2. ЛІСОЗНАВСТВО ТА ЛІСІВНИЦТВО ТА МИСЛИВСЬКЕ ГОСПОДАРСТВО

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@ ✉ Correspondence author
Valentyna Meshkova
Valentynameshkova@gmail.com
86 Pushkinska st., Kharkiv, 61024, Ukraine

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Prediction of changes in the health condition of silver birch (*Betula pendula* Roth.)

V. Meshkova[1], Y. Koshelyaeva[2], M. Kolienkina[3], I. Shvydenko[4]

Silver birch (Betula pendula Roth.*) forms softwooded broadleaved forests in various natural zones. It is widely used in protective afforestation and urban plantings, it is a pioneer species in the clear-cuts and burnt areas. However, the global warming and anthropogenic pressure promote the susceptibility of silver birch to pests and pathogens.*

The aim of the research was to assess the trends in the health condition dynamics of silver birch stands depending on forest site conditions and the initial health condition of the trees.

The research was carried out in the 2015-2019 period in the Silver birch forest stands in Kharkiv region in fresh fairly poor forest site conditions (B_2), fresh fairly fertile forest site conditions (C_2), and fresh fertile forest site conditions (D_2). All the stands were 40-45 years old and had a relative density of stocking 0.7–0.8.

Health condition class was visually assessed for each tree in July of each year according to "Sanitary rules in the forests of Ukraine". For each group of sample plots, which corresponded to the main types of forest site conditions, the probability of improvement of health condition, deterioration of health condition, and mortality in 2019 was calculated depending on their health condition in 2015.

In each year of the studies (2015-2019), the health condition of silver birch stands was the worst in fresh fertile site conditions, which was due to the bacterial wet wood disease. In the fresh fertile forest site conditions, no tree of the 4th class of health condition improved it during the 2015-2019 period, and in fresh fairly fertile forest site conditions 27.7% of silver birch trees improved their health condition. In each type of forest site conditions, the probability of mortality in

[1] *Valentyna Meshkova* – Full Member of Forestry Academy of Sciences of Ukraine, Doctor habil. (Agricultural Sciences), Professor, The G. M. Vysotsky Ukrainian Research Institute of Forestry & Forest Melioration. 86 Pushkinska st., Kharkiv, 61024, Ukraine. Tel.: +38(097)371-94-58. E-mail: Valentynameshkova@gmail.com ORCID: https://orcid.org/0000-0001-6483-2736

[2] *Yana Koshelyaeva* – PhD, The V. V. Dokuchaev Kharkiv National Agrarian University, 62483, Kharkiv region, Kharkiv district, "Dokuchaevske – 2", Ukraine. Tel.: +38(099)131-45-28. E-mail: yana120783@i.ua ORCID: https://orcid.org/0000-0002-5164-3204

[3] *Maryna Kolienkina* – PhD, Associate Professor at the Department of landscape design and landscape art. The O. M. Beketov Kharkiv National University of Urban Economy, 17 Marshal Bazhanov st., Kharkiv, 61002, Ukraine. Tel. +38(067)696-62-04. E-mail: kolenkinamarina@gmail.com ORCID: https://orcid.org/0000-0002-5612-0947

[4] *Inna Shvydenko* – PhD, Associate Professor at the Department of Horticulture. The V. V. Dokuchaev Kharkiv National Agrarian University, 62483, Kharkiv region, Kharkiv district, "Dokuchaevske – 2", Ukraine. Tel. +38(050)630-73-62. E-mail: i.shvydenko.mikulina@gmail.com ORCID: https://orcid.org/0000-0003-4383-7604

more weakened silver birch specimens is higher. The probability of silver birch mortality of any class of health condition was the highest in the fresh fertile forest site conditions and the lowest in the fresh fairly poor forest site conditions.
***Key words**: forest site condition; health condition class; tree mortality; death probability.*

Introduction. Silver birch (*Betula pendula* Roth.) forms softwooded broadleaved forests in various natural zones (Hytönen, Saramäki, & Niemistö, 2013; Vindstad et al., 2019). It is of great forestry importance as a forest-forming, fast-growing, and soil-improving species, it is widely used in protective afforestation and urban plantings, is a pioneer species in the clear-cut and burnt areas, it forms pure or mixed stands (Ozolinčius et al., 2016). The admixture of silver birch in the composition of pine stands helps to reduce the risk of spreading fires, some pine diseases, improving the conditions of litter decomposition, greater penetration of precipitation under the crowns (Maleki, & Kiviste, 2016).

