Morphological architecture of different ecotypes of Scots pine (*Pinus sylvestris* L.) in Poland

A. REMLEIN, T. JELONEK, A. TOMCZAK, M. JAKUBOWSKI, W. GRZYWIŃSKI
Poznań University of Life Sciences, Department of Forest Utilisation
Wojska Polskiego 71A, 60-625 Poznań, Poland

Abstract: *Morphological architecture of different ecotypes of Scots pine (Pinus sylvestris L.) in Poland.* In this paper, we attempted to accurately describe and compare the morphological architecture of Scots pine (*Pinus sylvestris* L.), representing three different ecotypes from Bolewice, Gubin, and Tabórz. The samples come from old pine stands aged from 104 to 113 years located in three areas. In total, over 580 pines representing the three ecotypes were analyzed. All trees have been measured with respect to their height, diameter at breast height. Crown ratio and slenderness coefficient have also been calculated for each tree. The results obtained in the study revealed significant morphological differences between the investigated ecotypes of Scots pine. The highest measurements of diameter at breast height, and tree height were obtained for Tabórz pines, while the lowest measurements were obtained for Gubin pines. Tabórz pines also proved to be the most slender of all analyzed ecotypes.

Keywords: Scots pine, architecture of trees, ecotype, slenderness coefficient, stability

INTRODUCTION

Over the years of evolution, populations adapted to local growth and development conditions have formed within local species. Significant differences between them have been observed, mostly with regard their morphological features (Białobok 1967, Krzakowa 1979, Szweykowski & Urbaniak 1982, Krzakowa et al 1994; Giertych 1995, 1997; Białobok et al. 1993, Szweykowski et al. 1994). Abiotic factors, such as temperature, light, soil type, available nutrients, and other derived factors (Pawlaczyk et al. 2010) lead to the development of local phenotypes (geographic races), that is populations with distinguishing characteristics. These populations are present in a given area within the range of the species. In Poland, many of the local populations of Scots pine, referred to as ecotypes, are considered to be valuable. Local populations develop optimal growth characteristics in the conditions, in which they have been growing for generations. Scots pine races have been known and valued in forestry for years. Due to their unique characteristics, typical for given populations, several attempts to describe them have been made. Most studies found in the literature investigate the population differences with regard to the morphological and anatomic characteristics of needles, cones, and seeds (Sokołowski 1931, Staszkiewicz 1961, Bobowicz, Korczyk 1994a, b, Urbaniak 1997, 2009, Skrzyszewski 2004, Pawlaczyk et al. 2010). Genetic studies are currently also gaining in popularity (Sokołowski 1931, Staszkiewicz 1961, Bobowicz, Korczyk 1994a, b, Urbaniak 1997, 2009, Skrzyszewski 2004, Pawlaczyk et al. 2005, 2007a, b, Nowakowska et al. 2014). On the basis of DNA analyses, genetic relationships between pine populations in different regions of Poland have been identified (Nowakowska et al. 2005, 2007a, 2010).

This paper attempts to describe and compare the morphology of three known Scots pine (*Pinus sylvestris* L.) ecotypes, i.e. the Bolewice ecotype, the Tabórz ecotype, and the Gubin ecotype (Figure 1). The Tabórz ecotype can be observed, among other places, in the Sosny Taborskie Nature Reserve, which was founded in 1958 in the area near Tabórz, in the Warmian-Masurian Voivodeship. This ecotype was highly valued around the world, as it was used in building masts for sailing ships. According to Fabijanowski (1961), a characteristic feature of

Tabórz pine is its longevity. Some of the stands are older than 180 years, and many of them are over

260 years old. Regardless of their economic value, Tabórz pines exhibit high ecological value and high timber quality. The Tabórz pine grows up to 43 meters, is rather lightly branched even in favorable environmental conditions, in which a regular pine would develop branches of considerable size, and has good adaptive characteristics (Fabijanowski 1961).

The Gubin pine can be found in the area of the Forest District Gubin, in the Lubusz Voivoidship, Crosno Odrzańskie County, to the right of the Lusatian Neisse, at the Lubsza River.

Bolewice pine is a local ecotype of Scots pine (*Pinus sylvestris* L.), found in part of the

Fig. 1. 1- Tabórz ecotype, 2-Bolewice ecotype, 3-Gubin ecotype

Forest District Grodzisk (Greater Poland Vovoidship). The population of this ecotype is considered to be one of the most valuable ones in Poland. Among the genetic resources of Scots pine that have already been identified, the Bolewice ecotype is characterized by an exceptionally high breeding quality.

