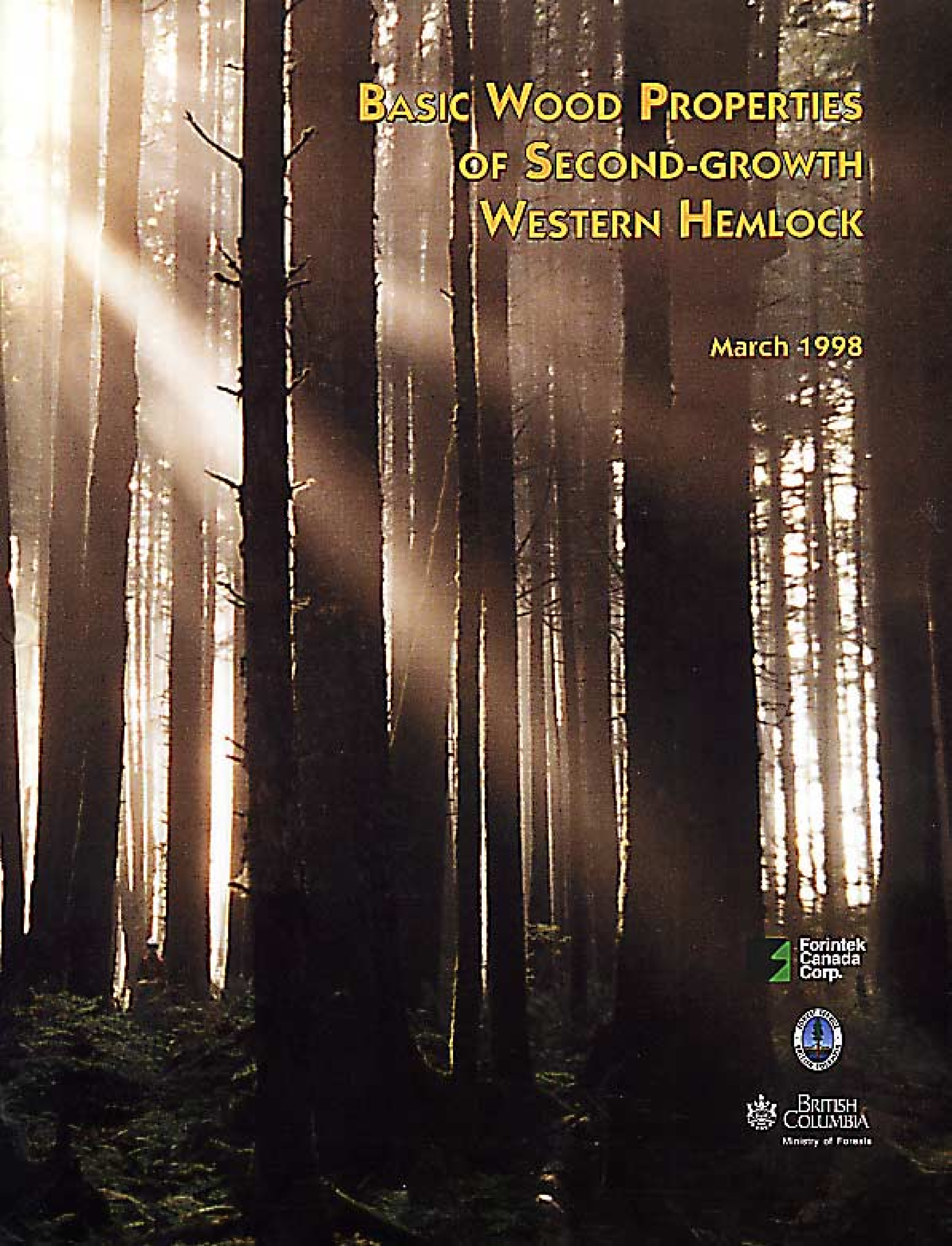

Basic Wood Properties of Second-growth Western Hemlock

March 1998

Forintek Canada Corp.

British Columbia
Ministry of Forests

Basic Wood Properties of Second-growth Western Hemlock

by

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prepared for

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Abstract

This report describes some of the background and results of work done to date on second-growth western hemlock basic wood properties at Forintek Canada Corp. The B.C. Ministry of Forests Research Branch, UBC Forestry Faculty and PAPRICAN were the other cooperating agencies on this project and they investigated live crown/tree growth relationships, strength properties of small clears, and pulping properties, respectively.

Properties that were assessed by Forintek, both within and between trees, include: relative density of wood, shrinkage, moisture content, relative proportions of heartwood-sapwood, bark thickness, content and distribution of compression wood, incidence and degree of spiral grain, incidence and severity of brown stain, and bending strength of small clear samples.

Naturally grown 90-year-old western hemlock stands represent much of the emerging timber supply in the B.C. coastal forest region. Information characterizing the commercial quality of this resource is needed now to support processing and marketing decisions and for product promotion. In addition, the Ministry of Forests and industry members are making stand management decisions today that will influence the future quality of western hemlock. We can reduce the risk of making wrong management decisions by providing information on how different growing conditions (e.g., biogeoclimatic zone, site, stand density, and thinning) affect second-growth wood quality.

Acknowledgements

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We thank Dr. Robert W. Kennedy, Dean Emeritus, Faculty of Forestry, UBC, Dr. Graham Mackay and Mr. Ron Nielson, Forintek Canada Corp. for reading the manuscript and for offering valuable comments. Special thanks are extended to Dr. Clayton Keith for his final pre-publication review. We remain solely responsible for the final contents.

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1 Objective

The objective of this study is to examine important physical and mechanical wood properties of rapidly grown second-growth western hemlock (*Tsuga heterophylla (Raf.)* Sarg.) from selected locations in British Columbia.

2 Introduction

Western hemlock was considered a "weed species" until the late 1930s because of excessive warp during drying. However, the development of suitable lumber drying schedules has made the wood suitable for a wide variety of products. Although western hemlock ranks only slightly behind Douglas-fir and western larch in strength, currently only 15% of the lumber cut in B.C. is used for structural purposes; 85% is used in non-structural products. The light, even colour of the wood, lack of pitch, its ability to take finishes and to glue well, and its excellent machining (cutting, planing, sanding, and turning) properties make the wood desirable for door, window and staircase components, moulding, panelling, flooring, joinery, and architectural trim.

3 Background

3.1 Variability in Wood Density

Old-growth forests remain an important part of B.C.'s annual timber production, and therefore, published data on basic wood properties are still based on old-growth wood.

The transition from old growth to second growth (first to natural stands, then to extensively managed stands), and ultimately to silviculturally manipulated stands, will result in changes to timber size and also to timber characteristics. One important change will be the increased proportion of juvenile wood relative to mature wood. This has implications for previously established standards of comparison. Wood density surveys during the last 50 years have established expected norms for all commercially important tree species. For example, we can find the following average basic relative density values for Douglas-fir (0.45), western larch (0.45), western hemlock (0.42), yellow-cedar (0.42), lodgepole pine (0.41), interior spruce (Engelmann and white) (0.36), Sitka spruce (0.35), western redcedar (0.33), and subalpine fir (0.33) (Jessome, 1977; Nielson *et al.*, 1985; Gonzalez, 1990). Because of the time of these density determinations, and the nature of the sample material, these values are essentially old-growth reference values, which are becoming increasingly less applicable as second-growth stands become more prevalent.

For second-growth western hemlock, very little published information is available for geographic, tree-to-tree, pith-to-bark, and within-annual-ring density variation. These concepts are illustrated in Figure 1. The only thing we can state with confidence is that, at the microscopic level, solid-wood substance basic relative density is 1.1 (1.53 on the oven-dry basis) and lumen (air cavity in the fibre) relative density is zero (Figure 1e).

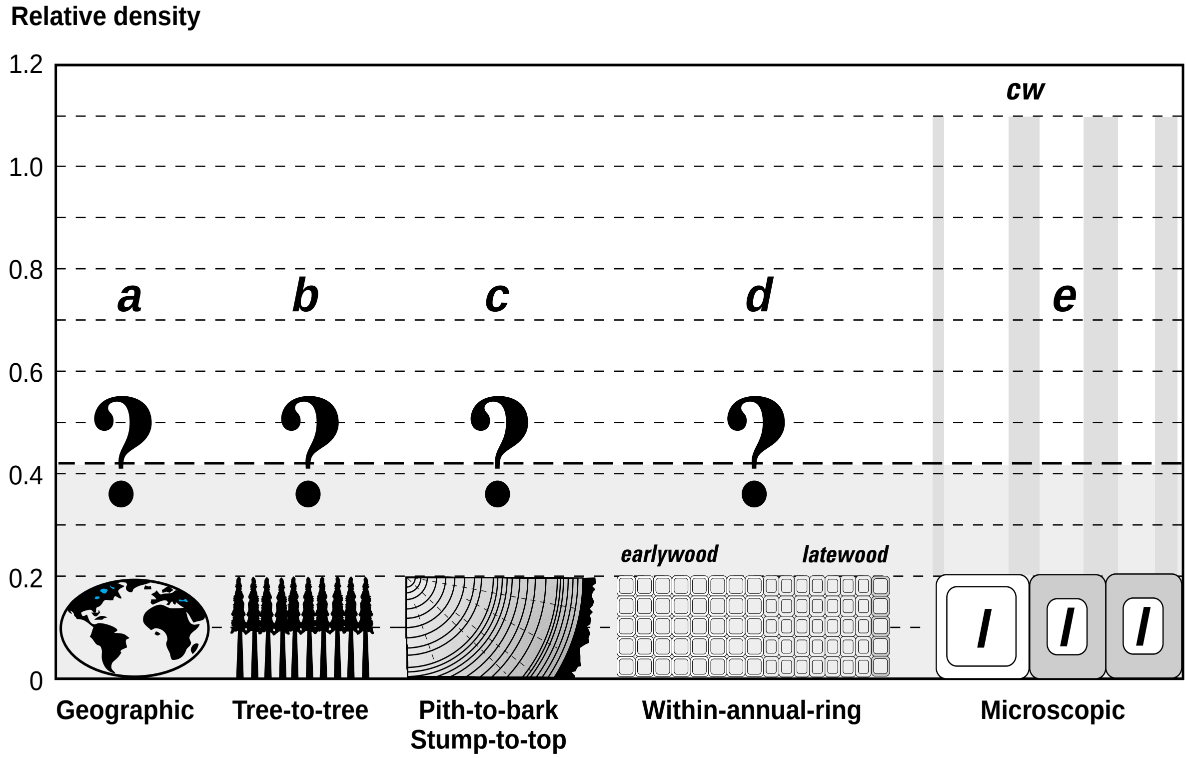


Figure 1. Relative density variation in western hemlock wood from different perspectives.

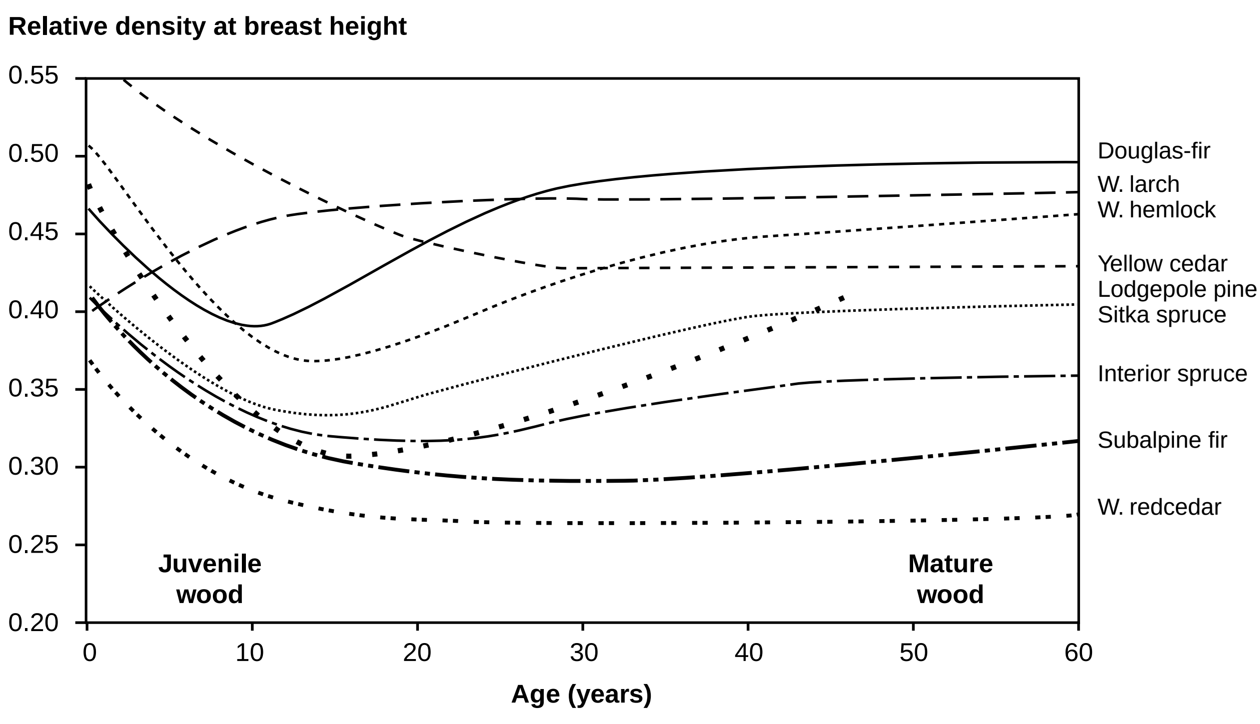
Generally, the relative density of wood for most tree species in North America has a coefficient of variation (COV) of about 10% (Haygreen and Bowyer, 1989; International Standard, ISO 3129–1975(E)). To estimate the range of wood densities one might normally expect to encounter in a given species, the COV is multiplied by the average density and by 1.96 (to include 95% of a normally distributed population). This figure is then added to and subtracted from the mean. For example, the average basic relative density of western hemlock stemwood from the technical literature is 0.42 (Jessome, 1977; Gonzalez, 1990). Therefore, the normal range of stemwood density to be expected in western hemlock is 0.42±0.08 or 0.34–0.50.

For western hemlock, the earliest systematic radial density data were collected by Weldwood and Smith (1962) on 94 young fast-grown trees, with rather uniform annual rings averaging about 5 mm wide from pith to bark. They noted the greatest density in rings 1–5 (0.47) and a steep decline to 0.37 in rings 16–20. This trend gradually was reversed, but the oldest wood of age 26–29 still had recovered to only 0.42. Another sample of 22 older trees showed minimum relative density (0.41) in a broad band from rings 21–30 through 41–50, after which density increased to 0.45 by 80 years.

Krahmer (1966) found highest relative density (slightly greater than 0.50) at ring 1, with a subsequent decrease through a distance of 5 cm (age not specified) from the pith after which it levelled off at slightly less than 0.40, from which it displayed only minimal regain. He noted that beyond the core zone (radius 5 cm), there was a significant negative relationship with rate of growth (r^2=0.23). Megraw (1985) shows a sample of 24-year-old western hemlock to have highest density (0.46) at ring 2, with a broad low point (0.36) from age 6 to about 20, with only a small recovery to about 0.38 in the oldest wood (at age 24).

Weldwood (1960), Kennedy and Swann (1969) and De Bell *et al.* (1994) all have shown density to be negatively correlated with growth rate. However, the two earlier studies did not look at the independent effect of age, it being confounded with ring width. The latest study compared trees within the confines of a similar age cohort (rings 20–24) and found a significant negative relation between density and growth rate (r^2=0.39) due largely to decreasing latewood percentages in wider rings. They found that latewood width was relatively constant regardless of growth rate so that percentage latewood was less in wider rings, leading to lower density.

Figure 2 shows a comparison between average ring density trends at breast height (BH) from pith to bark of a limited sample of rapidly grown second-growth woods. Wood juvenility can be evaluated by examining a number of different variables (e.g., fibre length, fibril angle, longitudinal shrinkage, lignin/cellulose ratio) but here average ring density was used. *It is important to note that not all species have low density juvenile wood (usually the first 20–30 years of growth).* In yellow-cedar, white/Engelmann spruce, western redcedar and subalpine fir, the inner juvenile wood is of comparatively higher density than the outer mature wood. Forintek has reported on the extent and distribution of low-density juvenile wood in second-growth Douglas-fir and lodgepole pine. Although lodgepole pine has a longer period of juvenility than Douglas-fir, the difference between low-density inner wood and high-density outer wood is about one half of that in Douglas-fir and western hemlock. Western hemlock's trend line shows a relatively long low-density juvenile wood period, possibly the result of its shade tolerance (crown persistence). *It is important to keep in mind that these examples represent the most vigorous forest-grown trees we could find.* The rationale was that if there were no problems with rapid growth, more normal growth rates would pose no problems either.



Note: Average trend lines are based on examinations and summaries of various numbers of trees as follows: Douglas-fir – 60 trees; lodgepole pine – 60 trees; Sitka spruce – 20 trees; subalpine fir – 15 trees; western hemlock – 26 trees; western larch – 15 trees; western redcedar – 10 trees; white/Engelmann spruce – 20 trees.

Figure 2. Average ring density trend from pith to bark in some second-growth woods.

Within-annual-ring density variation is illustrated in Figure 1(d). Density variation between earlywood and latewood can be just as important a measure of a wood's suitability for some end uses as the average density (Echols, 1972). For example, density uniformity makes old-growth yellow-cedar, white pine, lodgepole pine, and western hemlock such excellent carving and turning stocks. Veneer peeling and slicing are also processes where a high degree of uniformity is very beneficial.

Depending on species and the age of wood, within-ring minimum density values range from 0.25 to 0.40, while maximums are in the 0.6 to 0.9 range as shown in Figure 3. This illustration shows typical intra-ring density profiles at BH for Douglas-fir, yellow-cedar, western larch, and lodgepole pine. Data are plotted according to standardized ring width (for ease of comparison) for the juvenile wood (rings 5–9) and for the mature wood zone (rings 45–49). Figure 3 shows the earlywood–latewood boundary at 0.42 because of the low-density latewood in yellow-cedar and lodgepole pine. In this study, 0.52 was chosen arbitrarily for separating earlywood and latewood in western hemlock; that is, any portion of the annual ring that had relative density ≥0.52 was classified as latewood.

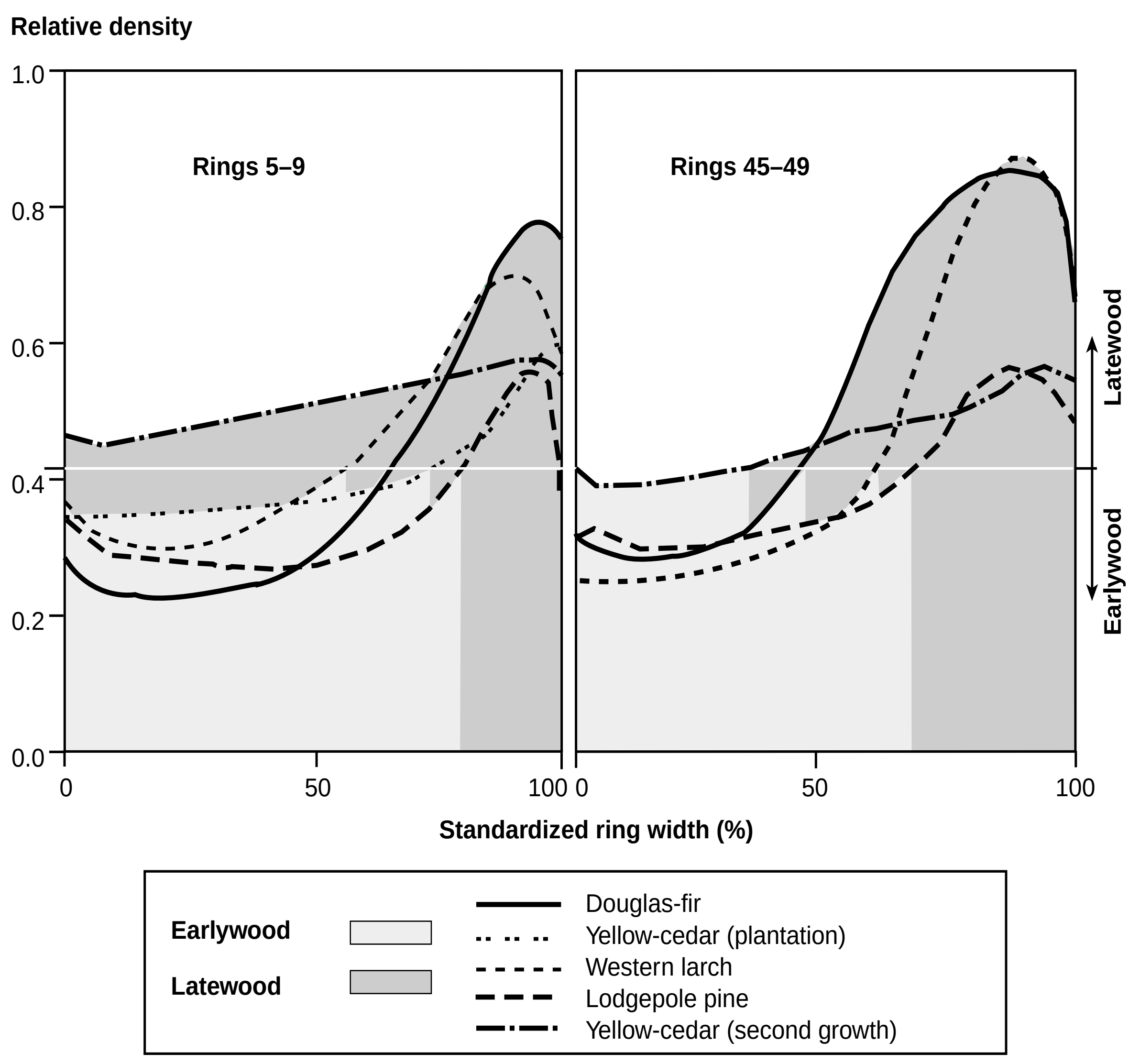


Figure 3. Intra-ring density profiles plotted according to standardized ring width.

With the exception of yellow-cedar (juvenile wood 5–9), a well-defined low-density earlywood is evident in both the juvenile and mature wood zones of the other three species (Figure 3). Note also that higher density wood in the mature wood of western larch, Douglas-fir, and lodgepole pine is the product of higher latewood density and a greater proportion of latewood. In Douglas-fir, a heterogeneous wood, the density range is between 0.25 to 0.85. In yellow-cedar, a homogeneous wood, the within-ring wood density range is between 0.4 and 0.6. The greater density variation in Douglas-fir is apparent on all wood surfaces (i.e., end grain, edge grain, and flat grain, through the visual contrast between the light-coloured earlywood and the dark-coloured latewood). Conversely, homogeneous woods have little contrast between earlywood and latewood; they do not show prominent figure.

3.2 Shrinkage, Dimensional Stability

Shrinkage of the fibre wall, and therefore of the whole wood, occurs as bound-water molecules escape from spaces between the long-chain cellulose molecules. These cellulose molecules can then move closer together. The amount of shrinkage that occurs is generally proportional to the amount of water that is removed from the wood, and the orientation of microfibrils in the cell wall and the relative density of the piece. Swelling is simply the reverse of this process (Panshin and de Zeeuw, 1970; Hoadley, 1986; Haygreen and Bowyer, 1989).

Figure 4 shows the volumetric shrinkage of western hemlock compared with 18 other Canadian softwoods from green condition to 12% equilibrium moisture content. It is apparent that higher density woods shrink more than lower density woods. Notable exceptions are eastern white pine, Jack pine, and yellow-cedar, which have lower than average shrinkage for their density; and amabilis fir, western hemlock and western larch, which have higher than average shrinkage (Nielson *et al.,* 1985).

