THE CAUSES OF UNDETERMINED FOREST FIRES: CASE STUDY FROM THE KIELCE FOREST DISTRICT (POLAND) IN 2010-2019

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ABSTRACT

The research area is located in central Poland (Świętokrzyskie Voivodeship). The Kielce Forest District (KFD) is one of the administrative forest divisions of Poland. The main goal of this district is to control and protect forest complexes. The area of the KFD is about 166 km2, and the average forest stand is 285 m³/ha. The study area is characterized by a predominance of coniferous habitats and the average age of pine is around 70 years. The fires monitoring in this area enables to their fast detection and extinguishing. The documentation shows the general characteristics of each forest fire, including its causes. Often the cause of each fire cannot be clearly identified (undetermined causes of forest fires). For this purpose, in the following studies, a summary of weather data from meteorological stations (air temperature and humidity, hot days, duff moisture) and data from fires with undetermined causes (location period and time of occurrence) were used. The comparison of these data with the existing knowledge on the occurrence of fires enables the estimation of the probability that the fire occurred as a result of human activity or natural events (ignition in favourable conditions). The results of these works are an attempt to explain these dependencies on the example of fires that occurred in the study area within 10 years.

Keywords: forest fires, Kielce Forest District, duff, meteorological conditions, fire protection system

INTRODUCTION

Weather conditions and duff moisture are the two main factors determining forest fire susceptibility. The ignition and combustion of forest duff in temperate forests are so far poorly understood. There is no doubt that the long-term lack of rainfall reduces the moisture of the duff. It is also favored by high air temperature and on this basis the fire hazard is determined in Polish forestry. Research conducted at the Forest Research Institute [1] showed that "fire weather" with an increase in the frequency of forest fires is characterized by: no precipitation, little cloud cover, high air temperature and low relative air humidity. Under the conditions temperate climate, the phenomenon of duff self-ignition was practically excluded [2], although it probably occurs in the forests of Canada [3], and is common in the eucalyptus forests of Australia [4].
Lightning discharges are often given among the natural causes of forest fires. According to data from the Polish State Forests this cause accounts for only 2% of all fires in the forests of Poland [5]. According to the European Union data, lightning strikes in Sweden

cause about 4% of forest fires [6]. Lightning strikes without rainfall pose a real threat, as the duff usually extinguish the fire before it will expand.

STUDY AREA

The research area is located in central Poland (Świętokrzyskie Voivodeship) (Fig. 1). The Kielce Forest District (KFD) is one of the administrative forest divisions of Poland. The main goal of this district is to control and protect forest complexes. The area of the KFD is about 166 km2, and the average forest stand is 285 m³/ha. The study area is characterized by a predominance of coniferous habitats and the average age of pine is around 70 years.

