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The influence of stand canopy openness on the growth of common yew (*Taxus baccata* L.)

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Abstract. The aim of this study was to evaluate the development of common yew, *Taxus baccata* L., with respect to canopy openness. The plants were growing in ex-situ conservation plantations (established in 2008) in the understory of different tree species. Eleven forest plantations belonging to the following five forest districts were inventoried: Rokita, Baligród, Kołaczyce, Międzylesie and Henryków. In each plantation, the height and height increment of 200 yews were measured and gap light transmission indices were determined.

The canopy species affecting yew growth most significantly were oak (*Quercus* sp.) and Scots pine (*Pinus sylvestris* L.), followed by Norway spruce (*Picea abies* Karst.), silver fir (*Abies alba* L.) and European beech (*Fagus sylvatica* L.). The most favorable development of yew occurred at 30% canopy openness. An increasing light transmission index correlated with a decrease in the proportion of treelike yews. An insufficient amount of light resulted in a low height increment of yews growing under the canopy and an extended period of direct competition of yews with herbaceous species.

Keywords: common yew, ex-situ conservation plots, canopy openness

1. Introduction

Common yew (*Taxus baccata* L.) is the only species of the genus *Taxus* growing in Europe. In Poland, this species reaches the eastern limit of its range (Namvar, Spethmann 1986; Dobrowolska et al. 2012). It grows up to 18–20 m in height and 50 cm in diameter at breast height (Szeszycki 2013). In historical times, yew occurred more commonly, however, due to its valuable wood and slow growth, the proportion of its occurrence has dropped to almost zero (Sokołowski 2000).

In order to increase the biodiversity of the forests in Poland, attempts have been made to restore the yew to the area of its natural range. In 2006, the State Forests National Forest Holding developed strategies, reviewed by the experts of the Forest Research Institute, for the protection and conservation of this species 'The restitution of common yew in Poland (2000).' This programme describes the guidelines for protecting this species *in-situ* and *ex-situ*. Active conservation activities were adopted as the basis for protecting the yew, through comprehensive measures such as conducting an inventory of existing yews, choosing populations for increased reproductive activities, improving the natural habitat of existing populations and restoring yews to forest ecosystems within its natural range. The programme identifies the main issues requiring additional investigation. These include the specific habitat and environmental requirements of the common yew and the level of genetic and population variability of existing yew communities in the country. Given the current state of knowledge, it is difficult to determine the guidelines for producing common yew with certainty (Zahara, Łukaszewicz 2002). However, the yew's tolerance for shade is unquestionable, outstanding in comparison with the light requirements of other tree species occurring in Poland (Włoczewski 1968, Seneta 1981).

As part of the common yew restitution programme, *ex-si-*

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tu conservative plots were established under the canopies of existing tree stands of the State Forests.

The aim of this study is to determine the effect of canopy openness and shade species on the growth of yews planted in conservation plots.

2. Methods

The study subjects were conservation plots of common yew established in 2008 under the canopies of older classes of tree stands in the forest districts of Rokita, Kołaczyce, Baligród, Henryków and Międzylesie. The only exception was two plots established in the Henryków Forest District made up of small clusters of yew. The conservation plots were located under canopies, which, depending on the stand, were made up of: Scots pine (*Pinus sylvestris* L.), silver fir (*Abies alba* Mill.), European beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.) Karsten), pedunculate oak (*Quercus robur* L.) and grey alder (*Alnus incana* (L.) Moench). Tree stand conditions are presented in Table 1. Five-year-old yew saplings were planted at a density of 1.5 × 1.5 m in all of the 11 plots established in 2008.

