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Silver birch health condition in the parks of Kharkiv National Agrarian University named after V. V. Dokuchaev

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*Recently health condition of silver birch (*Betula pendula* Roth.) stands worsens in the forest and ornamental stands. It is important to know the probability of its improvement or deterioration in particular stands to take the necessary measures in time.*

The aim of the research was to assess the trends in the health condition dynamics of silver birch stands depending on their age class and the initial health condition of the trees. The research was carried out in 2015-2019 in the Silver birch linear stands in two parks of Kharkiv National Agrarian University named after V. V. Dokuchaev (49°53' N, 36°27' E). Five sample plots of the 3rd age class are located in Veterans Park and the other 4 sample plots of the 5rd age class – in Arboretum of this University. For each inspected tree diameter at breast height (DBH) was measured in 2015 and 2019. Crown defoliation and health condition class were visually assessed in July of each year. Health condition index (HCI) was calculated as mean weighted from trees number of each category of health condition, separately for all living and dead trees (HCI_{1-4}) and for living trees only (HCI_{1-4}). Tree mortality was expressed as a percentage of lost (dead) trees for research period out of the total trees in 2015.

It was shown that the silver birch stands of the 3rd age class didn't change their health condition for 2015-2019 or improved it. The stands of the 5th age class worsened their health condition in three sample plots and improved it in one sample plot. Within each age class, the stands of lower diameter class had a worse health condition. Tree mortality was registered in two out of five sample plots in the stands of the 3rd age class and in three out of four sample plots in the stands of the 5th age class. In the stands of the 5th age class the trees from the stands of the smallest diameter class characterized by the highest mortality level (22.4%) and the worse health condition ($HCI_{1-4}=2.8$).

In pooled sample of plots, the death probability for silver birch trees, which 4 years ago had the 1st class of health condition is 3.5%, those of the 2nd class have the death probability of 10.7%, the trees of the 3rd class – 36.9%, those of the 4th class – 84.6%. As for an initially weakened stand, its trees which 4 years ago had the 1st, the 2nd, the 3rd or the 4th health condition class, have the death probability of 5%, 18.5%, 33.3%, and 100% respectively.

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Thus, 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). The weakened silver birch stand which has the trees of 1st – 4th health condition classes is most likely to weaken even more severely over 4 years.

Key words: age class; diameter (DBH); defoliation; health condition index for living trees (HCI_{1-4}); tree mortality; death probability.

Introduction. Silver birch (*Betula pendula* Roth.) is one of the most spread deciduous species in the forests, field protective forest belts and ornamental stands. Particularly in the forest fund of the State Agency of Forest Resources of Ukraine birch stands are only 5.7% from the forest-covered area (General characteristics, 2016). Birch timber is used for pulp and paper, plywood, sawmill, furniture, and also as firewood. Other parts of birch trees are used in the pharmaceutical and food industries (Ozolinčius et al., 2016).

Global warming promotes an increase in the birch proportion in boreal forests (Heimonen et al., 2015). At the same time, due to climate change and anthropogenic pressure, birch susceptibility to pests and pathogens increases (Nguyen et al., 2017, Shvidenko et al., 2017, Vindstad et al., 2019), particularly in the Forest-steppe zone (Parkhomenko et al., 2013, Skrylnik et al., 2019) and in Polissya (Goychuk et al., 2018).

The studies show the pathological birch mortality, particularly among trees with a diameter of over 20 cm (Meshkova et al., 2018). In the forest stands of the forest-steppe zone of Ukraine, the mean weighted age class of silver birch was estimated as IV.8 in vegetative stands and IV.6 – in artificial seed stands. It was greater for the northern part of the forest-steppe zone (V.1) and less (IV.6) for the southern part of it (Meshkova & Koshelyaeva, 2019). Survival of pure and almost pure stands is the lowest (Hytönen et al., 2013).

Tree health assessment and prediction is important for forest management strategy in forest and urban stands (Boeck et al., 2014, Bircher et al., 2015). Particularly in urban stands, silver birch is under the greater anthropogenic influence than in the forest due to a higher temperature and traffic pollution (Tubby & Webber, 2010, Hilbert et al., 2019, Klein et al., 2019).

