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DYNAMICS OF PINE ENGRAVER BEETLE-CAUSED FOREST DECLINE IN TETERIVSKE FORESTRY ENTERPRISE

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Analysis of declining pine stands infested by pine engraver beetle in Teterivske Forestry Enterprise for 2001–2017 shows increase in the infested area since 2009 with the maximum of selective sanitary felling area in 2013 and clear sanitary felling area in 2016. After 2013 total timber volume, obtained from clear and selective sanitary felling, as well as timber volume per hectare, has noticeably increased. Timber volume from selective sanitary felling in 2011–2015 and 2016–2017 exceeded the average value for 2001–2017 by 35.9 and 68 %, or in 1.4 and 1.7 times respectively. A negative correlation was evaluated between the area of clear sanitary felling and the date of stable transition of air temperature in spring over 0 °C, as well as between area of clear sanitary felling and precipitation for vegetation period. Several stages of increasing the area of forest decline were registered during vegetation period of 2014–2016. Selective felling was not able to stop forest decline. Selective sanitary felling 2–3 times repeated in the same forest plots for 2014–2017. In 2017 clear sanitary felling was carried out in the 28.6 % of plots with previous selective sanitary felling.

K e y w o r d s : Scots pine (*Pinus sylvestris* L.), forest decline, selective sanitary felling, clear sanitary felling.

Introduction. The area of pine forest decline has been increasing for the last decades in many European countries (Bigler et al. 2006, Wermelinger et al. 2008, Faccoli et al. 2011, 2012, Siitonen 2014) including Ukraine (Meshkova et al. 2015a, 2017).

The trees, weakened by drought or other unfavorable conditions, are successfully attacked by stem pests, which propagated and spread in the forest stands (Bigler et al. 2006, Meshkova & Zinchenko 2013). Ecological conditions of last decades become more favorable for pine engraver beetle *Ips acuminatus* (Gyllenhal 1827) (Coleoptera: Curculionidae: Scolytinae). This insect inhabits the branches and treetops making it difficult to find the first signs of tree colonization (Siitonen 2014, Meshkova et al. 2015a). The trees inhabited by this pest become available for other, less aggressive insects that develop in the lower parts of the stems and damage the most valuable wood (Meshkova 2017). Furthermore, *I. acuminatus* and other pine bark beetles are well known to be associated with fungal complexes including blue-stain fungi and pathogens worsening tree health (Davydenko et al. 2017). Pine engraver beetle is capable to develop in several generations per year, including sister broods (Colombari et al. 2013). Therefore, it attacks the trees almost permanently from May to the end of August. Inhabited trees become weakened and killed for several weeks, and crown color gradually changes from green to grayish and reddish. In Ukraine, pine engraver beetle was studied mainly in the Steppe and Forest-Steppe zones, particularly its phenology and occurrence (Meshkova et al. 2015a, 2015b, 2017). But only in Forest zone, this insect revealed the possibility to survive in thin branches of felled trees fallen to the ground, to propagate there and then to colonize the trees in the border of clear-cuts, which accelerates the spread the infestation.

Pine engraver beetle forms the foci as “spots” by attacks of weakened trees (Siitonen 2014). Research of pine engraver beetle foci dynamics in Italy for 6 years has shown that spots’ size and a distance between them depend on the number of susceptible trees as well as bark beetle population density and season (Faccoli et al. 2011, 2012, Colombari et al. 2013). An attention has not so far paid to the spread of this pest. Before 2012 there was a little concern regarding pine engraver beetle in Ukraine because it has never formed such large-scale decline of pine forest.

The aim of this work was the revealing the peculiarities of forest decline in the Scots pine (*Pinus sylvestris* L.) stand infested by pine engraver beetle using as example Teterivske Forestry Enterprise.

Materials and Methods. The research was carried out in 2014–2017 in the stands of Scots pine in the Teterivske Forestry Enterprise (Kiev region). Dynamics of forest decline was studied on the base of monitoring data of forest health condition and of selective and clear sanitary felling in

the stands. Data on forest fund, especially on pine stands area, were taken from forest inventory database as of 2016. Meteorological parameters (air temperature and precipitation) were taken from meteorological station Teteriv (50°41′54″ N; 29°35′57″ E). The dates of stable temperature transition over 0, 5 and 10 °C have been calculated using *MS Excel* applications (Meshkova 2009). Spatial analysis of forest decline "spots" was carried out using QGIS 2.18 (Borysenko 2017). Linear trend (R^2) and Spearman's rank correlation coefficient (r) were calculated by standard approach (Atramentova and Utevskaya 2008) using *MS Excel*.

Results and Discussion. The analysis shows that in Teterivske Forestry Enterprise in 2001–2017 selective sanitary felling was carried out on average on 1,231.5 ha per year (Fig. 1).

Area of stands, covered by selective sanitary felling, trended to decrease for analyzed years (R^2 = 0.1463; r = 0.38). However, after minimum at 398 ha per year in 2009, this parameter has increased dramatically up to 1,947 ha per year in 2013. Clear sanitary fellings were carried out in average on 30.9 ha per year, from 2.1 ha in 2006 to 124 ha in 2016. The area of clear sanitary felling trended to increase for analyzed years (R^2 = 0.3046; r = 0.55). Before 2010 the area of clear sanitary felling fluctuated slightly, but after 2010 it has increased steadily.

