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THE EFFECT OF SUNSHINE ON THE HEIGHT INCREMENT OF SCOTS PINE

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Abstract. One of the main dendrometric characteristics of Scots pine is the height increment. This characteristic is used to assess the condition of trees and determine radial increments in considered periods. Meteorological conditions have a large impact on the length increments, both during formation of buds and during tree growth. The duration of sunshine is one of the factors influencing the weather, thus the relationship between this factor and height increments was considered in this paper. The correlation coefficients and forward stepwise regression analysis were both used for this purpose. The significant dependences between increments in height of Scots pine and sunshine were shown. The sunshine in the vegetation season (current year) had the largest impact mainly in winter and spring months, as well as in July of the current year.

Key words: correlation, meteorological condition, regression, weather condition, *Pinus sylvestris* L.

INTRODUCTION

The pine is the next, after the larch, birch and aspen, of the most light-growing tree species in our country. In the drier and poorer habitats pine requires more light than in more fertile habitats. This species grows best in open surfaces and southern exposures. According to Jaworski [1995] the size of the minimum requirement of pine for the light is from 9 to 11% (sunshine relative). The real sunshine is the time (hours) while sun rays fall directly on the specific place on the surface of the earth.

The development of trees depends on many factors. Among them are the soil and the weather conditions. For instance, sunshine can be mentioned. In many studies the temperature and the precipitation and their impact on the radial growth are taken into account. For example, in Zienkiewicz [1946], Ermich [1953], Jasnowska [1977], Zielski [1997], Białobok et al. [1993], Wilczyński [1999] and Cedro [2001] works. However, less attention is paid to the influence of sunshine. The influence of sunshine on increments of tree-ring-width of *Alnus japonica* was considered by Haraguchi et al. [1999].

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Wilczyński and Podlaski [2007 a, b] considered this problem in the case of cucumber tree and black alder. In the available literature, little can be found concerning the following topic.

MATERIALS AND METHODS

The length of height increments of Scots pine is a very important characteristic for the determination of volume increment and condition of trees. Since the increments are affected by meteorological conditions in the year that preceded the considered vegetation season, as well as in vegetation season, the period from July of previous years to September of the given vegetation years is taken into account. The studied trees belong to eight age classes. In this study the relationships between height increments and the real sunshine will be considered.

The data concerns measurements of height increments of Scots pine. Sample trees were collected by Draudt methodology [Grochowski 1973] from stands of different ages. There are eight age classes and in each of them 25 trees were selected. Tree age was determined by counting the growth rings of a tree basal disc. For each separated tree, the length of current annual increments has been measured in ten years period (by branch whorls). This means that for each tree ten measurements were done, separately for all researched year. Research was done in the fresh mixed coniferous forest located in the Zielonka Experimental Forest District in the period from 1989 to 1998. Next, the considered ten-year period was divided into two current five-year periods, since in dendometric such periods are dealt. The main characteristics of age group of trees are given in Table 1. The respective groups of age classes of trees were designated as follows: IG1 – 19, IG2 – 28, IG3 – 38, IG4 – 50, IG5 – 57, IG6 – 67, IG7 – 79, IG8 – 87, IIG1 – 24, IIG2 – 33, IIG3 – 43, IIG4 – 55, IIG5 – 62, IIG6 – 72, IIG7 – 84 and IIG8 – 92, where the number on the right side of the dash, for example 19, stands for the age of the trees in which last measurement was done.

Table 1. Main characteristic of analysed trees
Tabela 1. Główne charakterystyki badanych drzew

Period Okres	IG1	IG2	IG3	IG4	IG5	IG6	IG7	IG8
1989-1993								
Minimum Minimalny przyrost wysokości	0.28	0.03	0.08	0.10	0.04	0.02	0.03	0.02
Maximum Maksymalny przyrost wysokości	0.85	0.68	0.50	0.55	0.42	0.36	0.38	0.33
Mean Średnia	0.58	0.40	0.31	0.30	0.22	0.15	0.16	0.10
Standard deviation Odchylenie standardowe	0.130	0.141	0.092	0.092	0.085	0.072	0.069	0.056

Table 1 – cont. / Tabela 1 – cd.

