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Production potential and ecological stability of mixed forest stands in uplands – VI. A beech/larch stand on a mesotrophic site of the Křtiny Training Forest Enterprise

V. Hurt, P. Kantor

Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry Brno, Brno, Czech Republic

ABSTRACT: The paper is the 6th report on the production potential and stability of mixed forest stands in uplands. A mixed beech/larch stand that was established by natural regeneration in 1934 to 1942 is assessed. The stand is situated at an altitude of 460 m above sea level. It has been left to its natural development since 1961. At that time, the stand was characterized as an individually mixed, diameter- and height-differentiated 25-year pole-stage stand. The proportion of larch and beech amounted to 40% and 17%, respectively. Hornbeam (25%), oak (11%) and to a lesser extent birch (5%) and spruce (3%) also occurred in the stand. In the course of 42 years, the proportion of larch in this stand without planned thinning measures decreased to 35%. On the other hand, the proportion of beech increased to 39%. During all 5-year inventories, the stand could be characterized as a stabilized one with high production potential. Its initial growing stock 63 m^3/ha at an age of 25 years increased to 497 m^3/ha at an age of 67 years in 2003. At present, current volume increment amounts to 9.8 to 12.5 m^3/ha/year.

Keywords: beech; larch; oak; hornbeam; mixed stands; natural development; production; mortality; slenderness ratio

Nine years ago, in 1997 the project *Production and ecological stability of mixed stands under anthropically influenced conditions of uplands as a basis for the proposal of target species composition* was presented in the Journal of Forest Science (Lesnictví-Forestry), No. 4. Results of the production potential and stability of five experimental stands in the Křtiny Training Forest Enterprise (TFE) were gradually analyzed in five studies (Kantor, Pařík 1998; Knott, Kantor 2000; Kantor et al. 2001; Jelínek, Kantor 2001; Kantor, Hurt 2003).

The presented sixth contribution evaluates the growth, development, production and stability of a mixed 67-year beech/larch stand on a mesotrophic site. In the stand, other four species (oak, hornbeam, birch, spruce) at important proportions are recorded as interspersed species. Based on the papers published so far, in the majority of sites of the 2nd and the 3rd forest vegetation zone of the Křtiny TFE, the extremely high vitality, stability and production potential of beech have been proved. Beech showed itself as the main autochthonous broadleaved species of target species composition.

European larch (*Larix decidua* Mill.) has a different position in the Křtiny TFE. It is not an autochthonous species there and its planting and growing started in the 70s of the 18th century (Opletal 1948; Nožička 1957; Truhlář 1999). In the course of about 250 years, the species has become an important and integral component of local forest ecosystems with quite exceptional production, stabilization and aesthetic position. In forestry groups of the whole Europe, it is known as the "Adamov population of larch" (according to one of the municipalities of the region).

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Particularly in mixed stands with beech, its production potential is unique. Data from "Haša's Sanctuary" are generally known and cited in forestry literature (Kantor et al. 2005). This overmature mixed beech/larch stand, registration No. 152C17, Forest District Habrůvka, is 175 years old at present. It serves as a recreational and educational area. With the mean height of beech 40 m and of larch 48 m its respectable growing stock amounts to 1,250 m^3/ha and current volume increment 11.4 m^3/ha/year.

However, interesting data on mixed beech/larch stands from other regions of the Czech Republic are available in older papers of Tichý (1949), Málek (1967) and Zakopal (1970). Important data on this mixture were published in papers of Šindelář (1977, 2000). In European literature, considerable attention is also paid to mixed beech/larch stands. Lüdemann (1990), Freist (1991), Schwanecke (1992) and Moser (1995) recommended to establish mixed stands of this type. Production potential was studied in papers of Bachmann (1967) and Preuhsler and Mayer (1992), stability in studies of Städtler (1991, 1995) and Duchiron (2000), competition relationships of both species were analyzed by Dippel (1988), Roth (1992), Guericke (2001), etc. From the aspect of the age and spatial structure of forest ecosystems the position of beech and larch was assessed by Burschel (1987), Seitschek (1989, 1991), Kenk (1992), Smaltschinski (1990), etc. 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 of production possibilities and stability of mixed beech/larch stands.

MATERIAL

Characteristics of experimental stand

Stand No. 131 F17/7b originated through natural regeneration of six tree species, viz beech, larch, oak, hornbeam, birch and spruce in 1934 to 1942, i.e. in the course of a short regeneration period. In this basic mixture, also fir and pine regenerated sporadically (in records unified with spruce) as well as mountain ash and aspen (in records unified with birch). For the first 25 years, the stand was left more or less to its natural development while only several moderate measures were taken aimed particularly at the removal of dead trees.

In 1961, when the stand age was 25 years, the Department of Silviculture (Prof. Vyskot) of the Faculty of Forestry, University of Agriculture, established permanent thinning plots in the traditional layout. The total area of the stand part is 1.14 ha. The stand is situated on a plateau sloping slightly northward at an altitude of 460 m above sea level (geographical co-ordinates 49°19´13.062´´N and 16°40´01.324´´E). Mean annual precipitation is 584 mm, mean annual air temperature 7.4°C. On the Brno eruptive rock granodiorite with overlays of aeolian sediments, soils of the mesotrophic Cambisol type and typical Luvisol were formed. From the viewpoint of typology, the stand was classified as forest type 3B2, i.e. rich oak/beech forest with *Asperula* sp. (management group of stands No. 45).