Different approaches have been developed for early detection of the first symptoms and signs of tree weakening as well as for prediction tree mortality for different tree species (Cailleret et al., 2016, Maleki & Kiviste, 2016, Hülsmann et al., 2017). For example, on the base of seven years monitoring, the probability of health condition change and mortality of Scots pine (*Pinus sylvestris* L.) trees was evaluated with considering forest site conditions, age and initial health condition of the stands (Meshkova & Kolienkina, 2016). Our current research is based on five-year monitoring data on the health condition of 450 birch trees in urban stands.

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

The aim of research was to assess the trends in the health condition dynamics of silver birch stands depending on their age class and the initial health condition of the trees.

Research was carried out in 2015-2019 in the Silver birch linear stands in two parks of Kharkiv National Agrarian University named after V.V. Dokuchaev (49°53' N, 36°27' E). Five sample plots (SP 1 – SP 5) of the 3rd age class are located in Veterans Park and the other 4 sample plots (SP 6 – SP 9) of the 5th age class in Arboretum of this University (Tab. 1).

In each sample plot, from 15 to 156 trees were represented.

For each inspected tree diameter at breast height (DBH) was measured in 2015 and 2019. Crown defoliation and health condition class were visually assessed in July of each year.

Defoliation was assessed in per cents and converted into ranges according to ICP monitoring score (Manual, 2010): 0 – 0-10% (defoliation is absent); 1 – 11-25% (slight defoliation); 2 – 26-60% – moderate defoliation; 3 – 61-99% – severe defoliation; 4 – 100% – dead trees.

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” (Anonymous, 1995) by the following classes: 1st – healthy; 2nd – weakened; 3rd – severely weakened; 4th – drying up; 5th – recently died; 6th – died over year ago. Health condition index (HCI) was calculated as mean weighted from trees number of each category of health condition, separately for all living and dead trees (HCI_{1-6}) and for living trees only (HCI_{1-4}).

Tree mortality was expressed as a percentage of lost (dead) trees for the research period out of the total trees in 2015.

Normality tests, summary statistics, one-way analysis of variance (ANOVA) with Mann–Whitney U test with a significance level of $p < 0.05$ (Atramentova & Utevskaia, 2008) were performed using Microsoft Excel applications and statistical software package PAST: Paleontological Statistics Software Package for Education and Data Analysis (Hammer et al., 2001).

Results and discussion. For four years, DBH increased significantly at the sample plots SP 1–SP 3 and SP 5, and insignificantly at SP 4 and SP6-SP 9 (see Tab. 1). An average DBH of the 3rd age class trees varied from 12.4 cm to 21.3 cm in 2015 and from 14.9 to 24.9 cm in 2019, and in both cases was the smallest at SP 2 and the largest at SP 3. An average DBH of the 3rd age class trees varied from 20.7 to 30.2 in 2015 and from 21.9 to 30.9 in 2019, and in both cases was the smallest at SP 9 and the largest at SP 7. An average DBH of the 3rd age class trees at SP 3, SP 4 and SP 5

(the 3rd age class) did not significantly differ from that at SP 9 (the 5th age class). Despite the significant difference in age, the average DBH only at SP 1 and SP 2 (age class 3) was significantly lower than that in the remaining sample plots, and at SP 6 and SP 7 (age class 5), it significantly exceeded the remaining sample plots. This is due to the fact that the growth of trees in

diameter decreases with age, and most of all in stands under adverse conditions or in weakened trees.

The trees in each sample plot are represented in a rather wide range. This is due to the heterogeneity of the growth conditions of the trees, as well as the fact that sometimes after the dying of the main stem there was a renewal of growth.

Table 1

The average diameter of silver birch trees in the sample plots (SP) in 2015 and 2019

Sample plot (age class)	Year of assessment	Number of trees	Mean DBH*±SE, cm**	Range of DBH, cm
SP 1	2015	25	16.9±1.08a	7.0–27.4
(3)	2019	23	20.3±1.26b	7.2–32.1
SP 2	2015	15	12.4±0.75a	8.0–17.8
(3)	2019	15	14.9±0.83a	9.5–21.0
SP 3	2015	19	21.3±0.91bc	10.5–28.3
(3)	2019	18	24.9±1.04c	13.1–33.1
SP 4	2015	16	19.2±1.11bc	12.7–28.3
(3)	2019	16	21.7±1.19bc	14.3–30.9
SP 5	2015	35	19.6±0.80bc	9.9–29.9
(3)	2019	35	22.4±0.86bc	13.1–34.7
SP 6	2015	57	26.8±0.56d	20.1–34.9
(5)	2019	57	28.4±0.61d	21.3–36.8
SP 7	2015	60	30.2±0.70e	16.9–45.5
(5)	2019	58	30.9±0.70e	17.2–45.8
SP 8	2015	156	22.9±0.46bc	8.8–38.2
(5)	2019	127	24.2±0.51c	8.9–39.5
SP 9	2015	67	20.7±0.74b	3.0–31.2
(5)	2019	52	21.9±0.86bc	4.5–32.1