METHODS

In this paper, we attempted to accurately describe and compare the morphology of Scots pine (Pinus sylvestris L.), representing three different ecotypes from Bolewice, Gubin, and Tabórz. The samples come from old pine stands aged from 104 to 113 years located in three areas (Fig. 1).

The methodology of this study involved measurements of approximately 200 trees from the chosen stands representing a given ecotype. We measured basic morphological characteristics, i.e. diameter at breast height ($D_{1.3}$), tree height (Hd), crown diameter (Dk), slenderness coefficient ($H/D_{1,3}$), and crown ratio (Hd/D_k).

Diameter at breast height ($D_{1,3}$) for each tree was measured to an accuracy of 0.1 cm, in two measurements that were made perpendicular to each other, i.e. N-S and E-W. The final measurement was calculated as a mean of the two perpendicular measurements. Tree height (Hd), height of the first knot, and crown depth were measured using a Nikon Forestry Pro laser rangefinder to the accuracy of 0.1 m. The lowest live branch, which was located < 1 m of the dense crown base, was taken as the crown base. Crown spread was measured in two directions, N-S and E-W, using BOSH Laser distance measurer. By using the longest spread and the longest cross-spread, the diameter of the crown (D_k), was measured to the accuracy of 10 cm.

In total, 580 pines representing the three ecotypes i.e. Bolewice, Gubin, and Tabórz were analyzed.

Collected empirical data were analysed using statistical methods with the application of the *STATISTICA 12* software package.

RESULTS

This study analyzed the height Hd, and the diameter at breast height $D_{1.3}$ of the trees, and two factors responsible for tree stability, i.e. slenderness coefficient $H_d/D_{1.3}$, and crown ratio H_d/D_k.

On average, Bolewice pines were characterized by lowest values of the described morphological characteristics (diameter at breast height, tree height), in comparison to the other analyzed ecotypes. On average, Tabórz pines were characterized by highest values of the analyzed characteristics. Dispersion analysis of tree height and diameter at breast height has shown greatest diversity of these characteristics in the Tabórz ecotype (Tab. 1).

Average height of the analyzed pines was 26.62 m, with standard deviation equal to 4.27 m, and variation equal to 18.26. Furthermore, statistically significant differences between the analyzed ecotypes were found (Fig. 2).

Table 1. Statistical profile of the morphology of Scots pine (*Pinus sylvestris* L.) representing the three ecotypes

Variable	Ecotype	Mean	N	Standard deviation	Coefficient variation [%]	Variance
$H_{d\ [m]}$	Bolewice	22.86	201	2.10	9.16	4.39
	Gubin	25.50	200	1.41	5.53	1.99
	Tabórz	31.82	188	2.63	8.25	6.90
	Overall	26.62	589	4.27	16.05	18.26
$D_{1.3}$ [cm]	Bolewice	31.64	201	5.68	17.96	32.29
	Gubin	36.54	200	4.63	12.67	21.44
	Tabórz	41.68	188	6.51	15.61	42.33
	Overall	36.51	589	6.95	19.05	48.35
$H_d/D_{1.3}$	Bolewice	74.10	201	12.20	16.46	148.84
	Gubin	70.68	200	7.93	11.22	62.91
	Tabórz	77.74	188	11.13	14.32	123.94
	Overall	74.10	589	10.93	14.76	119.55
H_d/D_k	Bolewice	3.75	201	1.06	28.27	1.13
	Gubin	4.36	200	0.85	19.49	0.72
	Tabórz	3.38	188	0.61	17.89	0.37
	Overall	3.84	589	0.95	24.76	0.90