In research plots (area of each of them 0.25 ha, a series of 4 partial plots 50 × 50 m), low thinning and crown thinning measures are compared in 5-year periods with control plots left to their natural development (only dead trees are removed). The present paper summarizes and evaluates only the natural development of Stand No. 131 F17/7b on a control plot (50 × 50 m – 0.25 ha) without intentional measures, namely in a period of 42 years – from 1961 to 2003.

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 the tree species was as follows: beech 17%, larch 40%, oak 11%, hornbeam 25%, spruce 3% and birch 5%. On the control plot, reserved trees from the original parent stand remained, viz two Scots pine trees and one European larch.

Methods of field studies and evaluation of results

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 cover are measured in all trees. Each of the trees is evaluated according to the classification scale of the Department of Silviculture (Kantor 1997). As in previous studies I–V, the present paper evaluates only a control plot which was left to its natural development without planned felling measures throughout the study (42 years). The total area of the plot is 0.25 ha (50 × 50 m).

In the 42-year time series of five-year periods (from 1961 to 2003), the following parameters were assessed separately in the particular species of the mixed stand: 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. To compile and assess evaluative criteria the following procedures were chosen:

Mortality (expressed in % of dead trees) in the particular intervals of five-year investigations is always related to the frequency of previous measurements. Within the analysis of the hypothesis of the dependence of dieback of subdominant trees standard parameters of differences between upper and lower limits were used. If the population normality was rejected, nonlinear Box-Cox transformation and exponential transformation were used to obtain quality estimates of mean values and their interval estimates. The programmes Statistica CZ 7 and QCExpert were used for statistical analysis.

At the time of the plot establishment in 1961, a number of beech and hornbeam trees survived on control plots as suppressed and subordinate trees which did not reach the given input parameters (dbh = 4 cm, h = 4 m). The majority of them died during the next development of the stand and, thus they were never recorded. However, if some of the trees survived in competition and reached dbh 4 cm during the five-year check measurements, they were newly included in the evaluation of the check database.

The stand growing stock and the periodic volume increment derived from it are related only to the dominant stand and the volume of dead trees is not included in the calculation. Stand density was calculated according to standard mensurational practice from the ratio of actual basal area of the particular species and tabular data. On the basis of reduced areas determined in this way the species composition was also found out. To determine tabular basal areas Mensurational Tables of the Institute for Forest Management Planning (1990 – Taxační tabulky ÚHÚL) were used to ensure comparability with the results of studies carried out on these plots in the past. On the basis of the evaluation described above the importance and the share of particular species in the production potential and stability of the studied mixed stand were assessed. Simultaneously, primary data were acquired to achieve 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 groups of stands of upland regions – in the given case for HS 45 (management group of stands 45).

RESULTS

Analysis of the natural development of stand No. 131f17/7b

Basic characteristics of the stand 131 F17/7b control plot in the year of establishment (1961) are given in Table 1. At that time (age 25 years), it was an individually mixed pole-stage stand neglected from the viewpoint of silviculture. Its basal area amounted to 13.339 m^2/ha and growing stock to 63.3 m^3/ha.

Stand density and mortality

The initial stand density 3,450 trees/ha (Table 1) in 1961 corresponded to age (25 years), site and species composition. However, a number of beech, hornbeam and birch trees with dbh smaller than 4 cmthat were not included in the check records survived as subdominant trees (see Methods). Some of the trees reached the value in the course of the next 6 years and, thus, the stand density during

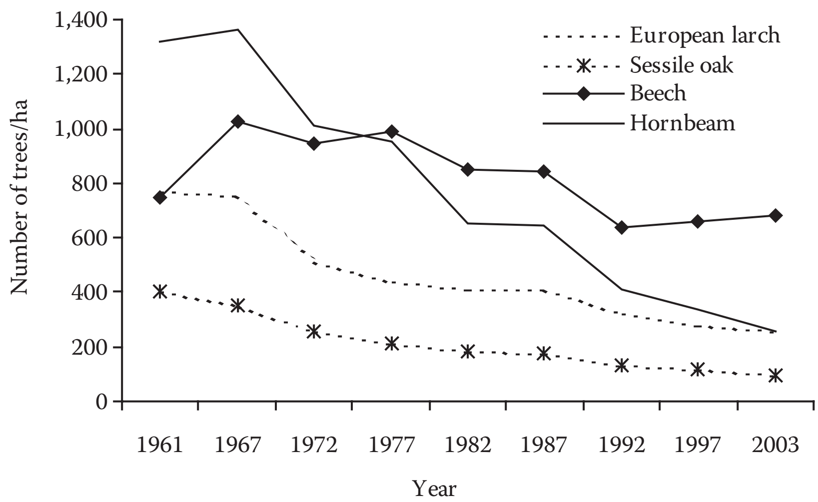

Fig. 1. Development of the number of beech, European larch, sessile oak and hornbeam trees in stand 131F17/7b in 1961 to 2003

