Influence of Surface Fires on State of Stands in Mossy Pine Forests *(Pinetum pleuroziosum)*

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Through long-term monitoring on permanent plots, the consequences of influence of average and weak intensity surface fires on the state of pine trees in mossy pine forests were studied. The size of their radial increment and defoliation, and the dependence between these parameters describe the state and productivity of trees after the influence of a fire was determined.

The reaction of stands on surface fires of various intensities is shown in an increase of defoliation and number of damaged trees, deterioration of vital state of stands, and a decrease in the increment. Damage of stands by fire brings to death a part of trees, the amount of which depends on the intensity of a fire. The maximum of accumulation of dead wood in pine forests, which were damaged by surface fires, is observed in first two post-fire years. In the future, this process is slowed down. The general improvement of the state of stands in the form of a decrease in the degree of defoliation, reestablishment of the number of undamaged trees and a decrease in the number of damaged trees, an increase in the indexes of vital state of stands is observed in 5 years after a fire of average intensity and in 2 years – weak intensity.

Statistically significant negative correlation between pine increment in diameter and defoliation is marked on plots damaged by surface fires. Regression dependence of absolute values of increment in diameter on the crown defoliation of current and last years was revealed on plots after a surface fire of average intensity.

Keywords: pine forests, surface fire, intensity of fire, state of stand, increment in diameter, defoliation of tree

Introduction

Independing of its origin, the fire is a serious natural disaster that causes damage or destruction of forest phytocenosis. Many studies were dedicated to the evaluation of consequences of fire on forest phytocoenoses (Sannikov & Sannikova 1984, Richter 1996, Sharay 1999, Hmelevsky 1999, *et al.*). The emphasis is usually placed on the influence of fire on the components of forest biogeocoenosis. Both direct and indirect influence of fire is examined. Stands, undergrowth and underwood, ground vegetation, floor covering, micro- and macrofauna are destroyed or damaged with direct impact. Indirect influence becomes apparent in the change of species composition of the flora and fauna, appearance of fallen trees, entomo- and phytopests, activation of erosive processes etc. (Richter 1996). Much attention is given to the issues of post-fire mortality and its forecasting (Demakov *et al.* 1982, Usenia *et al.* 2000).

On the other hand, fires were – and still are – an ecological factor that determines the structure and dynamics of forest cover. Fires affect not only qualitative and quantitative characteristics of stands and other components of natural complexes, but also their condition as a whole: soil and microclimatic conditions, hydrological regime, stability of communities to repeated fires, illnesses and pests. At that the sum of correlated and interconnected post-fire phenomena results in a change of ecological modes of natural complexes, a change of types and age generations, and as a whole causes specificity and an orientation of post-fire forest renewal process, which become pyrogenic-determined (Esseen *et al.* 1997, Gromtsev 2002, Ryan 2002, *et al*). According to the results obtained by S.S.Ziabchenko (Ziabchenko 1984), A.D.Volkov, A.N.Gromtsev and V.I.Sakovts (Volkov *et al.* 1997), A.V.Sudnik (Sudnik 2001, 2002) *et al.*, the pyrogenic factor plays a special role in the formation process of climax pine phytocoenoses. In Byelorusssia, pine retains vitality after surface fires since 50 years up to natural destruction of stands (Richter 1996). At the same time, some aspects of the state and growth of stands in the first years after damage by surface fires are investigated insufficiently.

The influence of surface fires on stands shows through appearance of fire traumas and associated weakening, damage of entomo- and phytopests and further decline of a part of trees. The kind and degree of fire damages to pine trees are determined by the character and force of a fire. At quick surface fires of weak intensity the influence of fire on trees is limited only to superficial burning of a bark. With more intense fires, dying off of cambium and appearance of fire predryings on stems are observed. Dying off of cambium on the whole circle of a stem or roots results in fast decline of tree (Richter 1996).

The following tasks were tackled in the present research: study of the consequences of influence of average and weak intensity surface fires on the state of pine trees in mossy pine forests based on size of their radial increment and defoliation; determination of dependence between these parameters describing the state and productivity of trees after the influence of a fire. The choice of parameters selected for an estimation of tree state was determined by their integrated character and wide use in forest monitoring, including the territories damaged by fire.

Materials and methods

Mossy pine forests (*Pinetum pleurozoisum*) in the Berezinsky State Biosphere Reserve (permanent plots (PP) 206 and 207) and in Polotsk forest enterprise (PP 316) were the objects of the research. PP 207 was damaged by a surface fire of average intensity and PP 316 was damaged by a surface fire of weak intensity in 1992. Intensity of the fires was determined by the height of fire trace on trees. PP 206 was used as the control. Forestry-stand characteristic of stands is given in Table 1.

All trees on PP were distributed in classes of growth (Kraft classification): I – predominant trees with mightily developed crowns and large on height and diameter stems; II – dominant trees with relatively well developed crowns; III – codominant trees with poorly developed crowns with attributes of oppression; IV – oppressed trees, the crowns of which are compressed, but the tops of crowns are included into the general canopy; V – oppressed trees with crowns entirely below the general canopy or dead trees (Merkul *et al.* 2001).

The percentage of defoliation (the whole crown and top third of crown) in comparison with a model tree that has full foliage (Muller & Stierlin 1990, Ozolincius 1996) and annual diameter increment were chosen as indicators of the state of trees. Visual evaluation of defoliation of I-III Kraft class tree crowns on PP has been carried out annually since 1990. All trees of I-III Kraft classes have been distributed into classes of damages based on the degree of defoliation: 0 (undamaged) – defoliation 0-10%; 1 (slightly damaged) – 11-25%; 2 (moderately damaged) – 26-60%; 3 (severely damaged) – 61-99%; 4 (dead trees) – 100%.

Stands on PP were distributed into categories of the vital state. The procedure for calculation of indexes of state (IS) of forest stands and V.A.Alekseeva's modified scale (Forest ecosystems... 1990), adapted with reference to the method of evaluation of defoliation, were used in distribution of stands into categories of the state. Stands with IS 0.90 and above are healthy, 0.80-0.89 – healthy with attributes of weakening; 0.70-0.79 – weakened; 0.50-0.69 – damaged; 0.20-0.49 – severely damaged, less than 0.20 – destroyed. The index of the state of stands (IS) was calculated by the following formula:

$$IS=1-(Df_1*P_1^2+Df_2*P_2^2+...+Df_{n-1}*P_{n-1}^2+Df_n*P_n^2) / (100*(P_1^2+...+P_{n-1}^2+P_n^2)),$$

where Df_i is defoliation of *i* tree,%; P_i is perimeter of *i* tree at the height of 1.3 m.

