Basic wood properties of European larch from fast-growth plantations in eastern Canada

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A number of basic wood quality characteristics were evaluated in 10 European larch (*Larix decidua* Mill.) trees, 5 from each of two rapidly growing plantations in eastern Ontario (approximately 30 years old) and western Quebec (approximately 25 years old). Characteristics evaluated included growth rate, relative density, fibre dimensions, longitudinal shrinkage, alcohol–benzene and water-soluble extractives, and Klason lignin. Radial and longitudinal patterns of variation in wood characteristics were examined and particular attention was given to the distribution of juvenile wood within the stems. Extractive contents were more closely related to the extent of heartwood and sapwood in the stems than to differences between juvenile and mature wood. Relative density was generally lower at the centre of the stem than in the mature outer wood, but the change was usually gradual, with no distinct boundary between juvenile and mature wood zones. The most useful characteristic for delimiting the juvenile wood zone appeared to be longitudinal shrinkage. On this basis, the transition from juvenile to mature wood occurs at about 15 rings out from the pith at breast height. Ranking of individual trees for wood density was judged to be reliable at about 7 years of age at this height level.

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Un certain nombre de caractéristiques fondamentales témoignant de la qualité du bois ont été évaluées à partir de 10 arbres de Mélèze d'Europe (*Larix decidua* Mill.), 5 arbres provenant de chacune de deux plantations, l'une étant située dans l'est de l'Ontario (âgée approximativement de 30 ans) et la deuxième dans l'ouest du Québec (âgée approximativement de 25 ans). Les caractéristiques évaluées étaient le taux de croissance, la densité relative, les dimensions des fibres, le retrait longitudinal, la teneur en extractibles après extraction à l'alcool–benzène et à l'eau chaude et la teneur en lignine selon Klason. Les modes de variation longitudinale et radiale des caractéristiques du bois ont été observés, tout en portant une attention particulière à la répartition du bois de jeunesse dans les tiges. Les teneurs en extractibles se sont avérées être plus étroitement reliées à l'importance relative du duramen dans les tiges qu'aux différences entre le bois juvénile et le bois adulte. La densité relative est généralement plus faible au centre des tiges que dans la partie externe de bois adulte; toutefois, le changement était généralement graduel sans montrer de limite très distincte entre le bois de jeunesse et le bois adulte. La caractéristique la plus utile permettant de délimiter la zone de bois de jeunesse s'est avérée être le retrait longitudinal. En se basant sur ce critère, la transition du bois de jeunesse au bois adulte se produit, à la hauteur de poitrine, approximativement au 15$^{\text{ème}}$ cerne annuel depuis la moelle. Le classement des arbres par ordre de densité relative a été jugé fiable à compter de la 7$^{\text{ème}}$ année à cette hauteur.

[Traduit par la revue]

Introduction

Forest industries in Canada are entering a period of transition from harvesting wood from natural forest stands to obtaining their raw material supplies from managed forest plantations. In the establishment of such plantations, the choice of species is very important. Desirable characteristics include ease of production and planting, good survival rates, rapid growth, low susceptibility to pests, and favourable wood properties (Vallee and Stipanicic 1983).

Larix species have most of these qualities and therefore appear to offer good potential for use under intensive management. They combine good form and rapid juvenile growth with moderately high wood density and fairly good fibre characteristics (Balatinecz 1983). A number of exotic and hybrid larches have been grown in plantations in eastern Canada, and some of these have shown considerable promise. European larch (*Larix decidua* Mill.) is noteworthy in this respect. It has been under investigation in eastern Canada for over 30 years and has aroused a great deal of interest among foresters from Newfoundland to western Ontario (Balatinecz 1983).

Our reasons for carrying out the present investigations of European larch were twofold. First, Forintek Canada Corp. is involved in a long-term program to evaluate properties of fast-grown wood of all species capable of growing rapidly under intensive management in Canadian forests. Second, not much information is available on the properties of wood of Canadian-grown European larch, except for one report (Doucet *et al.* 1983) dealing mainly with wood density variation in Quebec plantation material.

Experience with native species has shown that faster growth rates and shorter rotation ages result in raw material characteristics that are significantly different from those of old-growth or unmanaged second-growth forest stands. This occurs because the young or "juvenile" wood formed near the centre of the stem (and characterized by differences in structure and properties from the "mature" outer wood) forms a much higher proportion of the total wood volume in these young trees. The high proportion of juvenile wood influences the conversion, strength, and other utilization characteristics of the material.

Obviously, it is becoming increasingly important for the wood-using industries to be aware of the changing nature of the raw material supply and to have available all the technical information necessary for the wise use of the forest resource.

