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ORIGINAL PAPER

Changes in forest species composition over the last century in Świętokrzyski National Park

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ABSTRACT

The forests of Świętokrzyski National Park are an example of changes in tree species composition of stands which mainly occur spontaneously. The main forest-forming species in this area was the European silver fir *Abies alba* Mill. with a mixture of European beech *Fagus sylvatica* L. Both species seem to be beneficiaries of the climate changes occurring in this part of Europe: an increase in average temperature with a slight decrease in precipitation in upland and mountainous areas. This study aimed to analyse the changes occurring in the species compositions of stands in Świętokrzyski National Park from 1925 to 2014. As data from long-term studies of permanent sample plots characterising changes in the park area were not available, we used 299 random sample points distributed evenly over the study area and stand descriptions in which the points were located during the inventory periods. Inventory data from the years 1925, 1954, 1971, 1997 and 2014 were used. Data from the forest management plans were compiled into a database and processed to determine the role of species in each stand layer to indicate the forest-forming role of the species. The forest-forming role of the two species studied was linked to the forest habitat type, moisture variant, forest type and forest condition. Spatial analysis was based on a numerical terrain model, from which derived layers were calculated and their scores were attributed to their forest-forming role. An attempt was also made to analyse the relationship of the forest-forming role with a topographic moisture index, but no significant results were found for the generalized data within the boundaries of the forest stands. The widespread and persistent dominance of fir in the forest ecosystems of the study area was confirmed. In the case of beech, a correlation between its forest-forming role and altitude was observed. Up to a height of 480 m above sea level, its forest-forming role increases and then decreases at higher elevations. The results can be used to project the extent of regeneration of fir and beech forests in the Świętokrzyskie region.

KEY WORDS

European beech, forest habitat type, map analysis, Silver fir

Introduction

Changes in the role of forest-forming species are reported in many countries and are mainly related to climatic causes (Vrška *et al*., 2009; Sitzia *et al*., 2012; Dobrowolska *et al*., 2017; Dyderski *et al*., 2018; Kulla *et al*., 2023). The silvicultural management causes for these changes are less important

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in protected areas. The Świetokrzyski National Park (SNP) covers the main range area of the Świetokrzyskie Mountains that is known for the dominance of silver fir *Abies alba* Mill. in its forests. Over seventy years of protection within the SNP and its strict protection areas have meant that the forests in this area show a considerable degree of naturalness. The SNP was established on April 1st, 1950 with an area covering 6054.09 ha, however attempts to protect the area date back to the early 20th century. In 1921, Chełmowa Mountain was added to the reserve protection area and Święty Krzyż and Łysica added in 1924. In 1932, the Święta Katarzyna Forest District was granted the status of a special protected unit of State Forests to limit human activities (Jastrzębski, 2020). The latter area is the object of the present study as an example illustrating changes in forest structure occurring most spontaneously.

The local ecosystems of the SNP had been managed in the past and exposed to air pollutants (especially in the 1970s) that caused the dieback of fir trees. They have also been subject to regeneration processes observed in other forests and changes resulting from the impacts of climate change. It may be that the changes to which the area's stands have been subjected to over the last century will provide the opportunity for predicting the direction of further transformation.

Climate change has been affecting and will continue to affect forest ecosystems. Photosynthetic productivity is increasing as a result of increasing carbon dioxide in the atmosphere and from nitrogen in the soil. The lengthening of the growing season leads to an increase in tree growth. There may also be an increase in the sensitivity of young trees to high temperatures and frosts, especially in open areas of cultivation in managed forests. Further, an increase in temperature means an acceleration in the rate of humus mineralisation under suitable moisture conditions, and therefore the fertilisation of sites (Zajączkowski *et al.*, 2013; Borecki *et al.*, 2017).

