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ORIGINAL ARTICLE

Morphological changeability of cones of Norway spruce [*Picea abies* (L.) Karst.] in the Białowieża Forest

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Abstract

In the frame of research conducted in the year 2003 on masting of spruce in the Białowieża Forest, spruce cones were collected from trees differentiated with regard to their age as well as growing sites located in deciduous and coniferous forest. The collection of cones was conducted in managed forests of the Białowieża Forest District. Before taking out seeds, the cones were divided into 5 sectors: cone base (p), zone over cone base (np), cone central part (s), zone below cone-top (pw) and cone-top (w). This allowed evaluation of the size and shape of scales contained by cones.

The results showed that the biggest cones were formed by spruces 60–80 years old which were growing on deciduous sites. The longest scales were situated in the cone central part, and the widest were found in the zone over cone base. Differentiated size of cones and scales, situated in distinguished cone zones, can influence the speed of scale opening and the sequence of seed releasing. This can be applied in the process of harvesting of high quality seeds – necessary for the production of seedlings with the use of modern nursery technologies.

Key words

Norway spruce [*Picea abies* (L.) Karst.], cone morphology, cone scales, coniferous forest, deciduous forest

Introduction

Currently observed climatic changes can influence tree development to a great extent including the process of masting. A strong relationship between masting and weather conditions both during the year of development of fruit and seeds as well as in the previous years indicates a need of systematic research on the processes accompanying generative reproduction (Chałupka 1975). The influence of climate change, which is often called climate disturbance, on the process of masting can affect development and endurance of particular species of forest trees. One of the species which recently have become most vulnerable to external factors is the Norway spruce – *Picea abies* (L.) Karst. This has been recently proven by less and less abundant seed crops of this species (Załęski, Kantorowicz 2002, 2005) and high susceptibility to external factors (abiotic and biotic).

At the same time, the Norway spruce has developed multi-directional variability in its geographical range (Vogellehner 1977, Bobrov 1978, Boratyński, Bugała 1998), which in the process of regress of this species can have significant connotations. The cone is one of

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the elements that set apart both sub-species (Norway and Siberian spruce) and particular populations. Up to date research has been mostly focused on evaluation of relationships between spruce origin and morphological features of cones (Staszkiewicz 1966, Barzdajn 1996). Definitely less attention has been drawn to investigations on the influence of mother tree age and its habitat on cone features. The observations conducted in Karelia (Baksewa 1970) showed a somewhat connection between a shape of cone scales and the habitat. The material collected in the frame of research on masting of spruce conducted in the Białowieża Forest in 2003, allowed evaluations of relations of basic morphological features of cones and their scales with the age and habitat of mother trees. The size of cones can influence to a great extent the number of seeds produced for management purposes (Tyszkiewicz 1949). Moreover, according to the results reported by Barzdajn (1996) some features of cones can be used as diagnostic elements in delineation of spruce proveniences.

Materials and Methods

In the years 2000–2008, detailed evaluation of spruce masting was carried out on experimental areas of the Faculty of Sulviculture of the University of Life Sciences SGGW, which were situated within the forest sections No 284/285, 344, 526 and 582 of the Białowieża Forest (Buraczyk 2002). During supplementary investigations conducted in the winter 2003/2004, spruce cones were also collected in managed stands of the Białowieża Forest District (forest sections No.: 280, 311, 312, 414, 415, 439, 440, 441, 498, 525, 526, 550). The cones were collected from tree-top parts of spruces cut down within the frame of management activities and in addition – from standing trees. Two groups of spruce growing sites were selected for further observations: coniferous (fresh and mixed coniferous forest) and deciduous (fresh mixed, fresh and wet deciduous forest). Within these sites there were selected young (up to 40-year-old), middle age (60–80 years) and old (more than 120 years) spruce stands. The cones were collected from the total number of 300 spruce trees, with 50 trees of each age and site category. The spruces for research were selected from upper layers of stands, had properly shaped crowns with well developed top stems and produced abundant cone yield. The cones were collected from randomly chosen trees from each research group. This way, several factors that affect masting, such as tree-tops damage caused by growing under other trees' crowns, magnitude of cones per crown or bio-social position of the tree in stand, were eliminated (Buraczyk 2006).