Notes: * DBH – diameter at breast height;

**Means followed by different letters in each column are significantly different at the 95 % confidence level.

In the region of our research, no noticeable direct defoliation of silver birch as a result of insect damage was registered. Defoliation was mainly manifested as increased transparency of the crown of weakened trees.

In sample plots in the stands of the 3rd age class, defoliation rarely exceeded 1 point (at SP 1 in 2017 and 2018 it was 1.1 points), and the differences in this parameter in 2015 and 2019 were insignificant (Tab. 2). At SP 6, rather high defoliation was registered in 2015 (1.9 points) and a significant decrease in this parameter to 0.5 points in 2019. For the remaining sample plots

in the stands of the 5th age class over the years of research, the defoliation score significantly increased (to 1.5, 2.2 and 2.4 points for SP 7, SP 8 and SP 9, respectively). An average health condition index HCI_{1-6} is calculated for both living and dead trees. Therefore, at the high proportion of trees, which died over a year ago, the impression is that the stands are in poor health condition. In 2015 the health condition index show, that the stands at SP 3-SP 5 were healthy ($HCI_{1-6} < 1.5$), and at other sample plots they were weakened. The highest HCI_{1-6} was evaluated at SP 9 (2.1).

Table 2

The average defoliation score for silver birch trees in the sample plots (SP) in 2015-2019

Sample plot	Defoliation score ±SE					Defoliation score change for 2015–2019
	2015	2016	2017	2018	2019	
1	2	3	4	5	6	7
SP 1	0.7±0.14bc	1.0±0.19b	1.1±0.14b	1.0±0.19bc	0.8±0.23a	insignificant
SP 2	0.9±0.21c	0.6±0.19b	0.6±0.19a	0.5±0.13a	0.8±0.22a	insignificant
SP 3	0.4±0.11ab	0.9±0.22b	1.0±0.21b	0.9±0.21b	0.7±0.23a	insignificant
SP 4	0.3±0.11ab	0.3±0.17a	0.3±0.06a	0.2±0.10a	0.3±0.12a	insignificant
SP 5	0.4±0.08b	0.6±0.14b	0.7±0.15a	0.7±0.11ab	0.4±0.10a	insignificant

Continuation of table 2

1	2	3	4	5	6	7
SP 6	1.9±0.11d	1.0±0.11b	0.9±0.08ab	1.0±0.08b	0.5±0.12a	decreased (p<0.01)
SP 7	0.5±0.12a	1.0±0.16b	1.3±0.13b	1.8±0.15c	1.5±0.13b	increased (p<0.01)
SP 8	1.3±0.08c	1.8±0.09c	1.8±0.08c	2.1±0.08c	2.2±0.09c	increased (p<0.01)
SP 9	1.3±0.12c	1.9±0.12c	2.0±0.11c	1.9±0.12c	2.4±0.14c	increased (p<0.01)

* Defoliation score: 0 – undamaged (up to 10 %); 1 – slightly damaged (11–25 %); 2 – moderately damaged (26–60 %); 3 – severely damaged (over 60 %); 4 – dead (Manual, 2010)

**Means followed by different letters in each column are significantly different at the 95 % confidence level (Mann-Whitney test)

During our studies (2015-2019) at SP 1 and SP 6, the index of the health condition of silver birch stands significantly decreased (from 1.8 to 1.4 and from 1.8 to 1.3 respectively) (Tab. 3).

In four plots (SP 2 – SP 5) the health condition index changed slightly, and in three plots (SP 7 – SP 9) increased significantly. In accordance with “Sanitary rules in the forests of Ukraine” (Anonymous, 1995), in 2019 the stands at SP 1, and SP 3 – SP 6 should be

considered as healthy, at SP 2 and SP 7 as weakened, at SP 8 as severely weakened, and at SP 9 as drying out.

