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## Dynamics of pine stands condition in SE «Lymanske Forest Economy»

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*The issue of pine forest stands health condition and mortality at the scale of one state enterprise (SE «Lymanske Forest Economy»), located in the Northern part of the Steppe zone of Ukraine, is considered.*

*For the study data from two repeated observations at 8 permanent plots, laid in 2019, in forest stands with varying degrees of mortality and those damaged by fire was used. A re-survey was carried out in 2020. Using the GIS Field-Map, trees were mapped at the permanent plots and their health condition, mortality, and damage were assessed. For the background assessment of pine forests condition, the results of observations at 7 forest monitoring plots (I level) (surveys of 2015 and 2020) were used. The source of climate data was the online resource ClimateCharts.net.*

*It was found out that over the last 10 years, due to climate change, the temperature in the region increased and the amount of precipitation decreased, which led to the appearance of a dry period in August, which is unfavourable for the growth of pine forests at the limit of their range. Groundwater levels have changed, as evidenced by the drying of Lake Lyman during 2013-2020. Obtained results showed, that the condition of pine stands in the monitoring plots significantly deteriorated compared to 2015. Currently, the condition of pine forests are considered as «weakened» and «severely weakened» (the health condition index (HCI) of living trees varied from 1.53 to 2.70), the average defoliation and mortality of trees have increased significantly. In weakened stands, the proportion of trees with damage increases over time, in particular, due to the colonization of stem insects. Forest fires pose a significant threat to the pure artificial pine forests that predominate in the region. As a result of fires, the condition of the stands deteriorated (HCI 2.49-2.70) and the number of dead trees increased.*

**Key words:** Northern Steppe; dieback; forest fires; damage; forest monitoring; health condition index; climate change.

**Introduction.** Trees mortality associated with drought and climate change is a widespread problem in the world. Forest dieback is commonly reported near the geographic limits of tree species natural range (Allen, 2009) and thresholds of climatic suitability, where the most sensitive response to climate change would be expected.

A significant problem in Ukraine is the massive forest dieback due to the increased negative impact on forest ecosystems of natural and anthropogenic factors. The processes of dieback and degradation of pine stands have intensified in the last decade (Ткач, Мешкова, 2019). Scots pine (*Pinus sylvestris* L.) is one of the main forest-forming species in Ukraine and

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its forest stands have ecological, economic, and social importance (Krynytskyi, Chernyavskyy, Krynytska, 2016). The ecological precondition for the pine forests degradation is global climate change, first of all, changes in temperature and hydrological regimes. Pine forests in the steppe react especially sharply, as they grow at the limit of their natural range (Shvydenko, Buksha, Krakovska, & Lakyda, 2017). Fires, outbreaks of insects, and diseases pose a significant threat to weakened pine stands (McLauchlan et al., 2020; Allen, 2009).

In order to carry out effective measures to preserve the ecological and social functions of forests, it is extremely important to have comprehensive and reliable information on the condition of forest-forming species in forest stands.

Features of the functioning of pine stands of the Northern Steppe of Ukraine were studied by Lakyda & Lovinska (Лакида, Ловинська, 2014). The condition of pine forests according to the monitoring data in neighboring regions (Luhansk, Kharkiv regions) was analysed in 2011 (Букша, Пивовар, Букша, 2011). The influence of forest fires on forest stands was also studied (Сидоренко, Ворон, Мельник, Сидоренко, 2015; Koval, Sydorenko, 2019).

