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SHORT COMMUNICATION

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The use of remote sensing data sources and GIS in fire protection planning in Biebrza National Park, with special attention to non-forest ecosystems

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Abstract

In the spring of 2020, a large-scale fire destroyed 5,526 hectares of wetlands in Biebrza National Park. It was decided to modernize the park's fire protection system. It proved necessary to develop rules for fire protection in large natural areas where non-forest communities predominate. A team of experts from the Forest Research Institute, the Fire Department, and the Biebrza National Park developed methods for fire protection in the park based on open, publicly available remote sensing data sources. The following methods were developed or modified and adapted to the conditions of the park: determination of fire danger, prediction of fire danger, modeling of fire development, determination of the network of fire access roads, determination of water supply points, including water withdrawal points for helicopters, detection of fires, functioning of the alarm and communication system, firebreaks, places of concentration of forces and resources, equipment for fire fighting, and taking preventive measures. The developed principles of fire protection in the Biebrza National Park, based on open remote sensing data and the technology of GIS, will enable the creation and operation of a system that will reduce the probability of fires in the future.

Key words

Biebrza National Park, fire risk assessment, fire risk prediction, fire detection, non-forest communities, fire protection systems

Introduction

The observed changes in climate parameters are the reason for the increase in the frequency of various disturbances in the natural environment, including fires. The area affected by fires is expected to increase worldwide, especially in temperate zones (Senande-Rivera et al. 2022; Jones et al. 2022; Mortiz et al. 2012). Climate change poses new challenges to forest fire protection. As average temperatures rise, the number of wildfires in forests increases (Gilett et al. 2004). The expected increase in the frequency and size of fires is

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of particular importance for the protection of ecologically valuable areas, especially national parks. According to the National Forest Fire Information System 2007–2020 (KSIPL 2022) data, Biebrza National Park (BbNP) was ranked second (out of 23 national parks in Poland) in terms of the number of reported fires.Considering the size of the burned area in the BbNP, this represents 98% of the total burned area in all national parks during the described period. This was mainly due to the largest fire in the history of the BbNP so far, which broke out on 19 April 2020 and covered an area of 5526 ha of the Biebrza marshes and swamps. These types of non-forest communities (rushes, sedges, moss communities, meadow communities) are characterised by the presence of highly flammable fuels, especially in early spring.

Remote sensing (RS) data and techniques that provide spatially continuous information about the environment are of increasing importance in designing fire protection in environmentally valuable areas. Their main advantages include the ability to obtain consistent, objective, repeatable and up-to-date data sets on selected features of the natural environment. RS techniques make it possible to obtain data over large areas in a short time without interfering with valuable and often fragile ecosystems. RS data combined with descriptive databases and Geographic Information System (GIS) have great potential for modelling the risk of fire occurrence and progression and for planning fire protection systems for large natural areas.

The fire that occurred in April 2020 in the BbNP and the risk of further such events were the basis for the decision by the Ministry of Climate and Environment to develop a modern and appropriate fire protection system for the park to meet the changing threat. According to the authors' knowledge, no methodology has yet been developed for designing fire protection for such a large area of high-value natural environment characterised by a mosaic of forest and non-forest communities. This task was entrusted to a team of experts from the Forest Research Institute. The main objective of the team's work was to develop a methodology for designing the principles of fire protection of the park and, based on these assumptions, to create specific descriptive and cartographic materials that can be used in the operational planning of fire protection of the BbNP.

The purpose of this paper is to briefly present the scope of research and work conducted with BbNP as part of the project funded by the State Forests from the Forest Fund under contract number EZ.0290.1.4.2021, focusing on spatial analyses based on open RS data sources.

Scope

The scope of the planned research, which covered the entire area of the BbNP (59 223 ha), included the following tasks:

1) planning and establishing a network of sample plots to obtain information about aboveground biomass and determine fire load density for the major non-forest community groups of the BbNP under laboratory conditions;
2) developing a method for mapping fire risk in non-forest ecosystems;
3) organising a team of specialists consisting of employees of the Laboratory of Forest Fire Protection and the Department of Geomatics of the Forest Research Institute, representatives of the BbNP, the Voivodeship Headquarters of the State Fire Brigade in Białystok, the Voivodeship Headquarters of the State Fire Brigade in Mońki and Grajewo to jointly develop a method for planning fire protection of the BbNP, considering the following:
   – fire risk assessment of forest and non-forest ecosystems,
   – fire risk prediction,
   – fire detection,
   – organisation of alarm and communication system,
   – firefighting equipment,
   – fire access roads for selected classes of firefighting vehicles,
   – water supply, including helicopter access to existing and potential water supply points,
   – a network of firebreaks,
   – preventive measures,
   – fire spread modelling;
4) applying the developed rules and creating (using available open data sources) materials with high potential for use during the preparation of the fire protection plan.