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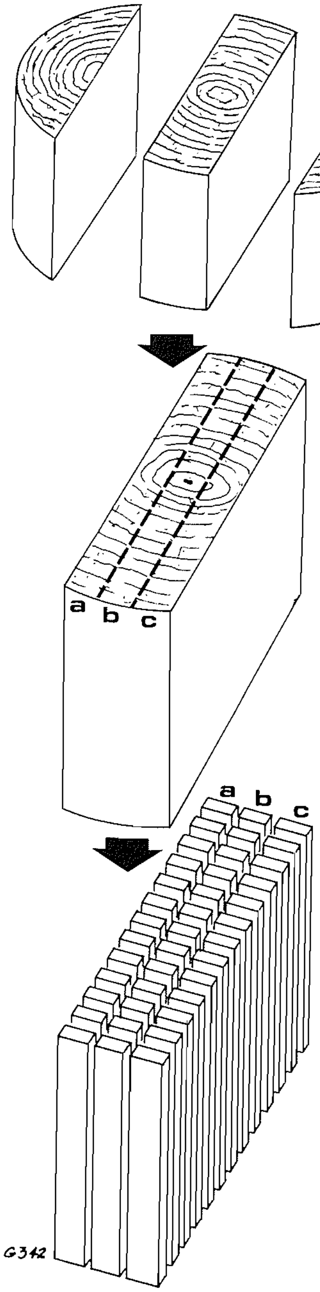

FIG. 1. Details of sample preparation for measurement of longitudinal shrinkage.

Materials and methods

Sample trees for study were obtained from two plantations of European larch, one at the Petawawa National Forestry Institute near Chalk River, Ontario, and the other at a Canadian International Paper Company research area near Harrington, Quebec. The Petawawa trees (site B) were 28 years old and ranged in diameter from 29 to 36 cm at stump level. The average diameter growth increment for the five trees was 1.2 cm per year. The trees in the Harrington stand (site A) were growing even faster. They were only 23 years old at stump level and ranged in diameter from 32 to 45 cm. The annual diameter growth increment for these trees averaged 1.6 cm and some of the largest trees had occasional radial growth increments of this width.

Five straight dominant trees on each site were selected and felled. Cross-sectional discs, approximately 15 cm thick, were cut from each tree at five height positions: breast height (1.4 m above ground) and successive intervals of one-fifth of total tree height. A disc (about 30 cm long) was also collected just above the breast height (BH) position as a source of material for longitudinal shrinkage measurements.

At the laboratory, all 15 cm thick discs were subdivided into three 5 cm thick discs which were designated for studies of (*i*) ring width and density, (*ii*) fibre dimensions, and (*iii*) chemical extractive contents. Discs for fibre-dimension studies were turned over to the University of Toronto.

Ring width and ring density data were determined by X-ray densitometry. The techniques and equipment used for this procedure were described in detail by Parker *et al.* (1980). Two basic forms of data were measured by the computerized densitometer: (*i*) distance, which represents the ring widths in 0.01-mm increments, and (*ii*) density, which represents the intraring density profiles with 0.05-mm resolution. Density values are expressed on the basis of oven-dry volume and weight, making them about 10% higher than basic density values, which are based on green volume and dry weight. Density profiles were prepared for two radii per disc and five discs per tree. To provide samples for measurement of longitudinal shrinkage, a short plank (approximately 20 cm long × 3.5 cm thick and containing the pith) was sawn through a selected clear diameter of each 30-cm bolt. The width of each plank corresponded to the bolt diameter. Three rows of individual test samples were cut from pith to bark along each radius (Fig. 1). These samples were 9.5 × 9.5 × 203 mm long, except that the length was frequently reduced to remove knots or other defects. A digital caliper coupled to a microcomputer was used to measure the length (to the nearest 0.01 mm) of samples when green and after oven-drying at 105°C. Shrinkage was calculated as a percentage of the original green dimension for each specimen.

Variation in extractives and lignin content was examined in all trees at two height levels: BH and 20% of total tree height. Individual samples were taken along selected radii in groups of 5 annual rings from the pith out to the 20th ring, and then in groups of 10 annual rings to the bark. These samples, consisting of about 10 g of air-dry wood, were ground in a Wiley Mill to pass a 40-mesh screen. For each sample, about 5 g of dry wood meal was extracted in a tared thimble in a Soxhlet apparatus. The first extraction solvent was alcohol-benzene (1:2, v/v); the second, after drying, was distilled water. Extractive contents were based on the dry weight of the extractive-free samples (TAPPI 1975).

The sequentially extracted and oven-dried samples were reacted with 72% sulphuric acid in micro-modifications of the Klason lignin determination (TAPPI 1974; American Society for Testing and Materials 1982).

Tracheid dimensions were measured at three radial and five vertical positions in each tree stem. Diameters were measured tangentially on transverse sections, normally in the latewood and in groups of 20 cells for each location. For fibre-length determinations, matchstick-sized samples of latewood from each of the three radial zones were macerated in a mixture of equal parts glacial acetic acid and hydrogen peroxide. Suspensions of washed fibres were deposited on glass slides and their images were projected onto a digitizer tablet. Twenty randomly selected whole fibres were scanned for each location and the information was fed directly into a microcomputer.

