Small-diameter trees used for thermomechanical pulps*

GARY C. MYERS, R. JAMES BARBOUR, AND SAID ABUBAKR

ABSTRACT

During the course of restoring and maintaining ecosystem health and function in the western interior of the United States, many small-diameter stems are removed from densely stocked stands. These materials are considered nonusable or underutilized. Information on the properties of these materials is needed to help managers understand when timber sales are a viable option to accomplish ecosystem objectives. Pulp is a logical use for small-diameter material.

Thermomechanical pulps (TMPs) were prepared and evaluated from (a) lodgepole pine and mixed Douglas-fir–western larch sawmill residue chips, (b) lodgepole pine, Douglas-fir, and western larch submerchantable logs, and (c) lodgepole pine, Douglas-fir, and western larch small trees. TMPs prepared from Douglas-fir and lodgepole pine small trees had equal or better paper properties than pulp from sawmill residue chips of the same species. TMPs prepared from Douglas-fir, western larch, and lodgepole pine submerchantable logs and western larch small trees had lower paper properties than pulps from sawmill residue chips of the same species. Thermomechanical pulps prepared from lodgepole pine submerchantable logs and western larch small trees had the poorest properties of the eight raw materials evaluated.

Application:

Douglas-fir and lodgepole pine small-diameter materials are suitable for thermomechanical pulping.

THE FOCUS OF FOREST MANAGEMENT on federal land has taken on a more ecological orientation during this decade *(1–3)*. Some of the common ecological themes in the western United States are (a) lack of diversity at the landscape level, (b) potential for large-scale disturbances, such as insect infestations and fire, and (c) development of functional late-successional stand structures within watersheds where they are currently in deficit. In some cases, active management will be required to change the developmental trajectory of stands or landscapes to either hasten the development of desired conditions or reach conditions that might never be achieved without interventions.

Landscape-level manipulations can be expensive, and funding for these activities must compete with other priorities in federal and state budgets that may have nothing to do with forest management. Accordingly, whenever possible, government land managers will attempt to use timber sale programs to fund management activities that have more to do with meeting ecological objectives than providing economic benefits from timber management. In practice, this means that state and federal land managers will offer a different type of resource for sale than they would have under a program oriented more toward timber production. This resource will often be of smaller diameter than the traditional resource *(4)*. Also, forest operations required to implement the silviculture prescriptions associated with meeting ecosystem objectives are often complex and required equipment with which established operators have little experience. The size of the resource and the complexity of the treatments combine to limit the economic feasibility of many proposed treatments *(5, 6)*. Managers often find themselves in the frustrating situation of timber sales being offered below cost, failing to meet the ecological objective, or failing to attract bidders.

The USDA Forest Service has instituted a program to help public land managers understand the complexity and economic difficulty of integrating biological, ecological, silvicultural, and social objectives in a climate where management activities must be self-supporting *(7, 8)*. This study is part of that effort. Since many of the trees removed under ecosystem management treatments are small in diameter (i.e., less than 254 mm at breast height), pulp is a logical use for them. This study examines the technical properties of the small-diameter resource through high-yield mechanical pulping. It clarifies quality characteristics of the resource that could add to or detract from its value. Such information will help entrepreneurs or corporations make better-informed decisions about whether to bid on marginal sales offered by public land managers. It will also help public land managers understand the economic

*The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This paper was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

Input material*	Total energy, W·h/o.d. kg	Pulmac shive <0.004 mm, %	KAJAANI FS-100 ANALYSIS LENGTH-WEIGHTED Average, mm	Fines, %	Coarseness, mg/m
Lodgepole pine SML	2314	0.10	0.67	8.52	0.323
Lodgepole pine ST	2958	0.42	1.05	4.43	0.298
Lodgepole pine SRC	5020	0.65	1.17	4.56	0.349
Douglas-fir SML	4405	0.67	0.86	6.67	0.306
Douglas-fir ST	2687	1.06	1.09	4.26	0.318
Western larch SML	4962	0.82	1.01	5.75	0.389
Western larch ST	2256	1.44	0.92	6.29	0.373
Douglas-fir–western larch SRC	3761	0.93	1.15	4.50	0.336