Methods and results

Access to up-to-date and comprehensive information about the condition of the area of interest (AOI) is necessary for the design and operation of the fire protection system. Constant access to such information is very important in firefighting actions. This is especially true for large natural areas, which include the BbNP. One of the main assumptions of the project was to make a maximum use of free, public, spatial data sources (including RS data and GIS tools) to provide information to facilitate the planning and operation of the park's fire protection system.

One of the basic information needed to evaluate the fire risk of natural areas is the data on the fire load density of the AOI. So far, the methods used in Poland to determine fire load have mainly been applied to forest areas. In the case of BbNP, there was a need to determine the fire load of non-forest ecosystems. Fire load density is determined by the amount and type of fuel stored, which, in the case of non-forested BbNP ecosystems, is related to the density and height of vegetation cover. To know the spatial variability of the fire load density of non-forest ecosystems in the BbNP, the park authorities obtained (1) elevation data in the form of the digital terrain model (DTM) and the digital surface model (DSM) and (2) information on the spatial range of non-forest communities. A network of 300 sample plots representing major groups of non-forest communities was established. The biomass of the aboveground part of the plant material was collected. The collected material was analysed in the laboratory to determine the dry mass of fuel. The results of the analyses allowed the development of three low-vegetation fuel models as the basis for determining the fire load of non-forest ecosystems of the BbNP. As a result of using the developed fuel models and calculating the fire load density of forest ecosystems based on the existing forest fuel models (Szczygieł et al.), a cartographic study was prepared containing the spatial distribution of fire load density of the entire BbNP area expressed by the mass of accumulated dry fuel per square metre.

A very important subject of the spatial analyses performed in the project was the issue of making the facility available for rescue-firefighting activities. This is especially important in areas with low road density, such as the BbNP. The project team considered the designated fire access network to be one of the most important information needed for firefighting operations. The criteria for establishing the network of fire access roads for forest areas are regulated in the current Decree of the Minister of Environment of 22 March 2006 on detailed regulations for forest fire protection (Law of ...2006). As part of the analytical work, criteria for determining the network of fire access roads for non-forest areas were developed. An analysis of the needs of users, that is, Representatives of the State Fire Service, Volunteer Fire Service and BbNP representatives, was conducted. The expected parameters of the minimum density of the fire access network for local roads were defined, and information on the class of firefighting vehicles that can operate on them was assigned based on the technical parameters of the roads. Based on data such as (1) the communication network from the National Database of Topographic Objects (BDOT10k) (URL 1), (2) the Airborne Laser Scanning data (ALS) from the park's database and (3) the up-to-date orthophoto map provided by the Head Office of Geodesy and Cartography (GUGIK) (URL 1), a preliminary network of potential fire access routes for the non-forested areas of the BbNP was identified after applying the defined criteria. The resulting access network was subjected to field verification by the park staff to ensure that it met passability criteria. The reviewed routes network was integrated into the existing layer of fire access roads for forest areas. As a result, a cartographic study was prepared that included a network of fire access roads for the entire park, as well as information on the classes of fire trucks that can move on these roads.

The analysis of the developed network of fire access roads confirmed the existence of areas in the park with a very low density of fire access roads. Based on the experience from the previous firefighting operations, it was decided to designate additional areas – terrain ridges. These are non-road areas that firefighters could access with light all-terrain vehicles or by foot. Spatial criteria for terrain elevations have been established based on minimum area, minimum width, continuity and connection to the access road network and subsurface structure. On the basis of (1) data on topography obtained from ALS, (2) developed network of fire roads, (3) up-to-date orthophotomap and (4) spatial information on soil types obtained from the park employees, spatial processing was performed (includ-

ing analysis of topography in the immediate vicinity) to reveal the network of ridges. The process of delineating the ridges was performed iteratively, each time verifying the preliminary results obtained with the park's field staff to confirm the actual existence and suitability of such terrain. As a result of the performed arrangements and analyses, a cartographic elaboration was obtained showing linear terrain elevations in the BbNP area, which can provide alternative and/or complementary areas to the fire access network, enabling rescue and firefighting units to reach the fire.