Period Okres	IIG1	IIG2	IIG3	IIG4	IIG5	IIG6	IIG7	IIG8
1994-1998								
Minimum Minimalny przyrost wysokości	0.18	0.02	0.07	0.12	0.06	0.03	0.05	0.01
Maximum Maksymalny przyrost wysokości	0.83	0.85	0.63	0.55	0.47	0.45	0.41	0.29
Mean Średnia	0.57	0.43	0.40	0.35	0.27	0.22	0.21	0.14
Standard deviation Odchylenie standardowe	0.136	0.153	0.115	0.098	0.096	0.083	0.076	0.060

The sunshine was measured in hours and the mean daily sunshine for each month was designated. The relationship between the sunshine (h) and height increments (m) was determined using correlation coefficients. Moreover, the multiple regression equations were designated using the forward stepwise regression procedure of SAS software package. In this procedure one variable is attached or removed in each step.

RESULTS

The average monthly sunshine (h) was presented in Figures 1 and 2, respectively in the first (Fig. 1) and second (Fig. 2) half in all the considered research years. In these Figures, the eleven-year period is given, because increments depend not only on the weather in the incremental season, but also on the weather in the time of the formation of buds. On the basis of the data, the months with the smallest and largest fluctuation of average daily sunshine throughout the considered years can be indicated. In the eleven-

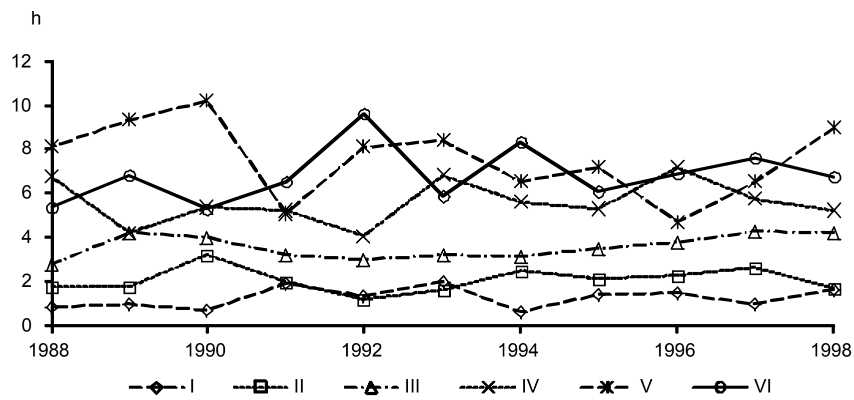

Fig. 1. The monthly sunshine in the first half of considered years, h
Rys. 1. Miesięczne usłonecznienie w pierwszej połowie badanych lat, h

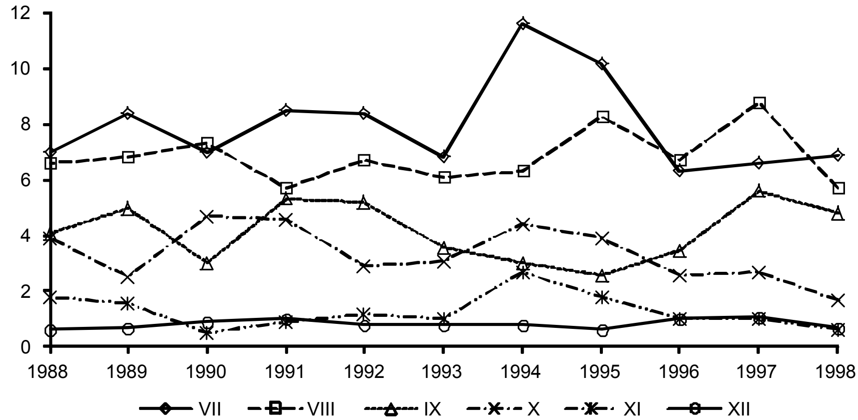

Fig. 2. The monthly sunshine in the second half of considered years, h
Rys. 2. Miesięczne usłonecznienie w drugiej połowie badanych lat, h