The response of tree species to changing climatic conditions are predicted to lead to changes in the competitive relationships between them and to shifts in their distribution ranges. Fertile deciduous forests, including beech *Fagus sylvatica* L., are seen as beneficiaries of climate change in Europe. Silver fir *Abies alba*, which is more vulnerable to extreme weather events (frost and drought), appears to be less adapted to the ongoing climate change effects than beech (Zajączkowski *et al.*, 2013; Mauri *et al.*, 2016). In the mountainous conditions of Central Europe, there is a decline of fir and spruce in favour of an increasing proportion of deciduous species, mainly beech (Dyderski *et al.*, 2018; Holeksa *et al.*, 2018). Fir is a more drought-tolerant species amongst other conifers in particular Norway spruce *Picea abies* (L.) Karst., and at higher elevations Douglas fir *Pseudotsuga menziesi* (Mirb.) Franco (Vitali *et al.*, 2017) may be important in managed forests but not in the protected ecosystems of the park where this alien species does not occur naturally. Fir is considered a species vulnerable to climate change in its northern range mainly due to droughts (Dobrowolska and Bolibok, 2019). However, in the Świętokrzyskie Mountains the drought threat may be less significant due to higher precipitation in the mountains. Further, fir is considered a key species in maintaining biodiversity and stability of forest ecosystems due to its characteristics and longevity (Dobrowolska *et al.*, 2017) which is of particular importance for the national park forests. The present day forests of SNP are dominated by fir and are diverse in terms of species composition and stand structure. Single-species stands (in the upper layer) occupy only 2% of the total area of SNP (Szczygielski *et al.*, 2020). Beech seems to be expanding to new sites while at the same time creating conditions under the canopy for the regeneration of a young generation of firs. This creates a mosaic of fir and beech stands with a complex spatial structure probably due to microhabitat conditions which have not yet been verified. Beech in the mountainous conditions of Central Europe has increased the potential to expand its current range and compete with other species including fir (Kulla *et al.*, 2023).

The forests of this area have been the subject of studies related to changes occurring in them. Changes in species composition were analysed on selected study plots (Grzeszczyk and Woch, 2011), but spatial analysis was not included. As part of the work related to the draft nature conservation plan, a network of circular plots was established, but a repeated recurrence of measurements is still missing. In this study, the presence of tree species in the species composition of individual stand layers was assumed to be quantifiable as the forest-forming role of the species and comparable in subsequent forest management plans. This study aimed to analyse the changes occurring in the species compositions of stands in SNP in the period from 1925 to 2014.

Materials and Methods

The data collection was carried out in the part of SNP with available archival documentation. The scope of the study includes the area of the former Święta Katarzyna Forest District, from within its primary boundaries SNP was created. Data from 299 sample points were used which were assigned a forest stands description in each of the five forest management plans (1925, 1954, 1971, 1997, 2014). The data was extracted and processed in 2019. A network of sample points was established in a 400×400 m grid that was a uniform set for all periods analysed. The sample points represent a spectrum of the forest sites and topographic features for the SNP area. Maps from the forest management plans were scanned and calibrated in QGIS software (version 3.18) to the PUWG 1992 coordinate system using the Georeferencer tool.

At the designated points the forest location and corresponding stand description were found for each of the analysed periods. Stand parameters were assigned to each point in the database which were the following: forest habitat type, moisture variant (if specified), site conditions, characteristics of individual layers (upper layer, second layer, third layer, saplings and seedlings), and tree species in layers were described with information on proportion and age. The data aggregated in the databases was used to determine the role of fir and beech as the main forest-forming species in the study area. The forest-forming role was determined based on the proportion of the species in each forest layer in the stand description. The classification method proposed in the study of the Jata Nature Reserve (Sałamacha, 2021) was used for this study. Each species was assessed individually and occurrence of investigated species was scored based on the occurrence of this species in stand layers (Table 1).

Additionally, 1 point was given for the following:

- presence of residual trees of analysed species in the stand;
- ≥50% share of analysed species in saplings, seedlings or shrub layer when analysed species was also present in canopy layer with a minimum of 10%;
- dominance of analysed species in understory layer.

The forest-forming role of the two studied species was related to the forest habitat type, moisture variant, forest type and conditions. Spatial analysis was based on a digital elevation model from which derived layers were calculated and their values were related to their forest-forming role. An attempt was also made to analyse the relationship of the forest-forming role using the topographic moisture index.