Results and discussion

Extractives

Data on extractive contents of sample material at breast height and at 20% of total tree height are summarized in Table 1. A series of pairwise comparisons revealed no significant differences between the two sampling heights in either alcohol–benzene or water-soluble extractive contents. Differences between the two sites, however, were significant at the 5% level of probability.

Radial distribution patterns of alcohol-benzene extractives for individual trees are illustrated in Fig. 2. It is

TABLE 1. Summary of chemical data for European larch wood at breast height and at 20% of total tree height

Age Group	Alcohol-benzene extractives (%)		Hot-water extractives (%)		Lignin content (%)	
	BH	20% ht.	BH	20% ht.	BH	20% ht.
Site A						
0–5 yr	1.87	1.34	7.78	8.09	29.97	29.64
	(0.44)	(0.37)	(3.74)	(2.17)	(2.22)	(0.98)
6–10 yr	2.09	2.17	8.51	11.43	32.78	28.21
	(0.55)	(0.41)	(2.35)	(2.66)	(2.91)	(2.86)
11–15 yr	3.44	0.82	14.44	5.09	28.69	27.39
	(0.39)	(0.48)	(2.86)	(1.92)	(1.77)	(1.47)
16–20 yr	0.73	0.62	4.21	3.33	26.73	26.63
	(0.33)	(0.29)	(0.79)	(1.23)	(0.48)	(0.80)
Site B						
0–5	4.26	3.02	8.93	8.62	29.22	28.37
	(1.20)	(1.80)	(1.30)	(2.54)	(1.04)	(1.99)
6–10	2.56	2.98	8.44	9.95	28.23	28.22
	(1.20)	(1.12)	(2.49)	(2.71)	(0.90)	(1.16)
11–15	3.82	3.28	14.46	9.10	28.37	28.36
	(0.83)	(1.46)	(2.67)	(1.37)	(0.73)	(1.00)
16–20	2.14	3.01	5.48	5.31	26.29	27.02
	(1.43)	(2.01)	(1.32)	(1.57)	(2.02)	(0.91)
21–30	1.79	2.22	5.52	5.28	26.21	26.73
	(1.50)	(0.92)	(0.91)	(1.08)	(1.27)	(1.80)

NOTE: Values are given as means, with standard deviation in parentheses (n = 5 trees from each site).

apparent that variability between trees is much greater on site B (Petawawa) than on site A (Harrington). Overall, however, the amount of alcohol–benzene extractives tends to remain relatively constant or increase slightly from the centre of the stem to the heartwood–sapwood boundary, then decrease markedly in the sapwood.

The amount of water-soluble extractives tends to increase from the pith to the heartwood–sapwood boundary, then decrease in the sapwood (Fig. 3). As observed with the alcohol–benzene extractives, there is considerable tree to tree variation. In this instance, site A trees show slightly greater variability than those on site B. The heartwood–sapwood boundary is the major factor influencing extractive level. It coincides with a drop in extractives in all trees examined.

The water-soluble extractives in larch consist mainly of the polysaccharide arabinogalactan (Côté *et al.* 1966). According to Simpson *et al.* (1968), wood from fast-growing trees (wide annual increments) tends to have more arabinogalactan than wood from slow-growing trees. As pointed out by Hillis (1971), the extractive content of conifers is related to heartwood formation, which in turn is a function of both age and growth rate. The low extractive contents (2–6% in most rings) of the 10-year-old Japanese larch trees studied by Isebrands and Hunt (1975) are explained by the fact that these young trees were composed mainly of sapwood. In trees 18–24 years old, Einspahr *et al.* (1982) found extractive contents of 3.9% (alcohol-benzene) and 5.3% (hot water) for Japanese larch, and 3.0% (alcohol-benzene) and 4.8% (hot water) for European larch. Depending on sample position in the tree, hot-water extractives of 8–12% were reported by Hakkila and his co-workers (Hakkila *et al.* 1972; Hakkila and Winter 1973) for Siberian larch wood.

