Comprehensive assessment of wildfire danger in exclusion zone of Chornobyl NPP

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The comprehensive evaluation of forest fire danger in the exclusion zone is done. The frequency of large wildfires cases indicates a high probability of uncontrolled fires occurrence in the coming years. The deterioration of trees health conditions and accumulation of clutter increases the wildfire hazard and causes of fires of high intensity. Wildfire cases depending of complex fire weather index are analyzed. The local fire weather danger scale is constructed.

Keywords: wildfire, Exclusion Zone, Chornobyl NPP, wildfire statistic, fire danger, complex fire weather index

The stability of forest ecosystems of the exclusion zone is essential for providing radiation and ecological safety of Ukraine. After the accident forest plantations deposited most of the radioactive fallout compared to other types of terrain. Radiological factor is the main factor that determines the features of specialized management in the exclusion zone and affects the forest. Transition from intensive forestry before the accident, which included thinning, sanitary felling, clutter cleaning on the territory of the exclusion zone to the regime of passive protection of forests in which artificial plantations grow in uncontrolled mode, causes a progressive increase of fire danger [4, 6, 3 8, 2].

High levels of contamination in the exclusion zone and risks of radionuclide migration in the atmosphere with the smoke from wildfires cause the need of forest fire prevention. This also stated in the current normative base [11]. Despite the special regime, which limits the presence of people in contaminated areas, natural fires occur regularly in the exclusion zone. Research shown that fires in contaminated forests accompanied by secondary transfer of radionuclides and are danger to firefighters, personnel of the exclusion zone and, in case of catastrophic wildfire, for

the population outside the zone [1, 2]. This determines the need of complex research and evaluation of fire danger in forests of the exclusion zone.

Purpose of research - determine the current state of forest fire danger in the exclusion zone of Chornobyl NPP.

Materials and methods of research. Acts of wildfires cases of SSCE "Chornobylska Puscha" for the period 1993-2011 years, the forest fund database of the exclusion zone, climatic data from the meteorological station of Chernobyl for 1993-2009 years were used for wildfire danger analysis. Data of 30 temporary sample plots of pure pine stands in predominant site conditions types were used for fuel loads evaluation. In research used methodology of wildfire statistic analysis proposed by Dusha-Gudym S. I., Zibtsev S. V. [2, 5]. Fire weather risks were analyzed by the methods of fire danger local scales constructing of M. P. Kurbatskyi [14]. Obtained data have been processed with statistical analysis methods. Assessment of ground fuel was obtained with FIREMON methodology [13]. Ground fuel were divided on forest duff (litter and duff) and deadwood (branches and trunks of trees of different diameters: 1-hr - $d \leq 0,6$ cm, 10-hr - d = 0,7-2,54 cm, 100-hr - d = 2,55-7,62 cm, 1000-hr - $d > 7,62$ cm) [13].

Results of research. Long-term analysis of wildfires cases shows that the number of fires and burned per year generally tends to decrease (Fig. 1). In 1995, there were 116 cases of fires in the area of 756 ha, in 2011 - 38 cases per area 40,27 ha. These data show decrease in the number of fire sources during analyzed period in the exclusion zone. Reduction of fires area in recent years shows the improvement of the fire protection system, mainly in the levels of detection, localization and fire suppression.

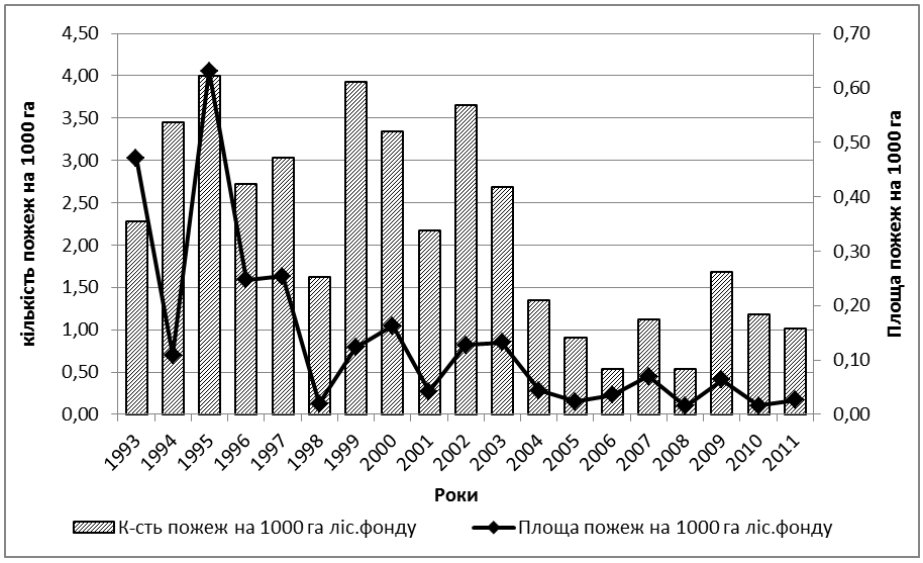

Figure 1. Ratios of long-term dynamics of wildfires numbers and areas for the period 1993-2011 years

