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The development and growth of larch stands in Lithuania

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Abstract

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Changing climate conditions and increasing demands for timber and wood products create a need to cultivate highly productive forest stands. High productivity, good wood quality and adaption to climate change make European larch a promising species for Lithuania. The aim of this research was to evaluate the productivity and sustainability of the larch stands. We tested the hypothesis that larch stands mixed with other species are more productive than the pure larch stands. In total, our study sampled 138 larch stands, mixed stands (91) and pure stands (47) that aged between 30 and 60 years old in Lithuania. We evaluated these stands using dendrologic, dendrometric and phytocoenological characteristics and determined the main factors affecting productivity and stability of larch stands. Our study showed that pure larch stands have higher mean annual increment and are more productive than mixed larch stands. However, we found that timber volumes decreased in both pure and mixed larch stands over 50 years of age. This happens due to the absence of forestry treatments, such as thinnings in the larch stands, thus resulting in natural tree dieback. The development of thinning guidelines could make larch stands a valuable and productive source of timber.

Keywords: larch stands; forestry; timber production; climate change; pure and mixed stands

The distribution range of the genus *Larix* Miller covers extensive areas in Europe, Asia and North America (Jankauskas 1954, 1962; Da Ronch 2016). The number of *Larix* species (10–40) is disputed among scientists due to its characteristics to interbreed easily when their distribution ranges overlap, thus creating numerous hybrids and ecological forms that sometimes are regarded as separate species (Keliauskas 1971). The growth and dynamics of larch trees and stands were well studied in Poland and Alpine Europe, however studies in its northern natural distribution range are scarce (Giertych 1980; Oleksyn, Fritts 1991; Lewandowski et al. 1994; Chylarecki 2000; Armalis et al. 2003; Rożkowski et al. 2011; Vitas 2015).

The planting of fast-growing larch species and hybrids offers great a potential to increase future softwood supplies (Einspahr et al. 1984; Pukienė, Bitvinskas 2000). Due to the fast growth and high productivity the European larch (*Larix decidua* Miller) and its hybrids with Japanese larch (*Larix kaempferi* (Lambert) Carriére) are cultivated in plantations by forest managers (Jankauskas 1954). The growth rate of such stands is almost equal to the growth rate of soft deciduous stands, which are well-known for their high productivity. In Lithuania only poplar (*Populus* sp.) and hybrid poplar stands are more productive, however timbre produced by larch is of better quality and thus more promising in forestry (Urbaitis, Suchockas 2017).

In Lithuania major scientific interest was focused on the genus *Larix* in the mid-20th century. Studies were undertaken on their growth and productivity (Jankauskas 1954), quality of larch seeds (Čibiras 1959) and their hybridization (Ramanauskas 1996).

Currently 9 species of larch occur in forests, parks and ornamental gardens in Lithuania (Januškevičius, Budriūnas 1987). Under general opinion of Lithuanian scientists (Jankauskas 1954; Keliauskas 1971; Danusevičius et al. 2006) larch species are characterized by different growth and sensitivity. The Siberian larch (*Larix sibirica* von Ledebour) is characterized by the worst growth. It grows only up to 30 years of age and later stops developing and dies. The Dahurian larch (*Larix dahurica* Maximowicz) grows also poorly. The Japanese larch (*L. kaempferi*) grows fast, producing a tall slender stem with a very branchy canopy. In Lithuania the Polish larch [a subspecies of European larch *Larix decidua* subsp. *polonica* (Raciborski ex Wóycicki) Domin] produces the best growth . Its productivity is much higher than that of the native coniferous species Scots pine (*Pinus sylvestris* Linnaeus) and Norway spruce (*Picea abies* (Linnaeus) H. Karsten).

However, the cultivation of larch (*L. sibirica* and *Larix archangelica* Lawson) in Lithuania was not common during the last century. Stands that were established were cultivated with the bad growth characteristics under Lithuanian climatic conditions.

