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CHANGES OF POPULATION STRUCTURE OF *TAXUS BACCATA* L. DURING 25 YEARS IN PROTECTED AREA (CARPATHIANS, WESTERN UKRAINE)

ABSTRACT: The aim of the study was to assess the present state of the *Taxus baccata* L. population in the Knyazhdvir Nature Reserve (West Ukraine) and to analyse the population structure changes that had occurred during 25 years. We found the tendency towards population ageing but with relatively numerous young individuals and seedlings. Surprisingly, specimens with bi- or trifurcate trunks (polycormic) were significantly thicker than those with single trunks (monocormic). This attests to some kind of dominance of polycormic specimens over monocormic ones.

KEY WORDS: *Taxus baccata,* population structure, population dynamics, plant protection, Ukraine

1. INTRODUCTION

Taxus baccata L. occurs in the West and South Europe and prefers temperate climatic conditions of Atlantic character (Meusel *et al.* 1965, Ellenberg *et al.* 1991, Zarzycki *et al.* 2002). It belongs to rare and endangered species in Central- and East-European countries, also in Ukraine (Kontny 1937, Czartoryski 1978, Stoyko and Tasenkevich 1996,Thomas and Polwart 2003). Numerous and regenerating populations of the species are rare, mostly due to land-use (e.g. Köpp 1991, Seidling 1999). In that context the very numerous and dynamically regenerating population of *T. baccata* in Knyazhdvir is an exception. It is located on the slopes along the Prut River at Knyazhdvir near Kolomya (Western Ukraine), just at the continental limit of the species geographical range (Meusel *et al.* 1965). Nevertheless, it has been described as the largest yew population in the Ukrainian part of the species range (Szafer 1913, Stoyko and Tasenkevich 1996, Boratyński *et al.* 2001).

The nature reserve was established in the early 20th century to protect this yew locality (Szafer 1913, 1932, Wróblewski 1921, Boratynski *et al.* 2001). Other 12 rare and endangered vascular plant species were reported from the protected territory of Nature Reserve (Szafer 1913, Boratyński *et al.* 2001, Shums'ka and Pryazhko 2003).

During the inventory of yew specimens in the reserve, carried out in 1976 by Lucak, 22 865 yew trees higher than 1.5 m were recorded (after Boratynski *et al.* 2001), while Prikhodko and Parpan (2000) found only 15 100 such individuals. The detailed inventory made in 1976 on 1 hectare reported on 748 specimens higher than 1.5 m, but most of them were less than 10 cm across

(diameter at breast height, d.b.h.) and 3 m high. The age, height and thickness structure of the population was diversified and characterized by dominance of young individuals, similarly as in other localities in the central Europe (e.g. Gieruszyński 1961, Król 1986, Gumińska and Marecka 1991, Saniga 2000, Bodziarczyk and Zator 2002). A numerous young generation, including about 13 500 of *T. baccata* seedlings and saplings, was found on the sample plot, but spontaneous regeneration was observed quite all over the reserve. The growth and increment of the seedlings was described as very intensive, predominantly without visible injuries. Unlike in many other localities (Boratyński *et al.* 1997, Tobolski 2002), the young specimens had not been damaged by herbivores, so their condition was usually good.

The height and diameter structures of the yew stands, both natural and secondary, have been described several time (e.g. Gieruszyński 1961, Król 1986, Boratyński *et al.* 1997, Svenning and Magård 1999, Thomas and Polwart 2003, Iszkuło and Boratyński 2005). The structure of natural numerous populations of the species, the closest to Knyazhdvir, were described from the West Carpathians in Poland (Gumińska and Marecka 1991, Bodziarczyk and Zator 2002) and in Slovakia (Saniga 2000). The changes of the stand structure during decades have not been analysed. The aim of this study was to determine what changes took place in the height and thickness structure of the population over the last 25 years.