Another important issue addressed by the team was the analysis of the density of existing water supply points. Conducting firefighting operations in the BbNP area depends, among other things, on the availability of an extinguishing means, mainly water. Despite the high humidity and the dense network of watercourses in the park, the existing network of water outlets was insufficient. The experience from the April 2020 fire and the analysis of the existing water supply network have shown that it is necessary to increase the number of withdrawal points, to establish additional reserve points and to designate suitable points for water withdrawal through the use of helicopters. As part of the work on the density of supply points for firefighting vehicles, spatial criteria were developed to characterise such locations. The minimum area, tangency to public roads, the required type of subsoil and the preferred types of water reservoirs were defined. Based on the location data of (1) rivers, watercourses and water channels obtained from BDOT10k, (2) lakes, ponds and other water reservoirs obtained from BDOT10k, (3) up-to-date ortophotomap, (4) previously developed fire access network, (5) soil types obtained from the park service and (6) DTM obtained from ALS data, spatial analyses were performed after applying the defined criteria. As a result, proposals for the location of new water supply points for firefighting vehicles were obtained. The proposed points were subjected to field verification by the fire brigades. As a result of the conducted work, decisions were made to determine new and reserve water supply points for firefighting vehicles. A special type of analysis regarding water supply points was the determination of optimal water intake locations for helicopters. Based on the experience gained during the 2020 fire, the team proposed spatial and descriptive criteria to automatically designate such sites. Requirements for minimum water surface area, reservoir depth, minimum distance of trees from reservoir boundaries, density of supply points, maximum distance from park boundaries and minimum distance from electric lines were defined. Based on the location data of (1) rivers, watercourses and water channels from BDOT10, (2) lakes, ponds and other water reservoirs from BDOT10k, (3) the up-to-date orthophotomap, (4) the DTM and the normalised DSM (nDSM) and (5) the power line network from BDOT10k, the proposed location of helicopter water reservoirs was determined. As a result of the water supply analyses, a cartographic elaboration was obtained that included the spatial distribution of water supply locations for firefighting vehicles, divided into main and alternate points, and water supply points for helicopters, divided into main and alternate points.

Conducting firefighting operations, especially in the case of large-scale fires, requires the commander of the operation to optimally distribute the forces and resources at his disposal. The project team recommended the designation of optimal points for accommodating forces and resources. With the aim of defining spatial criteria to determine such points, a requirement analysis was conducted. The minimum density of points, tangency with the fire access network, required type of soil, minimum area, required geometry of the area and preferred directions of accesses were determined. Based on data such as (1) the communication network from BDOT10k, (2) orthophotomap from GUGIK, (3) the locations of firefighting units from the archives of the State Fire Service, (4) the fire access network developed in the earlier phase of the project and (5) the soil types from the archives of BbNP, a preliminary proposal of places for accommodating forces and resources was prepared. The original list of these places was evaluated and supplemented by the project team. As a result of the analysis, a cartographic elaboration was made, showing the spatial distribution of the places where forces and resources can be accommodated, along with a description of their basic localisation parameters and directions.

An important element of fire protection in natural areas is the designation, construction and maintenance of barriers to limit the possibility of fire spread. For forest areas, this task is performed by a network of firebreaks, the design and maintenance of which is regulated by law (Law of ...2010). It was decided that it is necessary

to develop firebreak design rules for non-forested ecosystems of the BbNP. It is defined that the maintenance of firebreaks can only be done by mowing. Two types of firebreaks were proposed: permanent (maintained throughout the year) and temporary (created during a fire). Spatial criteria have been established that relate to the following: contact with the network of fire access roads, land ownership, protection status, minimum length, plant communities where mowing should occur, integration with the network of firebreaks in forest areas, course of firebreaks on the field–forest boundary and division of the park into smaller integrated areas. Based on data such as (1) communication network from BDOT10k, (2) orthophotomap from GUGIK, (3) Corine Land Cover satellite classification from BbNP, (4) land ownership information from the park's archives, (5) power lines locations from BDOT10k and (6) plant community data from BbNP, spatial analyses were conducted and the preliminary firebreak network was presented. As part of the arrangements made, based on the knowledge of the BbNP staff, the designed network of firebreaks was partially corrected and supplemented. As a result of the arrangements and spatial analyses carried out, a cartographic elaboration presenting the course of the planned permanent and temporary firebreaks was obtained.