The last maximum of clear sanitary felling area was registered three years after the maximum of selective sanitary felling area (see Fig. 1).

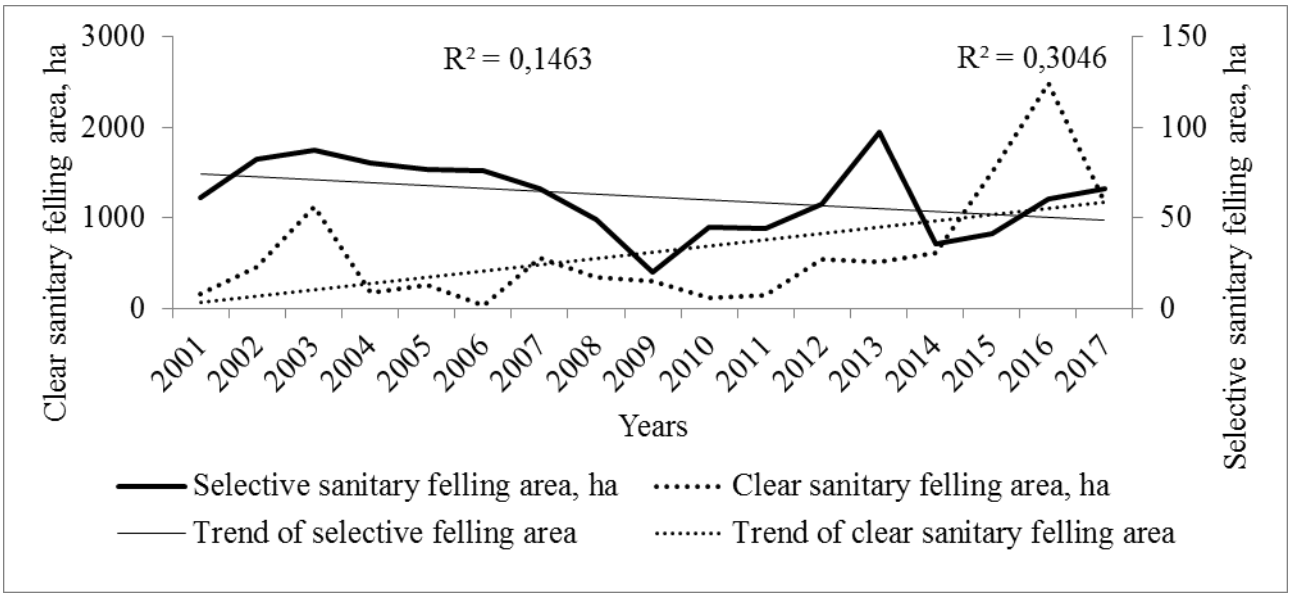


Fig. 1 – Dynamics of pine stands area, covered by sanitary felling in 2001–2017 (Teterivske Forestry Enterprise)

Total timber volume, obtained from clear and selective sanitary felling, as well as timber volume per hectare, has noticeably increased in the second half of analyzed period (Figs. 2, 3).

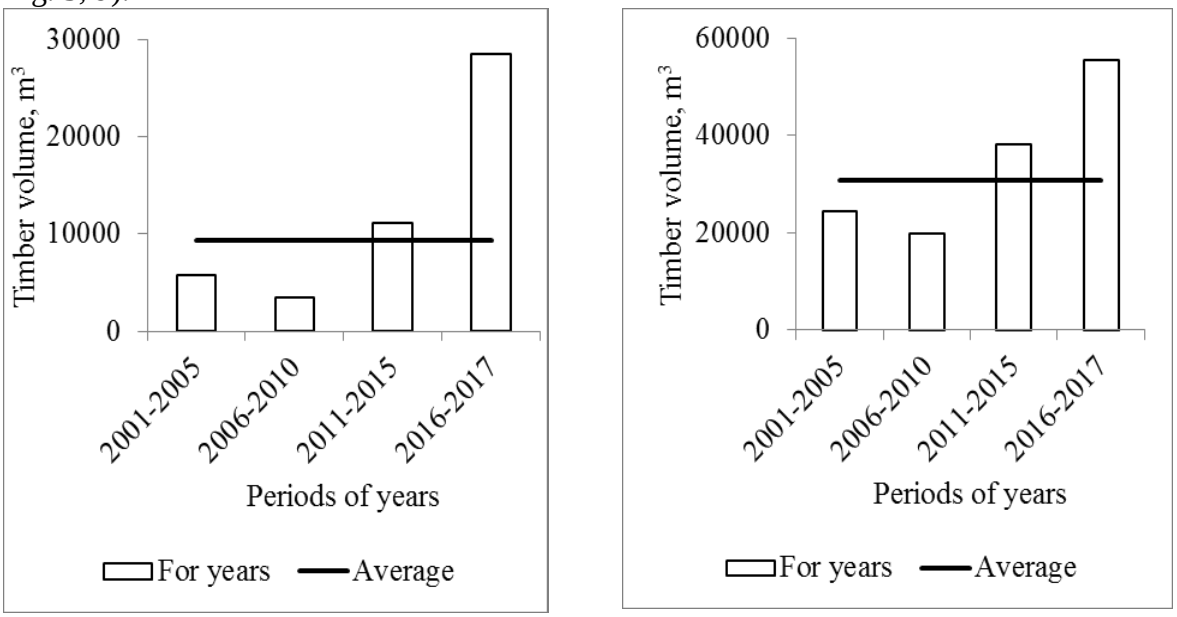
So the timber volume of clear sanitary felling in 2001–2005 and 2006–2010 was lower as compared with 2001–2017 by 38.6 and 62.9 %, or 1.6 and 2.7 times respectively, whereas timber volume of clear sanitary felling in 2011–2015 and 2016–2017 exceeded average value by 19.2 and 205.9 %, or in 1.2 and 3.1 times respectively (see Fig. 2).

