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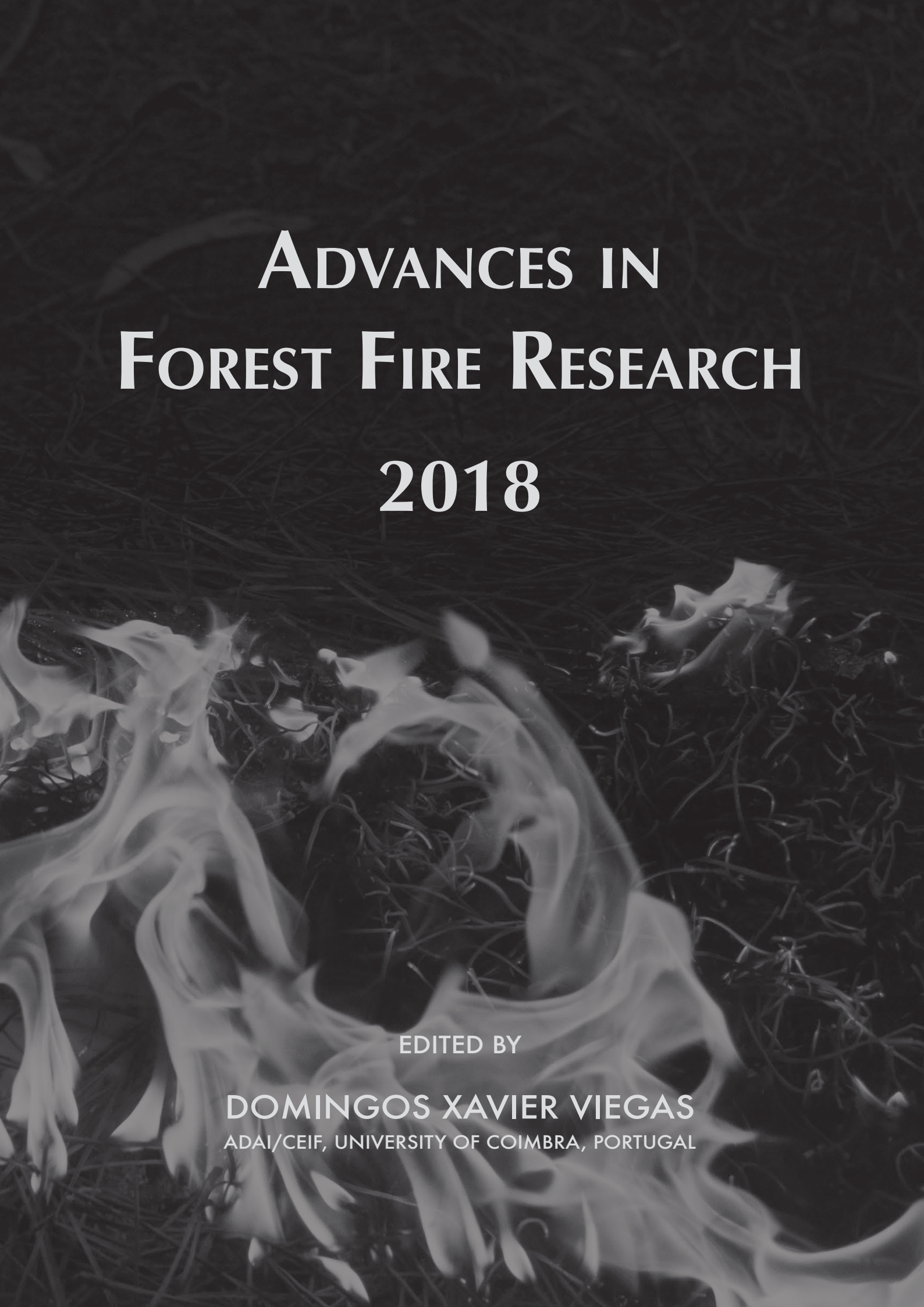

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The organisation of fire protection in disaster areas using as an example the case of Bialowieza Forest