If the health condition index is calculated only taking into account living trees (HCI_{1-4}), a real estimate of the viability of the stands can be obtained. In 2015 by health condition index for living trees the stands at SP 3 – SP 5 and SP 7 were healthy ($HCI_{1-4} < 1.5$), and at other sample plots they were weakened. The highest HCI_{1-4} was evaluated at SP9 (2.1) (Tab. 4).

Table 3

The average health condition index (HCI_{1-6}) for all silver birch trees in the sample plots (SP) in 2015-2019

Sample plot	Health condition index (HCI_{1-6}) ±SE *					HCI_{1-6} change for 2015–2019
	2015	2016	2017	2018	2019	
SP 1	1.8±0.18bc	1.5±0.18b	1.3±0.21a	1.5±0.25ab	1.4±0.28a	decreased (p<0.05)
SP 2	1.7±0.23b	1.9±0.27bc	1.3±0.19ab	1.5±0.19ab	1.7±0.21b	insignificant
SP 3	1.4±0.14ab	1.7±0.19b	1.3±0.21a	1.4±0.27ab	1.3±0.26a	insignificant
SP 4	1.1±0.06a	1.1±0.09a	1.1±0.09a	1.1±0.09a	1.1±0.06a	insignificant
SP 5	1.2±0.07a	1.4±0.11b	1.1±0.06a	1.1±0.07a	1.2±0.08a	insignificant
SP 6	1.8±0.09c	1.5±0.08b	1.4±0.07b	1.6±0.11b	1.3±0.10a	decreased (p<0.05)
SP 7	1.5±0.13ab	2.1±0.15c	1.7±0.16b	2.2±0.18c	2.3±0.18b	increased (p<0.01)
SP 8	1.8±0.07c	2.3±0.09c	2.2±0.11c	2.5±0.11d	2.8±0.12c	increased (p<0.01)
SP 9	2.1±0.11d	2.6±0.13d	2.5±0.16c	2.7±0.16d	3.5±0.17d	increased (p<0.01)

* Health condition index (HCI_{1-6}) considers all living and dead trees

**Means followed by different letters in each column are significantly different at the 95 % confidence level (Mann-Whitney test)

Table 4

The average health condition index (HCI_{1-4}) for living silver birch trees in the sample plots (SP) in 2015-2019

Sample plot	Health condition index (HCI_{1-4}) ±SE *					HCI_{1-4} change for 2015–2019
	2015	2016	2017	2018	2019	
1	2	3	4	5	6	7
SP 1	1.8±0.18bc	1.4±0.12ab	1.1±0.08a	1.2±0.08a	1.0±0.04a	decreased (p<0.05)
SP 2	1.7±0.23b	1.9±0.27bc	1.3±0.19ab	1.5±0.19a	1.7±0.21b	insignificant
SP 3	1.4±0.14ab	1.7±0.19bc	1.1±0.06a	1.2±0.09a	1.0±0.00a	decreased (p<0.05)
SP 4	1.1±0.06a	1.1±0.09a	1.1±0.09a	1.1±0.09a	1.1±0.06a	insignificant
SP 5	1.2±0.07a	1.4±0.11ab	1.1±0.06a	1.1±0.07a	1.2±0.08a	insignificant
SP 6	1.8±0.09c	1.5±0.08b	1.4±0.07ab	1.6±0.11ab	1.3±0.10a	decreased (p<0.05)

Continuation of table 4

1	2	3	4	5	6	7
SP 7	1.4±0.10ab	1.8±0.10bc	1.6±0.15b	1.9±0.11bc	1.8±0.08b	increased (p<0.01)
SP 8	1.8±0.06c	2.1±0.08c	1.9±0.08c	2.2±0.07d	2.4±0.08c	increased (p<0.01)
SP 9	2.1±0.11d	2.4±0.11d	2.2±0.12c	2.3±0.11d	2.8±0.11d	increased (p<0.01)

* Health condition index (HCI_{1-4}) considers only living trees

**Means followed by different letters in each column are significantly different at the 95 % confidence level (Mann-Whitney test)

Over the years of research, HCI_{1-4} significantly decreased by SP 1, SP 3, SP 6, slightly changed by SP 2, SP 4 and SP 5, and significantly increased by SP 7 – SP 9 (see Tab. 4). In accordance with HCI_{1-4} , in 2019 the stands at SP 1, and SP 3 – SP 5 should be considered as healthy, at SP 2, SP 7 and SP 8 as weakened, and at SP 9 as severely weakened.