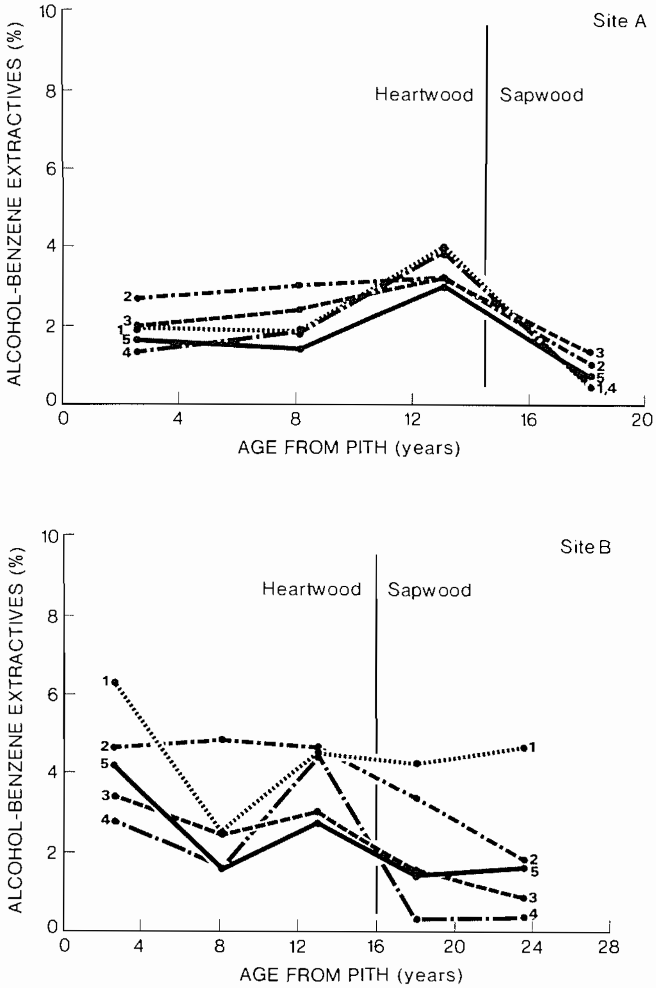

FIG. 2. Radial distribution of alcohol-benzene extractives in European larch trees (1–5) from two sampling locations.

Lignin content

Average lignin content at different radial positions in the five trees generally ranged from 26 to 30%, including both sites and both height levels in the stem (Table 1). An exception to this, however, occurred with the samples aged 6–10 at breast height on site A (Fig. 4), where high lignin content in four of the five trees resulted in an average of 33%. In general, lignin content tended to be higher near the pith, diminishing slightly toward the bark. This trend is much clearer for site B than for site A, which is characterized by considerable within-tree and between-tree variability.

Not much information is available on variation in lignin content within a tree. Increases in cellulose content during the first 6–10 years, shown by Wardrop (1951), are consistent with decreases in lignin during the same period. One possible explanation for this is that the shorter tracheids near the pith have a higher proportion of middle lamella associated with them.

Chemical summary

Our data on extractives and lignin content for both sites and two height levels are shown in Table 1. The contents of alcohol-benzene and water-soluble extractives corresponded closely to the transition from sapwood to heart-

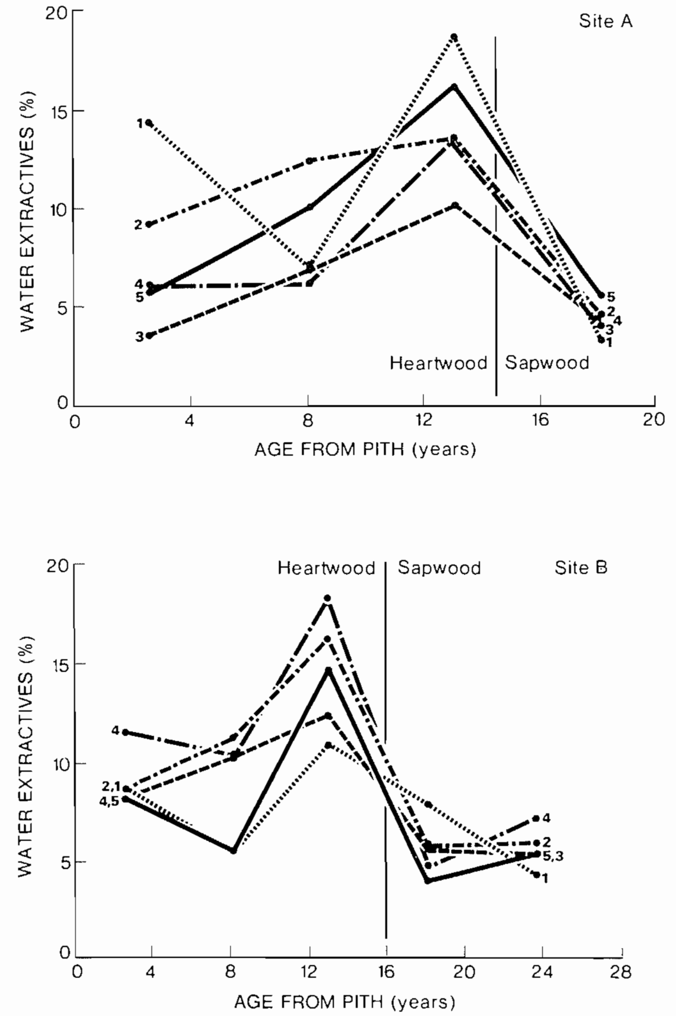

FIG. 3. Radial distribution of water-soluble extractives in European larch trees (1-5) from two sampling locations.