During the analyzed period (1993-2011 years) in the exclusion zone there were 1035 fires, which covered 2632,5 ha of contaminated areas. The average area of fire in the exclusion zone is 2,54 ha, which is higher than the average area in the forests of the State Agency of forest resources of Ukraine – 1,0 hectares [15]. It is caused by 5-6 times lower proportion of number of forest guard in the exclusion zone, limited funding for wildfire protection and complicated forestry and radiation conditions. Fig. 2 and 3 shows the frequency distribution of the number and area of fires.

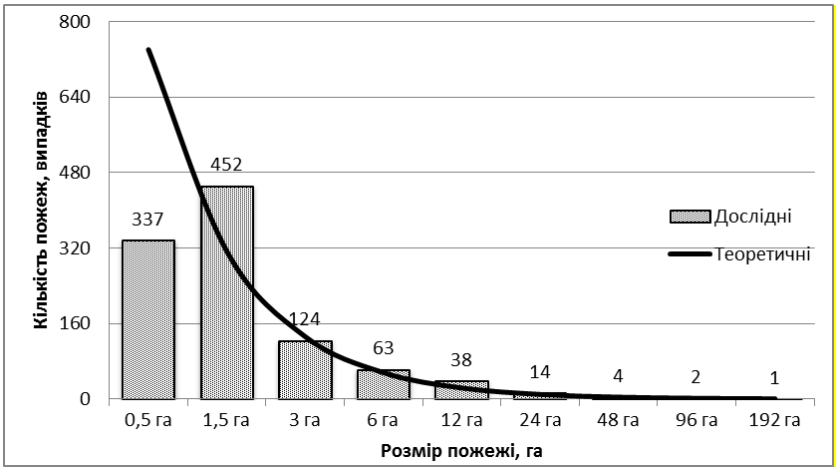

Figure 2. Actual and theoretical frequency distribution of wildfires by groups with various fire size (1993-2011 years)

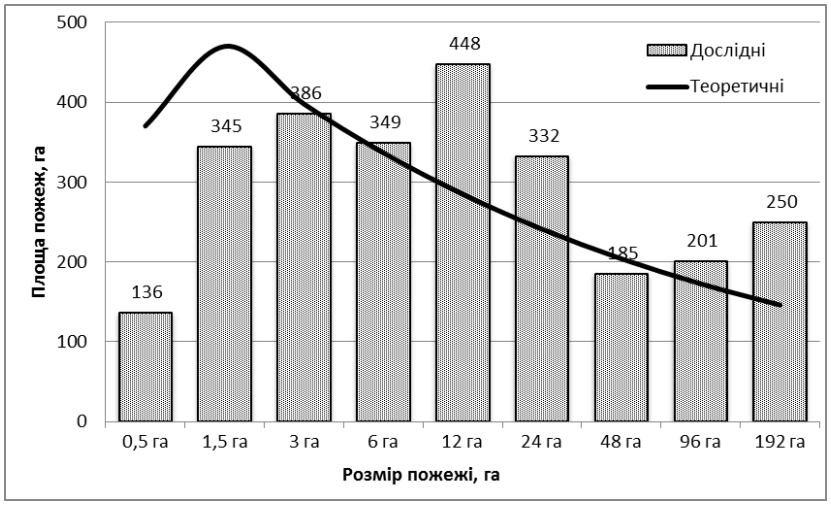

Figure 3. Actual and theoretical frequency distribution of the total wildfire area by groups with various fire size (1993-2011 years)

Analysis of the fire distribution for their size shows that the experimental distribution generally corresponds with theoretical. The differences observed in the number of fires area less than 1 ha, where actual amount is lower than modeled. The reason may be in the inefficient detection of fires in early stages of combustion or significant time of firefighting forces and facilities delivery to fire place.