Table 1. The development of stand basic data on the control plot in 1961–2003

Species	No. of trees/ha (*N*)	Mean tree			Stand basal area (b.a.) (m^2/ha)	Growing stock (m^3/ha)	Stand density	Species composition (%)
		h (m)	dbh (cm)	*v* (m^3)				
1961 – age 25								
Norway spruce	108	6.5	6.3	0.01	0.3878	1.5	0.02	2.7
Larch	768	9.8	8.7	0.05	5.8814	35.2	0.28	39.7
Oak	400	9.0	6.4	0.01	1.4527	5.4	0.08	10.8
Beech	744	8.4	5.8	0.01	2.1579	7.5	0.12	17.0
Hornbeam	1,316	9.3	5.1	0.01	2.8925	11.0	0.18	24.8
Birch	112	10.2	7.3	0.03	0.5662	2.8	0.04	5.0
Total	3,448				13.3385	63.3	0.71	100.0
1967 – age 31								
Norway spruce	48	8.1	8.0	0.03	0.2822	1.3	0.01	1.4
Larch	752	11.0	9.8	0.07	7.4981	52.5	0.33	37.0
Oak	352	10.3	7.9	0.03	1.9571	8.9	0.10	11.1
Beech	1,028	9.0	6.3	0.01	3.5697	13.4	0.19	21.3
Hornbeam	1,364	9.9	5.4	0.01	3.4914	13.5	0.21	23.3
Birch	128	11.5	8.6	0.04	0.8843	4.8	0.05	5.9
Total	3,672				17.6828	94.4	0.88	100.0
1972 – age 36								
Norway spruce	36	11.6	10.1	0.05	0.3096	1.9	0.01	1.2
Larch	516	16.2	13.4	0.17	9.0615	87.1	0.32	34.7
Oak	256	14.7	11.0	0.08	2.6695	19.3	0.12	12.4
Beech	944	11.8	7.6	0.03	4.9210	26.4	0.23	24.8
Hornbeam	1,012	11.7	6.3	0.02	3.5555	15.5	0.19	20.6
Birch	92	16.8	12.8	0.11	1.2885	10.0	0.06	6.3
Total	2,856				21.8056	160.2	0.93	100.0
1977 – age 41								
Norway spruce	20	12.3	10.8	0.06	0.1845	1.1	0.01	0.7
Larch	440	18.5	15.8	0.27	10.5904	116.9	0.34	32.8
Oak	216	16.7	13.2	0.12	3.1724	26.8	0.13	12.7
Beech	992	12.8	8.3	0.04	6.3960	40.1	0.29	27.9
Hornbeam	956	12.4	6.5	0.02	3.6806	17.0	0.20	18.8
Birch	104	17.0	13.7	0.14	1.7206	14.1	0.07	7.1
Total	2,728				25.7445	216.0	1.04	100.0
1982 – age 46								
Norway spruce	12	12.3	11.1	0.06	0.1181	0.7	0.00	0.4
Larch	408	20.2	16.4	0.30	10.4265	123.0	0.33	35.1
Oak	184	18.3	13.9	0.15	2.9747	27.3	0.12	12.7
Beech	848	14.3	8.9	0.05	6.1049	42.3	0.27	28.6
Hornbeam	656	13.5	7.1	0.02	2.9993	14.9	0.15	16.1
Birch	84	19.6	15.6	0.18	1.6784	15.0	0.07	7.1
Total	2,192				24.3020	223.2	0.93	100.0

the second measurement in 1967 was 220 trees/ha higher than at the initial measurement amounting to 3,670 trees/ha.

During subsequent time periods, however, the stand density naturally decreased due to competition and natural selection down to the present value of

Table 1 to be continued

Species	No. of trees/ha (N)	Mean tree h (m)	dbh (cm)	v (m^3)	Stand basal area (b.a.) (m^2/ha)	Growing stock (m^3/ha)	Stand density	Species composition (%)
1987 – age 51								
Norway spruce	12	13.3	11.3	0.07	0.1212	0.8	0.00	0.4
Larch	408	22.2	18.5	0.45	13.8221	183.5	0.39	34.6
Oak	176	19.3	15.5	0.20	3.5714	35.4	0.14	12.0
Beech	840	15.4	10.2	0.08	8.4300	70.6	0.35	31.1
Hornbeam	648	13.8	7.4	0.03	3.2589	16.9	0.16	14.1
Birch	84	21.2	18.7	0.28	2.4813	23.4	0.09	7.8
Total	2,168				31.6849	330.7	1.14	100.0
1992 – age 56								
Norway spruce	4	15.5	13.3	0.11	0.0556	0.4	0.00	0.2
Larch	320	25.1	22.5	0.66	15.1822	210.1	0.40	35.5
Oak	132	20.8	18.1	0.29	3.5764	38.4	0.13	11.6
Beech	640	17.3	12.5	0.14	9.4599	88.0	0.38	33.6
Hornbeam	408	14.7	8.7	0.04	2.8073	15.4	0.13	11.9
Birch	64	22.5	21.2	0.37	2.3816	23.5	0.08	7.3
Total	1,568				33.4630	375.8	1.13	100.0
1997 – age 61								
Norway spruce	4	16.5	13.3	0.12	0.0555	0.5	0.00	0.1
Larch	276	27.5	25.8	0.88	16.8584	242.8	0.42	35.3
Oak	116	21.9	19.5	0.35	3.6315	41.2	0.13	10.8
Beech	660	18.2	13.1	0.17	10.9949	112.7	0.43	36.1
Hornbeam	340	15.5	9.3	0.05	2.7037	15.4	0.13	10.7
Birch	64	23.5	21.8	0.40	2.5120	25.7	0.08	7.1
Total	1,460				36.7560	438.2	1.18	100.0
2003 – age 67								
Norway spruce	4	17.2	13.3	0.12	0.0556	0.5	0.00	0.1
Larch	256	28.8	28.1	1.06	18.3120	272.1	0.43	35.2
Oak	92	23.9	21.6	0.47	3.4763	43.3	0.12	9.6
Beech	680	17.8	13.5	0.21	12.5586	140.6	0.48	39.4
Hornbeam	256	15.8	10.4	0.06	2.5039	14.8	0.11	9.3
Birch	56	24.8	22.8	0.46	2.4027	25.6	0.08	6.3

1,340 trees/ha (natural mortality 61%) at an age of 67 years in 2003 (Table 1).

