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HEIGHT INCREMENTS OF SCOTS PINE (*PINUS SYLVESTIS* L.). THE EFFECT OF WEATHER CONDITIONS

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Abstract. The effect of weather conditions on height increments of trees was investigated within eight age classes. Weather conditions (temperature and precipitation) were presented using Sielianinow's hydrothermal index in the quarterly periods and the De Martonne index in the annual periods. Drought index in a given year was found to have a negative effect on height increments of trees in the following year. A significant effect of weather conditions found in a given increment year was observed only in the case of the youngest trees.

Key words: De Martonne index, Sielianinow's hydrothermal index, weather condition, *Pinus sylvestris* L.

INTRODUCTION

Scots pine is one of the most common tree species in Poland. For this reason attention is focused on factors having a potential effect on rapid tree growth, thus facilitating timber harvest within a relatively short time. This study investigated the effect of weather conditions using Sielianinow's hydrothermal coefficient (determined for quarterly periods) and the De Martonne index (1926; 1942) (for annual periods). Available literature sources concerning the subject of this study include publications discussing the effect of selected factors, e.g. temperature on growth of trees, both diameter and height (Jasnowska, 1977; Zielski, 1996; Zielski, 1997; Cedro, 2001); however, weather conditions were always considered separately. The factors are combined only when determining a regression dependence. To date similar dependencies have not been in-

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vestigated when applying coefficients incorporating several weather factors at the same time.

In this study the height increments were taken into consideration for two reasons: they exert a direct influence on the determination accuracy of the stand volume increment (Kaźmierczak and Zawieja, 2008) and thus they are considered as a major dendrometric characteristic.

EXPERIMENTAL DATA

The experimental material included ten-year measurements of 200 Scots pine stems. The sample trees were selected from eight age classes. All the considered Scots pine stands were located on fresh mixed coniferous forest sites in the Zielonka Experimental Forest District. The height increments were measured in a ten-year vegetation period (from 1989 to 1998). In the study period the average height increments of trees are presented in Figure 1 (only mean increments are presented since the total number of observations was 200). In this Figure the appropriate age class was marked by the number corresponding to the age of the tree, at which the last measurements were recorded.

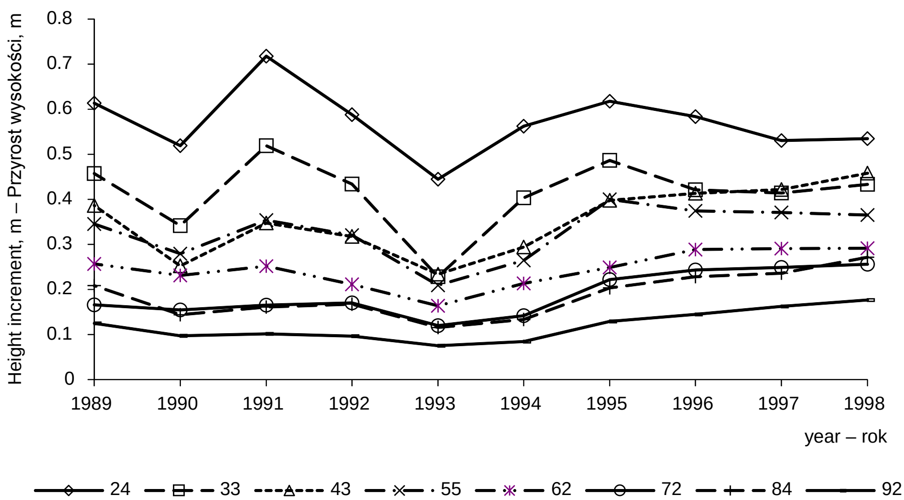

Fig. 1. Mean height increments of individual age classes of trees in the ten-year period
Rys. 1. Średnie przyrosty wysokości drzew poszczególnych klas wieku w dziesięcioletnim okresie przyrostowym

The considered indexes of weather conditions were measured at the Meteorological Station located in Zielonka. The average daily temperature (measured at the height of above two meters) and the sum of daily precipitation were taken into consideration.