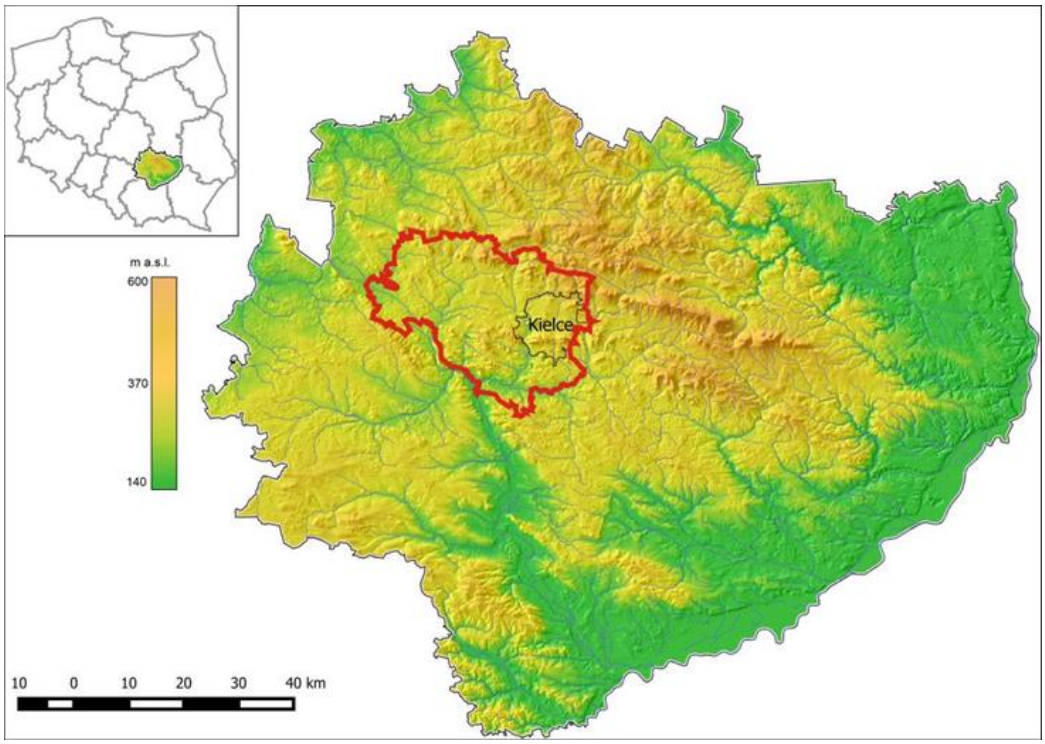

Figure 1. Location of Kielce Forest Department (KFD) area on DEM ed. by M. Frączek based on date from CODGiK (MGGP Aero, Nr GI-FOTO.703.44.2014)

AIM OF THE STUDY AND METHODS

The aim of the study is an attempt to explain the causes of fires, the ignition sources of which were not determined in 2010-2019, based on the example of the KFD (Fig. 1). In particular, it was about determining the weather and synoptic conditions in which such fires occurred and what role the moisture of the duff played in fire formation.

The course of selected meteorological data in the studied period, which could be conducive to fires, was analyzed. Basic data, such as monthly and annual averages: air temperature, maximum air temperature, rainfall, number of hot days, were obtained from the Kielce-Suków station and the IMGW (Polish Institute of Meteorology and Water Management) database. Data on the average temperature at the ground surface at a 5 cm level and the average duff moisture on a monthly basis were obtained. For selected fires with unexplained causes of their outbreak, measurements of duff moisture at 8:00 and

13:00 on a daily basis were obtained from the "TRAX elektronik" database for the station in Jędrzejów [7].
Source data on fires in the KFD in 2010-2019 were obtained from the digital database "Information System of State Forests - SILP, Llas.2" and the "Data Bank of Forests" system.

RESULTS

In the analyzed decade, 92 fires were recorded (140 reports). They were classified in terms of the number of fires that occurred in a specific year during the analysis period, the size of the fire in ha, the method of detection and the their occurrence reasons. The 54 fires were classified as unexplained (undetermined) of ignition causes (Fig. 2). Fires that occurred at the same time in the immediate vicinity, e.g. in the same department, were merged into one (49 fires in total). For these selected fires, additional synoptic data were obtained, which were then combined with each other in order to determine the weather conditions that could have caused to fire ignition, or could be related to human impact.
As the duff moisture content was not established in two cases, this limited the data to 47. On each day (except August 31, 2016, when the one measurement was missing), the duff moisture at 1:00 pm was lower than that at 8:00 am (Fig. 3). This indirectly indicates that there was no rainfall between these dates. from the Kielce-Suków synoptic station did not indicate rainfall in the days and periods before the fire was reported. The increase in air temperature and a decrease in relative humidity led to a decrease in duff moisture, which was also caused by an increase in radiation and wind speed. Therefore, it is so important to determine the weather conditions just before the fire.

