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ECOLOGICAL AND FIRE CHARACTERISTICS OF FOREST ECOSYSTEMS OF THE "DREVLYANSKY" NATURE RESERVE

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Abstract. The paper deals with the ecological and fire situation in the forest ecosystem of the "Drevlyansky" nature reserve. The relevance of this study is that every year Ukraine's forests suffer from fires that destroy significant areas, and forests with radiation pollution suffer from fires the most. The purpose of the study was to investigate the impact of radiation pollution on the fire situation in the forest ecosystem of the reserve. The main task was to distribute the area of the reserve according to the level of radiation pollution and fire hazard classes with and without taking into account radiation pollution. To achieve the results, the area of the forest ecosystem of the Reserve was distributed according to the levels of radiation pollution. The average fire hazard class between 2008 and 2018 ranged from 2.02 to 2.06, which in turn improves the fire situation. However, since the territory of the reserve has been exposed to radiation pollution, the distribution of areas by fire hazard classes has undergone changes between the years of forest management. Thus, the fire situation, taking into account radiation pollution, has deteriorated compared to the area that was not exposed to radiation pollution, and between 2008 and 2018 it improved and amounts to 1.16 and 1.17, respectively. Consequently, the distribution of area by fire hazard classes depends not only on the level of radiation pollution, but also on the taxational specifications (land category, and in plantations it depends on the type of forest vegetation conditions, age, and tree species). The results of the fire that occurred on the territory of the reserve in the spring of 2020 are shown, along with a map of the fire danger of the forest fund of the "Drevlyansky" nature reserve in 2018. The prospect of further research is to re-conduct a study of the level of radiation pollution and to carry out actual measurements every 10 years, without using calculation methods. This will provide a more reliable distribution of forest fund areas by fire hazard classes and affect the planning of strategic tasks to prevent fires in the reserve

Keywords: radiation pollution, fire situation, fire hazard class, forest ecosystem

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INTRODUCTION

As a result of the Chernobyl accident in 1986, the forests of Polissya region in Ukraine were subject to significant radioactive contamination [1]. Due to high radiation pollution, the probability of fire in such forests increases [2]. As a result of fires in radioactively contaminated forests, there is an increase in the radioactive background of the territory, as well as the deterioration of the ecological situation in the surrounding area. Every year in Ukraine, when the air temperature rises in the spring and summer, fire safety in forests becomes a major problem. In recent years, the number of fires and their area is growing steadily. Such an expansion is primarily due to an increase in air temperature and low precipitation [3].

The most dangerous are the crown fires that start from underbrushes and belong to the first class of fire danger. The onset of crown fires is also affected by the negative sanitary condition of forest stands (clutter and dead trees), which begins with surface fires, spreads to tree trunks and continues to spread to tree crowns, and burns a large area of forest [4]. However, a significant role in the fire situation is played by radiation contamination of the territory. The peculiarity of forests contaminated with radionuclides is that they increase the possibility of forest fires and reduce the effectiveness of the developed fire prevention system. Therefore, the question arises as to the study of the state of the radioactively contaminated forests and protection of forests from fires.

However, not only in Ukraine there are significant forest fires as a result of climate change and lack of precipitation. In the Amazon rainforest, fires also occur each year, which tend to increase [5]. In addition to climate change, it is also affected by human activities, mainly related to changes in land use [6]. Even the permafrost suffers from fires. Thus, during August 2017 in Greenland, more than 2.0 thousand hectares of forests were affected by fires. This indicates that the area under a layer of snow and ice becomes vulnerable to forest fires as a result of global warming [7]. Forest fires are not only detrimental to biodiversity, but also to human health. Particularly great damage is caused by fires that occur in radioactively contaminated lands [8; 9].

The *purpose* of the study is to determine how radiation pollution affects the fire hazard of forest ecosystems of the "Drevlyansky" nature reserve (hereinafter – the Reserve). In accordance with the purpose of the study, the following *tasks* were set:

– to distribute the area of forest ecosystems of the reserve according to the levels of radiation pollution;

– to distribute the area of forest ecosystems of the reserve according to fire hazard classes with and without radiation pollution;

– to estimate and compare the average fire hazard classes between 2008 and 2018.