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Abstract

The Bialowieza Forest is particularly precious, considering environmental aspects, forest land where recently an outbreak of bark beetle (*Ips typograpus*) took place on an unprecedented scale leading to disintegration of spruce stands. This phenomenon of a calamitous nature led to the increase of forest fire risk level due to appearance of large volume of dead wood and grassy cover as the results of the canopy openness. The grassy cover, when over-dried, is extremely flammable and conducive to fire outbreak and rapid fire behaviour. Before the outbreak of bark beetle (June 2012) the whole area of Bialowieza Forest (Forest District Białowieża, Brwosk, Hajnówka and Bialowieza National Park) was characterised by a low fire risk (on a three-level scale). The three forest districts manage their forest using the regular management plan for the rest of Poland while Bialowieza National Park is under strict protection. The forest fire protection system in place was a standard one, in compliance with the legal requirements laid down for this level of risk to managed forests. It does not include the current risk and the adaptation of the existing fire protection system for Bialowieza Forest is then indispensable and must be adequate to the actual risk. The unique environmental value of that region must be considered as well during that process.

Keywords: deadwood, natural habitats, bark beetle outbreak, fire risk, Bialowieza, fuel load

1. Forest fire risk analysis for Bialowieza Forest

1.1. Occurrence of forest fires

In the years 2000 - 2017 83 forest fires broke out in Bialowieza Forest (including 14 since the bark beetle outbreak - covering 3.83 ha) covering 38.66 ha of forest land. The mean burnt area was then 0.47 ha and it was higher than the mean burnt area for State Forests in Poland (amounting to 0.30 ha). The soil cover forest fires were the most frequent (amounting to 62.5%) and covered as much as 99.2% total burnt area. The very numerous, comparing to the average of less than 1%, were single tree fires amounting to 33.3%. Ground fire occurred only once while there was no total forest fire registered. Among the causes of fires, the domination of arson incidents was observed (37.5%), and those of which the cause is undefined (33.3%). Negligence was a cause of 16.7% of fire outbreaks. Attention should be given to the high percentage of fires due to lighting (8.3%) as the result the large number of high trees in that forest. Spot fires from adjacent ground constituted up to 4.2%. The coniferous stands (fresh coniferous forest and fresh mixed coniferous forest, covering 19.7% of the total area of Bialowieza Forest) together with the stands less than 40 years old (amounting to 14.3% of the total area of Bialowieza Forest) mostly determined the forest fire risk of that region before the bark beetle outbreak. The forest fire risk was also increased by communication trails, fuel bases, freight terminals and intensified tourism. Since the middle of 2012, the rapidly increasing amount of dead wood was the amplifying factor for fire risk followed by the appearance of the abundant grassy cover as the result of spruce dieback and unlimited access of the sun to the forest floor.

1.2. Forest fire risk - dead wood

The appearance of the dead wood due to a natural, gradual process does not cause any significant increase of the fire risk as the result of an excessive amount of fuel. From the environmental point of view dead wood, regardless of the amount, does not cause any fire risk, although standing dead trees can be dangerous for people in the forest, especially when they are located along the forest roads, touristic trails. Moreover, if located along the communication trails, a large amount of dead wood will increase fire risk. According to the data of the Large-scale inventory of the State of Forests in years 2012 - 2016 (BFMG, 2017), the average volume of dead wood, both standing and lying, of all property types in Poland amounting to 6.3 m^3/ha. Considering that coniferous species constitute around 54% of all dead wood, the mean fuel load was estimated at 4 ton/ha. Forest fire risk linked with dead wood depends mostly on the size, type and decomposition stage. In general the greater the size of the dead wood, the lower the risk is. The highest risk is caused by fine fuel (diameter up to 7 cm). Larger diameters, between 7 and 40 cm (medium size) and more than 40 cm (large size); so called coarse fuels because of their slow drying process and relative stability of moisture content close to the flammability threshold or even higher do not present a real fire risk. Including decomposition classes of dead wood by Maser (Maser, et al. 1979), from the fire risk perspective lying dead wood in decomposition class I creates the highest fire risk, concerning both ignition and spreading velocity. The main reasons for that are small branches with diameter up to 3 cm, often with dried needles or leaves at the beginning, intact bark and incompact structure when trunk with branches rests on the ground. The fire risk decreases when small branches fall off, texture is still intact or only insignificantly and the trunk has not touched the ground yet. When dead wood reaches 3 and 4 class of decomposition its density decreases due to better air access, especially when a trunk is uncovered and exposed to sunlight and there has been no precipitation for a long time in such a case decomposing wood can smoulder very slowly. There is almost no fire risk when dead wood reaches 5 class of decomposition. In the case of standing dead wood, the highest risk is created by trees that are still alive or already declining (1 and 2 phase), which is the result of fuel continuity of small, dried branches, which enables transformation from soil cover fire into crown fire. In the next phases, (3 - 8), fire risk decreases gradually but definitely. In the last phase (9) stumps smoulder and it is a long-lasting process. In general, higher fire risk is associated with fallen dead wood rather than standing, which is the result of no fuel continuity already in phase 3 of decomposition.