For determination of size of the annual increment on objects of research, the cores were selected by increment bores in pine trees of I-III Kraft classes at height 1.3 m (diameter at breast height). A total of 65 trees were measured on PP 207, 316 and 30 – on the control plot. Variability of the radial increment was estimated for the 20-year-period (1981-2000). The length of term of evaluation was chosen so as to carry out relative measurements of increment for the 10-year-period prior to and following a fire. The indexing of absolute values of defoliation and increment was carried out for evening the differences caused by the

Table 1. Forestry-stand characteristic of pine forests on permanent plots

PP	Composition	Number of trees per 1 ha	Age, years	Average height, m	Average diameter, cm	Site index	Sum of sectional areas, m²/ha	Stocking level (density)	Volume, m³/ha
Pre-fire									
206	100% Pine	1158	88	17.7	16.0	III	23.4	0.7	202
207	100% Pine	714	95	25.6	24.2	II	32.7	1.0	379
316	100% Pine	819	72	17.6	20.3	III	26.5	0.8	253
8 years after fire									
206	98%Pine 2%Birch	792	103	20.8	19.9	III	30.91	0.9	339
207	100% Pine	473	110	28.8	26.9	II	34.13	0.9	485
316	100% Pine	524	84	21.9	22.5	II	26.47	0.8	298

conditions of the growth and age of trees. Relative values of increment (indices (I_t) of increment) were obtained by division of the annual increment to average increment for 20-year period of evaluation:

$$I_t = Zd_i \,/\, \left(\sum_{i=1}^{20} Zd_i \,/\, 20\right),$$

where Zd_i refers to the tree increment in diameter, mm.

Statistics of distribution series (descriptive statistics), correlation and regression analysis were performed using of *Microsoft Excel* and statistical package *Statistica*.

Results

It is necessary to know weather-climatic conditions of vegetative seasons while analysing the obtained data on the dynamics of the state of stands (Ozolincius & Stakenas 1996). It is essential to note that droughty phenomena were observed in vegetation seasons almost in all years of observation (only 1998 was an exception). Summer droughts in 1992, 1994, 1996, 1997 years, which are characterized by maximal duration of vegetative seasons without significant precipitations, are most expressed. And only in 1998, the amount of precipitation was significant during the vegetative period. Most cool seasons of vegetation appeared in 1993 (average air temperature was 13.4 °C) and in 2000 (13.8 °C), the warmest – in 1992 (15.5 °C) and 1999 (16.1°C).

The dynamics of defoliation of tree crown on plots after surface fires differs from that in the control (Fig. 1). A general tendency of improvement of a tree state, evidenced in a decrease in defoliation, was observed on the control plot. In the stand damaged by surface fire of average intensity defoliation grew, having reached a maximum in 1997 (average defoliation of top third of crown – 43%, the whole crown –38%). In the stand damaged by fire of weak intensity defoliation also grew, having reached a maximum in 1994 (average defoliation of top third of crown – 27%, the whole crown – 25%). The increase in defoliation is attributed to the reaction of trees on damage by fire. The percentage of defoliation has begun to fall within the 2 years after a fire of weak intensity and within 5 years after a fire of average intensity. This indicates that stands have overcome the negative impact of a fire, and the general tendency to improve their state was planned.

The difference in defoliation of top third and the whole crown on the control plot is insignificant. On post-fire plots top third of crown appeared to react stronger to damage by fire (Fig. 1). The difference between defoliation of top third and the whole crown after 1992 (fire year) started increasing on plots after fires. The greatest difference in absolute values of defoliation of top third and the whole crown was marked in 5 years after a surface fire of weak intensity (12.9%) and in 7 years – after a fire of average intensity (17.9%). This difference is insignificant already after 7 years following a fire of weak intensity, and after a fire of average intensity even in 10 years it exceeded 10%.

The degree of damage to stands by surface fires depends on their intensity. The stand on plots after surface fire of average intensity in the period 1994-1999 was characterized as damaged (Fig. 1). The smallest coefficients of IS are marked in the fifth year after a fire, viz. 0.55 (was calculated for defoliation of top third of crown) and 0.61 (for defoliation of the whole crown). Since 1997, IS begins to grow. It means, that the stand has overcome negative influence of a fire, and its state began to be improved. Already by 2000, this stand has returned in category of weakened stand. On the plot after surface fire of weak intensity only for period 1994-1997, stand was characterized as weakened. On the control plot during all periods of research, the stand was characterized as healthy with attributes of weakening. IS on control has dropped to 0.75 (weakened) only in 1992 with extremely droughty vegetative season.

On the plot after a fire of average intensity till 1997, the number of undamaged and slightly damaged trees has decreased (33.3% and on 34.7%, respectively), and that of moderately damaged trees has increased (62.2%) (Fig. 2). In 1997, all trees were damaged to a greater or lesser extent. The greatest number of severely damaged trees (with defoliation more than 60%) was marked in the fire year – 8.9% and during five-year period following fire – 5.9%. After 1997, tendency on improvement of the state of trees was shown in an increase in the amount of undamaged and slightly damaged trees (15.2% and 33.9%, respectively) and in a decrease in the number of severe by damaged trees.

The fire of weak intensity did not exert essential influence on distribution of trees according to classes of damages. Some decrease (6.8%) in the amount of undamaged trees and an increase in the amount of moderately damaged trees are marked only in the second year after a fire. As a whole for the period of research the tendency similar to the control plot is observed. It is shown in an increase in the number of undamaged trees and in a decrease in the number of slightly and moderately damaged trees.

Damage of stands by fire brings to death a part of trees. The percentage of post-fire mortality in stands depends on the intensity of a fire. The greatest number of dead trees was in the first 2 years (Table 2) on plots after surface fires, and in the future this process is

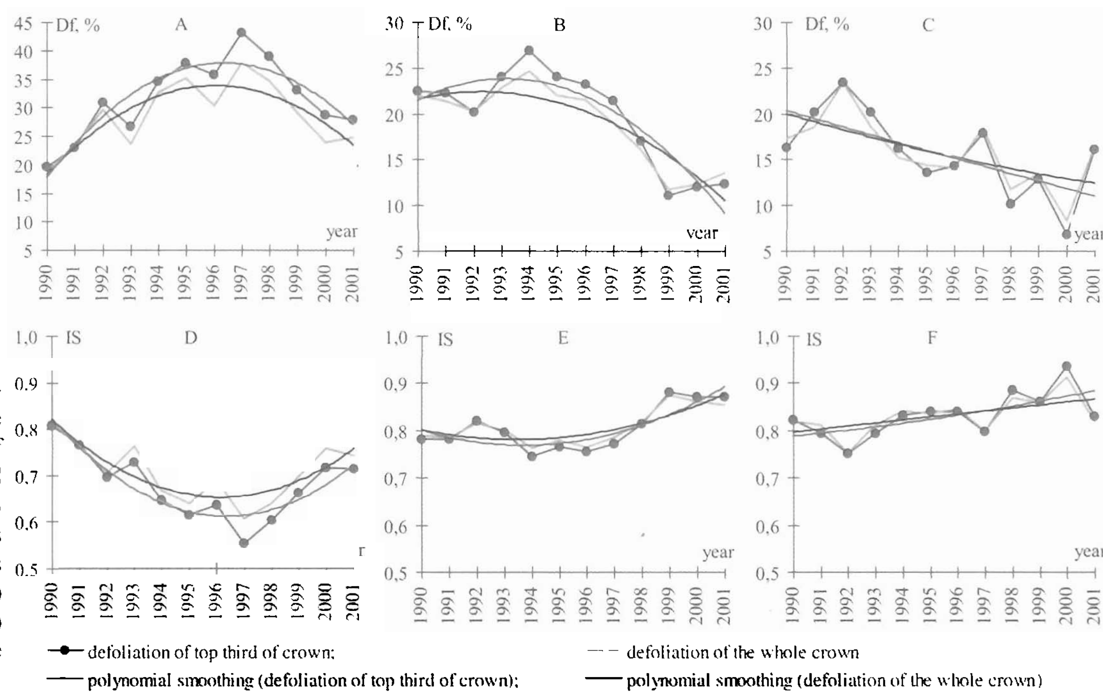

Figure 1. The dynamics of average defoliation Df of trees (A, B, C) and indexes of state IS (D, E, F) on plots after surface fires of average (A, D) and weak (B, E) intensity and the control (C, F)