MATERIALS AND METHODS

To establish the total area of contamination and fire hazard class, forest management materials (mensurational descriptions for 2008 and 2018) were used by the State Enterprise "Narodytske spetsializovane lisove hospodarstvo" (Narodytske, Klishchivske, Zaliske forestries), namely the natural areas included in the territory of "Drevlyansky" nature reserve [10]. The distribution of the territory of the Reserve according to the density of radiation pollution took place in accordance with the forest management instructions [11], which indicates the density of radiation pollution by zones. The main indicators for calculating the fire hazard class were: land category, species, composition, age, type of forest vegetation conditions, clutter, as well as radiation contamination of the territory. The fire hazard class of each division was established according to the scale of natural fire hazard assessment of forest land plots [12]. The average fire hazard class of forest ecosystems was determined by the equation 1 [13]:

$$F_{ca} = \frac{F_1S_1 + F_2S_2 + \cdots + \cdots F_nS_n}{\sum S} \quad (1)$$

where F_1, F_2, ..., F_n – fire hazard classes of allotments (quarters);

S_1, S_2, ..., S_n – corresponding areas of taxation plots (quarters).

When performing mathematical calculations according to equation 1, the share is the average class of fire hazard. A special feature is that the calculation of the average class of fire hazard does not require assigning a separate coefficient to each class of fire hazard. It is done when calculating the average class of plant quality, especially when there are plantations with class 1a.

For convenient grouping of taxation plots by ignition sources, filtering of ignition sources in a Microsoft Excel spreadsheet processor was used, where taxational specifications of research quarters will be listed. During the assignment of certain class of fire hazard to the stratum, it is also necessary to take into account the density of radiation pollution. Because in one case the stratum belongs directly to class 1, and in the other it increases the fire hazard class by one. After that, the summation of all areas for each class of fire hazard is carried out. The total area of fire hazard classes should be equal to the sum of the areas of taxation plots (quarters) in which the calculations were carried out.

RESULTS AND DISCUSSION

As a result of the survey of the forest fund in 1991-1992, the current territory of the Reserve is divided into three zones according to the density of ^{137}Cs pollution; the areas are presented in the table 1.

Table 1. *Division of part of the Reserve territory by zones of radiation pollution (density of soil pollution ^{137}Cs in Ci/km^2)*

Total area of pollution, ha/%	In particular by the pollution density					
	Zone 1	Zone 2			Zone 3	
	More 15.0	Subzone			Subzone	
		a	b	c	a	b
		5.1-7.0	7.1-10.0	10.1-15.0	1.1-2.0	2.1-5.0
16823.0	15450.0	58.0	55.0	1211.0	0	49.0
100.0	91.83	0.34	0.33	7.21	0	0.29

The largest area of forest ecosystems belongs to the first zone of radiation pollution and amounts to 15450.0 hectares or 91.83% of the reserve. The second zone of radioactive contamination includes 1324.0 ha or 7.88% of territory. For its part, the second zone is divided into 3 subzones. Subzone "a" includes 58.0 hectares or 0.33%. Subzone "b" is slightly smaller – 55.0 hectares or 0.33%. The largest area is occupied by subzone "b", which is 1211.0 hectares or 7.21%. Zone 3 includes 49.0 hectares or 0.29% of the territory. This zone is represented only by subzone "b".

There are villages in the forest ecosystems of the Reserve (Mali Klishchi, Shyshelivka, Zvizdal, Mali Minky, Khryplya, Severivka, Rohy, Peremoha). These villages are located near the territories with the level of radiation pollution over 15 Ci/km^2 which are referred to the zone of unconditional (obligatory) resettlement. [14]. Territories belonging to zone 2 are located near the Loznitsa village and near the road in the direction of village Mali Klishchi village, as well as alone in the middle of the forest. Furthermore, the quarters belonging to zone 2 (subzone "c") are located south of the Mali Klishchi village and north of the Mali Minki village. In the spring of 2020, the territory belonging to zone 3 was affected by fires, the radiation background of which became higher than the initial one. As the fire hazard class is established on the basis of taxational specifications (Tables 3-4), the forest ecosystem area of the Reserve was distributed by fire hazard classes for 2008 and 2018 without taking into account the level of radiation pollution (Table 2).