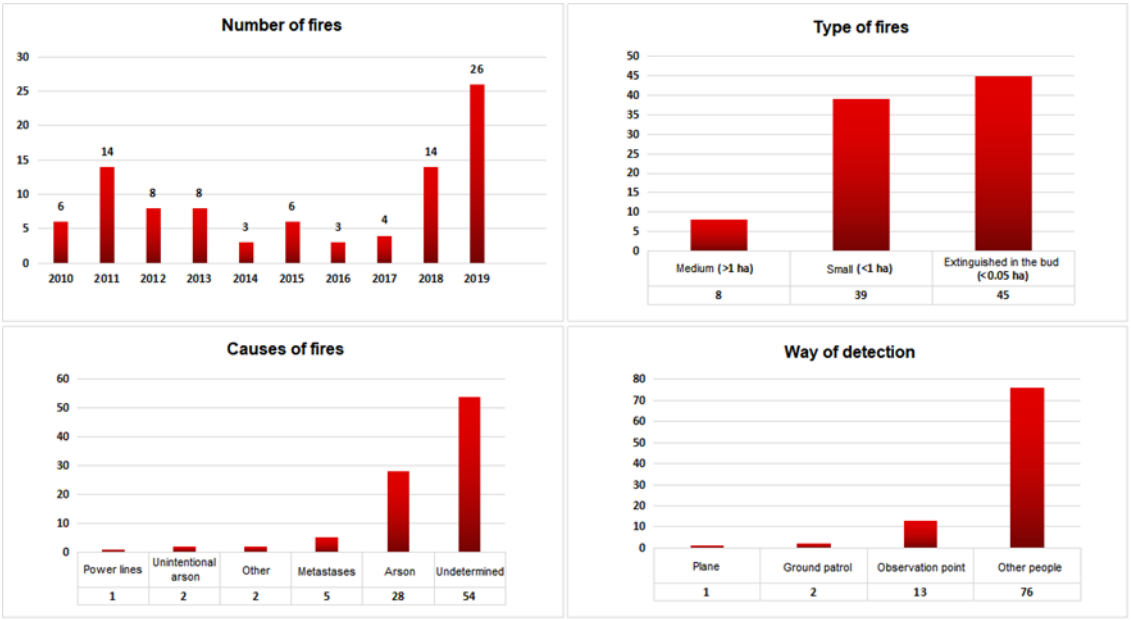

Figure 2. Summary data from „SILP, Llas.2" base about forest fires in the Kielce Forest District in 2010-2019

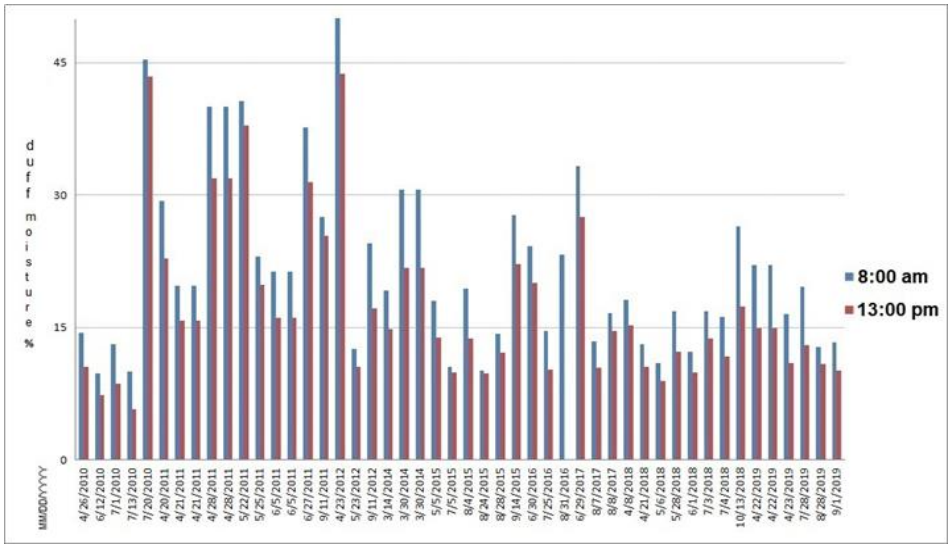

Figure 3. The duff moisture in % in two observation dates from days of fires with undetermined causes (FUC). Data obtained from the Jędrzejów Forest District station [7]