Troublesome uneven shrinkage results when shrinkage properties vary within a piece of wood—a situation associated with juvenile and compression wood. That might not be a problem if the degree of abnormality were uniform, but it never is. Typically, the extent of juvenile wood or the severity of compression wood varies within a given piece. Bow and crook are commonly traceable to the abnormal longitudinal shrinkage of these abnormal woods.

The longitudinal shrinkage of normal wood is negligible for most practical purposes. Here microfibril orientation is about seven degrees or less from the cell axis. Usually, some longitudinal shrinkage does occur in drying from green to oven-dry condition, but this is only 0.1–0.2% for most species and rarely exceeds 0.4% (Hoadley, 1986). As an example, a 2×4-in. stud, 8 feet long, for the wall of a house, would shrink 0.1–0.2 in. (2–5 mm) in length when drying from green (>30% moisture content) to oven-dry condition (if it were cut from normal wood). If this stud were cut from compression wood or juvenile wood, where microfibril orientation could be up to 45 degrees, then the longitudinal shrinkage would be about tenfold (1.0–2.0 in., or 2.5–5.0 cm) because of the microfibril orientation of such abnormal wood.

One of the objectives of this study was to evaluate the extent of juvenile wood in second growth western hemlock in terms of longitudinal shrinkage.

The increased proportion of juvenile wood relative to mature wood in second growth has quality implications for lumber production. Juvenile wood in all tree species can foster unusual warping problems. It can shrink excessively along the grain because of large fibril angles, or twist because of spiral grain.

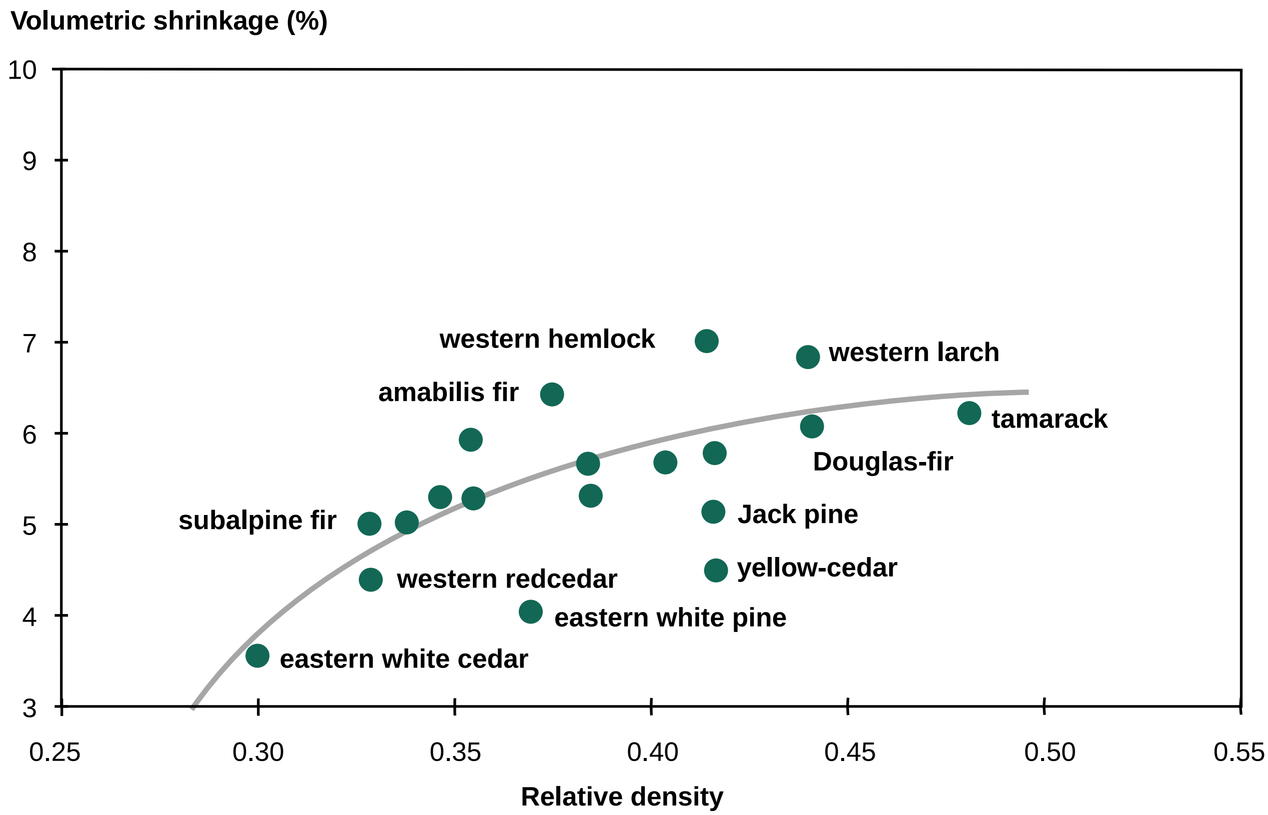


Figure 4. *Volumetric shrinkage of old-growth western hemlock compared with 18 other Canadian old-growth softwoods, from the green condition to 12% equilibrium moisture content.*

4 Materials and Methods

4.1 Tree Selection and Sampling Procedure

With the cooperation of Canadian Forest Products Ltd., MacMillan Bloedel Limited, Pacific Forest Products Limited, and TimberWest Forest Limited, thirteen 90-year-old western hemlock trees were selected and destructively sampled from each of five locations. In addition, two increment cores were taken at BH from another 20 trees at each location. The stands were selected to represent from 440 to 1000 stems/ha, from “open” to “closed” stand densities, growing on good sites.

The second-growth western hemlock sample material was augmented with 39-year-old trees from UBC’s Malcolm Knapp Research Forest spacing trial (the “Haney trees”), which was established by Dr. J.H.G. Smith in 1959 (Reukema and Smith, 1987). Three spacings were selected for this study with initial spacings of: 3×3 ft (11 960 stems/ha), 9×9 ft (1 329 stems/ha), and 12×12 ft (747 stems/ha). In the fall of 1995, because of mortality these three spacings had 2883, 814, and 519 stems/ha. These trees were sampled to investigate stand density effects on tree size, branch size, and stemwood density, where environmental factors were identical; only stocking density varied. Two 5 mm diameter increment cores (180 degrees apart) were collected at BH from 30 trees in each of the three spacings. At each installation, all the living trees encountered in the grid were sampled, until the number of trees sampled reached 30. In the 3×3 ft plot excessive windthrown areas were avoided (the north and southeast portions), and sample trees were taken from the most intact part of the stand. At the 20% tree height level a single increment core was obtained from 12 of the 30 trees, because preliminary work on 90-year-old trees had shown that the disk density at 20% tree height gave an excellent estimate of stemwood density. The largest branch diameter was measured with a caliper and its height position was noted within the 20% tree-height interval.

Branch diameter was measured inside bark, just outside the swollen branch collar, in a vertical projection. A pruning ladder and an extension ladder were used to access the 20% (~4 m) height level (a linesman's belt provided stability and safety). Sampling locations are shown in Figure 5.

In the five stands of 90-year-old trees, a random cruise of 30–50 trees was conducted to determine diameter distribution and stocking density. Based on this information, three small-diameter, seven medium-diameter, and three large-diameter trees were sampled at each location. The sample trees were dominants and codominants, free of visible pathogens. An attempt was made to sample straight, upright stems, with healthy symmetrical crowns. At each sample tree a 5.64 m fixed radius plot (0.01 ha) was established for measuring stand density. The UBC Faculty of Forestry obtained material needed for strength tests of small clears from BH and 40% height at three sampling locations (Port Mellon, Port Hardy, and Lake Cowichan), and PAPRICAN obtained material for pulping tests at two sites (Port Mellon and Port Hardy).

Twelve disks were cut for basic wood properties characterization: at stump height (30 cm), 70 cm height, BH, 10, 20, 30, 40, 50, 60, 70, 80 and 90% tree height. Longitudinal shrinkage samples were collected at BH and at 40% tree height. Samples for strength determination were collected at BH and at 40% tree heights. Pulping samples were obtained from the vicinity of BH and 80% tree height (to yield mature wood and top wood). The sampling plan is shown in Figure 6.

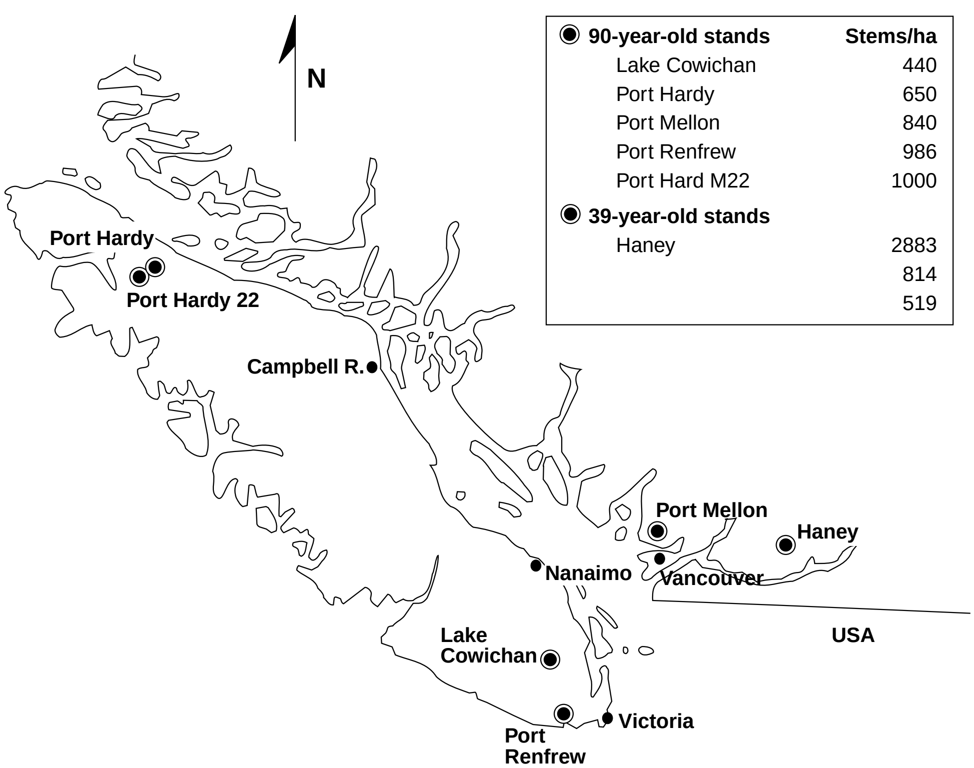


Figure 5. Second-growth western hemlock sampling locations.

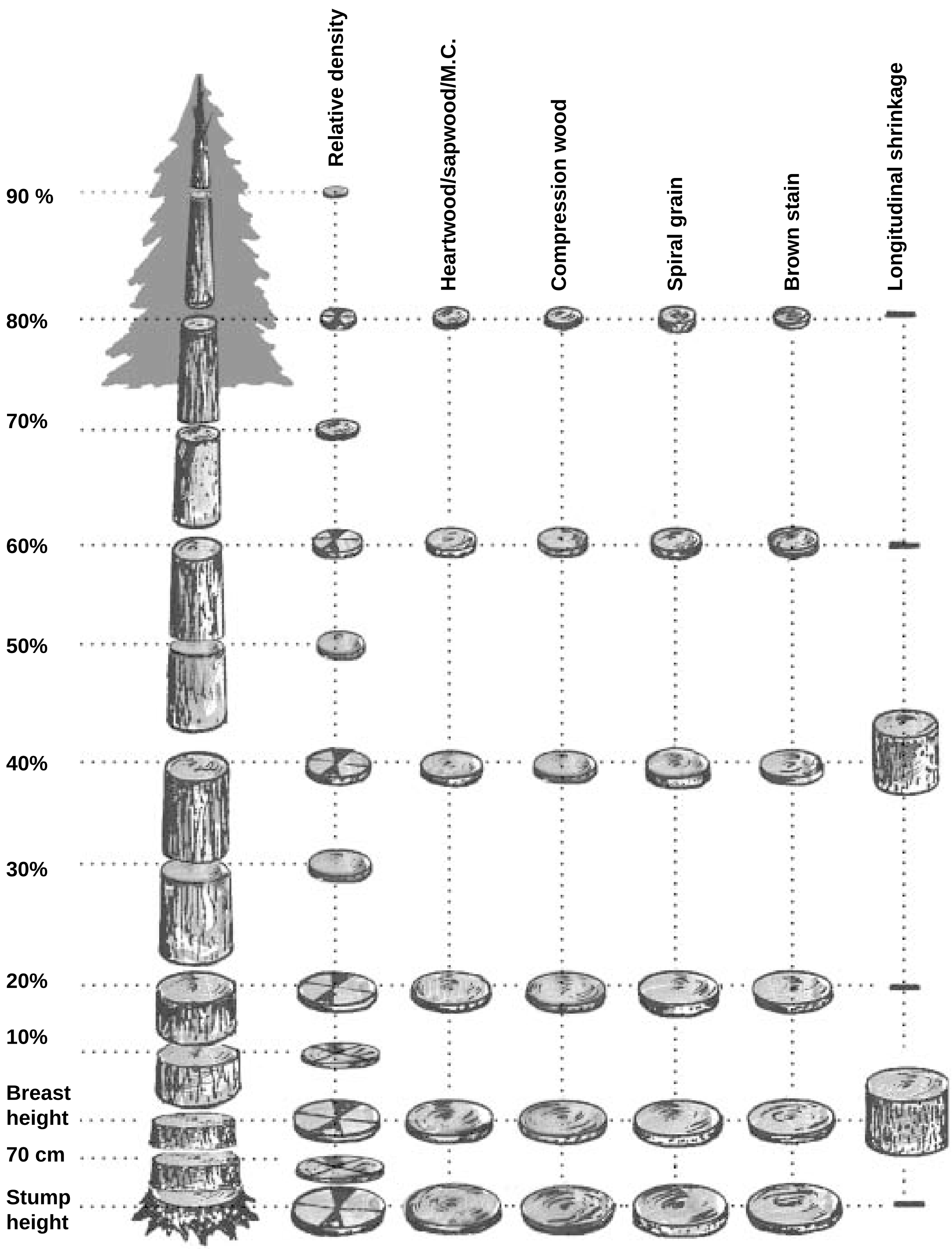


Figure 6. *Sampling plan for basic wood properties characterization of second-growth western hemlock.*

Disk samples were stored in a walk-in freezer until sample preparation in order to maintain biological freshness. Results were analyzed for all 13 sample trees and stratified to small, medium and large diameter class.

4.2 Relative Density by X-ray Densitometry

Two subsamples were cut from each disk, about 5 mm wide and 5 mm thick, from pith to bark. After air-drying they were cut to a uniform thickness of 1.57 mm on a twin-blade microsaw. The surfaced samples were extracted in a Soxhlet apparatus in alcohol-cyclohexene (1:2 by volume) for 24 hours, and in hot water for 24 hours. The extractive-free radial strips were air-dried to about 8% equilibrium moisture content. The samples were marked with calendar-year dates and the starting position for pith-to-bark x-ray scanning. The usual starting position was the end of the first, or the second ring from the pith. To obtain ring width and ring density data, 1560 radial subsamples were scanned on a computerized Direct Reading X-Ray Densitometer. Ring width components were measured with a resolution of 0.0254 mm (0.001 in.). Wood relative density values were expressed on a *green volume and oven-dry weight basis* (basic relative density). The data acquisition program recorded 100 intra-ring density values for each ring for mapping intra-ring density profiles. Disk densities were calculated by the weighted basal area of each ring. Whole-stem densities were calculated by the volume-weighted method. Yearly average ring densities and intra-ring density profiles were examined from pith to bark at each sampling height. Juvenile/mature wood distribution was documented and related to the extent of the live crown. Growth rates were related to relative density by comparing entire stemwood densities with tree diameters at BH, and by comparing average ring densities with ring widths at identical cambial ages. More detailed descriptions of X-ray densitometry techniques have been published by Parker *et al.* (1980), Jozsa and Myronuk (1986), and Jozsa *et al.* (1987).

4.2.1 Juvenile Wood Determination

In this study, with the exception of the pith-associated wood (usually the first five years of growth), we defined juvenile/mature wood distribution by relative density mapping. Average stem profiles were drawn to scale, representing tree height and stem diameter at 12 sampling heights. Density-contour lines were drawn with the aid of pith-to-bark ring density trend-line plots for each sampling height. Three arbitrary density zones were delineated and mapped in the stem:

1. average zone for western hemlock, 0.40–0.43;
2. below average, <0.40; and
3. above average, >0.43.

The above three density zones were superimposed onto stem profiles, depicting pith-to-bark and stump-to-top trends at the 12 sampling points along the bole. Juvenile wood encompassed the first two zones. Mature wood was that portion of the bole where high density (>0.43) wood was laid down by the growing tree.

Tree profiles were constructed by stem radius, and by basal area. A stem-radius plot provides a linear impression while the basal area distribution provides a more realistic volume-weighted distribution of density zones and juvenile wood content.

4.3 Compression Wood

Compression wood determinations were made on samples taken at five selected tree heights; BH, 20, 40, 60 and 80%. Four-millimetre thick cross sections were cut on a bandsaw. These sections were placed on a light table where the opaque compression wood zones were delineated by their darker colour. The percentage of each disk's cross sectional area represented by compression wood was determined with a planimeter.

4.4 Spiral Grain

Spiral grain measurements were made on 10 cm thick disks taken at five sampling heights: BH, 20, 40, 60 and 80% tree height. Disks were split using a wedge and a mallet to expose the pith and the grain angle on the split surface. Grain angle was measured from pith to bark, using a clinometer, at 1 in. intervals, starting at 0.5 in. from the pith. The pith was used as a reference point and measurements were made along two opposite radii for each disk.

Figure 7 shows Forintek's custom-made spiral grain measuring device. In this illustration the measuring probe (a) is in contact with the pith, the 0% reference. The measuring probe is moved in and out with the knurled knob (b). The "Pro Smart Level" is attached to the measuring probe and pivots around (c). The entire assembly moves along a track (d), supported by a base (e).

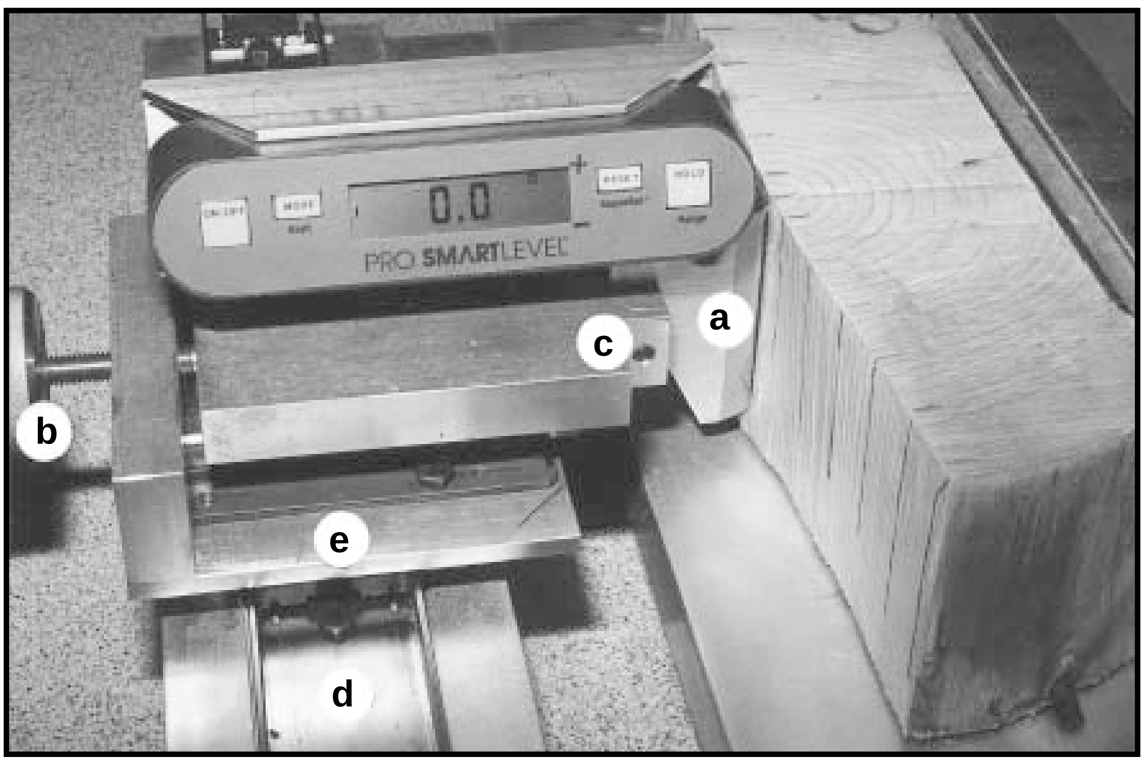


Figure 7. Forintek's spiral grain measuring device.

4.5 Longitudinal Shrinkage

Longitudinal shrinkage measurements were made for sample material taken at BH and at 40% of tree height. The 25 to 30 cm thick disks were cut on a bandsaw square to the pith, then parallel to the grain. Excess wood was trimmed away to reveal fresh green wood. Branch stubs were avoided as much as possible. Slabs of wood about 6 mm thick and 200 mm long were prepared with the pith on one edge and the bark on the other. The end grain was sanded smooth on both ends on a belt sander to facilitate accurate measurement. Segments 6 mm wide were subsequently cut on a radial arm saw and each segment was numbered. Two opposite radii were sampled for each disk and each radius was sampled in duplicate. Longitudinal shrinkage sample preparation is shown in Figure 8.

