery Mildew Perspective. In: Powdery Mildew Disease of Crucifers: Biology, Ecology and Disease Management (Springer, Singapore) doi: 10.1007/978-981-13-9853-7_1

[6] Mitchell R, Bellamy P, Ellis C, Hewison R, Hodgetts N, Iason G, Littlewood N, Newey S, Stockan J and Taylor A F 2019 Collapsing foundations: The ecology of the British oak, implications of its decline and mitigation options. Biological Conservation 233 316 doi: 10.1016/j.biocon.2019.03.040

[7] Woodward RC, Waldie JS, Steven HM, 1929 Oak mildew and its control in forest nurseries. Forestry 3 38 doi: 10.1093/oxfordjournals.forestry.a063129

[8] Corcobado T, Miranda-Torres J J, Martin-Garcia J, Jung T and Solla A 2017 Early survival of Quercus ilex subspecies from different populations after infections and co-infections by multiple phytophthora species. Plant Pathology 66(5) 792 doi: 10.1111/tpa.12627

[9] Covrig I, Oroian C, Burduhos P, Oroian I and Odagiu A 2017 Influence of some climatic factors
upon powdery mildew attack in oak forests located in Transylvania. *AgroLife Scientific Journal* **6**(2) 77 doi: 10.1088/1742-6596/899/3/032013

[10] Demeter L, Molnár ÁP, Öllerer K, Csóka G, Kiš A and Vadász Cand Molnár Z 2021 Rethinking the natural regeneration failure of pedunculate oak: The pathogen mildew hypothesis. *Biological Conservation* **253** doi: 10.1016/j.biocon.2020.108928

[11] Copolovici L, Väärttnõu F, Estrada V P and Niinemets U 2014 Oak powdery mildew (*Erysiphe alphitoides*)-induced volatile emissions scale with the degree of infection in *Quercus robur*. *Tree Physiology* **34**(12) 1399 doi: 10.1093/treephys/tpu091

[12] Marçais B and Desprez-Loustau M L 2014 European oak powdery mildew: impact on trees, effects of environmental factors, and potential effects of climate change. *Annals of Forest Science*. **71** 633 https://doi.org/10.1007/s13595-012-0252-x

[13] Bert D, Lasnier J-B, Capdevielle X, Dugravot A and Desprez-Loustau M-L 2016 Powdery mildew decreases the radial growth of oak trees with cumulative and delayed effects over years. *PLoS ONE*. **11**(5) e0155344 doi: 10.1371/journal.pone.0155344

[14] Solla A, Moreno G, Malewski T, Jung T, Klisz M and Tkaczyk M 2021 Phosphite spray for the control of oak decline induced by phytophthora in Europe. *Forest Ecology and Management* **485** doi: 10.1016/j.foreco.2021.118938

[15] Oztürk A, Ozüyigit I and Sumer S 2020 Investigation of powdery mildew disease in various oak (*Quercus*) trees; a case study from Istanbul/Turkey. *Fresenius Environmental Bulletin* **29**(7) 5029