Table 1. Fires of undetermined causes (FUC) [7] under specific weather and synoptic conditions for Kielce-Suków station [8], [9]

No.	Date of fire	Forestry (section)	Notification time	Forest stand Duff moisture	Tmax (h) Before fire	fmin (h) Before fire	Synoptic situation
1	26/04/2010	Słowik (97 a)	16.02	SO 85	21.0 (15)	33 (15)	SE a
2	12/06/2010	Niewachlów (124 d)	13.46	SO KO	29.6 (12)	43 (11)	SW c
3	01/07/2010	Dobrzeszów (25 g)	14.15	SO 70	26.4 (12)	41 (12)	SW c
4	13/07/2010	Oblęgorek (85 f)	14.54	JD 55	29.9 (14)	41 (13)	E a
5	20/07/2010	Oblęgorek (85 d)	14.30	JD 60	25.5 (14)	63 (13)	E a
6	25/03/2011	Bilcza (141 c)	no data	OL 9	9.0 (12)	59 (12)	W c
7	20/04/2011	Gruchawka (79 d)	16.50	SO 70	17.7 (14)	25 (14)	E a
8	21/04/2011	Oblęgorek (88 c)	19.50	SO KDO	20.4 (15)	25 (15)	SE a
9	**28/04/2011**	Oblęgorek (88 c)	12.35	SO KDO	22.0 (11)	29 (11)	SE a
10	**28/04/2011**	Niewachlów (108 c)	16.45	SO 79	22.0 (11)	29 (11)	SE a
11	22/05/2011	Dąbrowa (1 c)	18.05	SO 60, 28	25.3 (13)	42 (13)	S a
12	25/05/2011	Dąbrowa (1 p)	13.50	SO KO	16.6 (12)	35 (12)	NW a
13	05/06/2011	Oblęgorek (85 a)	10.04	SO 70	26.3 (10)	35 (10)	S a
14	05/06/2011	Oblęgorek (83 c)	16.05	JD 60, SO KO	27.8 (14)	32 (15)	SE a
15	27/06/2011	Oblęgorek (84 d)	11.30	JD 55	19.5 (11)	37 (11)	N a
16	11/09/2011	Dyminy (11 a)	19.34	SO 60	26.8 (14)	51 (14)	SW a
17	**23/04/2012**	Podzamcze (163 n)	no data	SO 55, 65,	13.0 (12)	57 (12)	W c
18	23/05/2012	Oblęgorek (85 i)	14.00	JD 55	26.9 (13)	29 (12)	NE a
19	11/09/2012	Oblęgorek (152 g)	15.04	SO KO	29 (13)	27 (13)	SW a
20	14/03/2014	Sojowa (133 g)	13.00	SO 57	15.3 (12)	26 (12)	NW c
21	30/03/2014	Oblęgorek (85 g)	14.12	JD 55	16.2 (14)	19 (14)	S a
22	30/03/2014	Gruchawka (79 a)	14.02	SO 70	16.2 (14)	19 (14)	S a
23	05/05/2015	Czartoszowy (81 a)	15.30	SO 82	23.9 (14)	46 (13)	SE a