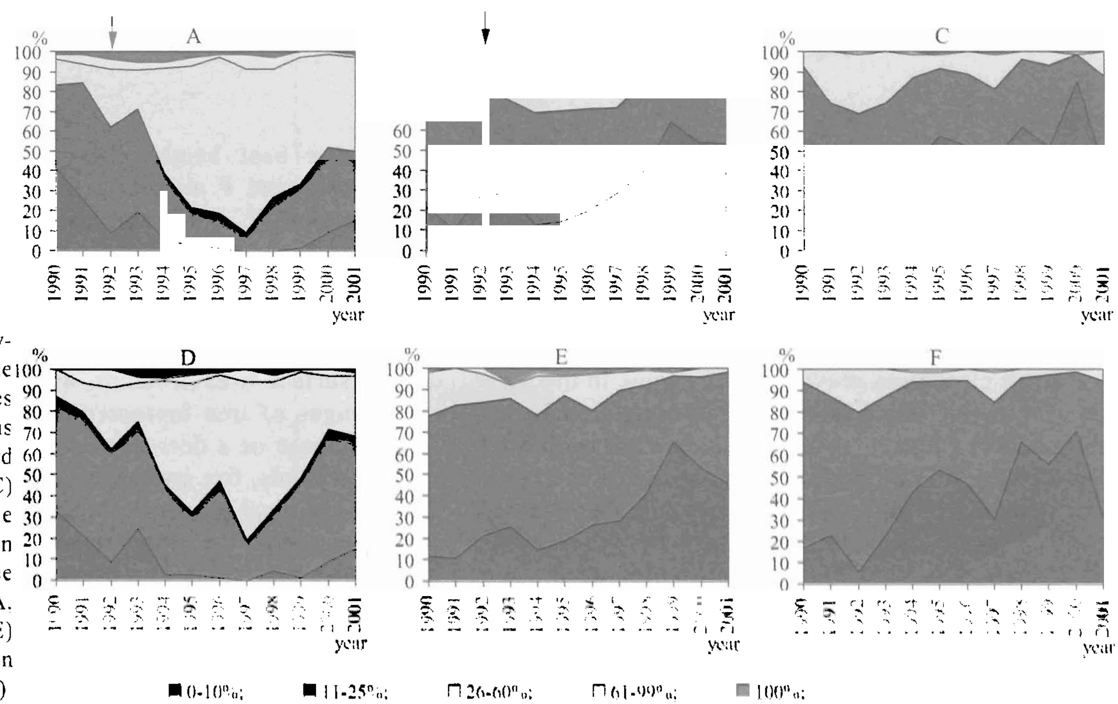

Figure 2. The dynamics of the number of trees (%) with various defoliation of third of crown (A, B, C) and the whole crown (D, E, F) on plots after surface fires of average (A, D) and weak (B, E) intensity and on the control (C, F)

slowed down. The similar results were obtained by V.V.Usenia and V.S.Churilo (Usenia & Churilo 2001), who had indicated that maximal post-fire accumulation of dead wood after surface fires both strong and weak intensity is observed in the first 2 years after a fire.

The number of trees of various Kraft classes, which have died after fires, depends on the position of a tree in the community. The greatest amount of dead wood for the period of research is among oppressed trees of V Kraft class (100% after a fire of average intensity and 73.7% – weak). Mortality of oppressed trees is not always explained by the influence of fire, as fire only accelerates their death. Only as a first approximation, mortality of IV-V Kraft class trees can

Table 2. The dynamics of mortality of various Kraft class trees on plots after surface fires of average and weak intensity and on control plots

Kraft class	Number of dead trees of various Kraft classes on years on 1 ha /% from number of trees of Kraft class												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
On plot after fire of average intensity													
II				7 / 2.2	13 / 4.4		7 / 2.2		13 / 4.4				**40 / 13.2**
III				13 / 10.5	7 / 5.3	13 / 10.5						7 / 5.3	**40 / 31.6**
IV					7 / 8.3	7 / 8.3	7 / 8.3		7 / 8.3				**28 / 33.2**
V	7 / 25.0	7 / 25.0	7 / 25.0	7 / 25.0									**28 / 100.0**
In total	**7 / 1.1**	**7 / 1.1**	**7 / 1.1**	**27 / 4.5**	**27 / 4.5**	**20 / 3.4**	**14 / 2.2**		**20 / 3.4**			**7 / 1.1**	**136 / 22.4**
On plot after fire of weak intensity													
I						5 / 4.5							**5 / 4.5**
II				14 / 4.3	5 / 1.4		10 / 2.9	10 / 2.9		5 / 1.4			**44 / 12.9**
III	5 / 3.3			24 / 16.7	5 / 3.3	10 / 6.7							**44 / 30.0**
IV		5 / 4.3	5 / 4.3	14 / 13.0	19 / 17.4								**43 / 39.1**
V	14 / 15.8	14 / 15.8	24 / 26.3	10 / 10.5		5 / 5.3							**67 / 73.7**
In total	**19 / 2.4**	**19 / 2.4**	**29 / 3.6**	**62 / 7.8**	**29 / 3.6**	**20 / 2.4**	**10 / 1.2**	**10 / 1.2**		**5 / 0.6**			**203 / 25.2**
On control plot													
III							17 / 10.0						**17 / 10.0**
IV							8 / 5.0		8 / 5.0	8 / 5.0	8 / 5.0		**32 / 20.0**
V			17 / 13.3	8 / 6.7	17 / 13.3				17 / 13.3		8 / 6.7		**67 / 53.3**
In total			**17 / 1.9**	**8 / 0.9**	**17 / 1.9**		**25 / 2.8**		**25 / 2.8**	**8 / 0.9**	**16 / 1.8**		**116 / 13.0**

be related to post-fire mortality. In particular, on the control plot and without a fire for 10 years 53% of V class trees have dropped out. Partly accelerated death of IV-V Kraft class trees is attributed to their relatively thinner bark in comparison with thicker prevailing pines.

The least number of dead wood is marked among I-II Kraft class trees prevailing in canopy. In the period of research only 1 tree of I Kraft class died after a fire of weak intensity. The number of dead trees of II Kraft class, after a fire of average and weak intensity, has made up 6.8 and 5.4% from total number of trees on PP, respectively, or 13.2 and 12.9% from the number of II Kraft class trees. On the control plot, dead wood among trees of I-II Kraft classes was not revealed: the trees most oppressed in growth (IV-V Kraft classes), due to which, basically, natural mortality descends in healthy stands, perished.