-year period the smallest sunshine fluctuation among years was in December and January, whereas the most changeable were in May and July. In two six-year periods the smallest fluctuation (in terms of average numbers of sunshine hours) were in November, December and January in the first period, and December and February in the second period. On the other hand, the largest fluctuation was in May and in July, respectively in the first and second periods.

In Figures 3, 4, 5 and 6 correlation coefficients between the monthly sunshine and both considered five-year increment periods were presented. The values of correlation coefficient equal 0.176 and –0.176 and are marked with dashed line. All values of coefficients greater than 0.176 are significant at the level 0.05. For the purpose of distinction, correlations concerned sunshine in the months that proceeded the vegetation season and during the vegetation. In the first case, before the number of a month, the letter

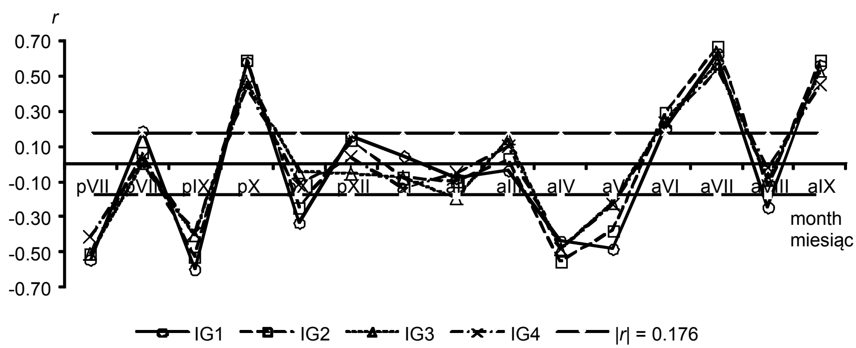

Fig. 3. The correlation coefficients (*r*) and their significances between height increments of trees and average monthly sunshine in 1989-1993 period: IG1, IG2, IG3 and IG4 – age group of trees
Rys. 3. Współczynniki korelacji (*r*) i ich istotność pomiędzy przyrostami wysokości drzew a średnim miesięcznym usłonecznieniem w okresie 1989-1993: IG1, IG2, IG3 i IG4 – grupy wiekowe drzew

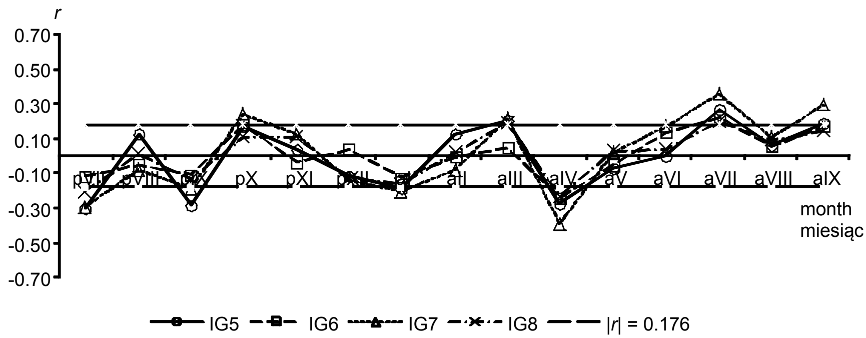

Fig. 4. The correlation coefficients (*r*) and their significances between height increments of trees and average monthly sunshine in 1989-1993 period: IG5, IG6, IG7 and IG8 – age group of trees