*SML=submerchantable logs, ST=small trees, SRC=sawmill residue chips

I. Estimated pulp properties at 100-mL CSF

Input material[a]	Apparent density, kg/m³	Burst index, kPa·m²/g	Tear index, mN·m²/g	Tensile index, N·m/g	TEA[b] J/m²	Smoothness, SU	ISO brightness, %	Printing opacity, %	Scattering coefficient, m²/kg
Lodgepole pine SML	416	0.64	1.86	19.3	9.30	234	45.2	98.4	49.2
Lodgepole pine ST	457	1.31	3.61	30.3	22.24	201	43.8	97.7	45.2
Lodgepole pine SRC	461	1.47	4.44	33.3	27.82	173	46.0	98.8	79.2
Douglas-fir SML	471	1.04	3.33	25.5	17.47	200	31.8	99.6	44.0
Douglas-fir ST	456	1.36	4.28	29.9	23.25	191	37.0	98.9	44.9
Western larch SML	443	1.06	3.37	26.8	17.98	221	32.6	99.3	41.0
Western larch ST	397	0.78	2.74	20.8	11.95	287	39.3	98.3	40.9
Douglas-fir–western larch SRC	456	1.13	3.89	26.3	19.04	197	34.4	99.6	61.0

[a]SML=submerchantable logs, ST=small trees, SRC=sawmill residue chips
[b]Tensile energy absorption

II. Estimated paper properties at 100-mL CSF

viability of the sales they design and enable them to offer sales that are more attractive to potential bidders while still achieving their ecological objectives.

EXPERIMENTAL

Raw materials

All raw materials used in this study were obtained from the Colville National Forest (eastern Washington) or the Idaho Panhandle National Forest (western Idaho). The species selected were Douglas-fir [*Pseudotsuga menziesii* var. glauca (Beissn.) Franco], lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and western larch (*Larix occidentalis* Nutt.). A Douglas-fir–western larch mixture and lodgepole pine sawmill residue chips (SRC) were obtained from Vaagen Bros. Lumber (Colville, WA). The submerchantable logs (SML) had less than an 89 mm end diameter and primarily were tree tops. The small trees (ST) had less than a 127 mm diameter at breast height and were the entire tree. These small-diameter resources were not removed from young, vigorously growing stands with high juvenile wood content *(9)*. They were from densely overstocked mature stands, where extreme competition and stressful growing conditions limited diameter growth. Consequently, juvenile wood was not an issue. All chips and logs were shipped to the USDA Forest Service, Forest Products Laboratory (FPL) for additional processing.

The logs were hand peeled to remove all bark and chipped to 19 mm long in a four-knife, commercial-size chipper. Chipped logs and sawmill residue chips were screened to remove all particles greater than 38 mm and less than 6 mm long. Screened chips were thoroughly mixed in a large V-mixer, weighed into 4 or 5 kg samples, placed in polyethylene bags, and stored at 4°C until used for pulping.

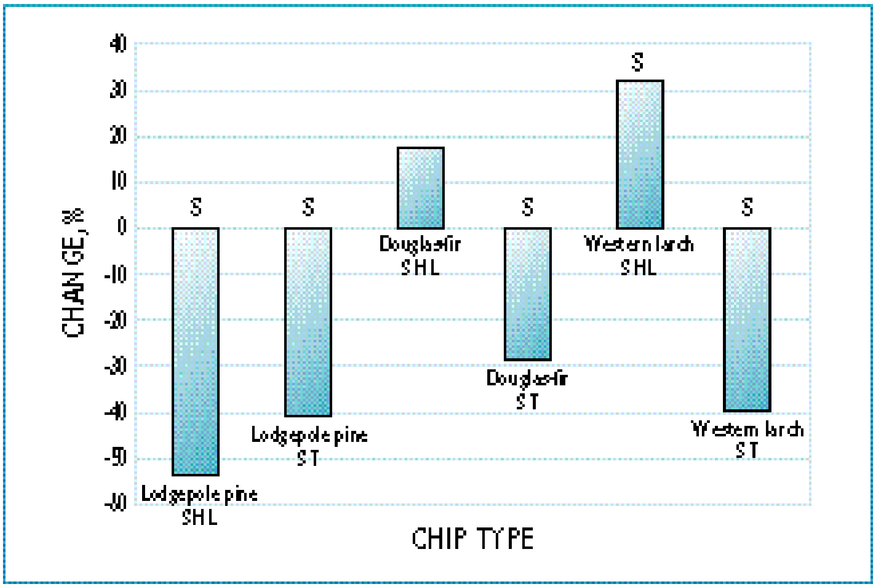
In this study, SRC are the controls, representing raw materials currently used for pulping. The SML and ST are the small-diameter resources.