The final analysis of the health condition of silver birch in the sample plots shows that the stands at SP 1 and SP 6 have different age and diameter class (Tab. 5). In both sample plots, the health condition of

trees has improved for the research period; however, low mortality was registered in the youngest stand. Therefore, the dynamics of HCI_{1-6} was almost similar, and HCI_{1-4} increased at SP 1 after removing the dead trees.

The health condition of silver birch trees at SP 2 was the worse among the sample plots with an insignificant change of health condition (SP 3 – SP 5) for the whole research period. It can be connected with the smallest diameter class of silver birch trees at SP 2 comparing to the other sample plots of the same age class.

Table 5

Summary information on health condition of silver birch stands in the sample plots (SP) in 2015–2019

Sample plot	Age class	Diameter class, cm	Trend of HCI_{1-4} for 2015-2019*	Health condition in 2019 **	Mortality level up to 2019 ***
SP1	3	16	decreased	healthy (1.0)	low (8.0)
SP6	5	28	decreased	healthy (1.3)	absent (0)
SP2	3	12	not changed	weakened (1.7)	absent (0)
SP3	3	20	not changed	healthy (1.0)	low (5.3)
SP4	3	20	not changed	healthy (1.1)	absent (0)
SP5	3	20	not changed	healthy (1.2)	absent (0)
SP9	5	20	increased	severely weakened (2.8)	moderate (22.4)
SP8	5	24	increased	weakened (2.4)	moderate (18.6)
SP7	5	30	increased	weakened (1.8)	low (3.3)

* Health condition index (HCI_{1-4}) considers only living trees

** HCI_{1-4} in brackets

*** Mortality percent for 2015–2019 in brackets

Among these four sample plots with an insignificant change of health condition, both health condition indices (HCI_{1-6} and HCI_{1-4}) stayed unchanged for the whole research period at SP 2. These indices for silver birch in other sample plots of this group had an increase in 2016 and a decrease in 2017 with a subsequent slight increase.

Silver birch trees at the sample plots SP 7 – SP 9 had the worse health condition among all sampling plots. Both health condition indices (HCI_{1-6} and HCI_{1-4}) increased for 2015-2019. In this group of sample plots, the trees of the smallest diameter class (SP 9 – 20 cm) characterized by the highest mortality level (22.4 %) and HCI_{1-4} (2.8), that is, were considered severely weakened. As the diameter increases in this group of sample plots, the values of both health condition indices and mortality of trees decrease. However,

when comparing two sample plots with almost similar diameter class (SP 6 and SP 7) we see large differences in health condition indices (1.3 and 1.8 respectively), health status (healthy and weakened respectively), mortality level (absent and low respectively), as well as in the trend of changes in health condition. The health condition of silver birch at SP 6 trends to improve (HCI decreases), and at SP 7 it trends to worsen (HCI increases).

The data obtained show that when predicting changes in the health condition of silver birch stands, it is necessary to take into account the trend to improvement or worsening the health condition of individual trees in a certain group of stands.

So among all trees (SP 1 – SP 9), the healthy ones were a little more than half (50.6%) in 2015 and 39.9% in 2019 (Tab. 6).

Table 6

Distribution of silver birch trees by health condition classes in 2019 depending on their health condition in 2015

In 2015*		In 2019 **							
		Distribution by health condition classes:						I ₁₋₄	I ₁₋₆
		1	2	3	4	5	6		
All sample plots (SP1 — SP9)									
1	50.6	52.6	30.7	12.3	0.9	0.9	2.6	1.6	1.7
2	33.3	33.3	20.0	28.7	7.3	4.0	6.7	2.1	2.5
3	12.6	17.5	8.8	22.8	14.0	8.8	28.1	2.5	3.7
4	2.9	0.0	0.0	0.0	15.4	7.7	76.9	4.0	5.6
5	0.7	0.0	0.0	0.0	0.0	0.0	100.0	–	6.0
Total	100.0	39.9	23.3	18.6	5.1	3.1	10.0	1.9	2.4
SP6 – decrease of health condition index for 2015–2019									
1	36.8	81.0	14.3	4.8	0.0	0.0	0.0	1.2	1.2
2	49.1	85.7	7.1	7.1	0.0	0.0	0.0	1.2	1.2
3	14.0	62.5	12.5	0.0	25.0	0.0	0.0	1.9	1.9
4	–	–	–	–	–	–	–	–	–
Total	100.0	80.7	10.5	5.3	3.5	0.0	0.0	1.3	1.3
SP9 – increase of health condition index for 2015–2019									
1	29.9	5.0	35.0	55.0	0.0	5.0	0.0	2.5	2.7
2	40.3	3.8	30.8	30.8	19.2	14.8	3.7	2.8	3.2
3	22.4	0.0	0.0	40.0	26.7	13.3	20.0	3.4	4.1
4	7.5	0.0	0.0	0.0	0.0	0.0	100.0	–	–
Total	100.0	3.0	22.7	37.9	13.6	10.4	13.4	2.8	3.5