METHODS

In the given period the measure of precipitation effectiveness is Sielianinow's hydrothermal coefficient $K = 10P/\sum t$ (Cherszkowicz, 1971), where P denotes the sum of precipitation in the period under consideration, while $\sum t$ is the sum of mean daily values of air temperature in the study period. Depending on the value of coefficient K (–∞; 0.4), [0.4; 0.7), [0.8; 1.0) and [1.1; 1.3) the extremely dry period, very dry, dry and fairly dry periods are distinguished. In turn, if the coefficient takes values greater than 1.3, then it can adequately distinguish different degrees of wetness. In the studies concerning height increments of trees when the division into two periods, "dry" and "wet", is more informative, the boundary between them is marked by K of 1.3. For the purpose of this study K coefficients were calculated for each quarter of corresponding increments years.

Another coefficient used to determine the degree of humidity is the index proposed by De Martonne (1926; 1942) referred to as the aridity index $AI = ½ [P/(\overline{T} + 10) + 12\, p_{min}\, (t_{min} + 10)]$, where P is the total precipitation in mm, $\overline{T}$ is the mean annual temperature in °C, p_{min} is precipitation of the driest month in mm and t_{min} is the mean temperature of the driest month. Values of coefficient AI were divided into the following intervals: (–∞, 5]; (5, 12]; (12, 20]; (20, 30], (30, 60] and (60,∞] (a given year is respectively arid, semi-arid, dry, sub-humid, humid and wet). Similarly as in the case of the K coefficient, the boundary between dry and wet periods is the most informative, namely AI equal to 20. The first coefficient is used most often to describe month periods, while the other is applied to year periods. In this paper the K coefficient is designated for quarterly periods.

Two situations were considered here. The first concerns the dependence of height increments on weather conditions occurring in the vegetation season and the other – the dependence on weather conditions occurring in the season before vegetation (the previous year). The 0.05 significance level was used for inferences in this paper.

RESULTS

The obtained values of Sielianinow's hydrothermal coefficients calculated for all quarters of each considered year are given in Figure 2. In the first quarter this coefficient is highly variable in the individual years. It turns out that the fourth quarter was always (in the study period) more or less wet, whereas the second and third quarters were alternately once wetter, once drier.

The values of the AI coefficient are presented in Figure 3. A certain regularity may be easily observed here; namely, one year semi-arid and two years sub-humid. This cycle changed after 1995 into one dry year and one sub-humid year. No such regularity was observed for the year quarters. Only in the third quarters some regularity could be observed, namely two years dry and one year wet. The dotted line marks the boundary between drought and humidity.

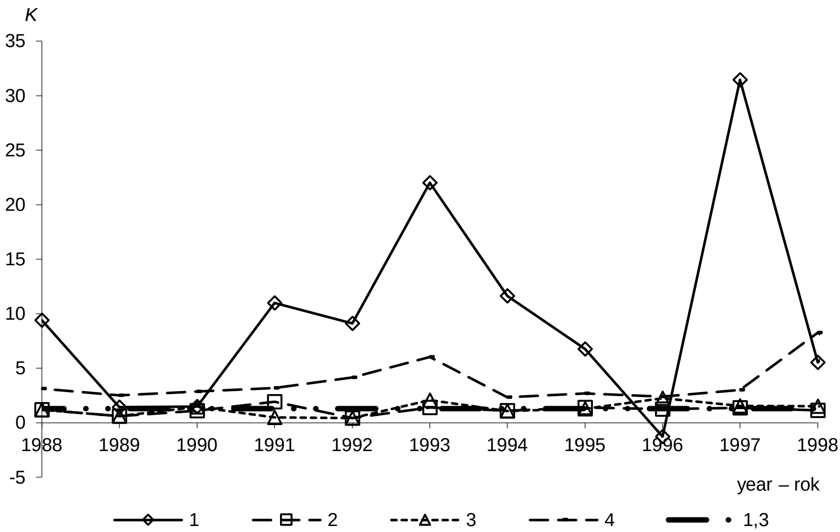

Fig. 2. The values of the *K* coefficients: 1 – first quarter, 2 – second quarter, 3 – third quarter, 4 – fourth quarter, 1.3 – border between dry and wet