**Objects and methods.** *The study object is pine forest stands of the State Enterprise (SE) «Lymanske*

*Forest Economy» (Lymanske Forest Enterprise). The study subject is the dynamics of pine forest stands' condition.*

*The aim of the research is to evaluate the condition dynamics of pine forest stands in the SE «Lymanske Forestry».*

Lymanske Forest Enterprise is located in the northern part of Donetsk region of Ukraine in the Steppe natural zone. According to forest typological zoning, the enterprise's territory belongs to the region of the dry relatively warm climate of the Donetsk ravine forest sector (Остапенко, Ткач, 2002). Forests in this region grow only in places with available groundwater: near water bodies. The forest stands of Lymanske Forest Enterprise mainly provide nature conservation, protective, and recreation functions. Pine stands here mainly grow in fresh poor ( $A_2$  – 29,2%), fresh relatively poor ( $B_3$  – 14,3%), and dry poor site conditions ( $A_1$  – 7,7%) (Приходько, Пастернак, & Яроцький, 2019) on sandy and sandy loam soils. The majority of pine stands are artificial monocultures, which are vulnerable to biotic damage and fire.

The study includes the results of two consecutive surveys (in 2019 and 2020) of 8 permanent plots and 7 monitoring plots (I Level) located in pine forest stands of Lymanske Forest Enterprise (Tab. 1, Fig. 1).

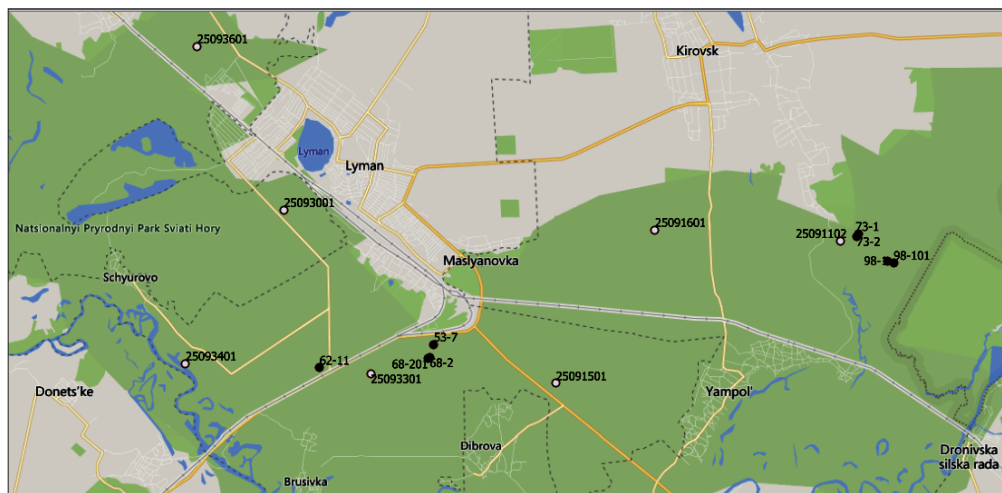


Fig. 1. Location of permanent plots (black) and monitoring plots (white dots) in the territory of Lymanske Forest Enterprise

In Lymanske forestry, the first group of permanent sample plots was allocated to study pine dieback in the region, registered from 2013-2014. Permanent plots include relatively healthy forest stand (62-11), which considered as control, two stands with significant pine mortality in previous years (68-2 and 53-7), and plot 68-201 which was allocated as healthy, but in spring 2020 it was damaged by a stable forest fire (See Tab. 1, Fig. 1).

In Yampilske forestry, another group of permanent plots was allocated in pine stands, damaged by ground forest fires in summer 2014, aimed to study the impact of forest fire on pine condition (See Tab. 1, Fig. 1). These plots were allocated as duplexes in forest stands with different grades of fire damage at the neighbour

forest subcompartments. For damaged trees the height of bark char and the perimeter of bark char were measured, other signs of damage were estimated.

All permanent plots are circular with an area of 0.1 ha, the indicators of the forest stands were evaluated on them, heights of model trees were measured, health condition index (HCI), and damage were estimated. Forest-taxational parameters of pine stands were studied by using generally accepted forestry and forest taxation methods (Гром, 2010; Площі пробні лісовпорядні, 2006). GIS Field-Map was used for field work and data management (Field-Map.com).