Tree health assessment and prediction of its health condition is important for forest management strategy (Boeck, Dieler, Biber, Pretzsch, & Ankerst, 2014; Bircher, Cailleret, & Bugmann, 2015). The effect of factors weakening forest stands does not always lead to their immediate death. In favorable forest site conditions and under favorable weather conditions, the health condition of trees can improve or remain stable for several years. Therefore, a comparison of the dynamics of the health condition of trees in different forest growth conditions is of practical interest. Different approaches have been developed for early detection of the first symptoms and signs of tree weakening as well as for prediction of tree mortality for different tree species (Cailleret et al., 2016; Maleki & Kiviste, 2016; Hülsmann, Bugmann, & Brang, 2017).

Our previous studies in urban plantings made it possible to evaluate the probability of surviving or dying of silver birch trees with the different initial health condition (Meshkova, Koshelyaeva, & Kolienkina, 2019). Taking into account the differences in the features in urban and forest stands, we made an attempt to assess changes in the health condition of silver birch trees in forest stands on the basis of five-year monitoring of different forest site conditions.

Objects and methods. *Object of research* – the trends in health condition dynamics for silver birch forest stands. *Subject of research* – the trends in the health condition dynamics of silver birch stands depending on forest site conditions and the initial health condition of the trees.

The aim of the research was to assess the trends in the health condition dynamics of silver birch stands depending on forest site conditions and the initial health condition of the trees.

The research was carried out in the 2015-2019 period in the Silver birch forest stands in Kharkiv region. Taking into account the results of the analysis of forest inventory databases of the forest fund of forestry enterprises of the Left Bank Forest-Steppe (Meshkova, & Koshelyaeva, 2015) regarding the predominance of silver birch in fresh fairly poor forest site conditions (B_2), fresh fairly fertile forest site conditions (C_2) and fresh fertile forest site conditions (D_2), we selected data on silver birch health condition from nine sample plots – three ones for each type of forest site conditions (Tab. 1). All the stands were 40–45 years old and had a relative density of stocking 0.7–0.8.

These sample plots are located in Zadonetske forest district of the Zmiiv Forestry Enterprise, as well as in Dergachivske and Pivdenne forest districts of Kharkiv Forest Research Station of the G. M. Vysotsky Ukrainian Research Institute of Forestry & Forest Melioration. In the forest stands of Zadonetske and Dergachivske forest districts, the birch was planted in rows together with Scots pine (*Pinus sylvestris* L.) (8 rows of Scots pine, 2 rows of silver birch).

Table 1

Characteristics of sample plots in silver birch stands

Code of sample plot	Index of the type of forest site conditions	Diameter, cm	Hight, m	Age, years	Number of birch trees
Zadonetske-1	B_2	21.5	19.5	45	59
Zadonetske-2	B_2	23.7	22.5	45	61
Zadonetske-3	B_2	19.0	18.0	45	73
Dergachivske-1	C_2	25.0	20.5	45	100
Dergachivske-2	C_2	25.2	21.5	45	100
Dergachivske-3	C_2	18.5	15.5	45	118
Pivdenne-1	D_2	25.4	22.0	40	103
Pivdenne-2	D_2	18.2	24.5	40	100
Pivdenne-3	D_2	19.2	22.5	40	209

In Pivdenne forest district, the birch was planted in 2–6 rows at the clear-cutting of oak stands. The stands with sample plots are allocated in separate subcompartments, and the composition of tree species in neighboring subcompartments is typical for the fresh maple-linden oak stand, particularly English oak (*Quercus robur* L.), small-leaved linden (*Tilia cordata* Mill.), and Norway maple (*Acer platanoides* L.).

Health condition class was visually assessed for each tree in July of each year.

The category (class) of health condition for each tree was evaluated on a range of visual characteristics according to "Sanitary rules in the forests of Ukraine" (Sanitary Forests Regulations, 2016) by the following classes: 1^{st} – healthy; 2^{nd} – weakened; 3^{rd} – severely weakened; 4^{th} – drying up; 5^{th} – recently died; 6^{th} – died over a year ago. Health condition index (HCI) was calculated as mean weighted from trees number of each class of health condition, separately for all living and dead trees ($HCI_{1–6}$) and for living trees only ($HCI_{1–4}$).