Rys. 2. Wartości wskaźnika *K*: kwartały – 1 – pierwszy, 2 – drugi, 3 – trzeci, 4 – czwarty, 1,3 – granica między wskaźnikiem suche i mokre

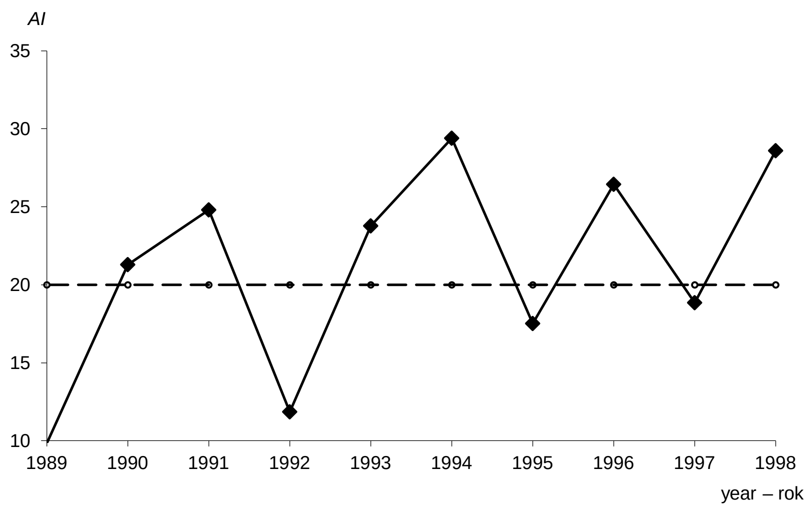

Fig. 3. The values of the *AI* coefficients: the dashed line – border dry weather

Rys. 3. Wartości wskaźnika *AI*: linia przerywana granicą suszy

The influence of the coefficients given above on the height increments of Scots pine was expressed using correlation coefficients. The obtained values of these coefficients as well as their significances are given in Table 1 for the *K* coefficients and in Table 2 for the *AI* coefficients. When the correlations between increments and weather conditions in a given increment year were considered, then it should be concluded that meteorological conditions influenced only the youngest group of trees (24-year old trees) in the first, third and fourth quarters of respective years. However, if the year preceding

Table 1. The linear correlation coefficients (*r*) between *K* coefficients and height increments of trees (significant coefficients indicated in bold)
Tabela 1. Współczynniki korelacji liniowej (*r*) między wskaźnikiem *K* i przyrostem wysokości drzew (współczynniki istotne pogrubiono)

Years and quarters Rok i kwartał		Age-group – Grupa wiekowa							
		24	33	43	55	63	72	84	92
Given year Dany rok									
1	*r*	**–0.18**	–0.160	–0.070	–0.130	–0.080	–0.020	–0.080	–0.010
	p-value *p*-wartość	0.040	0.076	0.435	0.159	0.394	0.830	0.350	0.909
2	*r*	0.090	0.030	0.030	0.060	0.050	0.060	–0.040	0.020
	p-value *p*-wartość	0.293	0.727	0.754	0.536	0.545	0.537	0.626	0.811
3	*r*	**–0.340**	**–0.310**	0.020	–0.080	0.040	0.160	0.090	0.130
	p-value *p*-wartość	0.000	0.001	0.812	0.356	0.652	0.068	0.314	0.145
Previous year Poprzedni rok									
1	*r*	–0.080	0.020	0.150	–0.020	0.010	0.080	0.160	0.100
	p-value *p*-wartość	0.351	0.813	0.097	0.801	0.939	0.386	0.083	0.258
2	*r*	0.220	**0.310**	**0.310**	**0.280**	0.150	**0.220**	**0.260**	0.160
	p-value *p*-wartość	0.013	0.000	0.000	0.002	0.095	0.014	0.004	0.071
3	*r*	0.110	**0.210**	**0.340**	**0.220**	**0.240**	**0.250**	**0.270**	**0.260**
	p-value *p*-wartość	0.220	0.019	0.000	0.015	0.006	0.005	0.003	0.003
4	*r*	–0.120	–0.160	**–0.300**	**–0.380**	**–0.230**	**–0.310**	**–0.330**	**–0.280**
	p-value *p*-wartość	0.190	0.067	0.001	0.000	0.009	0.000	0.000	0.001