Table 2. *Distribution of lands by fire hazard classes with and without taking into account radiation pollution between years of forest management*

The year of forest management	(Area,ha) / %	Fire hazard classes					Average class
		1	2	3	4	5	
Distribution by classes without taking into account radiation pollution							
2008	16823.0 / 100.0	5289.4 / 31.44	7930.5 / 47.14	2177.4 / 12.94	819.4 / 4.87	606.3 / 3.61	2.02
2018		4955.2 / 29.45	8084.0 / 48.05	2270.8 / 13.50	906.7 / 5.39	606.3 / 3.61	2.06
Distribution by classes taking into account radiation pollution							
2008	16823.0 / 100.0	15928.3 / 94.68	194.7 / 1.16	106.4 / 0.63	7.6 / 0.05	586.0 / 3.48	1.16
2018		15877.4 / 94.38	242.9 / 1.44	108.8 / 0.65	7.6 / 0.05	586.3 / 3.48	1.17

Table 3. *Distribution of taxational specifications by fire hazard classes without taking into account radiation pollution between forest management years*

Taxational specifications	Years of forest manage-ment	
	2008	2018
Class 1		
Coniferous plantations under 40 years old	3550.4	3319.2
Coniferous plantations over 40 years old (FST * 0 1)	416.2	420.4
Free-growing forest plantations	145.5	41.0
Cuttings after conifers	13.2	9.8
Other non-wooded lands located among coniferous plantations	1164.1	1164.8

Continuation of table 3

Class 2		
Coniferous plantations over 40 years old (FST 2)	7925.5	8079.0
Deciduous plantations (FST 0 1)	5.0	5.0
Class 3		
Coniferous plantations over 40 years old (FST 3 4)	1726.3	1810.5
Deciduous plantations (FST 2)	451.1	460.3
Class 4		
Coniferous plantations over 40 years old (FST 5)	17.1	17.1
Deciduous plantations (FST 3 4)	802.3	889.6
Class 5		
Deciduous plantations (FST 5)	20.0	20.0
Roads (forest), compartment line, fire line, etc	335.1	334.5
Water bodies	251.2	251.8

***Note**: *FST – forest site type*

***Table 4**. Distribution of taxational specifications by fire hazard classes taking into account radiation pollution between forest management years*

Taxational specifications	***Years of forest management***	
	2008	***2018***
Class 1		
Plantations of coniferous and deciduous species with the level of radiation pollution over 15 Ci/km^2	13714.6	13798.0
Meadows, bio-meadows	350.5	350.5
Aree-growing forest plantations	145.5	41.0
Cuttings after conifers	13.2	9.8
Coniferous plantations under 40 years old - radiation pollution 10.1-15.0 Ci/km^2 - radiation pollution 7.1-10.0 Ci/km^2 - radiation pollution 5.1-7.0 Ci/km^2	496.3 482.9 0.2 13.2	453.5 432.8 5.3 15.4
Coniferous plantations over 40 years old (FST 0 1) - radiation pollution 10.1-15.0 Ci/km^2	1.6 1.6	1.6 1.6
Coniferous plantations over 40 years old (FST 2) - radiation pollution 10.1-15.0 Ci/km^2 - radiation pollution 7.1-10.0 Ci/km^2 - radiation pollution 5.1-7.0 Ci/km^2 - radiation pollution 2.1-5.0 Ci/km^2	393.0 302.2 17.4 31.9 41.5	408.8 316.7 17.4 33.2 41.5
Other non-wooded lands located among coniferous plantations	813.6	813.6
Class 2		
Deciduous plantations (FST 2) - radiation pollution 10.1-15.0 Ci/km^2 - radiation pollution 5.1-7.0 Ci/km^2	60.9 58.9 2.0	68.6 66.6 2.0
Coniferous plantations over 40 years old (FST 3 4) - radiation pollution 10.1-15.0 Ci/km^2 - radiation pollution 7.1-10.0 Ci/km^2 - radiation pollution 5.1-7.0 Ci/km^2 - radiation pollution 2.1-5.0 Ci/km^2	133.8 111.2 11.1 5.2 6.3	174.3 151.7 11.3 10.4 6.3

Continuation of table 4

Class 3		
Deciduous plantations (FST 3 4)	93.9	96.3
- radiation pollution 10.1-15.0 Ci/km^2	87.8	90.2
- radiation pollution 7.1-10.0 Ci/km^2	4.9	4.9
- radiation pollution 5.1-7.0 Ci/km^2	1.2	1.2
Coniferous plantations over 40 years old (FST 5)	12.5	12.5
- radiation pollution 7.1-10.0 Ci/km^2	12.5	12.5
Class 4		
Deciduous plantations (FST 5)	7.6	7.6
- radiation pollution 10.1-15.0 Ci/km^2	5.1	5.1
- radiation pollution 7.1-10.0 Ci/km^2	2.5	2.5
Class 5		
Roads (forest), compartment line, fire line, etc	334.8	334.5
Water bodies	251.2	251.8