The natural development of the number of trees of 4 main species in the stand in the course of 42 years is also documented in Fig. 1.

The highest total mortality was observed in hornbeam. Of the initial number of 1,316 trees/ha some 1,060 trees/ha, i.e. 80.5%, died. Similar trends were also noted in the light-demanding oak: at the first survey 400 trees/ha, at the last survey 92 trees/ha (mortality 77%).

Relatively high mortality was also noted in the main production species of the studied stand, i.e. larch. Through natural development, 512 trees/ha, i.e. 67%, gradually died. Similarly like in oak, this natural mortality was exclusively observed in suppressed subdominant larch trees.

Beech shows quite a specific position in the studied stand. In the period 1961 to 1967, the number of registered trees with dbh exceeding 4 cm increased by 290 to 1,030 beech trees/ha. Also in the next years, beech survived in the competition with other species markedly best. During the last check in 2003, some 680 beech trees/ha were registered in all stand levels. As compared with the initial inventory in 1961, only 64 trees/ha died in the course of 42 years (natural mortality 9%).

Table 2. Basic statistical analysis of trees heights of *Fagus sylvatica* L. in 1967–2003 – smoothing of density 0.5, significance level 0.05, value tested 0 (with respect to an insufficient amount of data, the years 1961, 1982 and 1992 were not included)

Year of measurements		1967	1967–1972	1972	1972–1977	1977	1977–1982	1987	1987–1992	1997	1997–2003
Fagus sylvatica L.		living trees	dead trees	living trees	dead trees	living trees	dead trees	living trees	dead trees	living trees	dead trees
Traditional parameters	number of valid data	257	21	236	6	248	36	210	49	165	11
	mean	9.03	8.35	11.84	10.58	12.80	9.54	15.44	11.79	18.23	12.20
	lower limit	8.81	7.67	11.47	8.03	12.40	8.95	14.85	11.06	17.41	10.80
	upper limit	9.25	9.03	12.20	13.13	13.20	10.13	16.02	12.51	19.04	13.60
	variance	3.21	2.24	7.94	5.91	10.17	3.06	18.69	6.36	27.93	4.34
	standard deviation	1.79	1.50	2.82	2.43	3.19	1.75	4.32	2.52	5.29	2.08
	skewness	0.60	0.53	0.59	1.03	0.42	0.60	0.35	0.18	0.11	0.61
	deviation from 0	**significant**	insignificant	**significant**	insignificant	**significant**	insignificant	**significant**	insignificant	insignificant	insignificant
	acuteness (kurtosis)	3.24	2.32	3.09	2.89	2.81	4.25	2.45	2.77	2.34	2.16
	deviation from 3	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
	half-sum	9.70	8.95	13.45	11.60	14.60	11.00	17.30	12.55	18.90	13.10
	modus	8.34	7.93	10.68	9.05	11.75	10.29	14.14	12.41	17.55	10.33
Test of normality	normality	**rejected**	accepted	**rejected**	accepted	**rejected**	accepted	accepted	accepted	accepted	accepted
	calculated	9.73	1.66	9.01	2.84	6.02	2.80	4.09	0.44	0.50	1.46
	theoretical	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99
	probability	0.008	0.436	0.011	0.241	0.049	0.247	0.129	0.801	0.780	0.481
Box-Cox transformation of data											
	Validity	yes		yes		yes					
	Likelihood	422.09		387.83		403.58					
	Corrected mean	8.8		11.5		12.5					
Exponential transformation of data											
	Validity	yes		yes		yes					
	Corrected mean	8.8		11.5		12.5					
	Interval of reliability										
	Lower	8.63		11.16		12.13					
	Upper	9.05		11.85		12.91					

Table 3. Basic statistical analysis of tree heights of *Larix decidua* Mill. in 1961–2003 – smoothing of density 0.5, significance level 0.05, tested value 0 (with respect to an insufficient amount of data the years 1982 and 1997 were not included)

	Year of measurements	1961	1961–1967	1967	1967–1972	1972	1972–1977	1977	1977–1982	1987	1987–1992	1992	1992–2003
	Larix decidua Mill.	living trees	dead trees	living trees	dead trees	living trees	dead trees	living trees	dead trees	living trees	dead trees	living trees	dead trees
Traditional parameters	number of valid data	192	24	188	60	129	19	110	8	102	24	80	9
	mean	9.75	7.46	11.04	8.19	16.15	11.41	18.47	12.15	22.15	15.78	25.13	18.88
	lower limit	9.25	6.94	10.48	7.69	15.41	10.21	17.66	10.21	21.08	14.74	24.04	16.24
	upper limit	10.26	7.98	11.60	8.68	16.90	12.61	19.28	14.09	23.22	16.81	26.22	21.52
	variance	12.55	1.59	15.31	3.63	18.33	6.21	18.39	5.41	29.72	6.28	23.92	11.79
	standard deviation	3.54	1.26	3.91	1.90	4.28	2.49	4.29	2.33	5.45	2.51	4.89	3.43
	skewness	0.43	–0.02	0.70	0.67	0.04	1.83	–0.01	–0.01	–0.01	0.30	–0.30	0.15
	deviation from 0	**significant**	insignificant	**significant**	**significant**	insignificant	**significant**	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
	acuteness (kurtosis)	2.27	3.37	3.07	2.85	2.17	5.26	2.32	2.06	2.03	2.89	2.38	2.14344
	deviation from 3	**significant**	insignificant	insignificant	insignificant	insignificant	**significant**	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
	half-sum	8.85	7.15	9.73	7.64	15.70	9.14	17.67	11.64	21.70	14.71	26.22	17.89556
Test of normality	normality	accepted	accepted	**rejected**	accepted	accepted	**rejected**	accepted	accepted	accepted	accepted	accepted	accepted
	calculated	5.13	0.06	9.47	4.48	0.07	8.28	0.03	0.03	0.04	0.70	1.55	0.12618
	theoretical	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99
	probability	0.077	0.972	0.009	0.106	0.964	0.016	0.983	0.986	0.982	0.706	0.460	0.939
Box-Cox transformation of data													
	Validity			yes			yes						
	Likelihood			312.42			37.75						
	Corrected mean			10.47			10.83						
Exponential transformation of data													
	Validity			yes			yes						
	Corrected mean			10.36			10.64						
	Interval of reliability												
	Lower			9.86			10.11						
	Upper			10.89			11.41						