Also observations on seven I Level monitoring plots, located in pine stands in of Lymanske Forest Enterprise were carried out in 2020 according to (Букша,

Пастернак, Пивовар, Букаша, Яроцький, 2018). Taxation characteristics were estimated visually. The health condition index of trees was estimated according to (Санітарні правила в лісах України, 2016). Two monitoring plots are located in Yampilske forestry, one of them is close to a group of permanent plots damaged by a forest fire (See Fig. 1). Three monitoring

plots are located in Lymanske forestry. Plot number 250915 is located near the sand quarry, 250934 – on recreation area near Siverskyi Donets river with high anthropogenic pressure, plot 250933 is at the distance 1,6 km from a group of permanent plots in Lymanske with a high mortality rate. The rest monitoring plots are located in Drobyshesvske forestry.

Table 1

**Forestry-taxation characteristics of forest stands at permanent plots and level I monitoring plots (2020)**

Plot ID	Forestry	Forest site conditions	Age, years	Mean		Density of stocking	Site index	M, m <sup>3</sup> ·ha <sup>-1</sup>
				H, m	D, cm			
Permanent plots								
62-11	L	A <sub>2</sub>	61	19.4	18.8	0.80	II	320
68-2	L	B <sub>2</sub>	81	24.5	26.7	0.45	I	229
68-201	L	B <sub>2</sub>	81	21.0	23.9	0.55	II	248
53-7	L	A <sub>2</sub>	85	20.6	20.2	0.40	III	136
73-1	Y	B <sub>2</sub>	43	20.4	22.5	0.80	Ia	341
73-2	Y	B <sub>2</sub>	81	26.2	25.8	0.82	I	482
98-1	Y	B <sub>2</sub>	76	25.0	23.0	0.79	I	438
98-101	Y	B <sub>2</sub>	76	28.7	27.1	0.70	Ia	444
I Level monitoring plots								
250930	D	A <sub>2</sub>	40	15.0	17.1	0.68	I	173
250933	L	A <sub>1</sub>	38	13.5	14.2	0.54	II	120
250934*	L	A <sub>2</sub>	84	21.7	19.9	0.42	II	185
250936	D	A <sub>2</sub>	68	24.5	27.9	0.75	I	372
250911	Y	B <sub>2</sub>	79	28.0	38.8	0.73	Ia	455
250915	L	A <sub>2</sub>	43	16.5	16.9	0.75	I	220
250916	Y	A <sub>2</sub>	98	25.5	31.7	0.65	II	360

D – Drobyshesvske forestry; L – Lymanske forestry; Y – Yampilske forestry

Forest health condition dynamic was assessed on these plots, and a comparison with data of observations held in 2015 (the last year of regular observations on monitoring plots in Ukraine) was carried out. Average defoliation of pine stands of the Steppe natural zone from Kharkiv and Luhansk regions were calculated. The source of data – Forest monitoring database.

Sample plots are represented by fresh poor and fresh relatively poor forest site conditions of *Pinus sylvestris* L. (Scots pine) stands (according to Alekseev-Pogrebnyak classification (Остапенко, Ткач, 2002)). The age of studied forest stands varies from 40 to 98 years, the density of stocking in range 0.40-0.82, site index class Ia – III. These plots represent the pine forests of the enterprise (See Tab. 1).

**Results and discussion.** Due to climate change, at the territory of Lymanske Forest Enterprise temperature growth in winter and summer during the last decade (2010-2019) is revealed compared to climate norm (1961-1990) (Fig. 2).

According to the climate charts (See Fig. 2): a significant decrease of summer precipitation level is observed in August, which in combination with temperature growth led to the appearance of a drought period (indicated by bright colour). Such changes are unfavourable for forest vegetation, especially for pine stands, which grow on the southern limit of their natural range.