1.3. Dead wood of Bialowieza Forest

The amount of fuel load and its type are the basic criteria for the fire risk estimation as the fire energy balance, fire behaviour and size of loses are driven by it. The dead fuel load plays a particular role, not only during the initial phase of burning but also during fire spreading. The forest dead wood inventory was conducted in Bialowieza Forest in the years 2010 - 2011 in the framework of revision of the Forest Management Plans for Promotional Complex Bialowieza Forest, before the bark beetle outbreak. The mean amount of deadwood in the Forest Districts situated in the Forest was 24.9 m^3/ha. Including mean density of wood at the moisture content amounting to 15 % (spruce, pine, oak and hornbeam, the main trees species of Bialowieza Forest) the mean fuel load is 15.8 ton/ha (1.58 kg/m^2). For the purpose of comparison, mean volume of the dead wood in State Forests is 5.3 m^3/ha, private forest – 4.2 m^3/ha and national parks – 37.3 m^3/ha according to Bureau for Forest Management and Geodesy in years 2007 - 2011 (BFMG, 2007). Since June 2012, the volume of deadwood has increased twice up to 50.2 m^3/ha and in 2017 it was already 231.8 m^3/ha. Table 1 presents collective data (source: Regional Directorate of State Forests in Bialystok) regarding volume of infestation of spruce trees and its area with stands disintegration and also the volume of dead wood per unit of area before and after partial removal of infested trees.

Table 1 - The volume of infested trees and the area of dead stands in years 2012 - 2017

Year	Volume of planted spruce trees	Volume of removed spruce trees	Area of dead tree stands	Volume of dead wood	
				before removal	after removal
	m^3	m^3	ha	m^3/ha	
2012*	23289	6412	464	50.2	36.4
2013	102592	19610	689	148.9	120.4
2014	198123	25488	1482	133.7	116.5
2015	267080	42288	2088	127.9	107.6
2016	483683	39148	2498	193.6	1779
2017	366982	162020	1583	231.8	129.5

*since June

In the year 2017 the total volume of infested spruce trees was equal to 1.414.749 m^3 on the area of 8804 ha. Removal of the dead wood (totally 294.966 m^3) enabled slight (on average 20%) reduction of the volume of the dead wood during the analysed period. Changes in the average amount of the fuel load were calculated based on the presented data for particular years and also calculated in a cumulatively including total volume of infested spruce trees and its area, presented on the figure 1. The density of spruce wood at the moisture content of 15% was adopted as equal to 470 kg/m^3.