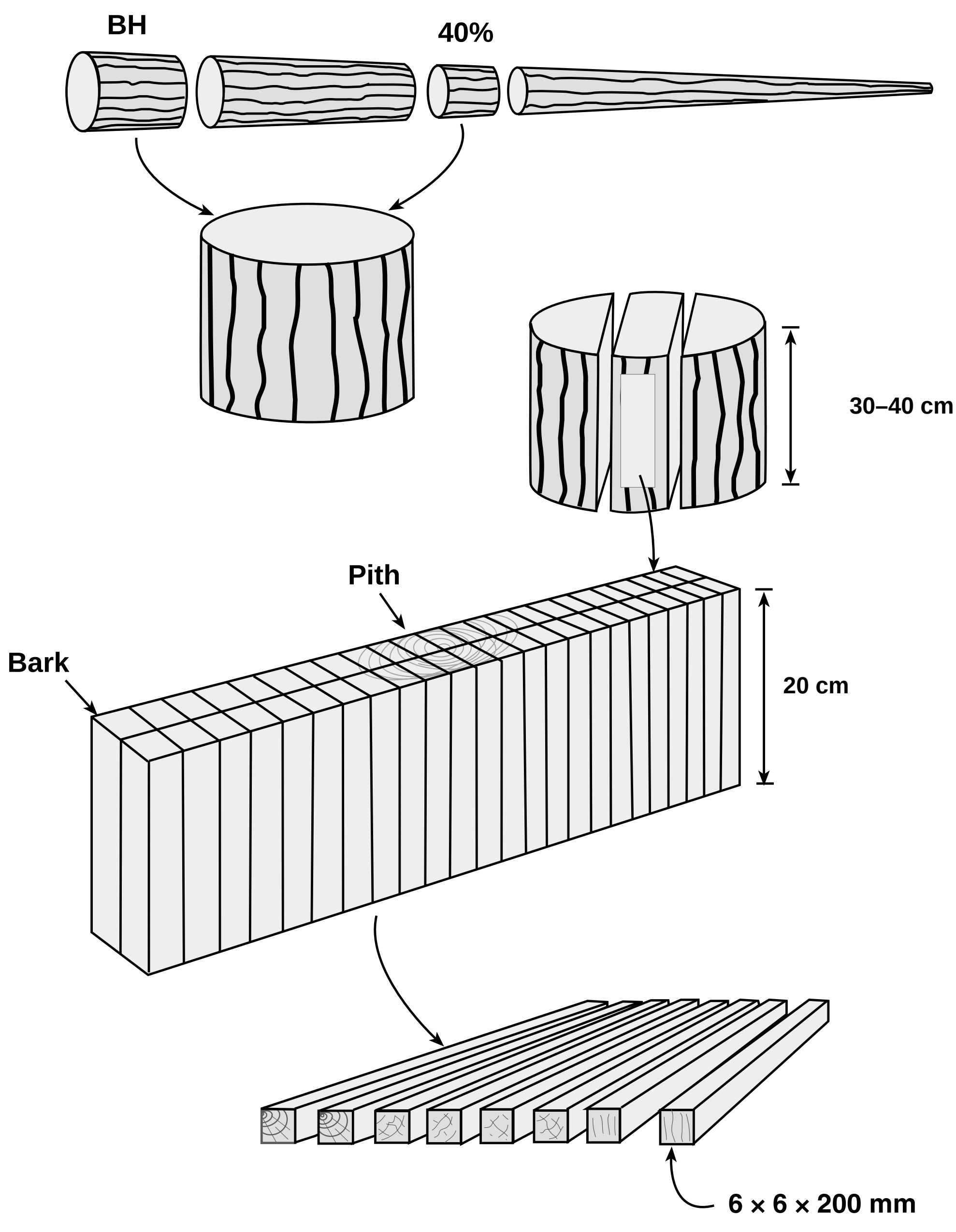


Figure 8. Longitudinal shrinkage sample preparation.

Each segment was measured to an accuracy of ±0.0001 in., using a digital caliper interfaced to a computer. Following green condition measurements, the segments were conditioned to 12% moisture content and were remeasured. Next, the segments were oven dried at 105° C for 24 hours, then each segment was measured again. Longitudinal shrinkage was expressed as a percent length loss based on the original green length.

5 Results and Discussion

A summary of stand and tree characteristics, based on 13 sample trees collected at each of five locations, is shown in Table 1.

Total volume-weighted stemwood density distribution is shown in Figure 9 for the five sampling locations. Port Mellon sample trees had significantly lower stemwood density than the Port Hardy M22 and Port Renfrew samples. Port Hardy samples were also significantly lower in stemwood density than the Port Renfrew samples (P <0.05). Brackets in Figure 9 delineate sampling locations where stemwood densities were not significantly different (P >0.05) from each other.

5.1 Stemwood Relative Density

The full range of total stemwood density data for the five sites is from 0.36 (at Port Mellon) to 0.51 (at Port Renfrew), with an overall mean of 0.426. The variability and average stemwood density in this sample of second-growth western hemlock are similar to the norms reported for old-growth timber—10% coefficient of variation, mean 0.42 and normal range 0.34–0.50. As location average wood density increases from 0.40 (Port Mellon) to 0.45 (Port Renfrew) so does the range between the low- and high-density trees, particularly at the upper end of the scale. Note that minimum density trees at the five locations are almost identical, 0.36–0.38.

Average tree profiles with the extent of the live crown and stemwood density zones are shown in Figure 10 for the five sampling locations. The same data are shown by stem radius, and by basal area.

Average stem profiles and density distributions by stem radius show that high-density wood (>0.43) was found in association with the pith, but the outer mature wood envelops the juvenile core in the stem and extends from stump to near the base of the live crown. An asterisk (*) marks the position of minimum ring density at each sampling height. Minimum ring density dipped as low as 0.34, but on average it was mostly between 0.35–0.39. At each sample location, and at each sampling height, minimum density values were attained at 10 to 20 year increments (approx. 3–7 cm) from the pith.

On average, the juvenile wood cylinder (with minor amounts of pith-associated high-density wood) had a 7 to 15 cm radius, extending from the stump to the top of the tree. Not surprisingly, the Port Hardy M22 and Port Renfrew samples, with 1000 stems/ha had the smallest juvenile wood cylinder, less than 10 cm in radius.

Volume-weighted juvenile/mature wood distribution is shown in the bottom half of Figure 10. This evaluation identified, left to right, 68, 41, 39, 30, and 30% juvenile wood, for Port Mellon, Port Hardy, Lake Cowichan, Port Hardy M22, and Port Renfrew, respectively. In this ranking, the Port Mellon sample appears to be an anomaly, because of its relatively high number of stems/ha (840).

Table 1. Summary of stand and tree characteristics of 90-year-old second-growth western hemlock

	Location					
	Port Mellon	Port Hardy	Lake Cowichan	Port Hardy M22	Port Renfrew	5 locations combined
Stocking density (stems/ha)	840	650	440	1000	986	783
Number of sample trees	13	13	13	13	14	66
Site index (at BH 50 years)	29	39	35	33	30	33
Total age						
Mean	97.9	86.1	92.2	85.4	92.9	90.9
Std. dev.	10.9	2.6	3.8	3.2	3.2	7.2
Diameter at breast height (cm)						
Mean	42.2	47.4	49.6	37.3	38.0	42.8
Std. dev.	7.0	9.2	8.0	7.9	8.3	9.3
Total height (m)						
Mean	36.6	47.2	42.3	39.7	38.7	40.9
Std. dev.	2.3	2.5	3.5	2.7	4.6	4.8
Rate of radial growth at breast height (cm/year)						
Mean	.248	.304	.289	.231	.215	.257
Std. dev.	.048	.055	.047	.048	.046	.059
Ratio of live crown length to tree height (crown ratio %)						
Mean	26.1	26.1	31.7	27.9	27.4	27.7
Std. dev.	7.5	4.1	10.7	2.4	6.1	6.7
Total stem wood density						
Mean	.404	.411	.426	.434	.453	.426
Std. dev.	.020	.023	.030	.043	.045	.037
Percentage volume latewood						
Mean	27.6	29.3	32.2	34.0	36.9	32.1
Std. dev.	4.7	6.8	6.3	7.3	7.7	7.3
Total stem volume including bark (m^3)						
Mean	2.69	4.03	4.25	2.16	2.19	3.05
Std. dev.	.86	1.50	1.47	0.92	1.11	1.47
Total stem volume excluding bark (m^3)						
Mean	2.40	3.67	3.84	1.93	2.01	2.76
Std. dev.	.79	1.40	1.35	.84	1.05	1.36
Bark volume (% of total volume)						
Mean	11.0	9.3	9.9	11.2	9.0	10.1
Std. dev.	1.0	1.2	.9	1.3	1.8	1.5

Information presented here could have important practical implications not only for resource management, but also for resource allocation and in manufacturing. For example, even at 1000 stems/ha, the Port Hardy M22 and Port Renfrew samples show that the top 12 to 16 m portion of the stem is 100% juvenile wood. This top log will not yield strong structural lumber, or high-density veneer.

It is encouraging to note that even in the Lake Cowichan sample, with only 450 stems/ha, there is 61% mature wood by volume. This outer mature-wood shell is about 15 cm thick and 17 m long and constitutes a substantial volume of wood for producing high-density solid wood products (e.g., MSR lumber, furniture wood), or veneer for LVL or Parallam. Even the top half of the stem falls within the 0.40–0.43 relative density range—not much different from the old-growth average of 0.42.

Table 2 lists average disk density, diameter, and the number of annual increments for the 12 sampling heights for the five locations. Weighted average stemwood relative density is shown as well. Note the excellent similarity between disk-relative densities at the 20% and 30% heights and respective average stemwood densities at the five sampling locations.

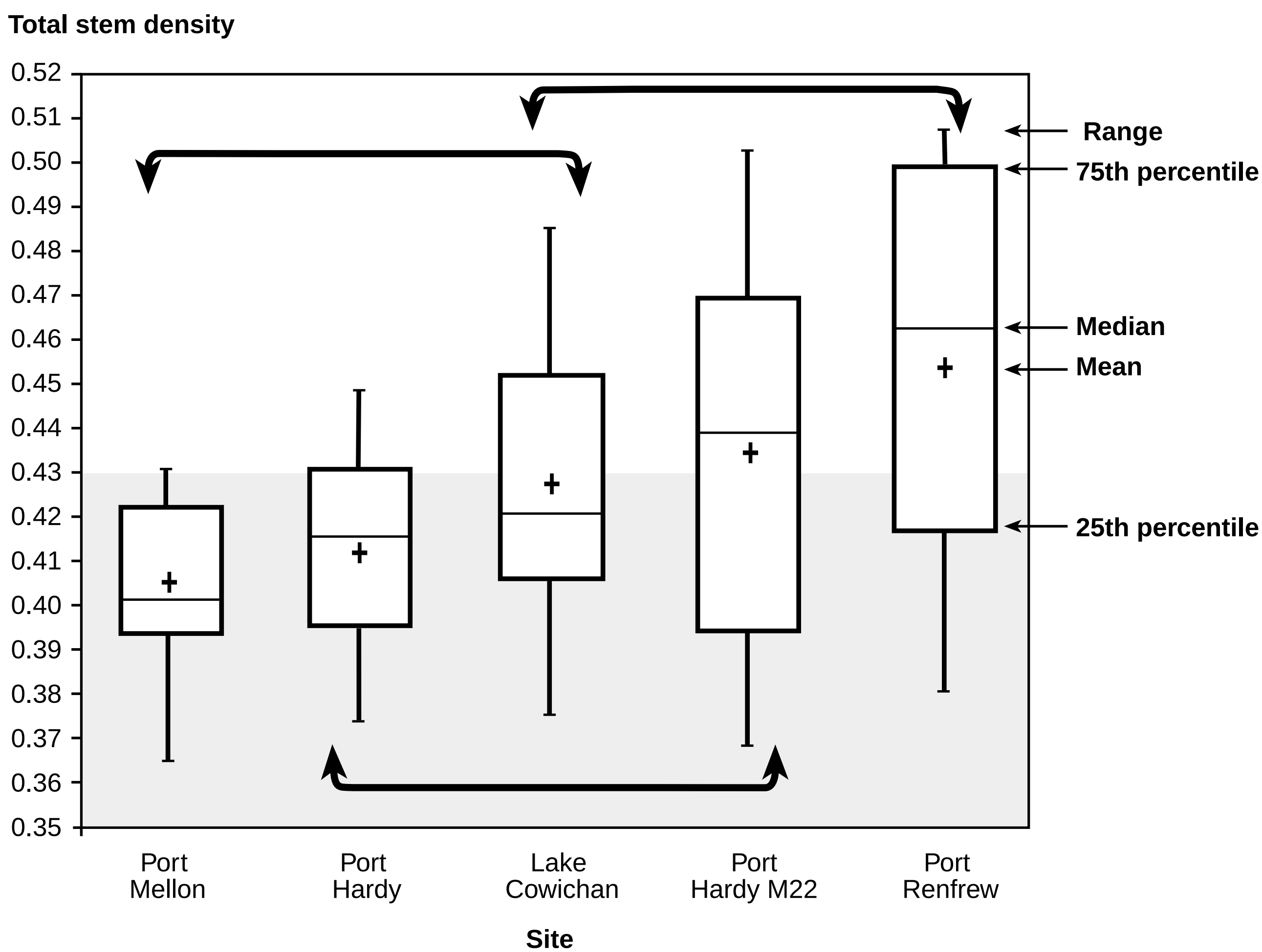


Figure 9. ***Stemwood relative density distribution in 90-year-old western hemlock trees at five sampling locations.***

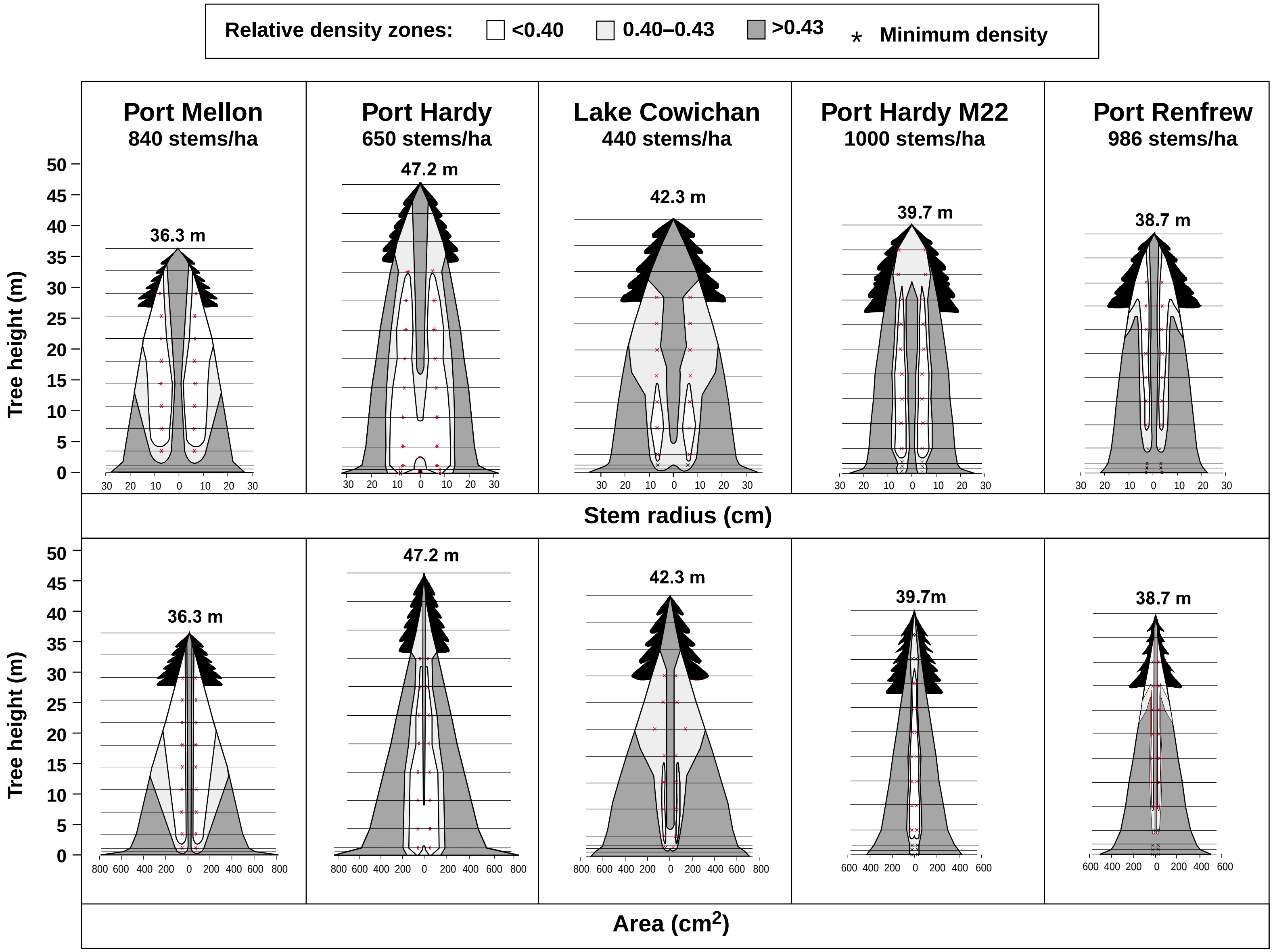


Figure 10. Average stem profiles, extent of live crown, and stemwood density distribution.

Table 2. Average disk density (g/cm³), diameter (cm) and the number of annual increments at 12 heights for five locations

Sampling height	Variable	Port Mellon	Port Hardy	Lake Cowichan	Port Hardy M22	Port Renfrew	5 locations combined
Stump	Density	0.44	0.44	0.48	0.47	0.49	0.46
	Diameter	52.30	66.10	65.80	48.40	44.30	55.38
	# of rings	94.80	84.40	91.00	83.40	90.70	88.86
70cm	Density	0.45	0.43	0.47	0.47	0.49	0.46
	Diameter	44.60	52.90	53.90	38.80	39.80	46.00
	# of rings	88.00	80.60	87.80	81.90	89.70	85.60
BH	Density	0.44	0.42	0.46	0.46	0.49	0.45
	Diameters	42.20	47.40	49.60	37.40	38.00	42.92
	# of rings	84.90	77.50	85.70	80.70	88.60	83.48
10%	Density	0.41	0.41	0.44	0.44	0.47	0.43
	Diameter	39.60	43.90	47.90	34.60	35.00	40.20
	# of rings	80.50	71.90	81.50	75.80	82.40	78.42
20%	Density	0.40	0.40	0.42	0.43	0.46	0.42
	Diameter	38.00	41.40	45.40	32.30	32.70	37.96
	# of rings	74.30	67.10	75.80	70.20	76.00	72.68
30%	Density	0.40	0.41	0.42	0.43	0.45	0.42
	Diameter	35.80	38.60	42.60	30.20	30.50	35.54
	# of rings	67.80	62.30	70.50	65.90	67.60	66.82
40%	Density	0.39	0.41	0.41	0.42	0.44	0.42
	Diameter	33.40	34.80	39.20	27.90	28.00	32.66
	# of rings	62.20	57.00	64.60	62.00	62.70	61.70
50%	Density	0.39	0.40	0.42	0.43	0.43	0.42
	Diameter	30.10	31.70	35.20	25.20	25.60	29.56
	# of rings	56.80	51.20	58.80	56.80	55.10	55.74
60%	Density	0.39	0.40	0.41	0.43	0.42	0.41
	Diameter	26.80	27.10	30.10	22.20	22.90	25.82
	# of rings	50.80	44.50	51.20	50.70	47.80	49.00
70%	Density	0.39	0.42	0.41	0.42	0.39	0.41
	Diameter	23.10	22.90	24.20	19.00	19.40	21.72
	# of rings	43.90	38.50	41.20	42.20	38.30	40.82
80%	Density	0.39	0.42	0.44	0.42	0.40	0.41
	Diameter	17.70	17.20	17.10	14.90	15.10	16.40
	# of rings	35.90	28.80	29.80	32.30	28.10	30.98
90%	Density	0.39	0.45	0.45	0.43	0.42	0.43
	Diameter	11.10	8.80	9.10	9.00	8.50	9.30
	# of rings	22.70	17.40	17.00	21.80	18.30	19.44
Weighted average relative density of whole stem		0.40	0.41	0.43	0.43	0.45	0.43
% juvenile wood		68	41	39	30	30	35
% mature wood		32	59	61	70	70	65

Figure 11 shows disk densities at 12 sampling heights, from stump to 90% of tree height, for the five locations. There are a number of noteworthy features in the disk density distributions. First, at each location high-density wood is at the base of the stem. The old-growth average density value of 0.42 is shown for reference purposes. Second, a rapidly declining trend from stump to the 20% height level is evident. Third, the widely divergent disk densities in the live crown, at the 80 and 90% heights where the stemwood is 100% juvenile wood (wood that was laid down under the influence of the live crown), are unexpected.

Table 3 and Figure 12 show density variation at BH for the five locations. Coefficients of variation in Table 3 for the five sites range from 9.5% at Port Renfrew to 14% at Lake Cowichan. The five sites combined with 166 BH disk density values, had a 12.7% coefficient of variation. Mean BH disk density was 0.44, with 95% of the population falling between 0.33 and 0.55.

It seems that the best estimate of whole-stem density can be obtained at the 20–30% height level at each sampling location; disk densities at these stem levels are within 0.01 of the average stem density. Regression analysis of disk density at 20% tree height and total stem density showed r^2 values of 0.83 to 0.85 at Lake Cowichan, Port Hardy, Port Renfrew and Port Hardy M22 (Figure 13). Similar comparisons at BH resulted in r^2 values of 0.65, 0.60, 0.86 and 0.63, respectively at these locations (Figure 14).

Table 3. Density variation at breast height for five locations

Location	No. of trees	Mean	Std. dev.	Minimum	Maximum	CV
Port Mellon	32	0.433	0.042	0.328	0.535	9.805
Port Hardy	32	0.409	0.043	0.320	0.501	10.607
Lake Cowichan	34	0.436	0.061	0.319	0.529	14.001
Port Hardy M22	34	0.446	0.055	0.369	0.557	12.465
Port Renfrew	34	0.488	0.046	0.401	0.588	9.484
5 locations combined	166	0.443	0.056	0.319	0.588	12.688

5.2 Growth Rate versus Relative Density

As a first test, BH tree diameters were compared with BH disk densities to examine the relationship between growth rate and relative density. The results of this comparison for 166 trees are shown in Figure 15. From the statistical point of view, a very weak negative relationship exists (coefficient of determination r^2=0.081) between disk diameter and disk density. From the biological perspective, the small-diameter slow-growing trees are more dense than the fast-growing large ones. Diameters range from 23 to 63 cm, while disk densities range from 0.32 to 0.58 in the sample.

On a smaller scale, individual annual ring widths were compared with their respective ring densities from age 1 to 90. Table 4 shows selected age intervals from the juvenile wood zone (age 5–10), the transition zone (age 20–25), and the mature wood zone (ages 50–55 and 70–75). In this comparison the five sampling locations and 12 sampling heights were combined into one data set. Correlations show a weak but consistently negative relationship between ring width and ring density. Note the rapidly decreasing ring widths corresponding with increasing ring density. Figure 16 shows diameter development at BH from age 1 to 80.

The Port Hardy stand (with 650 stems/ha) shows the most rapid diameter growth, especially in the first 20 years. On average these trees were growing 1 cm in diameter each year. This early rapid rate of growth had slowed to 0.5 cm/year from age 21 to 40, and to 0.25 cm/year from age 41 to 60. The slowest rate of diameter increment was recorded at Port Renfrew (986 stems/ha), where trees grew at a rate of 0.5 cm/year in diameter for the first 40 years. This rate of growth had slowed to 0.33 cm/year from age 41 to 80. At the other three locations (Port Mellon, Lake Cowichan and Port Hardy M22), the rate of diameter growth falls between the above two examples, especially in the first 40 years of growth. It is interesting to note that at the two high stand density locations (Port Hardy M22 and Port Renfrew), 30 cm DBH was reached at age 70 while following different patterns of growth.