Our analysis is the first wide-scale study of *Larix* sp. stands in the north of its natural distribution. Due to popularity in the mid-20th century hundreds of hectares of *Larix* stands were planted. Initial planting density in pure larch stands was 2,000–2,500 stems per hectare while in mixed stands it reached 2,700–3,500 stems per hectare. However, without clear prescribed forest practices for *Larix* sp. most of the stands remained unmanaged. In plantations, *Larix* trees were mixed with Norway spruce, Scots pine, small-leaved linden (*Tilia cordata* Miller) and other species. Mixing of complementary tree species may increase stand productivity, mitigate the effects of drought and other risks, and pave the way to forest production systems which may be more resource-use efficient and stable in the face of climate change (Pretzsch et al. 2015).

The changing environment and climate provides possibilities and rise the need to re-evaluate this species and collect the information about the tree species and environmental conditions, affecting the fast growth of the larches. The aim of this research was to evaluate the productivity and sustainability of the larch stands and to test the hypothesis, that mixed larch stands are more productive, than the pure larch stands.

MATERIAL AND METHODS

Study area. The selection of larch stands for our study was performed from all larch forests of Lithuania. Lithuania is situated in the transitional zone between temperate and hemiboreal forests. This means that Lithuania is farther northward than the native distribution of naturally occurring larch, so all larch stands in Lithuania are artificially planted.

The climate and tree growth conditions are determined by the geographical position of Lithuania. Lithuania is situated in the transitional zone from temperate to boreal forests that is greatly affected by humid marine climate, global air mass movement from the west and natural local conditions (relief, edaphic conditions). Average temperature on January varies from –2.5°C on the coast and –6°C in the east. During July the average temperature is 16°C. The annual precipitation is 800 mm and varies from 600 to 900 mm. In relation to climate and vegetation there are described 4 forest geographical regions that are characterized by different geomorphologic, edaphic features and vegetation (Januškevičius, Budriūnas 1987). The study covered all 4 regions.

Selection of stands. We used a hierarchical two-step approach of data collection. First, we analysed the State Forest Cadastre database. It represents all forested areas of the country and contains information about 2.05 million ha of forest stands. During this stage we selected potential *Larix* sp. stands for field work. The database does not distinguish the different species of *Larix*. During the mid-20th century many *Larix* species were planted: *L. decidua*, *L. sibirica*, *L. archangelica*, *Larix sukaczewii* Dylis, *Larix dahurica* Turczaninow ex von Trautvetter, however, only *L. decidua* and its hybrids created productive stands. We selected the larch stands of growth class Ia–II. We excluded Russian and Siberian larches from the research due to their low productivity in our region. The study covered larch stands with a relative stocking level between 0.5 and 1.0. We excluded stands with the stocking level of 0.3–0.4 due to the probable effect of negative disturbances and higher than 1.0 – it is a small proportion. To eliminate the edge effect, we collected data only from stands larger than 0.5 ha where the centre of the sample plot was more than 30 m from the stand edge. To evaluate the influence of other tree species on larch growth, we divided the studied sites by species composition. The sites with three and more species were excluded from the research. We surveyed the stands between 30 and 60 years of age. We did not perform any research in younger stands, because interspecific interactions may not be visible yet. In addition, the older stands were also excluded due to the possibility of selective harvesting of other species with shorter rotation ages. Thus, it would not be possible to evaluate their interactions with larch.

Using the above listed criteria, we chose the study objects distributed throughout the territory of Lithuania (Fig. 1).

Field data collection. After the first stage, we started field data collection, evaluating the site type, dendrologic and dendrometric parameters of larch stands. Systematically distributed sample plots were established in all studied stands. The size of the sample plots was according to the National Forest Inventory (Kuliešis et al. 2010). The area of horizontal projection of the sample plot reached 500 m^2, radius – 12.62 m. The sample plots were distributed evenly every 50–100 m, depending on the stand size. The sample plot distribution was created using ArcMap software (Version 10.1, 2012). The initial point was selected randomly, and with the others located by applying a net, oriented by the north-south and east-west directions. Using ArcMap software we marked and numbered all the sample plots and identified their coordinates.