The timber volume from selective sanitary felling in 2001–2005 and 2006–2010 was below the average value for 2001–2017 by 21 and 35.2 %, or in 1.3 and 1.5 times respectively, whereas timber volume of selective sanitary felling in 2011–2015 and 2016–2017 exceeded average value by 24.2 and 80.1 %, or in 1.2 and 1.8 times respectively (see Fig. 2). Average timber volume of selective sanitary felling (30,806.9 m^3) was in 3.3 times greater than of clear sanitary felling (9,332.1 m^3) (see Fig. 2).

Average timber volume per 1 ha of clear sanitary felling (269 m^3 per ha) was in 10.3 times more than from selective sanitary felling (26.1 m^3 per ha). Like clear timber volume from such felling, timber volume from 1 ha in 2001–2005 and 2006–2010 was less than the average value for 2001–2017 by 10.8 and 15.1 %, or in 1.1 and 1.2 times respectively. At the same time, timber

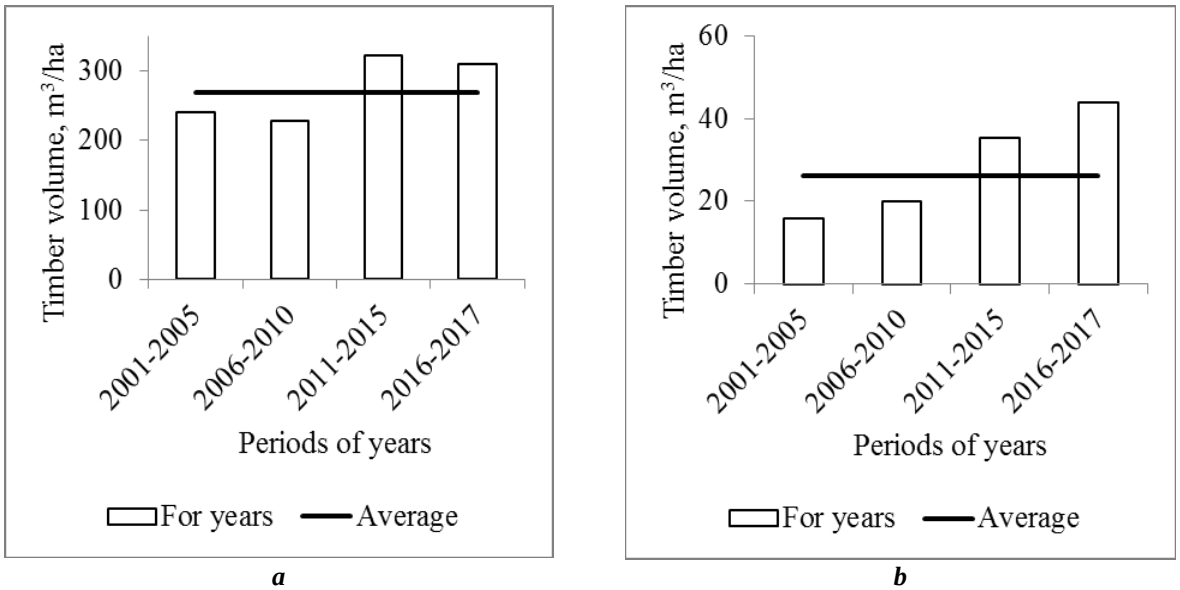
volume in 2011–2015 and 2016–2017 clear sanitary felling exceeded average value for 2001–2017 by 19.8 and 15.1 %, or in 1.2 and 1.2 times respectively (see Fig. 3, *a*).

Timber volume per 1 ha of selective sanitary felling in 2001–2005 and 2006–2010 was significantly lower than average value for 2001–2017 by 39.8 and 23.3 %, or in 1.7 and 1.3 times respectively, whereas timber volume of selective sanitary felling in 2011–2015 and 2016–2017 exceeded the average value for 2001–2017 by 35.9 and 68 %, or in 1.4 and 1.7 times respectively (see Fig. 3, *b*).



a ***b***

Fig. 2 – Timber volume obtained from clear (*a*) and selective (*b*) sanitary felling in different time periods in Teterivske Forestry Enterprise



a ***b***

Fig. 3 – Timber volume obtained from 1 ha of clear (*a*) and selective (*b*) sanitary felling in different time periods in Teterivske Forestry Enterprise

Considering dependence of forest health on weather conditions, correlation between area of forest decline in pine forests of Teterivske Forestry Enterprise and weather parameters has been evaluated using particularly air temperature for year and vegetation period, precipitation for year and vegetation period, as well as the dates of stable transition of air temperature in spring over 0, 5 and 10 °C in the current and previous year.