At the same time in the study area, significant changes in the hydrological regime are observed, which affect both surface water and, most likely, groundwater. So, since 2013, lake Lyman with an area of about 79 hectares has completely dried up. Changes in the hydrological regime are most likely associated with sand mining, which is exacerbated by the lack of precipitation that has been observed in recent years. For a more complete picture of changing the hydrological regime, hydrogeological studies are required.

Data of Global Forest Watch web service (Global Forest Watch, 2020) allows estimating the amount of

global tree cover loss in the region of study (former Krasnolymskyi district) (canopy density threshold > 30% was used) (Fig. 3), unfortunately without division by reasons as forest fires and mortality, or sanitary felling. On the other hand, as forests in the region are mainly recreational and protective, final felling is not applied there. Obtained results showed a trend to increase annual tree cover loss during the

last decade compared to the previous period (average annual loss for 2001–2010 was 47.7 hectares, and for 2011–2019 – 198.8 hectares). The critical point in the dynamics was 2011 when the trees cover loss increased almost by 5 times. Such a dynamic can be particularly related to pine dieback after forest fires (Гладунець, Пастернак, 2014; Гладунець, 2017), and other causes.

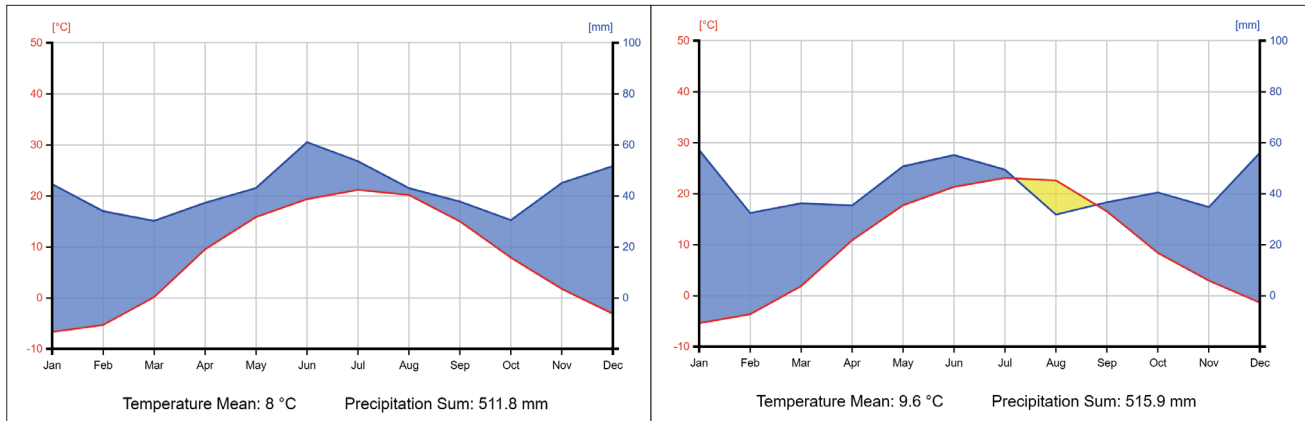


Fig. 2. Climate charts at the territory of SE «Lymanske forestry» for 1961-1990 (left) and 2010-2019 (right) periods (blue line – month sum of precipitations, mm, red line – month average air temperature, °C) (Zepner L., et al, 2020. ClimateCharts.net)

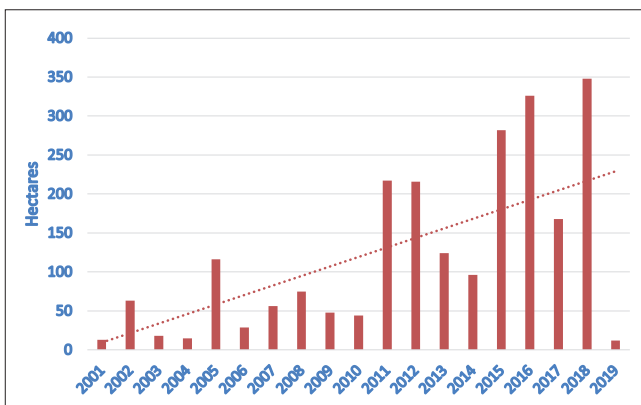


Fig. 3. Dynamics of annual forest cover loss in former Krasnolymskyi district according to Global Forest Watch data (Global Forest Watch, 2020).

