ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LX 17 Number 6, 2012

PRODUCTION POTENTIAL AND STABILITY OF A BROADLEAVED MIXED OAK/ HORNBEAM FOREST STAND SITUATED ON A EUTROPHIC SITE, ŽDÁNICKÝ LES

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Received: June 14, 2012

Abstract

HURT, V.: *Production potential and stability of a broadleaved mixed oak/hornbeam forest stand situated on a eutrophic site, Ždánický les.* Acta univ. agric. et silvic. Mendel. Brun., 2012, LX, No. 6, pp. 135–144

The paper focuses on assessing the growth and production of a mixed oak/hornbeam forest stand established by combined regeneration in 1940 to 1942. The stand is situated at an altitude of 460 m. Since 1961, it is left to its natural development. The 25–year–old stand was characterized as an individually mixed, both diameter- and height-differentiated pole-stage stand. The proportion of tree species was as follows: sessile oak 77 %, hornbeam 19 %, birch 1 %, lime 1 %, black poplar 1 %, wild cherry tree, wild service tree, and field maple. During 41 years of measurements, the proportion of oak slightly decreased to 76 %, on the other hand, the proportion of hornbeam increased to 22%. The initial growing stock of the 25–year–old stand, 75 $m^3.ha^{-1}$, increased to 323 $m^3.ha^{-1}$ at an age of 66 years in 2008. At present, current volume increment ranged between 6.3 $m^3.ha^{-1}.year^{-1}$ and 11.6 $m^3.ha^{-1}.year^{-1}$ during years 1967 and 1998. Since the age of 61, the growth of the stand has decreased and then even ceased due to increased mortality of oak.

sessile oak, hornbeam, birch, mixed stand, natural development, mortality, production

Among autochthonous species of oak, sessile oak (*Quercus petraea* Matusch) and pedunculate oak (*Quercus robur* L.) are most common in the Czech Republic. Pubescent oak (*Quercus pubescens* Willd.) and turkey oak (*Quercus cerris* L.) can be found in considerably lower proportions in warmer areas. According to Zelená zpráva [Green Report] (Mze, 2010), at present, oak occurs on nearly 7% of timber land, however, its proportion could reach up to 19%.

Oak is our autochthonous broadleaved species being ranked among the most abundant natural components of Central-Europen vegetation. At the same time, it belongs to the economically most important Central-Europen tree species. The sense of its cultivation (even on the most fertile soils) does not consist in the total production of wood. The primary purpose of oak stands is based on the production of quality timber assortments which can be grown on fertile soils at proper tending.

Oak is considered to be difficult to cultivate. Especially, forest tending must not be neglected and exceedingly slender trees or excessive release of stand allowed. In other case, decrease of annual increment of trees and spreading crowns occur. Quality oak stands usually do not occur in monocultures but in mixed stands. Considerable attention has been paid to problems of management of oak in the Czech Republic as well as in European countries. For example, it is possible to mention some monographs: VYSKOT *et al.* (1958), KLEPAC *et al.* (1996) and JOHNSON, SHIFLEY, ROGERS, (2009).

According to GAYER (1898), BOUDRU (1889) and SEKYRKA (1901), the most suitable mixtures for growing valuable oak logs are: sessile oak – beech, sessile oak – hornbeam, pedunculate oak – ash or elm. Moreover, authors recommend mixtures of: spruce – oak, pine – broadleaves (late-flowering

wild cherry and red oak), sessile oak – Scots pine, oak – maple. In uplands, mixtures of sessile oak with larch, beech and silver fir reach above-average yields (LEIBUNDGUT, 1967; KANTOR, HURT, 2003).

Management of mixed stands with sessile oak was studied by many authors, e.g. JACOBEE (1923), ZAKOPAL (1961, 1970), VYSKOT (1962), LANG, MAYER (1968), GADOW (1989), KLÍMA (1990), SCHÜTZ (1994), SANIGA (1999), KADLUS (2005).

ADOMAT (1965), LÜPKE (1982), FREIST (1991), SCHWANECKE (1992), RUHM (1997), VUKELIC, ANIC, (2000), BERGMANN (2003), BILKE, STÄHR (2003), NOACK (2004), OLDENBURG, PETERS, BILKE (2004), AMMER, ZIEGLER, KNOKE (2005) dealt with the establishment and transformation of stands to stands with oak. Problems of the quality of broadleaved stands with oak originated by the combined regeneration (FOLTÝN, 1984) and succession processes (SCHULZ, HEIN, KENK, KLÄDTKE, 2005) were also studied.