We surveyed larch stands during the vegetation periods 2015–2016. If the stand size was 0.5–1.0 ha, we established 3 sample plots, 1.1–2.0 ha – 4 sample plots, 2.1–3.0 ha – 5 sample plots, as well as in the stands > 3 ha – 7 sample plots. The number of

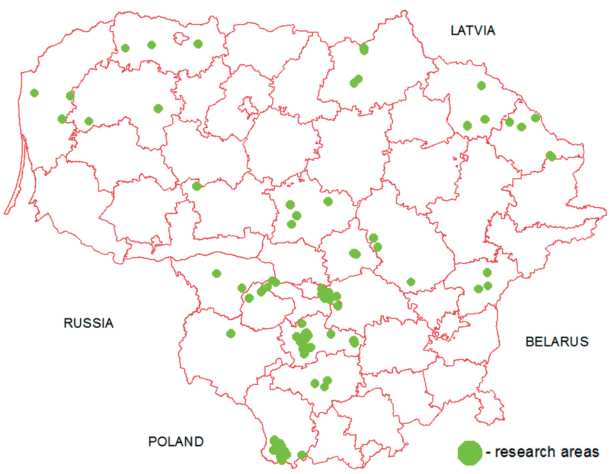

Fig. 1. The distribution of the *Larix* sp. research areas in Lithuania

the established plots was adjusted for every stand depending on the site configuration and dendrometric characteristics. During field works the sample plots were established with the portable GPS equipment Mobile Mapper 6 (Magellan, USA).

To evaluate the productivity of Lithuanian larch stands we considered the dendrologic and dendrometric aspects in each sample plot. We measured all the trees with diameter thicker than 8 cm (both living and dead) at breast height (1.3 m) and identified all larch species.

If the prevailing species in the stand were Siberian larch (*L. sibirica*), Russian larch (*L. archangelica*) or their admixture, we did not measure these stands and excluded them from any further part of this study.

For each tree in the sample plot meeting the above criteria we determined the following parameters:

(*i*) height – to the nearest 0.1 m, measured with a Vertex VL5 (Vertex, Sweden) combined ultrasound and laser height meter;

(*ii*) diameter – to the nearest 1.0 cm, at breast height, in two directions, using a calliper (Haglöf, Sweden);

(*iii*) tree condition (1–3 points, where 1 – good, 3 – bad) and its reasons, estimated visually.

For the larch trees, additionally we determined:

(*i*) Kraft development class – (I–V) – estimated visually, I – dominant trees, V – trees with poor and shaded crowns;

(*ii*) crookedness (1–3 points, where 1 – straight tree, 3 – crooked tree) – estimated visually;

(*iv*) type of crookedness (close to stump curvature, bow, zigzag, crookedness in the crown) – estimated visually;

(*v*) branch thickness (1–3 points, where 1 – thin branches, 3 – thick branches) – estimated visually. The volume of branches was automatically calculated using the formulas listed in the National Forest Inventory (Kuliešis et al. 2003).

The study covered 24.3% of the total area of larch stands in Lithuania with 50.5% of these stands selected during the first stage (e.g. potentially suitable for this research). We performed a field inventory in 138 stands (503 sample plots with the area of 207 ha) and measured 21,600 trees.

Statistical methods. All collected data was processed using MS Excel (Version 2003) and STATISTICA (Version 7.0, 2004) software. We calculated the Pearson correlation coefficient between the studied parameters, standard errors of the mean, average number per hectare and from this – the average growing space. We used analysis of variance to analyse the differences between group means.

RESULTS

General characteristics of stands

The analysis of the Forest Cadastre Database indicated that were 909 pure and mixed larch stands with the total area of 852 ha. The area of stands where the share of larch was at least 10% of the total stand volume was 2,358.3 ha or 0.1% of the total forest cover in Lithuania. The analysis of the ownership type showed that 53.6% of these stands were owned by the state, 43.3% by private owners, and 3.1% – other ownership types.

All larch stands in Lithuania were planted, and in many of them larch was mixed with other tree species. Larches were mostly mixed with Norway spruce (*P. abies*), Scots pine (*P. sylvestris*), common oak (*Quercus robur* Linnaeus), silver birch (*Betula pendula* Roth) and small-leaved linden (*T. cordata*). However, we found larch mixed with black alder (*Alnus glutinosa* (Linnaeus) Gaertner) and speckled alder (*Alnus incana* (Linnaeus) Moench). Larch stands comprising at least two other species were found on 45% of all sites. The proportion of pure larch stands where the volume of larch accounted for more than 86% of the total stand volume was only 35.6%.