A reliable negative correlation was obtained between the area of clear sanitary felling and the date of stable transition of air temperature in spring over 0 °C (r = -0.62), as well as between area of clear sanitary felling and precipitation for vegetation period (r = -0.56) (Fig. 4).

Such correlations are larger by absolute value for 2013–2017 (-0.72 and -0.76 for the date of stable transition of air temperature in spring over 0 °C and precipitation for vegetation period respectively), but data are not verifiable due to a small period of time was analyzed.

Indeed, early transition of air temperature over 0 °C in 2008 and low precipitation in 2009 were not being identified as the key reason of the growth of area of pine forest decline, but both parameters were rather low in 2015–2016 with the highest area of clear sanitary felling (see Fig. 4).

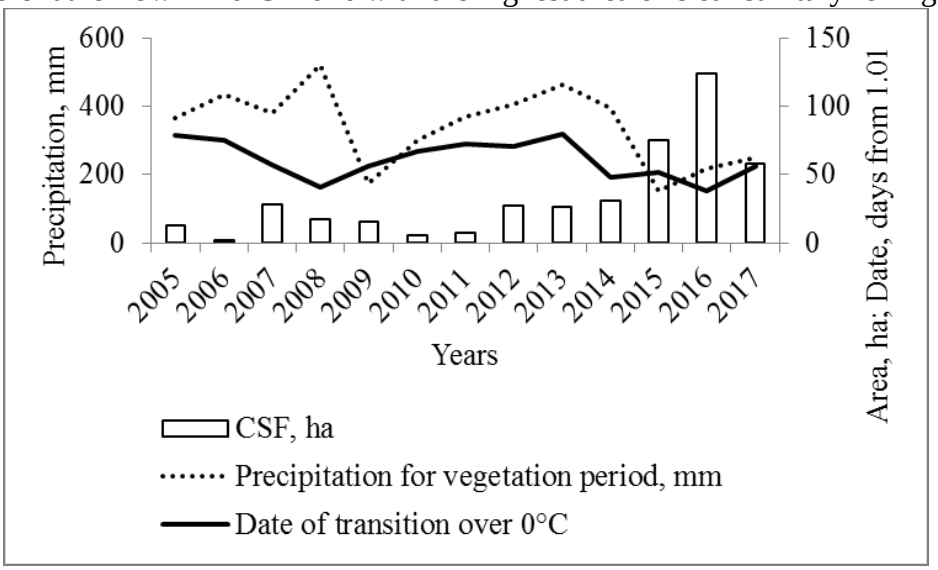


Fig. 4 – Dynamics of parameters, which reveal the highest correlation with area of clear sanitary felling (CSF)

In 2013 the area of selective sanitary felling has transcended average value for 2001–2017 by 72.2 % (see Fig. 1). Low precipitation levels in 2014–2017 were unfavorable for the forest, and early beginning of spring in these years was favorable for phytophagous insects, particularly for pine engraver beetle. It resulted in forest weakening in the large area and an increase of the area of clear sanitary felling.

So, the average date of stable temperature transition over 0°C for 13 years is March 2nd, over 5°C – March 24th. In 2014, 2015, 2016 and 2017 the date of stable temperature transition over 0°C was 13, 9, 23 and 5 days earlier than perennial average date. The date of stable temperature transition over 5°C was 14, 5, 3 and 11 days earlier than perennial average date. That is in 2014 the favorable conditions for pine engraver beetle abandonment of the place of hibernation developed on March 10, and in 2015, 2016 and 2017 on March 19, 21 and 13.

For abovementioned, the area of pine forest decline in Teterivske Forestry Enterprise has increased from 1,296.7 ha in 2014 up to 2,406.1 ha in 2017 (Table 1).

In 2014–2016 the area of forest decline has grown in all forestries, and in 2017 only for two (Blidchanske and Teterivske) out of the eight it became less than in previous year.

The area of forest decline in related years has shown an upward trend, increasing 1.1–1.5 times, and has reached a peak in certain forestries such as Blidchanske (increase in 2.1 times in 2016) and Kukharske where decline area has sharply increased in 3.4 times in 2015.

Percentage of foci area from the total area of pine stands of Teterivske Forestry Enterprise increased from 6.8 % in 2014 to 12.7 % in 2017. It means that at such rate of decline, the pine stands in the region may be totally killed for several decades.

As far as the main cause of tree mortality was their infestation by pine engraver beetle, the periods of new foci appearance were conditioned by the dates of tree colonizing by this pest, which develops in several broods per year, including the main and sister generations. After tree

colonization by pine engraver beetle, crown color rapidly changes. After 2–3 weeks the crowns become gray-green and dull, after 5–6 weeks they become yellowish, and after 6–8 weeks become reddish. Therefore the survey in the foci of pine engraver beetle must be carried out several times per year.