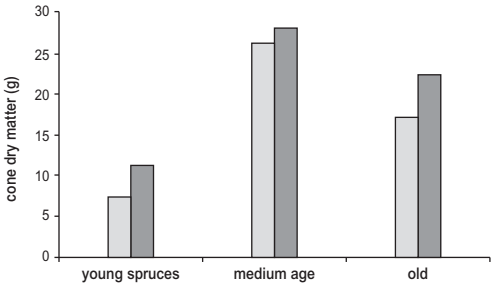
From each tree 10 cones were collected, and then their length and width were measured. During the measurements the cone shape was evaluated following the procedure by Holubcik (1969). Almost all investigated cones when wet appeared to be of ovoid and oblong shape and broadest at below the half-point of their length.

Next, in each age and site category there were 30 trees randomly selected and one cone from each tree was collected for further detailed analyses. Every selected cone was not insect-damaged and its measurements represented the average for the tree which from it was collected. Detailed measurements were conducted on the total number of 150 cones. Taking into account the total number of scale rows, all the cones were divided in 5 sectors: cone base (p), zone over cone base (np), cone central part (s), zone below cone-top (pw) and cone-top (w).

Following the above pattern of cone division, scales together with seeds were detached from the core of each cone and measurements of scale length and width on their outer surface were conducted. The division into the cone zones allowed detailed analyses of scales with regard to their position within cones. In this study, there was also assessed a ratio of the cone and scale length to their width and a share of seed scales per cone was evaluated. The seeds obtained were a subject of separate analyses. After the measurements all cone scales together with cone cores were dried out at the temperature 104°C and their dry matter was assessed. In this study, the dependency of scale form on the factors such as tree growing sites and age was not evaluated for the reason that in 87% of scales the *acuminata* form was observed. A substantial share of this scale form occurring in north-eastern Poland was confirmed by Staszkiewicz (1966) as well as by previous observations conducted by Korzeniewski within the area of Białowieża Forest in 1953 (in: Boratyński, Bugała 1998). Such a high share of the one scale form excluded a possibility of accurate evaluation of the re-

lation of the form with the growth site or the age of mother trees.

Obtained results were statistically analysed with the use of the means of feature values, ANOVA, the Duncan's test as well linear correlation between variables. For assessment of significance of differences between the means as well as correlation relationships, the P-value was calculated using Statgraphics Plus 4.0 software.



	young spruces	medium age	old
coniferous forest	7.3	26.3	17.2
deciduous forest	11.0	28.1	22.3

Fig. 1. Dry matter of spruce cones

Results

The cones collected from middle age spruces growing on deciduous sites had the largest dry matter (28.1 g), and the cones from spruces on coniferous sites were about 2 g lighter (Fig. 1). The cones obtained from the oldest trees were 17.2 g of weight on coniferous sites and 22.3 g on deciduous sites. The lightest cones were found in young spruces. On coniferous sites, cone their dry matter was only 7.3 g, and on deciduous sites – 11 g (Fig. 1). The value of correlation coefficient r indicated statistically significant relationships between cone mass and all their dimensions (Tab. 1).

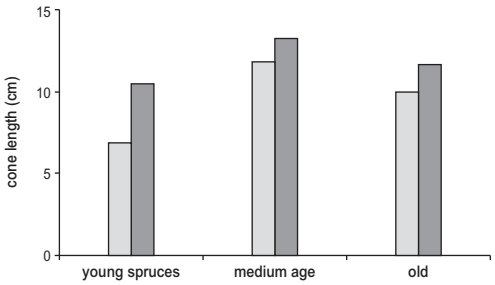
The largest cones were formed by spruces 60–80 years of age. On coniferous sites, the length of cones was 11.8 cm and their width was 2.7 cm, while on deciduous sites these dimensions were 13.2 and 3.1 cm, respectively (Fig. 2 and 3). In young spruces growing on coniferous sites, there were found the smallest cones. Their length was 6.8 cm and width was 2.0 cm. The cones collected from young spruce trees growing on deciduous sites were 10.4 cm long and 2.2 cm wide. Statistical analysis showed very strong positive relationship between the length and thickness of cones. Correlation

Table 1. Values of correlation coefficient r for relationships among the features of spruce cones collected on coniferous and deciduous sites in the Białowieża Forest in the year 2003