Problems of light increment of oak were dealt with by many authors. For example, it is possible to mention WIEHL (1903), ZATLOUKAL (1921), PROCHODA (1931), GROSS (1958), HLADILIN (1960), TRUHLÁŘ (1969), VINŠ, MRÁZ (1973), KADLUS *et al.* (2001), GURA (2010). Research of KADLUS (2005) and KOŠULIČ (2008) was aimed at the management of oak in coppice-with-standards.

Production of mixed stands with oak was studied by KOZAK, HOLUBETS (2001) and the production and development of stands with sessile oak was published by KNOTT, KANTOR (2000), KANTOR, KNOTT, MARTINÍK (2001), KANTOR *et al.* (2002) and KANTOR, HURT (2003).

It is neccessary to mention also papers of other authors aimed at problems of mixed stands and their production: CANNELL *et al.* (1992), KELTY (1992), BARTELINK, OLSHOORN (1999), OLSTHOORN *et al.* (1999), CASPERESEN, PACALA (2001) or LORE *et al.* (2001). The evaluations are based on long-term measurements, sample tests of volume and silvicultural measures in the unique net of pure and mixed research plots.

This brief and incomplete overview of papers indicates the wide range of problems under study.

As indicated above and as it follows from the title of the presented paper the study tries to enlarge and specify our knowledge particularly on production possibilities and stability of mixed oak/hornbeam/lime stands.

Characteristics of an experimental stand

The locality occurs in the cadastre of Dambořice, close to a state motorway from Slavkov near Brno to Kyjov, 4.3 km SE from Nížkovice. The land is administered by Lesy České Republiky (Forests of the Czech Republic, state enterprise), Forest Administration Bučovice.

Forest stand No. 108B7 (year 2012) in Forest District Bílý Vlk originated probably through combined regeneration during years 1940–1942, i.e. in the course of a short regeneration period. The plantation of sessile oak can be considered to be a basis of the stand, in which natural regeneration of many species (hornbeam, lime, birch, wild service tree, wild cherry tree, and black poplar) occurred gradually. For the first 25 years, low thinning measures were primarily applied and later negative crown thinning measures were made.

In 1967, when the stand age was 25 years, the Department of Silviculture (professor Vyskot) of the Faculty of Forestry, University of Agriculture in Brno established permanent thinning plots in the traditional lay-out. The total area of the stand part is 10.26 ha. The stand is situated on a plateau sloping slightly towards SE at an altitude of 400 m (geographical co-ordinates 49°4'43.964" N and 16°56'6.623" E). Mean annual precipitation is 600–650 mm, mean annual air temperature 8–9°C. It refers to a climatic district A3 – warm, slightly dry, with moderate winter (QUITT, 1975). On tertiary alpine furrowed rocks (sandstones, shales), soils of the arenic Pararendzina type have been created (CENIA 2012). From the viewpoint of typology, the stand was classified as a forest type 2H2, i.e. Fageto – Quercetum illimerosum trophicum (Loamy Beech – Oak Forest) with *Vincetoxicum* sp. (management set of stands No. 25).

On research plots (area of each of them 0.25 ha, a series of 4 partial plots 50 x 50 m), low thinning and crown thinning measures are compared in 5-year periods with checkplots left to their natural development (only dead trees are removed). The paper presented summarizes and evaluates only the natural development of Stand No. 108B7 on a check plot without intentional measures, namely in the period of 41 years – from 1967 to 2008.

At the time of establishing the research plots, the 25-year-old stand was characterized as an individually mixed, diameter and height-differentiated pole-stage stand. The proportion of species was as follows: oak 77 %, hornbeam 19 %, birch 1 %, lime 1 %, black poplar 1 %, wild cherry tree, wild service tree, and field maple.

MATERIAL AND METHODS

Methods of the evaluation of growth, development, mortality and production potential of particular experimental stands are uniform within the whole research project being presented in detail in the initial paper in the journal Lesnictví-Forestry (KANTOR, 1997). Therefore, we can give only basic information here. In regular five-year intervals, height, diameter at breast height (DBH), crown height, crown length and crown projection were measured at all trees. Each of the trees is evaluated according to the classification scale of the Department of Silviculture (KANTOR, 1997).