According to the forest monitoring data, the average defoliation of pines in the enterprise in 2015 was 8,8% (Tab. 2). This data is comparable with average defoliation in neighbour regions of Northern Steppe: the southern part of Kharkiv and northern part of Lugansk region (as of 2015) (8,8 and 13,8%, respectively).

Unfortunately, forest monitoring activity was stopped after 2015, so data for the later period are absent. In 2020 at all monitoring plots in Lymanske Forest Enterprise significant deterioration of pine stands health condition was observed: average defoliation significantly increased (up to 17%), and according to the health condition index these stands were weakened and severely weakened (See Tab. 2). The biggest relative change of the mean defoliation (more than twice) was

observed on three plots in Lymanske forestry and one plot in Yampilske forestry. Significant mortality of trees was observed on 4 plots (250933, 250915, 250916, and 250934), while on the last one sanitary felling was carried out and dead trees were removed. In 2020 resin flow signs were registered on three plots, at one plot few trees have lost apical dominance. In different compartments of Lymanske forestry according to visual observations, significant deterioration of pine health condition, and increased tree mortality and dieback of birch stands registered since 2013-2014. For comparison data of monitoring, plot 250933 was used. Generally, all studied pine stands in the Lymanske forestry were weakened and severely weakened (by health condition index) (See Tab. 2, 3). The evidence of trees mortality in past and/or sanitary felling in these stands are low values of the relative density of stocking in some stands (0.4-0.45), especially in older stands (See Tab. 1).

In 2019 the index of the health condition of permanent plots in Lymanske forestry varied from 2,19 to 2,52 which corresponds to weakened and severely weakened stands (See Tab. 3). The better condition was assessed at permanent plot 62-11, located at a distance of 3 kilometres of the rest permanent plots at this forestry in a middle-aged forest. In 2020 deterioration of health condition at this plot was observed: both health condition index and percentage of damaged trees increased. The health condition index at the monitoring plot 250933 was 2,3 in 2020, and average defoliation – 16,8%, so this stand didn't significantly differ from permanent plots by pine condition. Two permanent plots in this group with higher health condition index values were characterized by significant mortality in 2019:



the proportion of dead trees was 27,8 % at plot 68-2 and 58,9% at 53-7. The annual mortality rate at these plots exceeded the reference level (Forest inventory handbook, 2013). In 2020 the health condition index decreased on these two plots: due to sanitary felling at 53-7 and dieback of the weakened tree on 68-2 plot. At monitoring plot 250933 dead trees were absent in 2020, however, in the past (in 2011), this plot had a high percentage of dead trees (41,7%), which were removed during selective sanitary felling.

The part of plot 68-201 in spring 2020 was damaged by a stable forest fire that caused significant deterioration of pine condition and led to a significant increase of tree mortality at this plot (proportion of dead trees increased from 1,4 to 18,6%). Also, the proportion of damaged trees increased from 4,3 to 12,3 % (See Tab. 3). According to (Сидоренко, Ворон, Мельник, Сидоренко, 2015) the time of the fire is crucial for stand condition: as spring forest fires are more dangerous than summer ones.