Note: * – proportion of trees from total amount in 2015; ** – proportion of trees from total amount in 2019.

From trees of the 1st class of health condition in 2015, for 4 years 52.6% didn't change health condition class, 43 % changed it to 2nd–3rd class and 4.4 % changed it to 4th–6th health condition class. From trees of the 2nd health condition class in 2015, 33.3% improved their health condition to the 1st class, 20% of trees didn't change it, and the rest worsened. Among the trees of the 3rd class of health condition in 2015, 26.3% improved their health condition, 22.8% stayed without changes, and 50.9% worsened.

In general, within the range of 1-3 classes of health condition in 2015 this parameter in 2019 varied only within these classes. Trees of the 4th class did not change health condition (7.7%) or died. The probability of death for the tree in each successive class tends to increase.

The dependence of tree mortality in 2019 on the health condition index in 2015 is described by quadratic equation (Fig.).

However, it is difficult to clearly predict changes in health condition for all silver birch stands. For example, silver birch stands at SP 6 and SP 7 have a close diameter class (28 and 30 cm at SP 6 and SP 7, respectively) and are of the fifth age class, which is known to be the age of significant deterioration of silver birch in the

forest stands of the region (Meshkova & Koshelyaeva, 2019). In 2015-2019 the health condition of silver birch improves at SP 6 and worsens at SP 7 (see Tab. 5).

Another pair of stands has the same age and different diameter classes (28 and 20 cm at SP 6 and SP 9, respectively). For 2015-2019 the health condition of silver birch stand has improved at SP6 and worsened at SP9.

Figure. Probability of silver birch dying depending on the initial tree condition (General sample of 451 trees: $Y = 10.15x^2 - 23.82X + 17.3$, where Y – probability of dying; X – health condition class; $R^2 = 0.99$)

So at SP 6 in 2015 there were trees of only 1-3 classes of forest health condition (see Tab. 6), and in 2019 there were also trees of the 4th class of health condition. Since there were no dead trees, the values of both health condition indices (HCI_{1-6} and HCI_{1-4}) were the same in 2015 (1.8) and in 2019 (1.3). Most of the trees of the 1st health condition class in 2015 (81 %) didn't change it by 2019. From the trees of the 2nd health condition class in 2015, 85.7% improved it up to the 2nd class of health condition. From the trees of the 3rd health condition class in 2015, 62.5% have improved their health condition up to the 1st (62.5%) and 2nd (12.5%) health condition class, and 25% trees have worsened it up to the 4th class of health condition. In total, the trees of the 4th health condition class are only 3.5% from all trees in the stand and are able to improve or to worsen their health condition depending on environmental conditions.

At SP 9 the health condition index HCI_{1-6} increased for 2015-2019 from 2.1 to 3.4, and health condition index for living trees (HCI_{1-4}) increased from 2.1 to 2.8, respectively. In 2015, the trees of the 1st – 4th health condition classes were represented in the plot with the dominance of weakened trees (40.3% trees of the 2nd class of health condition).

Almost all trees of the 1st health condition class (95%) in 2015 have worsened their health condition up to the 2nd and 3rd class (35 and 55%, respectively), and 5% of trees have died. Among all trees of the 2nd health condition class (95 %) in 2015, only 3.8% improved their condition, 30.8 % didn't change it, and the rest trees died (in 2019 14.8 and 3.7% trees had 5th and 6th health condition class). None of the trees with the 3rd health condition class in 2015 improved it in 2018, 40% of trees didn't change it, and the rest trees worsened it. All trees of the 4th health condition class were dead by 2019.