Total composition of larch stand in Lithuania was: 80% *Larix* sp., 10% Norway spruce, 10% silver birch. Total composition of the mixed stand was: 60% *Larix* sp., 10% Scots pine, 10% Norway spruce, 10% silver birch, 10% other tree species.

Since larches are very productive, they often formed two-layered stands. The share of two-layered stands in Lithuania was 15% from the total area of larch stands and they were mostly formed by Norway spruce and lime trees (Table 1).

The second layer usually consisted of shade-tolerant species (93.2%), but it was not very dense and promising. The relative stocking level of the second layer was 0.1 (33%) and 0.2 (31.1%). Only 10.6% of the larch stands had the second storey with the higher relative stocking level 0.4–0.6 and the promising second layer was growing only on 5.3% of all sites.

According to the State Forest Cadastre stand database, larch stands were planted scattered. Prevailing are the stands with the area smaller than 1.0 ha (72.4% of all larch stands), the share of the sites of 1.1–3.0 ha was 24.1%, 3.1–5.0 ha – 2.7%. and 5.0 ha and more – 0.8% of all larch stands. The average area of the larch stand was 0.9 ha. Most of the larch stands were on soils with a normal moisture hydrological regime (Fig. 2).

Stand characteristics

We characterized stands by the relative stocking level, growth class, volume and stand density.

Larch stands in Lithuania have quite high relative stocking levels. The average relative stocking level of larch stand was 0.76 ± 0.004 (SE). On 57.0% of all cases we registered stands with a relative stocking level of 0.7–0.8. This equals to 495.3 ha. The relative stocking proportions < 0.3–0.6 and > 0.9–1.2 were

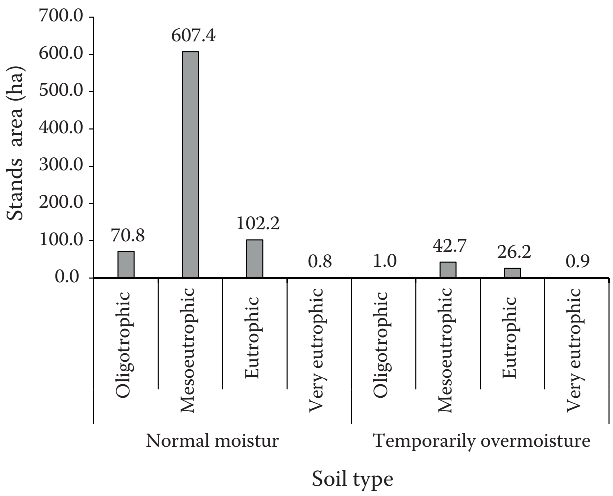

Fig. 2. The total areas of different site types covered by European larch stands

Table 1. The characteristics of the second layer in Lithuanian larch stands

Species	No. of stands	Area (ha)	Proportion (%)	Mean ± SE		
				age (yr)	height (m)	diameter (cm)
Picea abies (Linnaeus) H. Karsten	89	82.9	67.4	45.97 ± 1.04	13.83 ± 0.35	13.60 ± 0.35
Tilia cordata Miller	27	34	20.5	46.11 ± 1.32	17.96 ± 0.50	16.74 ± 0.49
Carpinus betulus Linnaeus	7	4.8	5.3	41.43 ± 3.40	15.86 ± 0.88	13.14 ± 0.59
Quercus rubra Linnaeus	2	1.1	1.5	42.50 ± 7.5	18.00 ± 1.00	19.00 ± 3.00
Acer platanoides Linnaeus	2	2.6	1.5	32.50 ± 7.50	14.00 ± 4.0	13.00 ± 3.0
Other species	5	4.2	3.9	29.60 ± 1.63	12.00 ± 1.34	11.20 ± 1.36
Total	132	129.6	100.0			

SE – standard error

18.8% (140.2 ha) and 24.2% (216.5 ha), respectively, from all Lithuanian larch stands. A higher relative stocking level was noticed for stands growing on light granulometric soils.