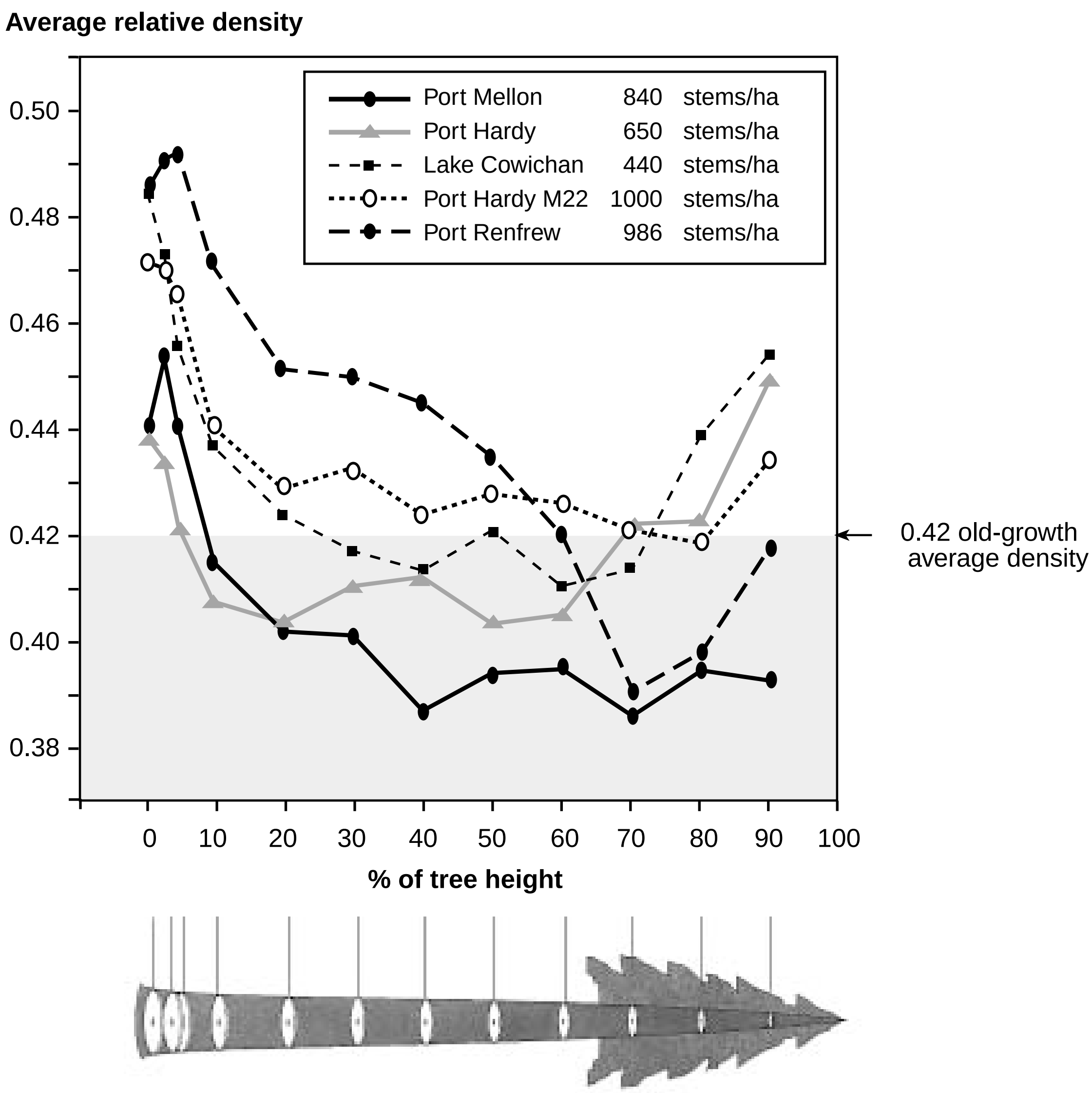


Figure 11. Second-growth hemlock disk densities.

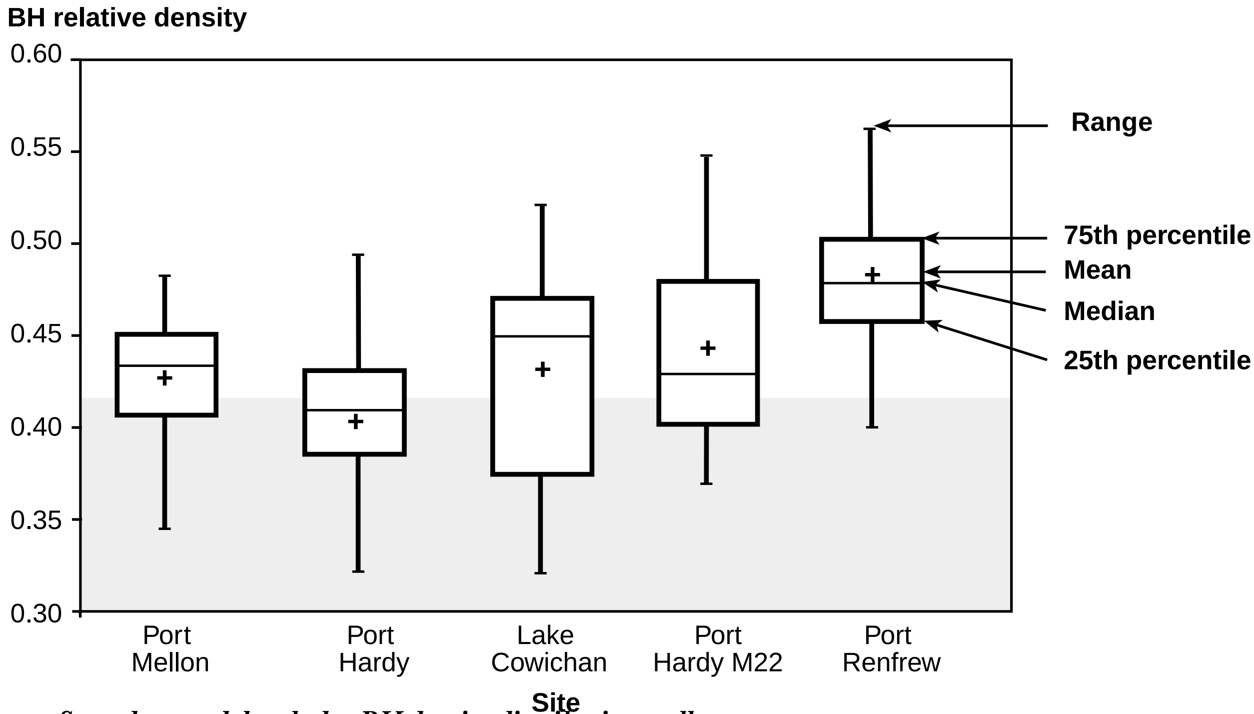


Figure 12. Second-growth hemlock – BH density distribution – all trees.

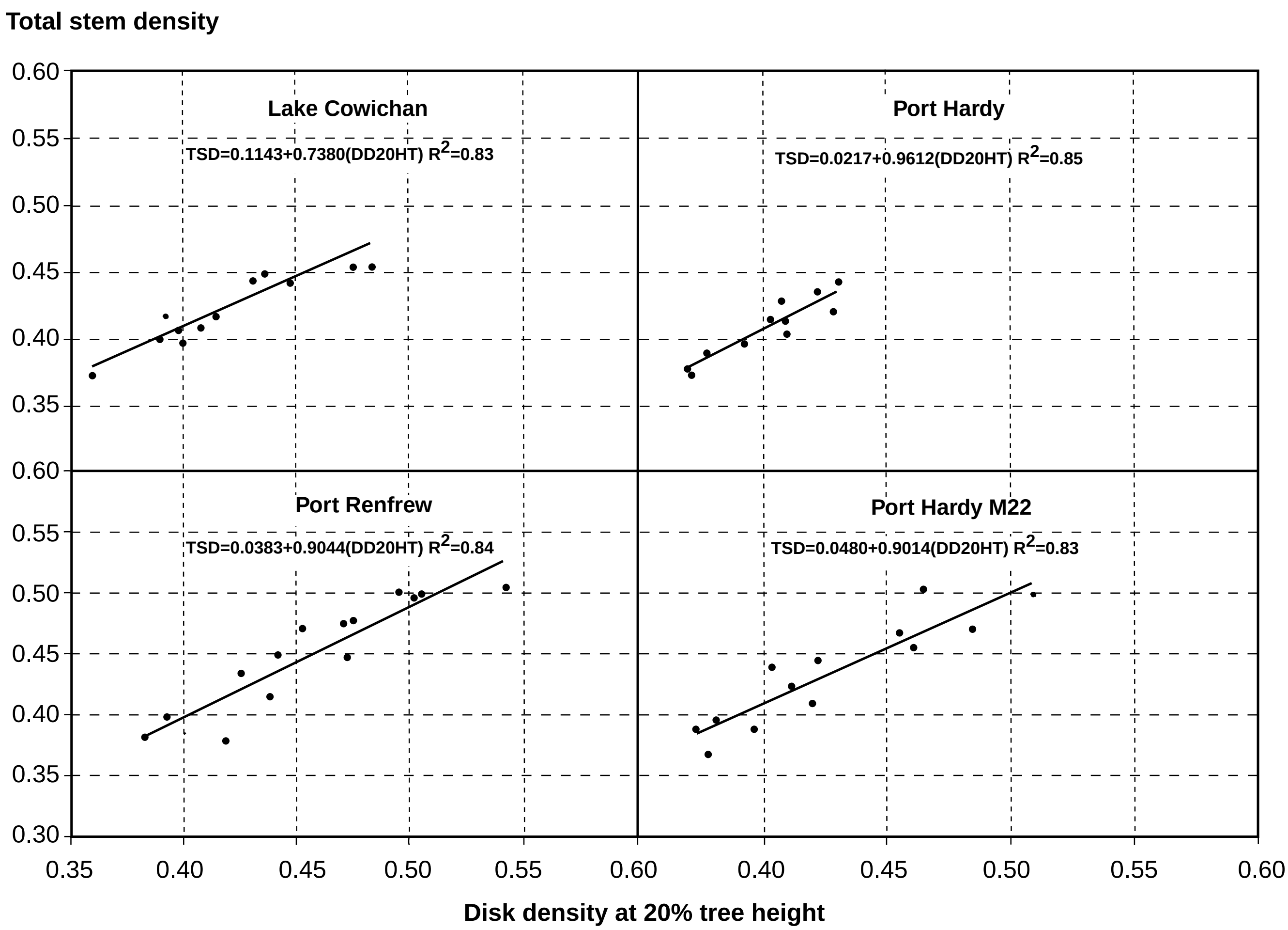


Figure 13. Disk density at 20% tree height related to total stem density.

Table 4. Ring width and ring density values and correlations for individual annual rings; five locations and 12 sampling heights combined

Age	Number of observations	Mean ring width (mm)	Mean ring density (g/cm^3)	r	r□
5	697	4.13	0.43	-0.55	0.257
6	710	4.19	0.42	-0.58	
7	717	4.15	0.41	-0.54	
8	720	4.12	0.40	-0.50	
9	722	4.07	0.40	-0.45	
10	724	3.91	0.39	-0.42	
20	696	2.69	0.41	-0.30	0.087
21	691	2.58	0.41	-0.29	
22	689	2.55	0.41	-0.28	
23	684	2.51	0.42	-0.29	
24	683	2.41	0.42	-0.32	
25	680	2.33	0.42	-0.29	
50	517	1.60	0.46	-0.19	0.048
51	507	1.60	0.46	-0.21	
52	498	1.58	0.47	-0.22	
53	488	1.59	0.47	-0.21	
54	480	1.56	0.46	-0.23	
55	467	1.50	0.47	-0.25	
70	288	1.43	0.48	-0.29	0.073
71	279	1.42	0.49	-0.30	
72	265	1.44	0.48	-0.24	
73	258	1.43	0.49	-0.25	
74	245	1.38	0.49	-0.23	
75	241	1.45	0.49	-0.31	

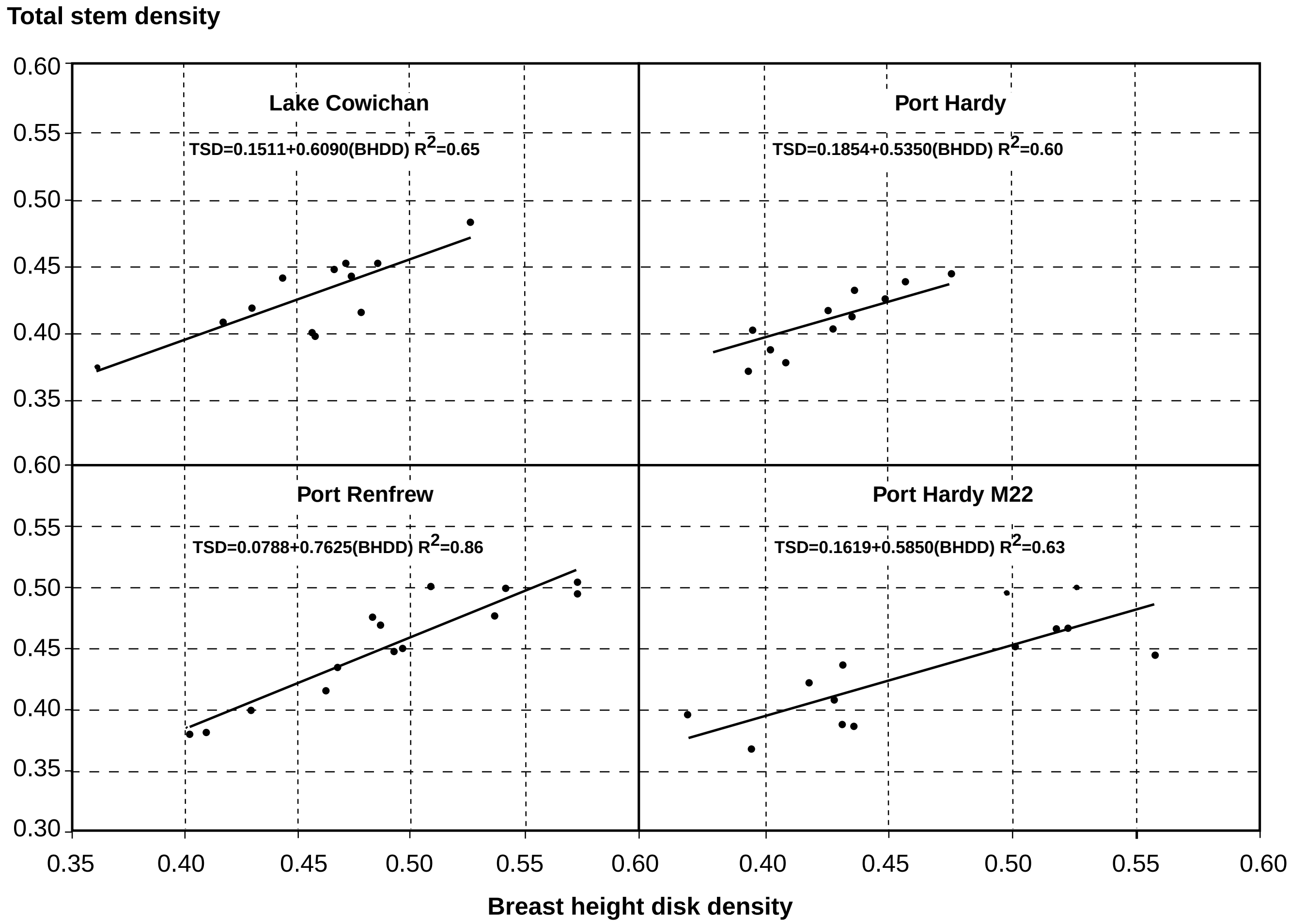


Figure 14. *Disk density at breast height related to total stem density.*

5.3 Average Ring Density and Ring Width Trends from Pith to Bark

Average ring density and ring width trends were examined at the 12 sampling heights as a function of age and radial distance from the pith. Figure 17 shows stand average and combined trends. The general trend in yearly average ring density, at all five locations and 12 sampling heights, is a declining one from the pith to about age 12 (Figure 17a and b). The low point in density (0.40) is located about 3–7 cm from the pith. A rapid increase in ring density is evident from age 15 to 35, from 0.40 to 0.45. Since the average stem density is 0.43, this increase is about 13%. From age 41 to 80 density increases at a slower rate, from 0.45 to 0.49. Figure 17b shows that, on average, these second-growth western hemlock trees achieve and surpass the old-growth wood density average of 0.42 at age 25 and beyond. On average the production of mature wood (≥0.43) occurs at age 30, ranging from 20 years at Port Renfrew to 45 years at Port Mellon.

Stand-average ring width trends are shown in Figure 17c. Maximum ring width is reached at all five sites between age 5–10, which is followed by a rapid decline to about age 30. From age 50 to 90 a very gradual decline is evident. Figure 17d shows the combined (five locations and 12 sampling heights) ring width trend. At about age 30, at the start of the mature wood zone, average ring width is 2.1 mm.

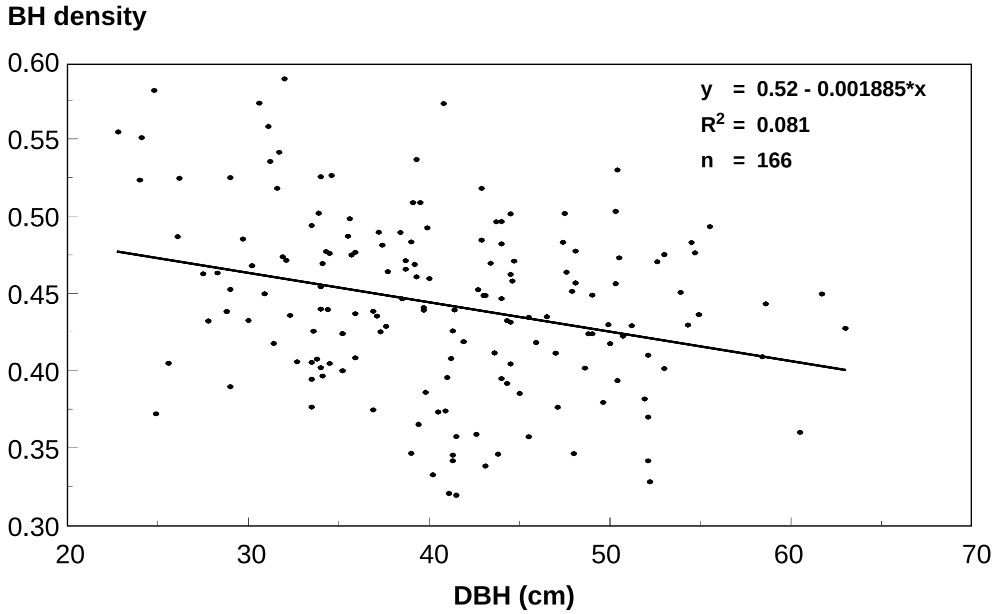


Figure 15. Breast height disk density vs. breast height disk diameter.

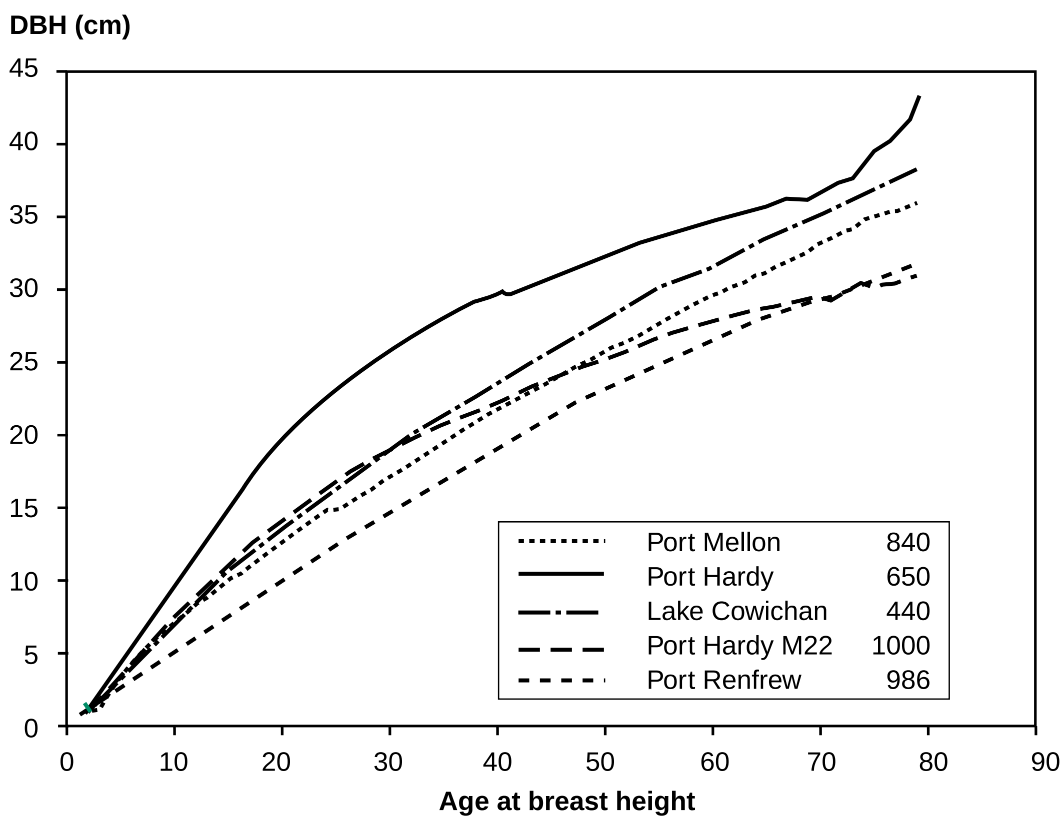


Figure 16. Diameter development at breast height from age 1 to 80.

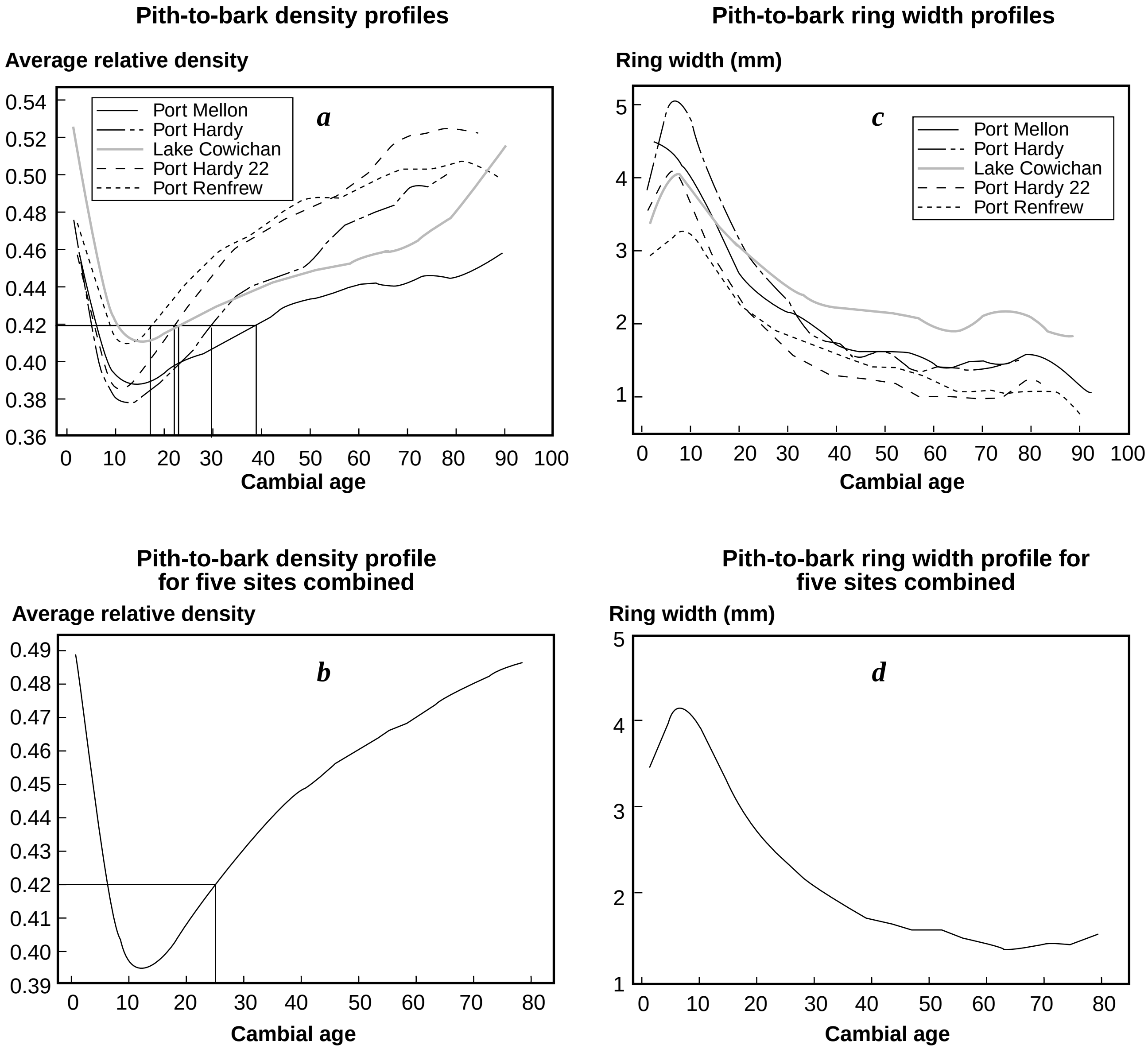


Figure 17. ***Pith-to-bark ring density and ring width trends.***

According to current NLGA grading rules "close grain" has six or more rings/inch, which translates to 4.23 mm or narrower rings. The top grade in vertical grain door stock requires at least eight rings/inch, or 3.18 mm maximum ring width.