The field work, carried out in three consecutive years – 2011 (Rokita), 2012 (Kołaczyce and Baligród), and 2013 (Henryków and Międzylesie), included measurements of he-

Table 1. Locality and characteristics of stands with ex-situ conservation plantations of common yew

Regional Directorate of State Forest	Forest District	Forest Sub-district	Compartemt	Coordinates (longitude, latitude	Forest Site Type *	Tree stand composition**	**Powierzchna (ha)** Area (ha)	**Liczba cisów***** Yew number***
Szczecin	Rokita	Imno	204f	53°42′81″N, 14°43′53″E	BMśw	8So(50)1Św1Brz	2	3000
		Rokita	727a	53°44′76″N, 14°47′35″E	LMśw	10So(43)	0,05	150
Krosno	Baligród	Bystre	49a	49°17′23″N, 22°17′29″E	LGśw	4Jd(108)2Bk(108)1Jd(57)1Bk(57) 1Jd(138)1Jd(78)	0,50	1980
			57Ab	49°17′0″N, 22°18′41″E	LGśw	3Bk(103)1Jd(103)2Bk(143) 2Jd(143)2Bk(63)	0,50	1980
			60Ab	49°16′38″N, 22°17′57″E	LGśw	4Jd(143)4Jd(88)2Jd(67)	0,50	1980
		Roztoki	89a	49°22′8″N, 22°15′14″E	LGśw	5Ol.s(63)5So(63)	0,50	1980
	Kołaczyce	Wola Komborska	57a	49°44′43″N, 21°53′4″E	Lwyżśw	4Jd(81)3Bk(81)1So(81) 1Bk(106)1Jd(106)	0,90	3980
			126d	49°42′44″N, 21°55′7″E	Lwyżśw	4So(61)3Md(61)1Db(61)1Brz(61) 1Jd(61)	1,00	4160
Wrocław	Henryków	Krzywina	85b	50°42′25″N, 17°6′43″E	LMwyżśw	5Db(56)3Św(56)1Brz(56)1Md(56)	0,07	214
		Strachów	121d	50°44′37″N, 16°52′46″E	Lwyżśw	7Św(91),1Db(91)2Św(71)	0,05	184
	Międzylesie	Idzików	34a	50°17′40″N, 16°44′16″E	LMGśw	9Św(90)1Md(90)	0,35	1150

* BMśw – fresh mixed coniferous forest, LMśw – fresh mixed broadleaved forest, LGśw – fresh mountain broadleaved forest, LMwyżśw – fresh upland mixed broadleaved forest, Lwyz św – fresh upland broadleaved forest, LMGśw – fresh mountain mixed broadleaved forest
** So – Scots pine, Św – Norway spruce, Jd – silver fir, Bk – European beech, Ol sz – grey alder, Db – oaks (sessile and pedunculate), Md –European larch. In the brackets – the age of trees is given
*** Total number of yews planted in 2008

Table 2. Height and height increment of yews planted under canopy and canopy openness

Forest District	Compart-ment	Canopy tree species	Height [mm]		Height increment [mm]		Canopy openness [%]	
			average	std err.	average	std err.	average	std err.
Rokita	727 a	So	373,81	10,60	67,37	3,32	33,23	0,45
	204 f	So	506,60	12,96	113,91	4,78	35,23	0,50
Baligród	49a	Jd	225,39	6,68	52,49	2,40	22,19	0,17
	57Ab	Bk	289,26	6,97	60,02	2,39	15,43	0,30
	60Ab	Jd	302,35	7,70	67,32	2,68	19,13	0,28
	89a	Ol-So	237,49	7,92	45,51	2,66	27,06	0,53
Kołaczyce	57a	Jd	325,40	8,07	81,36	3,31	17,74	0,23
	126d	So	465,54	10,96	147,05	4,52	19,55	0,16
Międzylesie	34a	Św	257,77	8,08	65,73	2,88	20,42	0,12
Henryków	121d	Św	322,62	12,82	81,30	5,18	43,40	0,48
	85b	Db	507,10	19,29	127,57	5,65	40,74	0,56