Majority of fires – 91,6% characterized by an area less than 5 ha, which are classified as "small" according to the Rules of fire safety in the forests of Ukraine. The total area of small fires is 39,3% of burned area of the exclusion zone. Category of large fires, the area of which ranges from 5 to 200 ha, characterized by opposite relationship: with small amount of fires – 1,2% their total area is 29,9%. Large fires recorded in all parts of the exclusion zone, including the most contaminated 10-km zone and the areas close to the "Shelter" [12]. Large fires in the exclusion zone are recorded every 1-2 years, their area is typically less than 20 ha, and most often they occur in the grasslands. Large fires in forests occur less often - every 2-3 years. Fires with area over 50 hectares occur every 5-6 years. Last fire area of more than 5 ha in the exclusion zone recorded in 2009 and area of more than 50 ha in 2007. Due to the periodicity in the coming years should be expected of large fires that under favorable weather conditions can be disastrous.

Large fires carry an increased radiation hazard. Essential for the effective wildfire protection in the exclusion zone is the implementation of prophylactic

measures designed to prevent them. Main directions of fire protection system improvement should be early detection of fires and effective organization of the territory, which would provide the presence of artificial or natural obstacles in the way of possible wildfires.

The development of fires, their intensity, and probability of crown fires development are determined by forest fuel loads and sanitary condition of forest [16]. Possibility of wildfires and their spatial distribution determined the structure of forest fund. These two factors determine the wildfire hazard. For the measurement of the wildfire hazard in the DSKP "Chornobylska Pusha" used "Scale of fire hazard assessment of forest fund lands". According to the forest fund distribution - 66% of forests classified as first class fire hazard, of which 47,6% have contamination above 555 kBq·m^{-2}, 13% of the forests belong to the second class of fire hazard. According to current scale of wildfire hazard assessment almost 80% of forest fund are classified with highest fire danger.

Under insufficient financing of forest industry needs in the exclusion zone inclusion rate of radiation contamination in the natural fire hazard class does not justify itself. This approach does not allow concentrating on the most fire dangerous forest areas both in terms of wildfire prevention (limiting) and suppression. On the other hand the class of fire hazard clearly reflects the increased risk of radiation exposure due to fires.

Because of the lack of thinning in forests of the exclusion zone occurring negative processes, which are expressed in the accumulation of a large number of weakened (8-23%) and dry (10-37%) trees in stands, deterioration coenotic structure, which leads to increase the intensity of intraspecific competition and stagnant growth of trees. The total potential mortality of the trees in the coming years in research stands reach 9-26 m^3 per hectare, which is 2-5 times higher than allowed by current Sanitary regulations in the forests of Ukraine [17]. Future development scenarios of forests with high fire hazard depends on such factors as weather conditions, the probability of forest disease and insects outbreaks, wildfire situation. The worst scenario would be a sharp falling of trees 3-6 state categories as a result of natural

factors (wind, snow, icebreaker, etc.), which is much worsen the sanitary condition of forests and increase their fire hazard.

The sanitary condition of forest stands and clutter data is essential to determine the probability of catastrophic fire. Type of fire and its characteristics will be determined by characteristics of forest fuel, part of which is cluttering. Forest type, forest age and forestry caring predetermined the intensity of fuel accumulation at a certain area. Forestry activities prohibited by law in areas with contamination greater than 555 kBq·m^{-2} and not performed after the accident. This restriction leads to forest density increasing and fuel accumulation.

The results of research showed that loads of ground fuel depends on several factors: stands age, relative density, stands stock, average tree diameter, number of trees etc. Total loads of ground fuel of pine forests in fresh relatively poor site types (subir) higher on 16% compared with fresh poor sites (bir). However, analysis of variance showed that the samples are homogeneous, and the influence of the type of site conditions on the ground fuel loads is not significant (at $\alpha = 0{,}05$, $F = 0{,}56 < F_{cr} = 0{,}814$). In Fig. 4 shows the effect of age and relative density of forests on fuel loads in pure pine stands in fresh bir and subir.