Figure 18 shows average ring density trends by radial distance from the pith for all 12 sampling heights for the five locations. This graphical presentation of ring density and radial dimensions was used as an aid in mapping the distribution of juvenile and mature wood in the stem (Figure 10).

We can see in Figure 18 that low-density wood (<0.40) is contained within a 5 to 15 cm radius from the pith. In addition, at all five sampling locations high-density wood is mostly at the base of the stem; stump, 70 cm, BH, and 10%.

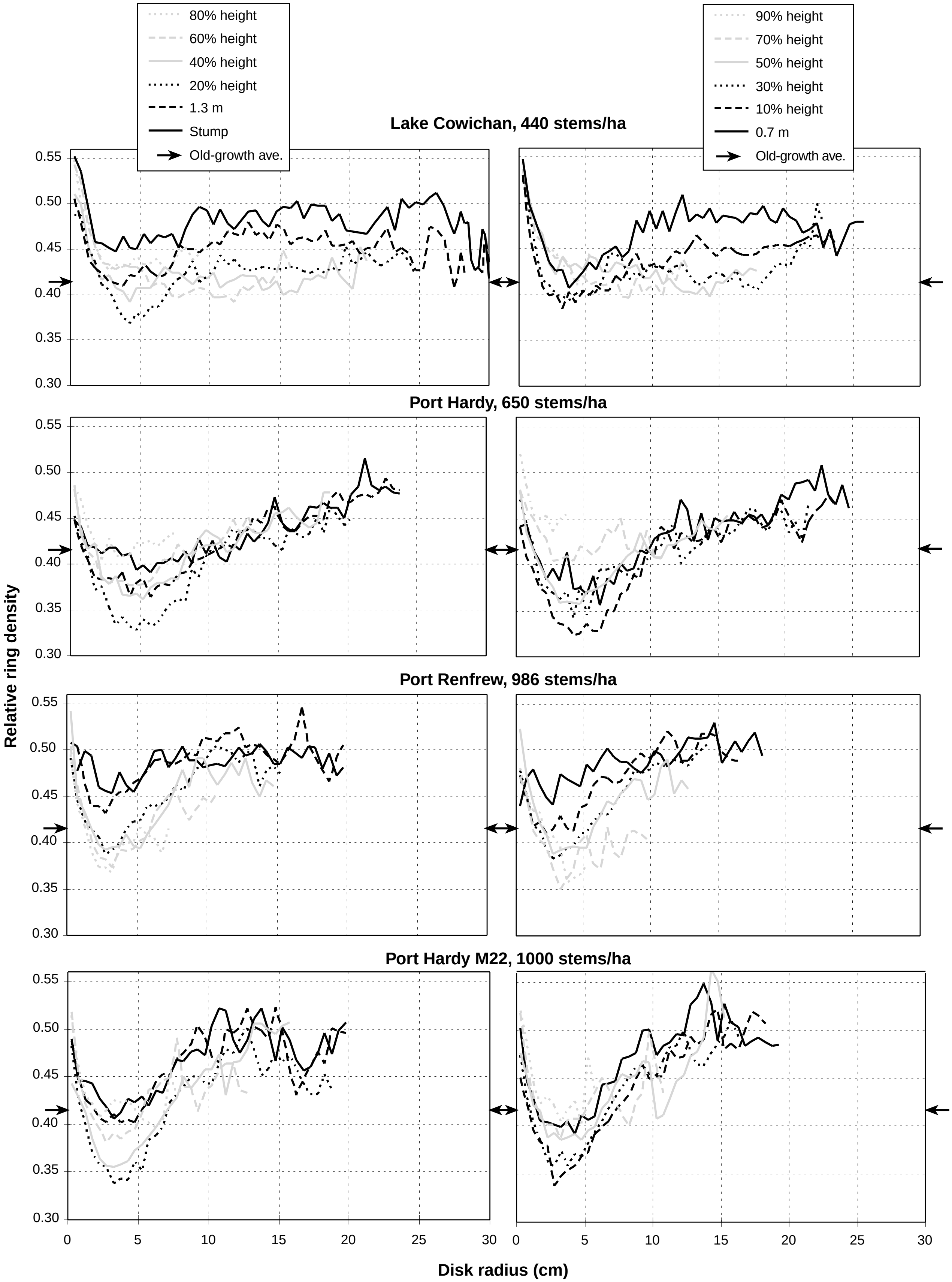


Figure 18. Average density trends by radial distance from pith to bark at 12 heights.

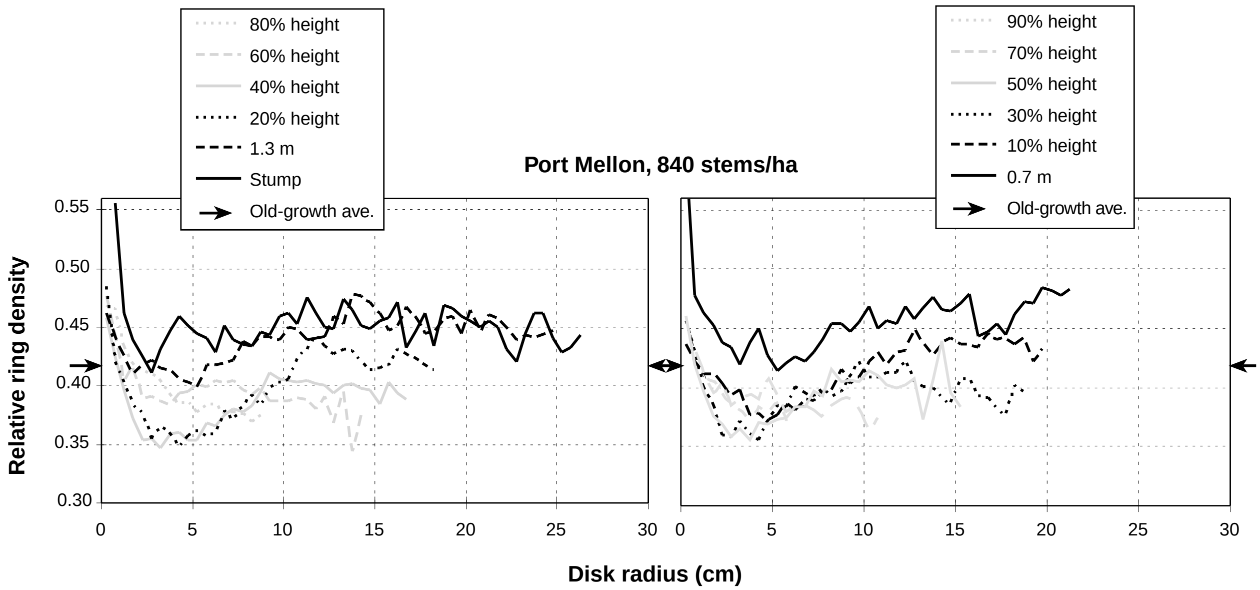


Figure 18. Continued.

Figure 19 shows average ring density trends by age from pith to bark at 12 sampling heights for each of the five locations.

5.4 Intra-ring Density Profiles

Intra-ring density profiles are presented in Figure 20 for the five locations at 12 sampling heights. In addition to the yearly profiles, average profiles were prepared at each sampling height by summarizing all the rings from pith to bark. Yearly minimum density values in the earlywood zone show a declining trend from pith to age 10, then level off and range mostly between 0.25 and 0.30. Maximum ring density values show little change from pith to bark and range between 0.6 and 0.7. Therefore, because the lower and upper limits are fairly well defined in a narrow range, it is the proportion of latewood that dominates in determining the relative density of each annual ring.

The average intra-ring density profiles in Figure 20 show a decreasing trend in latewood width from stump to 90%, which supports the decreasing disk density trends from stump to top (in Figure 11).

The most important feature of these western hemlock intra-ring density profiles explains the excellent machinability property of the species; there is very little of both the lowest density earlywood and the highest density latewood. Note how, from the very beginning of the annual ring, there is an immediate gradual increase in density, similar to yellow-cedar shown in Figure 3. This robust transitional earlywood will make the wood tougher to wear and tear in furniture, panelling, doors, windows, etc. Density homogeneity will help in veneer peeling and in wood turning as well.

To examine density homogeneity, 0.40–0.60 density zones were isolated in the average ring profiles at 12 sampling heights for Port Hardy (650 stems/ha) and Port Hardy M22 (1000 stems/ha) tree samples, as shown in Figure 21 (highlighted in black). This comparison shows that an average 40 to 50% of the annual ring resembles yellow-cedar in terms of ring width and ring density uniformity. Only small amounts of earlywood dip below 0.40 and only small amounts of latewood surpass the 0.60 limit.

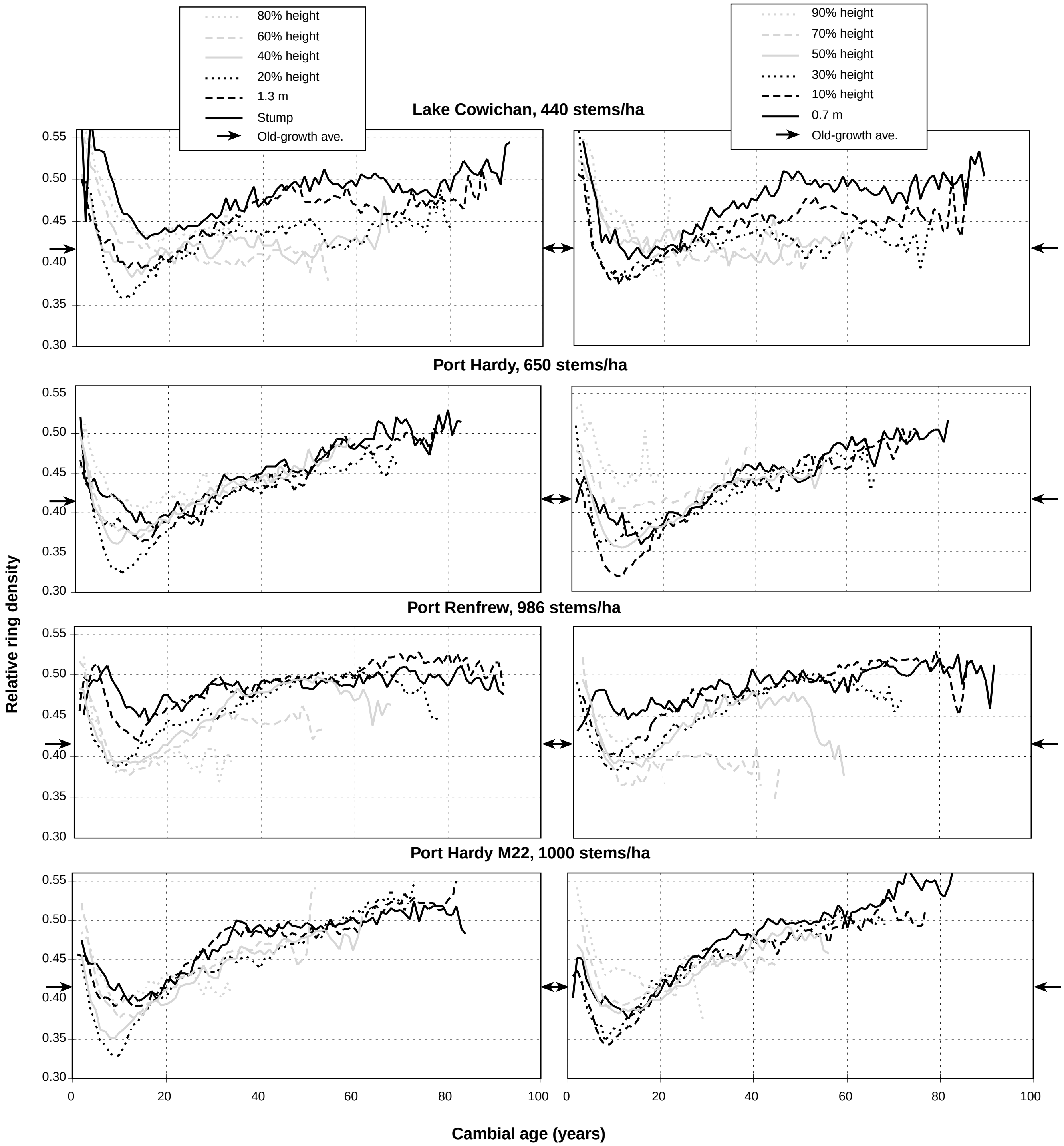


Figure 19. Average ring density trends by age from pith to bark at 12 heights.

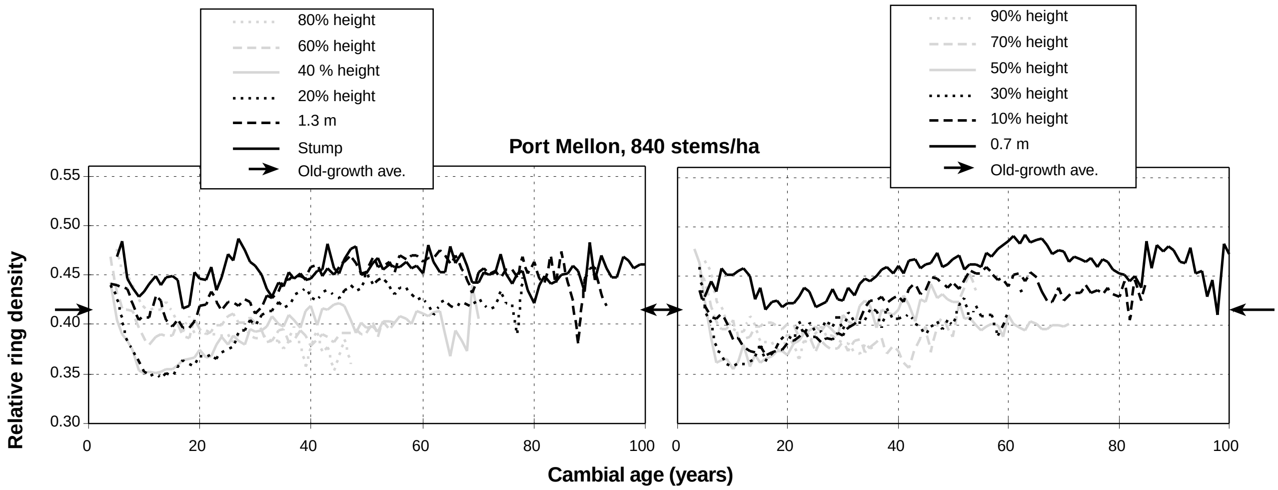


Figure 19. Continued.

In summary, this relative tissue uniformity explains why western hemlock behaves so well in turning and other machining properties.

Figure 22 shows BH intra-ring density profiles, by combining 166 trees at all of the five locations. These superimposed intra-ring profiles were produced by summarizing rings 6–15, 16–35, 36–50, 51–70, and 71–90. For these interval summaries, minimum ring density ranges between 0.29 and 0.32, while maximum latewood density is between 0.58 and 0.65.

In the first interval, rings 6–15 from the low-density juvenile wood zenith average ring contains only 15% latewood. Latewood width increases pith to bark from 15% to 28, 40, 45, and 48% from rings 6–15 to rings 16–35, 36–50, 51–70, and 71–90, respectively. For the same age intervals average ring width was 3.92, 2.64, 1.92, 1.44, and 1.1 mm.

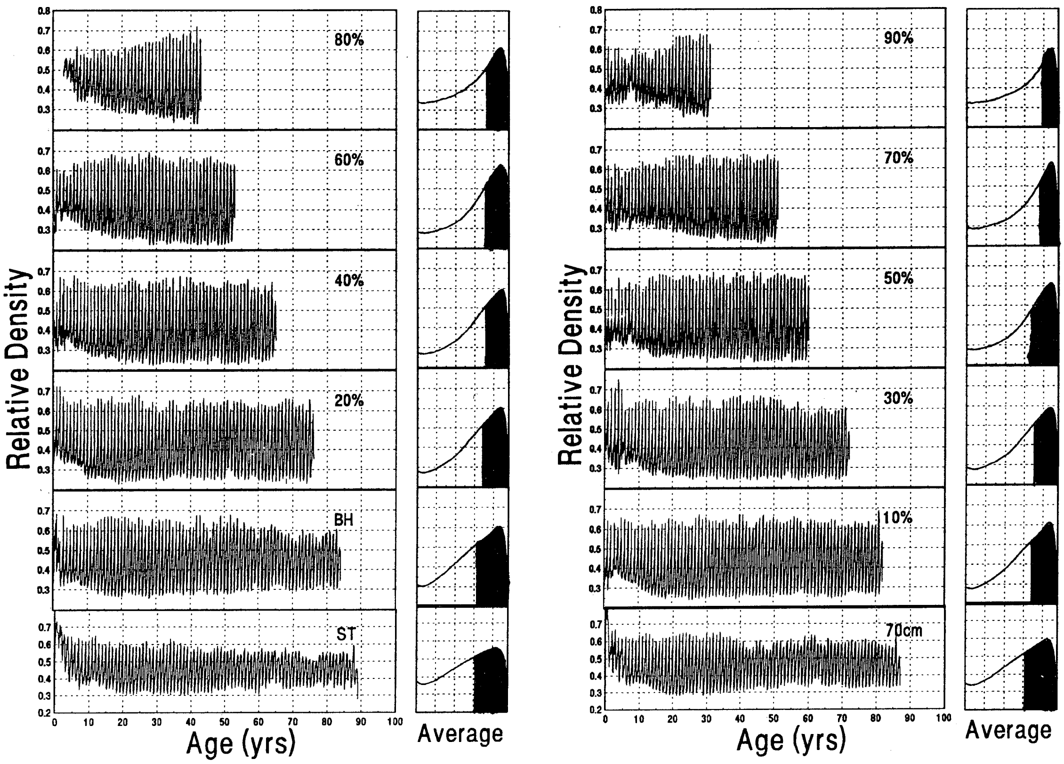
Individual stand average intra-ring density profiles are shown in Figure 23. Here ring data were combined for the bottom 1.3 m portion of the stem, by summarizing stump, 70 cm, and BH values. This represents the most dense portion of the stemwood (see Figure 10). Summaries were prepared by combining tree rings from the 20, 30, and 40% heights as well; this is where the least dense wood zones were identified by the pith-to-bark ring density trends. At all five sampling locations, low-density in the juvenile core, rings 6–15 and rings 16–35 (within 10 cm from the pith), was mainly the product of little latewood (Figure 23).

5.5 Moisture Content, Compression Wood, and Spiral Grain

Average heartwood and sapwood moisture content is shown in Table 5 for the five sampling locations. According to the literature (Nielson *et al.* 1985), old-growth western hemlock has an average sapwood moisture content of 143%, and an average heartwood moisture content of 55%. Therefore, this sample of second-growth western hemlock has markedly lower sapwood moisture content at 113%. Stand averages range from 72% at Port Renfrew to 134% at Port Mellon and Lake Cowichan. Average heartwood moisture content was 51%, ranging from 40% at Port Renfrew to 58% at Lake Cowichan.

Figure 24 (a and b) shows heartwood and sapwood moisture content distribution at BH, 20, 40, 60, and 80% tree height for the five sampling locations.

Summary of 13 Trees - Port Mellon



Summary of 13 Trees - Port Hardy

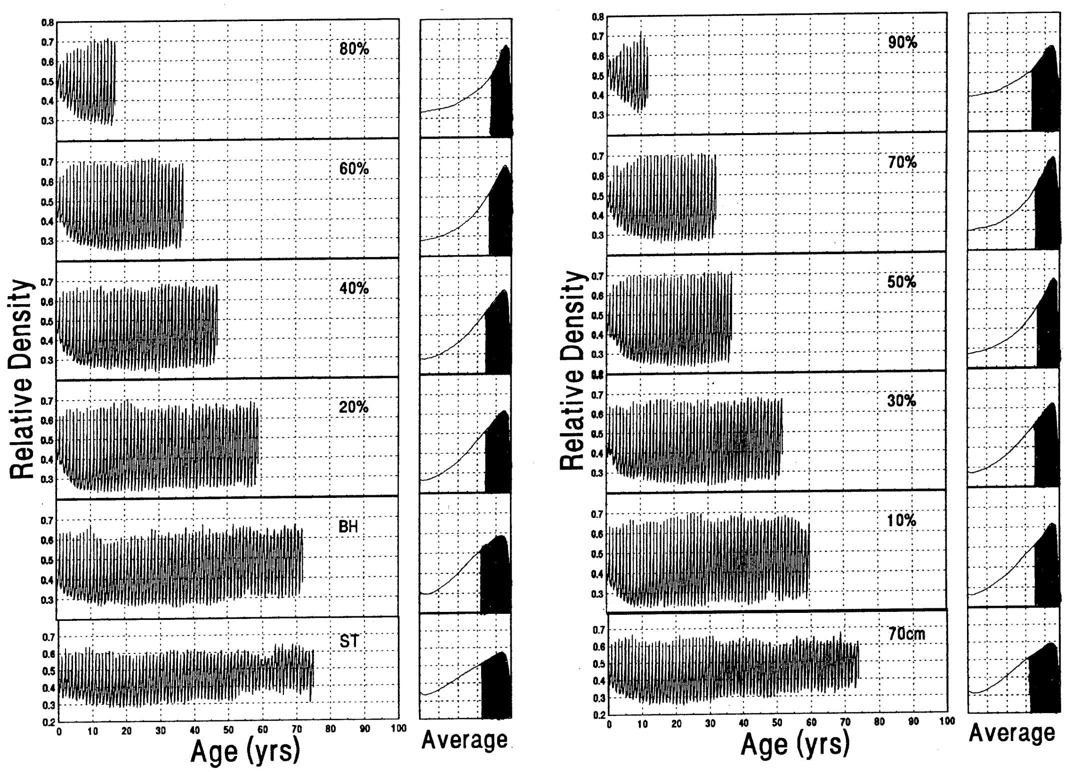
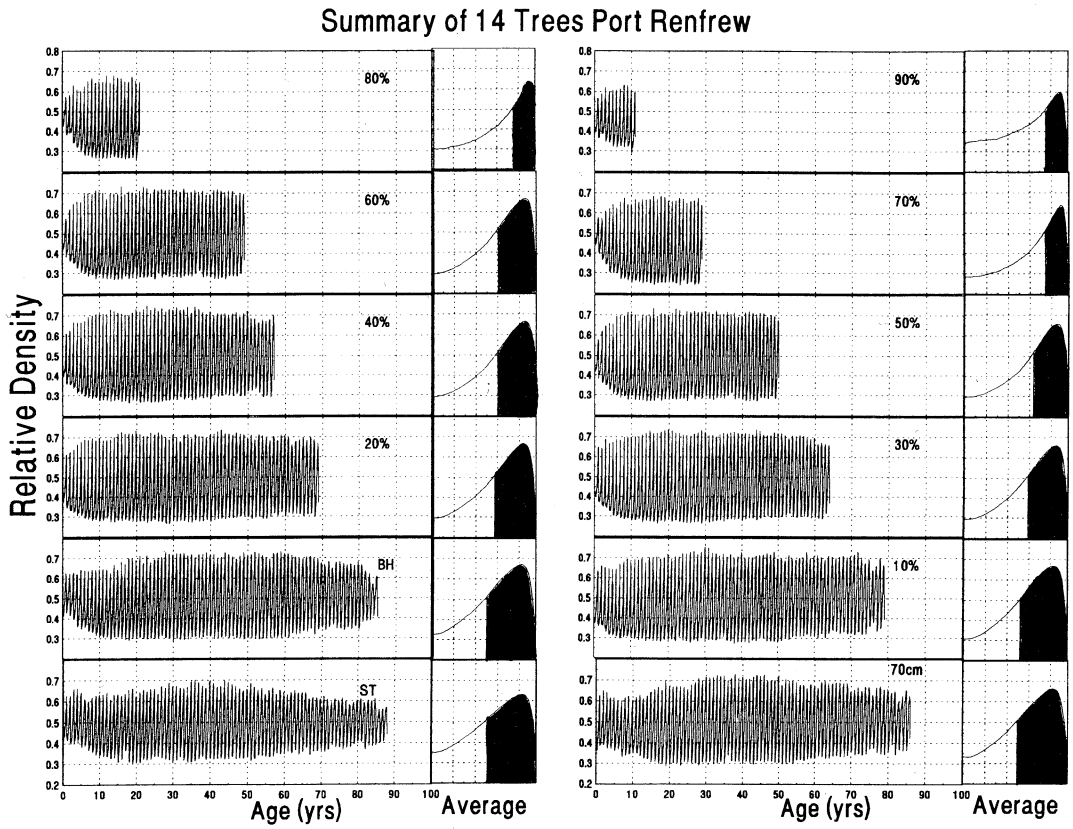


Figure 20. Intra-ring density profiles for 12 heights at five sites.