Another analyzed characteristic was diameter at breast height ($D_{1.3}$). Average diameter at breast height of the analyzed pines was 36.51 m, with standard deviation equal to 6.95 m, and variation equal to 48.35. Statistically significant differences in diameter at breast height between the analyzed ecotypes were found (Fig. 3). Trees of the Tabórz ecotype were characterized by a statistically significantly higher diameter at breast height than trees of other ecotypes. On average, trees of the Tabórz ecotype were the thickest (41.68 cm), while trees of the Bolewice ecotype were the thinnest (31.64 cm) (Tab. 1, Fig. 3). Greatest dispersion of the $D_{1.3}$ variable was found in the Tabórz population and the Bolewice population. Greatest variation equal to 42.33 was found in the Tabórz pine, while the coefficient of variation of the diameter at breast height was highest in tree group representing the Bolewice ecotype (Tab. 1).
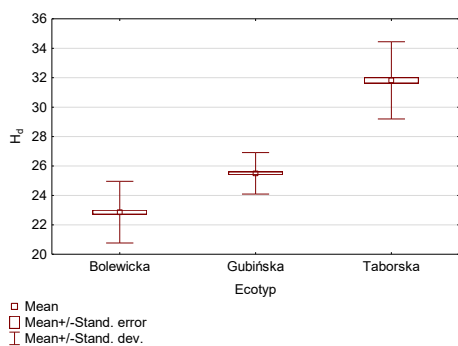
Fig. 2 Height profile of Scots pine (*Pinus sylvestris* L.) representing the three ecotypes of the species found in Poland.
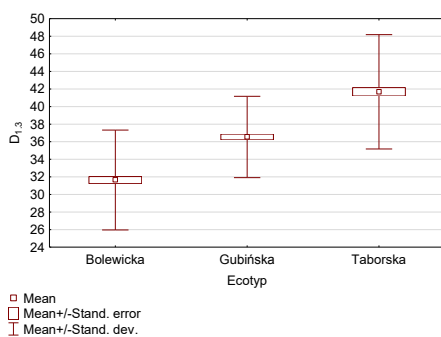
Fig. 3 Diameter at breast height profile of Scots pine (*Pinus sylvestris* L.) representing the three ecotypes of the species found in Poland.

Results of Tukey's HSD test for the average tree height

Hd	Bolewice	Gubin	Tabórz
Ecotypes			
Bolewice		0.000022	0.000022
Gubin	0.000022		0.000022
Tabórz	0.000022	0.000022	

* differences statistically significant at the significance level p<0.05 are marked

Results of Tukey's HSD test for the average tree height

$D_{1.3}$	Bolewice	Gubin	Tabórz
Ecotypes			
Bolewice		0.000022	0.000022
Gubin	0.000022		0.000022
Tabórz	0.000022	0.000022	

* differences statistically significant at the significance level p<0.05 are marked

Additionally, an analysis of two coefficients calculated on the basis of the morphological characteristics of the trees was conducted.

The average value of the slenderness coefficient ($H_d/D_{1.3}$) was equal to 74.10, with standard deviation of 10.93, and variation of 119.55 (Tab. 1).

Statistically significant differences in the average slenderness coefficient were observed between all three analyzed pine ecotypes (Fig. 3). On average, highest values of the slenderness coefficient (77.74) were found for the Bolewice pine ecotype. On the other hand, the lowest values of the slenderness coefficient, which were equal to 70.68 on average, were observed in the Gubin pine. Greatest population diversity with respect to the slenderness coefficient was observed in the Bolewice pine, while lowest diversity was observed in the Gubin population (Tab. 1, Fig. 4).

Similarly, statistically significant differences between all of the analyzed pine ecotypes were found with regard to the crown ratio (H_d/D_k) (Fig. 4).

The average value of the crown ratio was equal to 3.84, with standard deviation of 0.95, and variation of 0.90. Significantly highest value of the crown ratio, which was equal to 4.36 on average, was observed for pines from the Gubin ecotype. The lowest value of crown ratio was observed for the trees from the Tabórz ecotype, being equal to 3.38 on average (Fig. 5, Tab. 1).
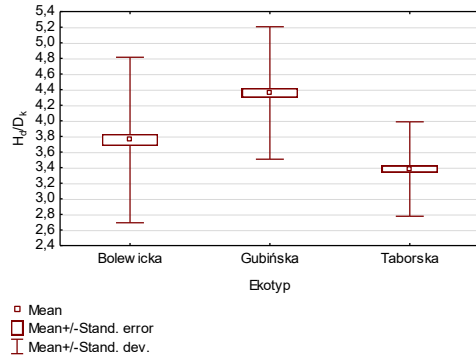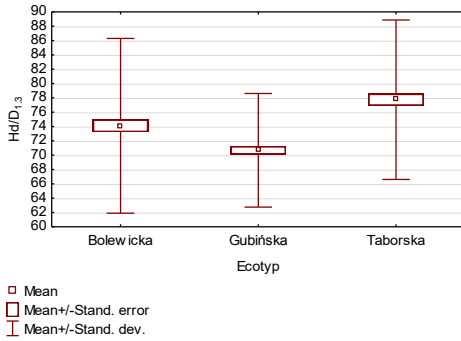
Fig. 4 Slenderness coefficient profile of Scots pine (*Pinus sylvestris* L.) representing the three ecotypes of the species found in Poland.