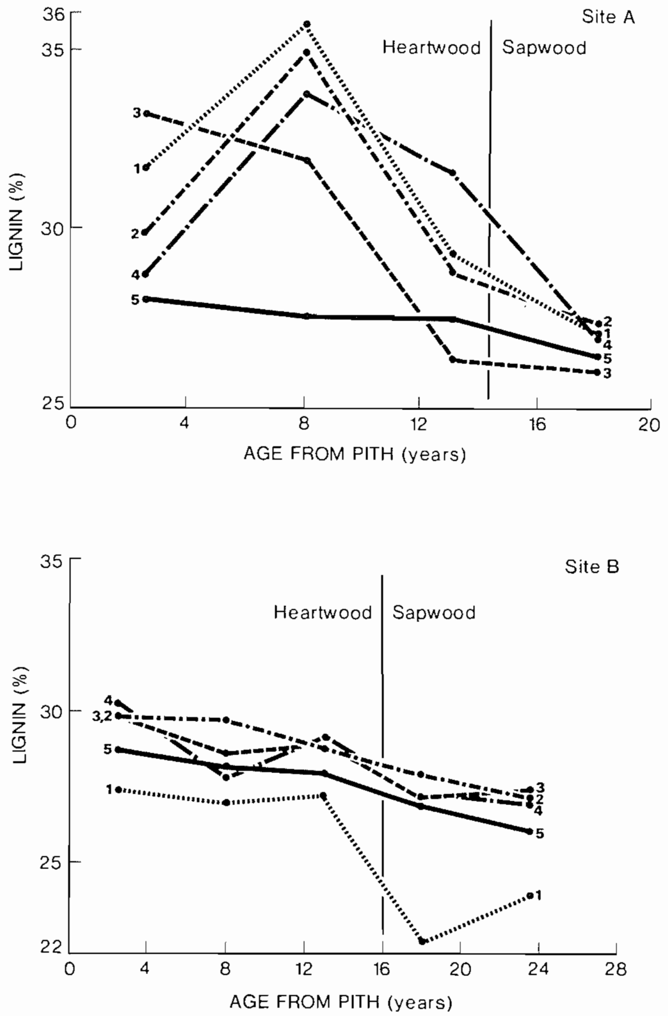

FIG. 4. Radial distribution of lignin content in European larch trees (1-5) from two sampling locations.

wood, rather than to the transition from juvenility as such. Lignin content, on the other hand, did not appear to be similarly related. Rather, it tended to decrease very slightly and gradually outward from the pith.

Longitudinal shrinkage

Normal longitudinal shrinkage of wood is typically very low: only about 0.1-0.2% from green to oven-dry condition (Panshin and de Zeeuw 1970, p. 205). However, a number of wood characteristics can cause longitudinal shrinkage to exceed normal levels. These include the presence of knots, cross-grain, and conditions associated with abnormally high microfibril angles, such as compression wood and juvenile wood. In normal, straight-grained wood there is a direct relationship between longitudinal shrinkage and cellulose microfibril angle in the secondary cell wall (Harris and Meylan 1965; Meylan 1968). In such wood, therefore, longitudinal shrinkage should serve as an indirect measure of fibril angle. As high microfibril angle is a characteristic feature of juvenile wood, the possibility of using longitudinal shrinkage information to assess the extent of juvenile wood in these young, fast-growing trees was examined.

Our data on longitudinal shrinkage are plotted for both sites in Fig. 5, and not only illustrate the relationship between longitudinal shrinkage and juvenile wood, but also reflect the influence of other characteristics on the variability of longitudinal shrinkage data. For example, the correspondence between the high longitudinal shrinkage points in the area of rings 6-8 for site A, shown in Fig. 5, and the high lignin values of the same rings in some trees (Fig. 4) suggests the influence of compression wood in this area. On both sites, longitudinal shrinkage is typically highest in wood close to the pith, declining rapidly in older growth layers to eventual stability at values of about 0.2% or lower. In spite of the variability in the longitudinal shrinkage data associated with other factors, Fig. 5 can be used to estimate the transition age between juvenile and mature wood. On this basis, the transition appears to occur at approximately 12-16 rings from the pith for site A and at approximately 10-14 rings for site B.

Closer assessments of the influence of juvenile wood and the other factors on longitudinal shrinkage were made by plotting shrinkage patterns from pith to bark separately for the two sample radii on each tree. Differences between radii within stems were indicators of abnormal wood characteristics (such as cross-grain and compression wood) in specific parts of the stem. The presence of substantial between-tree variation in longitudinal shrinkage suggests the potential for selection of individuals with less longitudinal shrinkage in the juvenile zone.