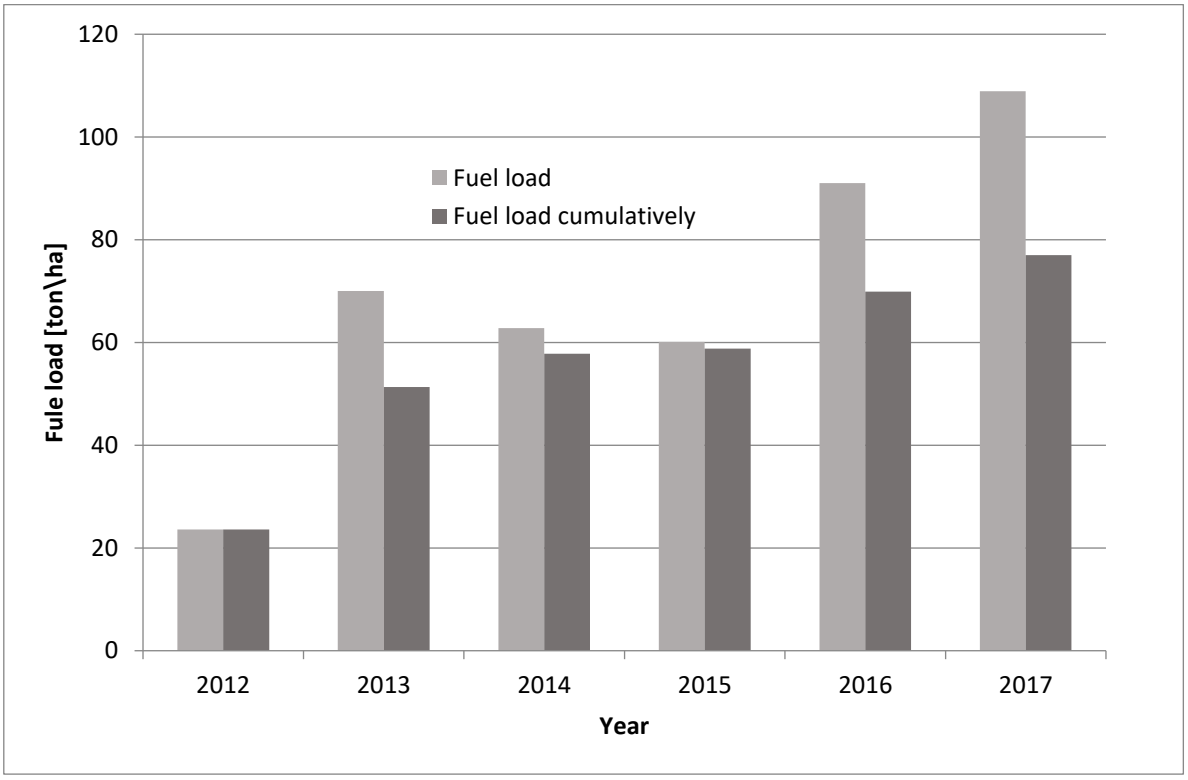

Figure 1 - Changes in the volume of fuel load in years 2012 - 2017 in Bialowieza Forest

The smallest amount of fuel load, equal to 23.6 ton/ha, was at the beginning of the bark beetle outbreak in 2012. The next years brought an increase in fuel load of up to 60-70 t/ha with the maximum of 108.9 ton/ha in year 2017. According to the precise data the maximum amount of dead wood in some sub-compartments was equal to 629 m^3/ha, which corresponds to 295.6 ton/ha of fuel load.

Figure 2 presents spatial distribution of standing dead spruce wood in Bialowieza Forest in year 2017 determined by airborne laser scanning (ALS), conducted as part of the Life+ ForBioSensing project.