Results

The forest-forming score of beech ranged from 0 to 23 with a mean of 6.1 points and a median of 6.0 points while that of fir ranged from 0 to 20 with a mean of 10.1 points and a median of 10.0 points. The assessment of the forest-forming score of the species studied is shown in Fig. 1.

Table 1.

Scoring given to layers in the forest stand (Sałamacha, 2021). Canopy layer – crowns of most of the forest's trees meet and form a thick layer, understory layer – immature trees and small trees that are taller than 0.5 m and shorter than the main canopy level, seedlings – trees in their first year of life, saplings – trees shorter than 0.5 m, and shrub layer – tree species forming a shrub-like shap

Layer	Age	Share [%]	Score
Canopy layer	>60	>50	4
		30-50	3
		<30	2
	≤60	>50	3
		30-50	2
		<30	1
Understory layer (>0.5 m)		>50	3
		30-50	2
		<30	1
Saplings and seedlings (<0.5 m)		≥50	2
		<50	1
Shrub layer			1

The forest-forming score of beech was variable over time (Fig. 1). In the first study (1925), it ranged from 0 to 7 with a mean of 0.9 points and a median of 0 points. This means that most of the results were equal to zero – beech was almost non-existent, especially as the dominant species in stands. The 1954 results were similar with forest-forming score values ranging from 0 to 5 with an average of 0.3 points with more than 50% of them being zero. In subsequent periods, the role of beech began to grow dynamically. In 1971, the maximum value of the forest-forming score increased to 10 points and the average to 2.8 points with more than 75% of the values greater than zero. In 1997, the maximum value was already 13 and the average was 3.7 points. The trend observed in this process indicates a significant increase in the forest-forming role of beach both as related to an increase in intensity with time and probably climate change related effects. This suggests that beech will continue to take advantage of the opportunity to dominate.

The forest-forming score of fir showed similar variability over time (Fig. 1). In the first period, it had score values from 0 to 7 with a mean of 3.3 points and a median of 4.0 points. The vast majority of observations had a value greater than zero. In the second period, it ranged from 0 to 7 with a mean of 3.0 points and a median of 3.0 points. As before, most values were greater than zero. In 1971, the forest-forming role of fir ranged from 0 to 12 with a mean of 6.2 points and a median of 6.0 points. Observations equal to zero were found in two sample plots. In 1997, the interval size ranged from 0 to 15 with a mean of 6.8 points and a median of 7.0 points. Only three sample plots showed a value of zero. In 2014, forest-forming scores ranged from 0 to 20 with a mean of 10.1 points and a median of 10.0 points. Only one sample plot showed a zero value. Fir was therefore present in stands surveyed throughout the period of the study. The increase in its forest-forming role was similar to that of beech, and there was no indication of a reduction in its role in the near future. During the study period both species complemented each other by increasing their dominance, not only by occupying the space of pine stands but also by significantly increasing their share in the lower layers of the stand, increasing the overall value of their forest-forming roles. The relatively low value in the first period (1925) for both species was mainly due to the scarcity of information about the lower layers in the stand descriptions.