Rys. 4. Współczynniki korelacji (*r*) i ich istotność pomiędzy przyrostami wysokości drzew a średnim miesięcznym usłonecznieniem w okresie 1989-1993: IG5, IG6, IG7 i IG8 – grupy wiekowe drzew

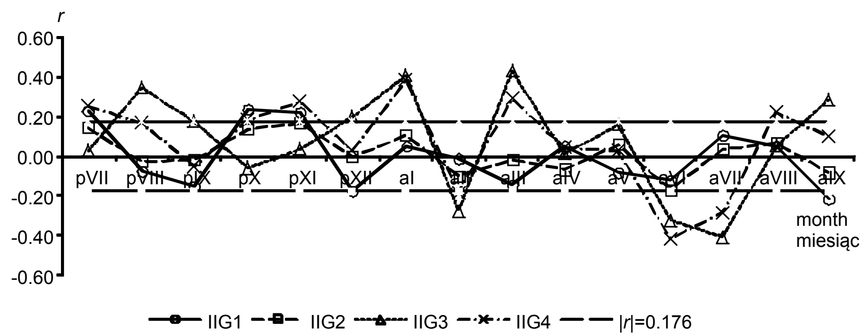

Fig. 5. The correlation coefficients (*r*) and their significances between height increments of trees and average monthly sunshine in 1994-1998 period: IIG1, IIG2, IIG3 and IIG4 – age group of trees

Rys. 5. Współczynniki korelacji (*r*) i ich istotność pomiędzy przyrostami wysokości drzew a średnim miesięcznym usłonecznieniem w okresie 1994-1998: IG1, IG2, IG3 i IG4 – grupy wiekowe drzew

p was placed, and in the second one the letter *a*. In the following part of the work the same signs were used.

In the first five-year increments period (Fig. 3 and 4) the sunshine in October had a positive influence on the height increments (*pX*), in the time of buds formation, moreover in July (*aVII*) and September (*aIX*), in the vegetation season. In these months the correlation coefficients were significant in almost all age-group of trees. The sunshine in July (*pVII*), in September (*pIX*) of the year that preceded increments, and in April (*aIV*) of the given incremental year had a negative influence on increments in the case of the majority age-groups. In the second period (Fig. 5 and 6) correlation coefficients had a large values in August (*pVIII*), January (*aI*), March (*aIII*) and September (*aIX*), whilst the negative influence was noted in June (*aVI*) and July (*aVII*) for older trees.

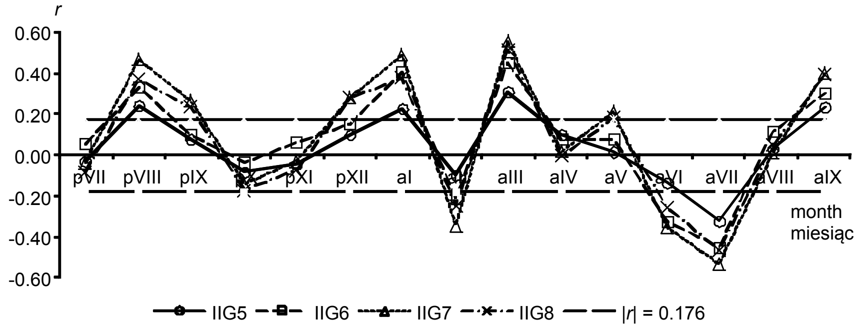

Fig. 6. The correlation coefficients (*r*) and their significances between height increments of trees and average monthly sunshine in 1994-1998 period: IIG5, IIG6, IIG7 and IIG8 – age group of trees

Rys. 6. Współczynniki korelacji (*r*) i ich istotność pomiędzy przyrostami wysokości drzew a średnim miesięcznym usłonecznieniem w okresie 1994-1998: IG5, IG6, IG7 i IG8 – grupy wiekowe drzew

For younger trees (IIG1) the positive influence of sunshine time was noted in July (*pVII*), October (*pX*) and November (*pXI*), whereas negative in September (*aIX*). In the first period closer relationship was in summer months, both previous and incremental years. In the second period similar dependences were in the case of trees from IIG1 and IIG2 age classes. In the case of the other trees winter sunshine had also a big impact in this period.

