Proceedings

Impact of Climate Change on Forest Management: Białowieża Primeval Forest Case Study†

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Abstract: Ecosystems of Białowieża Primeval Forest are characterized by a high degree of naturalness and biodiversity. Changes in species and age structure in the long-term period resulted from both natural processes and human impact (indirectly and directly). The assessment of changes and knowledge about the current state allows to decide what protective measures should be taken to improve the condition of forest ecosystems. One can also evaluate the processes taking place and their direction, and therefore also assess the need for any actions. In the conducted research, the changes occurring in forest ecosystems with particular emphasis on spruce were assessed. An almost 100-year process of evolution of the species share in stands was analyzed up to 2015 using historical forest management and present spatial information data. Habitat data was used to asses the suitable and unsuitable conditions for spruce dominance. In addition, long-term development model was used for forecasting of the share of this species using data from beginning of 2015. Those results were compared with data from more than 500 sample plots measured in 2016-2018, just after bark beetle (*Ips typographus*) outbreak in 2015. Spruce has doubled from 12 to 25% its share of the Bialowieża Forests area in the first half of twentieth century and was stable for the second half. Development model run just before the outbreak suggested stable decrease of spruce share in the horizon of 2065 down to 23%. Habitat model from 2015 was suggesting that spruce suitable sites cover only 12% of the area and only 50% of that area being dominated by spruce; the residue growing in unfavorable habitat conditions. Recent outbreak, with no management control, has dwindled spruce share down below 9%, showing habitual model results being better than development model scenario.

Keywords: Białowieża Primeval Forest; *Picea abies*; development model

1. Introduction

In north-eastern Poland, the Norway spruce (*Picea abies* (L.)) is one of the main forest-forming species, being part of many forest communities, including those characteristic of the Białowieża Primeval Forest [1]. The deteriorating health condition of spruces within the limits of their natural occurrence in the lowlands seems to be more and more noticeable in recent years. The current sanitary condition of spruce stands is primarily related to the outbreak of the spruce bark beetle. Nevertheless, in the light of current knowledge, the increased phenomena of the spruce bark beetle and companion species on spruce are an inherent feature of natural forest ecosystems with a large share of this tree species [2-5] .

In parallel with the entomological aspect of spruce dieback in the Białowieża Primeval Forest, analyzes of the potential impact of climate change on the degree of threat to tree species occurring in the Białowieża National Park Strict Reserve are carried out. Out of 11 analyzed species, spruce was considered relatively safe. Nevertheless, due to the systematic decline in the share of spruce in the species composition, it eventually found itself in the group of the "most endangered" species [6].

Due to a series of interdisciplinary studies currently conducted in the Białowieża Primeval Forest, we have an enormous, though still incomplete, knowledge about the changes taking place in forest stands over the last several decades. In our research, we refer to the past, based on available sources and historical messages, presenting the history of changes in the occurrence of Norway spruce in the Białowieża Forest in spatial terms. Bearing in mind the fact that most of the research conducted in the Białowieża Primeval Forest concerns primarily the area within the Białowieża National Park, in our research we decided to focus on forest stands in which forest management has been carried out for many years.

Our aim in this research was to analyze spruce domination historical and recent changes as well as potential for this species in the managed part of Białowieża Primeval Forest.

2. Materials and Methods

Our research focused on stands located in the area of the Białowieża Primeval Forest that are under the maintenance of Polish State Forests. (We excluded Białowieża National Park from the research.) This area is known under the name of Forest Complex "Puszcza Białowieska", covering the area of three forest divisions: Browsk, Hajnówka and Białowieża – a total of 50 559.45 ha (Figure 1.).
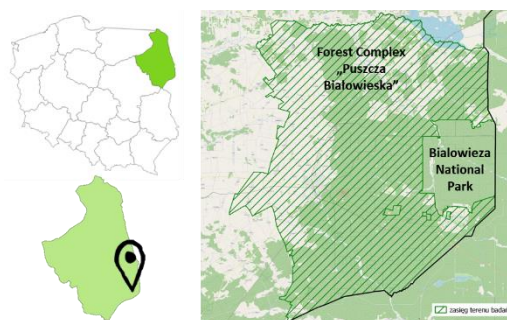

Figure 1. Forest Complex "Puszcza Białowieska" consisting of three forest divisions: Browsk, Hajnówka and Białowieża that occupy more than 50 thousands hectares.