Thermomechanical pulp preparation

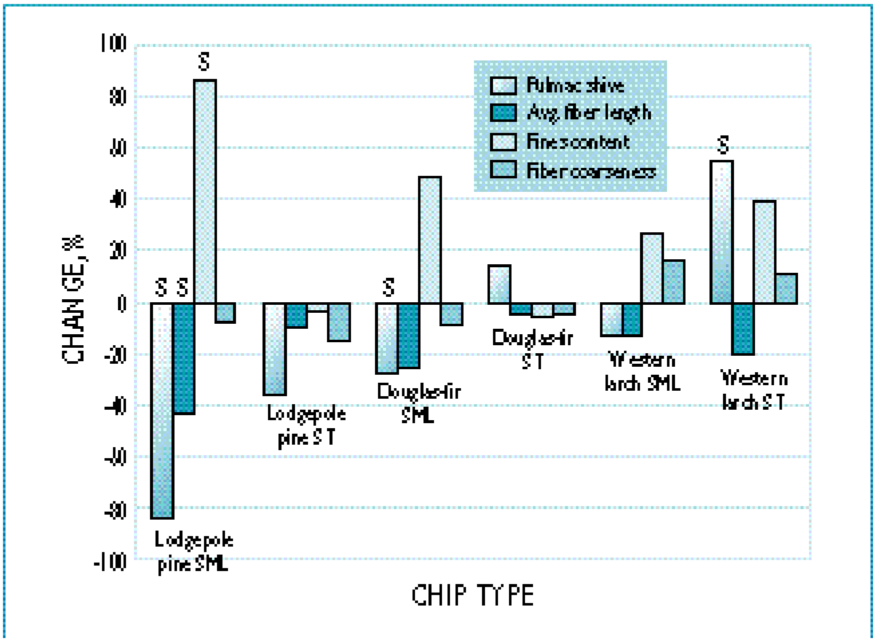
An Andritz Sprout-Bauer Model 12-1CP 305 mm diam pressurized refiner, fitted with plate pattern D2B505, was used for fiberization. All raw materials were steamed for 10–20 min at

206.8 kPa before fiberization. Fiberized pulp was wet screened through a 0.2 or 0.3 mm slot flat screen. Screen accepts and rejects were refined separately in a Sprout-Waldron Model 105-A 305 mm diam atmospheric refiner, also fitted with plate pattern D2B505. A constant volume of shredded pulp was delivered to the refiner inlet by a constant-speed belt conveyor, and dilution water was added to the shredded pulp to adjust refiner consistency to approximately 20%. Multiple passes were necessary to reduce pulp Canadian Standard Freeness (CSF) to approximately 200 mL, when the accepts and rejects were combined. An additional pass was run on the combined pulp to reduce CSF to less than 100 mL.

Energy consumed during fiberization and refining was measured using an Ohio Semitronic Model WH30-11195 integrating watt-hour meter attached to power supply of the 44.8 kW electric motor, measuring amperes, volts, and power factor. Energy consumption values for fiberizing and refining were reported in watt-hours per kilogram (ovendry weight basis), with the idling energy subtracted. Latency was removed from the pulp after fiberization and each refining step by soaking the pulp in 90°C water for a minimum of 30 min, with occasional stirring. A minimum of four replicates were prepared for each of the eight raw materials. Pulp yield was not determined.