Upper mortality, for the account of decline of I-III Kraft class trees, is ceased only in 7 years after a fire of weak intensity. After surface fire of average intensity upper mortality of trees was marked even in 2001. According to the results obtained by A.F.Agafonov (Agafonov 1989) upper mortality of trees after a surface fire is observed during 8-10 years. However, it is caused not so much by damage by fire, as invading of weakened trees by stem pests (big and small pine bast beetle *(Tomicus (Blastophagus) piniperda L.* and *T. minor Hart.)*, top bark beetle *Ips acuminatus Gyll. et al.*) and lesion by fungal diseases (resin cancer *Peridermium pini Lev. et Kleb.*, zonated tinder fungus *Fomitopsis pinicola Karst* et al.).

According to the results obtained by I.E.Richter (Richter 1996), as a result of direct or indirect influence of surface fires in stands, which have kept vitality, changes of tree increment, which is shown in: 1) an increase or a decrease in the increment resulting fire wounds, fire swamping, changes in the physical and chemical properties of the soil; 2) building of soil-light stimulation of increment under the influence of post-fire mortality; 3) a decrease in the increment under the influence of entomo- and phytopests etc. are observed. The dynamics of absolute and relative values of the annual increment in diameter of I-II Kraft class pine trees on the objects of research for 20 years is given in Figure 3.

A decrease in the tree increment in diameter begins after damage caused by fire (Fig. 3A). The degree of a decrease in the increment is determined by the intensity of fire influence. In stands damaged by a fire of average intensity the difference in absolute values of the increment for the 5-year period after a fire (1995-1999) in comparison with pre-fire period (1987-1991) comprised 66.5%. In comparison with the

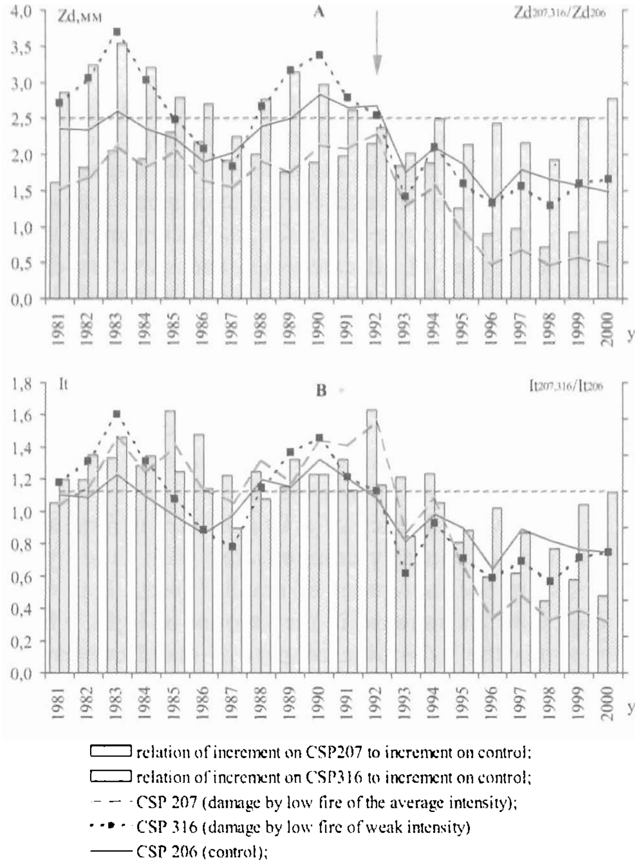

Figure 3. The dynamics of pine increment Zd (A) and indexes of increment It (B) in diameter of I-II Kraft class trees on plots after surface fires of the average (CSP 270), weak (CSP 316) intensity and on the control (CSP 206)

control plot, the difference in average attitudes of the increment in diameter for the same periods before and after a fire made up 50.1%. The surface fire of weak intensity exerted smaller influence on the increment. The difference in absolute values of the increment for the same periods before and after surface fire of weak intensity constituted 46.7% in comparison with the control – 18.7%.

The analysis of changes in relative values of the increment (Fig. 3B) shows that I_t on plots, which had been exposed to pyrogenic influence, also began to decrease after a fire. The difference of I_t on plot after a surface fire of average intensity on average for 5-year period (1995-1999) has decreased 65.9% as compared with a pre-fire period (1987-1991). In comparison with the control plot the difference in the values of I_t for the same periods before and after a fire has constituted 50.7%. After a surface fire of weak intensity the difference in relative values of the increment for the same periods before and after a fire has made up 45.2% in comparison with the control plot – 18.9%.

The dynamics of the increment of various Kraft class trees has essential differences (Fig. 4). On all plots the greatest values of the increment in diameter are marked on trees of I Kraft class, the smallest values are typical of trees of III Kraft class. A fire has affected the increment of I and II Kraft class trees most considerably. On the plot after a surface fire of average intensity, the average annual increment for the period 1995-1999 in comparison with the pre-fire increment for the period 1987-1991 for trees of I Kraft class

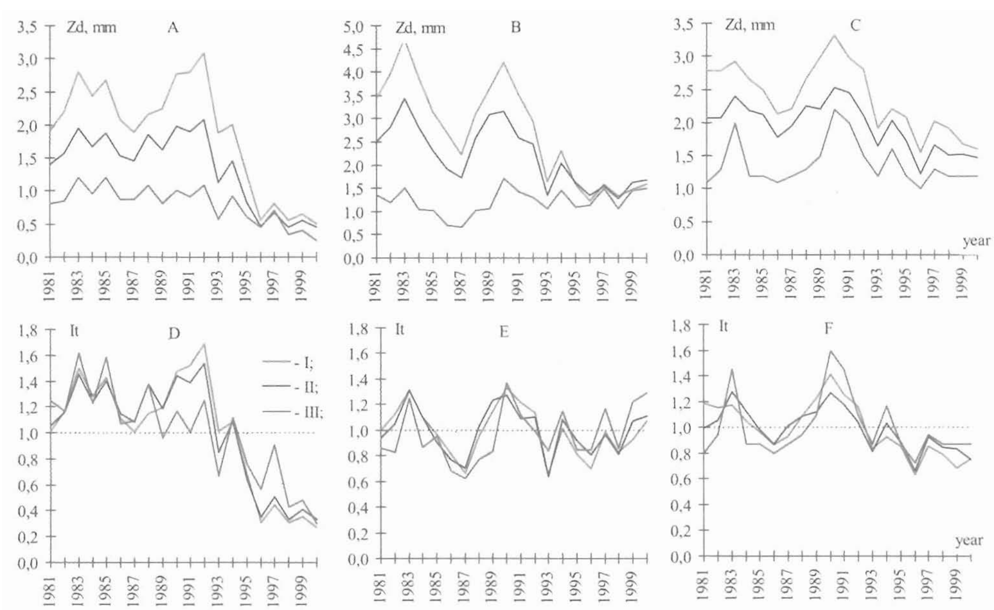

Figure 4. The dynamics of increment Zd (A,B,C) and indexes of increment It (D, E, F) in diameter of pine trees of various Kraft classes on plots after surface fires of average (A, D) and weak (B, E) intensity and on the control (C, F)

has decreased 67.6% (3.1 times); for II Kraft class– 66.0% (2.9 times); for III Kraft class – 46.1% (1.9 times). On the plot after a surface fire of weak intensity for the same periods of research for trees of I Kraft class the increment has decreased 56.7% (2.3 times), for I Kraft class– 43.5% (1.8 times), for III Kraft class – has even increased 6.3% (1.1 times). The increase in the increment of trees of III Kraft class descends, apparently, due to a decrease in the competition for light and due to other reasons owing to decline of a part of prevailing trees in stand canopy.