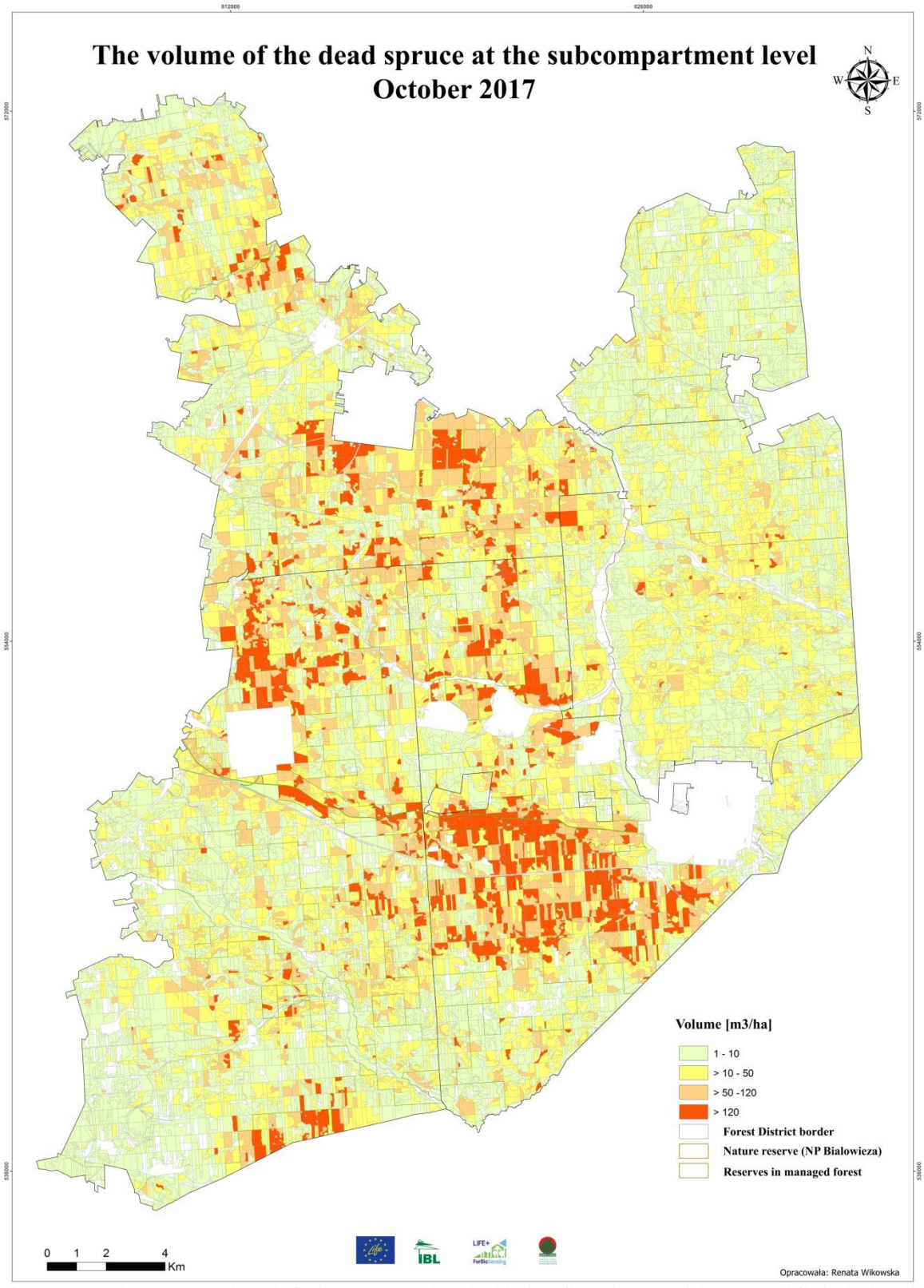

Figure 2 - The volume of the dead spruce at the subcompartment level - October 2017

Because dead fine fuel is the most risky, fuel load field measurements were conducted, choosing randomly 5 areas with the greatest amount of fallen dead wood for estimation of the maximum amount. Each plot was separated (average area 16 m^2) and all the lying down dead wood was weighted. The amounts of dead wood differ from 86.76 up to 139.88 ton/ha, on average 105.77 ton/ha air-dried. That amount of dead wood intensifies the risk of fire outbreak with increased dynamic in its behaviour. The risk increases particularly where dead trees with dried branches lying on the forest floor. Their incompact structure stimulates ignition and the intensity of fire enables the transition of fire into the crowns of still living trees and dead trees with dried crown. Standing dead spruce will fall down with time or break (it will take between 3 and 6 years according to the experts), which leads to an increase of fallen fuel load, it is more dangerous than a standing fuel load. Trunks lying on the forest floor, because of their density, present lower risk due to less susceptibility to ignition compared to other forest materials. As the decomposition of dead wood continues with time, its role will change and in the case of fire outbreak these trunks will be more susceptible for ignition and the fire will be prolonged. Fallen dead wood creates obstacles for conducting rescue action by blocking fire trails and the access to fire spots.

1.4. Soil cover

Grassy cover occurred massively on the areas with bark beetle outbreak, mainly reed grass but also fern and raspberry. This type of vegetation, in dried stage (early spring, summer droughts, early autumn), creates high fire risk, conducive to fire outbreak and its rapid behaviour. The inventory of the grassy areas (area and cover percentage) was conducted in 2016 for forest districts of Bialowieza Forest including infested areas. The results of the collective inventory are presented in table 2 together with the list of areas by dominant type of vegetation and its cover percentage.

Table 2 - Grassy cover inventory results

Dominant type of vegetation	Cover percentage [%]				
	10	20	30	40-100	total
Heather and juniper	159.73	219.28	218.96	20.48	618.45
Fern	288.90	440.34	269.99	216.39	1215.62
Grass	1539.50	1446.66	1290.54	1416.99	5693.69
Total	1988.13	2106.28	1779.49	1653.86	7527.76

Total area with the vegetation type of high fire risk equals 7527.76 ha, which constitutes 15% of the total forest land of Bialowieza Forest. The largest area was covered by grass, followed by mixture of raspberry and bracken, and lastly heather with juniper.

For the purpose of fuel load estimation field measurements were conducted on the area with canopy openness and on the reference area in the case of grass. All the vegetation on 1 m^2 was weighted for the purpose of calculation of dry fuel load. All together measurements were conducted on total area of 35 plots, including 15 with grass, 10 with fern, 5 with raspberry and 5 as reference plots. Mean values of the fuel load of risky vegetation type are presented in table 3.