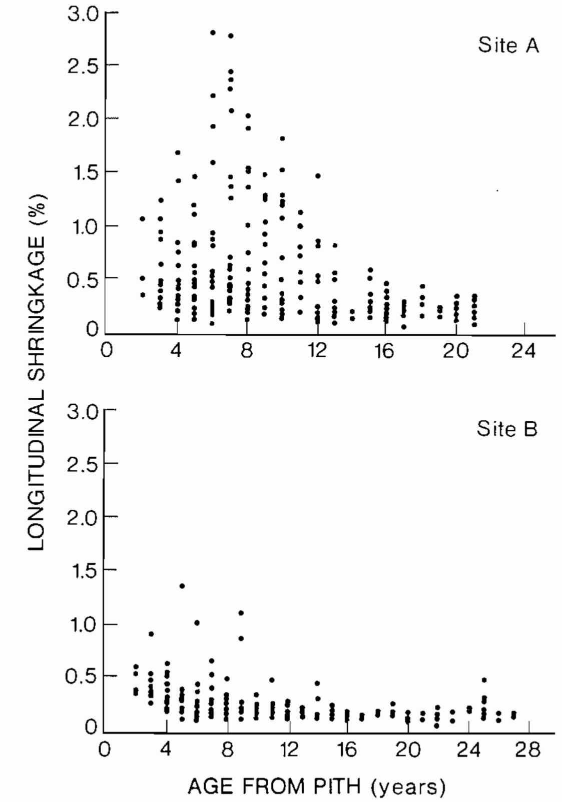

FIG. 5. Longitudinal shrinkage of European larch wood in relation to age from the pith.

TABLE 2. Longitudinal shrinkage of juvenile wood

	% longitudinal shrinkage		No. of rings from pith to 0.2% longitudinal shrinkage	
	Mean	Range	Mean	Range
Site A	0.87	0.37–1.59	12	5–19
Site B	0.52	0.34–1.33	10	5–16

NOTE: Only data from radii where longitudinal shrinkage was 0.2% or less in the outer wood are included.

Longitudinal shrinkage plotted along individual radii (two per tree) sometimes did not reach the normal low of 0.2% expected for mature wood. We tried to minimize the influence of abnormalities in the sample material by carrying out a second analysis which excluded the data from these radii. The results are shown in Table 2. Shrinkage values declined rapidly during the early years, reaching the 0.2% level after an average period of about 10–12 years. As an estimate of the length of the juvenile period for European larch, it agrees with that suggested by Isebrands and Hunt (1975) for Japanese larch grown in the north central United States.

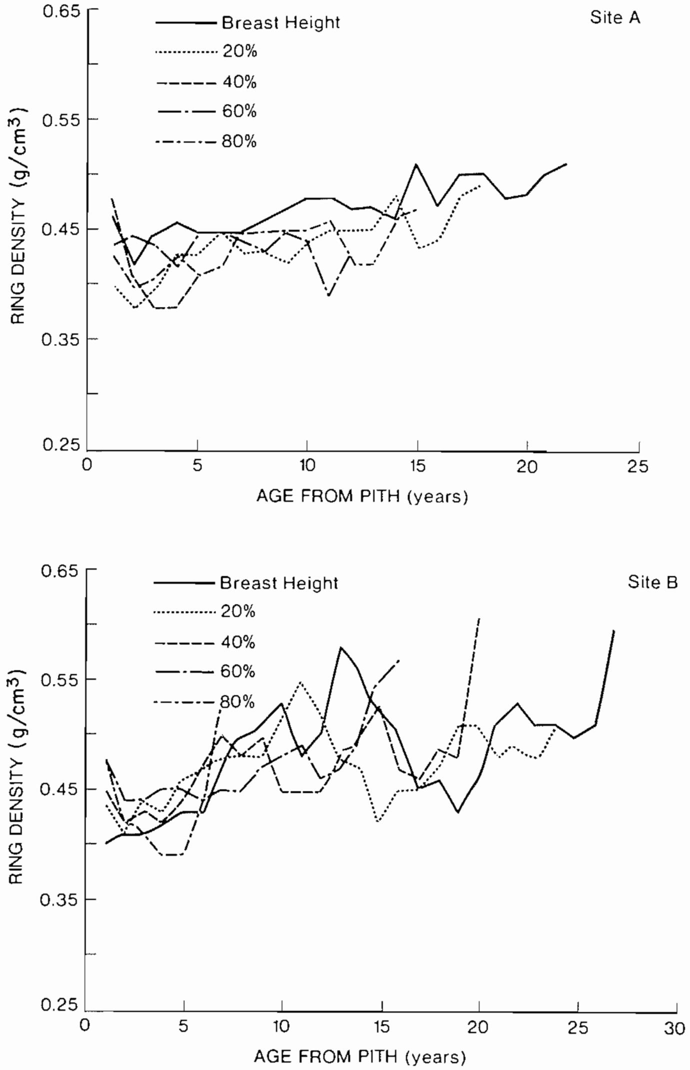

FIG. 6. Average ring densities for five European larch trees at five height levels.

Relative density

Average ring densities from pith to bark for the five trees at the five sampling height levels are shown in Fig. 6. Declines in density in the first few annual rings adjacent to the pith were generally followed by gradual increases with age. On site A, density was generally highest at breast height, declining somewhat toward the upper height levels. The tendency for wood density of *Larix* species to decrease with height in the stem was reported by Okkonen *et al.* 1972 and by Einspahr *et al.* 1982. This pattern was not evident in the site B trees. Fluctuations in ring to ring density occurred at all height levels. These fluctuations, assumed to be associated with climate and other factors, were much more pronounced on site B than on site A.