Table 4. The development of larch frequency in height classes (m) and *mortality* on the control plot of stand 131 F17/7b (0.25 ha) in 1961–2003

Height class (m)	1961	1961–1967	1967	1967–1972	1972	1972–1977	1977	1977–1982	1982	1982–1987	1987	1987–1992	1992	1992–1997	1997	1997–2003	2003
4	5	1	1														
5	16		2	2													
6	21	3	17	10													
7	23	9	21	12	1												
8	21	8	22	17	2		1	1									
9	12		15	6	5	3											
10	24	3	15	3	6	6	3	1	1		1	1					
11	12		18	5	10	7	3	2	1								
12	12		14	3	6	1			1								
13	15		12	1	9		9	2	5		5	4					
14	9		18		7		7	1	3		3	2	2	2			
15	12		10		13	1	4		7		10	7	2	1	1	1	
16	4		9		12		9	1	2		1		1	1			
17	1		4		8	1	15		7		4	3	1	1			
18	5		2		9	1	8		13		5	1	3	2	1		
19			1		8		7		10		5	3	2	1	1	1	1
20			2		13		7		7		7		4	1	1		2
21			1		4		6		8		8	1	5		6	2	4
22			4		7		11		7		9		6				1
23					5		4		7		2		6	1	3		2
24					1		7		9		5		2	1	6		2
25					3		4		2		7		7		2		4
26							2		5		6		5		7		5
27							3		1		5		5		4		2
28									5		3		8		6		4
29									1		3		4		4		4
30											8		7		8		9
31											4		5		7		5
32											1		2		4	1	6
33													1		3		6
34													1		3		3
35													1		2		1
36																	1
37																	2
Total	192	24	188	59	129	20	110	8	102		102	22	80	11	69	5	64
Per ha	768	96	752	236	516	80	440	32	408		408	88	320	44	276	20	256
Mean height	9.8	7.5	11.0	8.1	16.2	11.4	18.5	12.2	20.2		22.2	15.8	25.1	18.3	27.5	21.6	28.8

Statistical analysis of the results of biometrical studies shows considerable differentiation of tree layers of dying and living trees, particularly of larch (in the period 1961–2003) but also of the shade-tolerant beech. The analysis demonstrated a hypothesis of the dieback of mainly subdominant trees. This assumption was proved mainly in the light-requiring larch (Tables 2 and 3).

Table 5. The development of beech frequency in height classes (m) and *mortality* on the control plot of stand 131 F17/7b (0.25 ha) in 1961–2003

Height class (m)	1961	*1961–1967*	1967	*1967–1972*	1972	*1972–1977*	1977	*1977–1982*	1982	*1982–1987*	1987	*1987–1992*	1992	*1992–1997*	1997	*1997–2003*	2003
4			1														5
5	5																6
6	17		12	2					1	1					1		3
7	41	1	46	5	11		8	5	2		2	2			1		2
8	48	1	56	6	14	1	13	6	7		5	4	1				7
9	29		50	2	23	2	14	5	6		5	4	1	1	2		3
10	30		48	4	44		31	10	20		23	8	13	1	10	3	4
11	8		24	2	33	2	32	9	14		11	5	5		6	3	8
12	3		8		21		29		22	1	19	9	11	2	7		5
13	5		8		33		23		24		14	5	7		10	3	5
14			3		19		31		27		23	6	11	1	5		8
15			1		13	1	21	1	22		17	3	12		13	1	11
16					8		12		14		14	2	17		11	1	5
17					9		14		16		8		5		14		8
18					3		8		12		20	1	16		6		7
19					1		2		8		12		9		14		11
20					4		8		9		9		12		8		7
21							1		3		6		11		8		4
22									4		10		11		13		12
23							1				8		5		6		6
24									1				5		7		7
25											2		3		8		12
26											1		2		7		7
27													1		4		8
28											1				1		2
29													2				2
30															2		2
31																	2
32															1		
33																	1
Total	186	2	257	21	236	6	248	36	212	2	210	49	160	5	165	11	170
Per ha	744	8	1,028	84	944	24	992	144	848	8	840	196	640	20	660	44	680
Mean height	8.4	7.4	9.0	8.3	11.8	10.6	12.8	9.5	14.3	9.3	15.4	11.8	17.3	11.8	18.2	12.2	17.8

The frequency of larch and beech in height and diameter classes

The development of larch and beech frequency in height classes in the course of 1961–2003 is given in Tables 4 and 5, and in diameter classes in Tables 6 and 7. These surveys also show the distribution of dead trees depending on their height or dbh.