2. STUDY AREA

The study was performed in the Knyazhdvir (Kniaździwór) Nature Reserve in West Ukraine, at longitude and latitude 24°50'05" and 48°30'41", respectively. It is located at the North-Eastern Carpathians foothills, on the north-facing slopes above Prut river, at elevation of 320–460 m (Szafer 1913, Boratyński *et al.* 2001) (Table 1). Geologically the slopes are composed of Neogene sandstones covered with Pleystocene deposits, mostly loams and/or sandy-clays. It is undercut by Prut river, with exposures of several water-bearing horizons. The steepness and permanent water logging of the slopes are the reason of landslides. The brown or slightly acid brown soils, frequently leached and permanently humid, predominate within the nature reserve (Boratyński *et al.* 2001). The soils are fertile and form the favorable conditions for the forest vegetation.

The broadleaved forests of *Querco-Fagetea* class, intermediate between alliances of *Fagion sylvaticae* and *Carpinion betuli*, cover the area under study. *Fagus sylvatica* L. and

Table 1. Long-term studies of *Taxus baccata* in the Carpathian foothills; characteristics of sampled plots for 2001.

Plot no.	Exposure	Inclination	Canopy trees	Undergrowth	% of canopy closure
1	NNE	15–20°	*Fagus sylvatica, Abies alba, Picea abies*	*Taxus baccata, Abies alba, Fagus sylvatica, Corylus avellana, Cornus sanguinea, Sambucus nigra, Acer campestre, Acer platanoides*	96–100
2	NNE	10–20°	*Fagus sylvatica, Picea abies, Acer pseudoplatanus, Cerasus avium*	*Taxus baccata, Abies alba, Corylus avellana, Sambucus nigra, Acer pseudoplatanus*	81–95
3	NNE	10–15°	*Fagus sylvatica Acer pseudoplatanus, Abies alba*	*Taxus baccata, Abies alba, Fagus sylvatica, Acer pseudoplatanus, Corylus avellana*	75–80

Abies alba Mill. form the two-stored stand with single participation of *Acer pseudoplatanus* L., *A. platanoides* L., *Picea abies* (L.) H. Karst., *Carpinus betulus* L., sometimes also with *Cerasus avium* (L.) Moench (Table 1). The beech is about 100–110 and European silver fir 90–100 years old. The first detailed description of the stand with yew in Knyazhdvir (Szafer 1913) suggested that it was a remnant of the primeval Carpathian forest. It was partly cut down in the first years of 20th century and than injured during the First World War (Boratyński *et al.* 2001). Presently *Taxus baccata* occurs frequently in the second layer of the stand.

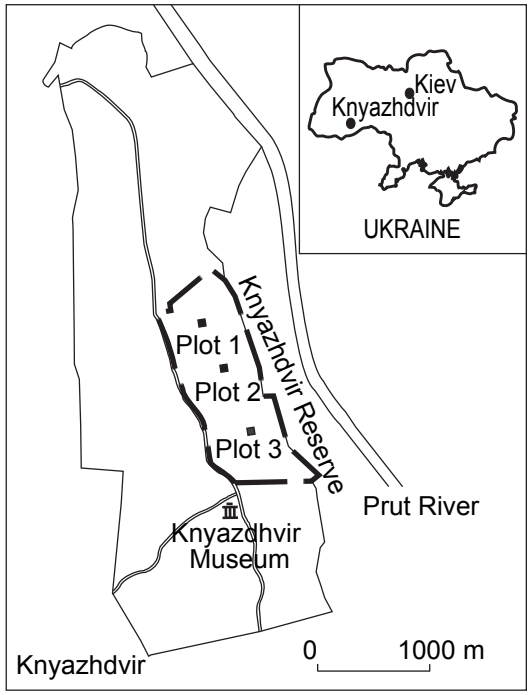

Fig. 1. The scheme of Knyazhdvir nature reserve with location of plots

The sub-canopy shrubby layer is developed in some places. It is composed of *Corylus avellana* L., *Euonymus europaea* L., *Sorbus aucuparia* L., *Sambucus racemosa* L. and *Daphne mezereum* L. At the forest bottom species characteristic for Carpathian beech wood, as *Dentaria bulbifera* L., *Salvia glutinosa* L., *Euphorbia amygdaloides* L., *Festuca gigantea* (L.) Vill. and *Senecio ovatus* (P. Gaertn., B. Mey. & Scherb.) Willd., grow together with commonly occurring in the hornbeam woods, as *Asarum europaeum* L., *Pulmonaria officinalis* L., *Hepatica nobilis* Schreb., *Lathyrus vernus* (L.) Bernh., *Hedera helix* L., *Carex digitata* L and other (Szafer 1913, Boratyński *et al.* 2001, Shums'ka and Pryazhko 2003).