* So – Scots pine, Św – Norway spruce, Jd – silver fir, Bk – European beech, Ol – black alder, Db – oaks (sessile and pedunculate)

ight and the height increment of the main shoot of 200 current, 2-year-old and 3-year-old yew saplings in each plot (to the extent that such an amount was confirmed). Additionally, we also assessed the morphological form of the yews and prevailing light conditions in the stands where the yews were planted. The latter of these tasks was performed using a Nikon D5000 camera with a Sigma 4.5 mm F2.8 EX DC 'fisheye' lens, enabling photographs to be taken of the forest canopy at a 180° angle. The camera was on a tripod, positioned above the saplings with the plane of the lens (top lens) positioned horizontally (Strzeliński 2006). To achieve this, we used a tripod head equipped with a level. The camera was placed at a height of 130 cm above the ground. Photos were taken when the sky was cloudy or at dawn. Exposure settings were manually adjusted (Bolibok 2010a, 2010b). The hemispheric photos were analysed using the Gap Light Analyser programme (Frazer et al., 1999). The hemispheric photographs were classified on the basis of separating the pixels in the matrix into open ones (sky) and those obscured by the tree canopy (Frazer et al. 1999). The canopy openness factor was calculated as the ratio of the total amount of open space to the total area of the canopy (Matusz 1960; Frazer et al. 1999).

In order to be able to compare the height results collected in three consecutive seasons, we used retrospective data on yew growth from 2011. Thus, from the height results obtained in 2012 and 2013, we subtracted the growth attained by yews from one and two years earlier, respectively. To assess the impact of the main species represented in the tree stand (quality predictor) on yew height and height increment, while taking into account canopy openness (continuous variable), the correlation was determined by using the one-way analysis of covariance (ANCOVA) and Tukey's *post-hoc* test. The Statistica 10 programme was used for the calculations.

3. Results

The height attained by yews in individual conservation plots varied and ranged from 225 mm in compartment 49a of the Baligród Forest District to 507 mm in compartment 85b of the Henryków Forest District. The general growth trend reflected the height increments attained by yews in 2011, where the average ranged from 45 mm in compartment 89a of the Baligród Forest District to 147 mm in compartment 126d of the Kołaczyce Forest District (Table 2).

Stand canopy openness was on average from 15% in area 57Ab of the Baligród Forest District to 43% in area 121d of the Henryków Forest District (Table 2). The significance of the linear correlation between stand canopy openness and height of the yew ($r = 0.2637$, $P < 0.0001$) and its height increment ($r = 0.1709$, $P < 0.0001$) indicates that the transmission of light through the trees is one of the important factors influencing the growth of yew, though not the only one. In general, the higher the ratio of stand canopy openness, the greater the increase in the height increment of the yew.

The results of the ANCOVA confirm this relationship and the significant influence of the species forming the canopy on the height of yews (Table 3). In order to correct for the influence of stand canopy openness, its average value was used and the average height was estimated of the saplings under the canopies of specific species (Fig. 1).

Table 3. Results of covariance analysis (ANCOVA) of height of yews

Features	SS	Degree of freedom	MS	F	*p*
Absolute term	262730412	1	262730412	10786,19	<0,0001
Canopy openness	4965056	1	4965056	203,84	<0,0001
Canopy tree species	13427244	5	2685449	110,25	<0,0001
Error	53027462	2177	24358		

Table 4. Analysis of covariance (ANCOVA) between the height increment of yews and canopy openness and canopy tree species

Features	SS	Degree of freedom	MS	F	p
Freedom word	14937456	1	14937456	4733,786	<0,0001
Canopy openness	241300	1	241300	76,470	<0,0001
Canopy tree species	1154173	5	230835	73,153	<0,0001
Error	6869521	2177	3155		