1. Percentage change in energy consumption from sawmill residue chips (SML=submerchantable logs, ST=small trees, S=significant)



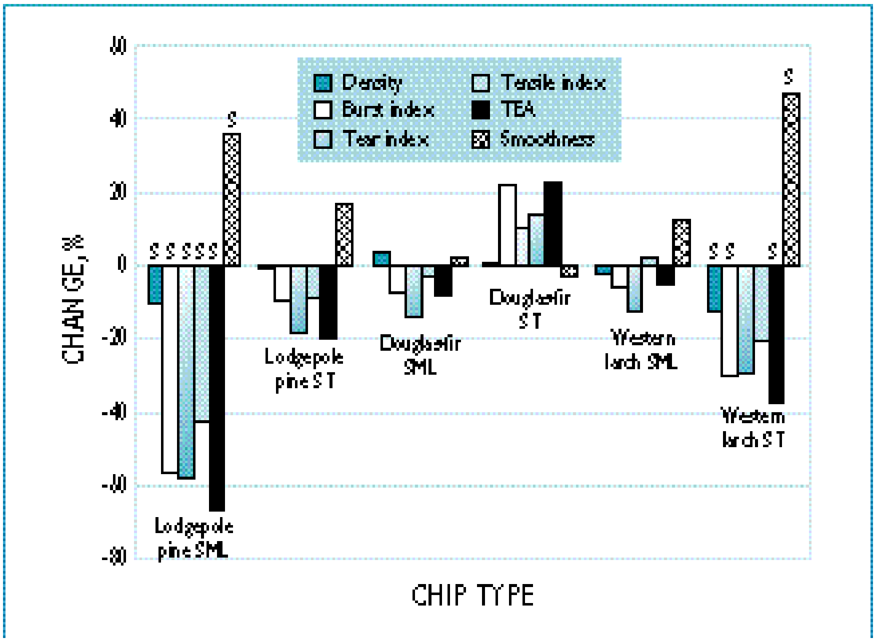
2. Percentage change in pulp properties from sawmill residue chips (SML=submerchantable logs, ST=small trees, S=significant)

Pulp testing and handsheet formation and testing

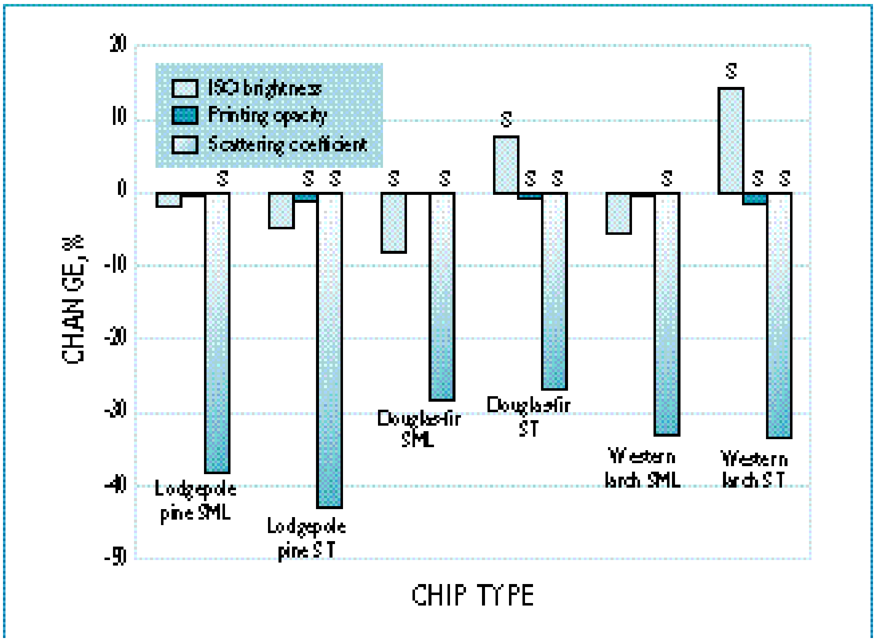
The CSF was measured according to TAPPI Test Method T227. Shive contents were determined with a Pulmac shive analyzer, using a disk with 0.10 mm slot openings. Average fiber length, fines content, and fiber coarseness were performed using a Kajaani FS-100 analyzer. Handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T205. Burst and tear indexes were measured according to TAPPI Test Methods T403 and T414, respectively. Tensile breaking properties and paper smoothness were measured according to TAPPI Test Methods T494 and T538, respectively. Brightness, printing opacity, and light-scattering coefficient were measured with a Technidyne Corp. Technibrite Model TB-1 diffuse brightness apparatus according to TAPPI Test Method T525.