Table 2. The linear correlation coefficients (*r*) between *AI* coefficients and height increments of trees (significant coefficients indicated in bold)
Tabela 2. Współczynniki korelacji liniowej (*r*) między wskaźnikiem *AI* i przyrostem wysokości drzew (współczynniki istotne pogrubiono)

Years Rok		Age-group – Grupa wiekowa							
		24	33	43	55	63	72	84	92
Given year Dany rok	*r*	–0.100	–0.100	–0.010	–0.110	0.030	0.060	–0.020	0.030
	p-value *p*-wartość	0.283	0.258	0.915	0.209	0.707	0.538	0.794	0.760
Previous year Poprzedni rok	*r*	**0.240**	**0.340**	**0.320**	**0.340**	0.120	**0.230**	**0.200**	0.150
	p-value *p*-wartość	0.006	0.000	0.000	0.000	0.182	0.010	0.024	0.088

the increments was considered, then it was shown that in the first, second and third quarters these dependences were significant for all groups of trees excluding the youngest trees (24). Moreover, in the second quarter these dependences were non-significant in the case of 63- and 92-year old trees, while in the fourth quarter it was in the case of 33-year old trees. From the results given in Table 2 it can be concluded that the increments are clearly dependent on the weather conditions occurring in the year preceding the increments.

DISCUSSION

There are no significant references in the literature to the impact of weather conditions on the current growth of the tree height. Previously conducted research was related to the impact of this weather feature on the radial increment. In presented paper we consider the joint impact temperature and precipitation, expressed by the coefficient of drought, on the height increments.

Zinkiewicz (1946) and Ermich (1953) were the first scientists who were interested in the effect of atmospheric conditions on diameter increment of trees (radial growth) in Poland. Next, the dependence was studied by Jasnowska (1977) and Zielski (1996; 1997). Cedro (2001) stated that a negative effect on radial increments had a high temperature in September. It was also recorded that variation of temperature throughout the year (ranges) had a positive effect on diameter increments. Junttila and Heide (1981) showed a relationship between mean temperature in June and August in the preceding year and the length of the apical shoot in 20-year old pines. A significant correlation between temperature and diameter increments of pine in February and March was established by Zielski (1996). The results obtained by Feliksik (1988), for pine trees from the forest areas in Dąbrowa Tarnowska, were similar (increments in width of wood were strongly dependent on temperature from January to March). Oleksyn et al. (1993) noted that there was a significant relationship between radial growth and winter temperatures.

Wilczyński (2004) obtained that the width of annual rings is positively dependent on warm and short winters and wet and warm summers, while frosty and long winters and dry and hot summers cause a reduction of radial increments, as it was concluded.

CONCLUSION

A marked effect on height increments of trees was observed for weather conditions found in the year preceding the height increments (the *K* drought index in the quarter periods and the *AI* index in the yearly periods).

Height increments of trees aged 33–92 years were significantly influenced by weather conditions found in the second, third and fourth quarters of the year preceding the growth increments. An excessively wet fourth quarter had a negative effect on height increments of these trees in the following year.

Height increments of trees in the age class of 24 years depend mainly on the conditions found in a given increment year. This effect is negative, which means that a wetter year does not promote height increments of trees from this year class.

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PRZYROST WYSOKOŚCI SOSNY (*PINUS SYLVESTRIS* L.). WPŁYW WARUNKÓW POGODOWYCH

Streszczenie. Badano wpływ warunków pogodowych na przyrost drzew ośmiu klas wieku. Warunki pogodowe (temperatura i opady) zostały przedstawione za pomocą wskaźnika hydrotermalnego Sielianinowa dla okresów kwartalnych i wskaźnika de Martonne’a w rocznych okresach. Wskaźnik suszy wskazuje na negatywny wpływ na przyrost drzew w roku następnym. Tylko w przypadku młodszych drzew stwierdzono istotny wpływ warunków atmosferycznych na przyrost w danym roku.

Słowa kluczowe: wskaźnik de Martonne’a, wskaźnik hydrotermalny Sielianinowa, warunki pogodowe, *Pinus sylvestris* L.

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