3. MATERIAL AND METHODS

The census and measurements of *Taxus baccata* specimens were made on three plots 50 m × 50 m (Fig. 1, Table 1), established in 2001 in approximately the same place where Lucak's inventory (in Boratyński *et al.* 2001) was made in 1976, each in slightly diversified light conditions. The plots were divided into subplots 10 m × 10 m.

Table 2. The average numbers, heights and diameters of *Taxus baccata* specimens on sampled plots – data for 2001.

Plot no.	Number of specimens per 1 ha	Statistics	Characters		
			Height (m)	Diameter at base (cm)	Diameter at breast height (cm)
1	1036	Arithmetical mean	4.15	9.32	7.65
		Standard deviation	2.87	6.36	5.29
		Maximum value	12.00	36.00	27.10
2	1016	Arithmetical mean	4.38	9.47	7.06
		Standard deviation	2.47	4.97	3.90
		Maximum value	12.20	30.00	19.60
3	1268	Arithmetical mean	2.50	4.06	3.28
		Standard deviation	1.67	3.40	2.97
		Maximum value	12.00	25.00	19.60

The canopy closure was estimated for each subplot 10 m × 10 m separately by evaluation of presence and dimensions of gaps between tree crowns, following the forest methods (Puchalski and Prusinkiewicz 1990). The average canopy closures for each of the three plots were calculated to determine the light conditions of yews.

The individuals higher than 0.5 m (saplings and trees) were listed and measured on the total area of the plots, while seedlings up to 0.5 m high on one subplot of each plot with average canopy density.

The height of young specimens, up to 3.0 m, was measured with a measuring rod, whereas the higher ones with Suunto height meters. For all specimens higher than 1.3 m, diameters at breast (1.3 m) height (d.b.h.) and at the trunk base (D) were measured with the tree calliper. In polycormic individuals, only the thickest trunk was measured at breast height.

The habit and vitality of specimens were determined in the field, according to Król's classification (1986):

The habit:

1 – monocormic (one main trunk without ramification)

2 – polycormic (trunk bi- or trifurcate)

3 – shrub-like

The vitality and health:

1 – no visible necroses and no reduction in number of needles

2 – small necroses and/or slightly reduced number of needles on tops of main branches

3 – large necroses and significantly reduced number of needles on most branches

4 – dead specimen

The plant names follow Mirek *et al.* (2002).

The dependence of height and diameter on the tree habit and degree of canopy closure were analysed with Tukey-Kramer's, *t*-Student's, and χ^2 tests (Underwood 1997, Zar 1999) using of JMP software (SAS Institute).

4. RESULTS

The number of yew specimens on particular plots varied between 1016 and 1268 per 1 hectare (Table 2). The number of individuals depended, at least partly, on their average height, diameter and, consequently, age. The youngest were specimens on plot 3, where the largest number of individuals was recorded. The lowest and thinnest yews dominated there, with only a small number of old ones (Figs 2A and 2B).

The vitality (health) of yew specimens was similar on all plots (Table 3), with a great percentage (22%) of dead specimens on plot 2. There was no interaction between the number of individuals per hectare and vitality ($P > 0.05$, Tukey-Kramer's test).

Monocormic individuals predominated on all three plots (Table 4). The number of shrub-like specimens was low and did not exceed 2.5–3.5%, while individuals with bi- or trifurcate trunks were more numerous.

Diameters of monocormic specimens were statistically significantly smaller than those of ramified ones ($P = 0.01$, *t*-Student's test) (Fig. 3). The average heights of monocormic individuals were slightly smaller than those of specimens with bi- or trifurcate trunks, but the differences (tested with

Table 3. Health classes (according to Król's classification (1986), modified by authors) of *Taxus baccata* specimens in the Knyazhdvir nature reserve – data for 2001.

Plot no.	Frequency (%) of individuals in health classes			
	1	2	3	4
1	31	38	16	15
2	35	30	13	22
3	31	33	22	14

Table 4. Growth habit structure of *Taxus baccata* specimens in the Knyazhdvir nature reserve – data for 2001.