Table 3 - Mean fuel load for selected high risk vegetation types

Vegetation type	**Mean height [cm]**	**Mean fuel load[ton/ha]**
grass	129	2,50
fern	116	3,67
raspberry	89	2,87
grass/reference	15	0,97

Measured fuel load for grassy cover varied between 1.17 up to 4.56 ton/ha, for raspberry between 2.36 to 3.27 ton/ha and for fern between 1.92 up to 7.99 ton/ha. It shows the variety of flammable biomass for all the vegetation types. On the reference area the mean fuel load for grassy cover was 2.5 times less compared to the area with open canopy and varied between 0.44 to 1.36 ton/ha. The fuel load for previously measured lowland forest is equal to the average 0.5 kg/m^2. It was 5 times less compared to the stands with open canopy. The highest risk is presented by grass cover when it is dry due to its loose spatial structure, height of the fuel bed and the fact it is found in open terrain, which influences its rapid drying. According to model calculations the fire behaviour in these conditions shall be characterised by a 6 times faster spreading of the fire front and at the same time the burnt area will be 30 time larger compared to the situation before the bark beetle infestation outbreak and disintegration of the stands.

1.5. Fire risk classification

According to the existing rules, Forest District Bialowieza, Browsk and Hajnowka together with Bialowieza National Park are marked as III, the lowest forest fire risk category considering the frequency of forest fires, stands conditions, climate, and anthropogenic pressure. Figure 3 presents the fire risk according to the forest fire risk category (in accordance with existing regulations) for three forest districts of Bialowieza Forests - Browsk, Hajnowka and Bialowieza.

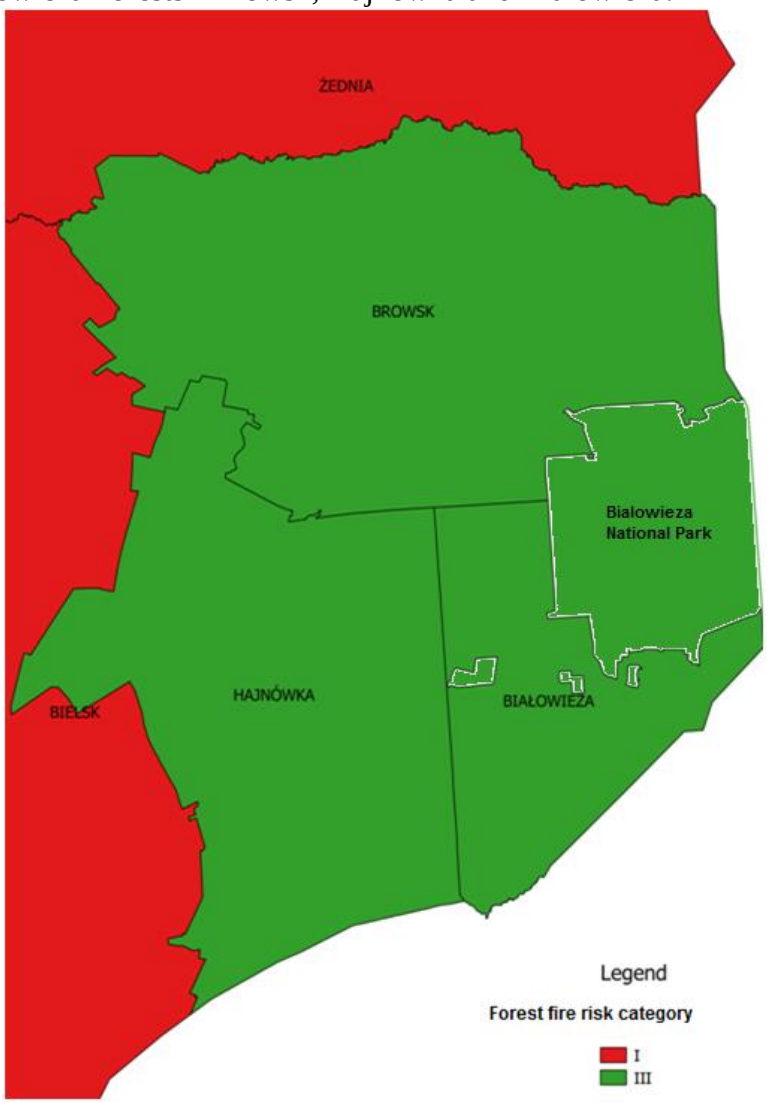

Figure 3 - Forest fire risk according to the forest fire risk category for three forest districts of Bialowieza Forests - Browsk, Hajnowka and Bialowieza.