Another important element of the BbNP fire protection system, which was upgraded as part of the project work, was the fire detection system. According to the Regulation of the Minister of Environment of 22 March 2006 on the modalities of forest fire protection, national parks are obliged to establish and maintain a monitoring and alarm system. The task of the system is to detect a fire in the forest as soon as possible, determine its location and alert the rescue and firefighting services. The network of constant ground observation is the most important means of detecting forest fires. It can be formed by fire towers and substitute observation points located on other tall structures. The preliminary assessment of the possibility of effective observation of the existing fire observation towers showed the necessity to supplement them with additional observation points. A decision was made to develop the optimal location of fire observation posts in two variants. In the first variant, it was assumed that a network of towers would be built based on the park's own infrastructure on land managed by the BbNP. The second variant assumed that the existing fire observation towers of the forest districts adjacent to the park would be used. Spatial analyses were conducted using the following data: (1) land ownership from BbNP resources, (2) nDSM from the park repository, (3) orthophotomap from GUGIK, (4) power line network from BDOT10k and (5) locations of existing fire monitoring towers from BbNP. Two cartographic studies have been prepared showing the optimal network of fire towers with their observation area that would allow monitoring of the entire BbNP area: a version based only on the park infrastructure and a version that includes the State Forest towers.

The ability to predict fire spread in plant communities (forest and non-forest ecosystems) in BbNP provides the basis for appropriate planning and organisation of fire suppression activities. According to the project team, in order to effectively initiate and conduct firefighting operations, it is necessary to know the type of fire, its size and the speed of fire spread. This information is necessary to ensure the right amount of forces and resources to extinguish the fire. The size of the fire depends on the time of free development (the time from the outbreak of the fire to the start of extinguishing operations), the type of fire, meteorological conditions and the moisture content of the fuel. The project used a modified application of the 'Forest Fire Model' (Szczygieł et al. 2013, Szczygieł et al. 2017) developed at the Forest Research Institute and adapted to non-forest areas. As part of the changes, the algorithms were modified to adapt them to a much higher fire load density of non-forest ecosystems. Based on data from (1) fire development model for non-forest areas, (2) fire model for forest areas, (3) location of fire units from the archives of the State Fire Service, (4) different speed of firefighting vehicles depending on the category and surface condition of public roads, (5) assumed different travel speeds on unpaved roads depending on their technical parameters and maintenance condition, (6) assumed different response times from the alarm to the departure of fire trucks, (7) assumed arrival time of firefighters to the fire scene and the start of firefighting operations and (8) fire access routes, after conducting iterative network analyses, information on the type of fire and the time of free development of fire was obtained. The data allowed calculations and cartographic studies that contained information on the entire area of the park, including time of free development of the fire

expressed in minutes, speed of free development of the fire expressed in metres per minute and size of the fire after the time of free development of the fire expressed in hectares.

Assessing the fire hazard of the facility is the basis for planning adequate fire protection.The territory of the BbNP is covered by a mosaic of forest and non-forest communities, with the latter predominating. Polish forests are classified based on fire risk in accordance with the Regulation of the Minister of the Environment of 9 July 2010 on the detailed rules for forest fire protection. The category of forest fire danger is determined for the area of the forest district or national park. In order to assess the fire risk of the entire BbNP area, it was necessary to develop a methodology for assessing the fire risk of non-forest ecosystems, which was done in the first part of the project (Szczygieł et al. 2022). As a result of using both methods to assess fire risk assessment, a cartographic study was prepared showing the spatial distribution of forest and non-forest ecosystems by flammability class. In addition to the spatial information described above, which is part of the BbNP fire protection rules developed as part of the project, the project team also developed guidelines related to the functioning of the alarm and communication system, prediction of fire hazards, functioning of the BbNP director's authorised representative, adequate provision of firefighting equipment bases and preventive measures.

Summary

The rules, guidelines, recommendations, spatial data and information and analytical models developed as part of the project were handed over to BbNP staff. Conducting spatial analysis based on public, open data repositories provides access to current information needed to conduct ongoing activities related to BbNP fire protection. They allow updating of the tools developed under the project according to the changing situation over time, such as the expansion of the access road network. It should be added that these data can be downloaded and used free of charge and without restrictions, in accordance with the Open Data Act (Act of ... 2021). The solutions developed in several project meetings by a team of specialists will allow the park staff to update information that will affect the development of a fire protection system appropriate to the risk in one of the most valuable natural areas in Poland, the BbNP.

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