Plot no.	Frequency (%) of individuals in growth habit categories		
	monocormic	polycormic	shrub-like
1	74	24	2
2	81	16	3
3	87	10	3

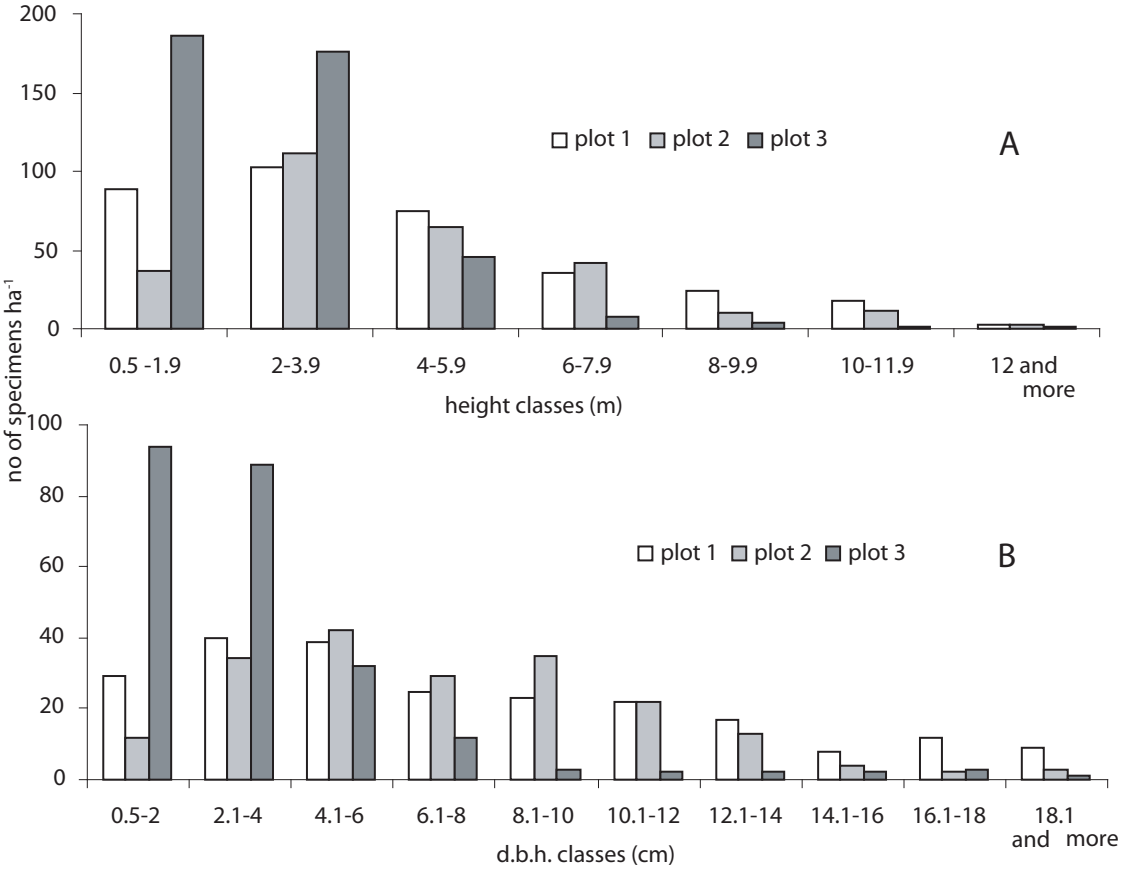

Fig. 2. The height (A) and thickness (B) structures of individuals of *Taxus baccata* higher than 0.5 m in the Knyazhdvir Nature Reserve in 2001

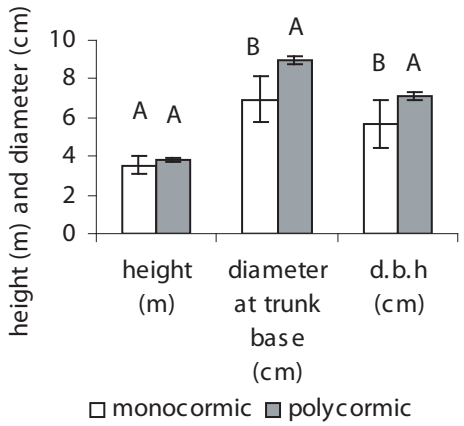

Fig. 3. Mean (± 1 SE) height, diameter at breast height (d.b.h.) and diameter at base of *Taxus baccata* depending on plant habit in 2001; (A–B differences statistically significant at $P = 0.01$, *t*-Student's test)