The tree mortality was expressed as a percentage of dead trees for the research period out of the total trees in 2015.

For each group of sample plots, which corresponded to the main types of forest site conditions, the probability of improvement of health condition, deterioration of the health condition, and mortality in 2019 were calculated depending on their health condition in 2015. For example, if in 2015 there were 20 trees of $HCI_{1–6} = 1$, and in 2019 10 trees worsened the $HCI_{1–6}$ to class 2 and 5 trees to class 3, the probability of deterioration to $HCI_{1–6} = 2$ is 50% (10: 20 × 100%), and deterioration to $HCI_{1–6} = 3$ is 25% (5: 20 × 100%).

Summary statistics (Atramentova, & Utevskaya, 2008) was performed using Microsoft Excel applications and statistical software package PAST: Paleontological Statistics Software Package for Education and Data Analysis (Hammer, Harper, & Ryan, 2001).

Results. In each year of the study (2015–2019), the health condition, determined taking into account all viable and dead trees ($HCI_{1–6}$), was the worst in fresh fertile site conditions (Tab. 2). The value of the health condition index in fresh fertile site conditions defined taking into account only viable trees ($HCI_{1–4}$), briefly decreased in 2018 but increased the following year. In the fresh fairly fertile forest site conditions, the situation was similar – a decrease in the indices of health condition of birch trees in the year of selective sanitary felling (2018), followed by an increase in this index.

Table 2

Dynamics of health condition index of the birch stands in different types of forest site condition (numerator – $HCI_{1–6}$, denominator – $HCI_{1–4}$)

Index of the type of forest site conditions	Years				
	2015	2016	2017	2018	2019
B_2	1.90 / 1.80	2.10 / 1.90	2.30 / 2.10	1.60 / 1.60	1.76 / 1.69
C_2	2.15 / 2.00	2.24 / 2.10	1.75 / 1.60	2.26 / 1.70	2.34 / 1.80
D_2	2.10 / 2.10	2.50 / 2.30	2.80 / 2.37	3.10 / 2.26	3.24 / 2.41

The average index of the health condition $HCI_{1–6}$ of silver birch stands for the 2015–2019 period was 1.9, 2.1, and 2.7 in the fresh fairly poor, fresh fairly fertile and fresh fertile forest site conditions, respectively, and $HCI_{1–4}$ was 1.8, 1.8, and 2.3 at the same forest site conditions, respectively.

The birch trees of the 1st class of health condition could either remain healthy or worsen the condition to the 2^{nd} – 6^{th} classes. The analysis of the data shows that most trees with $HCI_{1–6} = 1$ did not change the health condition in fresh poor forest site conditions (Fig. 1).

87.7% of trees in the fresh fertile forest site conditions, 54.7% in the fairly fertile forest site conditions, and 34.5% in fairly poor forest site conditions worsened the condition to $HCI_{1–6} = 3$. The mortality in 2019 of trees that had the 1^{st} class of health condition in 2015 was the lowest in fairly poor forest site conditions and almost similar in the fresh fairly fertile and fresh fertile forest site conditions (see Fig. 1).

Silver birch trees, which in 2015 had the 2^{nd}, 3^{rd}, and 4^{th} classes of health condition, over four years could improve the condition, worsen or remain unchanged. In the total sample set of data, the share of trees that did not change the health condition from $HCI_{1–6} = 2$ is very close in different types of forest conditions and averages 33.4% (Fig. 2). The proportion of trees that improved their health condition over four years is the largest in the fresh fairly poor forest site conditions (42.6%) and it is the lowest in the fresh fertile forest site conditions (3.7%). However, the proportion of trees which worsened their health condition for these years increased from fresh fairly poor forest site conditions (17.6%) to the fresh fertile forest site conditions (51.7%) (see Fig. 2).

Most of the trees of silver birch which had the 3^{rd} class of health condition in 2015 did not change their health condition over four years in the fresh fairly poor forest site conditions (73.9%) (Fig. 3). In the fresh fertile forest site conditions, only 25.5% did not change their health, and most of the trees (44.4%) worsened it.