In the first five-year period the average increments in height were smaller than in the second one. Likewise the mean sunshine in the first period was shorter than in the second one. The average sunshine concerning each the analysed month was given in Figure 7, and average increments were shown in the Figure 8. In the first period the sunshine time was longer than in the second period only in September (*pIX*), October (*pX*), May (*aV*) and September (*aIX*).

At the time that preceded the vegetation season there are more hours with the sun, most of height increments are positively correlated with sunshine, but in the vegetation season the correlation coefficients can be negative (without trees from age class IIG1 and IIG2).

For the purpose of finding the months in which sunshine had the biggest influence on height increments, the forward stepwise analysis of regression was used separately

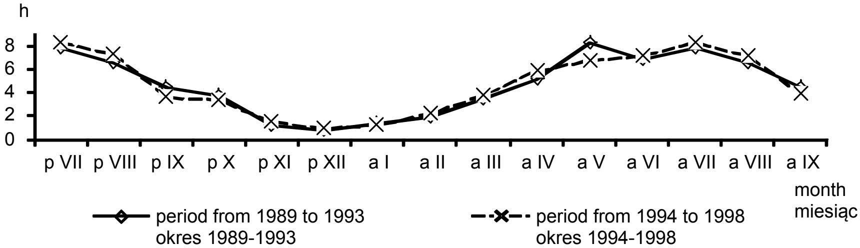

Fig. 7. The average sunshine in two five-year periods, h

Rys. 7. Średnie usłonecznienie w dwóch okresach pięcioletnich, h

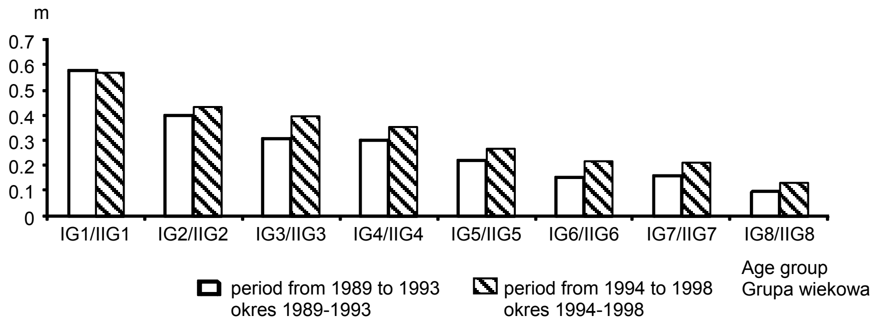

Fig. 8. The average increments of trees in two five-year periods: horizontal axis – age of tree, vertical axis – average increments

Rys. 8. Średnie przyrosty wysokości drzew w dwóch pięcioletnich okresach: pozioma oś – wiek drzew, pionowa oś – średnie przyrosty wysokości

for each age group of trees. The regression coefficients and their significance were presented in Tables 2 and 3. According to the results it is easy to see that in the first period there is the biggest impact on increments noted in April and July in the incremental years. In the year that preceded the vegetation season the influence of sunshine was less visible. In the case of the age group IG6 and IG8 only sunshine in April had an influence on increments. In the second period there was a more varied situation. In the vegetation season the sunshine had also bigger impact, but mainly in March.