Statistics

Each TMP was processed to a freeness level above and below the 100 mL target. A set of 10 handsheets were made and tested for each pulp. The individual test results were used to perform a Dunnett's multiple comparison procedure, which provided



3. Percentage change in paper properties from sawmill residue chips (SML=submerchantable logs, ST=small trees, S=significant, TEA=tensile energy absorption)



4. Percentage change in optical properties from sawmill residue chips (SML=submerchantable logs, ST=small trees, S=significant)

statistical significance at a 95% confidence interval. Mean, standard deviation, and coefficient of variation were computed for each property tested in a handsheet set. Mean values from the four replicates were combined and averaged to provide a value above and below 100 mL CSF, which were interpolated to estimate a value for 100 mL CSF.

RESULTS AND DISCUSSION

Presentation of results

Instead of presenting data for all TMP evaluations, the estimated values for 100 mL CSF are presented in **Tables I and II** for the eight raw materials.

Comparisons between raw materials were accomplished by computing a percentage change from the controls (SRC) **(Figs. 1–4)**. The SML and ST were considered alternative raw materials, and we were interested in how they compared with a traditional raw material (SRC). The Douglas-fir–western larch SRC was the control raw material for comparison with the other Douglas-fir and western larch raw materials, and the lodgepole pine SRC was used for comparison with the other lodgepole pine raw materials. The results of the statistical analysis were added to Figs. 1–4, and the presence of a capital *S* indicates that a specific property was significantly different from the SRC.

Pulp preparation and properties

Pressurized and atmospheric disk refiner operating conditions were similar for all raw materials; this helped reduce variables as we looked for differences between raw materials. Admittedly, the selected operating conditions might not be optimum for all raw materials.

Energy consumption is traditionally high in preparing mechanical pulp; therefore, any new raw material that reduces energy consumption would be desirable. All raw materials, except for the Douglas-fir and western larch SML, saved electrical energy (compared with energy use of SRC) during pulp preparation (Fig. 1). All the energy changes, except for the Douglas-fir SML, were statistically significant compared with the control. Pulmac shive declined for all but the western larch and Douglas-fir ST, which increased (Fig. 2). Shive reduction implies a more complete fiber-to-fiber separation for the small-diameter resources. The percentage shive changes in lodgepole SML, Douglas-fir SML, and western larch ST were significantly different. Fiber length declined for all the small-diameter resources (Fig. 2), and the decline for lodgepole pine SML was significant. A reduced fines content is desirable, but fines increased for all but lodgepole pine ST and Douglas-fir ST (Fig. 2). These fines were probably generated from fiber breakage and shortening and materials being removed from the fiber surface. Coarseness also decreased for everything except the western larch SML and ST (Fig. 2). Because most western softwood species are rather coarse-fibered, a reduction in coarseness might be desirable.

The fiber length, fines, and fiber coarseness results indicated that the lodgepole SML was severely damaged during TMP preparation. Western larch ST might also have been damaged. This might be partially or totally avoided by process optimization.

Strength properties

Handsheet density decreased (Fig. 3) for all but Douglas-fir SML and Douglas-fir ST, while that for lodgepole pine SML and western larch ST decreased significantly. Since fiber length and coarseness decreased and fines content increased for all pulps, a density increase might be anticipated. Since most strength properties are density dependent, these handsheet density reductions could affect the strength properties. Burst index decreased for all small-diameter raw materials except Douglas-fir ST, and the decreases were significant for lodgepole pine SML and western larch ST (Fig. 3).

Tear index decreased for all but the Douglas-fir ST. The lodgepole pine SML had a large and significant tear index decrease (Fig. 3). Tear index mirrors fiber length reduction, since tear is primarily dependent on fiber length. Tensile index and tensile energy absorption (TEA), for the most part, followed the general trend of burst index. Lodgepole pine SML had significant reductions in tensile index and TEA, and western larch ST had a significant TEA reduction. The Douglas-fir ST was the only raw material to show an increase in all strength properties. Surface smoothness increased for all small-diameter raw materials except the Douglas-fir ST, which had a small decrease. Surface smoothness was probably influenced by the changes in pulp properties (Fig. 2).