Our research focused on spruce was divided into three main parts: (I) analysis of spruce domination from historical materials, (II) modelling of spruce domination in Business-as-Usual situation and (III) assessing the spruce domination under bark beetle outbreak.

For achieving the first goal we have used forest maps from 20th century that were provided by State Forests in Poland. They were scanned and calibrated. Spatial analyzes of changes in the area share of spruce as the dominant species were performed in the ArcGIS software. Statistical analyzes concerning general changes in the share of dominant species and detailed changes in the spruce share in the sample circular plots were performed in the R environment.

Second goal was achieved using forest management modeling techniques. We have focused on changes in wood resources, with particular emphasis on stands in which spruce was the dominant species. We have used Business-as-Usual (BaU) approach trying to identify potential stand structure in 60 years time frame. A single stand was the starting point for calculations and further analyzes. The forecast was made for the time period 2015-2075.

Third goal was achieved using data from circular sample plots established in 2016 and remeasured twice: in 2017 and 2018. There were 1139 sample pots located randomly in research area. All living and dead trees as well as their location and dimensions were measured.

We have additionally prepared two analyses: (I) we have analyzed suitable and unsuitable conditions for spruce dominance in the research area using stands habitat data from management plans and (II) we have compared bare beetle outbreak periods with Sielianinow hydrometeorological index (K). The climate database was built on the basis of standard meteorological measurements recorded in the years 1951-2018 at the Station of the Institute of Meteorology and Water Management in Białowieża.

3. Results

Results from spatial analyses of species domination in the research area show that at the beginning of the 20th century the share of stands in which the dominant species was spruce was 12%. In 1948, the area of spruce stands increased to ¼ of the area of the forest stands. By introducing the principles of forest management to the research area, the share of spruce stands was maintained at a similar level for the next decades (Figure 2.).

The proprietary forecasting model, taking into account the principles of management planning in BaU model, showed that activities carried out in accordance with rational forest management would lead to a gradual reconstruction of stands and, consequently, a reduction in the share of spruce stands to 25% in 2075 (Figure 2.). The forecast adopted the forest management scenario, without taking into account the potential significant threats to the stand.

In the last part of analysis, due to rapid bark beetle outbreak, sample plots were established to assess its impact on research area. The analysis of data collected on the sample plots showed a drastic decrease in the share of spruce as the dominant species: from 27% to 9% (Figure 2.).
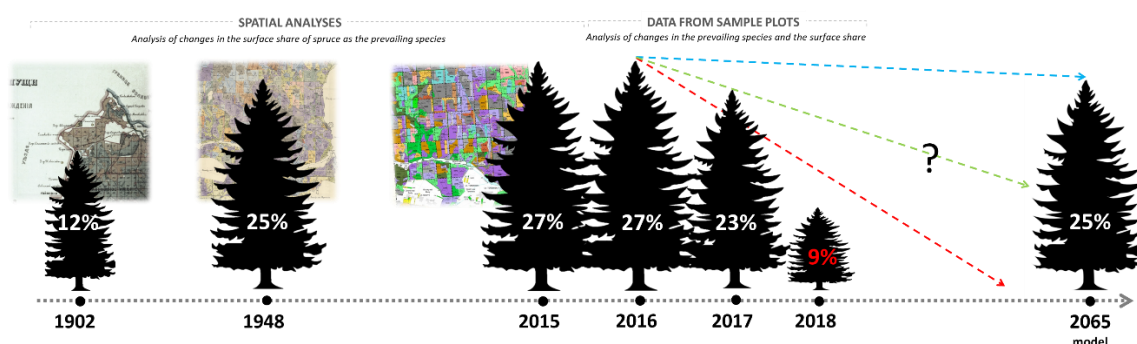

Figure 2. Changes in the percentage of forest area dominated by spruce. Spatial analyses were performed on cartographic material as well as using current forest management planning data. Modelling (blue dashed line) was performed using BaU approach. Sample plots data (red dashed line) were focusing on situation during and after bark beetle outbreak. Green dashed line symbolizes uncertain ideal future share of the forest area dominated by spruce.