The probability of improvement and deterioration over 4 years of the health condition of trees that had the 3^{rd} class of health condition in 2015 is almost the same in the overall sample (23.6 and 25.9%). The probability of improving the health condition of trees in the fresh fairly poor forest site conditions is almost three times more than its worsening (19.4 and 6.7%, respectively), and in fresh fairly fertile and fresh fertile forest site conditions the probability of worsening of the health condition of silver birch is slightly greater than its improvement (1.1 and 1.5 times, respectively) (see Fig. 3).

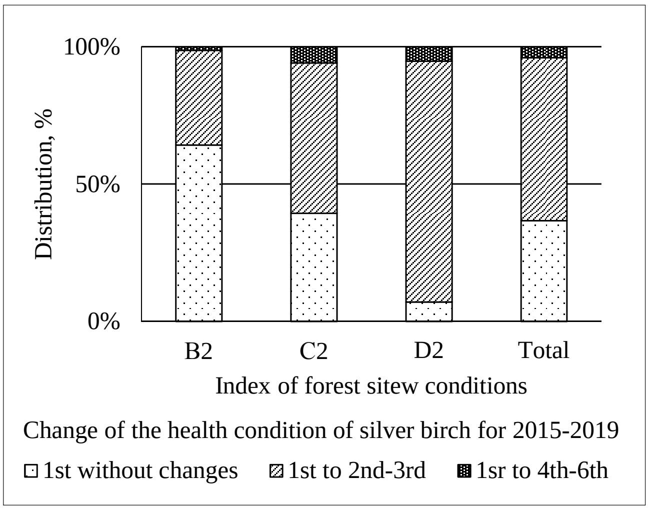

Fig. 1. Probability of the change of the health condition of silver birch of the 1st class of health condition for 2015-2019 in different types of forest site conditions

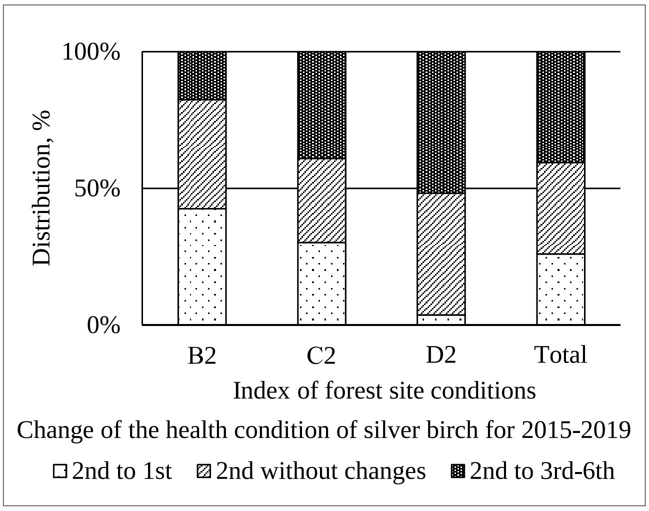

Fig. 2. Probability of the change of the health condition of silver birch of the 2nd class of health condition for 2015-2019 in different types of forest site conditions

In the fresh fairly poor forest site conditions, the trees of silver birch of the 4th class of health condition in 2015 were removed the following years by selective sanitary felling. Most of the trees of the 4th class of the health condition in 2015 died in 2019 (72.3 and 93.8% in the fresh fairly fertile and fresh fertile forest site conditions, respectively) (Fig. 4).

In the fresh fertile forest site conditions, no tree of the 4th class of health condition improved the health condition over 4 years, and in fresh fairly fertile forest site conditions 27.7% of silver birch trees improved their health condition (see Fig. 4).