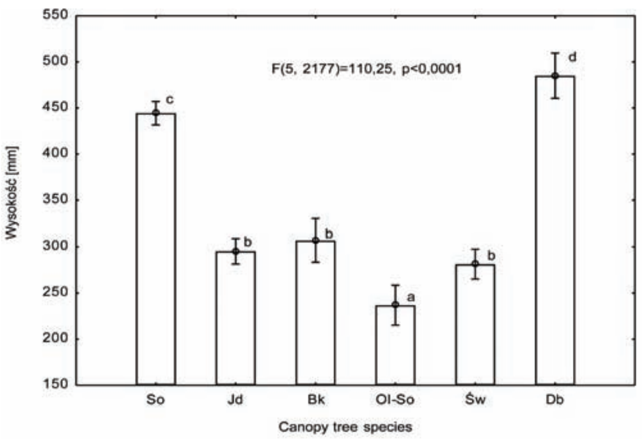

Figure 1. Height of yews under canopy of different tree species (expected value). The same letters show no statistically significant differences (the Tukey's test): So – Scots pine, Św – Norway spruce, Jd – silver fir, Bk – European beech, Ol – alder, Db – oaks (sessile and pedunculate)

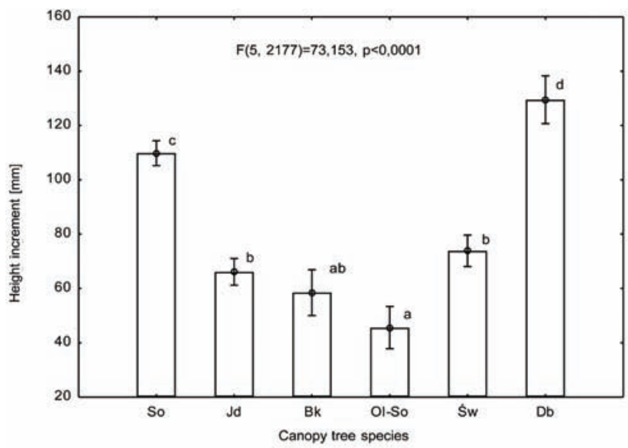

Figure 2. The height increment of yews under canopy of different tree species (expected value). For others symbols see the Figure 1.

The Tukey's *post-hoc* test showed that the best growing conditions for yew are in oak stands, and next in Scots pine. Growth is moderate in beech, fir and spruce, and the weakest in the alder-pine stand (Fig. 1).

The ANCOVA performed for height increment in yews in 2011 showed trends similar to those found for height (Table. 4). Tukey's test showed four homogeneous groups and oak as having the best influence as a canopy species in contrast to the alder-pine stand, under which yews exhibited the least growth and the lowest annual height increment (2011) (Fig. 2).

The morphological form of yews in the conservation plots was predominantly treelike, although the proportion with which this form occurred in specific plots was varied. The smallest percentage of treelike individuals was in the Henryków and Rokita Forest Districts (Fig. 3). The correlation between the proportion of tree-like individuals and average stand canopy openness was negative and statistically significant. This means that as the amount of light passing to the forest floor increases, the number of tree-like individuals decreases in favour of shrub-like yews (Fig. 4).