Total-stem densities of the sample trees plotted against breast-height age illustrate the differences between individual trees (Fig. 7). These differences are substantial (20–25%) on both sites and demonstrate the tremendous potential for controlling this important property of wood through selection and breeding programs. Rankings of the individual trees by wood density show variation in the early years (especially on site A), but reasonable stability is achieved beyond a breast-height age of about 7 years.

When averaged over all trees on site A, total-stem density declines for a few years initially, then increases gradually until it levels off at a breast-height age of about 15 years (Fig. 8). Perhaps this can be considered as the point at which a mature wood density value (approximately 0.43 g/cm^3, Fig. 8) is reached. The curve for site B lacks the initial decline and stabilizes at the slightly higher density value of 0.47 g/cm^3 (Fig. 8). Wood density increases about 15% by

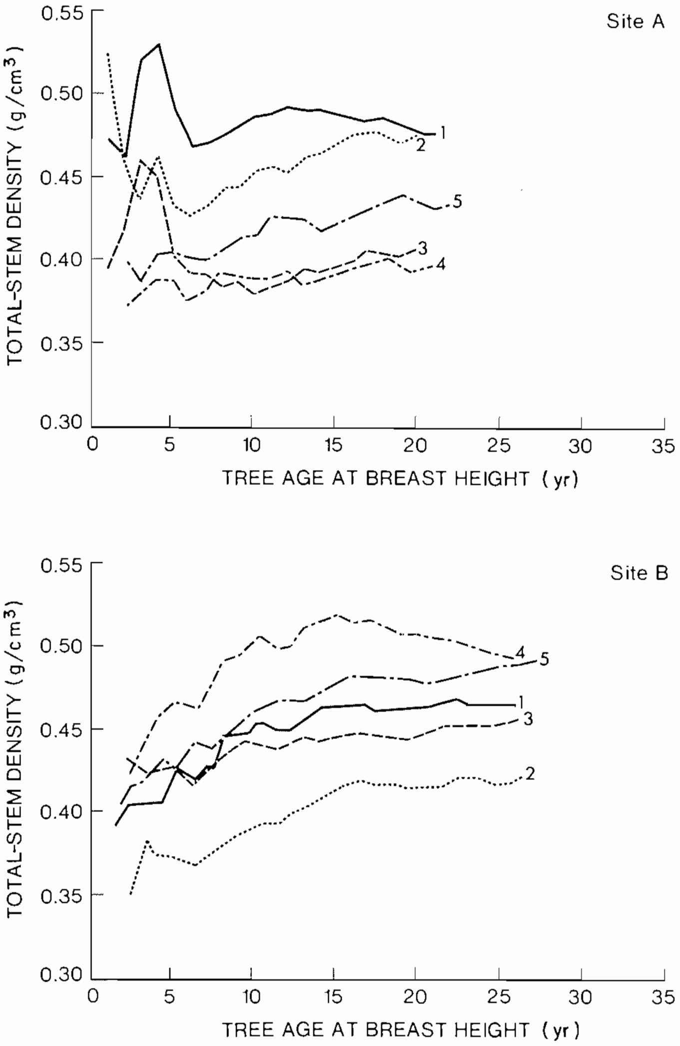

FIG. 7. Patterns of variation in total stem density with age for individual trees (1-5).