The paper presented evaluates only the check plot, which was left to its natural development without intentional felling measures throughout the study (41 years). The total area of the plot is 0.25 ha (50 × 50 m).

In the 41-year time series of five-year periods (from 1967 to 2008), following parameters were assessed separately in particular species of the mixture: total frequency and mortality of trees, frequency in height and diameter classes, mean stand height, mean DBH, basal area, growing stock, stocking (stand density), species composition. In compiling and assessing evaluative criteria following procedures were chosen:

Mortality (expressed in % of dead trees) in particular intervals of five-year investigations is always related to the frequency of previous measurements. Due to the extent of tables, only the most important results are described in the text.

At the time of the plots establishment in 1967, a series of hornbeam trees survived on check plots as suppressed and subordinate trees which did not reach given input parameters (DBH = 4 cm, h = 4 m). The majority of them died during the next development of the stand and, thus, it was never recorded. However, if some of the trees survived in the competition and reached DBH 4 cm during the five-year checking measurements they were newly included into the evaluation of the check database. Due to the involvement of these trees, the increased number of trees occured in 1972 (see Tab. I and Fig. I).

The stand growing stock and the periodical volume increment derived from it are related only to the dominant stand and the volume of dead trees is not included into the calculation. Stand density was calculated according to standard mensurational practice from the ratio of the actual basal areas of particular species and tabular data. On the basis of reduced areas determined in this way species composition was also determined. On the ground of keeping the comparability with results of studies carried out on these plots in the past, to determine tabular basal areas of sessile oak, wild service tree, lime, and wild cherry tree „Růstové a taxační tabulky" (Growth and mensurational tables) by ČERNÝ, PAŘEZ, MALÍK (1996) were used, and to determine tabular basal areas of other species "Taxační tabulky ÚHÚL" (1990) (Mensurational Tables of the Institute for Forest Management Planning) were used.

On the basis of evaluation described above, the importance and proportion of particular species in the production potential and stability of the studied mixed stand were assessed. Simultaneously, primary data were obtained to fulfil the strategic goal of the whole project, i.e. specification and presentation of the proposal (variants) of the target species composition in the most important management sets of stands of upland regions of the 2nd altitudinal vegetation zone – in the given case for HS 45 (management set of stands No. 25).

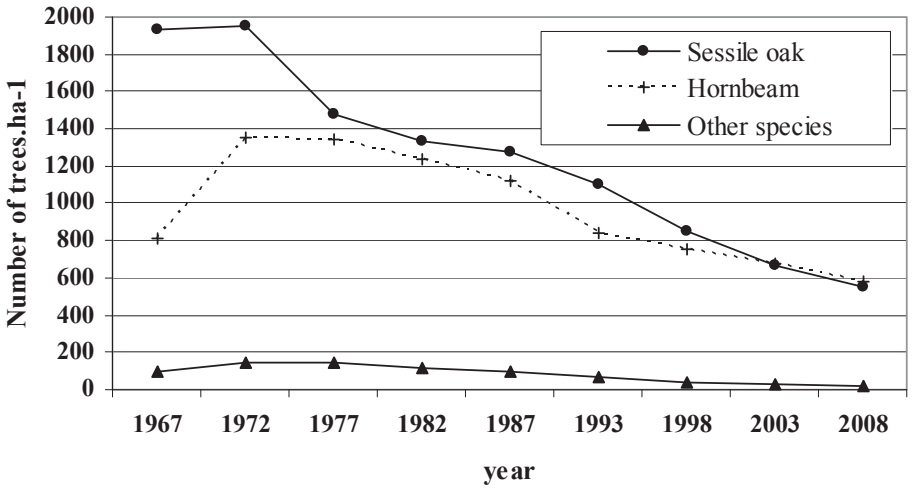
RESULTS

Analysis of the natural development of the forest stand 108B7

Basic characteristics of the stand 108B7 check plot in the year of establishment (1967) are given in Tab. I. At that time (age 25 years), it referred to an individually mixed pole-stage stand with basal area 20.47 $m^2.ha^{-1}$ and growing stock 74.72 $m^3.ha^{-1}$.