Thus, the distribution of forest lands without radiation pollution is as follows: 5289.4 ha (31.44%) belonged to class 1 in 2008, and 4955.2 ha (29.45%) in 2018; to class 2 – 7930.5 ha (47.14%) and 8084.0 ha (48.05%); to class 3 – 2177.4 ha (12.94%) and 2270.8 ha (13.50%); to class 4 – 819.4 ha (4.87%) and 906.7 ha (5.39%) respectively; 606.3 ha (3.61%) belonged to the class 5 in 2008 and 2018. As can be seen from the distribution of the territory, the largest area is occupied by class 2 and 1, so the average class of fire danger between 2008 and 2018 decreased from 2.02 to 2.06.

But given the fact that the territory of the Reserve is in the zone of radioactive contamination, where radiation affects the fire situation, the distribution of fire hazard classes is as follows: class 1 – 15928.3 ha (94.68%) and 15877.4 ha (94.38%); class 2 – 194.7 ha (1.16%) and 242.9 ha (1.44%); to class 3 – 106.4 ha (0.63%) and 108.8 ha (0.65%); class 4 – 7.6 hectares (0.05%) in 2008 and 2018; to class 5 – 586.0 ha (3.48%) and 586.3 ha (3.48%). Thus, the fire situation taking into account radiation pollution increased by 0.86 and 0.89 units between 2008 and 2018 without and taking into account radiation pollution and is 1.16 and 1.17. Therefore, the fire danger, taking into account radiation pollution between 2008 and 2018, has hardly changed.

Given the fact that in the Reserve the average class of fire danger, taking into account radiation pollution is close to the first, throughout the fire-hazardous period, ground fires are possible, and in areas with a forest stand – crown fires [15]. As a confirmation of this fact, a fire broke out on the territory of the Reserve in the spring of 2020, as a result of which more than 3.0 thousand hectares of the forest ecosystem were burned (Fig. 1).

A **B**

Figure 1. *Consequences (A) and scale (B) of the fire on the territory of the "Drevlyansky" nature reserve, which occurred in April 2020*

Source: *A) author of the photo M.P. Lutsko; B) view from the Sentinel-2 satellite*

Since the taxational specifications are divided into fire hazard classes, the first class is formed by: coniferous plantations under the age of 40 (3550.4 ha or 67.12% of the area of the class, 21.20% of the area of the Reserve in 2008 and 3319.2 ha or 66.98%, 19.73% in 2018), planting of coniferous plantations over 40 years of age in very dry (0), dry (1) conditions (416.2 ha or 7.87%, 2.47% and 420, 4 ha or 8.48%, 2.50%), forest

lands not covered with forest vegetation (158.7 ha or 3.00%, 0.94% and 50.8 ha or 1.03%, 0.30%), others not covered with forest vegetation and non-forest lands along with coniferous plantations (1164.1 ha or 22.01%, 6.92% and 1164.8 ha or 23.51%, 6.92%).

The largest area is occupied by lands belonging to the class 2, which include lands of coniferous plantations over 40 years of age in fresh (2) conditions (7925.5 ha or 99.94%, 47.11% and 8079.0 ha or 99.94%, 48.02%) and deciduous plantations in very dry (0) and dry (1) growth conditions (5.0 ha or 0.06%, 0.03% in 2008 and 2018). In the class 3 a significant area is occupied by deciduous plantations in fresh (2) conditions (451.1 ha or 20.72%, 2.68% and 460.3 ha or 20.27%, 2.74%) among deciduous plantations species and a slightly smaller area among coniferous plantations over 40 years old are occupied by plantations in moist (3) and damp (4) conditions (1726.3 ha or 79.28%, 60.26% and 1810.5 ha or 79.73%, 10.76%).

The largest area forming the class 4 is deciduous plantations in moist (3) and damp (4) conditions (802.3 ha or 97.91%, 4.77% and 889.6 ha or 97.91%, 5.29%). The smallest area among coniferous plantations over 40 years of age is occupied by plantations in wet (5) conditions (17.1 ha or 2.09%, 2.20% in 2008 and 2018, respectively). The main part of class 5 belongs to infrastructural facilities and water bodies, which total 586.3 hectares. Deciduous plantations in wet (5) conditions (alder near rivers [16]) amount to 20.0 ha. Areas did not change between the years, the same situation in the total share of the area of the class and the Reserve (infrastructural facilities and water bodies – 96.70% and 3.48%), deciduous plantations – 3.30% and 0.13%).