Cone features	Correlation coefficient r calculated for cone features									
	Cone length		Cone width		Scale length		Scale width		Number of scales per cone	
	conifer. forest	decid. forest	conifer. forest	decid. forest	conifer. forest	decid. forest	conifer. forest	decid. forest	conifer. forest	decid. forest
Cone dry matter	0.889 **	0.875 **	0.916 **	0.798 **	0.809 **	0.783 **	0.791 **	0.819 **	0.691 **	0.819 **
Cone length			0.864 **	0.721 **	0.805 **	0.780 **	0.776 **	0.727 **	0.744 **	0.420 *
Cone width					0.786 **	0.771 **	0.787 **	0.806 **	0.736 **	0.453 *
Scale length							0.868 **	0.772 **	0.460 **	0.263
Scale width									0.385 *	0.315

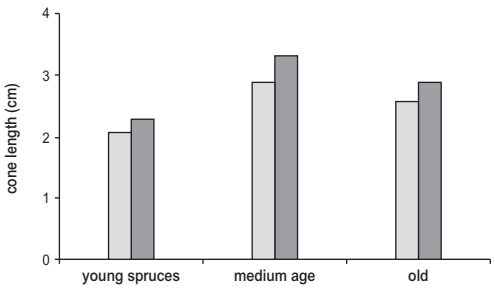
* significance level $0.01 < P < 0.05$
** significance level $P < 0.01$

coefficient r on coniferous sites was 0.864, and on deciduous sites it was 0.721 (Tab. 1).



	young spruces	medium age	old
coniferous forest	6.8	11.8	10.0
deciduous forest	10.4	13.2	11.7

Fig. 2. Length of spruce cones

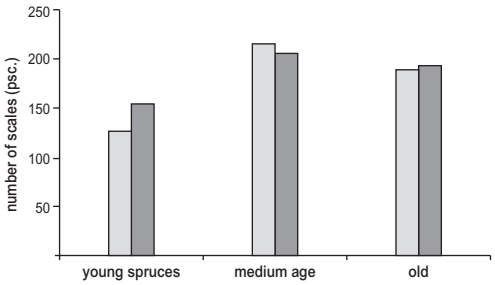


	young spruces	medium age	old
coniferous forest	2.0	2.7	2.4
deciduous forest	2.2	3.1	2.7

Fig. 3. Width of spruce cones

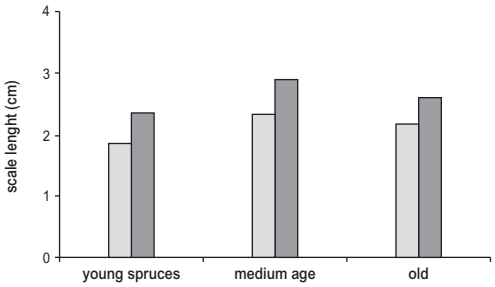
The biggest number of scales per cone (214) was found in the middle age spruces growing on coniferous sites. In the cones from deciduous sites there were about 10 scales fewer (Fig. 4). On coniferous sites, the cones in young spruces had nearly half fewer scales than in middle age spruces (127), while on deciduous sites the number of scales in spruce cones was ¼ lower. The cones collected from 120-year-old spruces growing on both sites had approximately 120 scales (Fig. 4). On coniferous sites, the number of scales per cone significantly depended on cone features (length, width, dry matter) at the significance level $P < 0.01$, while on deciduous sites such strong relationship was observed only for cone dry matter (Tab. 1). The number of scales per cone on this site was significantly correlated with scale dimensions.

Both the length and width of scales showed very strong positive correlation with cone dimensions as the values of correlation coefficients r were higher than 0.7 at $P < 0.01$ (Tab. 1) The biggest scales were found in the biggest cones, in that case derived from middle age trees growing on deciduous sites. The smallest scales were observed in cones from young trees growing on coniferous sites (Fig. 5 and 6).