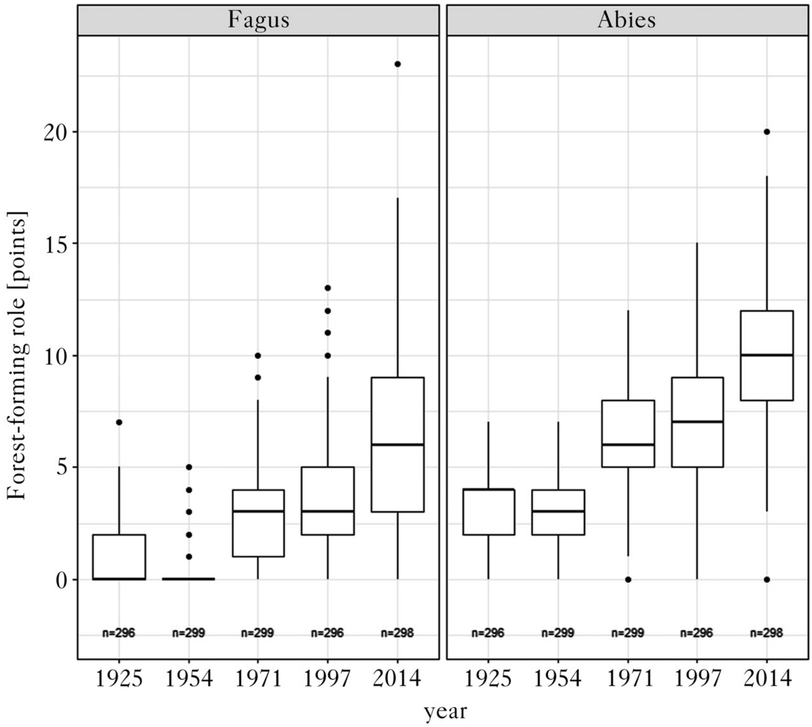

Fig. 1.
Forest-forming score of beech *Fagus* and fir *Abies* in the following inventory cycles

An analysis was carried out to show the relationship of the forest-forming role of beech to taxonomic characteristics. The highest values were observed at the sites of mesic mountain deciduous forest and mesic mixed mountain deciduous forest. The lowest values of this trait were in the mesic mixed highland deciduous forest and wet mixed highland deciduous forest sites (Fig. 2). Lower values were observed in variants of habitat types with higher moisture content (Fig. 3). Higher values were observed in those stands with the approved stand type of 'Fir-Beech and Fir' in the stand description, and lower values for 'Beech-Fir'. Site condition N1 ('Natural') was characterised by higher values for the forest-forming role of beech.

A correlation was observed between the forest-forming role of beech and altitude. For an altitude of 480 m and above sea level the forest-forming role value started to decline (Fig. 4).

Analysis of the forest-forming role dependence of fir on forest characteristics showed that the values of this trait were lower in the mixed highland deciduous mesic forest site, while the other forest habitat types were characterised by similar values (Fig. 5). No dependence was observed on the moisture variant or the forest type and site condition in the forest-forming role of either species and only a slight dependence on altitude.

Discussion

The study showed the forest-forming role of beech and fir based on their proportion in specific stand layers. It is more common to use a site index (Kędziora *et al.*, 2020; Socha *et al.*, 2020) as a measure of species development under local site conditions, however changing environmental conditions may affect the results in a long-time analysis (Barańska and Kędziora, 2021).

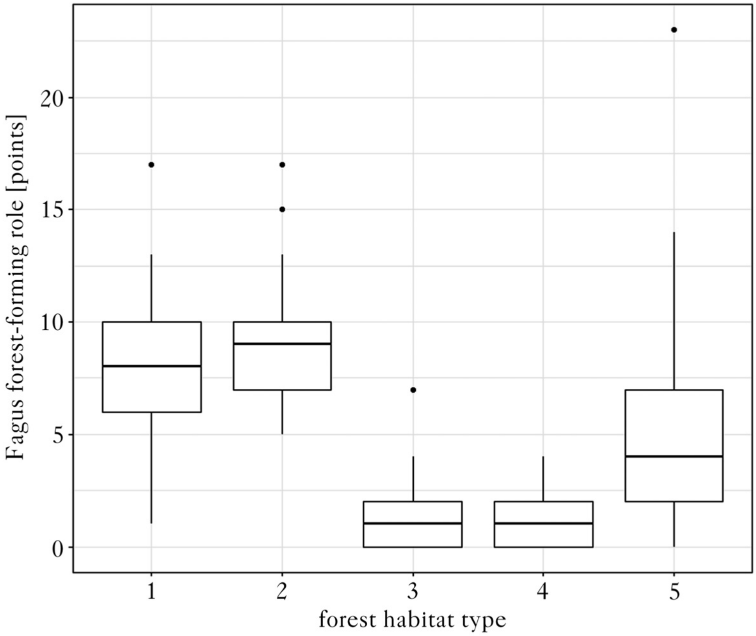

Fig. 2.