Table 1

Dynamics of pine forest decline area in Teterivske Forestry Enterprise (2014–2017; numerator – area, ha; denominator – percentage from pine forest area, %)

Forestry	Year			
	2014	2015	2016	2017
Blidchanske	182.3 / 4.7	136.2 / 3.5	290.6 / 7.5	249.1 / 6.4
Kodryanske	247.5 / 5.5	253.8 / 5.6	230.9 / 5.1	311.2 / 6.9
Mygalske	123.9 / 3.6	152.2 / 4.5	206.2 / 6.1	321.8 / 9.4
Mirchanske	180.9 / 7.3	150.4 / 6.0	235.4 / 9.5	256.7 / 10.3
Potashnyanske	107.2 / 2.9	175.5 / 4.8	307.2 / 8.3	342.2 / 9.3
Teterivske	293.3 / 6.7	269.7 / 6.2	433.7 / 9.9	312.3 / 7.2
Kukharske	49.1 / 1.0	169.3 / 3.5	252.0 / 5.1	347.9 / 7.1
Piskivske	112.5 / 3.7	154.9 / 5.1	185.1 / 6.1	264.9 / 8.7
Total	1296.7 / 6.8	1462.0 / 7.7	2141.1 / 11.3	2406.1 / 12.7

Due to the fact that survey of the pest is carried out regularly in Teterivske Forestry Enterprise, dynamics of forest foci area can be described by dynamics of selective and clear sanitary felling. Analysis of such data showed that at the beginning of 2014 the area of forest decline was 821.7 ha or 54.5 % from the area at the end of given year (Fig. 5).

Already in March of 2014, the foci area of forest decline was 53.4 ha, in June 507.2 ha, in July 109.2 ha. From March to August 2014 the total area of new foci has reached 689.6 ha. It is important that 73.8 % of this area was added in June, due to the emergence of the progeny of the beetles, which inhabited the trees in spring. Less population of sister brood colonized trees in July (15.9 %).

In general, in 2014 the area of selective sanitary felling was 96.3 % of the total area of sanitary felling. However, their implementation could not stop the spread of forest decline.

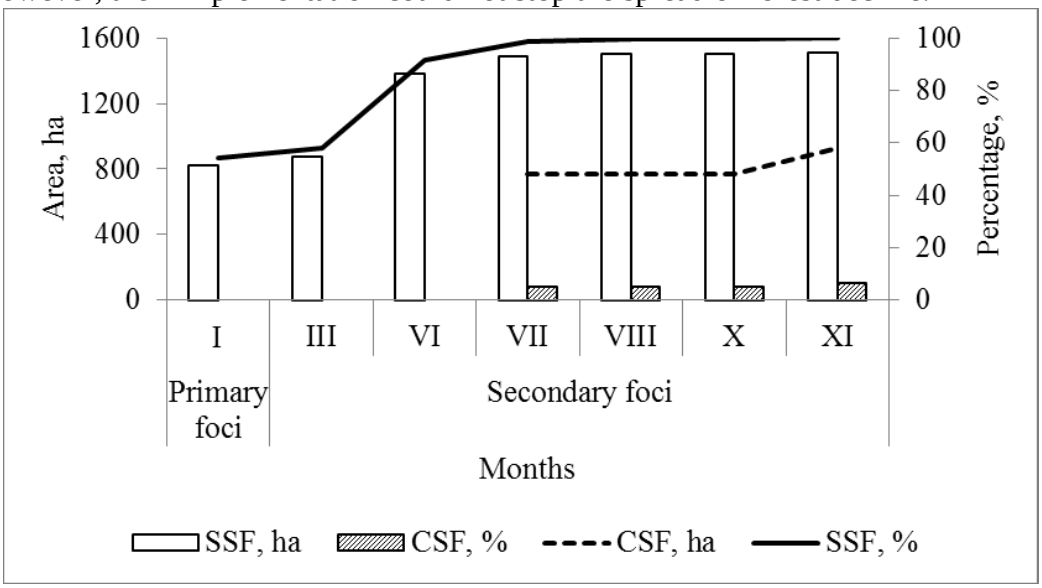


Fig. 5 – Dynamics of pine forest area covered by selective (SSF) and clear (CSF) sanitary felling in 2014 in Teterivske Forestry Enterprise

The area of pine forest decline in Teterivske Forestry Enterprise at the beginning of 2015 was 928.8 ha (Fig. 6).

Like in 2014, the area of forest decline continued to increase in 2015, and the most part of new foci area developed in June and July (27.1 and 35.3 % respectively). Due to the prolongation of forest decline in the foci of the previous year, the considerable area of stands covered by selective sanitary felling in 2014 had to be felled as clear sanitary felling. In March it was found that the inhabited in autumn trees died, and the area of clear sanitary felling increased from projected 125.7 ha to 207.6 ha (see Fig. 6).