Stand density and mortality

The initial stand density in 1967–2 832 trees.ha^{-1} (see Tab. I) at an age of 25 years was slightly lower (KANTOR, SLODIČÁK, 2004) or corresponded to rules for tending oak stands, age (25 years) as well as site and species composition. However, a number of hornbeam, lime and field maple with DBH smaller than 4 cm, which were not included into the check records, survived as subdominant trees (see Methods). Some of the trees reached the value in the course of next 5 years and, thus, the stand density during the second measurement in 1972 was higher by 620 trees.ha^{-1} than at the initial measurement amounting to 3 452 trees.ha^{-1}.



1: *Development of the number of sessile oak and hornbeam trees in stand 108B7 (trees.ha^{-1}) in 1967 to 2008*

During next time periods, however, the stand density naturally decreased due to competition and natural selection down to the present value of 1152 trees.ha^{-1} (natural mortality 67 %) at an age of 66 years in 2008 (see Tab. I and Fig. 1).

The natural development of the number of trees of 2 main species in the stand in the course of evaluated 41 years is also documented in Fig. 1.

The highest total mortality was shown by oak, of the initial number of 1932 trees.ha^{-1} some 1384 trees. ha^{-1} i.e. 72 % died. Similar trends were also noted in shade-tolerant lime: at the first survey 50 trees.ha^{-1}, at the last survey 16 trees.ha^{-1} (mortality 67 %).

Lower mortality was noted in the second main production species of the studied stand, i.e. hornbeam. Through natural development, 228 trees.ha^{-1}, i.e. 28 % gradually died. Similarly as in lime, this natural mortality was exclusively focussed on suppressed subdominant hornbeam trees.

I: *The development of stand basic data on the check plot in 1967–2008*

Species	N	Mean tree			BA (m^2.ha^{-1})	V (m^3.ha^{-1})	Stand density	Species composition (%)
		h (m)	DBH (cm)	V (m^3)				
1967 – 25 years								
Sessile oak	1932	9.0	10.3	0.03	16.51	60.04	0.80	77.0
Hornbeam	808	6.5	6.9	0.01	3.30	11.92	0.20	19.3
Lime	48	6.3	6.4	0.01	0.18	0.56	0.01	1.0
Birch	28	9.8	11.4	0.04	0.29	1.12	0.01	1.4
Black poplar	8	12.8	14.5	0.10	0.13	0.76	0.01	1.0
Wild cherry tree	4	14.1	12.0	0.07	0.05	0.28	0.00	0.2
Wild service tree	4	6.2	6.5	0.01	0.01	0.04	0.00	0.1
Field maple								
Total	2832				20.47	74.72	1.04	100
2008 – 66 years								
Hornbeam	580	13.5	10.1	0.06	5.17	35.44	0.24	22.2
Sessile oak	548	22.9	23.2	0.52	23.99	283.76	0.81	76.1
Lime	16	14.4	13.3	0.14	0.27	2.16	0.01	1.0
Wild cherry tree	4	21.5	21.6	0.34	0.15	1.36	0.01	0.5
Wild service tree	4	16.5	11.5	0.07	0.04	0.28	0.00	0.2
Birch								
Black poplar								
Field maple								
Total	1152				29.62	323.00	1.07	100

Legend:
N – Number of trees per hectare (trees.ha^{-1}),
V – Growing stock (m^3.ha^{-1}),
BA – Stand basal area (b.a.) (m^2.ha^{-1}).

II: *The development of stand basal area on the check plot (m^2.ha^{-1}) and its increase in per cent in 1967–2008*

Species	1967	1972	1977	1982	1987	1993	1998	2003	2008	Increase with respect to the year 1967	
	25 years	30 years	35 years	40 years	45 years	51 years	56 years	61 years	66 years	abs.	(%)
Sessile oak	16.51	19.99	20.48	22.88	25.87	27.53	27.41	25.79	23.99	7.48	145
Hornbeam	3.30	4.31	4.77	5.23	5.58	5.65	5.91	5.98	5.17	1.87	157
Lime	0.18	0.27	0.31	0.26	0.25	0.21	0.24	0.27	0.27	0.09	152
Black poplar	0.13	0.20	0.23	0.26	0.27	0.44					
Birch	0.29	0.37	0.44	0.57	0.60	0.58	0.42				
Wild cherry tree	0.05	0.08	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.10	324
Wild service tree	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.03	310
Field maple		0.01	0.02	0.02	0.01						
Total	20.47	25.25	26.37	29.35	32.72	34.57	34.15	32.21	29.62	9.15	145