Forest-forming role of beech *Fagus* in forest habitat types

1– fresh montane broadleaved, 2 – fresh montane mixed broadleaved, 3 – fresh upland mixed broadleaved, 4 – moist upland mixed broadleaved, 5 – fresh upland broadleaved

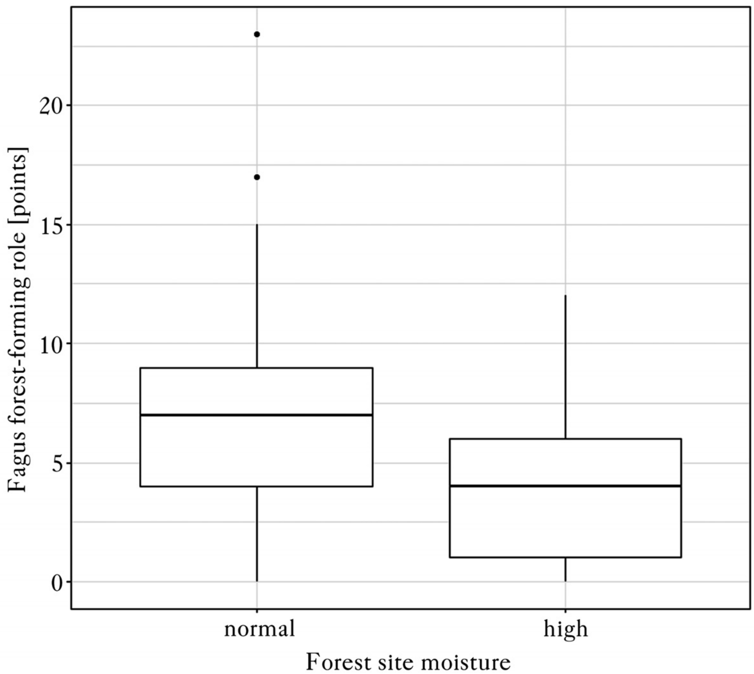

Fig. 3.

Forest-forming role of beech *Fagus* compared to site moisture variant

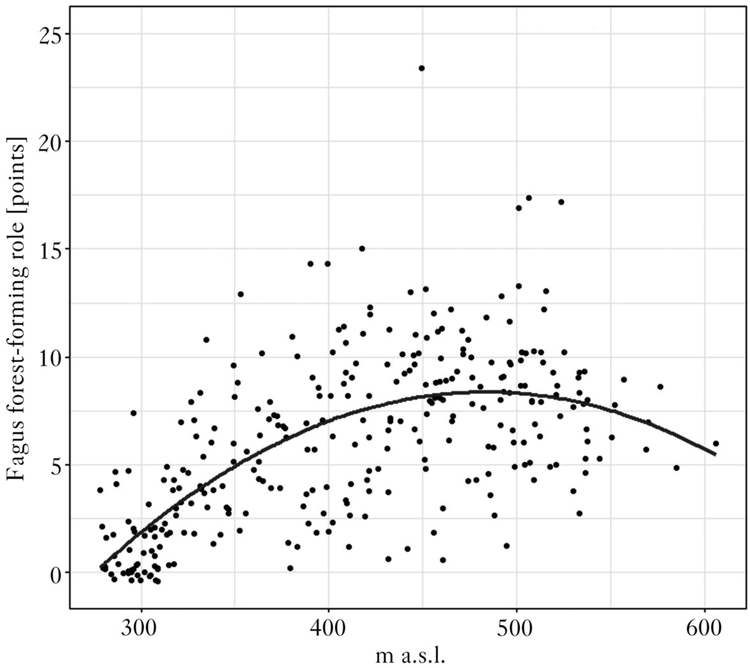

Fig. 4.