Trees of different diameter also react to a fire differently (Fig. 5). After a surface fire of average intensity the regression dependence of the average annual increment for 5-year period prior to a fire (1987-1991) and after a fire (1995-1999) on the diameter of tree is described by a parabolic curve of the 2-order with high coefficient of determination (r^2=0.93 (prior to fire) and r^2=0.69 (after fire)). The coefficient of the correlation between the increment for the period 1987-1991 (prior to fire) and diameter of tree is equal 0.56. After a fire, the correlation coefficient has decreased to 0.17 (between increment for period of 1995-1999 and diameter of tree). On a plot after a fire of weak intensity the coefficients of the correlation between the diameter of tree and increment for the same period before and after a fire are 0.32 and 0.08, respectively. On the control plot, the correlation coefficients for the same periods are 0.30 and 0.29, respectively.

Thus, the influence of a pyrogenic factor on pine stands practically destroys the dependence "size of

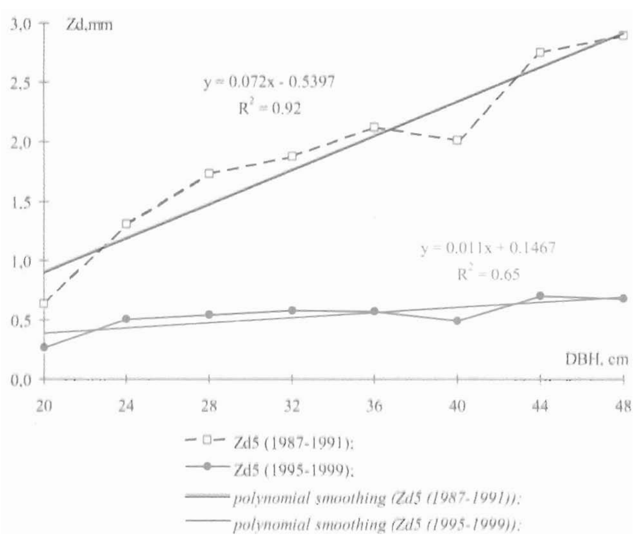

Figure 5. Dependence of the average annual increment of a pine from diameter of trees on plot after surface fire of average intensity for the 5-year periods prior to a fire (1987-1991) and after a fire (1995-1999)

tree – size of the radial increment", which is regulated by competitive relations between trees of various social ranks (Fig. 4 A, B, C).

Without influence of a fire larger trees are characterized by big sizes of increment in comparison with small trees (Fig. 5). The increment of the largest trees (48 cm) prior to a fire exceeded that of small pines (20 cm) 4.6 times. As a result of a fire, the increment of trees decreases. Trees of all categories and sizes are damaged. However after a fire, the increment of large trees exceeded that of small trees only 2.7 times. The increment of large trees has decreased 4.4 times, and small – only 2.5 times. Consequently, larger trees are more sensitive to a fire, and losses of the increment of stand mainly occur because of their reaction to the influence of an external destabilizing factor.

Negative influence of a fire on the increment of large trees is partially compensated with time by an increase in the increment of smaller trees. It is connected with an increase in the amount of light, which penetrates the subordinated part of stand canopy as a result of an increase in defoliation and decline of a part of large trees. The complex of conditions for a soil-light increment at residuary in canopy of stand of III-V Kraft class trees is formed.

Thus, an increase in defoliation and a decrease in tree increment (including the increment in diameter) are important forms of reaction of stands to surface fires. There is no common opinion regarding narrowness of connection between these parameters. Some authors state that there is just a weak correlation between defoliation of tree and its increment (Kramer 1986; Watzig 1991), others indicate that this connection is rather close (Huber 1987) (is quoted Ozolincius 1996).

Connection between defoliation and the radial increment becomes closer, when the analysis is conducted on high values of defoliation (Ozolincius 1996). On the control plot, where the defoliation of stand averaged at 16.5% (at a maximum of 40 % only for 1 tree in 1992) for the whole period of research, significant correlation between the increment and tree defoliation was not observed (Table 3).

On the plot after a surface fire of weak intensity for the period of research the average defoliation of stand did not exceed 27%. Only on separate trees in various years it reached 50%. Therefore, as on the control, statistically significant correlation between the tree increment on diameter and defoliation of the current year was not revealed.

On the plot after a surface fire of average intensity the average defoliation of stand was found to be 38 and 43% (in 1997, respectively for the whole crown and top third of crown). In some years, the maximal

Table 3. The coefficients of the correlation between defoliation and tree increment on diameter on plots after surface fires of average and weak intensity and on the control plot

Parameters	Number of trees	Increment in diameter	
		Relative	Absolute, mm
The stand damaged by surface fire of average intensity			
Defoliation of the whole crown of current year	715	-0.33	-0.33
Defoliation of top third of crown of current year	715	-0.41	-0.38
Defoliation of the whole crown of last year	650	-0.50	-0.48
Defoliation of top third of crown of last year	650	-0.53	-0.49
Sum defoliation of the whole crown for last 3 years	585	-0.52	-0.50
Sum defoliation of top third of crown for last 3 years	585	-0.56	-0.51
The stand damaged by surface fire of weak intensity			
Defoliation of the whole crown of current year	706	-0.04*	-0.04*
Defoliation of top third of crown of current year	706	-0.02*	-0.03*
Defoliation of the whole crown of last year	647	-0.16	-0.12
Defoliation of top third of crown of last year	647	-0.12	-0.10
Sum defoliation of the whole crown for last 3 years	589	-0.17	-0.15
Sum defoliation of top third of crown for last 3 years	589	-0.14	-0.19
Stand on control plot			
Defoliation of the whole crown of current year	330	-0.01*	-0.08*
Defoliation of top third of crown of current year	330	0.01*	0.01*
Defoliation of the whole crown of last year	300	-0.10*	-0.11*
Defoliation of top third of crown of last year	300	-0.05*	-0.02*
Sum defoliation of the whole crown for last 3 years	270	-0.04*	-0.11*
Sum defoliation of top third of crown for last 3 years	270	-0.01*	0.01*

* - Dependence between parameters is not statistically significant

values of defoliation in surveyed trees reached 85% for all crowns and even 90% – top third of crown. Therefore, a correlative dependence between the parameters of defoliation and the tree increment in diameter has been revealed, which is characterized by statistically significant negative correlation coefficients (Table 3). The coefficients of the correlation between absolute values of increment and tree defoliation of current year for all data file over a 10-year period of research in separate years reached -0.40 and -0.46 (respectively for defoliation of all crowns and top third of crown).

Negative influence of fire in the form of a decrease in the diameter increment is strengthened with an increase in a degree of tree defoliation and mostly is shown in the loss of needles of the current and last year (Ericsson, Larsson & Tenow 1980). Therefore, correlation coefficients between the increment and defoliation of the last year were calculated. On the plot after surface fire of average intensity negative correlation dependence of the increment in defoliation of the last year is characterized by higher coefficients of the correlation, than from defoliation of the current year (Table 3).