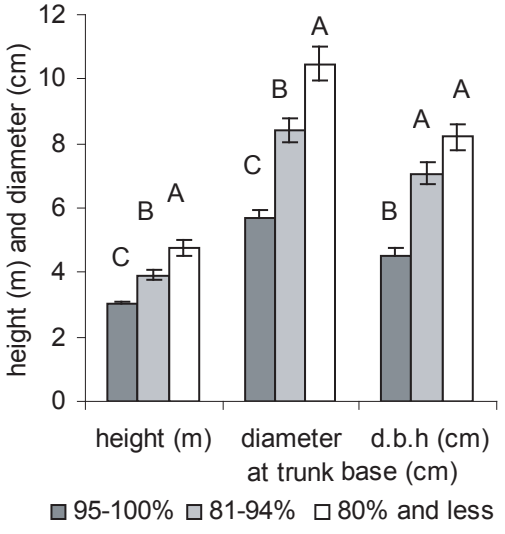

Fig. 4. Dependence of mean (± 1 SE) height, diameter at breast height (d.b.h.) and diameter at base of *Taxus baccata* individuals higher than 0.5 m on degree of canopy closure (%) in 2001 (A–B–C differences statistically significant at $P = 0.01$, Tukey-Kramer's test)

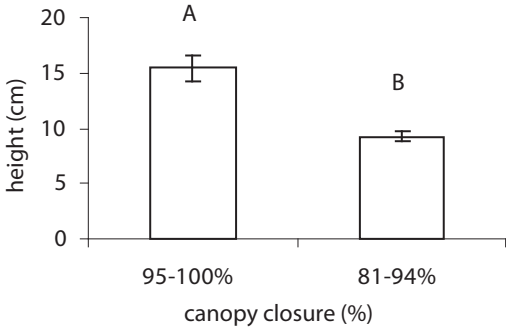

Fig. 5. Dependence of mean (± 1 SE) height of *Taxus baccata* seedlings (to 0.5 m height) on degree of canopy closure (%) in 2001 (A–B differences statistically significant at $P = 0.01$, *t*-Student's test)

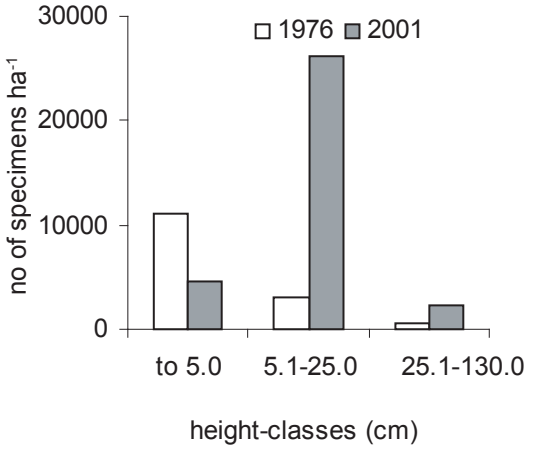

Fig. 7. Comparison of mean numbers of *Taxus baccata* individuals per hectare in 1976 and 2001 in three height classes.