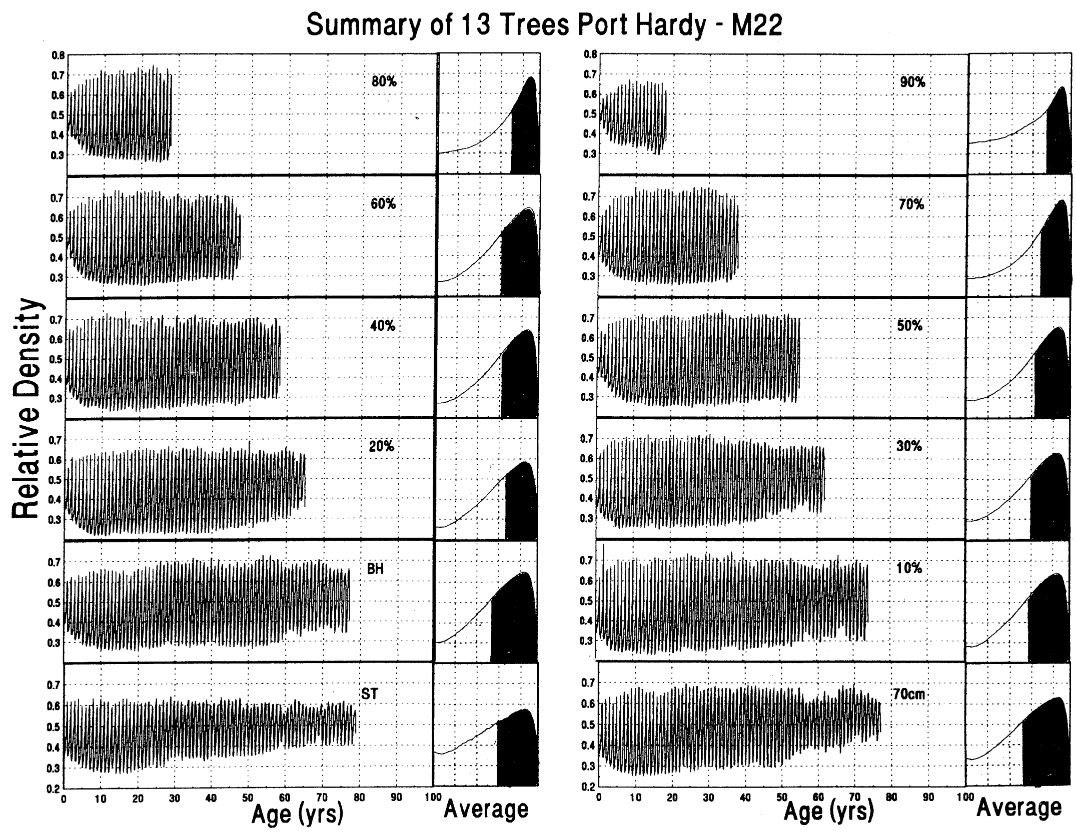


Figure 20. *Continued.*

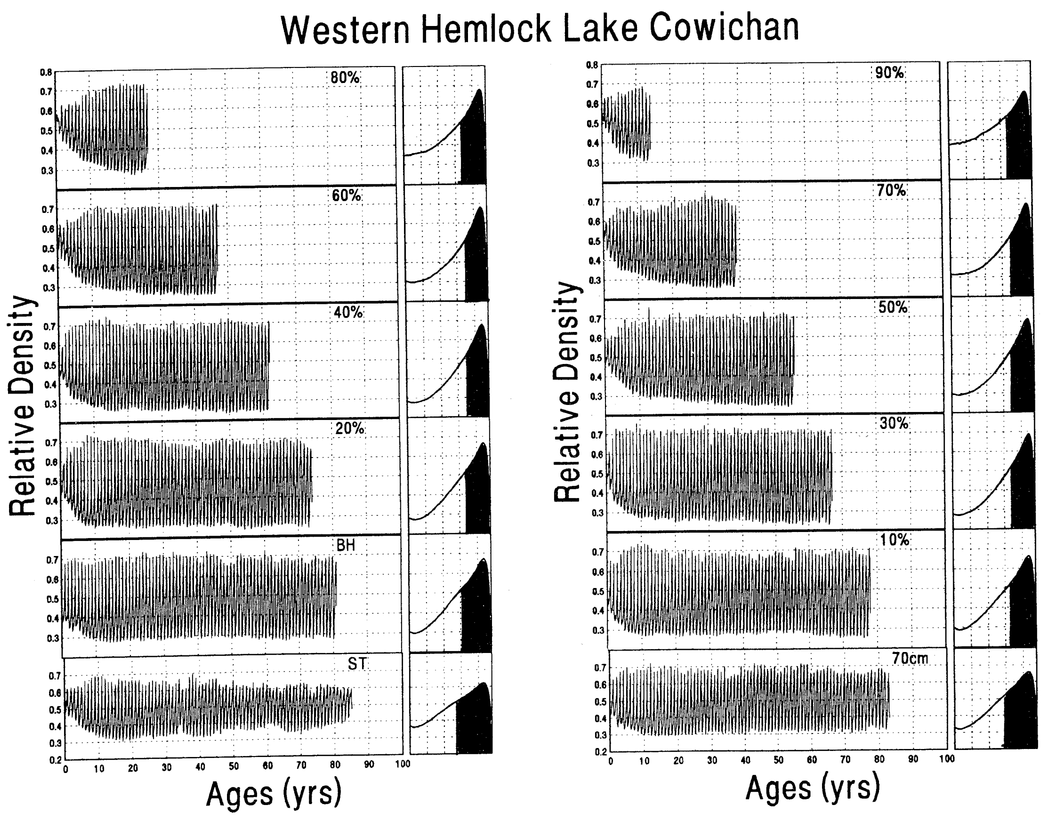
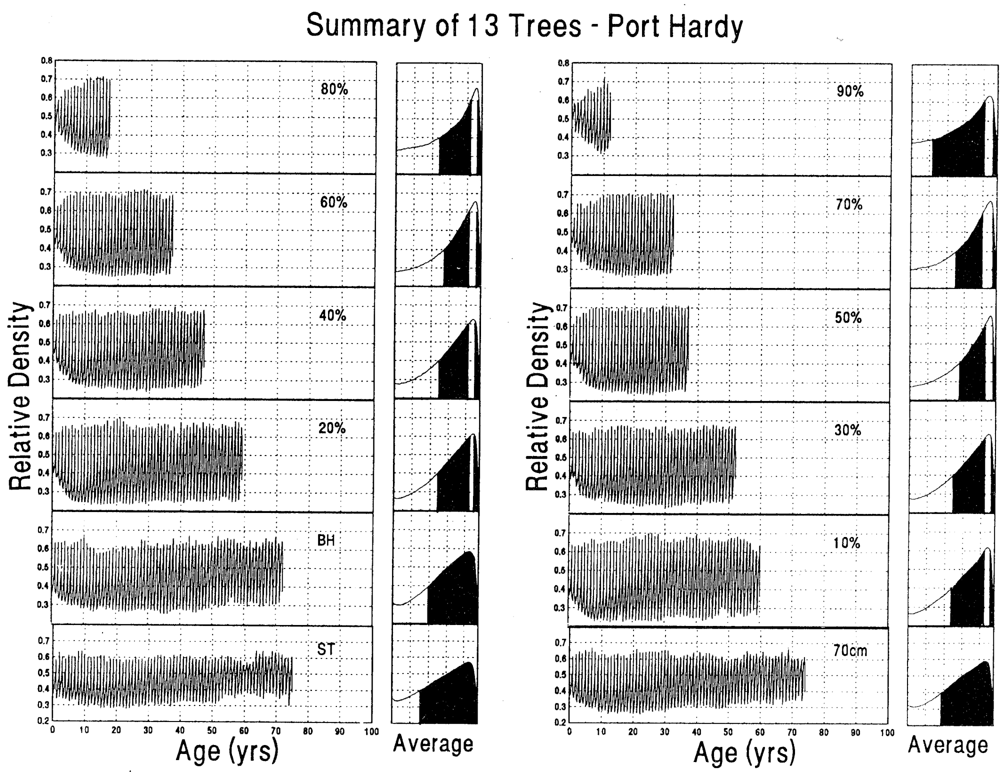


Figure 20. *Continued.*



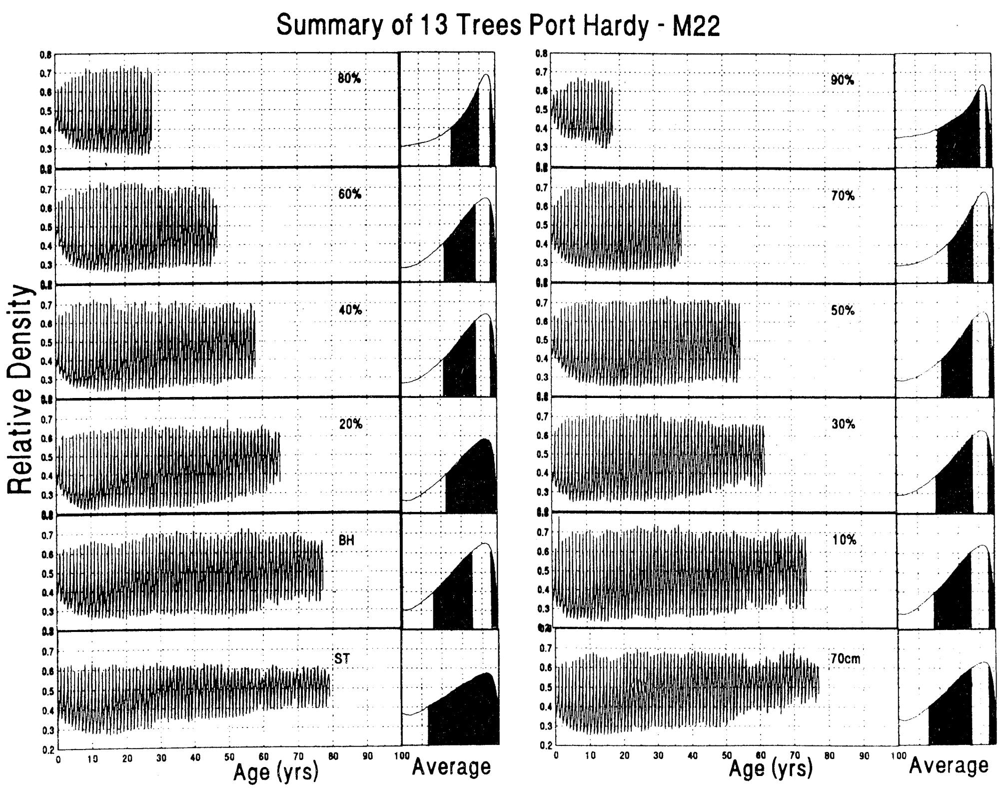


Figure 21. Wood density uniformity in two Port Hardy sites.

Table 5 and Figure 24d show compression wood content. Overall average compression wood content was 6.3%, ranging from 4.8% at Port Hardy M22 (1000 stems/ha) to 10.5% at Port Hardy (650 stems/ha). No stand-to-stand differences or BH-to-80% height-level trends were evident.

Table 5 also shows average spiral grain index values for each of the five sampling locations. The overall average spiral grain index was 0.94, ranging from 0.51 (at Port Hardy) to 1.34 (at Port Hardy M22). Figure 24c shows spiral grain index values for five height positions in the stem for each of the five sampling locations. Figure 25 shows the actual grain angle frequency distribution with a mean of 2 degrees of spiral grain. This amount of spiral grain is negligible from the solid wood products perspective, and should not cause any significant loss in strength or problem with warp.

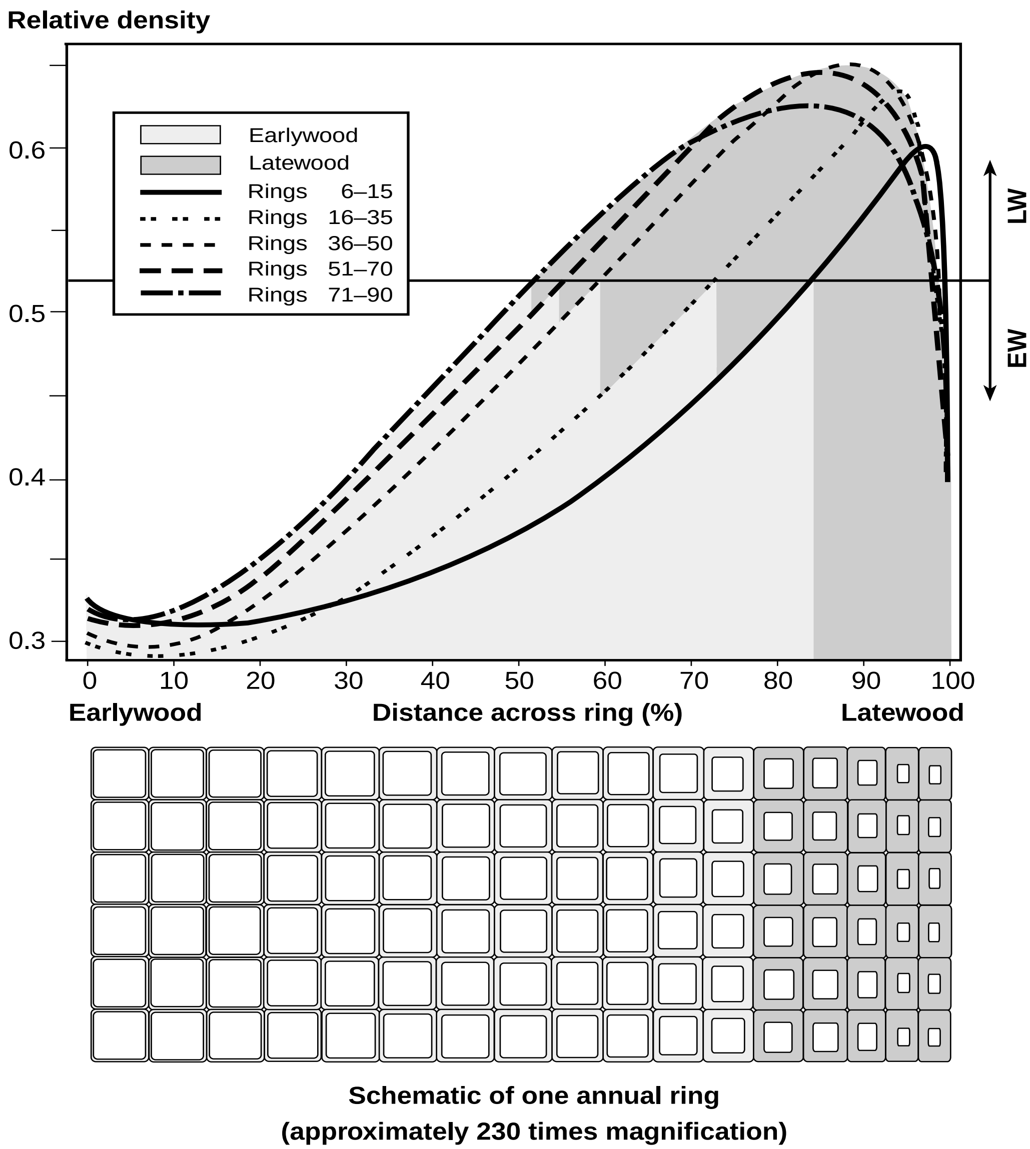


Figure 22. Combined intra-ring density profiles at BH for five age intervals.

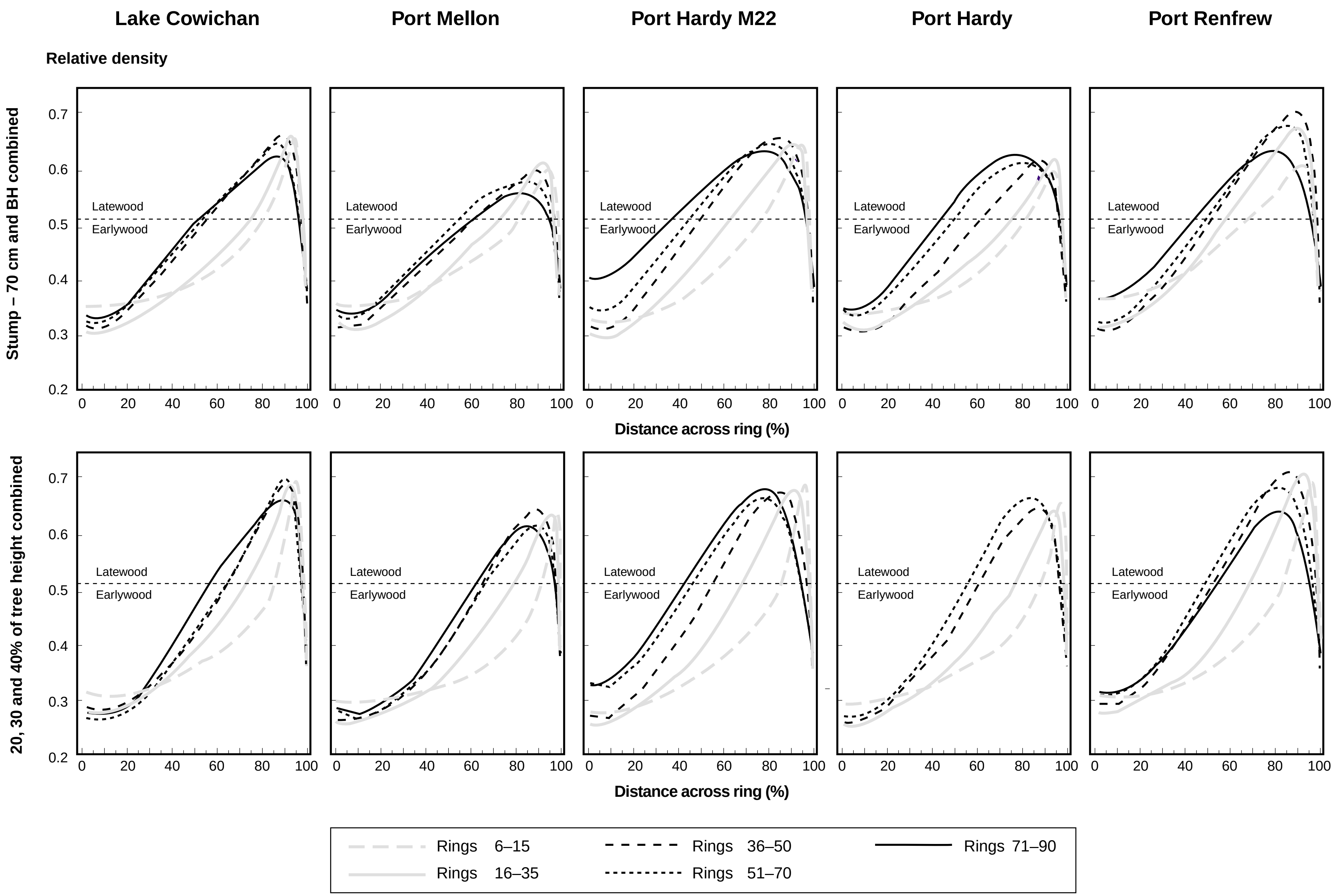


Figure 23. Intra-ring density profiles combined for stem base and at 20–40% stem height.