The very broad range of larch heights from 4 to 18 m already at the establishment of research plots in 1961 documents an important position of the species both as a subdominant, co-dominant as well as dominant tree. However, the best part of the trees was rather slender having an unfavourable slenderness ratio. Based on Table 4 it is evident that 65% of larch trees had dbh of only 4 to 8 cm at the first survey. The ma-

Table 6. The development of larch frequency in diameter classes (m) and *mortality* on the control plot of stand 131 F17/7b (0.25 ha) in 1961–2003

Diameter class (cm)	1961	1961–1967	1967	1967–1972	1972	1972–1977	1977	1977–1982	1982	1982–1987	1987	1987–1992	1992	1992–1997	1997	1997–2003	2003
4	57	20	31	24	1	1											
6	42	3	48	28	20	12	7	4	3		3	3					
8	25	1	25	5	19	6	13	3	10		10	8	2	2			
10	21		23	2	16		9		9		9	5	4	4			
12	17		17		13	1	17	1	16		11	3	6	2	4	3	1
14	13		15		21		12		12		11	3	6	2	4		3
16	7		11		9		12		12		11		12	1	6	1	4
18	3		5		9		14		14		7		7		10		7
20	2		3		6		6		6		8		5		4	1	7
22	2		3		4		3		3		7		6		6		5
24	1		1		1		5		5		7		5		4		3
26	1		3		1		2		2		2		8		6		4
28	1		1		4		1		1		2		3		7		5
30			2		2		1		1		2		1		1		5
32					1		3		3		1		3		2		3
34					2		3		3		2				2		1
36											1		2		1		3
38							1		1		3		2		1		2
40							1		1		3		2		1		
42													1		2		1
44											1		3		3		1
46													1		1		2
48															2		4
50											1		1		1		2
52																	
54																	
56															1		
58																	1
Total	192	24	188	59	129	20	110	8	102		102	22	80	11	69	5	64
Per ha	768	96	752	236	516	80	440	32	408		408	88	320	44	276	20	256
Mean diameter	8.7	4.9	9.8	5.7	13.4	6.8	15.8	7.8	16.4		18.5	9.5	22.5	11.4	25.8	14.6	28.1

jority of them died already in the course of the first decade in 1961 to 1972 (see Tables 4 and 6).

Simultaneously, a group of co-dominant and dominant ash trees has however been differentiated in the stand since the first measurements (in 1961 height 12 to 18 m, dbh 12 to 28 cm) forming gradually a basis of the high production and stability of the whole stand. During the last check in 2003, it was possible to include as many as 130 larch trees/ha 30 to 37 m tall with dbh 30 to 58 cm in this group (see Tables 4 and 6).

Beech trees were nearly exclusively subdominant and co-dominant ones in the whole period of evaluation. Data in Table 5 demonstrate considerable vitality and also the quite extraordinary potential of beech to survive in lower layers. In 1961, the height range of beech was 5 to 13 m and in 1982 from 6 to 24 m. The height range even increased in the next years and in the last check it was from 4 to 33 m. Only a few beech trees have occurred as co-dominant trees in the last years (Table 5). In the course of

Table 7. The development of beech frequency in diameter classes (m) and *mortality* on the control plot of stand 131 F17/7b (0.25 ha) in 1961–2003

Diameter class (cm)	1961	1961–1967	1967	1967–1972	1972	1972–1977	1977	1977–1982	1982	1982–1987	1987	1987–1992	1992	1992–1997	1997	1997–2003	2003
4	93	2	85	16	43	5	45	23	22		21	16	3		5		20
6	59		98	5	82	1	71	10	61	2	55	24	25	4	24	9	11
8	25		42		53		47	3	44		34	8	23	1	25	1	25
10	8		21		29		32		32		27	1	27		27	1	22
12			9		14		23		22		15		15		13		15
14	1		1		10		12		13		19		15		12		13
16			1		4		10		10		17		17		13		13
18					1		6		6		8		11		17		14
20							2		2		7		8		5		9
22											3		8		9		5
24											4		4		7		9
26													4		2		4
28															3		5
30															3		3
32																	2
Total	186	2	257	21	236	6	248	36	212	2	210	49	160	5	165	11	170
Per ha	744	8	1,028	84	944	24	992	144	848	8	840	196	640	20	660	44	680
Mean diameter	5.8	4.0	6.3	4.5	7.6	4.6	8.3	5.2	8.9	6.2	10.2	5.7	12.5	6.2	13.1	6.3	13.5

42 years of monitoring, particularly subdominant trees and extremely slender beech trees with unfavourable slenderness ratio died. Nevertheless, even at an age of 67 years, 170 beech trees/ha were registered as overtopped trees (height 4 to 12 m). Therefore, particularly the mean values of height and dbh in beech (Tables 5 and 7) are markedly lower than in larch (Tables 4 and 6).

Stand basal area

It was already stated in previous papers (Kantor, Pařík 1998; Kantor, Hurt 2003) 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 13.339 m^2/ha in 1961 increased 3 times after 42 years reaching 39.309 m^2/ha (Table 8).

At the same time, the basal area of larch increased from 5.881 to 18.312 m^2/ha, i.e. to 315%. An even more dynamic increase in basal area was noted in beech, viz to 582% (from 2.158 m^2/ha to 12.559 m^2/ha).

An increase in basal area (however, not substantial in absolute values) was also noted in oak and birch. In spruce and hornbeam, these values even decreased due to high mortality of the species during the years of evaluation (Table 8).

Growing stock

The growing stock development (m^3/ha) compiled again according to the particular species in five-year intervals is given in Table 9. The total growing stock increased from initial 63.3 m^3/ha in 1961 to 496.9 m^3/ha (i.e. 7.8 times) in 2003.