Average lifetime of pine needle in Byelorussia is 3 years (Ivanov *et al* 1975, Stepanchik & Savluk 1994). Therefore, an attempt was made to estimate the correlation between absolute values of the increment and sum defoliation of the current year and 2 previous years. It turned out that after a surface fire of average intensity the values of correlation coefficients between increment and sum defoliation for 3 years have increased in comparison with defoliation of the current year and have attained 0.50 and -0.51 for the whole crown and its top third, respectively.

In the stand after a surface fire of weak intensity the coefficients of the correlation between the tree increment in diameter and defoliation of the last year and sum defoliation over a period of 3 years have also increased. It allows us to conclude about statistically significant, though weak dependence between these parameters.

Thus, there is a significant negative correlation between the parameters of defoliation and the increment of trees damaged by surface fire, allowing for regression analysis between these parameters. The analysis of dependence of the increment on tree defoliation on plot after a surface fire for a 10 year period of research shows that the loss by tree of photosynthetic device results in the loss of the increment of wood (Fig. 6, Table 4). This dependence is not rectilinear and functional. Pines with defoliation 5% have smaller increment, than trees with defoliation 10%, and maximal increment was marked on separate trees with defoliation of the current year 25-30% for the whole crown and 35% – top third of crown and also on trees with defoliation of the last year – 20-25%.

A decrease in the annual increment of stand in diameter descends with an increase in defoliation by more than 10%. Relative stabilization comes with defoliation reaching 35-40%. With defoliation rising over 80-85%, a sharp decrease in the increment is also observed. The increment falls down to 0 at 95-100% of crown defoliation of trees. A. Augustaitis and E. Bartkevichius (Augustaitis & Bartkevichius 1990), and R.Ozolincius (Ozolincius 1996) have obtained similar

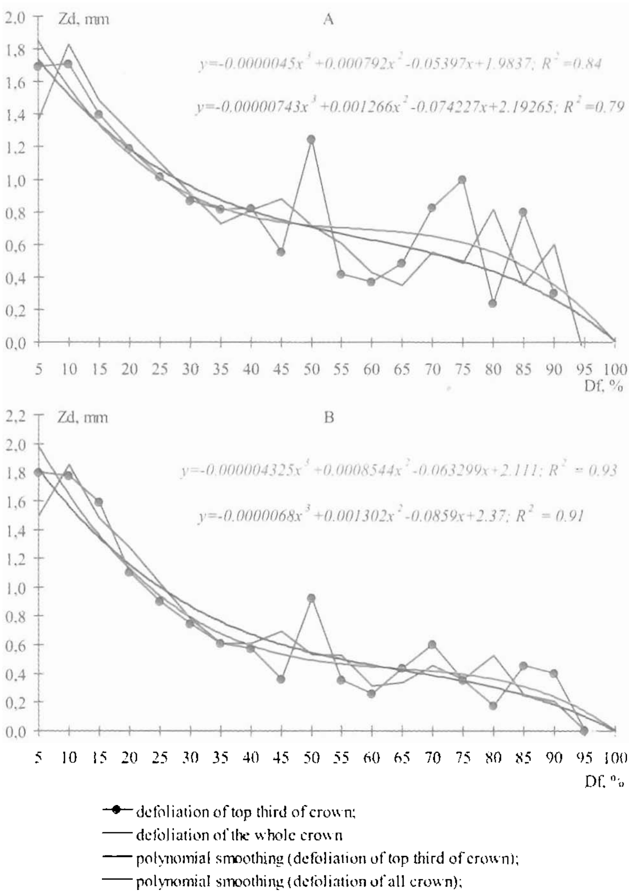

Figure 6. Dependence of the average tree increment in diameter (Zd) on defoliation (Df) of the top of crown and the whole crown of current (A) and last (B) years after surface fire of the average intensity

results in research of the influence of crown defoliation on the increment of pine forests, damaged by industrial emissions.

Regression dependence of the tree increment in diameter on the current year defoliation of all crowns and top third of crown is approximated by a parabolic curve 3-rd order with high coefficients of determination (Fig. 6):

$Zd=-7{,}43*10^{-6}*Df_{3/3}^{3}+1.266*10^{-3}*Df_{3/3}^{2}-7.4227*10^{-2}*Df_{3/3}+2.19265, \quad r^2=0.79;$

$Zd=-4.5*10^{-6}*Df_{1/3}^{3}+7.92*10^{-4}*Df_{1/3}^{2}-5.397*10^{-2}*Df_{1/3}+1.977, \quad r^2=0.84;$

The regression dependence between the tree increment in diameter and last year defoliation of the whole crown and top third of crown is also approximated by parabolic curve of the 3-rd order:

$Zd=-6.8*10^{-6}*Df_{3/3}^{3}+1.302*10^{-3}*Df_{3/3}^{2}-8.59*10^{-2}*Df_{3/3}+2.37, \quad r^2=0.91;$

$Zd=-4.325*10^{-6}*Df_{1/3}^{3}+8.544*10^{-4}*Df_{1/3}^{2}-6.3299*10^{-2}*Df_{1/3}+2.111, \quad r^2=0.93;$

Zd is the tree increment in diameter, mm; $Df_{1/3}$ is defoliation of top third of crown; $Df_{3/3}$ is defoliation of the whole crown.

Distribution of size of the annual increment in diameter of trees with defoliation of 25-55% are positively asymmetric and have the increased excess, which reflect domination of similar to average values, in spite of high variation in aggregate as a whole (Table 4)

The following tendency has been detected in the analysis of distribution of maximal values of the tree increment depending on defoliation: with defoliation increasing up to 50% relative stability in fluctuations of maximal values is marked; sharp fall of the increment is observed at transition of boundary in 50% of defoliation. The coefficient of variation in the tree increment in diameter is higher in case an increase in defoliation is up to 50%. The increase of a coefficient of variation is caused by a decrease in average values of the increment at high maximal values. The greatest coefficients of variation are marked when defoliation of the whole crown is found to be 45-50%, at defoliation of top third of crown – 50-55%. Variation in the tree increment in diameter begins to be reduced at an increase in defoliation above these limits (Table 4).

Discussion and conclusions

Surface fires produce a strong effect on the state of stands. Reaction of stands to surface fires of various intensities is shown in an increase in defoliation and number of damaged trees, deterioration of vital state of stands, a decrease in the increment. The damage rate of stands is determined by the intensity of a fire.

Damage of stands by fire brings to death a part of trees, the number of which depends on the intensity of a fire. The maximum of accumulation of dead wood in pine forests damaged by surface fires is observed in the first two post-fire years. In the future, this process is slowed down. Trees of all Kraft classes dry. The greatest amount of dead wood is among oppressed trees of V Kraft class, the smallest – among trees of I-II Kraft classes.

The general improvement of the state of stands in the form of a decrease in the degree of defoliation, reestablishment of the number of undamaged trees and a decrease in the number of damaged trees, increases of indexes of vital state of stands is observed in 5 years after a fire of average intensity and in 2 years – of weak intensity.