Forest-forming role of beech *Fagus* in relation to altitude. Line is the second order polynomial model fit

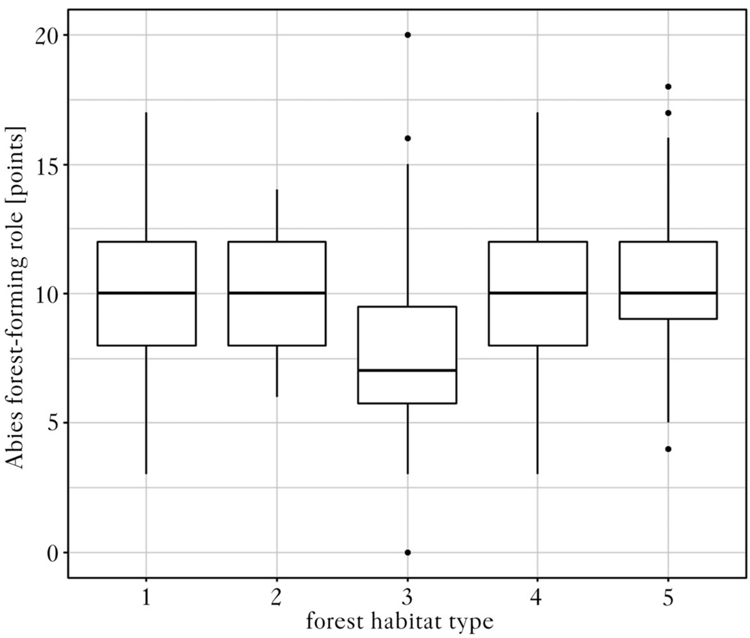

Fig. 5.

Forest-forming role of beech *Fagus* compared to site moisture variant

1– fresh montane broadleaved, 2 – fresh montane mixed broadleaved, 3 – fresh upland mixed broadleaved, 4 – moist upland mixed broadleaved, 5 – fresh upland broadleaved

A score based metric that was comparable throughout the study period starting in 1925 was adopted. The use of traits derived from the stand descriptions of sequential forest management plans was subject to a drawback of over-generalization. There is a risk that in each comparison period the measurement point fell into different sub-compartments for which data from other sets of trees was generalized. This risk was low due to the length of the study period and the stability of the spatial divisions of SNP forests. The source material comes from forest management plans (FMPs) prepared according to a variety of methods but the differences did not significantly affect the basic characteristics of the stands used in the study. Species composition and dominant species were defined the in the same way in each FMP period. The only differences were related to forest habitat types, therefore only the most recently described units were used.

The changes occurring among the stands of SNP seem to be part of a trend indicated in historical studies from the Carpathian Mountains and supported by measurements in the eight preserved fir and beech forest reserves in the region (Vrška *et al.*, 2009). They showed that the evolution of fir and beech forests was a linear human-induced trend and that the replacement of beech by fir occurred between the 15th and 18th centuries, mainly as a result of grazing and litter raking which affected the regeneration of the forest under the canopy. In the Carpathians, fir was replaced by beech as a result of economic impacts, and in the second half of the 20th century the process was the result of air pollution and other factors (Elling *et al.*, 2009). The dynamics of spontaneous development of beech and fir forests were influenced by high game numbers at the beginning of the 21st century (Vrška *et al.*, 2009). Our study confirmed a decline in the forest-forming role of fir only in the high forest floor layer during the periods of pollution-induced dieback of this species. However, it was not shown that this was the direct cause of the development of beech forests.

A surprising result is the effect of altitude which increases the forest-forming role of beech up to about 480 m a.s.l. Studies in five mountain national parks have shown, on the basis of aboveground biomass analysis, that the occurrence of beech was positively correlated with an increase in site altitude starting at about 400 m a.s.l. with lower altitudes occupied by other tree species including fir (Dyderski and Pawlik, 2020). Perhaps this is a particularity of the Świętokrzyskie Mountains, which were not included in this study. On the other hand, the results of the aforementioned studies show a significantly disproportion dominance between beech and fir in different mountain ranges between 400-600 m a.s.l. which may confirm the mosaic nature of forests or the dynamic impermanence of fir and beech dominance at the relevant sites. However, one should keep in mind the observed trend of the success of beech regeneration in the mountains of Central Europe (Kulla *et al.*, 2023) which may lead to the emergence of beech-dominated forests (Dyderski *et al.*, 2018). A correlation between the forest-forming role of beech and altitude is in apparent contradiction to habitat type analysis indicating that beech has a higher forest-forming role in mixed mountain forests. This could be due to the methodology adopted to determine the forest-forming role of beech based on its occurrence in all stand layers as higher-altitude habitat types are probably more likely to have single-layer stands with a lower proportion of young beech generations under the canopy of the shading beech forest.