Table 2

**Dynamics of indicators of pine stands condition on monitoring plots**

Plot	Average. Defoliation		HCI with dead trees*	HCI of living trees	Proportion of dead trees, %	Proportion of damaged trees, %
	2015	2020	2020	2020	2020	2020
250911*	8.9	12.0	2.2	2.2	0.0	4.2
250916	9.2	18.7	2.6	2.3	12.5	0.0
250915	9.2	20.2	2.9	2.6	8.3	4.2
250930	9.1	16.2	2.5	2.5	0.0	8.3
250933+	7.6	16.8	2.3	2.3	0.0	0.0
250934s	8.5	20.0	2.7	2.7	0.0	12.5
250936	8.9	15.5	2.4	2.4	0.0	0.0

\* – control plot for group of permanent plots at Yampilske forestry; S – sanitary felling;  
+ – neighbour group of permanent plots at Lymanske forestry; HCI – health condition index

Table 3

**Pine stands health condition dynamics at permanent plots**

Plot	Forestry	HCI with dead trees		HCI of living trees		The proportion of dead trees		The proportion of damaged trees	
		2019	2020	2019	2020	2019	2020	2019	2020
62-11	L	2.27	2.50	2.19	2.40	3.1	3.1	2.4	5.5
68-2	L	3.13	3.39	2.41	2.24	27.8	31.5	7.7	10.8
68-201**	L	2.27	2.99	2.23	2.51	1.4	18.6	4.3	10.5
53-7s	L	4.15	2.18	2.52	1.80	58.9	11.8	4.5	4.4
73-1*	Y	2.69	2.57	2.59	2.43	4.2	4.2	5.5	9.9
73-2*	Y	2.80	2.70	2.49	2.40	12.2	8.9	10.3	25.6
98-1*s	Y	2.87	2.54	2.69	2.51	7.9	1.1	3.2	6.5
98-101*s	Y	3.23	2.30	2.70	2.21	22.8	3.1	5.1	11.5

\* plots, damaged by a forest fire in 2014  
\*\* plot, damaged by a stable forest fire in 2020  
s – plots, where sanitary felling was carried out between 2019 and 2020

On permanent plots in Lymanske forestry, only some cases of resin flow were fixed in 2019. In 2020 the proportion of damaged trees increased in the majority of plots. The main types of tree damage were: resin flow, mechanical damage, loss of apical dominance, or top dieback, and stem pests. Resin flow was the most common type of damage, which was registered in almost all plots.

Generally, tree mortality is a result of multiple interacting factors, including drought and complex biotic damage, so it is not easy to reveal the single cause (Allen, 2009). Our results showed that observed pine dieback in Lymanske Forest Enterprise is the general process. Obtained data on pine condition at permanent plots in Lymanske forestry are comparable with the monitoring data, as well as with increased

dieback (mortality) in birch stands at neighbourhood according to visual observations. That all proves the trend in the deterioration of pine condition in the region of study. Pine growth in the Steppe zone is limited by water availability, and frequency of droughts, so further climate change will negatively influence pine health condition. Climate-induced water stress may directly cause tree mortality through short-term acute effects such as irreversible disruption of water columns within tree stems and foliage. Chronic water stress causes the weakening and dieback of trees, either directly or indirectly through the attacks of pests such as bark beetles of such weakened trees. The population dynamics of forest insects and fungal pathogens also depends on the climatic conditions, so massive outbreaks of forest pests and diseases may be launched by climate drivers. Trees dieback can emerge abruptly at a regional scale when ecological (climatic, weather, and hydrologic) conditions exceed physiological thresholds of tolerance trees species or cause outbreaks of insect pests (Allen, 2009).

In Lymanske Forest Enterprise the probability of fires during the fire risk period is high (the average class of forest fire danger is about 2), taking into account a dominance of pure pine stands and dry forest site conditions (Гладунець, Пастернак, 2014). In Yampilske forestry in 2014, there were 16 forest fires in a total area of 1184 hectares (Гладунець, 2017), mainly they appeared as a result of active fights in the region in summer 2014.