Thus, in coniferous plantations there is an increase in the average age of plantations in each type of FST, which in turn affects the reduction of the area in young stands with appropriate typological conditions. The increase in the area of deciduous plantations (different typological conditions) is due to the decrease in the area of free-growing forest plantations [17]. However, the territory of the Reserve is located in the zone of radioactive contamination, so radiation pollution is taken into account to establish the areas of fire hazard classes.

The largest area, just like the general indicator of the fire hazard class, is occupied by deciduous and coniferous plantations with the level of radiation pollution over 15.0 Ci/km^2 (13714.6 ha or 86.11% of the total area of the class, 81.52% of the area Reserve in 2008 and 13798.0 hectares or 86.91%, 82.01% in 2018). Almost equal parts of the area are occupied by forest lands not covered with forest vegetation (5092.2 ha or 3.71%, 3.03% and 501.3 ha or 3.16%, 2.98%), coniferous plantations under 40 years of age (496.3 ha or 3.12%, 2.95% and 453.5 ha or 2.86%, 2.70%), coniferous plantations over 40 years of age in very dry (0), dry (1), fresh (2) conditions (394.6 ha or 2.48%, 2.35% and 410.4 ha or 2,585, 2.44%), other forest lands not covered with forest vegetation, located near plantations with coniferous species (813.6 ha or 5.84% of the class and 4.84% of the area of the Reserve in 2008, 5.12% of the class and 4.84% of the Reserve in 2018).

Other classes of fire danger are formed with much smaller areas. Class 2 consists of deciduous plantations in fresh (2) conditions (60.9 ha or 31.28%, 0.36% and 68.6 ha or 28.25%, 0.41%) and coniferous plantations aged over 40 years in moist (3) and damp (4) conditions (133.8 ha or 68.72%, 0.80% and 174.3 ha or 71.76%, 1.04%). Class 3 consists of deciduous plantations that grow in moist (3) and damp (4) conditions (93.9 ha or 88.25%, 0.56% and 96.3 ha or 88.51%, 0.57%) and coniferous plantations in wet (5) growth conditions (12.5 ha or 11.75%, 0.07% in 2008, as well as 11.49%, 0.07% in 2018). The smallest area is represented by deciduous plantations in wet (5) growing conditions (7.6 ha or 0.05% of the area of the Reserve), which forms the class 4. Infrastructural facilities and water bodies together amount to 586.0 ha in 2008 and 586.3 ha in 2018, which is 3.48% of the area of the Reserve [17].

As can be seen, the areas of plantations that belonged to the 2, 3, 4 and 5 classes of fire danger due to the radiation background were classified as class 1 (over 15.0 Ci/km^2) and increased by one class (2.1-15.0 Ci/km^2). According to the streamlining of 2018 on the official website of SE "LIAC" in the section "Map" (Fig. 2) there is a map of fire danger of land plots of the forest fund, a significant area of which (almost all) is marked with colour 1 (most dangerous class). Separate "islands" can be observed in forest areas of 2, 3 and 4 classes of fire danger. Class 5, which are water bodies and the quarter grid (other infrastructural objects are not marked on the map due to the scale) are not shown because they are "superimposed" with a "compartment line" layer. The rivers are the boundaries between forests in a specialized forest economy or environmental research units (ERU) in the Reserve, as well as outside the quarters. Therefore, this map is a confirmation of the distribution of forest ecosystem areas of the Reserve by fire hazard classes, taking into account radiation pollution in 2018 (Table 4).