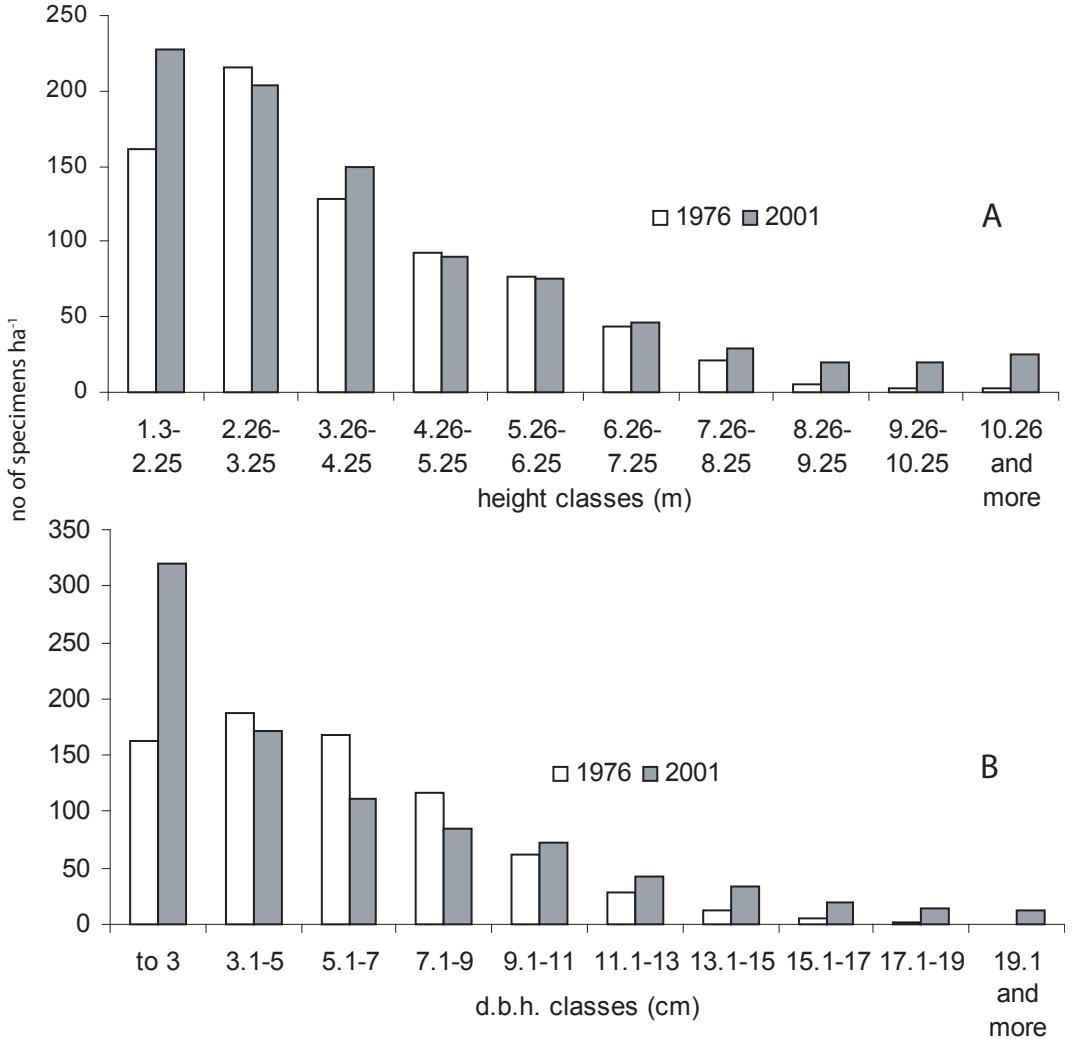

Fig. 6. Comparison of the height (A) and thickness (B) structures of *Taxus baccata* population (excluding seedlings) in 1976 and 2001

t-Student's distribution) were statistically insignificant.

Canopy closure had a significantly negative influence on the height and diameter of individuals higher than 0.5 m (Fig. 4) (Tukey-Kramer's test). An inverse significant relationship was observed in the case of seedlings up to 0.5 m high (Fig. 5) (*t*-Student's test).

The number of yew trees in the younger age classes (height ≤2.25 m, d.b.h. ≤3.1 cm) and the oldest ones (height > 6.25 m, d.b.h. > 9.0 cm) increased considerably, as compared with data from 1976 (Fig. 6A and 6B). The number of specimens in the middle age classes (height 2.26–6.25 m, d.b.h. 3.2–9.0 cm) was lower than 25 years earlier. Nevertheless, the differences between structures of height and diameter in 1976 and 2001 were statistically insignificant ($c^2 = 47.02$ and $c^2 = 99.61$, df = 9, $P = 0.001$, for height and diameter, respectively).

Yew seedlings were abundant on all three plots examined. As compared to data from 1976, a greater number of the youngest seedlings (height ≤5 cm) had been observed in 1976, whereas numbers of middle-aged (height 5.1–25.0 cm) and oldest seedlings and saplings (height <1.3 m) were significantly greater in 2001 (Fig. 7).