Fig. 5 Crown ratio profile of Scots pine (*Pinus sylvestris* L.) representing the three ecotypes of the species found in Poland.

Results of Tukey's HSD test for the average tree height

$Hd/D_{1.3}$	Bolewice	Gubin	Tabórz
Bolewice		0.003463	0.002421
Gubin	0.003463		0.000022
Tabórz	0.002421	0.000022	

Ecotypes

* differences statistically significant at the significance level p<0.05 are marked

Results of Tukey's HSD test for the average tree height

H_d/D_k	Bolewice	Gubin	Tabórz
Bolewice		0.000022	0.000106
Gubin	0.000022		0.000022
Tabórz	0.000106	0.000022	

Ecotypes

* differences statistically significant at the significance level p<0.05 are marked

CONCLUDING REMARKS AND DISCUSSION

The size, shape, and structure of a tree have a considerable impact on its stability under static and dynamic loads (James et al. 2006). According to Kim (2000), the stability of a tree is influenced by the relation between the average bole diameter and tree height, and the allocation of foliage biomass.

The most commonly measured biometric characteristics is diameter at breast height, which is positively correlated with the length and the width of the crown (Jelonek 2013). These characteristics are considered to be the main indicators of tree and tree stand development dynamics (Lemke 1971). They also constitute a major criterion in assessing the risk of damage caused by wind (Peltola & Kellmäki 1993, Bruchwald & Dmyterko 2011, 2012).

The basic biometric characteristics of the analyzed trees, i.e. diameter at breast height (36.5 cm) and height (26.6 m) were typical for pines that reached felling age, and similar to those provided by Meixner et al. (1979) and Beker (2007). The only exception was the Tabórz pine, which height and diameter at breast height was well above the obtained average.

In statistical analyses of trees and tree stands, and their resistance to wind, stability is most often defined in terms of the slenderness coefficient (Erteld & Hengst 1966, Zajączkowski 1991, Jaworski 2004, Peltola 2006). Therefore, as a relevant measure of tree stability, this study adopted allometric functions based on morphological characteristics of a tree i.e. the slenderness coefficient, which is a reflection of the relation between the diameter at breast height of a tree

and its height, and the crown ratio, which has a significant impact on the statistics of the tree, and involves the width of the crown, which by self is an important parameter.

Pine slenderness in Poland is in the range between 50 and 150 (Orzeł 2007, Rymer-Dudzińska 1992a) and decreases with the age of the tree, reaching about 70 at the felling age. The difference in slenderness between the pines from the analyzed groups was negligible, being equal to 74 ± 11 on average for the three populations. Tabórz pines were found to be the most slender trees from the analyzed ecotypes, with the slenderness coefficient equal to 78. Tabórz pines also showed the lowest (3.3) crown ratio.

The highest crown ratio was observed in the Gubin pines, which, when combined with the lowest slenderness coefficient of these pines, confirms Jelonek's (2013) hypothesis on the adaptive pine growth that optimizes the architecture for transferring mechanical loads by the tree. The higher the crown ratio is, or in other words, the wider the crown is in relation to the height of the tree, the less slender the bole needs to be to carry greater loads from wind or snow-caps.

In general, tree stands grown in a given environment develop local ecotypes, which are characterized by a set of specific allometric features, which provide the trees with proper stability. Furthermore, significant differences in the results of the analysis were observed with regard to the analyzed ecotypes. This means that specific modifications in tree architecture have developed within each of the ecotypes. The analysis conducted in this study is by no means comprehensive. Many practical and scientific issues connected with the topic presented in this study require further investigation.