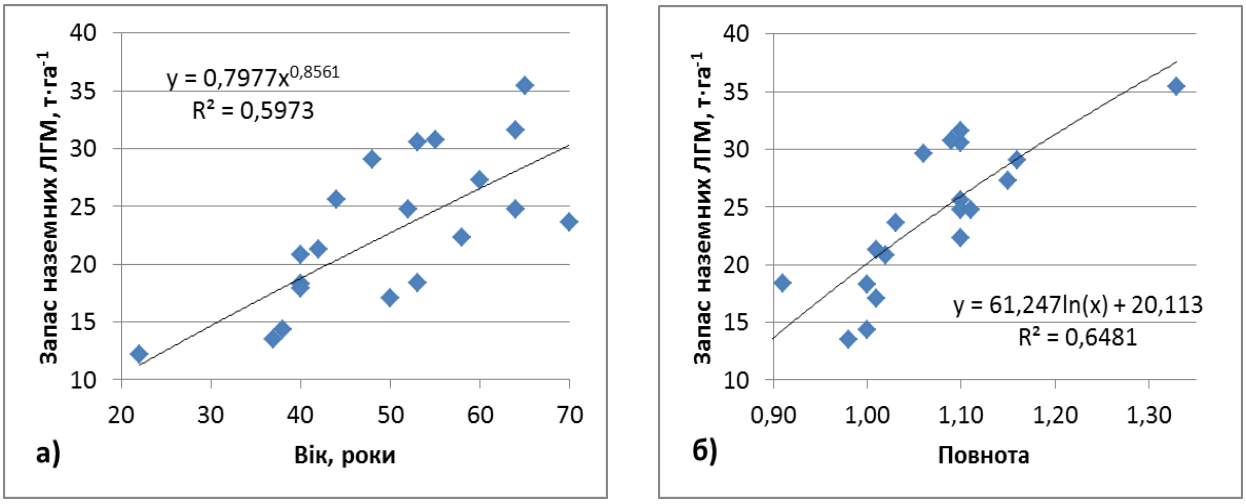

Figure 4. Dependence of ground fuel loads in pure pine stands from the age (a) and relative density (b) in fresh bir and subir

The analysis showed the relation between age and loads of ground fuel. The results indicate a tendency to increase of ground fuel loads with age from 20 to 70

years. Besides there is dependence of growing of ground fuel loads with increasing of relative density of forest stand. On sample plots are observed large fluctuations in ground fuel loads, which are caused by peculiarities of individual stand. Under the same conditions and same stand age differences in ground fuel loads on sample plots can reach to 45%. The greatest influence on ground fuel loads difference in certain areas makes forest duff load.

In addition to total ground fuel loads, which determines the intensity of the fire burning, the important role has their factional structure. In total mass of ground fuel, forest duff load in fresh bir and subir are on average 71-73%. In the duff structure in bir amount of litter is 52% on average, duff 48% and in subir 32% and 68% respectively. This is caused by differences in the rate of decomposition of litter and living herbaceous phytomass cover, which extinction contributes to forest duff loads. Stocks of deadwood, which forms cluttering and affects to vertical distribution forest fuel is 24-27% of total ground fuel load. Stocks of large branches and tree trunks (1000-hr) are on average 8%, in some stands reaching 20% of total ground fuel load. Branches d = 2,54-7,62 cm (100-hr) is about 10%, stock of small twigs (d <2,54, 1 10-hr) ranged from 2 to 12% of total ground fuel load. Stocks of live herbaceous coverage is up to 1,5% of the total ground fuel load.

The determining factor of wildfire is weather conditions. In general, in the exclusion zone regularly formed favorable meteorological conditions for occurrence and spreading of wildfires. In Ukraine to determine fire weather danger conditions using complex weather index [10]. Based on the analysis of the complex fire weather index and wildfires distribution within the fire period we have selected spring and summer-autumn part (Fig. 5).