Of the European larch stands 60.5% were of growth class IA, 26.5% – growth class I, 11.0% – growth class II, and the share of the larch stands of growth class III was only 2.0%. Our study indicated that larch stands are among the most productive forest stands in Lithuania. Larches of both pure and mixed stands have high growth rates. Young stands (1–40 years) on average produced the volume of 168 $m^3·ha^{-1}$, mid-aged (41–90 years) – 369 $m^3·ha^{-1}$, pre-mature (91–100 years) – 457 $m^3·ha^{-1}$, mature (101–130 years) – 563 $m^3·ha^{-1}$, and overmature (> 130 years) – 625 $m^3·ha^{-1}$ of wood.

Pure stands of all age classes cumulated the higher average stand volume compared with mixed stands (Fig. 3a). The intensive volume increment was up to 40 (mixed) –50 (pure) years of age of European larch stands. In older pure and mixed stands (e.g. > 50 years of age) we observed the stabilization of volume increment.

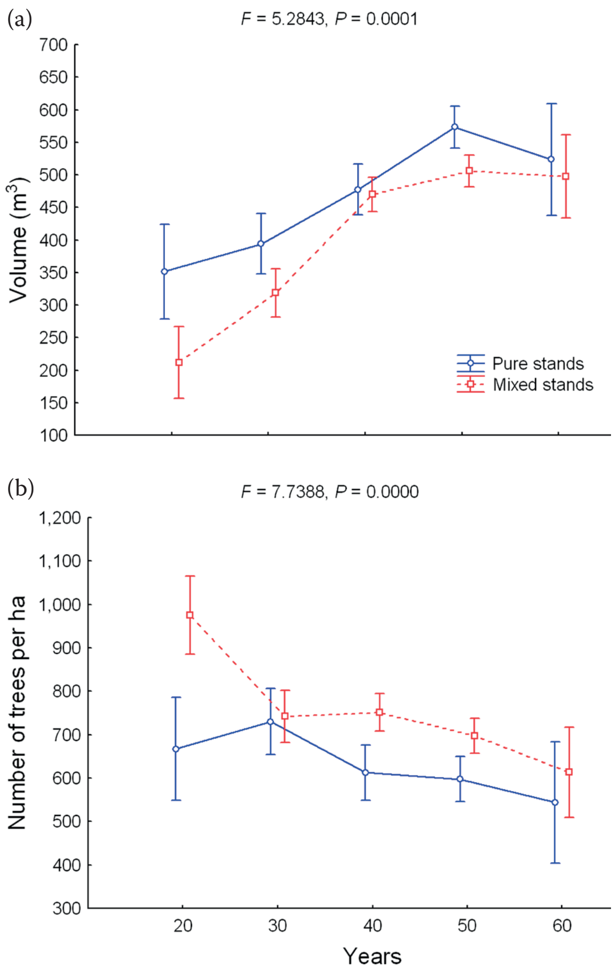

Fig. 3. Average volumes (a), number of trees per hectare (b) of larch in pure and mixed stands in Lithuania

The highest stand density was observed in the 3rd age class of European larch stands (Fig. 3b). At this age, the average nutrition area of a tree was 14.5 ± 0.515 m^2. The average nutrition area of a tree was 29% larger for stands of 4th and 5th age class. Finally, the average nutrition area of a tree increases up to 19.6 ± 0.920 m^2 in the 6th age class. The main drivers of an increasing nutrition area were natural tree selection and survival, i.e. this was evaluated in sites without any past management operations.

Pure larch stands were less dense compared to the mixed ones (Fig. 3b). The average tree number of the 2nd age class mostly differed, however that of the 3rd age class was mostly similar. The density of mixed stands mostly decreased during the period from 20 to 30 years. The density of pure larch stands during this period remained stable or insignificantly increased. A slow decrease of tree density observed later. The stand density influenced the average volume of the stem. The average volume of the stem of the 3rd age class reached 0.475 ± 0.009 m^3, 4th – 0.6257 ± 0.010 m^3, 5th – 0.936 ± 0.011 m^3, 6th – 0.971 ± 0.020 m^3.

Tree status and stem characteristics

The share of the trees of Kraft class I (dominant trees) in the larch stands was only 9.2%. The trees of Kraft class II with well-developed crowns dominated (34.8%), trees of Kraft class III (with slightly suppressed crowns) accounted for 31.1% , and the shares of the larches of classes IV and V (with poor crowns and shaded) were 11.6 and 13.3%, respectively.