Another group of permanent plots was allocated in Yampilske forestry. As the monitoring plot 250911 located in this forestry at the neighbour of a group of permanent plots damaged by fire, at the same forest site condition ( $B_2$ ), and similar age, it was considered as control. Forest stands at control monitoring plots were slightly weakened, had no signs of a forest fire, and no dead trees. The average defoliation at this plot was 12% in 2020, and defoliation growth was the lowest from 2015, comparing to other monitoring plots. At permanent plots 73-1, 73-2, 98-1, and 98-101 in Yampilske forestry, almost all trees had signs of fire damage after the forest fire in summer 2014. According to the average values of the indicator «height of bark char», the trees in plots 73-2 and 98-101 were more affected, as the average height was over than 2 m ( $2.6 \pm 1.0$  and  $2.2 \pm 0.8$  m, respectively), while the other two plots 98-1, and 73-1 had significantly lower values of an average height of bark char ( $1.3 \pm 6.3$  and  $1.7 \pm 0.9$  m, respectively). By the health condition index (HCI of living trees varied from 2.49 to 2.70), the pine stands at these permanent plots in 2019 were severely weakened (see Tab. 3). Such values are significantly higher than at a control monitoring plot (HCI=2.2). At the first observation in 2019, the proportion of dead trees at these permanent plots was significant and varied from 4,2% to 22,8%. At less damaged plots (73-1 and 98-1) the mortality rate was significantly lower compared to another pair of plots (73-2 and 98-101), where the mortality exceeded the reference level (Лісотаксаційний довідник, 2013).

In 2020 the health condition of trees at all permanent plots in Yampilske forestry slightly become better, especially at plots 98-1 and 98-101, where selective sanitary felling between surveys took place. Despite the selective sanitary felling with the removing of dead and dying trees (HCI=4) and decrease of health condition index of studied stands, the process of pine stands dieback didn't stop, as new dead trees appeared at the plots and the number of damaged trees has increased. At all plots, the proportion of damaged trees almost doubled (See Tab. 3). The worst condition in terms of the presence of damage was assessed at plot 73-2, where 25,6% of trees were damaged, the majority of them had resin flow, which may indicate in particular the attempts of stem insect colonization, 3 trees had signs of stem insects. Such increase in biotic damage is explained by the gradual weakening of stands after a forest fire and may bring to further condition deterioration and mortality.

So, observations at permanent plots damaged by a forest fire in dynamics and combined with background data on forest monitoring plots, showed, that forest fires are one of the main factors influencing forest condition and mortality. Obtained data on the significant negative effects of forest fires are comparable with data (Сидоренко, Ворон, Мельник, Сидоренко, 2015) on a high positive correlation of health condition and trees mortality with the height of bark char. Projected climate change will probably cause significant changes in fire regimes, towards increasing frequency, area, and duration of forest fires. Artificial pure pine forests in the Steppe natural zone are especially vulnerable to such disturbance.

**Conclusions.** Significant deterioration of pine stands condition and their mortality is observed in Lymanske Forest Enterprise during the last decade. Pine stands of the enterprise are mainly weakened, due to unfavourable conditions for the growth of stands, climate change, changes in ground water regime, anthropogenic impact (sand mining, fires). Forest fires led to the deterioration of trees' condition and mortality, weakening of trees, and increased their susceptibility to biotic damage. Pure pine stands in the region should probably be replaced with more drought-resistant species or mixed forests.

The selective sanitary felling just temporarily improved the forest stands condition, but did not stop the degradation process, on the contrary, the elimination of dead trees changes the microclimate and further reduces humidity. On the other hand, the elimination of dead trees and dead logs reduces the level of fire hazard in pine forests, because reduces the reserves of forest combustible materials.

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## Динаміка стану соснових деревостанів у ДП «Лиманське лісове господарство»

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Розглянуто питання санітарного стану та всихання соснових насаджень на рівні одного державного підприємства (ДП «Лиманське лісове госпо-

дарство»), розташованого у Північній частині Степової зони України.