5. DISCUSSION AND CONCLUSIONS

Most of individuals on plot 3 represented the lowest height and thickness classes. This type of height and thickness structure indicates that this part of the population was formed in the last few decades. Similar height and diameter structures were also observed in other populations of *Taxus baccata* (Gieruszyński 1961, Król 1986, Boratyński *et al.* 1997, Iszkuło and Boratyński 2005). The height and diameter structure observed on plots 1 and 2 showed that the processes of yew stand regeneration in the whole protected area of the nature reserve took place in various periods and had a wave-like character. It is possible that yew stand regeneration followed thinning of the forest canopy in the past, but lack of evidence of technical interventions in the stand make impossible the more exact interpretation.

The presence of old individuals in the area dominated by young specimens (plot 3) reflects the specific strategy of regeneration, which enables the perpetuation of the species in the same area. The high density of seedlings and saplings growing together with tree-like individuals suggests lack of negative influence of the adult yew trees on the species regeneration. The lack of young individuals under canopy of old *Taxus baccata* trees was reported several times (e.g. Gieruszyński 1961, Boratyński *et al.* 1997, Giertych 2000). The negative or even allelopathic influence of yew trees was also described and commented (Del Moral and Cates 1971, Pelliser and Souto 1999, Thomas and Polwart 2003, Iszkuło and Boratyński 2004). Only in dispersed population of *T. baccata* in Denmark the negative influence has not been found (Svenning and Magård 1999).

Taxus baccata can survive in unfavourable light conditions and compete with other tree taxa for some period of time. When the light conditions improve, it can react by forming new leaves and shoots and regenerate the crown. The yew frequently forms a seedlings bank (Iszkuło and Boratyński 2005), as other shade-tolerant tree species do (Faliński and Pawlaczyk 1991, 1993). The seedlings survive in shady places, tolerate competition with herbs for some time, and – like *Abies alba* (Jaworski 1973) – react by faster growth when conditions become more favourable.

Yew seeds need 1 or 2 years of stratification to germinate (Suszka 1985). Due to this feature, it forms in the soil a seed bank, which can germinate every year. The bank of seeds and seedlings enable yew to colonize favourable ecological microniches in forest communities.

In other parts of the Knyazhdvir Nature Reserve, the height and diameter structure of *Taxus baccata* is much more complex. Individuals of various age, height and diameter grow together, side by side, which indicates that these parts of the population were formed over long time periods.

Large numbers of dead yew trees were observed on plot 2 (Table 3). Several old specimens of *Fagus sylvatica* and *Abies alba* were cut down there and some yews were

injured. Also the rapid change in light, and more probably the thermal conditions, can be a reason of elimination of some specimens of *Taxus baccata*, as was the case in the Cisowy Jar Nature Reserve (NE Poland) in the early 20th century (Iszkuło 2001).

The small numbers of specimens with bi- or trifurcate trunks and shrub-like yews also indicate that the conditions in the Knyazhdvir nature reserve are favourable for *Taxus baccata*. The polycormic individuals were frequently formed as a result of damage of the terminal bud by ungulate browsing or by frost. The polycormic individuals, however, were frequently higher and thicker than monocormic ones. This is probably connected with their larger photosynthetic apparatus, as compared with specimens with single trunks.

In spite of the common opinion that *Taxus baccata* is a shade-loving species (Voliotis 1986, Puchalski and Prusinkiewicz 1990, Ellenberg *et al.* 1991, Zarzycki *et al.* 2002), the average height and diameter of specimens from shadiest places were lower than those of growing in better light conditions (Fig. 4). This confirms that yew saplings grow well only if the amount of sunlight is sufficient (Köpp and Chung 1997, Saniga 2000, Boratyński *et al.* 2001, Iszkuło and Boratyński 2005). Yew seedlings have low light demands and can grow, at least for some years, in very shady conditions, comparable with the seedlings of other tree species, such as Norway spruce (Künstle after Modrzyński 1998), European silver fir (Jaworski 1973), and broad-leaved tree species (Faliński and Pawlaczyk 1991, 1993). But yew seedlings grow very slowly and probably due to this feature they finally cannot compete with seedlings of other trees and with herbs (Iszkuło and Boratyński 2005).