24	05/07/2015	Oblęgorek (87 a)	13.40	SO 109	31 (13)	40 (13)	S a
25	04/08/2015	Oblęgorek (91 d)	16.33	JD 75	31.5 (13)	30 (13)	SE a
26	24/08/2015	Niewachlów (138 f)	15.00	SO 50	26.9 (13)	37 (13)	SE a
27	28/08/2015	Niewachlów (108 d)	14.20	SO KO	32.4 (13)	32 (13)	S a
28	14/09/2015	Niewachlów (137 i)	8.25	SO 56	17.5 (8)	66 (8)	SE c
29	30/06/2016	Niewachlów (105 c)	21.00	SO 79	30.2 (14)	35 (14)	SW a
30	25/07/2016	Niewachlów (133 c)	17.30	SO 79	28.5 (15)	40 (15)	S a
31	31/08/2016	Sojawa (112 c)	8.43	JD 60	18.1 (8)	57 (8)	NW a
32	**29/06/2017**	Niewachlów (111 f)	13.14	no forest stand data	27.7 (13)	42 (13)	SW c
33	07/08/2017	Oblęgorek (89 f)	18.07	SO 11	21.0 (15)	44 (16)	E a
34	08/08/2017	Oblęgorek (98 f)	15.41	SO 11	23.2 (15)	48 (14)	SE a
35	08/04/2018	Gruchawka (71 j)	17.48	SO 74	21.5 (14)	40 (14)	S a
36	21/04/2018	Oblęgorek (86 z)	18.03	SO 94	24.8 (12)	37 (14)	W a
37	**06/05/2018**	Oblęgorek (98 d)	17.00	SO 57	19.6 (14)	36 (16)	NE a
38	28/05/2018	Niewachlów (121 a)	13.50	SO 76	25.7 (13)	36 (12)	SE a
39	**01/06/2018**	Niewachlów (121 h)	13.18	SO 15	29.1 (13)	32 (13)	SE a
40	03/07/2018	Dobrzeszów (38 h)	14.34	SO 105	22.6 (14)	36 (14)	N c
41	04/07/2018	Oblęgorek (157 c)	13.12	DB 100	26.5 (12)	28 (12)	W a
42	13/10/2018	Oblęgorek (157 c)	10.30	JD 65	19.0 (10)	52 (10)	NE a
43	06/11/2018	Gruchawka (62 b)	12.15	JD 70	17.2 (12)	49 (12)	S a
44	22/04/2019	Dąbrowa (59 f)	10.28	JD 65	13.4 (10)	59 (10)	E a
45	22/04/2019	Dąbrowa (68 a)	12.55	SO 5	14.4 (12)	47 (12)	SE a
46	23/04/2019	Oblęgorek (98 g, 161 a)	18.20	SO 16	17.4 (15)	30 (16)	SE a
47	28/07/2019	Sojawa (151 g)	15.15	SO 90, 4	31.7 (15)	33 (15)	SE a
48	**28/08/2019**	Niewachlów (137 a)	17.41	SO 73	29.8 (14)	45 (14)	S a
49	01/09/2019	Podzamcze (203 h)	16.37	SO 18	29.3 (15)	46 (14)	S a