In absolute values, larch participates in this total to the largest extent (272.2 m^3/ha, i.e. 55% of the total growing stock), nevertheless, the dynamics of its mean annual increment (4.9–6.5 m^3/ha/year) approached the level of beech increment in the last ten years (4.7 to 4.9 m^3/ha/year). In the next years, it will be of interest to compare the trend of current increments of both species. Similarly like in basal area, the highest relative increase in the growing stock was noted in beech, viz from the initial value of 7.5 m^3/ha in 1961 to 140.6 m^3/ha (28% of the total growing stock) in 2003. Of course, interspersed species participated in the growing stock as well, particularly oak (an increase from initial 5.4 m^3/ha to 43.3 m^3/ha) and

Table 8. The development of stand basal area on the control plot (m^2/ha) and *its increase* in per cent in 1961 (age 25 years) to 2003 (age 67 years)

Species	1961	1967	1972	1977	1982	1987	1992	1997	2003	Increase with respect to 1961	
Norway spruce	0.3879	0.2823	0.3097	0.1845	0.1181	0.1212	0.0556	0.0556	0.0556	−0.3324	*−86*
Larch	5.8814	7.4981	9.0615	10.5904	10.4264	13.8221	15.1822	16.8584	18.3119	12.4306	*211*
Oak	1.4527	1.9571	2.6695	3.1724	2.9747	3.5714	3.5764	3.6315	3.4763	2.0237	*139*
Beech	2.1579	3.5697	4.9209	6.3960	6.1050	8.4300	9.4600	10.9949	12.5586	10.4008	*482*
Hornbeam	2.8925	3.4914	3.5555	3.6806	2.9993	3.2589	2.8073	2.7037	2.5039	−0.3886	*−13*
Birch	0.5662	0.8843	1.2885	1.7206	1.6784	2.4813	2.3816	2.5120	2.4027	1.8365	*324*
Total per ha	13.3385	17.6828	21.8056	25.7445	24.3020	31.6849	33.4630	36.7560	39.3091	25.9706	*195*

hornbeam (an increase from initial 11.0 m^3/ha to 14.1 m^3/ha).

The high production potential of the mixed stand is also documented by the values of current volume increment which ranged from 9.8 to 12.5 m^3/ha/year during the last decade.

Stocking and species composition

Data on the development of stocking and species composition throughout the studied period are given in Table 1.

The stand can be considered to be fully stocked throughout the period of evaluation. The calculated very low or low stocking of the stand at an age of 25 to 35 years (0.71–0.93) was inaccurate, not corresponding to reality. At that time, a large part of the stand consisted of subordinate extremely slender broadleaved species (beech, hornbeam) with an extremely low basal area. Its value was then markedly undervalued by the method of stocking calculation. In the last four inventories, however, calculated stocking ranged between 1.1 and 1.2.

At the initial measurement, the stand was characterized as an individually mixed pole-stage stand with the following species composition: larch 40%, beech 17%, oak 11% and hornbeam 25%. Birch (5%) and spruce (2%) occurred as interspersed species there.

In the next years, the proportion of larch slightly decreased, nevertheless, the species has taken up steadily 35% of the reduced stand area in the last 20 years.

On the other hand, the proportion of the second main species, i.e. beech, gradually increased at all inventories up to 39% at the present time.

Oak (10%), hornbeam (9%) and birch (6%) take up the position of interspersed species even at present.

DISCUSSION

The exceptional production potential of mixed beech/larch stands in the Křtiny Training Forest Enterprise (TFE) was mentioned on the example of Haša's Sanctuary (Hašova svatyně) already in the introduction of the study (Kantor et al. 2005). Not only the growing stock of the overmature 175-year-old stand (1,250 m^3/ha) but also its current volume increment (11.4 m^3/ha) are worthy of remark. Similarly high production like in the assessed 67-year-old stand 131F17/7b (497 m^3/ha) was mentioned also in other stands of the Křtiny TFE. Truhlář (1996) reported data from stand 154B6 with the proportion

Table 9. The development of growing stock on the control plot (m^3/ha) in 1961 (age 25 years) to 2003 (age 67 years)

Species	1961	1967	1972	1977	1982	1987	1992	1997	2003
Norway spruce	1.45	1.30	1.92	1.10	0.73	0.82	0.44	0.48	0.48
Larch	35.23	52.53	87.07	116.89	122.96	183.54	210.12	242.80	272.15
Oak	5.37	8.89	19.34	26.78	27.29	35.39	38.41	41.18	43.31
Beech	7.46	13.40	26.45	40.10	42.34	70.59	88.02	112.72	140.58
Hornbeam	11.03	13.54	15.48	16.95	14.89	16.87	15.39	15.36	14.80
Birch	2.80	4.75	9.97	14.13	14.99	23.45	23.46	25.66	25.56
Total per ha	63.34	94.42	160.22	215.95	223.20	330.65	375.84	438.20	496.87
Stand density	0.71	0.88	0.93	1.04	0.93	1.14	1.13	1.18	1.22

of beech and larch 30 and 70%, respectively, where the growing stock amounted to 457 m^3/ha. Klíma (2000) reported an even higher potential of a mixed beech/larch stand in the same enterprise. At an age of 51 years, the stand with the proportion of beech and larch 80 and 20%, respectively, had the total growing stock of 430 m^3/ha. With the proportion of beech and larch 60 and 40%, respectively, the growing stock was however already markedly higher, namely 537 m^3/ha.