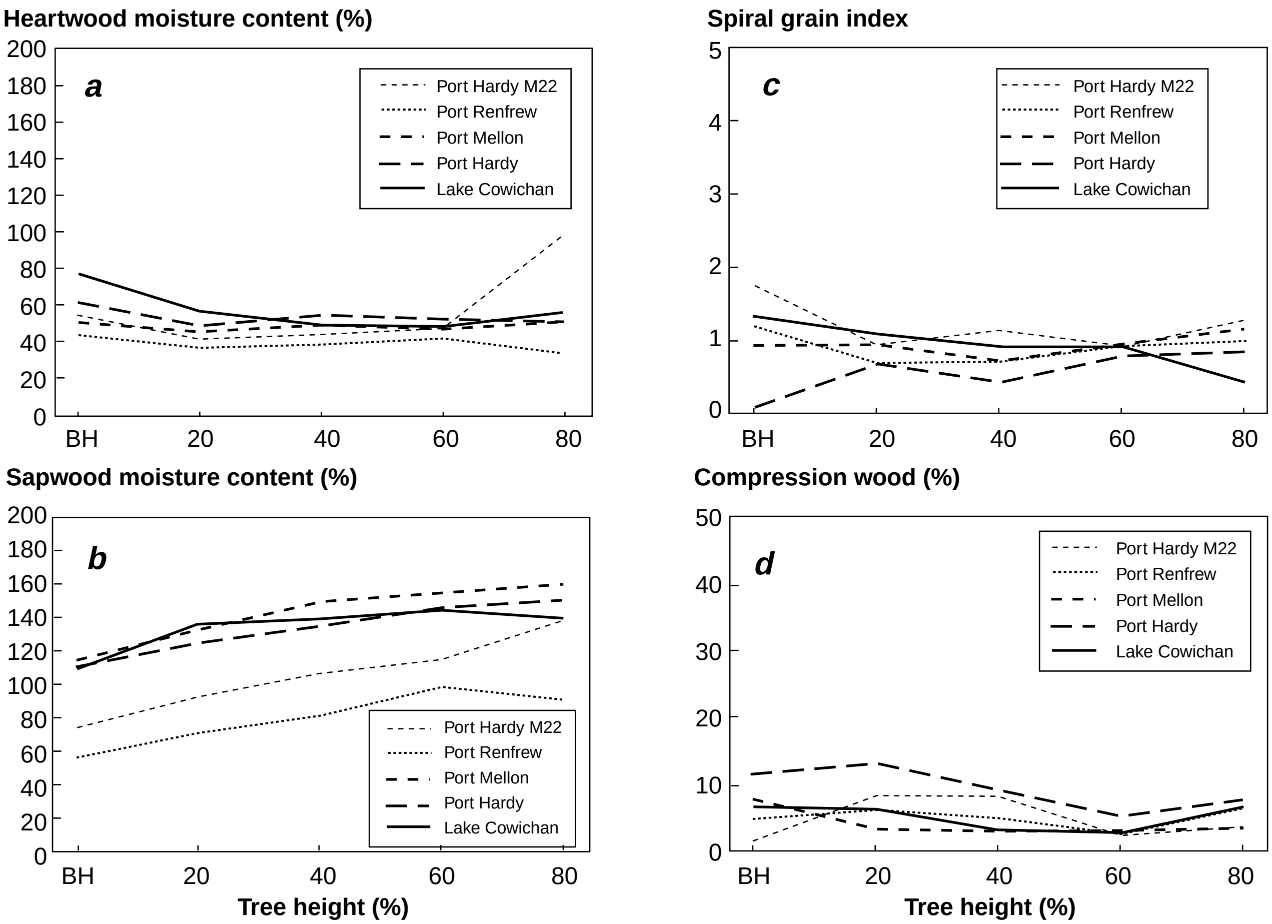


Figure 24. *Sapwood and heartwood moisture content, spiral grain index, and percent compression wood.*

Table 5. *Average sapwood and heartwood moisture content, percent compression wood, and spiral grain index*

	Location					
	Port Mellon	**Port Hardy**	**Lake Cowichan**	**Port Hardy M22**	**Port Renfrew**	**5 locations combined**
Sapwood moisture content (%)						
Mean	134	129	134	100	72	113
Std. dev.	11	13	17	20	17	29
Heartwood moisture content (%)						
Mean	48	56	58	54	40	51
Std. dev.	7	8	8	19	7	13
Compression wood (%)						
Mean	5.6	10.5	5.6	4.8	4.9	6.3
Std. dev.	5.2	5.7	2.7	3.7	4.3	4.8
Spiral grain index						
Mean	.91	.51	1.04	1.34	.89	.94
Std. dev.	.76	.27	.33	1.12	.51	.70

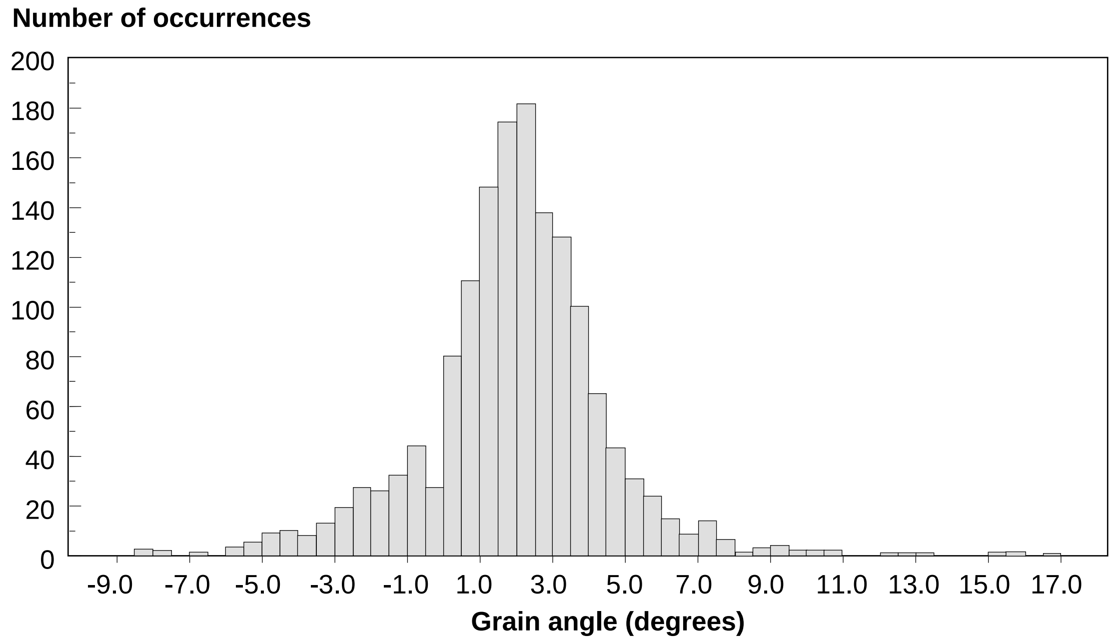


Figure 25. Grain angle frequency distribution.

5.6 Longitudinal Shrinkage

Figure 26 shows longitudinal shrinkage values for the BH and 40% tree height samples at 12% moisture content and at oven-dry condition. At both sampling heights oven-dry shrinkage was consistently below 0.3%, and at 12% moisture content longitudinal shrinkage was less than 0.1%. These values are well within the normal limits published in the literature and therefore should not cause problems with excessive warp in lumber from these 90-year-old second-growth western hemlock trees.

5.7 Strength Properties

Appendix 1 shows the results of mechanical tests of small clears 25×25×410 mm (1×1×16 in.) for Port Mellon, Port Hardy, and Lake Cowichan. Two interesting features are noteworthy in terms of microfibril orientation. First, in Figure 1 (of Appendix 1) while very little change is evident in relative density between 3 to 6 cm from the pith, modulus of elasticity increases sharply. This is attributable to declining fibril angles outward from the pith. Second, in Figure 3A (of Appendix 1) the pith-associated high-density wood has very low strength properties because of excessive fibril angles.

5.8 Stem Profiles and Density Distributions at Age 60

Appendix 2 shows average stem profiles and stemwood density distributions at age 60. Each stem profile represents the summary of 13 trees per stand at age 60 and is shown superimposed onto the 90-year-old tree profiles. It can be seen that reduction in tree size was at the expense of the outer high-density mature wood shell. For example, the 86-year-old Port Hardy trees reached minimum stemwood density (0.37) at age 25. By age 60 and 86 stemwood density was 0.40 and 0.41, respectively.

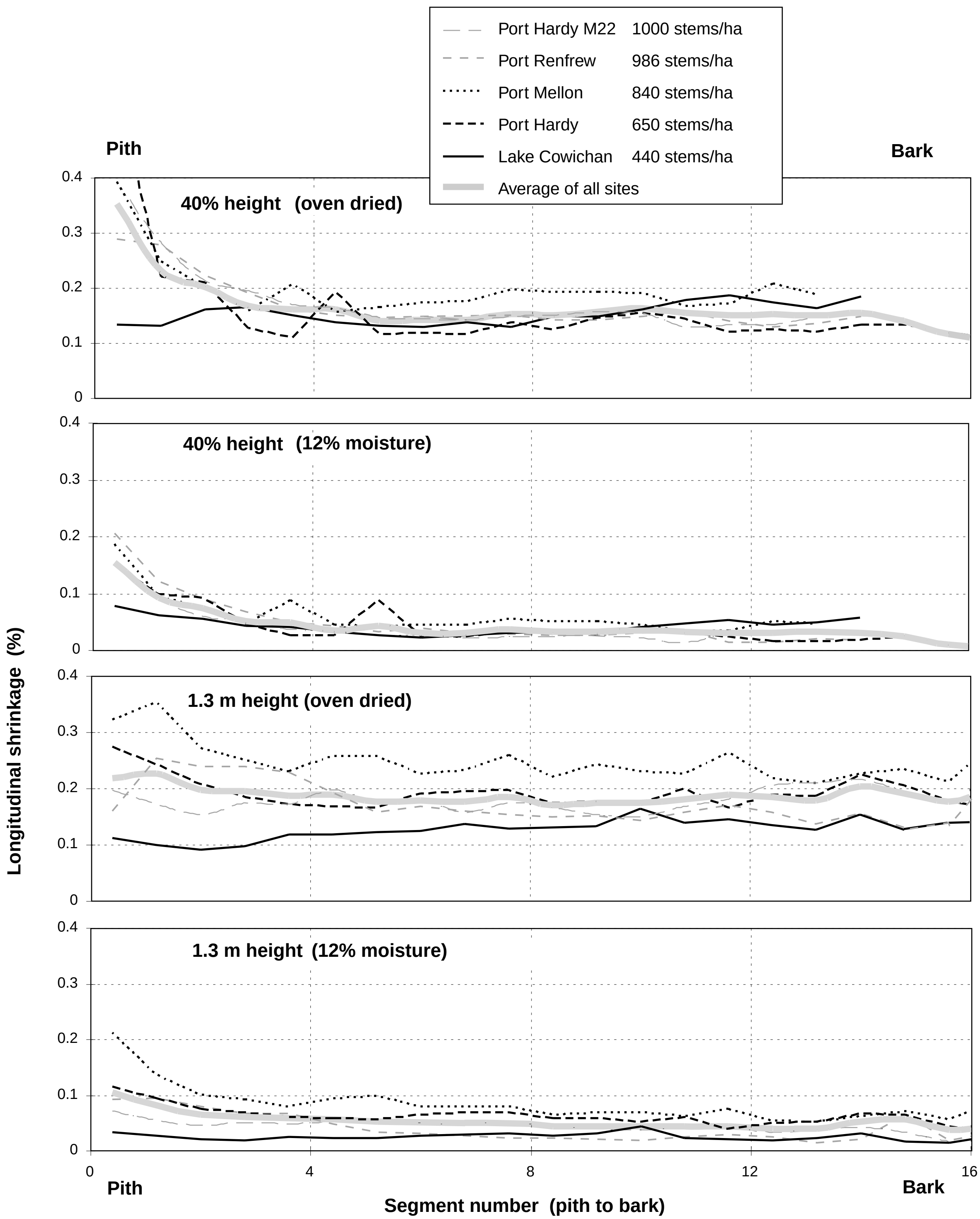


Figure 26. Longitudinal shrinkage values at breast height and 40% stem heights.

This information is presented here in the context of product expectations from commercial thinnings, and future harvests of good site western hemlock stands. Industry experts feel that harvesting such stands will occur at ages significantly less than 90 years. This will mean not only smaller stem sizes but also increased proportions of juvenile wood, relative to mature wood. This will have implications for previously established standards (based on old growth), in terms of strength and stiffness, dimensional stability, and appearance.

5.9 Stem Profiles and Density Distributions in Small, Medium, and Large Diameter Class Trees

To get a better appreciation of stemwood density differences between the small- and large-diameter trees, stem profiles and wood density distributions were examined according to three diameter classes. At each sample location the three smallest and the three largest diameter trees (at BH) were averaged to provide the small- and the large-diameter stemwood profiles and density distributions. Seven trees made up the medium diameter class at each location.

Table 6 shows and confirms that the rate of growth in these 90-year-old western hemlock trees has little effect on stemwood density. For example, when we combined the three small trees from each of the five locations, the average DBH of the 15 trees was 33 cm, with a stemwood density of 0.43. While the 35 medium-diameter trees were on average 42 cm DBH, their average stemwood density was 0.43 as well. The 15 large-diameter trees' average stemwood density was 0.414 (only 3.7% less dense than the small and medium trees), with an average DBH of 54 cm.

Appendix 3 shows average stem profiles, extent of live crown, and stemwood density distributions for the small, medium, and large diameter classes for each of the five tree sample locations.

Table 6. Stem diameters and density distributions grouped into three diameter classes

	Small diameter			Medium diameter			Large diameter		
Location	DBH (cm)	Stem density	Tree height (m)	DBH (cm)	Stem density	Tree height (m)	DBH (cm)	Stem density	Tree height (m)
Port Mellon	34	0.40	34	41	0.41	37	50	0.40	39
Port Hardy	36	0.42	44	46	0.41	45	60	0.41	46
Lake Cowichan	39	0.46	38	51	0.42	42	60	0.41	45
Port Hardy	28	0.43	36	36	0.44	40	50	0.43	43
Port Renfrew	28	0.44	33	36	0.47	39	50	0.42	42
5 sites combined	33	0.430	37	42	0.430	41	54	0.414	43

6 Haney Trees

Table 7 shows stand density, DBH, tree height, BH disk density, proportion of earlywood and latewood, disk density at 20% height, and branch diameter at 20% tree height (from the ground). The results of a September, 1995 live stem count showed 2 883 814 and 519 stems/ha at the 3×3, 9×9, and 12×12 foot initial spacings, respectively. The 3×3 spacing produced 16.9 cm DBH at age 39, with 0.442 BH disk density, which was significantly higher ($p < 0.05$) than the 9×9 and 12×12 spacings, both of which produced 0.42 BH disk density. These results are encouraging because even at the very open stand density (12×12 with 519 stems/ha), these 39-year-old western hemlock trees equal the old-growth resource average value (0.42).

At the 20% height level, disk densities were significantly different ($p < 0.05$) between 3×3 (0.44) and 9×9 (0.39), but not between 3×3 and 12×12 (0.42), and not between 9×9 and 12×12 spacings.

Tree diameter at BH increased from 16.9 cm to 22.0 and 27.6 cm with increasing growing space from 3×3 to 9×9 and 12×12 foot spacings, respectively. Tree heights were almost identical. Although earlywood and latewood densities were almost identical at BH at all three stand densities, it was the proportion of latewood that explained the wood density differences. At 3×3 spacing the average annual ring had 33.3% latewood by width, while the 9×9 and 12×12 spacings had 26.2 and 26.0%, respectively.

Branch diameter at 20% tree height (about 4.0 m above ground) increased from 11.8 to 21.4, and 31.2 mm in the 3×3, 9×9, and 12×12 spacing, respectively. These were all dead branches, since the first live branches on these trees were at least 8 m above ground level.

Ring width and ring density trends from pith to bark are shown in Figure 27. Figure 27a shows that at BH maximum ring width was reached at age five at all three spacings. For the 3×3 trees, ring width dropped from 6 mm at age 5, to 2 mm by age 15. In the same time interval ring width is reduced to only 4 mm at the 9×9 and 12×12 plots. By age 30, ring width is 1.5 mm at the 9×9 and 12×12 plots, while at the 3×3 spacing ring width is 1.2 mm.

Figure 27b shows ring width trends for the 20% height level samples. At this position in the stem the 12×12 spacing produced 5–6 mm wide rings from age 3 to 13. Although early growth produced 5–6.5 mm wide rings at all three spacings, progressively more suppressed growth is evident at the 9×9 and 3×3 locations. By age 20, ring width dropped to 2.8, 2.2, and 1.3 mm at 12×12, 9×9 and 3×3 spacings, respectively.

Figure 27d shows average ring density trends at BH. An identical trend is evident at the three spacings from pith to age eight, density drops rapidly from 0.50 near the pith to 0.41–0.42 by age eight. This trend is very similar to what was observed in the 90-year-old trees. For the 9×9 and 12×12 spaced trees a very gradual decline follows from age 8–14 (to 0.40). From this point (14 years) to age 28, density increases gradually to 0.45. The 3×3 trees showed a rapid increase in ring density from age 8 (0.41) to age 28 (0.48). At all three spacings wood density decreased somewhat for the last five years (from age 28 to 33).

At the 20% height level, average ring density trends for the three spacings are shown in Figure 27c. These trend lines are similar to the BH results, with one major exception; ring density at the 9×9 spacing is 0.03 lower than at the 12×12 spacing.

The 39-year-old Haney tree results, in conjunction with the 90-year-old tree results, indicate that although high stocking densities produced trees with high relative density wood, even the more open stands produced stemwood densities equalling old-growth standards. This is a very important attribute for second-growth western hemlock, particularly as we move from utilizing old growth to increasing harvest of second-growth stands.

Table 7. Summary of stand and tree characteristics for 39-year-old western hemlock trees at Haney

		Initial spacing (ft × ft)		
		3×3	9×9	12×12
Stand density (stems/ha)				
	Initial (1959)	11 960	1 329	747
	Current (1995)	2 883	814	519
Number of sample trees		31	30	34
Site class		Good	Good	Good
DBH (cm)				
	Mean	16.9	22.0	27.6
	Std. dev.	3.8	7.0	8.2
Total height (m)				
	Mean	20.6	20.2	21.1
	Std. dev.	1.3	2.8	2.5
BH total density				
	Mean	0.442	0.416	0.420
	Std. dev.	0.034	0.050	0.045
BH earlywood density				
	Mean	0.370	0.356	0.365
	Std. dev.	0.023	0.030	0.031
BH latewood density				
	Mean	0.585	0.575	0.579
	Std. dev.	0.025	0.025	0.019
Percentage volume latewood				
	Mean	33.3	26.2	26.0
	Std. dev.	8.1	10.8	10.3
Branch diameter @ 20% ht. (mm inside bark)				
	Mean	11.6	24.0	31.2
	Std. dev.	2.9	5.8	7.3
Disk density @ 20% ht.		0.44	0.39	0.42

7 Summary

This report describes the results of basic physical wood property analyses of 39- and 90-year-old coastal western hemlock trees from British Columbia. The results of this study show that second-growth western hemlock trees can produce stemwood densities equalling the old-growth standard of 0.42 even in relatively open stands.

The average second-growth western hemlock tree chosen for this study was 91 years old, growing in a stand with 783 live stems/ha. This average tree, with 27.7% live crown, was 40.9 m tall, with 42.8 cm diameter outside bark at BH. Its weighted average stemwood relative density was 0.426. Stemwood volume including 10.1% bark was 3.05 m^3. Thirty-five percent of the stemwood volume was juvenile wood, and 65% was mature wood.

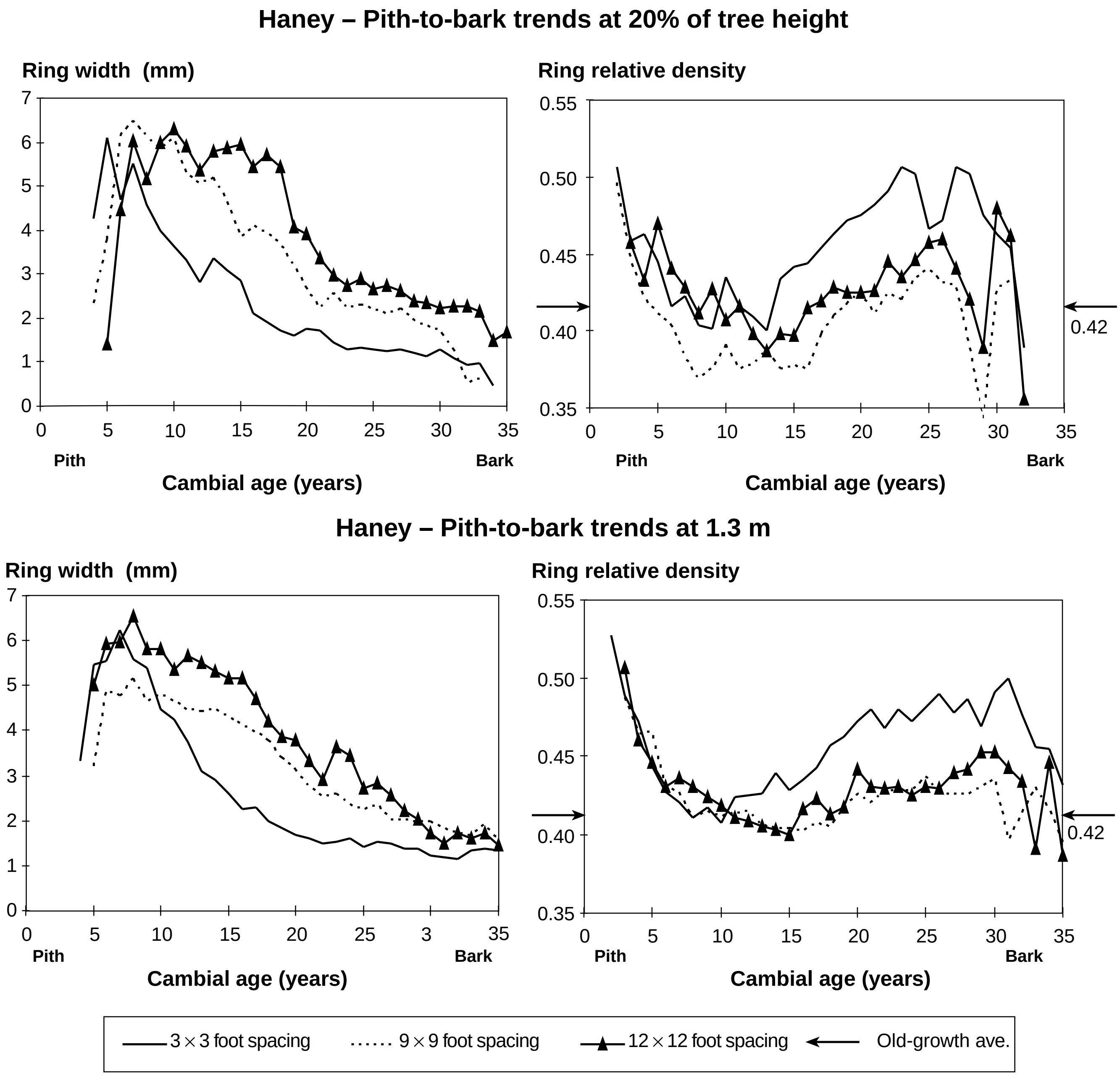


Figure 27. Ring width and ring density trends for 3×3, 9×9, and 12×12 foot spacing.

Average stemwood weight was 1176 kg (oven-dry weight basis; volume × density). Average sapwood and heartwood moisture contents were 113% and 51%, respectively (compared with old-growth averages of 143% and 55%). Only 6.3% of the stemwood was compression wood. Average volume weighted spiral grain index was 0.94; ranging from -5 to +8 degrees, with a mean of 2 degrees. Average rate of radial growth was 2.57 mm/year. The average annual ring in the average tree was composed of 32% latewood and 68% earlywood. On average, minimum densities in the earlywood ranged from 0.29–0.33, and maximum densities from 0.57–0.70.

High stand density western hemlock forests produced high relative density stemwood, approaching the Douglas-fir reference value of 0.45.

From a stand management perspective, our attention was focussed on describing juvenile wood characteristics and distribution, based on relative density and longitudinal shrinkage. From the utilization perspective of wood and fibre, relative density variation was examined and compared within annual rings, within trees, between trees, between locations, and to the degree possible between second-growth and old-growth material.

The data base generated in this study may ultimately be used as input variables in growth prediction models. Such models will permit testing of various forest management strategies that will influence the volume of the juvenile wood core and the mature wood shell. This information will be useful in allocating raw material for appropriate secondary products manufacturing decisions for dimensional lumber, composite products, and for pulping.

Tree-to-tree average stemwood density ranged from 0.36 to 0.51 for the 65 trees, with a mean of 0.426 and a standard deviation of 0.037. This variability in stemwood density in 90-year-old second-growth western hemlock is similar to the old-growth western hemlock norm of 10% COV (mean 0.42, range 0.34–0.50).

At each of the five sampling locations, the 20% and 30% height disks had an average relative density that was within 0.01 density unit of whole stemwood density. Therefore, if whole stemwood density values were required for coastal western hemlock at this age, the 20% and 30% height disks could provide reliable estimates of stemwood density.

Average bark volume, expressed as a percent of total stem volume including bark, was 10.1% (std. dev. 1.5) for these 65 second-growth western hemlock trees. For old-growth coastal western hemlock the average bark volume is 16.3%.

Juvenile wood content of the average 90-year-old western hemlock tree was 35% on a volume-weighted basis, and it was contained within the inner 14–30 cm diameter of the stem, from the stump to the top of the tree. Mature wood was contained outside the juvenile cylinder and below the live crown. On average, mature wood formation started at about the 25th ring from the pith at all height levels.