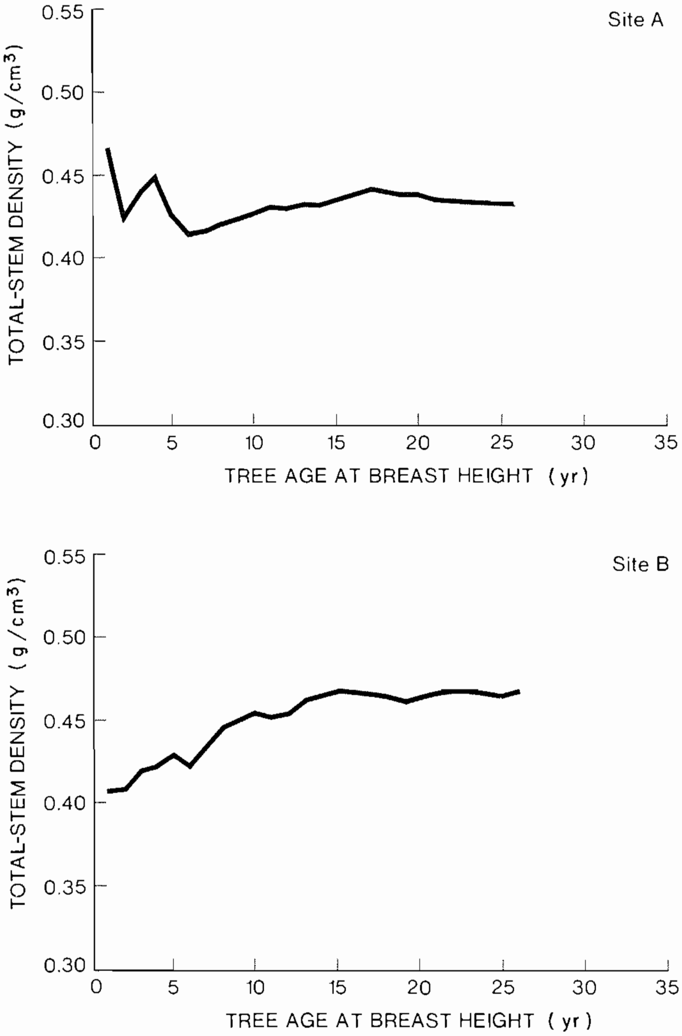

FIG. 8. Average patterns of variation in total-stem density with age.

TABLE 3. Average tracheid length (mm) in European larch

Height level	Near the pith (rings 1-2)	5-6 rings from the pith	Outermost two rings	No. of rings to the bark
		Site A		
BH	1.29 (0.30)	1.88 (0.29)	3.39 (0.39)	22
20%	1.17 (0.24)	2.81 (0.22)	3.71 (0.41)	18
40%	1.10 (0.13)	2.39 (0.27)	3.59 (0.17)	15
60%	1.17 (0.10)	2.73 (0.20)	3.29 (0.41)	12
80%	1.26 (0.36)	2.49 (0.28)	3.04 (0.16)	7
Avg.	1.20 (0.22)	2.46 (0.25)	3.40 (0.31)	15
		Site B		
BH	1.22 (0.09)	2.41 (0.25)	3.58 (0.51)	27
20%	1.10 (0.13)	2.46 (0.13)	3.46 (0.40)	24
40%	1.27 (0.30)	2.26 (0.30)	3.38 (0.37)	20
60%	1.33 (0.29)	2.42 (0.25)	3.63 (0.47)	16
80%	1.26 (0.25)	2.15 (0.36)	2.88 (0.17)	7
Avg.	1.24 (0.14)	2.34 (0.11)	3.19 (0.18)	19

NOTE: Values are given as means, with standard deviation in parentheses.

age 15 on site B, compared with an increase of only about 5% on site A.

Fibre dimensions

Data on tracheid length and tangential diameter, measured at three radial and five vertical positions in the tree stems, are summarized in Tables 3 and 4. The patterns of variation in tracheid length and diameter are essentially similar. Radial variation is significant; cell dimensions increase outward from the pith at all height levels. At a given

TABLE 4. Average tracheid diameter (μm) in European larch

Height level	Near the pith (rings 1–2)	5–6 rings from the pith	Outermost two rings	No. of rings to the bark
		Site A		
BH	42.7 (6.3)	50.8 (4.7)	59.5 (6.9)	22
20%	40.2 (4.1)	54.0 (5.0)	57.8 (3.6)	18
40%	39.2 (1.5)	51.5 (1.6)	53.8 (9.5)	15
60%	39.5 (3.1)	50.7 (2.1)	49.8 (3.5)	12
80%	41.5 (2.5)	53.3 (1.4)	51.0 (3.3)	7
Avg.	40.6 (3.5)	52.1 (3.0)	54.4 (5.4)	15
		Site B		
BH	36.2 (1.0)	51.8 (4.7)	58.4 (5.3)	27
20%	36.4 (2.7)	50.8 (5.8)	60.4 (6.2)	24
40%	39.2 (3.1)	51.2 (3.0)	53.4 (6.3)	20
60%	40.0 (4.9)	48.0 (3.6)	49.6 (8.9)	16
80%	38.4 (1.7)	49.0 (6.9)	48.6 (8.0)	7
Avg.	38.0 (2.2)	50.2 (3.3)	54.1 (3.2)	19

NOTE: Values are given as means, with standard deviation in parentheses.

radial position, variation with height in the stem is insignificant. In most instances, cell dimensions are still increasing at the bark, indicating that they have not yet reached their maximum size in these relatively young trees.

Conclusions

European larch is capable of extremely rapid growth (40 cm in diameter and 60 m in height in about 25 years) on good sites in eastern Canada. Oven-dry density of wood from such trees averaged 0.45 g/cm^3, or approximately 0.40 g/cm^3 basic density. Density was generally lower near the centre of the stem than in the mature outer wood. Mature density values were usually reached at about 15 rings from the pith. Ranking of individual trees for wood density was reliable at about 7 years of age at breast-height level.

Significant amounts of water-soluble extractives were found, as expected in larch trees. Extractive contents were highest in the outer heartwood, reaching almost 20% in this region for some trees. On the basis of longitudinal shrinkage, the transition from juvenile to mature wood occurs at about 15 rings from the pith at breast height. Tracheid dimensions, on the other hand, do not appear to reach fully mature values in these relatively young trees.

Acknowledgements

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