III: *The development of growing stock on the check plot ($m^3.ha^{-1}$) in 1967–2008*

Species	1967	1972	1977	1982	1987	1993	1998	2003	2008
	25 years	30 years	35 years	40 years	45 years	51 years	56 years	61 years	66 years
Sessile oak	60.04	93.40	120.08	158.76	209.80	259.40	284.68	288.56	283.76
Hornbeam	11.92	15.68	19.12	22.52	27.88	33.00	36.24	39.04	35.44
Birch	1.12	1.96	2.64	3.76	4.48	4.84	3.88		
Lime	0.56	0.88	1.00	1.00	1.28	1.36	1.68	1.96	2.16
Black poplar	0.76	1.20	1.40	1.76	2.04	3.96			
Wild cherry tree	0.28	0.48	0.68	0.80	1.00	1.12	1.24	1.28	1.36
Wild service tree	0.04	0.04	0.04	0.08	0.12	0.20	0.20	0.20	0.28
Field maple		0.04	0.08	0.08					
Total	74.72	113.68	145.04	188.76	246.64	303.88	327.92	331.04	323.00
Stand density	1.04	1.26	1.26	1.35	1.44	1.43	1.33	1.19	1.07

The frequency of sessile oak, hornbeam, and lime in height and diameter classes

Ecological demands and growing strategies of particular tree species are obvious according to the development of frequency of sessile oak, hornbeam, and lime in height and diameter classes during period 1967–2008 as described in the following text.

An exceedingly broad range of heights of oak from 4 to 15 m already at the establishment of research plots in 1967 documents an important position of the species both as a subdominant, co-dominant as well as dominant tree. The majority of them died already in the course of the first decade in 1967 to 1977.

Simultaneously, a group of co-dominant and dominant oak trees is, however, differentiated in the stand since the first measurements (in 1967, height 8 to 15 m, DBH 10 to 14 cm) forming gradually a basis of the high production and stability of the whole stand. During the last check in 2008, it was possible to include into the group already 124–137 oak trees. ha^{-1} of 21 to 26 m height with DBH 22 to 34 cm.

Hornbeam includes nearly exclusively subdominant trees in the course of the whole period of evaluation. Data obtained during the measurements demonstrate considerable vitality and in the given case also quite extraordinary potential of hornbeam to survive in lower layers. In 1967, the height range of hornbeam was 4 to 12 m and in 1982, some 4 to 14 m. The height range spectrum even increased in next years and in the last check amounted to 4 to 22 m. Only a few hornbeam trees occur as co-dominant trees in recent years. In the course of 41 years of monitoring, particularly subdominat trees and exceedingly slender hornbeam trees with unfavourable slenderness ratio died. Nevertheless, even at an age of 66 years, 170 hornbeam trees.ha^{-1} were registered as overtopped trees (height 4 to 17 m). Therefore, particularly medium values of height and DBH in hornbeam are markedly lower than in oak.

Althoug the amount of lime trees in our study was quite low (88 trees.ha^{-1} in 1972), two growth strategies could be distinguished there. The first strategy includes the long existence of subdominant trees in lower layers of the stand (in some cases for even 20 years). In case of available adequate growing space in the first stage of growth, lime is able to grow and sustains a co-dominant position (20 m in 2008).

Birch and poplar were represented by co-dominant trees. In 1967, diameter range was 8 to 14 cm and heigh diameter 8 to 12 m. According to the last measurement of birch in 1998, its diameter range was 16 to 24 cm and heigh range 20–24 cm.

Stand basal area

Already in previous papers (KANTOR, PAŘÍK, 1998; KANTOR, HURT, 2003), it was stated that the basal area increment dynamics was the most objective criterion for assessing the production potential of particular species in naturally developing mixed stands. The total stand basal area amounting to 20.47 $m^2.ha^{-1}$ in 1961 increased after 41 years 1.5 times reaching 29.62 $m^2.ha^{-1}$. During recent measurements (years 2003 and 2008), a decrease from 34.15 $m^2.ha^{-1}$ in 1998 to 32.21 $m^2.ha^{-1}$and 29.62 $m^2.ha^{-1}$ was recorded. The highest increase of basal area was measured at oak namely from 16.51 $m^2.ha^{-1}$ to 23.99 $m^2.ha^{-1}$, i.e. by 7.5 $m^2.ha^{-1}$. Thus it reached the same value as an increase of the whole stand basal area (see Tab. II). More dynamic increase in basal area was noted in hornbeam and lime, see to 157 % and 152 % (from 3.30 $m^2.ha^{-1}$ to 5.17 $m^2.ha^{-1}$, and from 0.18 $m^2.ha^{-1}$ to 0.27 $m^2.ha^{-1}$).