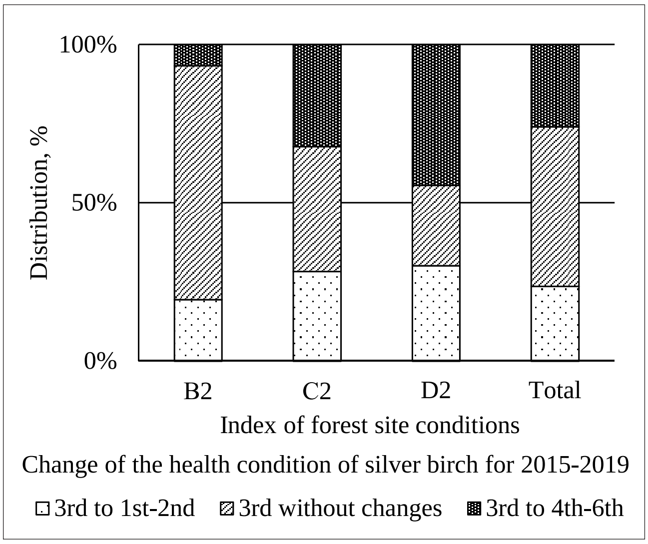

Fig. 3. Probability of the change of the health condition of silver birch of the 3rd class of health condition for 2015-2019 in different types of forest site conditions

We calculated the probability of mortality of silver birch trees that had the 1st, the 2nd, the 3rd and the 4th classes of the health condition, depending on the type of forest site conditions (Fig. 5).

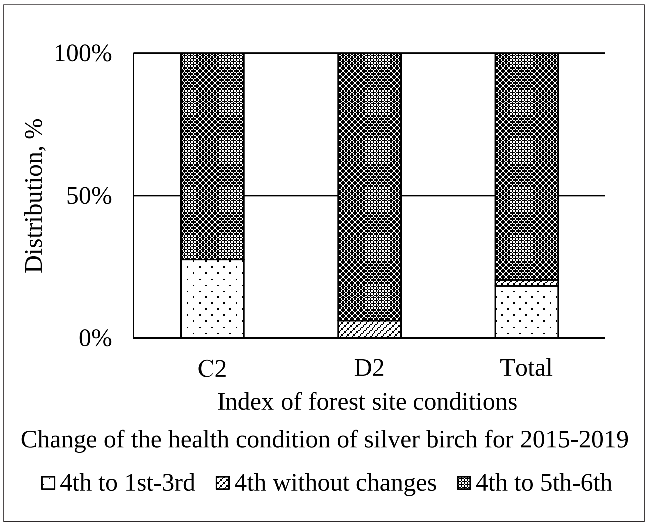

Fig. 4. Probability of the change of the health condition of silver birch of the 4th class of health condition for 2015-2019 in different types of forest site conditions (the trees which had the 4th class of health condition in 2015 in the fresh fairly poor forest site conditions were removed the following years by selective sanitary felling)

As in each type of forest site conditions, and in the joint sample of silver birch trees, the probability of mortality in more weakened specimens is higher.

Thus, in the joint sample of data, the probability of mortality of silver birch trees of the 1st, the 2nd, the 3rd, and the 4th classes of the health condition is 3.9; 16.4; 30.4, and 62.4%. The probability of silver birch mortality of any class of the health condition is the highest in the fresh fertile forest site conditions and the lowest in the fresh fairly poor forest site conditions (see Fig. 5).

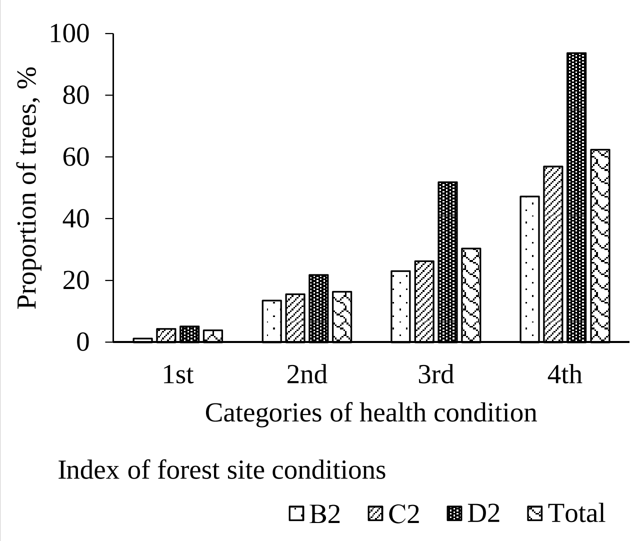

Fig. 5. Probability of mortality in 2019 the trees of silver birch with a different health condition in 2015 in different types of forest site conditions

The relationship between the probability of mortality of silver birch trees (Y) and the initial class of the health condition (X) is satisfactorily described by the polynomial dependency of degree 2 (Fig. 6).