The height and diameter structures of the population of European yew in the Knyazhdvir Nature Reserve are typical for shade-tolerant tree species of terminal phases of succession. The diameter structure of tree-like individuals in the Reserve is comparable with described from other Carpathian populations characterized by dynamic regeneration processes (Gumińska and Marecka 1991, Saniga 2000). The thinnest (young) individuals prevail, while the thickest classes are represented by few or single individuals. The same tendency presents the height structure (Fig. 6). Similar diameter and height structures present also other shade-tolerating trees, as for example *Abies alba* (Jaworski 1973, Filipiak 2002) in dynamically developing stands. The old populations of *Taxus baccata* without saplings are also dominated by thin individuals, but the differences between numbers of thin and thick individuals are much lower (e.g. Gieruszyński 1961, Boratyński *et al.* 1997).

The changes in height and thickness structure of *Taxus baccata* population in the Knyazhdvir Reserve observed between 1976 and 2001 (Fig. 6A and 6B) demonstrate the tendency towards population ageing. The individuals that were in the middle classes of height and d.b.h. in 1976, were assigned to higher classes in 2001. The lower numbers of individuals in the middle classes in 2001 resulted from rather small representation of the lowest class of height and d.b.h. observed in 1976 (Boratyński *et al.* 2001). In 2001 a very numerous young generation was observed, which has the chance to prolong the existence of the species in the reserve. The success of reproduction is also demonstrated by promotion of many seedlings from the first, lowest/youngest class to the next, higher one (Fig. 7). The more limited number of the youngest seedlings in 2001 can be explained by a lower intensity of seed production in the last years (authors' observations during 1994–2000).

The successful natural reproduction and presence of the vigorous young generation is rather rare in other large natural populations of *Taxus baccata* in Europe. The lack of regeneration of natural stands of the species was described in many Central European localities (Gieruszyński 1961, Mańka *et al.* 1968, Findo and Stefančik 1988, Köpp 1991, Hulme 1996, Boratyński *et al.* 1997). The young generation of *T. baccata* in Knyazhdvir is not damaged by herbivores, such as roe-deer and deer, which are considered to be responsible for lack of regeneration in many other localities (Ostrowski 1968, Findo and Stefančik 1988, Hulme 1996). In spite of location on the continental limit of distribution, the climatic and site

conditions of the locality appear favourable for the yew and make possible its ample reproduction. It can be interpreted as an effect of climate warming; this, however, shall be verified in special study.

The good shape of the population, manifested by a generally very good health condition of numerous individuals and dynamic development of the young generation show that this population of European yew is very interesting and important for further studies and shall be carefully protected.

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6. SUMMARY

The structure of *Taxus baccata* population in the Knyazhdvir Nature Reserve (Fig. 1) (West Ukraine) in 2001 was compared with data from 1976. The age structure was different in various part of the Nature Reserve (Fig. 2).

The individuals were vigorous and there was no interaction between the number of individuals per hectare and vitality in three various places in the Nature Reserve (Table 3). Individuals with bi- or trifurcate trunks were significantly thicker (Fig. 3) than those with single trunks (Table 4). The latter were the most numerous in the whole population.

The main reason of deterioration of development of yew seedlings higher than 0.5 m was lack of light (Fig. 4). However, excessive access of sunlight can be also a reason of elimination of the youngest seedlings (to 0.5 m high) (Fig. 5), as they cannot compete with fast-growing herbs and seedlings of broad-leaved trees.

The changes that had occurred during 25 years indicate the tendency towards population ageing (Fig. 6A and B), but with relatively numerous young individuals and seedlings. The numbers of the youngest and oldest individuals found in 2001 increased when compared with data from 1976. Nevertheless, the differences between structures of height and diameter in 1976 and 2001 were statistically insignificant.

The young generation was found as sufficient to prolong the existence of the species in the reserve, however in 2001 the youngest seedlings were statistically significantly less numerous than in 1976 (Fig. 7).

The good conditions of the population, manifested by a generally very good health state of very numerous individuals and dynamic development of the young generation show that this population of the species is very interesting and important for further studies.

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