Growing stock

The growing stock development ($m^3.ha^{-1}$) compiled again according to particular species in five-year intervals is given in Tab. III. Total growing stock increased from the initial 74.72 $m^3.ha^{-1}$ in 1967 to 323.00 $m^3.ha^{-1}$ in 2008. A decrease of growing stock and average annual increment was noticed during recent measurements (1998, 2003 and 2008), as well as at stand basal area.

In absolute values, sessile oak participated in this growing stock increase mostly (283.76 $m^3.ha^{-1}$, i.e. 90 % of the total growing stock). Nevertheless, the dynamics of its mean annual increment (4.9–

6.5 $m^3.ha^{-1}.year^{-1}$) approached the level of oak increment in last ten years (4.7–4.9 $m^3.ha^{-1}.year^{-1}$). In next years, it will be of interest to compare the trend of current increments of both species. The high production potential of the evaluated mixed stand can be exemplified by values of the total current volume increment which ranged from 6.3 $m^3.ha^{-1}.year^{-1}$ to 11.6 $m^3.ha^{-1}.year^{-1}$ during 1967–1998.

Stand density and species composition

Data on the development of stocking and species composition throughout the studied period are given in Tab. I.

The stand can be considered to be fully stocked throughout the period of evaluation. Calculated high values of stocking of the stand at an age of 25 to 56 years (1.26–1.33 corresponded to the situation of the increase and decrease of stand basal area and growing stock. At that time, important part of the stand was created by subordinate exceedingly slender broadleaved species (hornbeam, lime, and birch) with an extremely low basal area. Its value was then markedly overvalued by the method of stocking calculation. In last four inventories, however, calculated stocking amounted to 1.07.

At the initial measurement, the stand was characterized as an individually mixed, diameter and height-differentiated pole-stage stand with the following species composition: oak 77 %, hornbeam 19 %. Birch 1 %, lime 1 %, black poplar 1 %, wild cherry tree, wild service tree, and field maple occurred there as interspersed species.

In next years, the proportion of sessile oak slightly decreased; nevertheless, the species occupied steadily 76 % reduced stand area in recent 15 years. On the other hand, the proportion of the second basic species, i.e. hornbeam gradually increased at all inventories up to 22 % at the present time. Lime, wild service tree, and wild cherry tree show the position of interspersed species at present.

DISCUSSION AND CONCLUSIONS

Results of the study conformable with other studies of our and foreign authors have proved that even a simple and operationally easily manageable mixture of oak and hornbeam fulfils requirements for the high production potential and stability on eutrophic sites of upland regions of the 2nd altitudinal vegetation zone. Moreover, an admixture of other site-suitable species favourably affects biodiversity of these ecosystems.

Problems of the production of mixed stands were already dealt with by HARTIG (1791) in PRETZSCH (2002) and HARTIG (1804). HARTIG (1791) was afraid of significant losses of production of mixed stands and, therefore, suggested the management of monocultures. Contrary to this opinion, COTTA (1828) points out that an effort to reach monocultural stands is based on old and harmful prejudices. Demands of species on space, and nutrients extensivelly differ; therefore, mixed stands are much more suitable for their growth and resistence to insect attack or wind. This statement is supported by GAYER (1886) who declares that mixed stands are able to produce not only more timber but even more valuable industrial wood quality timber than monocultural stands.

ČERNÝ, PAŘEZ, MALÍK (1996) also ascertained that mixed oak/hornbeam stands show increased production in comparison to tabular data of productivity of monocultural oak stands. Our results can be compared only to statements of WIEDEMANN (1942) who mentions that in case of the proportion of oak exceeding 20% the production of mixed oak/beech stands is higher than the production of similar monocultural stands of oak and beech. Also PRETZSCH (2003) mentions the higher produktivity and quality of wood in mixed stands.