Optical properties

High opacity and light-scattering properties are desirable for mechanical pulps, which are heavily used to produce various printing and writing papers. None of the small-diameter resources had optical properties that were better than their corresponding SRC. Brightness decreased for all small-diameter resources except western larch ST and Douglas-fir ST (Fig. 4). The actual printing opacity (Table II) was high for all small-diameter resources, but the percentage changes were small and several were significant. Scattering coefficient, which is affected by fiber length, fines content and characteristics, and bonding, had some large and significant decreases for all the small-diameter resources (Fig. 4).

CONCLUSIONS

After examining all pulp production, pulp characteristics, and paper properties, Douglas-fir ST and lodgepole pine ST appear to be suitable for producing TMP. Both used less electrical energy during pulp preparation than did the SRC, although the two STs yielded pulps with shorter fiber length, less fines, and less coarseness than pulps produced from SRC. Paper made from the pulps had nearly equal or better strength, although optical properties (opacity and light-scattering coefficient) were reduced. The pulp preparation procedures selected were obviously detrimental to pulp and paper properties of lodgepole pine SML and western larch ST. **TJ**

Myers is a research forest products technologist and Abubakr is a supervisory research chemical engineer at the USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Dr., Madison, WI 53705. Barbour is a research forest products technologist at the USDA Forest Service, Pacific Northwest Research Station, 1221 SW Yamhill, Suite 200, Portland, OR 97205.

We thank the following people for their assistance in conducting this study: Dean Parry, USDA Forest Service, Pacific Northwest Station, for obtaining the raw materials and arranging shipping; Vaagen Bros. Lumber for the sawmill residue chips and submerchantable logs; Colville Ranger District, Colville National Forest, and Priest Lake Ranger District, Idaho Panhandle National Forest, for the logs; David Bormett, Charles Hillary, and Robert Kelly for peeling, chipping, screening, and bagging chip samples, and the latter two for TMP preparation; Nancy Ross-Sutherland, Sara Fishwild, and Richard Shilts for pulp testing, handsheet making, and testing; and Steve Verrill for statistical analysis.

Received for review July 8, 1997.
Revised June 15, 1998.
Accepted Sept. 8, 1998.

LITERATURE CITED

1. Anon., USDA Forest Service and USDI Bureau of Land Management, Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl, USDA and USDI, Portland, OR, 1994.
2. Anon., USDA Forest Service and USDI Bureau of Land Management, Interior Columbia Basin Ecosystem Management Project, Eastside draft environmental impact statement, USDA Forest Service, Portland, OR, 1997.
3. Iverson, G. C., Hayward G. D., and Titus, K. in *Conservation and resource assessments for the Tongass land management plan revision* (C. G. Shaw III, technical coordinator), Gen. Tech. Rep. PNW-GTR-387, USDA Forest Service, Pacific Northwest Research Station, Portland, OR, 1996.
4. Anon., *Colville National Forest, CROP creating opportunities—A study of small-diameter trees of the Colville National Forest,* USDA Forest Service, Colville National Forest, Colville, WA, 1994.
5. Barbour, R. J., McNeel, J. F., Tesch, S., *et al., Proceedings of the 18th Annual Meeting of the Council on Forest Engineering,* Oregon State University, Corvallis, OR, 1995, p. 187.
6. Spelter, H., Wang, R., and Ince, P., *Economic feasibility of products from Inland West small-diameter timber,* Gen. Tech. Rep. FPL-GTR-92, USDA Forest Service, Forest Products Laboratory, Madison, WI, 1996.
7. Skog, K., Barbour, R. J., Baumgras, J., *et al., Proceedings of the 1995 National Silviculture Workshop,* Gen. Tech. Rep. RM-GTR-267, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, p. 153.
8. Barbour, R. J., and Skog, K., Eds., *Proceedings of the Sustainable Forest Working Group at the IUFRO All Division 5 Conference,* Pullman, WA, Gen. Tech. Rep. FPL-GTR-100, USDA Forest Service, Forest Products Laboratory, Madison, WI, 1997.
9. Zobel, B. J. and van Buijtenen, J. P., *Wood variation. Its causes and control,* Springer-Verlag, New York, 1989, pp. 82–100.