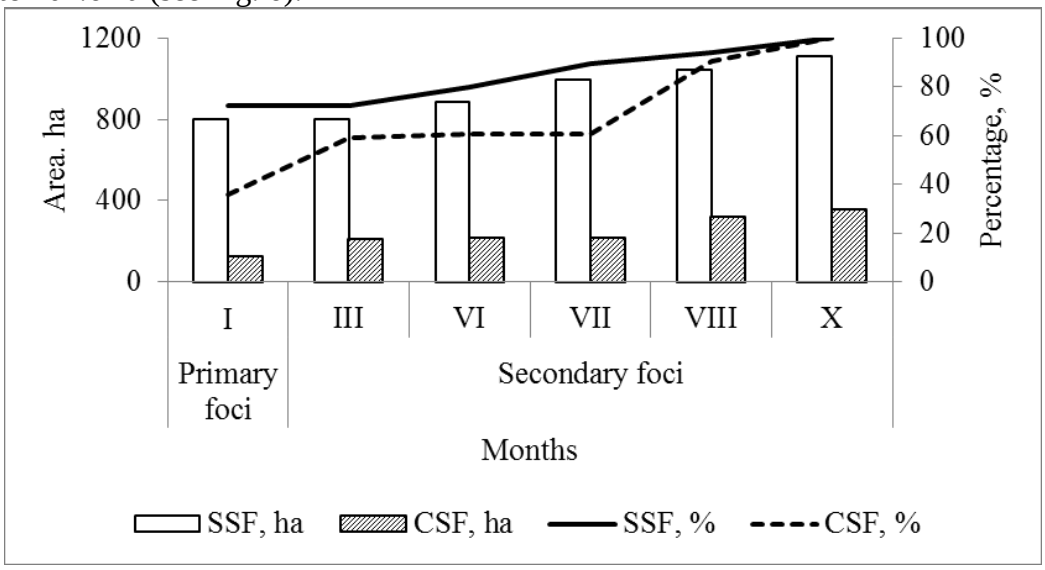


Fig. 6 – Dynamics of pine forest area covered by selective (SSF) and clear (CSF) sanitary felling in 2015 in Teterivske Forestry Enterprise

In 2016, the area of forest decline increased during the whole vegetation period (Fig. 7).

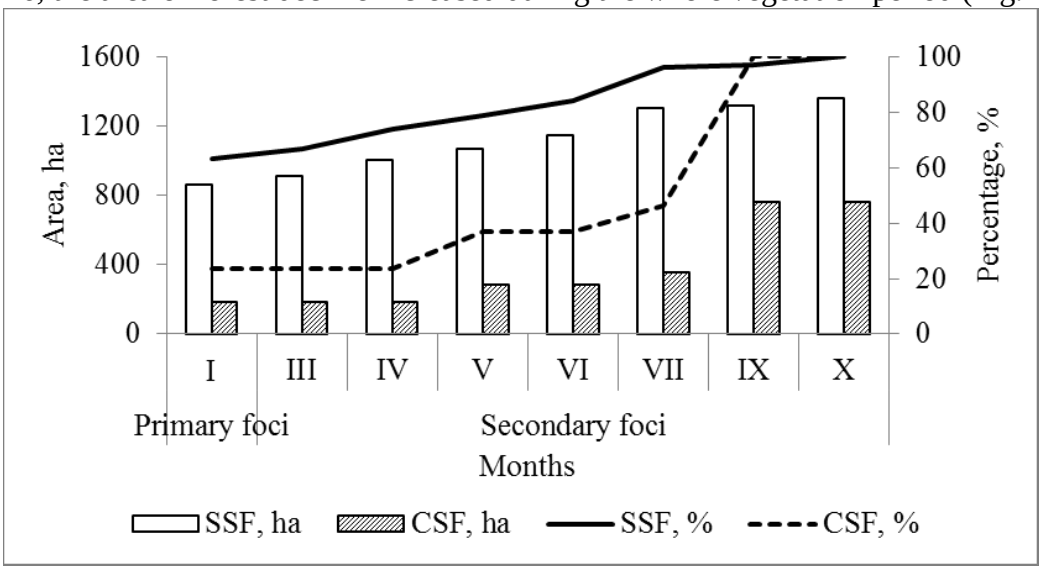


Fig. 7 – Dynamics of pine forest area covered by selective (SSF) and clear (CSF) sanitary felling in 2016 in Teterivske Forestry Enterprise

The most part of selective sanitary felling area in “secondary” foci (31.7 %) also was estimated in July, and the most part of clear sanitary felling in September (405.8 ha from 756.7 ha of clear sanitary felling area in 2016).

The part of the area, covered by clear sanitary felling, from the total area of sanitary felling in 2015 exceeded in 6.5 times that of 2014 (3.7 and 24.1 % in 2014 and 2015 respectively). In 2016 such part achieved 35.8 % and exceeded in 9.6 times that of 2014 and in 1.5 times that of 2015. Obtained data show, that selective sanitary felling does not give the possibility to stop the spread of forest decline, although it repeated 2–3 times in the same forest subplots for 2014–2017 (Fig. 8). In

2017 in Teterivske Forestry clear sanitary felling was carried out at the 28.6 % of plots with previous selective sanitary felling.