REFERENCES

1. BAKER C.J. 1995: The development of a theoretical model for the wind throw of plants, J. Theor Biol. 175(3): 355-372
2. BIAŁOBOK S., BORATYŃSKI A., BUGAŁA W. 1993: Biologia sosny zwyczajnej, Poznań – Kórnik, Sorus Press
3. BOBOWICZ M. A. KORCZYK A. F. 1994a: Interpopulational variability of *Pinus sylvestris* L. in eight Polish localities expressed in morphological and anatomical traits of needles, Acta Soc. Bot. Pol. 63(1): 67-76
4. BOBOWICZ M. A. KORCZYK A. F. 1994b: Variability of eight Polish populations of *Pinus sylvestris* L. expressed in traits of cones, Acta Soc. Bot. Pol. 63: 191–198
5. BOROWSKI M., DZIEKOŃSKI H. 1974: Rozkład przyrostu grubości wzdłuż strzał sosen w zależności od stanowiska socjalnego drzew, Sylwan 118 (11): 8−15
6. BOURIAUD O., BRĚDA N., MOGUĚDEC G. LE., NEPVEU G. 2004: Modeling variability of wood density in beech as affected by ring age, radial growth and climate, Trees, vol. 18, p. 264-276
7. BRUCHWALD A., DMYTERKO E. 2011: Zastosowanie modeli ryzyka uszkodzenia drzewostanu przez wiatr do oceny zagrożenia lasów nadleśnictwa, Sylwan 155 (7):459-471
8. BRUCHWALD A., DMYTERKO E. 2012: Ryzyko powstawania szkód w drzewostanach poszczególnych nadleśnictw Polski, Sylwan 156 (1): 19-27
9. BURSCHEL P., HUSS J. 1997: Grundriss des Waldbaus. Berlin, Parey Buchverlag
10. ERTELD W., HENGST E. 1966: Waldertragslehre. Neumann, Radebeul

11. FABIJANOWSKI J. 1961. Kilka uwag dotyczących ras sosny zwyczajnej w Polsce oraz o sośnie mazurskiej, Sylwan 4: 21−30

12. FABIJANOWSKI J. 1961: Kilka uwag o badaniach dotyczących rasy sosny zwyczajnej w Polsce oraz o sośnie mazurskiej. Sylwan. 105(4): 21-27

13. GIERTYCH M. 1997: Zmienność proweniencyjna sosny zwyczajnej (*Pinus sylvestris* L.) w Polsce, Sylwan 8: 5-20

14. JAMES K., HARITOS N., ADES P. K. 2006: Mechanical stability of trees under dynamic loads. Am. J. Bot. 93: 1522–1530

15. JAWORSKI A. 2004: Podstawy przyrostowe i ekologiczne odnawiania oraz pielęgnacji drzewostanów. PWRiL, Warszawa

16. KIM D. 2000: Tree Biomechanics Series Stem Length & Diameter Taper Limits. The University of Georgia

17. KRZAKOWA M. 1979: Enzymatyczna zmienność miedzypopulacyjna sosny zwyczajnej (*Pinus sylvestris* L.), Wyd. UAM, ser. Biol. Nr 17.

18. KRZAKOWA M. URBANIAK L. KORCZYK F.A. 1994: Chromatographic studies on phenolic compounds in Scots pine (*Pinus sylvestris* L.), Bull. Soc. Amis Scienc. Lettr. Poznań. 30: 11–21

19. LEMKE J. 1971: Przydatność korony i wysokości drzew do szacowania ich właściwości przyrostowych w drzewostanach sosnowych II i III klasy wieku. Pr. Kom. Nauk Roln, Kom. Nauk Leśn. PTPN 32: 73-87

20. MEIXNER J., KAŹMIERCZAK K., NAJGRAKOWSKI T. 1997: Wiek drzewostanu sosnowegoa zmienność sum powierzchni przekroju i miąższości drzew na powierzchniach próbnych różnych wielkości, Sylwan 141 (2): 49-58

21. NOWAKOWSKA J. 2007a: Zmienność genetyczna polskich wybranych populacji sosny zwyczajnej na podstawie analiz poliformizmu DNA .Rozprawy i Monografie IBL

22. NOWAKOWSKA J. 2007b: Zmienność genetyczna sosny zwyczajnej na podstawie mitochondrialnych markerów DNA, Notatnik Naukowy 4(78) IBL

23. NOWAKOWSKA J. 2010: Określenie struktury genetycznej populacji sosny zwyczajnej i świerka pospolitego w wybranych regionach pochodzenia z weryfikacją granic regionów po uwzględnieniu zróżnicowania genetycznego populacji. Dokumentacja naukowa z tematu badawczego BLP-309, Sekocin Stary 2010, s. 217

24. NOWAKOWSKA J., RAKOWSKI K. 2005: Charakterystyka zmienności genetycznej sosny napiwodzko-ramuckiej i spalskiej na podstawie analiz mitochondrialnego DNA, Leśne Prace Badawcze 2:73-91

25. NOWAKOWSKA J., ZACHARA T., KONECKA A. 2014: Genetic variability of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L. Karst.) natural regeneration compared with their maternal stands, Leśne Prace Badawcze (Forest Research Papers), 75 (1): 47–54