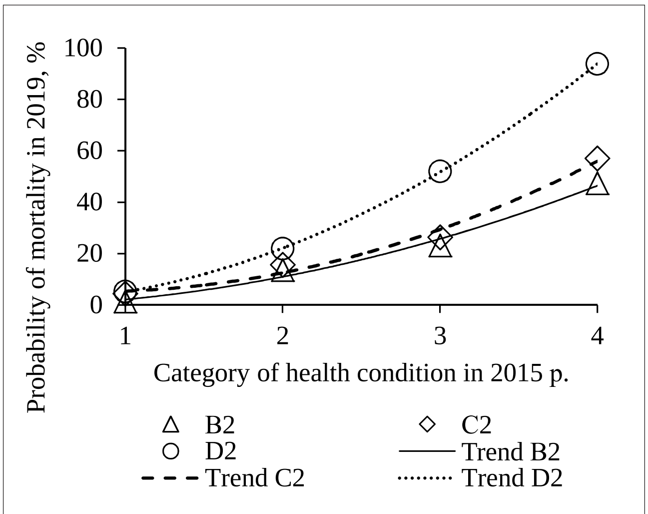

Fig. 6. Probability of mortality in 2019 the trees of silver birch depending on forest site conditions and the health condition index in 2015 (in B_2: $Y = 2.97 x^2 – 0.06 x – 0.8$; $R^2 = 0.9866$; in C_2: $Y = 4.86 x^2 – 7.43 x + 7.93$; $R^2 = 0.9862$; in D_2: $Y = 6.28 x^2 – 1.80 x + 0.59$; $R^2 = 0.9898$)

For each forest site condition, the coefficient of determination R^2 exceeds 0.98, and the correlation coefficient $R > 0.99$ (Fig. 6). At 3 degrees of freedom and $P = 0.05$, the limit value of the correlation coefficient R is 0.83. The calculated correlation coefficient exceeds this value. Hence the dependence of tree mortality in 2019 on the health condition index in 2015 is confirmed statistically.

Comparison of the data for assessing the mortality rate of birch trees of different classes of the health condition shows very similar values obtained in the forest (see Fig. 6) and park stands, where the probability of mortality of silver birch trees of the 1st, the 2nd, the 3rd and the 4th classes of the health condition for 2015–2019 was evaluated as 3.5, 10.7, 36.9, and 84.6% (Meshkova et al., 2019).

Discussion. The global warming and anthropogenic pressure promote the susceptibility of trees to pests and pathogens (Heimonen et al., 2015; Nguyen et al., 2017; Shvidenko, Buksha, Krakovska, & Lakyda, 2017; Vindstad et al., 2019), particularly silver birch in the Forest-steppe zone (Parkhomenko, Chernyshov, & Hromova, 2013; Skrylnik, Koshelyaeva, & Meshkova, 2019) and in Polissya (Goychuk, Drozda, & Shvets, 2018).

The tree mortality was predicted by different research teams using spatially explicit competition indices (Boeck et al., 2014), empirical mortality models (Bircher et al., 2015), logistic tree mortality models based on ring-width data (Cailleret et al., 2016), using forest inventory data (Hülsmann et al., 2017).

We evaluated the probability of the changes in the health condition and mortality of trees of different initial health condition when studying urban plantations of silver birch (Meshkova et al., 2019). It was shown that the weakened silver birch stand which contains trees of 1st – 3rd classes of health condition is able to restore condition to a healthy one, and the deterioration may be expected only for severely weakened trees (having 3rd class of health condition in 2015). A silver birch stand which has the trees of 2nd – 4th health condition classes is most likely to weaken even more severely over 4 years.

However, the urban plantings are under stronger influence of higher temperature and traffic pollution than forest stands (Tubby, & Webber, 2010; Hilbert et al., 2019; Klein, Koeser, Hansen, & Escobedo, 2019). This could have an effect on the health condition of silver birch.

Current research in the forest stands has shown that in each year of research the health condition of silver birch was the worst in fresh fertile site conditions.