Considerable differences are observed in the dynamics of the increment of various Kraft class trees in the intact pine forests: the greatest values of the

Table 4. The increment in diameter of I-II Kraft class trees at various degrees of defoliation for the period 1990-2000 (on the plot after surface fire of average intensity)

Defoliation,%	Number of trees	Increment in diameter, mm			Excess	Asymmetry	Coefficient of variation	Number of trees	Increment in diameter, mm			Excess	Asymmetry	Coefficient of variation
		Average	Min	Max					Average	Min	Max			
Defoliation of the current year														
	The whole crown							Top third of crown						
5	10	3.38±0.47	1.35	5.05	-1.90	-0.21	43.7	9	3.24±0.67	1.35	6.85	-0.47	0.94	61.7
10	46	3.93±0.28	0.80	8.00	-0.71	0.41	48.8	56	3.84±0.23	0.75	7.30	-0.49	0.16	44.5
15	91	2.86±0.18	0.25	7.00	-0.66	0.28	58.6	76	3.06±0.21	0.30	8.00	-0.42	0.36	58.8
20	107	2.44±0.17	0.15	7.65	-0.56	0.67*	71.4	67	2.67±0.20	0.25	8.55	1.97*	1.07*	62.4
25	96	2.09±0.17	0.15	8.55	3.23*	1.71*	81.6	82	2.29±0.20	0.15	7.65	-0.25	0.93*	79.9
30	80	1.90±0.18	0.15	8.55	2.79*	1.65*	86.7	76	1.94±0.18	0.15	7.90	2.19*	1.39*	79.0
35	60	1.71±0.18	0.15	6.15	1.22*	1.26*	82.2	73	1.56±0.17	0.15	8.55	7.81*	2.57*	94.8
40	43	1.77±0.24	0.15	6.15	1.22*	1.37*	89.1	56	1.72±0.20	0.25	6.15	0.83	1.23*	85.7
45	28	1.05±0.23	0.15	6.25	12.44*	3.24*	116.1	44	1.92±0.26	0.15	6.55	1.26	1.45*	90.9
50	14	2.49±0.65	0.15	6.55	-1.27	0.77	97.5	22	1.43±0.31	0.15	6.00	3.90*	1.95*	101.3
55	9	0.89±0.16	0.20	1.45	-1.82	-0.08	54.7	11	1.20±0.42	0.30	5.05	6.78*	2.56*	115.3
60	5	0.73±0.27	0.25	1.75	2.78	1.68*	82.9	10	0.85±0.17	0.15	1.75	-1.11	0.19	63.2
65	11	0.97±0.11	0.30	1.50	-0.29	-0.50	37.0	9	0.69±0.15	0.20	1.45	-0.92	0.69	65.0
70 и >	5	1.24±0.32	0.35	2.00	-2.56	-0.46	58.1	14	1.07±0.14	0.30	2.00	-1.02	0.14	48.7
Defoliation of last year														
	The whole crown							Top third of crown						
5	9	3.59±0.48	1.50	5.45	-1.40	-0.18	40.0	8	3.54±0.74	1.50	6.90	-0.98	0.73	59.5
10	42	3.99±0.26	0.80	7.45	-0.62	0.22	42.7	52	3.83±0.24	0.40	7.90	-0.09	0.30	44.4
15	77	3.31±0.19	0.25	7.90	0.07	0.36	51.0	71	3.09±0.19	0.40	7.15	-0.74	0.15	53.1
20	92	2.28±0.16	0.15	6.55	-0.04	0.81*	67.1	58	2.69±0.24	0.25	8.55	1.13	1.06*	68.2
25	90	1.84±0.16	0.15	8.55	5.20*	2.08*	82.2	70	2.16±0.19	0.15	6.55	0.44	1.10*	75.0
30	75	1.63±0.15	0.15	6.25	2.80*	1.71*	79.9	67	1.63±0.15	0.15	5.90	2.97*	1.57*	73.4
35	55	1.33±0.14	0.15	5.50	3.92*	1.70*	78.0	68	1.30±0.13	0.20	5.40	6.32*	2.32*	79.6
40	40	1.17±0.15	0.20	4.90	5.88*	2.29*	82.8	54	1.29±0.14	0.15	5.50	4.75*	1.88*	79.4
45	28	0.61±0.05	0.15	1.25	-0.41	0.18	45.5	41	1.49±0.20	0.20	5.05	1.20	1.28*	84.2
50	14	1.84±0.49	0.15	6.00	0.80	1.34*	100.2	19	1.06±0.13	0.25	2.80	4.77*	1.72*	52.5
55	9	0.71±0.13	0.20	1.30	-1.23	0.29	57.3	11	1.05±0.50	0.15	6.00	10.61*	3.23*	157.4
60	5	0.51±0.17	0.15	1.10	1.19	1.14	73.2	9	0.62±0.11	0.15	1.10	-1.17	-0.25	54.5
65	10	0.87±0.16	0.30	1.65	-1.17	0.60	57.6	9	0.67±0.18	0.15	1.60	-1.18	0.78	82.8

increment are typical of trees of I Kraft class, the smallest – III-V. Surface fires affect the increment of largest trees of I and II Kraft classes most heavily. Basic losses in the increment of wood descend because the reaction of the prevailing part of stand to the influence of a pyrogenic factor. Negative influence of a fire on the increment of large trees partly is compensated by an increase in the increment in smaller pines due to a decrease in competition with damaged trees of I-II Kraft classes and decline of a part of stand.

Statistically significant negative correlation between the annual pine increment in diameter and defoliation is marked on plots damaged by surface fires. The values of correlation coefficients increase along with the intensity of a fire. The closest connection is marked between the increment and total defoliation over 3 years and defoliation of the last year.

The interrelation between defoliation of crown and the increment in diameter is not rectilinear. The results of long-term survey on a plot after a surface fire of average intensity reveal regression dependence of absolute values of the increment in diameter on tree defoliation of the current and last years. This dependence is approximated by parabolic curve of the 3-rd order with high coefficients of determination.

It is important, that surface fires even of relatively low intensity, not destroying stands, substantially change the system of competitive interactions and productive structure in coenoses of pine. These changes are realized predominantly through defoliation of tree crowns, mainly in a prevailing part of stand canopy. The defined value, undoubtedly, has also death of a part of trees. Negative trends of an increase in the degree of defoliation and a decrease in the increment are kept in stands from 2 till 5-7 years depending on the intensity of a fire. However, even in 10 years after a fire, the system of relations between trees as well as level of wood production is not restored.

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References

Gromtsev, A. 2002. Natural disturbance dynamics in the boreal forests of European Russia: a review. – Silva Fennica, vol.36 (1): 41-55.

Ericsson, A., Larsson, S. & Tenow, O. 1980. Effects of early and late season defoliation on growth and carbohydrate dynamics in scots pine. – J. Appl. Ecol., 17 (3): 747-769.

Esseen, P.-A., Ehnstrom, B., Ericson, L. & Sjoberg, K. 1997. Boreal forests. Ecol. Bull., vol. 46: 16-47.

Muller, E. & Stierlin, H.-R. 1990. Tree crown photos (with percentages of foliage loss) Swiss federal institute for forest, snow and landscape research, Birmensdorf. 2nd Rev. and extended. 132 p.