Medium fire is marked in bold

SPRING	<15%		
SUMMER	very dry duff	25.1 - 30.0 °C hot	30 -49% dry
AUTUMN	>27%		
	non-flammable duff	> 30.0 °C very hot	< 30% very dry
	no data		

DISCUSSION

In general, fires of undetermined causes (FUC) can arise from carelessness or even intentional human action. Because these reasons cannot be verified, and the perpetrator may not even know that he set fire to the forest. For this purpose, attempts were made to link FUC with factors occurring without human intervention, i.e. weather conditions and the moisture content of the duff.

The intensity of the fire spread depends primarily on the amount and type of combustible materials covering the soil surface (forest duff) and the wind speed. Pine duff has the best flammable properties. The duff of other conifers (spruce, fir, larch), due to its compact structure, ignites worse than pine. Beech duff after the growing season, i.e. in late autumn, is also a good combustible material [10].

Out of 49 FUC, only in one case the type of forest stand was not established (Tab. 1). Among the specified communities, the most, 32 communities (66.6%) were pine forests, 10 fir forests (20.8%), 4 mixed forests (8.3%) and 1 oak and alder (2.1%). The vast majority of 95.8% of fires for unknown causes occurred in coniferous stands, where the duff is the most flammable. In the analyzed decade, FUC occurred in every year except 2013. The highest number was 12 in 2011 and 10 in 2018. In total, 44.9% of FUC occurred in the summer months (June-August) (Tab. 1).

In the spring period (March-May) there were as many as 42.9% of FUC, while in the autumn period (September-November) only 12.2%. Spring fires resulted largely from the lowest relative air humidity in the year [11], [12]. The FUC was reported the earliest on March 25, 2011, and on November 6, 2018 at the latest (Tab. 1). In the KFD, conditions conducive to FUC were recorded on very dry days of April 2011 (Gruchawka, Oblęgorek - medium fire and Niewachlów - medium fire), as well as in May 2012 (Oblęgorek) and March 2014 (Sojawa, Oblęgorek and Gruchawka Forests) (Tab. 1).

Weather favorable to fires was the 43% of all days with FUC. In total, FUC occurred mostly in anticyclone situations (83.6%) and in advection from the southern sector (77.6%). The most common situations were SEa (28.5%) and Sa (22.4%). It can be concluded with high probability that FUC in more than half of the cases were associated with the inflow of very warm and dry tropical air mass. This mass causes a quick drying of the forest duff.

Non-flammable duff occurred only in six fire terms (12.8%), which indicates a intentional forest fire ignition (5 of them is the Oblęgorek, one is Podzamcze). In 16 cases (34%), the fire was registered at the duff which was not too dry (16-27%), but could have caught the fire due to intentional or accidental arson. Especially could happen when the duff has a moisture content of less than 15%. There were 26 such dates, which accounts for 55.3% of unidentified fires. As far as forest stands are concerned, in 21 cases (80%) they were pine forests, in three (12%) fir forests and in one oak-hornbeam forest. Since boron assemblages are characterized by a high content of volatile flammable substances in the duff, the initiation of ignition with even a single spark may lead to a violent forest fire.

The favorable thermal and humidity conditions with very dry duff occurred in 15 FUC (30.6%). In 2010, this concerned three fires (Niewachlów, Dobrzeszów, Oblęgorek) and once in 2012 (Oblęgorek). In 2015, there were 4 fires (2 each in the Oblęgorek and Niewachlów) and all of them were associated with summer heat waves that were passing through Poland at that time [13]. Hot and very hot days also occurred during a fire in the summer of 2016 (Niewachlów), in spring and summer 2018 (Niewachlów - medium fire in summer) and 3 times in 2019 (Sojawa, Niewachlów - medium fire, Podzamcze) (Tab. 1). Unfortunately, due to the very local nature of the occurrence of storms, especially

lightning, it was very difficult to establish such a cause for the KFD. The meteorological conditions at the Kielce-Suków synoptic station were taken into account, but no Cumulonimbus storm clouds with precipitation were found on the dates of FUC. Of course, such a possibility cannot be completely exclude, although it is very unlikely after additionally analyzing the thermal, humidity and circulation conditions (atmospheric fronts). There is no evidence to conclude that lightning was the cause of any FUC in the KFD in the analyzed decade.

CONCLUSIONS

FUC in the analyzed decade ware mostly in coniferous communities, especially in the most flammable pine forests. Their causes were mainly anthropogenic and natural. They were caused by the convergence of the strong flammable properties of the forest duff in time, favourable weather and synoptic conditions, and anthropogenic ignition of fire. It can be assumed with high probability that the human-initiated accidental ignition of forest litter occurred in about half of the FUC. The causes of intentional arson should be sought due to high moisture of the duff. Lightning discharges were practically excluded among FUC. Also, self-ignition is practically impossible in the conditions that take place in the studied area.

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