The worst condition of silver birch in the fresh fairly fertile and fresh fertile forest site conditions is associated with its infection by bacterial wet wood disease (Meshkova, & Koshelyaeva, 2017). The wet wood disease is one of the most injurious diseases of birch caused by the bacterium *Enterobacter nimipressuralis*. Stem insects play a great part in its dissemination because they are contaminated with the pathogen during development under the bark or in the wood and then convey the infection to the healthy tree during maturation feeding or tree colonizing (Goychuk et al., 2018).

Our studies, conducted during the 2015–2019 period, showed that the proportion of trees which worsened their health condition for these years from the 1st, 2nd, 3rd of 4th class of health condition increased from fresh fairly poor forest site conditions to the fresh fertile forest site conditions. The probability of silver birch mortality of any class of the health condition was also the highest in the fresh fertile forest site conditions.

The dependence of silver birch tree mortality in 2019 on the health condition index in 2015 is confirmed statistically for each type of forest site conditions.

Comparison of the data for assessing the mortality rate of birch trees of different classes of health condition shows very similar values obtained in this research for forest and those obtained in previous research for park plantings.

The probability of mortality of silver birch trees of the 1st, the 2nd, the 3rd, and the 4th classes of health condition for the 2015–2019 period in urban plantings was evaluated as 3.5, 10.7, 36.9, and 84.6 % (Meshkova et al., 2019), and in the current research, it was 3.9, 16.4, 30.4, and 62.4 % for the pooled sample of data.

The wet wood disease was the main cause of silver birch weakening and mortality. Our prediction makes it possible to evaluate the probability of mortality of the silver birch in different forest site conditions and to decrease the losses of timber by survey and selective sanitary felling in time.

The analysis can be deepened taking into account the increase in the duration of monitoring and the involvement of meteorological indicators.

Conclusions. In each year of research (2015–2019), the health condition of silver birch was the worst in fresh fertile site conditions. The worst health condition of silver birch in the fresh fairly fertile and fresh fertile forest site conditions is associated with its infection by bacterial wet wood disease.

During the 2015–2019 period, the health condition changed from the 1st class to the 3rd one in 87.7, 54.7 and 34.5% of birch trees in the fresh fertile, fresh fairly fertile, and fresh fairly poor forest site conditions, respectively. The proportion of trees which worsened their health condition for these years from the 2nd class of health condition increased from fresh fairly poor forest site conditions (17.6 %) to the fresh fertile forest site conditions (51.7 %). The probability of improving the health condition of trees of the 3rd class of health condition in the fresh fairly poor forest site conditions is almost three times more than its worsening (19.4 and 6.7 %, respectively), and in fresh fairly fertile and fresh fertile forest site conditions the probability of worsening of the health condition of silver birch is slightly greater than its improvement (1.1 and 1.5 times, respectively).

In the fresh fertile forest site conditions, no tree of the 4th class of health condition improved it during the 2015–2019 period, and in fresh fairly fertile forest site conditions 27.7% of silver birch trees improved their health condition.

In each type of forest site conditions, the probability of mortality in more weakened silver birch specimens is higher. The probability of silver birch mortality of any class of health condition was the highest in the fresh fertile forest site conditions and the lowest in the fresh fairly poor forest site conditions.

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Прогнозування зміни санітарного стану берези повислої (*Betula pendula* Roth.)

В.Л. Мєшкова[1], Я.В. Кошеляєва[2], М.С. Колєнкіна[3], І.М. Швиденко[4]

Береза повисла (*Betula pendula* Roth.) утворює м'яколистяні насадження у різних природних зонах. Її широко застосовують у захисному лісорозведенні та міських насадженнях, вона є піонером на зрубах і згарищах. Водночас, в умовах глобаль-

[1] *Мєшкова Валентина Львівна* – академік Лісівничої академії наук України, доктор сільськогосподарських наук, професор, Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г.М. Висоцького, вул. Пушкінська, 86, Харків, 61024, Україна. Тел.: +38(097)371-94-58. E-mail: Valentynameshkova@gmail.com ORCID: https://orcid.org/0000-0001-6483-2736

[2] *Кошеляєва Яна Вікторівна* – кандидат сільськогосподарських наук, кафедра фітопатології. Харківський національний аграрний університет ім. В.В. Докучаєва, 62483, Харківська область, Харківський район, «Докучаєвське – 2», Україна. Тел.: +38(099)131-45-28. E-mail: yana120783@i.ua ORCID: https://orcid.org/0000-0002-5164-3204