Forest fire risk category determines the organisation of the forest fire protection system, including formation of forest structure in case of fire. The applied macro-scale method for fire risk estimation corresponds with the total classified area of forest district or national park, excluding local risk. The new method (presented in paper "The stand flammability classes" included in conference materials) applied to estimate fire risk of Bialowieza Forest enables determination of the risk at the level of sub-compartment, compartment and forest range. Flammability class (three-stage scale) is established on the basis of forest habitat type and soil cover type and expresses the susceptibility of forest flammable materials to fire, with flammability indices based on statistical calculation. The above mentioned method expresses more accurately the real fire risk in the forest - figure 4.

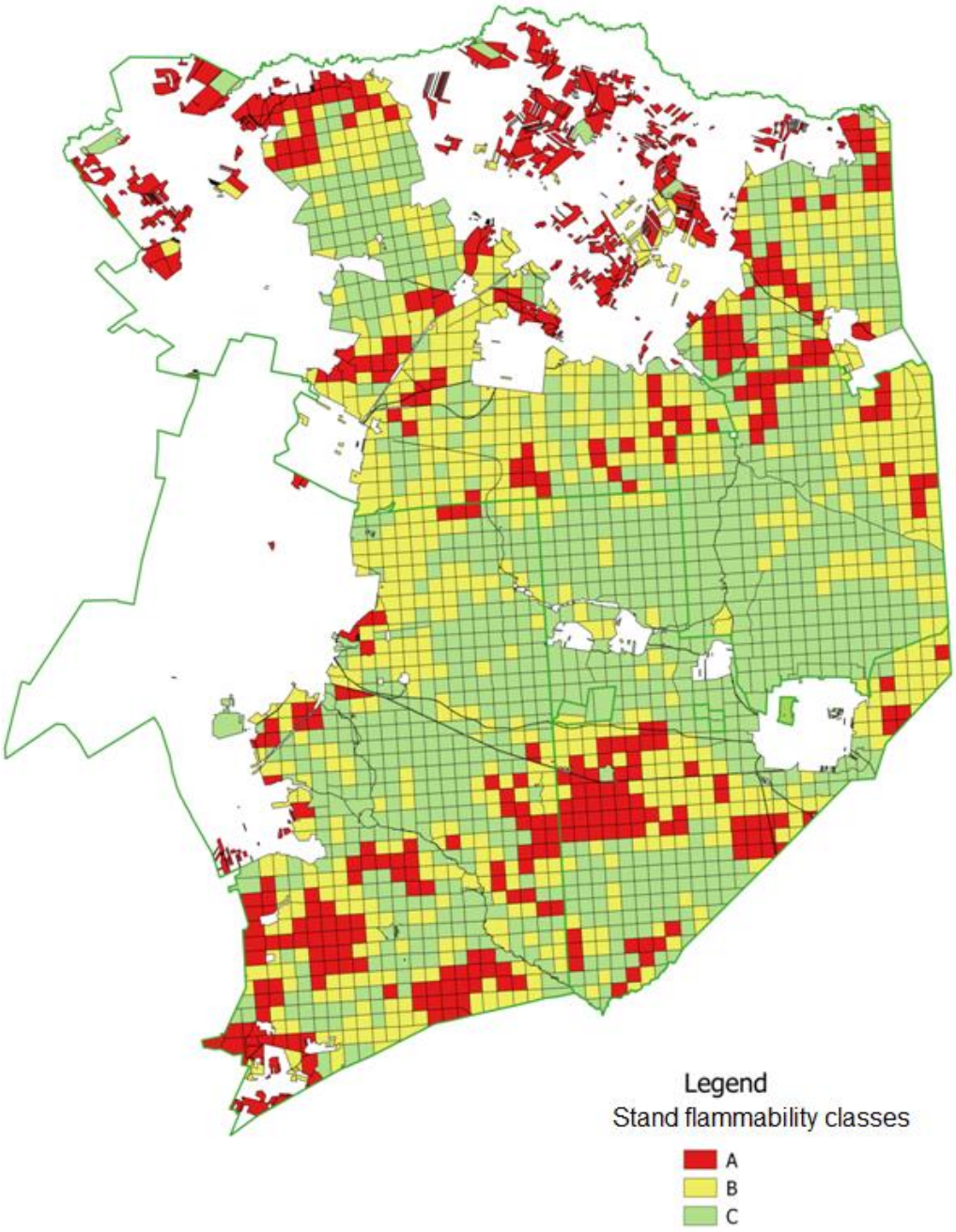

Figure 4 - The stand flammability classes of Bialowieza Forest - compartment level - 2017

2. Forest fire protection system of Bialowieza Forest

The analysis of the fire risk and existing fire protection system, including the result of forest inventory of selected elements of fire infrastructure, were the base for modification of fire protection system of Bialowieza National Park according to the current risk. Due to the limited volume of this paper all the rules are presented only in an abbreviated version.