Problems of the importance of a larch admixture for increasing the production of oak/beech stands in the Křivoklát region were dealt with by Zakopal (1970). His study was based on the analysis of 5 plots at an age of 90 to 120 years with different proportions of European larch. From the aspect of soil typology there were medium-gleyed Podzols in this locality. The author draw a conclusion that at the larch admixture of about 30% the growing stock increased by 27% compared to a pure broadleaved stand (i.e. by 90 m^3/ha at an age of 120 years on medium site classes). It roughly corresponds to 50 to 60 larch trees per ha. Thus, the average spacing of larch trees in a mixed 140-year-old mature stand of beech and oak should be ± 15 m. However, the higher proportion of larch up to 50% led to a markedly lower proportion of large-diameter assortments.

In Germany in the Lower Saxony Upland in the region of Unterer Solling (altitude 200 to 400 m), Dippel (1988) and Guericke (2001) studied mixed beech/larch stands.

Dippel (1988) demonstrated the high production of this mixture compared to pure stands in his paper aimed at the growth potential in tended beech/larch stands. He also analyzed the relation of the total growing stock to the variable proportion of larch. All studied stands (aged 55 to 150 years) were supported by sandy soils overlaid by a 35 to 70cm layer of loess. As for the soil type, it was slightly podzolic soil or pseudogleyic Cambisol. Dippel found that the optimum basal area, production and quality of stands were related to the proportion of larch. He recommended 25 to 45% of the total number of stems as an optimum proportion, which roughly corresponded to the basal area of 40 m^2/ha at an age from 50 to 85 years. Up to the limit, the negative relation between the proportion of larch and the quality and particularly production of beech was not proved. In connection with inappropriately performed tending measures the higher proportion of larch (over 45%) can decrease the total production. As a rule, the volume production of the mixture of beech with larch is, however, higher as compared with table values.

Guericke (2001) established a series of research plots in mixed beech/larch stands aged 30 to 160 years. In total, 25 plots were situated on brown soils overlaid by a 40 to 100cm loess layer and predominating humus form "moder". To establish a good-quality and highly productive mixed stand the author recommended to use larch during regeneration, namely always with sufficient advance. The proportion of larch in regeneration need not be higher than 400 to 500 trees per ha. In the pole-stage stand, the number of larch trees should be reduced to 120 to 180 trees per ha. In the stage of maturity, 35 to 50 larch trees per ha are quite sufficient. Simultaneously, it is advisable to mark and release 100 to 120 target beech trees per ha. To achieve higher quality production, the author recommended the pruning of selected larch trees up to a height of 6 m already in the pole-stage stand.

CONCLUSION

Results of our study presented in this paper conformable with other Czech and foreign studies have proved that even a simple and easy-to-manage mixture of larch and beech meets the requirements for the high production potential and stability on mesotrophic sites of uplands. Moreover, an admixture of other site-suitable species favourably affects the biodiversity of these ecosystems.

Mixed beech/larch stands are also characterized by quite an exceptional aesthetic value. The statistical analysis of biometric data demonstrated a hypothesis of the dieback of mainly subdominant trees. This assumption was proved mainly in light-requiring larch.

Similarly like in previous studies, it has been demonstrated that beech is a basic broadleaved species of the target species composition of uplands.

Larch in a mixture with beech has to take up the position of an individually admixed species. Clump- or group-mixture is unsuitable from the viewpoint of silviculture. Moreover, larch has to be grown from the juvenile age with a sufficient height start as a dominant species or even as markedly dominant trees with free crowns.

From the aspect of ensuring all priority functions (production, stabilization, aesthetic) of beech/larch stands it is possible to recommend the optimum proportion of larch to range from 20 to 40% on mesotrophic sites of uplands.

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Produkční potenciál a ekologická stabilita smíšených lesních porostů v pahorkatinách – VI. Bukomodřínový porost na živném stanovišti ŠLP Křtiny

ABSTRAKT: Příspěvek je v pořadí šestým sdělením o produkčním potenciálu a stabilitě smíšených lesních porostů v pahorkatinách. Je v něm posuzován smíšený bukomodřínový porost založený v letech 1934 až 1942 přirozenou obnovou. Porost se nachází v nadmořské výšce 460 m a od roku 1961 je ponechán přirozenému vývoji. V té době byl charakterizován jako jednotlivě smíšená, tloušťkově a výškově diferencovaná 25letá tyčkovina až tyčovina. Zastoupení modřínu činilo 40 %, buku 17 %. V porostu byl dále zastoupen habr (25 %), dub (11 %) a v menší míře i bříza (5 %) a smrk (3 %). V průběhu 42 let se v tomto porostu bez úmyslných probírkových zásahů ustálilo zastoupení modřínu na 35 %, naopak zastoupení buku vzrostlo na 39 %. Při všech pětiletých inventarizacích i v současnosti lze porost charakterizovat jako stabilizovaný s vysokým produkčním potenciálem. Jeho počáteční zásoba 63 m^3/ha ve věku 25 let vzrostla na 497 m^3/ha ve věku 67 let v roce 2003. Běžný objemový přírůst činí v současné době 9,8 m^3/ha/rok až 12,5 m^3/ha/rok.

Klíčová slova: buk; modřín; dub; habr; smíšený porost; přirozený vývoj; produkce; mortalita; štíhlostní kvocient

Corresponding author:

Ing. Václav Hurt, Mendelova zemědělská a lesnická univerzita v Brně, Lesnická a dřevařská fakulta, Lesnická 37, 613 00 Brno, Česká republika
tel.: + 420 545 134 124, fax: + 420 545 134 125, e-mail: vhurt@email.cz