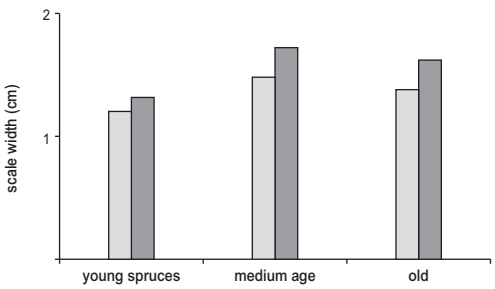
	young spruces	medium age	old
coniferous forest	127	214	190
deciduous forest	154	205	193

Fig. 4. Number of scales in spruce cones



	young spruces	medium age	old
coniferous forest	1.8	2.3	2.2
deciduous forest	2.4	2.9	2.6

Fig. 5. Lenght of cone scales



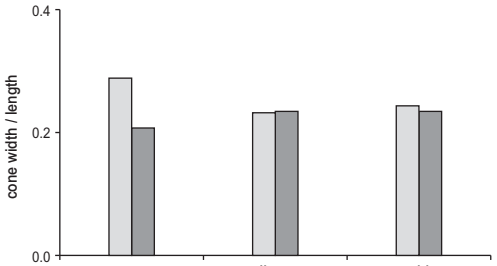
	young spruces	medium age	old
coniferous forest	1.2	1.5	1.4
deciduous forest	1.3	1.7	1.6

Fig. 6. Width of cone scales

The length of scales in the cones of spruces growing on coniferous sites was significantly positively correlat-

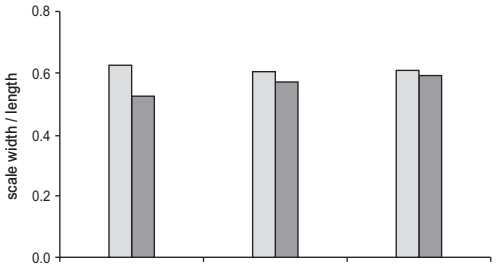
ed with the total number of scales per cone, being on the other hand less correlated with the scale width. On deciduous sites no significant correlations between the total number of scales and their width were observed. The values of correlation coefficients r were 0.263 and 0.315 on coniferous and deciduous sites, respectively (Tab. 1).

Figure 7 shows that the ratio of cone width to length amounted from 0.21 – in the cones collected from young spruce trees growing on deciduous sites – to 0.29, also in the cones from young trees, however growing on coniferous sites. In other spruce age groups growing on both sites the length: width ratios were not overly differentiated with the values of 0.23 to 0.25. The length: width ratios in cone scales were differentiated in the cones from young stands and amounted 0.56 and 0.66 in the cones from deciduous and coniferous stands, respectively (Fig. 8). In the middle age and old stands on coniferous sites the ratio amounted to 0.64 , and on deciduous stands it amounted to 0.60 in middle age stands and 0.62 in the oldest stands.



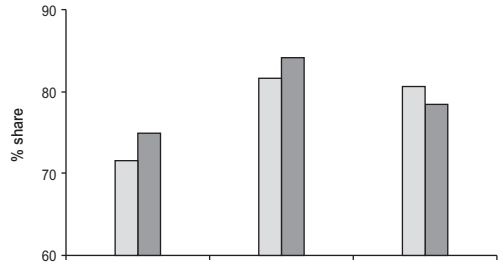
	young spruces	medium age	old
coniferous forest	0.29	0.23	0.25
deciduous forest	0.21	0.24	0.24

Fig. 7. Ratio of cone width and length



	young spruces	medium age	old
coniferous forest	0.66	0.64	0.64
deciduous forest	0.56	0.60	0.62

Fig. 8. Ratio of scale width and length



	young spruces	medium age	old
coniferous forest	71.5	81.5	80.7
deciduous forest	74.8	84.3	78.5

Fig. 9. Percentage share of scales with seeds per cone

The biggest number of scales with seeds was observed in the biggest cones. In the cones of middle age trees on deciduous stands 84.3% scales had seeds and 71.5% scales with seeds were observed in cones collected from young trees on coniferous sites (Fig. 9).

ANOVA showed that the site as well as the age of mother trees had significant effects ($P < 0.05$) on almost all features of the cones of spruce trees masting in the Bałowieża Forest in the year 2003 (Tab. 2). Only the number of scales in cones did not depend on the site ($P = 0.498$). The analysis also showed that the variability factor such as trees significantly affected all cone features except for the average number of scales per cone. The cones collected from one tree were not different in terms of length and width given that the significance level obtained was $P > 0.05$ (Tab. 2).

Table 2. Significance levels P for differences of average values for spruce cone features

Variability factor	Calculated significance level P for the features:					
	cone dry matter	cone length	cone width	number of scales per cone	scale length	scale width
Site	0.0162	0.0000	0.0010	0.4981	0.0000	0.0001
Age	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
Trees	0.0001	0.0015	0.0038	0.0602	0.0033	0.0103
Cones	–	0.4378	0.5258	–	–	–

The results of calculations conducted for the total number of cones showed that the scales situated at cone base and on cone-top were shortest (1.5 cm long) and significantly different with regard to this feature than the scales situated in other cone zones (Tab. 3).