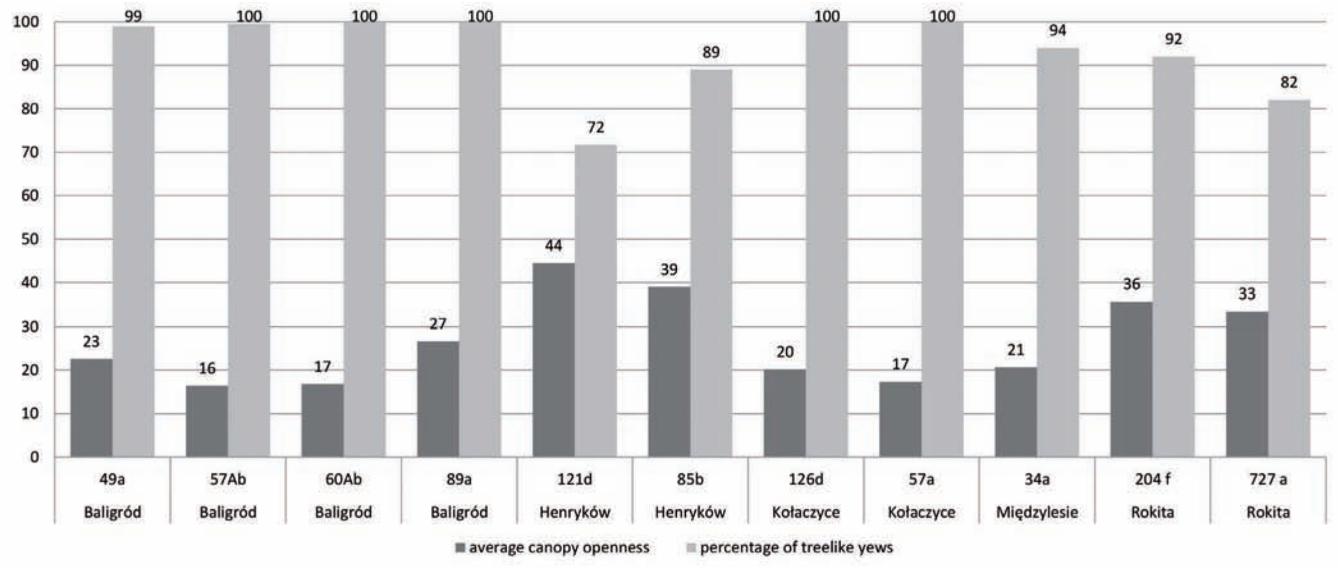

Figure 3. Percentage of treelike yews in studied plantations and average cannopy openness of stand

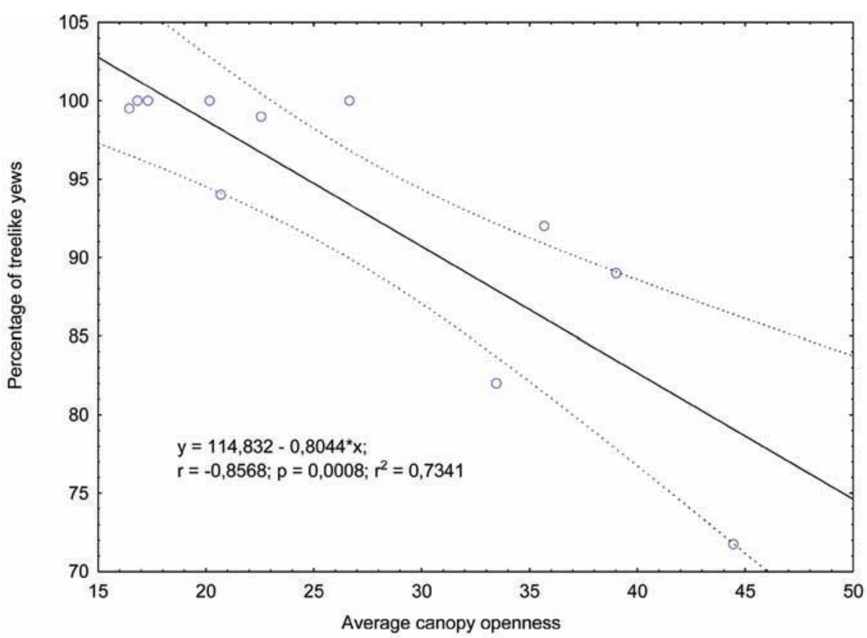

Figure 4. Correlation and regresion of percentage of treelike yews and canopy openness (statistically significant differences at the level 0.05)