Table 2. The regression coefficients of dependences between height increments (m) and average monthly sunshine (h) in 1989-1993 incremental season

Tabela 2. Współczynniki regresji zależności pomiędzy przyrostami wysokości (m) i średnim miesięcznym usłonecznieniem (h) w sezonie przyrostowym 1989-1993

Age groups *p*-value Grupy wiekowe *p*-wartość	Equations of regression Równanie regresji											$adjR^2$ $poprR^2$
1	2											3
IG1	–	2.15986	+	0.06915	*pVII*	+	0.13757	*pVIII*	+	0.16398	*aVII*	0.4935
p-value		0.0009		0.0316			<0.0001			<0.0001		
IG2	–	0.87923	+	0.05777	*aII*	+	0.14857	*aVII*				0.5064
p-value		<0.0001		0.0002			<0.0001					
IG3	–	0.17583	–	0.16118	*pXII*	+	0.07829	*aVII*				0.3840
p-value		0.0142		0.0014			<0.0001					
IG4	–	0.3835	+	0.03404	*aII*	+	0.07865	*aVII*				0.3330
p-value		<0.0001		0.0034			<0.0001					
IG5		0.57912	–	0.03888	*pVII*	–	0.03677	*aI*				0.1369
p-value		<0.0001		0.0002								

Table 2 – cont. / Tabela 2 – cd.

1	2							3
IG6	0.24541	–	0.01760	*aIV*				0.1073
p-value	<0.0001		0.0067					
IG7	0.41949	–	0.01803	*pVII*	–	0.02313	*aIV*	0.1841
p-value	<0.0001		0,0343			0.0002		
IG8	0.16555	–	0.01285	*aIV*				0.0518
p-value	<0.0001		0.0117					

Table 3. The regression coefficients of dependences between height increments (m) and average monthly sunshine (h) in 1989-1993 incremental period
Tabela 3. Współczynniki regresji zależności pomiędzy przyrostami wysokości (m) i średnim miesięcznym usłonecznieniem (h) w sezonie przyrostowym 1989-1993

Age groups *p*-value Grupy wiekowe *p*-wartość	Equations of regression Równanie regresji											a*djR*^{2} *poprR*^{2}
IIG1		0.41364	+	0.04557	*pX*							0.0552
p-value		<0.0001		0.0087								
IIG2		0.66749	–	0.03313	*aVI*							0.0274
p-value		<0.0001		0.0652								
IIG3		0.01251	+	0.07794	*aI*	+	0.07657	*aIII*				0.2293
p-value		0.1739		0.0073			0.0017					
IIG4		0.50483	+	0.06715	*aII*	+	0.04461	*aIII*	–	0.06590	*aVI*	0.2293
p-value		<0.0001		0.0415			0.0168			<0.0001		
IIG5		0.38394	–	0.01413	*aVII*							0.1026
p-value		<0.0001		0.0003								
IIG6	–	0.26338	+	0.16579	*aIII*	–	0.03617	*aIX*				0.2239
p-value		0.0014		<0.0001			0.0048					
IIG7	–	0.12057	+	0.05735	*aI*	+	0.07615	*aIII*				0.3660
p-value		0.0118		0.0011			<0.0001					
IIG8	–	0.12037	+	0.06869	*aIII*							0.2573
p-value		0.0035		<0.0001								

The received results can be compared with fluctuations of the average monthly sunshine shown in Figure 1 and 2. In the first period in July (*aVII*) there were small fluctuations of the sunshine through years (from 6.8 to 8.5 h) and in the second one, in this months, there were very large fluctuations of the sunshine (6.3-11.6). The conclusion is

Table 4. The correlation coefficients and their significances between annual height increments [m] of trees and average sunshine [h]
Tabela 4. Współczynniki korelacji oraz ich istotność pomiędzy rocznymi przyrostami wysokości drzew [m] i średnim usłonecznieniem [h]

Period Okres	Age groups – Grupy wiekowe							
1989-1993	IG1	IG2	IG3	IG4	IG5	IG6	IG7	IG8
	–0.02	–0.00	**–0.27**	**–0.20**	**–0.20**	**–0.29**	**–0.36**	**–0.26**
1994-1998	IIG1	IIG2	IIG3	IIG4	IIG5	IIG6	IIG7	IIG8
	0.02	0.15	0.10	**0.18**	0.16	0.16	**0.21**	0.14

that if the number of hours with sun is short, the increments are longer, but if this time is long, increments are smaller. In the second period the sunshine in March was often longer than in the first period and the long time of sunshine positively influenced increments (Table 3).