2.1. Activities limiting fuel load

Fuel load should be limited, if possible, where the possibility of ignition is high; for example along the communication trails (also considering the probability of blocking roads by fallen trees and other obstacles to the rescue service), and touristic paths and places. Formation of the piles made of dried wood (especially small dimensions) creates high fire risk and its rapid spread to the adjacent land and should therefore be forbidden.

2.2. Alarm and communication system

The existing communication system in the forest districts of Bialowieza and Bialowieza National Park (mobile) does not guarantee the expected quality and possibility of communication and early alarm together with the lack of coverage for the whole area of Bialowieza Forest. Some areas have limited communication or even work without it. The communication should be provided over the whole area of Bialowieza Forest, which is obviously connected with financial support and new organisation of the communication.

2.3. Observation network

Due to lack of the coverage from lookout towers estimated up to 30% - including areas with A and B flammability classes located on southern part of Forest District Bialowieza and Hajnowka - it is necessary to built a new lookout tower. By the time of incorporating new lookout tower into the system ground patrolling should be launched covering areas with high forest fire risk when the calculated forest fire risk degree is 3 (the highest).

2.4. Fire trails

The possible localization of the new fire trails was elaborated basing on the results of terrain inventory, taking into account current and future forest fire risk and the needs derived from existing fire protection rules. For the purpose of providing access to the most endangered areas, 127 km of new fire trails were appointed. For the purpose of improving access for the rescue services renovations were ordered including stabilization of road surface and its extension where needed. The fire trails leading to forest areas marked as A and B flammability class will be renovated first, especially parts with destroyed surface and very narrow ones.

2.5. Water supplying

Basing on the results of terrain inventory potential localization of two new water supplying points was chosen. Only the objects most adopted for the fire engines requirements were selected. Taking into account that water supplying for Bialowieza Forest is seasonally insufficient (summer and droughts) and limited possibility of water collection (ground water level too low) it was decided to use deep wells located near forestry lodge.

2.6. Fire fighting equipment

Due to improvement of the effectiveness of fire suppression using airplanes, it was suggested to use private airfield (after signing of the appropriate agreement), located on the edge of Bialowieza Forest and which shall be used as operational airfield. It will shorten the distance needed for the airplane to reach the target (before it was 80 km). The retrofitting of the existing fire units was suggested as well

including foldable water tanks with minimum capacity of 8 m^3 and replacement of fire fighting equipment. In case of buying new fire engines, four wheel drive should be preferred.

2.7. Forest fire risk forecasting

For the purpose of improving accuracy of the forecasting forest fire risk degree it is necessary to separate new smaller prognostic zones for Bialowieza Forest with the prognostic and auxiliary meteorological points located in place. Forest fire risk degree determines everyday activities related to forest fires and operational readiness of rescue services.

2.8. Education and prevention

It was recommended to prepare educational campaign regarding current fire risk in Bialowieza Forest including rules while visiting forest and for limitation of ignition risk. Effective campaign should be professionally designed, with long term perspective and target groups, especially local people. The problem of increasing fire risk of that region should be the part of everyday work of people working in education and webmasters of official web pages and Facebook profiles of forest districts in Bialowieza Forest.

2.9. Activities related to planning and organization of rescue action

Actualization of the rescue plans, prepared by the forest and fire service, for the region of Bialowieza Forest was commissioned including current situation with bark beetle outbreak. It was recommended to organize common manoeuvres of forest service, park rangers and other units involved in fire suppression on the area directly affected by the bark beetle outbreak. In the framework of trans-boundary agreement between Poland and Belarus regarding mutual help in case of fire outbreak it is necessary to elaborate fire procedures and rules for crossing the border.

The above recommendations for improvement of fire protection system of Bialowieza Forest are gradually implemented by forest administration and State Fire Service and should lead to decrease in fire risk and limit effects of potential outbreaks.

3. Literature

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