4. Discussion and conclusions

Yew is a species very sensitive to light conditions. On the one hand, better growth parameters are achieved in stands where more light reaches the forest floor, while on the other hand, more access to light results in a greater proportion of yews with a shrub-like form. It is therefore difficult to determine optimal light conditions. It depends on the purpose for which the yews are being produced, but still, the transmission of light in the stand should not be less than approximately 30%. Helberg's research (1997) indicates that there is a linear dependence between the height increment of yews and the amount of light. This relationship is observed up to a range of 60% of full light, after which, the growth rate of the yew decreases. The provision of more light (over 80% of full light) does not increase the yew's rate of growth. Our study also found this relationship to be positive and statistically significant. Establishing a 30% or slightly higher canopy openness is related to the growth rate of yews in their earliest phase of development. The higher it is, the faster the seedlings emerge, overcoming the direct competition of herbaceous vegetation and tree seedlings of faster growing species (Czartoryski 1975), as well as the pressure of game animals. Köpp and Chung (1997), who studied seedlings growing under different light conditions (0.3%, 3%, 8%, 30%, 60%, and 100%), also determined a level of 30% as the optimal light intensity. These authors observed a similar tendency as the one described in our study, where the proportion of shrub-like yews increased with greater access to light. According to Muhle (1979), yews achieve the best health and longevity at a light level of 30%, whereas they have significantly less resistance to frost as the amount of shade increases.

According to Król (1975), certain conditions must be met for a yew to grow into a tree with a straight trunk, primarily, a long period of growth in more or less evenly distributed light. In order for yews to reach the sapling stage, it is best to weakly thin the tree stand canopy at a frequent rate. For this reason, dense tree canopies transmitting little light, such as those found in the forest districts of Baligród, Międzylesie and Kołaczyce, should be weakly thinned to open up the canopy.

The study shows that oak and pine canopies provide good conditions for the regeneration of yew, and to a lesser extent, spruce, fir and beech. The least appropriate among the species considered in this study for the growth and development of the yew is the alder-pine canopy. Partially convergent information can be found in Krysztofik's research (1983), conducted in the habitat conditions of the Świętokrzyskie Mountains, who found pine, spruce, larch, sycamore, maple, linden, birch and alder as favourably affecting the height increment of yew, while beech, hornbeam, ash and fir were unfavourable. However, these data are contrary to what Szafer (1913) found in the Kniaźdwór Reserve, where many yews were developing under a canopy of beech and fir. The work of Tomanek and Witkowska–Żuk (2008) provides information about weakly regenerating yews in the alders of the Tuchola Forest. Iszkuło and Boratyński (2004) write about the most abundant occurrence of regenerating yews (2-year-old seedlings) under a canopy of coniferous species, as well as under a canopy of lime and hornbeam.

The information presented here, often contradictory, highlights the gaps in knowledge about the ecology of the common yew. In order to preserve the yew in Poland and to promote its presence in forests, foresters should focus on measures promoting the active protection of this species, those that have already been undertaken, as well as new activities based on the experiences gained thus far.

The results of the measurements and observations conducted in this study should be considered as an introduction to a wider debate on the environmental determinants of producing common yew in forests. Based on information obtained from the inventory of 11 conservation plots of various forest districts in Poland, we can conclude that:

– adequate height increment and development of the yew in a tree stand requires the provision of moderate light transmission through the canopy, maintained at a stable level of about 30%;

– the percentage of shrub-like yews increases in direct proportion to an increase in stand canopy openness;

– when the tree stand canopy is very dense, with an openness remaining well below 30% (20% or less), height increments of yew seedlings are small, which prolongs the period of direct competition with small trees and herbaceous vegetation;

– the height increment of yews is greatest under a tree stand canopy of oak or Scots pine, and then spruce, fir and beech.

Conflict of interest

None declared.

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References

Bolibok L. 2010a. Sprzęt i ekspozycja zdjęć w fotografii hemisferycznej w badaniach leśnych [Equipment and photo exposure in hemispherical photography in forest research]. *Leśne Prace Badawcze* 71 (1): 105–115.

Bolibok L. 2010b. Zastosowanie zdjęć hemisferycznych do opisu struktury warstwy koron i modelowania warunków świetlnych pod okapem drzewostanów [The use of hemispherical photographs for canopy description and light condition modeling in tree stands]. *Leśne Prace Badawcze* 71 (2): 175–188.