In all stands with high initial density (both pure and mixed ones) we could observe large variation in the diameters of trees based on the Kraft classes (Fig. 4). The diameter of Kraft class I trees increas-

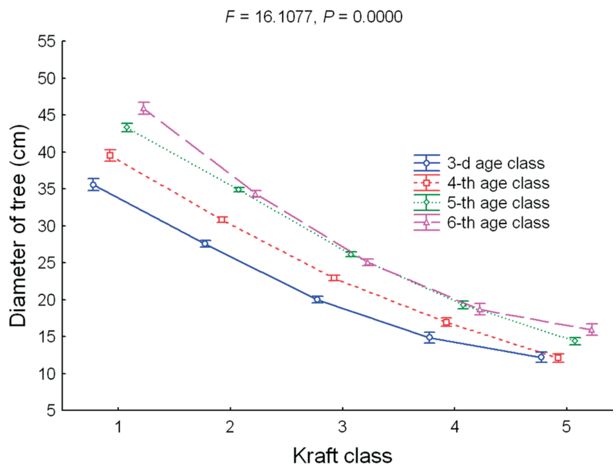

Fig. 4. The distribution of larch trees by the Kraft classes

es during 30–60 years of age (3rd–6th age classes), however trees belonging to Kraft class II-V at 60 years of age show reduced growth.

In the studied stands of the 3rd–6th age classes only 43.4% of larch trees were of good condition. The share of the trees with satisfactory condition was 41.8%, and bad condition 6.8%. Dead trees accounted for 10.7% of all evaluated larch trees.

The degeneration of the larch tree condition can be caused by many factors, however shading was the most frequent. The share of shaded trees was 82.2% of all trees in satisfactory and bad condition, 7.7% of such trees were wounded, 5.3% rotten and 4.8% were suppressed with broken and dry tops.

Although the studied larch stands were very productive and dense, the straightness of the stems varied, with 68.6% of high quality straight stems, followed by trees with average crookedness (22.4%), and trees with crooked stumps (8.9%). For the above-mentioned trees we evaluated the type of crookedness.

The most frequent crookedness was a zigzag shape, which could be noticed along the whole length of the stem. The proportion of the trees with such crookedness was 65.5% of all crooked larches or 20.5% of all studied larches. The share of the bow-formed larches was 15.9% of crooked trees and 5% of all studied larches. In the crown, the zigzag crookedness was observed in 5.3% of all cases and the bow type in 3.7% of cases. Close to the stump we most often registered crookedness of a bow type (6.7% of all crooked trees) or zigzag shape (3.0% of all crooked trees).

Canopy and branches

The economic value of trees depended on the amount and number of branches. Usually the crown of the larches took less than a half of the total stem length (Table 2). The most scarce cases were when the crown took < 25 or 50–74% of the stem length.

Table 2. Proportion of the stem length covered by the crown

Stem covered by the crown (%)	*N*	Proportion (%)
0–24	1,196	12.0
25–49	7,099	71.5
50–74	1,521	15.3
75–99	98	1.0
100	17	0.2

N – number of trees

European larches with thin branches were dominant (62.5% of cases) in the studied stands. The share of the larches with thick branches was 23.5%, and with very thick branches 14.3%.

The length of the larch stem, occupied by the crown, was similar both in pure and mixed stands. In the pure stands the crowns are smaller, however the difference was very small – 1.2%. The average volume of the larch branches was 0.07 ± 0.001 m^3, what was about 12.5% of the volume of the whole tree.

We evaluated branch thickness visually, dependent on the diameter of the trees and its position in the stand (Fig. 5).

DISCUSSION AND CONCLUSIONS

European larch is one of the most valuable introduced coniferous species in Lithuania. Larch is a fast-growing species, forming highly productive and resistant stands. Currently, the interest in larch cultivation has decreased due to poor cultivation selection during the 1960s. Unfortunately, neither *L. sibirica* nor *L. archangelica* was able to adapt to Lithuania's climatic conditions and as a result they were strongly affected by larch cancer and subsequently removed (Danusevičius et al. 2006).