[3] *Колєнкіна Марина Сергіївна* – кандидат сільськогосподарських наук, доцент кафедри ландшафтного проектування та садово-паркового мистецтва. Харківський національний університет міського господарства ім. О.М. Бекетова, вул. Маршала Бажанова, 17, Харків, 61002, Україна. Tel. +38(067)696-62-04. E-mail: kolenkinamarina@gmail.com ORCID: https://orcid.org/0000-0002-5612-0947

[4] *Швиденко Інна Миколаївна* – кандидат сільськогосподарських наук, доцент кафедри садово-паркового господарства. Харківський національний аграрний університет ім. В.В. Докучаєва, 62483, Харківська область, Харківський район, «Докучаєвське – 2», Україна. Тел.: +38((050)630-73-62. E-mail: i.shvydenko.mikulina@gmail.com ORCID: https://orcid.org/0000-0003-4383-7604

ного потепління та антропогенного навантаження підвищується сприйнятливість берези повислої до шкідників і патогенів, зокрема до бактеріальної водянки та стовбурових шкідників, які її поширюють.

Метою досліджень було оцінювання тенденцій динаміки санітарного стану насаджень *Betula pendula* залежно від типу лісорослинних умов і початкового санітарного стану дерев.

Дослідження здійснено у 2015-2019 рр. у насадженнях берези повислої Харківської області в умовах свіжого субору (B_2), свіжого сугруду (C_2) та свіжого груду (D_2). Всі насадження мали вік 40-45 років і відносну повноту 0,7-0,8. Категорію санітарного стану визначали візуально для кожного дерева у липні згідно із положеннями «Санітарних правил в лісах України». Для кожного типу лісорослинних умов розраховували ймовірність поліпшення та погіршення санітарного стану берези повислої, а також її відпад. Відпад виражали у відсотках як співвідношення дерев, що загинули за період 2015-2019 рр., до їхньої кількості у 2015 році.

У кожен рік досліджень (2015-2019 рр.) санітарний стан насаджень *Betula pendula* був найгіршим у свіжому груді. Середній індекс санітарного стану з урахуванням усіх дерев у 2015-2019 рр. становив 1,9; 2,1 та 2,7 у свіжому суборі, свіжому сугруді та свіжому груді відповідно, а з урахуванням лише життєздатних дерев – 1,8; 1,8 та 2,3 відповідно у таких самих лісорослинних умовах. Найгірший стан берези у свіжому сугруді та свіжому груді пов'язаний із поширенням бактеріальної водянки. Впродовж 2015-2019 рр. категорію санітарного стану змінили від 1-ої на 3-ю 87,7; 54,7 і 34,5% дерев берези у свіжому груді, свіжому сугруді та свіжому суборі відповідно. Серед дерев 2-ої категорії санітарного стану частка особин, що погіршили стан, зростає від свіжого субору (17,6%) до свіжого груду (51,7%). Ймовірність поліпшення санітарного стану дерев 3-ої категорії санітарного стану у свіжому суборі майже втричі більша, ніж імовірність його погіршення (19,4 та 6,7% відповідно), а в свіжому сугруді та свіжому груді ймовірність погіршення санітарного стану *Betula pendula* не набагато менша, ніж його поліпшення (в 1,1 та 1,5 рази відповідно). У свіжому груді жодне дерево 4-ї категорії не покращило стан впродовж 2015-2019 рр., а в свіжому сугруді 27,7% дерев його покращило. У кожному типі лісорослинних умов ймовірність відпаду найбільш ослаблених дерев берези є більшою. Для сукупної вибірки даних вона становить 3,9; 16,4; 30,4 та 62,4% дерев, що мали 1, 2, 3 та 4 категорії санітарного стану у 2015 році. Ймовірність відпаду дерев *Betula pendula* будь-якої початкової категорії санітарного стану була найбільшою у свіжому груді та найменшою – у свіжому суборі. Порівняння даних оцінювання інтенсивності відпаду дерев берези повислої різних категорій санітарного стану показує дуже подібні значення, одержані в цьому дослідженні та у попередніх дослідженнях у паркових насадженнях.

Ключові слова: лісорослинні умови; категорія санітарного стану; відпад дерев; ймовірність відпаду.