Для дослідження використовували дані двох повторних спостережень на восьми ділянках, закладених у 2019 р. у насадженнях із різним ступенем всихання та пошкоджених пожежею. Повторне обстеження здійснено у 2020 році. За допомогою польової ГІС Field-Mar на пробних ділянках виконано картографування дерев та оцінено їхній санітарний стан, відпад і пошкодження. Для фонові оцінки стану соснових лісів використано результати спостережень на семи ділянках лісового моніторингу І рівня (обстеження 2015 та 2020 рр.). Джерелом кліматичних даних слугував он-лайн ресурс ClimateCharts.net.

Встановлено, що за останні 10 років унаслідок зміни клімату середньорічна температура повітря у регіоні зросла, а сума опадів зменшилася, що спричинило появу посушливого періоду у серпні, який є несприятливим для росту соснових лісів на межі їхнього ареалу. Відбулися зміни рівня ґрунтових вод, про що свідчить висихання озера Лиман впродовж 2013-2020 рр. Встановлено, що, порівняно з даними 2015 р., стан соснових деревостанів на ділянках моніторингу суттєво погіршився. На цей час соснові ліси за станом є «ослабленими» та «сильно ослабленими» (індекс санітарного стану живих дерев становить від 1,53 до 2,70), значно збільшилися середня дефоліація та відпад дерев. В ослаблених деревостанах з часом зростає частка дерев із пошкодженнями, зокрема внаслідок заселення стовбуровими комахами. Значну загрозу для штучних чистих соснових насаджень, що переважають у регіоні, становлять лісові пожежі. Внаслідок впливу пожеж відбулося погіршення стану деревостанів (ІС 2,49-2,70) та збільшився відпад дерев.

**Ключові слова:** Північний Степ; всихання; пожежі; пошкодження; моніторинг лісів; індекс санітарного стану; зміна клімату.

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## Динамика состояния сосновых древостоев в ГП «Лиманское лесное хозяйство»

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Рассмотрены вопросы санитарного состояния и усыхания сосновых насаждений на уровне одного государственного предприятия (ГП «Лиманское лесное хозяйство»), расположенного в Северной части степной зоны Украины.

Для исследования использованы данные двух повторных наблюдений на восьми участках, заложенных в 2019 г. в насаждениях с разной степенью усыхания и поврежденных пожаром.

Повторное обследование проведено в 2020 году. С помощью полевой ГИС Field-Map на пробных участках проведено картографирование деревьев и оценено их санитарное состояние, отпад и повреждения. Для фоновой оценки состояния сосновых лесов использованы результаты наблюдений на семи участках мониторинга лесов I уровня (обследования 2015 и 2020 гг.). Источником климатических данных служил онлайн ресурс ClimateCharts.net.

Установлено, что за последние 10 лет в результате изменения климата среднегодовая температура воздуха в регионе возросла, а сумма осадков – уменьшилась, что привело к появлению засушливого периода в августе, который является неблагоприятным для роста сосновых лесов на границе их ареала. Произошли изменения уровня грунтовых вод, о чем свидетельствует высыхание озера Лиман в течение 2013-2020 гг. Установлено, что состояние сосновых древостоев на участках мониторинга существенно ухудшилось по сравнению с данными 2015 года. Сейчас по состоянию сосновые леса являются «ослабленными» и «сильно ослабленными» (индекс санитарного состояния [ИС] живых деревьев составляет от 1,53 до 2,70), значительно возросла средняя дефолиация и усыхание деревьев. В ослабленных древостоях со временем увеличивается доля деревьев с повреждениями, в том числе, в результате заселения стволовыми насекомыми. Значительную угрозу для искусственных чистых сосновых насаждений, которые преобладают в регионе, представляют лесные пожары. Вследствие влияния пожаров произошло ухудшение состояния древостоев (ИС 2,49-2,70) и увеличился их отпад.

**Ключевые слова:** Северная Степь; усыхание; пожары; повреждения; мониторинг лесов; индекс санитарного состояния; изменение климата.

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