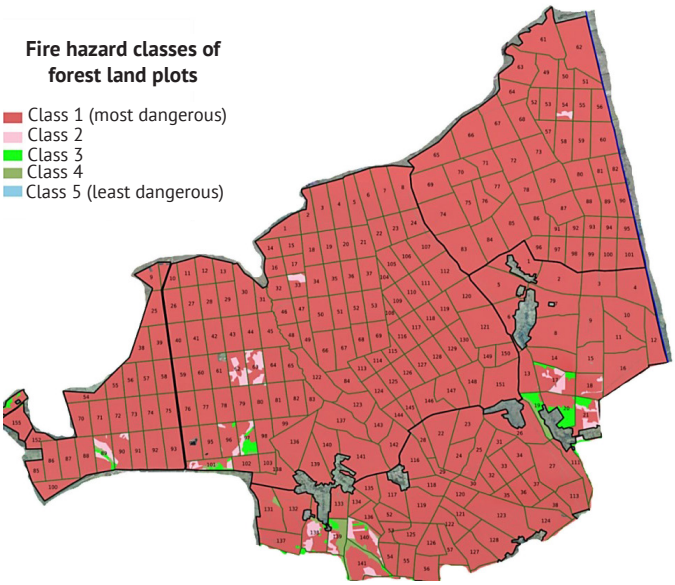

Figure 2. *Fire hazard map of the "Drevlyansky" nature reserve according to SE "LIAC" in the section "Map"*

Source: *[18]*

CONCLUSIONS

In the process of computational analytical study, the area of the Reserve was divided by zones of radiation pollution and fire hazard classes.According to the results of the distribution, it was established that the territory of the Reserve has a density of radiation pollution over 15.0 Ci/km^2 (15450.0 ha or 91.83%). According to the results of the division of the Reserve territory by fire hazard classes without radiation pollution, almost half of the area belongs to the class 2 (in 2008 the area was 7930.5 ha or 47.14% of the Reserve territory, and in 2018 – 8084.0 ha or 48.05%), and the average class between 2008 and 2018 decreased from 2.02 to 2.06

Distributing the areas of the Reserve taking into account radiation pollution, almost the entire area belongs to class 1 (in 2008 15928.3 ha or 94.68% of the territory, and in 2018 – 15877.4 ha or 94.68%), and the average class changed from 1.16 to 1.17. This sharp increase was conditioned by the fact that the radiation background was more than 15.0 Ci/km^2, which refers the area immediately to class 1. Given that 30 years have passed since the radiological survey, the density of ^{137}Cs contamination in the area has decreased (except for areas affected by fires). The result of this survey may be changes in the distribution of areas of radiation pollution, which will improve the average class of fire hazard.

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ЕКОЛОГО-ПОЖЕЖНА ХАРАКТЕРИСТИКА ЛІСОВИХ ЕКОСИСТЕМ ПРИРОДНОГО ЗАПОВІДНИКА «ДРЕВЛЯНСЬКИЙ»

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Анотація. У роботі представлено екологічну та пожежну ситуацію у лісовій екосистемі природного заповідника «Древлянський». Актуальність цієї роботи полягає у тому, що щороку ліси України потерпають від пожеж, які знищують значні площі, а найбільшої шкоди від пожеж зазнають ліси із радіаційним забрудненням. Метою статті є встановити вплив радіаційного забруднення на пожежну ситуацію у лісовій екосистемі Заповідника. Головним завданням було розподілити площу Заповідника за рівнями радіаційного забруднення та за класами пожежної небезпеки з та без врахування радіаційного забруднення. Для досягнення результатів було розподілено площу лісової екосистеми Заповідника за рівнями радіаційного забруднення. Середній клас пожежної небезпеки між 2008 та 2018 роками становив від 2,02 до 2,06, що зі свого боку покращує пожежну ситуацію. Але, оскільки територія Заповідника зазнала радіаційного забруднення, розподіл площ за класами пожежної небезпеки між роками лісовпорядкування зазнав змін. Отже, пожежна ситуація із врахуванням радіаційного забруднення погіршилася, як порівняти із територією, що не зазнала радіаційного забруднення, а між 2008 та 2018 роками покращилася і становить відповідно 1,16 та 1,17. Отже, розподіл площ лісового фонду за класами пожежної небезпеки залежить не тільки від рівня радіаційного забруднення, а й від таксаційних показників (категорія землі, а в насадженнях від типу лісорослинних умов, віку та деревної породи). Також показано результати пожежі, яка відбулася на території Заповідника весною 2020 року та продемонстровано карту пожежної небезпеки лісового фонду природного заповідника «Древлянський» за даними лісовпорядкування 2018 року. Перспективою подальших досліджень є повторне проведення дослідження рівня радіаційного забруднення, а також кожні 10 років разом із лісовпорядними роботами проводити фактичні заміри без використання розрахункових методик для проведення більш достовірного розподілу площ лісового фонду за класами пожежної небезпеки, що зі свого боку вплине на планування стратегічних завдань щодо недопущення пожеж на території Заповідника

Ключові слова: радіаційне забруднення, пожежна ситуація, клас пожежної небезпеки, лісова екосистема