The stands with at least a small proportion of larches occupy 0.12%, and the stands dominated by larch – 0.04% of the entire forest area in Lithuania. Although larch stands occupy only a small share of the forests, they have accumulated big wood volumes. The most productive overmature stands (Degsne larch stand) accumulated up to 1,300 m^3 of wood per hectare (Lithuanian State Forest Ser-

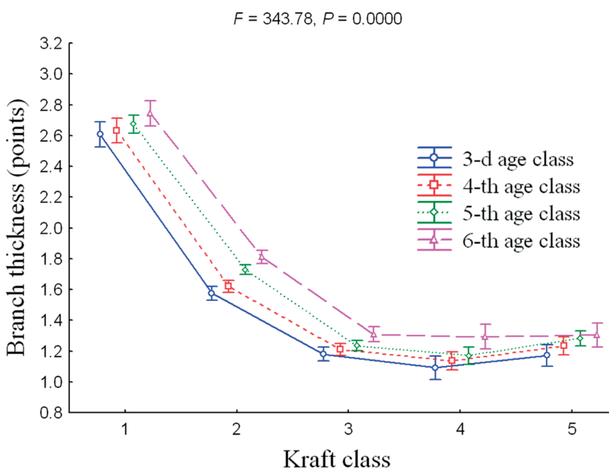

Fig. 5. Evaluation of branch thickness of European larch trees

vice 2017). At the age of 50 years, a larch stand can contain the same volume as a 100-year-old Scots pine stand. However, larch stands are not widely promoted in Lithuanian forestry. In neighbouring Poland the most productive larch stands accumulate around 700 $m^3 \cdot ha^{-1}$ of wood at the age of 70 years (Filipiak 1992).

The mean annual increment of larch stands in Lithuania is around 20 $m^3 \cdot ha^{-1}$, this results in the total stand volume of approximately 1,000 $m^3 \cdot ha^{-1}$ available for commercial cuttings applying a 50-year rotation (Jankauskas 1954). According to the modelling of spruce stands maximum productivity is 8.3 $m^3 \cdot ha^{-1}$, this results in the total volume of approximately 665 $m^3 \cdot ha^{-1}$ during an 80-year spruce rotation (Kairiūkštis, Juodvalkis 1985; Kuliešis 1989). The comparison of volume increments between the larch stands and the stands of other species within similar growth conditions showed that the difference between larch and birch stand volume increments increases with the age of 20 years – 20%; 50 years – 48%. The difference between volume increments of larch and pine stands is stable between 20 and 50 years (volume increment of pine stands is about 40% smaller than that of larch stands). Volume increment of spruce stands is also 23–32% lower than that of larch stands.

The stands of the main tree species are thinned according to the approved thinning regulations in Lithuania. However, no thinning regulations exist for European larch. During this research, we evaluated 138 stands, and none of them was thinned recently; this can be identified as the major problem for forest management of larch stands in Lithuania.

Due to fast growth and high accumulated standing volume, larch trees need larger nutrition areas than the other species. In the stands with the 6th age class, on average there are still more than 620 trees per hectare, this can probably reduce the average volume of the stem. After the comparison of the larch stands of the 5th and 6th age classes we can assume that the average volume of such stands is almost the same. In pure stands of the 6th age class it is up to 50 m^3 smaller than in the stands of the 5th age class. The reason for that could be that the stands of the 6th age class contained a high number of the trees of Kraft classes IV and V. The proportion of such trees was > 25%. Moreover, in such stands the volume of dry trees on average exceeded 10 $m^3 \cdot ha^{-1}$. Such growth conditions cause a higher volume loss than production. These results are consistent with Gradeckas and Malinauskas (2005). However, the described effect is much weaker in mixed stands, as other species compensate for the loss of growth in larch on such conditions.

The average difference between the stem volumes of the larch trees in the stands of the 5th and 6th age class is only 0.036 m^3, this means that if the stands were not thinned, it would result in large losses in timber volume. In the stands of the 6th age class, where the nutrition area for each tree is 20 m^2 and more, the average stem volume reaches up to 1.311 m^3. At the same time in the stands with higher density, where the nutrition area for each tree is smaller than 20 m^2, the average stem volume is 48% smaller. Due to the above-mentioned and other reasons, in the studied stands there are 56.6% of larch trees of satisfactory and bad condition.

Our study indicates that larch could be a good productive source of timber for the future in Lithuania. However, this would require the development of guidelines and regulations for larch stand forest management.

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