Analysis of the pooled silver birch tree sample shows that the probability of death by 2019 is $2.6+0.9=3.5\%$ for trees, which had the 1st health condition class in 2015. In the healthy stand like SP 6 without drying trees, this probability is 0%, and in the weakened stand ($HCI_{1-4} \geq 2.5$) it is 5%.

The probability of death by 2019 for silver birch tree of the 2nd health condition class in 2015 is 10.7% for the pooled sample. It is 0% in a healthy stand and $14.8+3.7=18.5\%$ in a weakened stand. The probability of death by 2019 for a silver birch tree of the 3rd health condition class in 2015 is 36.9%. It is 0% in a healthy stand and $20+13.3=33.3\%$ for a weakened stand. The probability of death by 2019 for a silver birch tree of the 4th health condition class in 2015 is 84.6% for pooled sample, and 100 % – in a weakened stand (see Tab. 6).

Thus, 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).

At the same time, the weakened silver birch stand which has the trees of the 1st – 4th health condition

classes is most likely to weaken even more severely over 4 years.

Conclusions. Silver birch stands of the 3rd age class didn't change their health condition for 2015-2019 or improved it. The stands of the 5th age class worsened their health condition in three sample plots and improved it in one sample plot.

Within each age class, the stands of lower diameter class had a worse health condition. Tree mortality was registered in two out of five sample plots in the stands of the 3rd age class and in three out of four sample plots in the stands of the 5th age class. In the stands of the 5th age class the trees from the stands of the smallest diameter class characterized by the highest mortality level (22.4%) and the worse health condition ($HCI_{1-4}=2.8$).

In pooled sample of plots, the death probability for silver birch trees, which 4 years ago had the 1st class of health condition is 3.5%, those of the 2nd class have the death probability of 10.7%, the trees of the 3rd class – 36.9%, those of the 4th class – 84.6%. As for an initially weakened stand, its trees which 4 years ago had the 1st, the 2nd, the 3rd or the 4th health condition class, have the death probability of 5%, 18.5%, 33.3%, and 100% respectively.

Thus, 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 initially the 3rd class of health condition). The weakened silver birch stand which has the trees of 1st – 4th health condition classes is most likely to weaken even more severely over 4 years.

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Санітарний стан берези повислої у дендропарку Харківського національного аграрного університету ім. В. В. Докучаєва

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Останнім часом санітарний стан берези повислої (*Betula pendula* Roth.) погіршується у лісових і декоративних насадженнях. Важливо знати ймовірність погіршення або покращення стану окремих насаджень, щоб вчасно вжити необхідні заходи.

Мета досліджень полягала в оцінюванні тенденцій зміни санітарного стану насаджень берези повислої залежно від класу віку та початкового санітарного стану дерев. Дослідження здійснені впродовж 2015-2019 рр. у лінійних насадженнях берези повислої у двох парках Харківського національного аграрного університету ім. В. В. Докучаєва (49°53' пн.ш., 36°27' сх.д.). П'ять пробних площ із насадженнями III класу віку розташовані у парку Ветеранів, а чотири пробні площі з насадженнями V класу віку – у Дендропарку цього ж університету.

Вимірювали діаметр кожного дерева на висоті 1,3 м у 2015 та 2019 рр. Дефоліацію крон і категорію санітарного стану оцінювали візуально у липні кожного року. Індекс санітарного стану кожного насадження розраховували як середнє зважене від кількості дерев кожної категорії санітарного стану, окремо з урахуванням усіх живих і мертвих дерев ($НСІ_{1-6}$) і лише живих дерев ($НСІ_{1-4}$). Відпад дерев виражали у відсотках втрачених (загиблих) особин за період досліджень до загальної кількості дерев у 2015 році.

Встановлено, що насадження берези повислої III класу віку не змінили санітарного стану впродовж 2015-2019 рр. або поліпшили його. Насадження V класу віку погіршили санітарний стан на трьох пробних площах і поліпшили – на одній. У межах кожного класу віку насадження меншої середньої ступені товщини мали гірший санітарний стан. Відпад дерев зареєстровано на двох із п'яти пробних площ у насадженнях III класу віку і на трьох із чотирьох пробних площ – у насадженнях V класу віку. У насадженнях V класу віку дерева найменшо-

го діаметра характеризувалися найбільшим рівнем відпаду (22,4%) та найгіршим санітарним станом ($НСІ_{1-4}=2,8$).