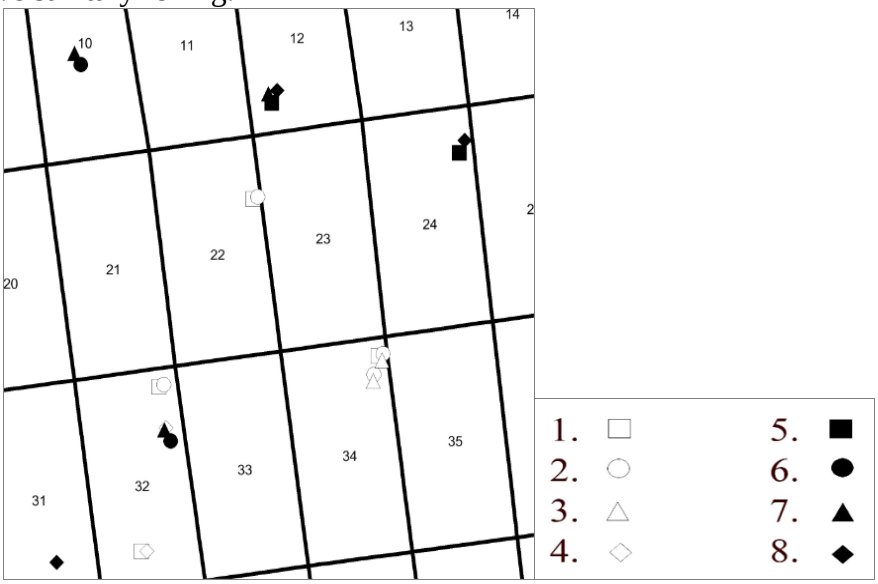


Fig. 8 – Fragment of Teterivske Forestry scheme. Forest plots covered with one or several selective (SSF) and clear (CSF) sanitary felling are indicated (1 – SSF in 2014; 2 – SSF in 2015; 3 – SSF in 2016; 4 – SSF in 2017; 5 – CSF in 2014; 6 – CSF in 2015; 7 – CSF in 2016; 8 – CSF in 2017)

Conclusions. Area of pine forest decline in Teterivske Forestry Enterprise has increased since 2009 with a maximum of selective sanitary felling area in 2013 and clear sanitary felling area in 2016. A negative correlation has been evaluated for the area of forest decline with the date of stable transition of air temperature in spring over 0 °C and precipitation for vegetation period. Area of forest decline has been increasing every year (2014–2016) in several distinct stages, which correspond to the periods of pine engraver beetles attacks. Selective felling was not able to stop forest decline. Selective sanitary felling 2–3 times repeated in the same forest plots for 2014–2017. In 2017 clear sanitary felling was carried out in the 28.6 % of plots with previous selective sanitary felling.

REFERENCES – ПОСИЛАННЯ

Bigler, C., Bräker, O.U., Bugmann, H., Dobbertin, M., Rigling, A. 2006. Drought as an inciting mortality factor in Scots pine stands of the Valais, Switzerland. Ecosystems. 9: 330–343. http:// dx.doi.org/10.1007/s10021-005-0126-2.

Borysenko, O. I. 2017. Fire hazard assessment for the stands of the State Enterprise "Kreminske Forest Economy" using GIS technology. Forestry and Forest Melioration, 130: 139–145 (in Ukrainian).

Colombari, F., Schroeder, M. L., Battisti, A., Faccoli, M. 2013. Spatio-temporal dynamics of an *Ips acuminatus* outbreak and implications for management. Agricultural and Forest Entomology, 15: 34–42. doi: 10.1111/j.1461-9563.2012.00589.x

Davydenko, K., Vasaitis, R., Menkis, A. 2017. Fungi associated with *Ips acuminatus* (Coleoptera: Curculionidae) in Ukraine with a special emphasis on pathogenicity of ophiostomatoid species. European Journal of Entomology, 114: 77–85. doi: 10.14411/eje.2017.011

Faccoli, M., Finozzi, V., Colombari, F. 2012. Effectiveness of different trapping protocols for outbreak management of the engraver pine beetle *Ips acuminatus* (Curculionidae, Scolytinae). International Journal of Pest Management, 58(3): 267–273. doi: 10.1080/09670874.2011.642824

Faccoli, M., Finozzi, V., Gatto, P. 2011. Sanitation felling and helicopter harvesting of bark beetle–infested trees in Alpine forests: an assessment of the economic costs. Forest Products Journal, 61(8): 675–680. doi: 10.13073/0015-7473-61.8.675

Meshkova, V. L. 2009. Sezonnoye razvitiye khvoyelistogryzushchikh nasekomykh [Seasonal development of foliage browsing insects]. Kharkov, Novoe slovo, 396 p. (in Russian).

Meshkova, V. L. 2017. Evaluation of harm (injuriousness) of stem insects in pine forest. Scientific Bulletin of UNFU, 27(8): 101–104. doi: 10.15421/40270816.

Meshkova, V. L., Kochetova, A. I., Zinchenko, O. V. 2015a. Verkhivkovyy koroyid *Ips acuminatus* (Gyllenhal, 1827): Insecta: Coleoptera: Scolytinae u Pivnichno-Skhidnomu Stepu Ukrayiny [The pine engraver beetle *Ips*

acuminatus (Gyllenhal, 1827) (Coleoptera: Curculionidae: Scolytinae) in the NorthEastern Steppe of Ukraine]. The Kharkov Entomol. Soc. Gaz., XXIII(2): 64–69. (in Ukrainian).

Meshkova, V. L., Zinchenko, O. V., Skrylnik, Yu. Ye, Aristova, A. I. 2015b. Sroki razvitiya stvolovykh vrediteley sosny v Levoberezhnoy Ukraine [The dates of development of pine stem pests in the Left-bank Ukraine]. Izvestiya Sankt-Peterburgskoy lesotekhnicheskoy akademii, 211: 59–67 (in Russian).