8 Recommendations

We recommend a product conversion study by utilizing the complete diameter spectrum of 90-year-old second-growth western hemlock, from 15 to 60 cm DBH, because smaller trees will contribute a significant portion of harvest volume from denser stands, while larger trees will come from more open stands. For minimizing geographical and site differences we further recommend obtaining tree samples from the Port Hardy area, concentrating on a relatively open (ca. 600 stems/ha) and a closed stand density (ca. 1000 stems/ha) location. This strategy will permit maximum range in DBH. Randomized complete block design should be used to select trees from four to five diameter classes for producing three product lines:

1. Structural lumber (both visually graded and machine-stress-rated)
2. Joinery products (doors, windows, furniture)
3. Veneer peeling (for plywood, LVL, Parallam, etc.)

We could also accommodate membership client-pull by including 60-year-old tree samples from the same geographical location. Appendix 2 shows the reduction in tree size and in the outer shell of high-density mature wood as we go from age 90 to 60. Young trees are needed to approximate the financial rotation (estimated by some to be as young as 35–38 years).

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Appendix 1

Mechanical Properties of Second-growth Western Hemlock

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July 17, 1995

Methods

Bolts of wood were cut at close to breast height and 40% tree height for the trees sampled at Port Mellon, Port Hardy and Lake Cowichan. Specimens for testing in static bending and in compression parallel to the grain were prepared according to ASTM D143-83. Specimens were conditioned to a moisture content of 9% prior to testing. Bending specimens were prepared from diametric strips while compression specimens were taken from strips adjacent to those taken for the bending specimens. Thus specimens containing the pith were not available for compression testing. The density of each specimen at the time of test was determined according to ASTM D2395-83. Modulus of rupture (MOR) and modulus of elasticity (MOE) values were calculated for the samples tested in static bending. Maximum crushing strength (C_{max}) and MOE values were calculated for the samples tested in compression parallel to the grain.

Results

The relative density values from the pith to the bark showed the same trends for the two heights sampled at each of the three locations. The relative density had a high value at the pith, dropped to a minimum value at samples close to the pith and then increased at greater distances from the pith. This trend was more evident for the bending specimens than for the compression specimens since the former included specimens containing the pith while the latter only included specimens taken adjacent to these pith-containing specimens.

For the static bending tests, both strength (MOR) and stiffness (MOE) values showed a general increase from pith to bark (Figure A1). The strength values for the specimens taken at breast height in the mature-wood region of the Port Mellon and Lake Cowichan samples exceeded the old-growth value (shown in Figures A1 to A4 as the dashed horizontal line) (Jessome, 1977). However, the samples taken at 40% tree height did not meet the old-growth value and the samples taken at breast height at Port Hardy only exceeded the old-growth value at the outermost portion of the stem. The stiffness values for the specimens taken at both heights in the mature-wood region of the trees from all three locations met the old-growth value. There was a strong dependence of the bending strength and stiffness on the specimen relative density (Figure A2). The exception to this trend was the pith samples which were relatively dense but exhibited low strength and stiffness. Table A1 shows the values for the regression coefficients calculated for the regressions of each of the mechanical properties determined and relative density. The values calculated when the pith-associated samples were included are shown as are those values calculated when the pith-associated samples were excluded.

For the compression parallel to grain tests both strength (C_{max}) and stiffness (MOE) values showed a general increase from pith to bark (Figure A3). The only samples to exceed the old-growth strength values were those taken from the mature-wood region at breast height of the Port Mellon trees and the outermost samples for the equivalent wood region from the Port Hardy trees. Only a few samples from the outermost mature-wood regions sampled at breast height from all three locations exceeded the old-growth stiffness value. Again there was a strong dependence of strength and stiffness values on the specimen relative density (Figure A4). The pith-associated wood was not noticeably weaker than might have been expected for its relative density but the stiffness values for the samples were lower than might have been expected based on density values alone.

For a given density, for the samples from Port Mellon and Port Hardy, the samples at 40% tree height were stiffer (higher MOE) than the corresponding samples at breast height. This is probably due to the larger microfibril angle (as indicated by the higher longitudinal shrinkage) determined at breast height than at the 40% tree height (Jozsa, 1995).

Table A1. Regression coefficient values (r^2) calculated for the dependence of mechanical property on the specimen relative density.

	Mechanical property			
	Static bending		Compression parallel to grain	
Data points used	Modulus of rupture	Modulus of of elasticity	Maximum crushing strength	Modulus of elasticity
Pith samples included	0.31	0.04	0.76	0.52
Pith samples excluded	0.85	0.44	0.79	0.64

Notes

The final data point (furthest from the pith) shown for each curve in Figures A1 to A4 is based on only a very few samples (three or less).

The horizontal line shown on each curve in Figures A1 to A4 represent the old-growth values (Jessome, 1977).

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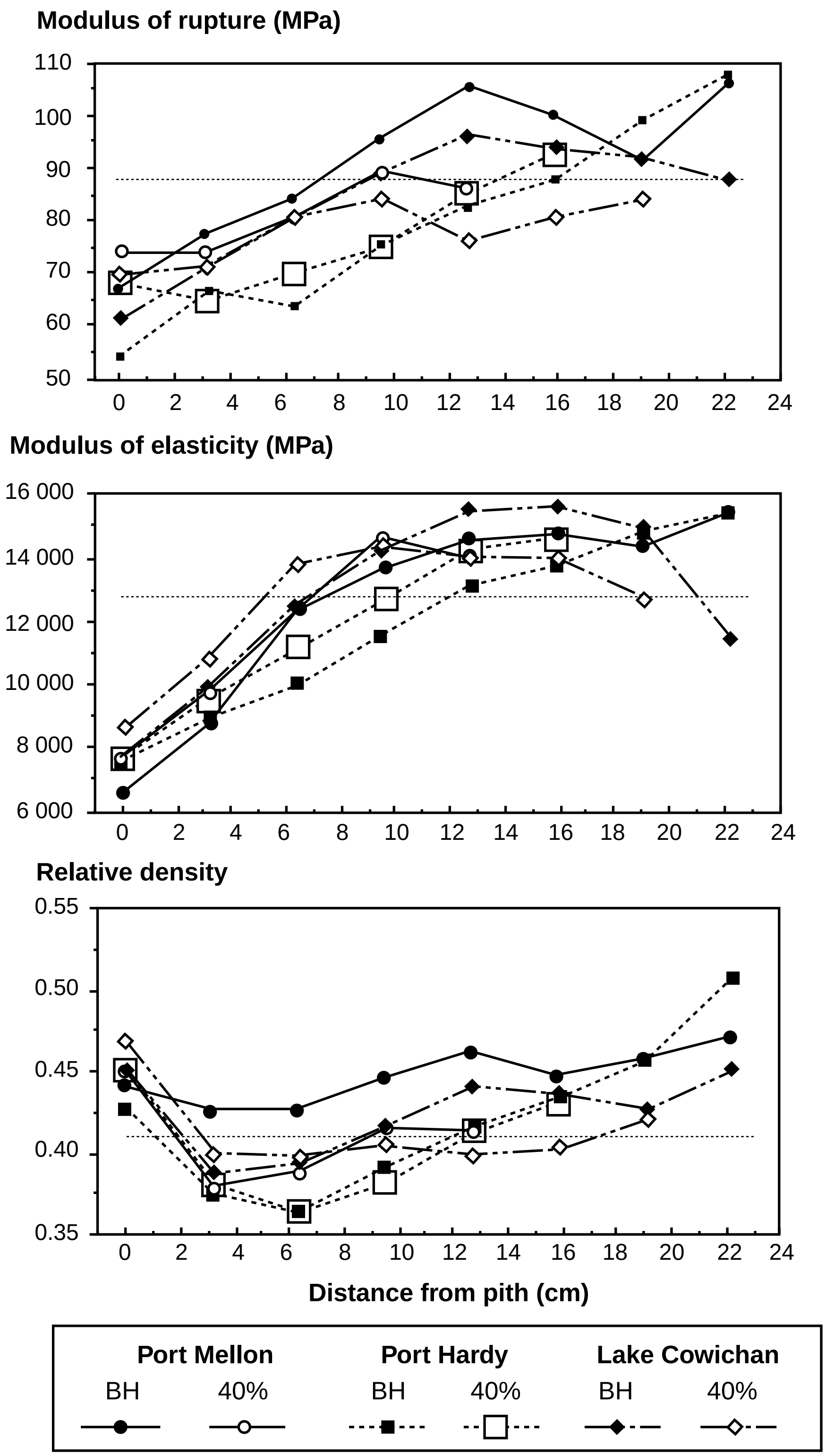


Figure A1. *Static bending – average trees.*

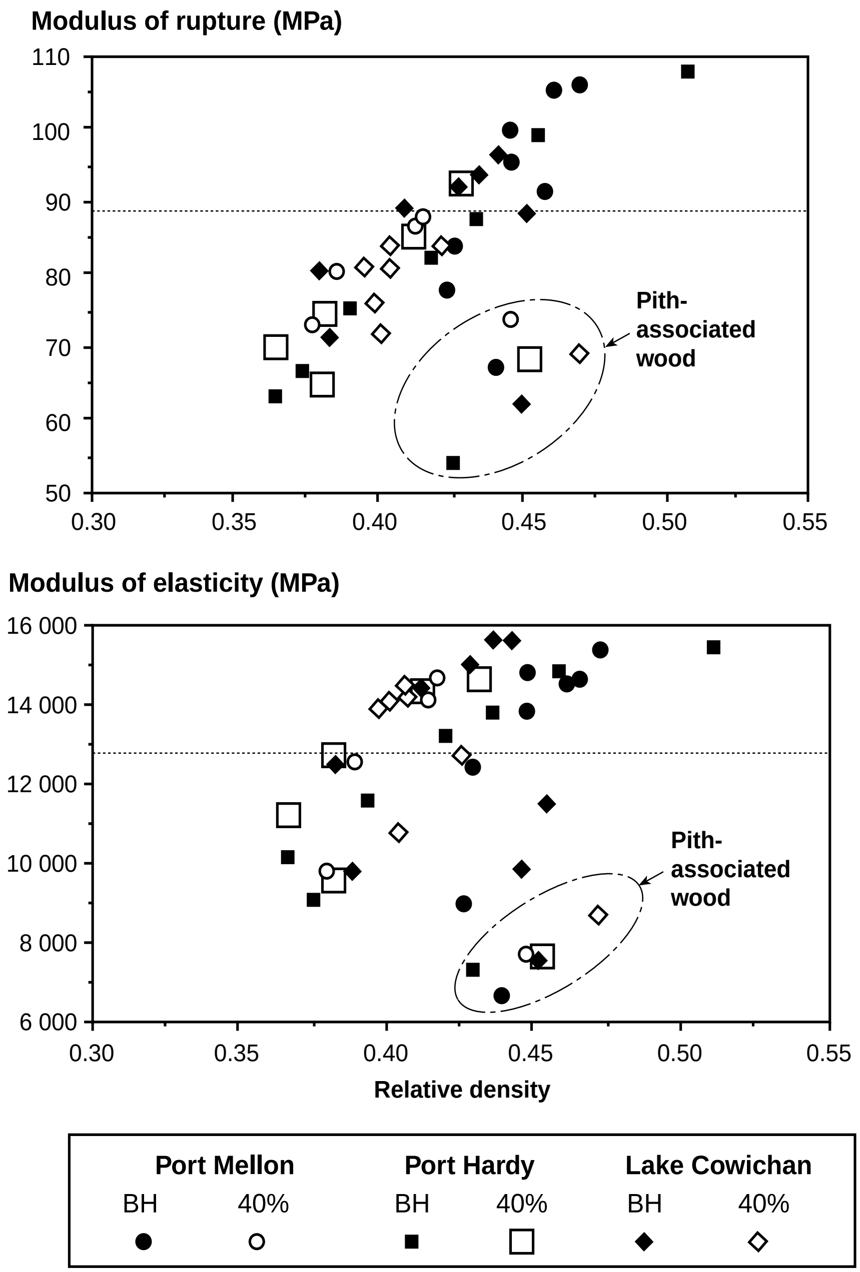


Figure A2. *Static bending – average trees.*

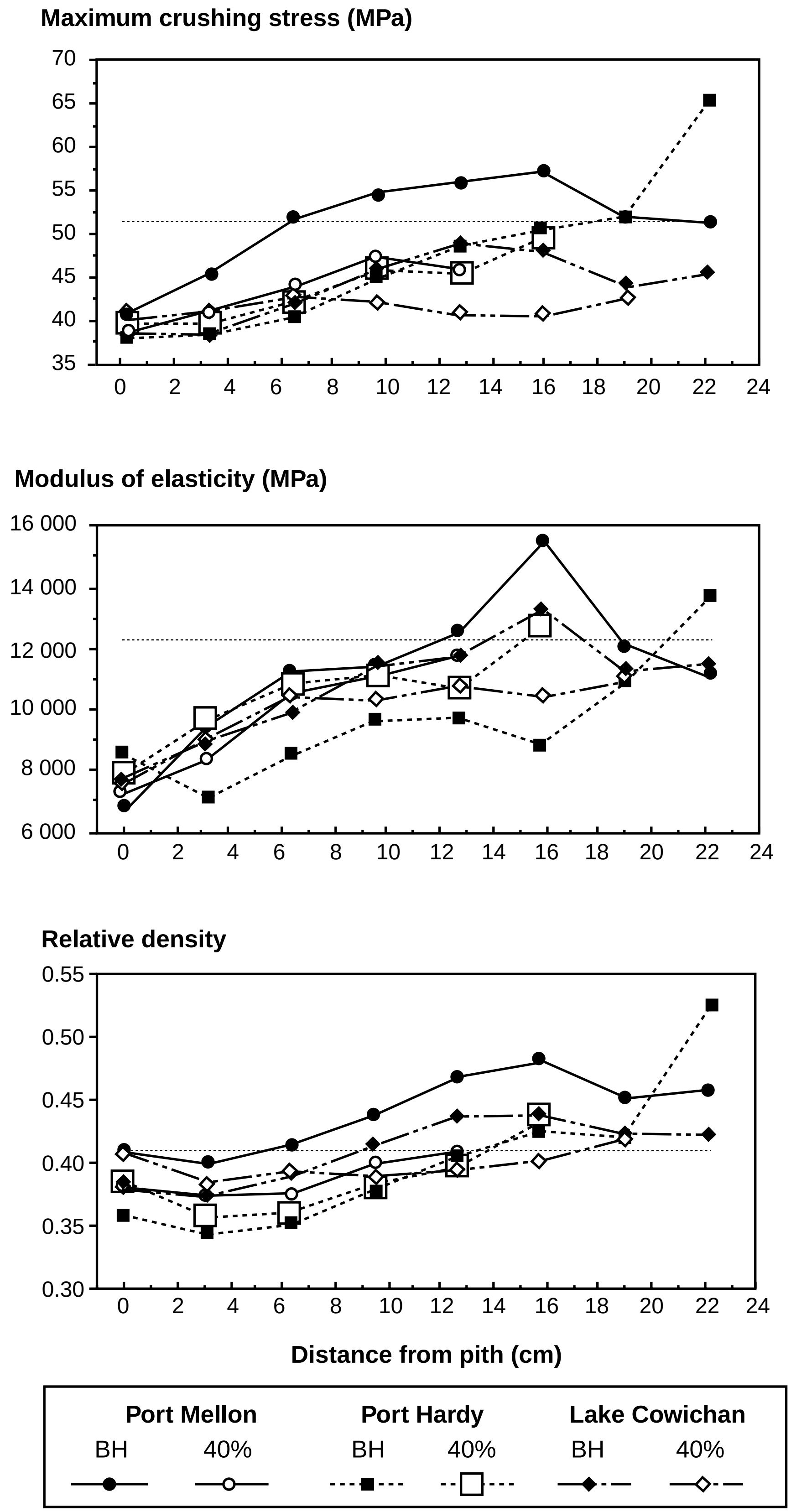


Figure A3. Compression parallel to grain – average trees.

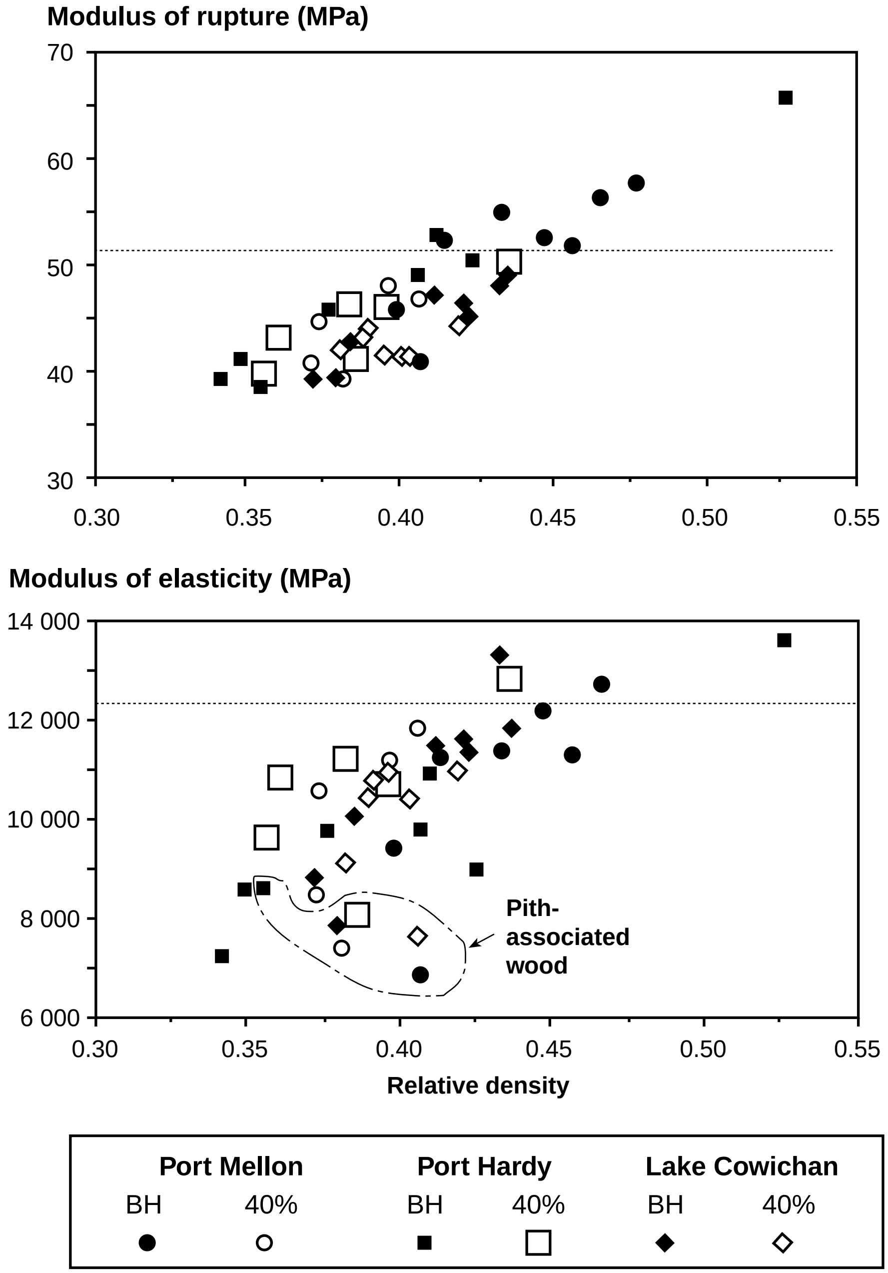
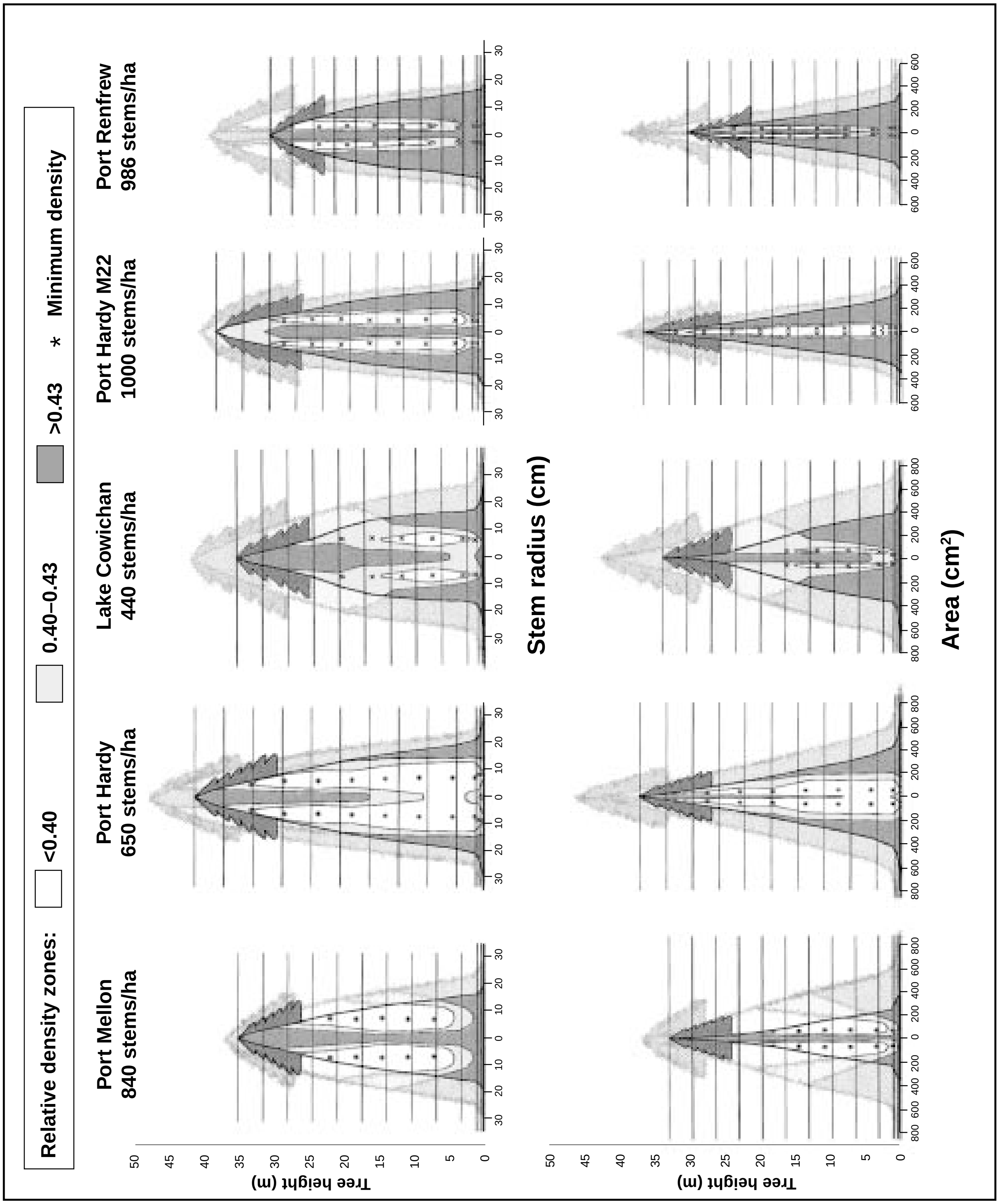


Figure A4. *Compression parallel to grain – average trees.*

Appendix 2

Average Tree-Stem Profiles and Density Distributions at 60 Years of Age



Appendix 3

Stem Profiles and Density Distribution in Small, Medium, and Large Diameter Class Trees