The fir forests of the SNP are now subjected to much less anthropomorphic pressure. The abandonment of intensive forest management, especially the clear-cutting management system, favors this species as was shown in the 1925 forest management plan for the Święta Katarzyna Forest District.

Changes in forest structure as a result of intensive use and air pollution have been shown to be the cause of the former regression of fir forests in the Czech Republic (Volarik and Hedl, 2012) and in other regions of Europe (Sitzia *et al.*, 2012; Dobrowolska *et al.*, 2017). The regeneration of fir forests excluded from use was also shown with significant changes recorded after 50 years (Sitzia *et al.*, 2012). It has also been demonstrated that moderate silvicultural measures can contribute to more intensive growth of fir stands (Volarik and Hedl, 2012) as well as influencing the dimension structures of the trees (Podlaski *et al.*, 2019). Dendrochronological studies in mixed fir and beech forests indicate changes in tree radial increments related to environmental limitations (Bosela *et al.*, 2018). In this study, long-term growth patterns and the climate sensitivity of fir and beech were not significantly different between managed and unmanaged forests. It is therefore likely that the forests of the analysed area of SNP are mainly subject to the phenomena and processes resulting from general trends typical of the highland and mountain forests of Europe.

In a study on the natural regeneration of fir forests sites in the Świętokrzyskie Mountains and the Western Carpathians were compared (Paluch, 2004; Paluch and Jastrzębski, 2013), indicating that the regeneration capability of young trees in mixed stands was higher than those in pure fir stands. Due to the generalizing effect of stand data, our study does not allow us to confirm such a theory. However, we have shown an increase in the share of lower layers in the stands of SNP and an increase in the share of fir in lower layers. This may influence the persistence dominance of fir despite an increase in the share of beech in the upper layers and mixed stands should positively influence the growth of young firs.

The results based on habitats may be surprising if we consider the habitat preferences of this species which is clearly dependent on high site moisture. In the analysed area, fir seems to be in optimal conditions, therefore it is difficult to statistically demonstrate local variations in habitat-humidity preferences. The demonstrated increase in its forest-forming role in successive periods of analysis may indicate the stability of fir's occurrence in the stands studied and the persistence of fir forests in SNP. With increasing global warming and shortage of groundwater, fir may allow the development of beech forests, especially in the higher mountain locations and on southern slopes of mountains.

Conclusions

- The share of Silver fir and European beech in the surveyed stands of SNP changed from 1925 to 2014 and currently dominate the local forests.
- The forest-forming role of beech as the dominant species and the component of the stands showed a very even increase suggesting a sustained trend in this process. The most significant increase in the forest-forming role of beech occurred in the fertile and lower-lying (up to 480 m above sea level) sites of the upland forests and not in the highest parts of the mountain ranges.
- In the lower layers of the stands, the proportion of fir increased over the course of study period. This applies to both second story and undergrowth layers. This increase suggests that the area of fir will increase in SNP if the population of this species remains healthy. Fir is still potentially the main forest-forming species at this stage of expansion in forest ecosystems.
- Analysis of habitat factors (location, moisture content, topographic moisture index, *etc.*) potentially influencing the occurrence and forest-forming role of fir and beech did not significantly demonstrate optimal conditions without using information on microhabitat variation which likely conditioned the dominance process.

Authors' contributions

M.O. – conceptualization, literature review, supervision of the database, manuscript preparation; W.K. – statistical analyses, proofreading of the text.

Conflicts of interest

The authors declare no conflict of interest.