Загалом на всіх пробних площах ймовірність відпаду дерев берези повислої, що мали у 2015 р. I категорію санітарного стану, становить 3,5%, II категорію – 10,7%, III категорію – 36,9%, а IV категорію – 84,6%. У насадженнях, ослаблених у 2015 р., ймовірність відпаду дерев, що мали чотири роки тому I, II, III і IV категорії санітарного стану, становить 5; 18,5; 33,3 та 100% відповідно.

Таким чином, ослаблені березові насадження, які містять дерева I-III категорій санітарного стану, спроможні відновитись до стану «здорових». Погіршення стану очікується для сильно ослаблених дерев (III категорії стану у 2015 р.). Ослаблене березове насадження, яке мало у 2015 р. дерева I-IV категорій санітарного стану, ослабиться ще більше через чотири роки.

Ключові слова: клас віку, діаметр (DBH); дефоліація; індекс санітарного стану, визначений для життєздатних дерев ($НСІ_{1-4}$); відпад дерев; ймовірність відпаду.

Санитарное состояние березы повислой в дендропарке Харьковского национального аграрного университета им. В. В. Докучаева

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В последнее время санитарное состояние березы повислой (*Betula pendula* Roth.) ухудшается в лесных и декоративных насаждениях. Важно знать вероятность ухудшения или улучшения состояния отдельных насаждений, чтобы вовремя принять необходимые меры.

Целью исследований была оценка тенденций изменения санитарного состояния насаждений березы повислой в зависимости от класса возраста и начального санитарного состояния деревьев. Ис-

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следования проведены в 2015-2019 гг. в линейных насаждениях березы повислой в двух парках Харьковского национального аграрного университета им. В.В. Докучаева (49°53' с.ш., 36°27' в.д.). Пять пробных площадей в насаждениях III класса возраста расположены в парке Ветеранов, а четыре пробные площади в насаждениях V класса возраста – в Дендропарке этого же университета.

Измеряли диаметр каждого дерева на высоте 1,3 м в 2015 и 2019 гг. Дефолиацию крон и категорию санитарного состояния оценивали визуально в июле каждого года. Индекс санитарного состояния каждого насаждения рассчитывали как средневзвешенное от количества деревьев каждой категории санитарного состояния, отдельно с учетом всех живых и мертвых деревьев ($НСИ_{1-6}$) и лишь живых деревьев ($НСИ_{1-4}$). Отпад деревьев выражали в процентах утраченных (погибших) особей за период исследований от общего количества деревьев в 2015 году.

Показано, что насаждения березы повислой III класса возраста не изменили санитарного состояния в период 2015-2019 гг. или улучшили его. Насаждения V класса возраста ухудшили санитарное состояние на трех пробных площадях и улучшили на одной. В пределах каждого класса возраста насаждения меньше средней ступени толщины имели худшее санитарное состояние. Отпад деревьев зарегистрирован на двух из пяти пробных площа-

дей в насаждениях III класса возраста и на трех из четырех пробных площадей в насаждениях V класса возраста. В насаждениях V класса возраста деревья наименьшего диаметра в насаждениях характеризовались наибольшим уровнем отпада (22,4 %) и наихудшим санитарным состоянием ($НСИ_{1-4}=2,8$).

В совокупности всех деревьев на всех пробных площадях вероятность отпада деревьев березы повислой, имевших в 2015 г. I категорию санитарного состояния, составляет 3,5 %, имевших II категорию, – 10,7 %, III категорию – 36,9 %, а IV категорию – 84,6 %. В насаждениях, ослабленных в 2015 году, вероятность отпада деревьев, имевших четыре года назад I, II, III и IV категорию санитарного состояния, составляет 5, 18,5, 33,3 и 100 % соответственно.

Таким образом, ослабленные березовые насаждения, содержащие деревья I-III категорий санитарного состояния, способны восстановиться до состояния «здоровых». Ухудшение состояния ожидается для сильно ослабленных деревьев (имевших III категорию состояния в 2015 г.). Ослабленное березовое насаждение, содержащее в 2015 г. деревья I-IV категорий санитарного состояния, ослабится еще больше через 4 года.

Ключевые слова: класс возраста, диаметр (DBH); дефолиация; индекс санитарного состояния, определенный для жизнеспособных деревьев ($НСИ_{1-4}$); отпад деревьев; вероятность отпада.