Meshkova, V. L., Kochetova, A. I., Zinchenko, O. V., Skrylnik Yu. Ye. 2017. Biology of multivoltine bark beetles species (Coleoptera: Scolytinae) in the North-Eastern Steppe of the Ukraine. The Bulletin of Kharkiv National Agrarian University. Series "Phytopathology and Entomology", 1–2: 117–124.

Meshkova, V. L. and Zinchenko, O. V. 2013. Zaselenist' stovburovymy komahamy sosnovyh nasadzhen', oslablenyh riznymy chynnykamy [Colonization by stem insects of pine plantations weakened by various factors]. The Bulletin of Kharkiv National Agrarian University. Series "Phytopathology and Entomology", 1−2: 126–131 (in Ukrainian).

Siitonen, J. 2014. *Ips acuminatus* kills pines in southern Finland. Silva Fennica, 48(4), article id 1145. 7 p. http://dx.doi.org/10.14214/sf.1145.

Wermelinger, B., Rigling, A., Schneider, Mathis D., Dobbertin, M. 2008. Assessing the role of bark- and wood-boring insects in the decline of Scots pine (*Pinus sylvestris*) in the Swiss Rhone valley. Ecological Entomology, 33: 239−249. http://dx.doi.org/10.1111/j.1365- 2311.2007.00960.x.

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ДИНАМІКА ПЛОЩІ ВСИХАННЯ ЛІСІВ, СПРИЧИНЕНОГО ВЕРХІВКОВИМ КОРОЇДОМ, У ДП «ТЕТЕРІВСЬКЕ ЛГ»

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Аналіз усихання соснових насаджень, заселених верхівковим короїдом, у ДП «Тетерівське ЛГ» у 2001–2017 рр. виявив ріст площі осередків усихання з 2009 року з максимальною площею проведення вибіркової санітарної рубки у 2013 р. та суцільної санітарної рубки у 2016 р. Починаючи з 2013 року, об'єм деревини, заготовленої під час проведення суцільної та вибіркової санітарних рубок, а також об'єм деревини на 1 га помітно збільшилися. Об'єм деревини, заготовленої під час проведення вибіркової санітарної рубки в 2011–2015 та 2016–2017 рр., перевершив значення для 2001–2017 рр. на 35,9 і 68 %, або в 1,4 та 1,7 разу відповідно. Виявлено від'ємну кореляцію між площею, охопленою суцільною санітарною рубкою, та датою стійкого переходу температури повітря навесні через 0°С, а також між площею, охопленою суцільною санітарною рубкою, та сумою атмосферних опадів за вегетаційний період. Відзначено наявність декількох етапів наростання площі всихання лісів за вегетаційні періоди 2014–2016 рр. Проведення вибіркових рубок не змогло зупинити всиханя насаджень. Вибіркові рубки довелося повторити 2–3 рази в одних і тих самих виділах за період 2014–2017 рр. У 2017 р. суцільні санітарні рубки були проведені у 28,6 % виділів, де в попередні роки проводили вибіркові санітарні рубки.

Ключові слова: сосна звичайна (*Pinus sylvestris* L.), всихання лісу, вибіркова санітарна рубка, суцільна санітарна рубка.

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ДИНАМИКА ПЛОЩАДИ УСЫХАНИЯ ЛЕСОВ, ВЫЗВАННОГО ВЕРШИННЫМ КОРОЕДОМ, В ГП «ТЕТЕРЕВСКОЕ ЛХ»

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Анализ усыхания сосновых насаждений, заселённых вершинным короедом, в ГП «Тетеревское ЛХ» в 2001–2017 гг. выявил рост площади очагов усыхания с 2009 года с максимальной площадью проведения выборочной санитарной рубки в 2013 г. и сплошной санитарной рубки в 2016 г. Начиная с 2013 года, объем древесины, заготовленной при проведении сплошной и выборочной санитарной рубки, а также объем древесины на 1 га заметно возросли. Объем древесины, заготовленной при проведении выборочной санитарной рубки в 2011–2015 и 2016–2017 гг., превысил значение для 2001–2017 гг. на 35,9 и 68 %, или в 1,4 и 1,7 раза соответственно. Выявлена отрицательная корреляция между площадью, охваченной сплошной санитарной рубкой, и датой устойчивого перехода температуры воздуха весной через 0°С, а также между площадью, охваченной сплошной санитарной рубкой, и суммой атмосферных осадков за вегетационный период. Отмечено наличие нескольких этапов нарастания площади усыхания лесов за вегетационные периоды 2014–2016 гг. Проведение выборочных рубок не смогло остановить усыхание насаждений. Выборочные рубки пришлось повторить 2–3 раза в одних и тех же выделах за период 2014–2017 гг. В 2017 г. сплошные санитарные рубки были проведены в 28,6 % выделов, где в предыдущие годы проводились выборочные санитарные рубки.

Ключевые слова: сосна обыкновенная (*Pinus sylvestris* L.), усыхание леса, выборочная санитарная рубка, сплошная санитарная рубка.

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