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STRESZCZENIE

Zmiany w składzie gatunkowym lasów Świętokrzyskiego Parku Narodowego w ostatnim stuleciu

Lasy Świętokrzyskiego Parku Narodowego są przykładem zmian w składzie gatunkowym drzewostanów, które zachodzą głównie spontanicznie. Wynika to z historii gospodarki leśnej i ochrony przyrody na tym terenie. Głównym gatunkiem lasotwórczym była tam i jest jodła pospolita *Abies alba* Mill. z domieszką buka zwyczajnego *Fagus sylvatica* L. Oba gatunki tworzą mozaikę zdominowanych przez siebie lasów i wydają się być lokalnymi beneficjentami zmian klimatycznych zachodzących w tej części Europy: wzrostu średniej temperatury przy niewielkim na terenach wyżynnych i górskich spadku opadów. Jodła traktowana jest jako gatunek bardziej zagrożony, zwłaszcza na północnym skraju zwartego zasięgu. Ze względu na troficzność siedlisk i ochronę przyrody w parku narodowym w lokalnych warunkach nie stanowią tego zagrożenia metody gospodarki leśnej preferującej hodowlę gatunków lekkonasiennych i światłożądnych na ubogich glebach nizinnych lasów. Wciąż niepoznane są relacje pomiędzy lasami bukowymi i jodłowymi występującymi w podobnych warunkach siedliskowych i klimatycznych. Założono, że analiza opisów taksacyjnych i map pozwoli na określenie zmian, jakim podlegały lasy tworzone przez oba gatunki i pozwoli wskazać dalsze tendencje tych zmian w przyszłości. Celem pracy była analiza zmian zachodzących w składach gatunkowych drzewostanów dawnego Nadleśnictwa Święta Katarzyna i później Świętokrzyskiego Parku Narodowego w latach 1925-2014. Na tym obszarze i w założonym horyzoncie czasowym nie były dostępne dane z wieloletnich badań prowadzonych na sieci

stałych powierzchni próbnych charakteryzujących zmiany na większości obszaru parku. Wykorzystana zatem została metoda oparta na analizie dawnych i współczesnych opisów taksacyjnych drzewostanów. Wykorzystano 299 losowych punktów próbnych rozmieszczonych równomiernie na całym obszarze badań oraz opisy taksacyjne drzewostanów, w których punkty te znajdowały się w kolejnych okresach inwentaryzacji. Dane inwentaryzacyjne pochodziły z lat: 1925, 1954, 1971, 1997 i 2014. Dane z planów urządzenia lasu i późniejszego planu ochrony parku narodowego zostały zestawione w bazie danych i przetworzone w celu określenia roli gatunków w poszczególnych warstwach drzewostanu – roli lasotwórczej gatunków, którą obliczano w oparciu o ich udział w poszczególnych warstwach drzewostanów (tab. 1). Lasotwórczą rolę dwóch badanych gatunków powiązano ze współczesnym typem siedliskowym lasu (ryc. 2 i 5) i jego wariantem uwilgotnienia (ryc. 3) oraz parametrami stanu lasu w kolejnych okresach. Ze względu na niepełną porównywalność danych archiwalnych wynikającą ze zmian zasad klasyfikacji siedlisk przyjęto wykorzystanie współczesnych danych siedliskowych. Analizy przestrzenne oparto na numerycznym modelu terenu, z którego obliczono warstwy pochodne, a ich wartości odniesiono do roli lasotwórczej.

Podjęto również próbę analizy związku roli lasotwórczej z topograficznym wskaźnikiem wilgotności, jednak dla danych generalizowanych w granicach drzewostanów nie uzyskano zadowalających wyników. Potwierdzono powszechną i trwałą dominację jodły w ekosystemach leśnych obszaru badań (ryc. 1), wzmacnianą powiększaniem udziału w dolnych warstwach drzewostanów. W przypadku buka zaobserwowano wzrost roli w lasach parku oraz zależność między rolą lasotwórczą a wysokością nad poziomem morza (ryc. 4). Do poziomu 480 m n.p.m. siła ta wzrasta, a na większych wysokościach maleje. Uzyskane wyniki mogą być wykorzystane do prognozowania zasięgu lasów jodłowych i bukowych w regionie świętokrzyskim.