The obtained modeling results prompted our team to undertake further analyzes in order to explain the reasons for the gradual decrease in the share of spruce as a dominant species in forest stands. We wanted to focus on habitats and their suitability for spruce domination – only some of them are suitable for spruce domination however not in all of their variants. In 2015, the area of stands with spruce as a dominant species was approximately 13 thousand ha. Spruce is dominating in only ~3300 ha out of total of ~6500 ha suitable habitats (50% of area). Remaining ~10 thousand ha (77% of spruce dominated stands) of stands with spruce domination grow in unsuitable habitat condition (Figure 4.). Connecting that fact to the predicted decreasing share of spruce stands, it can be assumed that under conditions of forest management undisturbed by external factors, the target decline in the share of stands with spruce as the dominant species would stop at the pre-World War II level, i.e. approx. 12%.

Figure 3. Habitat suitability of spruce domination.
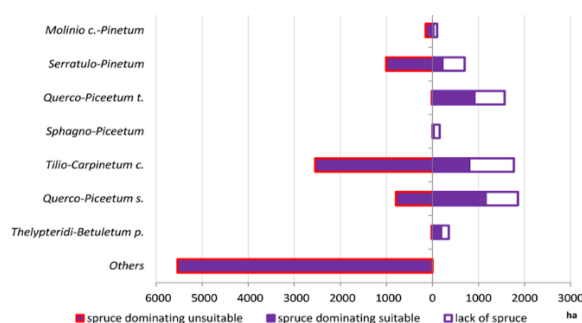
The analysis of climatic data showed significant changes from the point of view of spruce biology. A trend of increasing the average annual air temperature was observed. In the case of atmospheric precipitation, relatively small changes are observed in general, but there is a clear trend of increasing the number of days in a year with rainfall, with a downward trend in the number of days a year with snowfall and the number of days with snow cover. Therefore, we observe a significantly shorter period of snowfall and snow cover deposition. Additionally, when analyzing the Seljaninow hydrometeorological index (K) curve, indicating the optimal thermal and humidity conditions for the forest, there were 28 years with a moisture deficit (Figure 4.), and the average value of the K-index reached only the lower limit of the optimum (1.56).
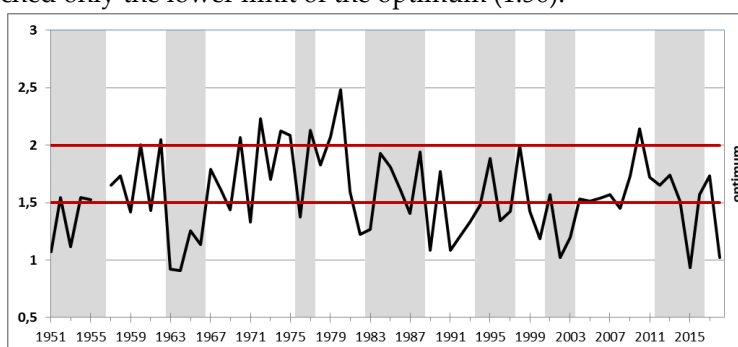

Figure 4. Sielianinow hydrometeorological index (K) for Białowieża meteorological station for the period 1951-2018 and bark beetle outbreaks (grey background).

4. Conclusions

The results of the spatial analyzes conducted by our team concern the period from the beginning of the 20th century. The reconstruction of the course of changes in the share of Norway spruce occurring in the forest stands made it possible to determine the spatial extent of the spruce stands and to trace subsequent changes in chronological terms. Additionally, by relating the obtained results to human activity in the Białowieża Primeval Forest, it was also possible to determine the anthropological impact on changes in the share of spruce over the last several dozen years.

Analyzing the historical materials, it was found that the significant expansion of spruce in the Białowieża Primeval Forest over the last 100 years was related primarily to human activity in this area. The rapid increase in the number of game and forest grazing at the turn of the 19th and 20th centuries was the direct cause of the reduction and disappearance of the sapling of many deciduous tree species in favor of spruce regeneration. Another action, which undoubtedly had a strong impact on the changes in the species composition of forest stands, was the intensified exploitation of the Forest: World War I and methodical deforestation by the Germans, then the interwar period, during which deforestation of many hectares was carried out without renewal (concession for felling granted to The European Century Timber Corporation).

Uncovering the already existing spruce regeneration and renewing the multi-hectare felling areas with spruce of foreign origin resulted in a significant increase in its share. Currently, the share of spruce as a dominant species in forest stands is lower than at the beginning of the 20th century.

The drastic decline in the share of this species in the last few years is mainly related to the outbreak of the spruce bark beetle.

Conflicts of Interest: The authors declare no conflict of interest.

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