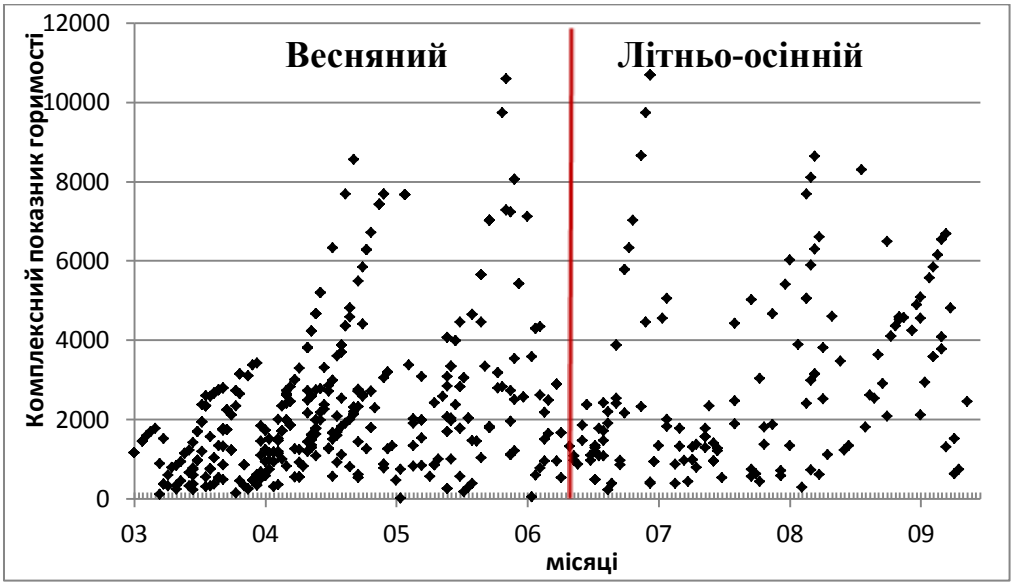

Figure 5. Distribution of wildfires cases by date and size of the complex weather index for the period of 1998-2009 years

Analysis of long-term wildfire distribution by month during fire period shows that most cases occur in May and August. Due to the seasonality of wildfires spring and summer-autumn seasonal fire peaks exist (set by graphical methods). Spring peak is formed due to the accumulation of large amounts of forest fuel during the previous year (dead herbaceous) and its quick drying with increasing air temperature. Certain influence has an early start (mid-March) of fire period compared to the legally prescribed date (April 1). Summer-autumn peak is formed by dry conditions that traditionally formed in July-August (high air temperature, low air humidity, long duration of the growing season).

Analysis of the wildfires number and area distribution within the meaning of the complex weather index individually by parts of fire period showed that in the first part average area of a fire for a range of values of the complex index of 500-1500 is about 2 ha. The fire peak in size and the number of wildfires is established in this range. The opposite situation is observed for the second summer-autumn part of the fire period, where the average area of wildfire in the range of complex weather index of 500-1500 less than 1 ha. Fire peaks are observed at higher meanings of complex fire weather index. Based on the wildfire statistics analysis and the complex fire weather index by the method of M. P. Kurbatskyi were built the local scale of fire weather danger (Table 1).

Table 1 - Local scale of fire weather danger

Fire weather danger class	Meanings of complex fire weather index		
	Spring part of fire season (March 10 – June 9)	Summer-autumn part of fire season (June 10 – October 30)	Current scale
1	<250	<1400	< 400
2	251-1000	1401-3550	401-1000
3	1001-2100	3551-5400	1001-3000
4	2101-2800	5401-6400	3001-5000
5	>2800	>6400	> 5000

According to the table, the current scale underestimates fire weather danger assessment especially for the highest 4 and 5 fire danger classes, where the value of complex fire weather index overestimated to 1,5-1,8 times, while at 3 class of current scale (1001-3000) formed the highest fire danger weather conditions for the spring period. Aforementioned determines the need to revise the current regulations of firefighting services in the exclusion zone in order to improve quick response to wildfire incidents.

Conclusions

During the period from 1993 to 2011 in the exclusion zone registered 1035 cases of fires in the area over 2600 ha, which indicates a permanent presence of sources of fire and high fire danger in contaminated areas. The frequency of large wildfires cases indicates a high probability of uncontrolled fires occurrence in the coming years.

Stocks of deadwood and clutter 2-5 times higher than regulations, which affects the fire state of forest. Due to imperfect fire hazard scale there is a need of it revision. The primary steps of reducing fire hazard should be reducing clutter and high intensity thinning in high density artificial pine plantations. Fire restrictive measures at first must be carried in the forest of low relative density, where due to unfavorable vertical structure of forest fuel there is a high probability of crown fires.

Ground forest fuel loads increased from 10-15 $t \cdot ha^{-1}$ in 40-year-old stands to 30-35 $t \cdot ha^{-1}$ in 65-year-old stands. In general stock of ground fuel is about 70% of

duff and 30% wood clutter. The predominance of small fractions of ground fuel contributes to the development of moving fires of low or medium intensity. Substantial loads of large factions and duff contribute to the development of persistent high-intensity wildfires; determine the damage of forest stand and emissions of radionuclides during a fire.

Current scale underestimates fire weather danger assessment for the highest 4 and 5 fire danger classes, where the value of complex fire weather index overestimated to 1,5-1,8 times. Using of local fire weather scale and revise of the current regulations of firefighting services in the exclusion zone will help improve early detecting and quick response to wildfire incidents.

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