Ozolincius, R. & Stakenas,V. 1996. Tree crown defoliation: influencing factors. Baltic Forestry, 2 (1): 48-55

Ryan, K. 2002. Dynamic interactions between forest structure and fire behavior in boreal ecosystems. – Silva Fennica, vol. 36 (1): 13-39.

Sudnik, A. 2001. Role of low fires in natural dynamics of pine phytocenosises in Belarus. – Актуальні проблеми ботаніки та екології. Матеріали конференції молодих вчених-ботаніків Україні. Ніжин. сс. 105-106.

Агафонов, А.Ф. 1989. Усыхание чистых сосняков по пожарищам [Decline of clean pine forests on site of fire]. Лесн. Хоз-во. №12: 37-39 (in Russian).

Аугустайтис, А.А., Барткявичюс, Э.Л. 1990. Влияние дефолиации кроны на прирост поврежденных промышленными выбросами средневозрастных деревьев сосны обыкновенной [Influence of crown defoliation on a increment of average-age trees of Scots pine damaged by industrial emissions]. – Тез. 11 коми респ. молод. науч. конф. Сыктывкар, pp. 121 (in Russian).

Волков, А.Д., Громцев, А.Н., Саковец, В.И. 1997. Коренные леса северо-запада таежной зоны России: природные особенности, современное состояние и проблемы сохранения. Препринт доклада [Radical forests of northwest of a taiga zone of Russia: natural features, a modern condition and problems of preservation]. Петрозаводск, pp. 33 (in Russian)

Демаков, Ю.П., Калинин, К.К., Иванов, А.В. 1982. Послепожарный отпад в сосняках и его прогнозирование [Post-fire mortality in pine forests and its forecasting]. Лесн. хоз-во. № 6: 51-53 (in Russian)

Зайцев, Г.Н. Математика в экспериментальной ботаники [Mathematics in experimental botany]. – М.: 1990. – 263 с.

Зябченко, С.С. 1984. Сосновые леса Европейского Севера [Pine forests of Europe North]. Ленинград. 248 с. (in Russian)

Иванов, А.Ф., Дерюгина, Т.Ф., Кравченко, Л.В. и др. 1975. Биология древесных растений [Biology of wood plants]. Минск.: Наука и техника, 264 с. (in Russian)

Лесные экосистемы и атмосферное загрязнение [Forest ecosystem and atmospheric pollution]ю 1990/ под ред. В.А.Алексеева. Ленинград: Наука 200 сс. (in Russian)

Меркуль, Г.У., Грыгор'еу, В.П., Лахтанава, Л.І., Рыхтэр, І.Э. Лесаводства: Вучэбны дапаможнік [Forestry. The manual] – Мінск.: БДТУ, 2001. – 434 с. (in Byelorussian)

Озолинчюс, Р. 1996. Хвойные – морфогенез и мониторинг [Conifers: morphogenesis and monitoring]. – Каунас. 340 сс. (in Russian)

Рыхтэр, І.Э. 1996. Лясная піралогія з асновамі радыеэкалогіі: Вучэбны дапаможнік [Forest pyrology with bases of radioecology: the manual]. – Минск. 290 с. (in Byelorussian).

Санников, С.Н., Санникова, Н.С. 1985. Экология естественного возобновления сосны под пологом леса [Ecology of the natural regeneration of the Scots pine under forest cover]. – Москва. 152 с. (in Russian).

Степанчик, В.В., Савлук, С.В. 1997. Состояние и рост культур сосны в условиях снижения техногенного пресса [State and growth of cultures of a pine in conditions of decrease of technogenic press]. Лесная наука на рубеже XXI века: Сб.науч. тр. ИЛ НАНБ. Гомель: ИЛ НАНБ. Вып.46. сс. 387-390. (in Russian).

Судник, А.В. 2002. Факторы, определяющие формирование разновозрастных сосняков в Беларуси [The factors, which determine formation of multi-age pine forests in Belarus] – Сб. тез. докл. 6-ой Пущинской школы-конференции молодых ученых "Биология – наука 21го века". Пущино. Том 2. сс. 174-175. (in Russian).

Усеня, В.В. 2000. Влияние почвенных пожаров на отпад деревьев в сосновых насаждениях [Influence of soil fires on mortality of trees in pine plantings]. Леса Беларуси и их рациональное использование. Материалы конференции. Минск сс 226-229 (in Russian).

Усеня, В.В., Чурило, В.С. 2001 Динамика послепожарного отпада деревьев в сосновых насаждениях [Dynamics of pos-tfire mortality of trees in pine stand]. Проблемы лесоведения и лесоводства: Сб. науч. тр. ИЛ НАНБ, Гомель: ИЛ НАНБ. Вып. 52. сс. 382 (in Russian).

Хмелевский, В.И. 1999. Динамика верхних ярусов растительности в сосновых фитоценозах национального парка "Припятский" [Dynamics of the top layers of vegetation in pine phytocenosises of national park "Pripiatsky"]. Биологическое разнообразие Национального парка "Припятский" и других особо охраняемых природных территорий. Сб.науч.тр. Туров. сс. 104-107. (in Russian).

Шарай, О.Н. 1999. Послепожарные сукцессии нижних ярусов растительности в суходольных сосновых лесах Национального парка "Припятский" [Post-fire succession of low layers of vegetation in dry pine forests of national park "Pripiatsky"]. Биологическое разнообразие Национального парка "Припятский" и других особо охраняемых природных территорий. Сб.науч.тр. Туров. сс. 108-118 (in Russian).

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ВЛИЯНИЕ НИЗОВЫХ ПОЖАРОВ НА СОСТОЯНИЕ ДРЕВОСТОЕВ В СОСНЯКАХ МШИСТЫХ *(PINETUM PLEUROZIOSUM)*

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Резюме

По результатам многолетних наблюдений изучены последствия влияния низовых пожаров средней и слабой интенсивности на состояние древостоев сосны в сосняках мшистых по величине их прироста и дефолиации и выявлена зависимость между этими показателями, характеризующими состояние и продуктивность деревьев, после воздействия огня.

Реакция древостоев на низовые пожары различной интенсивности проявляется в увеличении дефолиации и количества поврежденных деревьев, ухудшении жизненного состояния древостоев, снижении прироста. Повреждение древостоев огнем приводит к гибели части деревьев, доля которых зависит от интенсивности пожара. Максимум накопления сухостоя в поврежденных низовыми пожарами сосняках наблюдается в первые два послепожарных года, а в дальнейшем этот процесс замедляется. Общее улучшение состояния древостоев в форме снижения степени дефолиации, увеличения количества неповрежденных и уменьшении поврежденных деревьев, увеличения индексов жизненного состояния древостоев наблюдается уже через 5 лет после пожара средней интенсивности и через 2 года - слабой интенсивности.

Между годичным приростом сосны по диаметру и дефолиацией отмечена достоверная отрицательная корреляционная связь на участках, поврежденных низовыми пожарами. По результатам многолетних наблюдений на участке после низового пожара средней интенсивности выявлена регрессионная зависимость абсолютных значений прироста стволов по диаметру от дефолиации деревьев текущего и прошлого годов.

Ключевые слова: сосняки, низовой пожар, интенсивность пожара, прирост по диаметру, дефолиация дерева