26. ORZEŁ S. 2007: A comparative analysis of slenderness of the main tree species of the Niepołomice forest, Electr. J. Pol. Agric. Univ. Ser. For. 10 (2), #13. [http://www.ejpau.media.pl/volume10/issue2/abs-13.html]

27. PAWLACZYK E., BOBOWICZ M., KORCZYK A. 2010: Zmienność trzech naturalnych populacji *Pinus sylvestris* L. z różnych siedlisk Puszczy Białowieskiej oszacowana cechami igieł, Leśne Prace Badawcze, 71(1): 83–92

28. PELTOLA H. 2006: Mechanical stability of trees under static loads. Am. J. Bot. 93

(10):1501-1511

29. PELTOLA H., KELLOMÄKI S. 1993: A mechanistic model for calculating windthrow andstem breakage of Scots pines at stand edge, Silva Fenn. 27 (2): 99-111

30. RYMER-DUDZIŃSKA T. 1992: Zależność średniej smukłości drzew w drzewostanach sosnowych od różnych cech taksacyjnych drzewostanu, Sylwan 12:19-25

31. RYMER-DUDZIŃSKA T. 1992a: Smukłość drzew w drzewostanach sosnowych, Sylwan 136 (11): 35-44

32. RYMER-DUDZIŃSKA T. 1992b: Zależność średniej smukłości drzew w drzewostanach sosnowych od różnych cech taksacyjnych drzewostanu, Sylwan 136 (12): 19-25

33. SAVIDGE R.A., BARNETT J.R., NAPIER R. (EDS) 2000: Cell and Molecular Biology of Wood Formation, BIOS Scientific, Oxford, UK

34. SOKOŁOWSKI S. 1931: Prace biometryczne nad rasami sosny zwyczajnej (*Pinus silvestris*) na ziemiach Polski, Prace Rolniczo-Leśne PAU 5: 1–106

35. STASZKIEWICZ J. 1961: Zmienność współczesnych i kopalnych szyszek sosny zwyczajnej (*Pinus silvestris* L.), Fragmenta Floristica et Geobotanica 7: 97–160

36. SZWEYKOWSKI J. URBANIAK L. 1982: An interesting chemical polymorphism in *Pinus sylvestris* L., Acta Soc. Bot. Pol. 51(3-4): 441–452

37. SZWEYKOWSKI J., PRUS-GŁOWACKI W., HRYNKIEWICZ J. 1994: The genetic structure of Scots pine (*Pinus sylvestris* L.) population from the top of Szczeliniec Wielki Mt. Central Sudetes, Acta Soc. Bot. Pol. 63 (3–4): 351–324

38. URBANIAK L. 1997: Biometric characters of seeds and wings as markers of geographical differentiation between European Scots pine (*Pinus sylvestris* L.) provenances. Acta Soc. Bot. Pol. 3–4: 371–378

39. URBANIAK L. 2009: Badania porównawcze cech morfologicznych igieł populacji *Pinus sylvestris* L. z terenów Wielkopolskiego i Słowińskiego Parku Narodowego oraz borów tucholskich. Wielkopolski Park Narodowy w badaniach przyrodniczych. B. Walna, L. Kaczmarek, M. Lorenc, R. Dondajewska (red.) Poznań-Jeziory 2009, s. 135-142.

40. ZAJĄCZKOWSKI J. 1991: Odporność lasu na szkodliwe działanie wiatru i śniegu. Świat, Warszawa

Streszczenie: *Architektura morfologiczna drzew reprezentujących różne ekotypy sosny zwyczajnej (Pinus sylvestris L.) w Polsce.* W pracy podjęto próbę d okładnego opisania oraz porównania architektury morfologicznej sosny zwyczajnej (Pinus sylvestris L.) reprezentujących ekotyp bolewicki, gubiński oraz taborski. Materiał doświadczalny pochodził ze starych drzewostanów sosnowych w wieku od 104 do 113 lat zlokalizowanych na trzech powierzchniach. W sumie analizie poddano 580 sosen reprezentujących jej trzy ekotypy. W przypadku wszystkich drzew pomierzono wysokość i pierśnicę, orazobliczono współczynnik smukłości i współczynnik wychylenia koron.

Corresponding author:

Agnieszka Remlein
PhD Student
e-mail: agnieszka.remlein@up.poznan.pl
Poznań University of Life Sciences
Department of Forest Utilisation
Wojska Polskiego 71A, 60-625 Poznań, Poland
Phone +48 61 8487754
Tel (fax) 061 848 77 56/54