The relationship between the average sunshine [h], calculated from January to October of previous year, and annual increments were seen. Appropriate correlation coefficients were given in Table 4. Most of them had a significant value (> 0.176). In the first period (1989-1993) the negative correlations were recorded, but in the second one, correlation coefficients had positive values. It is found very interesting, why in both periods these correlations were once positive, once negative. One of the reasons is the influence of many factors on the growth of trees (weather condition, soil etc.).

DISCUSSION AND CONCLUSIONS

There are no significant references in the literature to the impact of sunshine on the current growth of the tree height. Previously conducted research was related to the impact of this particular weather feature on the volume increment.

The monthly sunshine during June showed the highest positive correlation with tree-ring-width indices of *Alnus japonica*. The high precipitation is typically accompanied by low durations of sunshine, the high precipitation in June is correlated with the reduced growth of *Alnus japonica* [Haraguchi et al. 1999]. The sunshine during August of the previous year also showed a significant positive correlation with tree ring-width indices of *Alnus japonica* [Haraguchi et al. 1999]. The large amount of sunshine in August of the current year had a positive effect on the growth of the cucumber tree in the Świętokrzyski National Park [Wilczyński and Podlaski 2007 a].

The duration of the direct solar radiation in the current growing season had a significant influence on tree growth of the black alder [Wilczyński and Podlaski 2007b]. The increased amount of sunshine in May, July and August had a positive effect on radial increment. Standardized dendroecological methods were used to study the effects of the climatic variability on radial growth of *Abies faxoniana* in the Wolong National Natural Reserve of Western Sichuan (China). The tree radial growth showed time-dependent relationships to inter annual climate variation [Zong-Shan et al. 2010]. The tree growth responded more strongly to the sunshine time – positive and winter temperature – negative (1977-2008). Poljanšek et al. [2013] concluded that summer (mean of June-July) sunshine contributes to the moisture stress, which influences the radial growth of *Pinus nigra* in mountainous sites in the Bosnia and Herzegovina area.

The paper shows that increments in Scots pine height are correlated with the sunshine. The sunshine in the current year had a greater impact mainly in spring months and also in July. In the second considered period the biggest influence on increments often had the sunshine in winter months. Since this influence was not the same for both considered periods, it is very important to check the impact of other climatic aspects, which simultaneously affect the growth of trees.

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WPŁYW USŁONECZNIENIA NA PRZYROST WYSOKOŚCI SOSNY

Streszczenie. Przyrost wysokości jest jedną z podstawowych cech dendrometrycznych sosny zwyczajnej. Jest on wykorzystywany do oceny kondycji drzew oraz określania okresowego przyrostu na promieniu. Duży wpływ na wielkość przyrostu wysokości mają warunki meteorologiczne w czasie kształtowania się pąków drzewa oraz podczas ich wzrostu. Długość czasu usłonecznienia jest jednym z takich czynników pogodowych. W prezentowanej pracy zajmowano się wpływem usłonecznienia na wielkość bieżących przyrostów wysokości sosen. W analizach wykorzystano współczynnik korelacji oraz postępującą regresję krokową. Wykazano, że badane zależności są istotne statystycznie. Okazało się, iż usłonecznienie występujące podczas sezonu wegetacyjnego, zwłaszcza w miesiącach zimowych, wiosennych oraz w lipcu, miało największy wpływ na przyrosty wysokości badanych sosen.

Słowa kluczowe: korelacja, warunki meteorologiczne, analiza regresji, warunki pogodowe, sosna zwyczajna

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