Table 3. Differentiation of scale measurements depending on situation in designated cone zones[1]

Cone zone	Average (cm)	Uniform groups
Scale length		
top	1,44	|
base	1,54	|
below top	2,10	|
above base	2,20	|
centre	2,26	|
Significance level		**
Scale width		
top	0,76	|
base	1,08	|
below top	1,34	|
centre	1,54	|
above base	1,57	|
Significance level		**

[1] analysis performed on the total number of cones
** – $P < 0,01$

The length of scales situated in the zones: over cone base, central part and below cone-top were from 2.1 to 2.26 cm. The average values of scale length in these zones resulted in obtaining the statistically uniform group.

The scales situated at the cone-top were 0.79 cm wide, and thus the least broad. The scales at the cone base were 1.08 cm wide and those in the zone below cone-top were 1.34 cm wide. With regard to the width these scales formed 3 uniform groups which were different among each other and differed from the scales at the central cone part as well as those situated over the cone base. The widest scales (1.57 cm) were found in the zone over cone base (Tab. 3).

Discussion

The collected empirical material indisputably shows great effects of the site and age of spruces on basic morphological features of cones. The values for almost all cone parameters produced on fertile deciduous sites were higher than those for coniferous sites. On these sites, only the total number of scales in cones collected from middle age spruce trees as well as the share of scales with seeds observed in the oldest trees were somewhat higher when compared with the deciduous sites. These results confirm information reported by other authors about beneficial influence of more fertile and damp soils on masting of forest trees including the spruce (Tyszkiewicz 1949, Załęski 1995, Boratyński and Bugała 1998).

The results of the study also showed that the biggest cones were formed by middle age spruces. The cones collected from young and old trees were of smaller size, had smaller scales and showed lesser share of scales with seeds. These results can be used during seed harvesting procedures as well as at selecting seed stands. The average size of cones collected in 2003 in the Białowieża Forest was in the interval reported both by Tyszkiewicz (1949) and Załęski (1995). However, the cones in this study were much bigger than the cones used at diagnostic evaluations of morphological features for delineation of proveniences in the investigation reported by Barzdajn (1996). Moreover, the cones collected in spruce stands in the Gorczański National Park (Żuchowska and Sabor 1998) were much smaller than those from the Białowieża Forest.

The results obtained indicated the relation between the size of scales and their location within the cone. The longest scales were observed in the central cone part, and the widest were situated above the cone base. This pattern could the reason why the cones were broadest below the cone central part.

The analysis of correlations showed high significance of relationships between morphological features of spruce cones. Only on deciduous sites the increase of the number of scales was not significantly correlated with the increase of the length and thickness of the cones. This can indicate differences in the architecture of cones formed on different habitats. Inconsistent sizes of scales in the distinct cone parts when combined with the specific chemical content (Aniszewska 2002, Mikłaszewicz 2000) can have an influence on the speed of scale opening and sequence of seed releasing from particular cone zones. This information can be useful during the processes of seed harvesting, especially for the purpose of seedlings production with the use of modern nursery technologies, which utilize the seeds of the highest quality.

The results of the investigation conducted by Barzdajn (1996) in 22-year-old spruce stands on the

provenience areas in Siemianice where there was also represented the provenience of spruce of the Białowieża Forest, showed that the length of spruce cone scales as well as the relationships between their length and width had important diagnostic implications for evaluation of membership of spruces in populations. On the other hand, the results of this study showed that these features changed depending on the site and the age of mother trees. The analysis indicated particularly strong relationships between the size of cones and scales originating from different growing sites. At young age spruces from the Białowieża Forest area that grew on deciduous sites formed bigger cones than on coniferous sites. On the other hand, the length/width ratios of the cones and scales were higher in the material collected on coniferous sites. At the same time these values were most similar to the data obtained by Barzdajn (1996) on the provenience area with the offspring of the two Białowieża derivations. The data collected in the Białowieża Forest show that some morphological features of cones and scales used as diagnostic indicators for delineation of spruces as members of population can be changeable with the change of spruce age and their growing site.

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