During the development of the studied stand from its age of 61 years, the stand increment gradually decreased and then even ceased, which caused decreased values of basal area and growing stock. The increased mortality of oak was considered to be a main factor. BURSCHELL and HUSS (2003) confirmed fluctuations of growth development of mixed beech/oak or oak/pine stands. Despite the temporary decrease of growing stock and basal area, it has been demonstrated that oak is a basic broadleaved species of the target species composition of upland regions. Generally, it is mentioned that the growth of mixed stands is higher than the growth of pure stands (KADLUS, 2001; PRETZSCH, 2005). This process can be logically substantiated by more effective using the mixed stand growth space.

Potentially quality individuals of lime, field maple, and wild cherry tree in a mixture with oak have to occupy the position of an individually admixed co-dominant species. Clump- or group-admixtures are unsuitable from the viewpoint of silviculture. In case of the production of valuable assortments, these species have to be grown from the juvenile age with a sufficient height start as dominant or co-dominant species or even as markedly dominant trees (SCHMALTZ, RIBAS, 2001). Hornbeam and lime are suitable species for treatment purposes and sufficient pruning on these sites. Commonly is present that growth of mixed stands is higher than growth of monocultures (CLARK, 1990; REHFUESS *et al.* (1999); KADLUS, 2001; PRETZSCH, 2005).

From the viewpoint of ensuring all priority functions (production, stabilization, aesthetic) of oak/hornbeam stands, it is possible to recommend the optimum proportion of oak to range from 60 to 80 % and to increase the proportion of valuable broadleaved species up to 20–30 % on mesotrophic sites of upland regions (see Fig. 1 and Tab. I – III).

From the analysis of heigh growth of the mixed oak/hornbeam stand, our results as well as data of POLENO (1980) show that adequate growth space has to be ensured for supressed tree species in early

stages of development. Neglected treatment can not be fully repaired later.

Results achieved have proved the suitability of oak for given sites of the forest type group 2H. Problems were demonstrated to maintain other valuable broadleaved species if their dominant position is not ensured already from the beginning. It has been also proved that it is not possible to take into account longer rotation of silver birch than 60 years even in mixed stands.

On the basis of the development of hornbeam and lime, the ability of shade-tolerant species to survive in lower layers of stands even for decades have been verified which corresponds with results from previous studies (KNOTT, KANTOR, 2000; KANTOR, KNOTT, MARTINÍK, 2001; KANTOR *et al.* 2002; KANTOR, HURT, 2003).

SUMMARY

The paper summarizes and evaluates natural development of the stand control plot 108B7 on a check plot (area of 50 × 50 m) without intentional measures in the period of 41 years –from 1967 to 2008. The stand is situated in the Dambořice cadastre and administered by Lesy České Republiky, state forest enterprise Bučovice.

Forest stand No. 108B7 (in year 2012) in Forest District Bílý Vlk originated probably through combined regeneration during years 1940–1942, i.e. in the course of a short regeneration period. On the research plot (50 × 50 m) periodical surveys are carried out in regular 5–year intervals (only died trees are removed).

From the viewpoint of typology, the stand was classified as a forest type 2H2, i.e. loamy oak/beech forest with *Vincetoxicum* sp. (management set of stands No. 25).

Up to 25 years of the stand age low thinning measures were applied first and later negative crown thinning (aimed at co-dominant and dominant trees). At the time of establishing the research plots, the 25-year-old stand was characterized as an individually mixed, diameter and height-differentiated pole-stage stand neglected from silvicultural aspects. The proportion of species was as follows: oak 77 %, hornbeam 19 %, birch 1 %, lime 1 %, black poplar 1 %, wild cherry tree, wild service tree, and field maple.

In 41 years of the stand age, the proportion of sessile oak slightly decreased, nevertheless, the species occupied steadily 76 % reduced stand area in recent 15 years. On the other hand, the proportion of the second basic species, i.e. hornbeam gradually increased at all inventories up to 22 % at the present time. Lime, wild service tree, and wild cherry tree show the position of interspersed species at present. The proportion of species was as follows: sessile oak 77 %, hornbeam 19 %, birch 1 %, lime 1 %, black poplar 1 %, wild cherry tree, wild service tree and field maple. Typologically, the stand was classified as a forest type 2H2 – loamy Beech/Oak Forest with *Vincetoxicum* sp. (management set of stands No. 25). In next years, the proportion of oak slightly decreased, nevertheless, in recent 15 years this species occupied steadily 76 % reduced stand area. The proportion of the second stand species – hornbeam gradually slightly increased up to present-day 22 % at all inventaries. Lime 1 %, wild cherry tree and wild service tree preserved the position of an interspersed species in the given stand to the present.