Czartoryski A. 1975. Opieka nad cisem i jego ochrona, in: Cis pospolity (*Taxus baccata* L.). PWN, Warszawa-Poznań: 141–166.

Dobrowolska D.,Olszowska G., Niemczyk M. 2012. Struktura drzewostanów a populacje cisa pospolitego (*Taxus baccata* L.) w rezerwatach przyrody „Cisy Rokickie" i „Bogdanieckie Cisy" [Stand structure and populations of yew (*Taxus baccata* L.) in the Cisy Rokickie and Bogdanieckie Cisy reserves]. *Leśne Prace Badawcze* 73(4): 313–322.

Frazer G.W., Canham C.D., Lertzman K.P. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Burnaby, British Columbia, Simon Fraser University. 1–36.

Helberg U. 1997. Analyse der Konkurrenz zwischen Eibe und Eiche in der Jugendphase um den Faktor Licht. Dipl. –Arbeit., Univer. Gottingen.

Iszkuło G., Boratyński A. 2004. Interaction between canopy tree species and European yew *Taxus baccata* (Taxaceae). *Polish Journal of Ecology*, 52(4): 523–531.

Köpp R., Chung D.J. 1997. Entwiclung von Eibenjungpflanzen (*Taxus baccata* L.) in einem Beschattungsversuch. *Forstarchiv* 68: 24–29.

Król S. 1975. Zarys ekologii, in: Cis pospolity (*Taxus baccata* L.). Warszawa-Poznań, PWN: 78–103.

Krysztofik E. 1983. Kłopoty z restytucją cisa w lesie. *Las Polski* 5: 27–30.

Matusz S. 1960. Metoda określania ażurowości pułapu drzewostanu. *Prace Instytutu Badawczego Leśnictwa*, 202. 1–80.

Muhle O. 1979. Ruckang von Eiben-Waldgeselschaften und Moglichkeiten ihrer Erhaltung; in Willmans O., Tuxen R. (ed.). Werden und Vergehen von Pflanzengesellschaften. Vaduz, Cramer: 483–501.

Namvar K., Spethmann W. 1986. Die Eibe (*Taxus baccata* L.). Allg. Forst. Zeitsch, 23: 568–571.

Seneta W. 1981. Dendrologia. Warszawa, PWN. 1-568. ISBN 8301022493.

Sokołowski A. W., Grzywacz A., Gutowski J.M., Farfał D., Dobrowolska D., Zachara T. et al. 2000. Ekspertyza ochrony cisa oraz opracowanie założeń krajowej strategii ochrony tego gatunku. Instytut Badawczy Leśnictwa, maszynopis. p. 157.

Strzeliński P. 2006. Zastosowanie zdjęć hemisferycznych w badaniach ekosystemów leśnych. *Roczniki Geomatyki* 4, 2: 103–112.

Szafer W. 1913. Cisy w Kniaźdworze pod Kołomyją jako ochrony godny zabytek przyrody leśnej. *Sylwan* 31: 447–452.

Szeszycki T. 2013. Cis pospolity (*Taxus baccata* L.) historia, ochrona, hodowla, przyszłość. Szczecin, SoftVision. ISBN 978-83-61070-60-3.

Tomanek J., Witkowska-Żuk L. 2008. Botanika leśna. Warszawa, PWRiL. ISBN 978-83-09-01018-0.

Włoczewski T. 1968. Ogólna hodowla lasu. Warszawa, PWRiL. 1–373.

Zachara T., Łukaszewicz J. 2002. Propozycje postępowania hodowlanego z cisem (*Taxus baccata* L.) w lasach. *Sylwan* 4: 5–16.

Authors' contribution

M.N. – wrote the manuscript, collected data, developed field data, performed the statistical analysis; A.Ż. – collected and worked on the data; P.W. – worked on the data.

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