The initial stand density in 1967 was 2 832 trees.ha^{-1} (see Tab. I). A number of hornbeam, lime, field maple with DBH smaller than 4 cm, which were not included into the check records, survived as subdominant trees till present (see Methods). In the course of the stand development, the stand density naturally decreased due to competition and natural selection down to the present value of 1 152 trees.ha^{-1} (natural mortality 67 %) at an age of 66 years in 2008 (see Tab. I and Fig. 1). The highest total mortality showed oak tree, of the initial number of 1 932 trees.ha^{-1} some 1 384 trees.ha^{-1}, i.e. 72 % died. Similar trends were also noted in a shade-tolerant lime: at the first survey 50 trees.ha^{-1}, at the last survey 16 trees.ha^{-1} (mortality 67 %). Significantly lower mortality was noted in the second main production species of the studied stand, i.e. hornbeam. Through natural development, 228 trees. ha^{-1}, i.e. 28 % gradually died. Similarly as in lime, this natural mortality was exclusively focussed on suppressed subdominant hornbeam trees.

Since the first measurements, a group of co-dominant and dominant oak trees is differentiated in the stand (in 1967 height 8 to 15 m, DBH 10 to 14 cm) gradually forming a basis of the high production and stability of the whole stand. During the last check in 2008, it was possible to include into the group already 124 out of 137 oak trees.ha^{-1} of 21 to 26 m height with DBH 22 to 34 cm.

Hornbeam includes nearly exclusively subdominant trees in the course of the whole period of evaluation. According to data obtained during measurement, hornbeam is considerable vital and in the given case has also quite extraordinary potential to survive in lower layers. In 1967, the height range of hornbeam was 4 to 12 m and in 1982 some 4 to 14 m. The height range spectrum even increased in next years and in the last check amounted to 4 to 22 m. Only a few hornbeam trees occur as co-dominant trees in recent years. In the course of 41 years of monitoring, particularly subdominat trees and exceedingly slender hornbeam trees with unfavourable slenderness ratio died. Nevertheless, even at an age of 66 years, 170 hornbeam trees.ha^{-1} were registered as overtopped trees (height 4 to

17 m). Therefore, particularly medium values of height and DBH in hornbeam are markedly lower than in oak.

The total stand basal area of year 1961, ie 20.47 $m^2.ha^{-1}$ increased after 41 years 1.5 times, reaching 29.62 $m^2.ha^{-1}$. During recent measurements (years 2003 and 2008), a decrease of stand basal area from 34.15 $m^2.ha^{-1}$ in 1998 to 32.21 $m^2.ha^{-1}$a 29.62 $m^2.ha^{-1}$ was recorded. The highest increase of basal area was measured by oak, from 16.51 $m^2.ha^{-1}$ to 23.99 $m^2.ha^{-1}$, i.e. to 7.5 $m^2.ha^{-1}$ which represents the same value of increase of stand basal area (see Tab. II). More dynamic increase in basal area was noted in hornbeam and lime, see to 157% and 152 % (from 3.30 $m^2.ha^{-1}$ to 5.17 $m^2.ha^{-1}$, and from 0.18 $m^2.ha^{-1}$ to 0.27 $m^2.ha^{-1}$).

Results of the study have confirmed that oak is suitable for sites of forest type 2H. Problems related to the preservation of supressed broadleave species (lime, wild cherry tree, wild service tree), and neccessity of suitable growth space for them from the first growth stage have been proved. According to the results, even in mixed stands, birch can not be expected to reach rotation period above 60 years. On the basis of development of hornbeam and lime, the ability of shade-tolerant species to survive in lower layers of stands even for decades has been verified.

Acknowledgement

The paper was worked out within support of the project of The Ministry of Agriculture of the Czech Republic NAZV No. QI102A085 “Optimization of silvicultural measures to increase biodiversity in commercial forest”.

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