Seasonal Impacts of Bark Loss on Simulated Payloads, Bark Delivery, and Transport Costs for Freshly Harvested Logs

Glen E. Murphy
Stephen J. Pilkerton

Abstract

Quantification of seasonal bark loss for two Oregon commercial tree species, Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*), was conducted at monthly intervals beginning in late October to early November 2009 and finishing in August 2010. All assessments were carried out on harvesting operations that were using mechanized processor heads with chains over rubber feed wheels. A total of 450 stems were assessed.

There was a substantial (up to five times) increase in areal bark loss, expressed as a percentage of log surface area, during late spring and early summer compared with the loss in winter. Areal bark loss appeared to be species dependent, with Douglas-fir incurring more than twice as much bark loss as ponderosa pine.

Seasonal differences in postharvesting bark volume and weight were determined by accounting for bark thickness and bark density. In winter, bark could be expected to account for 3 to 4 percent more of a stem's weight than in late spring to early summer. There were considerable differences between species in the contribution of bark to total weight, but not in the percent drop in weight between seasons.

It is shown that the seasonal changes in bark loss could be expected to lead to changes in solid wood truck payloads, transport costs, bark, and available energy (from bark) delivered to mills.

Meyer (1946) and Philip (1994) report that bark makes up 10 to 25 percent of the over-bark volume and weight of a tree. Bark has gone from being a waste product to a by-product of wood use. For example, Oregon Forest Resources Institute (2006) reports that over 99 percent of bark residues produced in Oregon in 2002 (estimated to be 1.444 million bone dry tons) were used, the major uses of these being industrial fuels (82%) and miscellaneous by-products (17%).

Although only a few harvesting systems today intentionally remove bark prior to transporting logs to the mill, little is known about how much bark is lost during harvesting operations at different times of the year. Depending on where you are located in the forest-to-mill supply chain, the presence or absence of bark can be seen as a cost or a benefit (Ohman 1970, Marshall et al. 2006, Lowell et al. 2010). Postharvesting bark loss ranging from 0 to close to 100 percent has been reported for individual logs (Murphy and Amishev 2008), and from less than 5 percent to over 60 percent for multiple stems (Granlund and Hallonborg 2001; Murphy and Pilkerton, in press). Understanding the magnitude of bark loss and the factors that affect it should lead to minimization of the costs and maximization of the benefits.

Factors affecting harvesting-associated bark loss could be grouped into those that relate to the season, those that relate to the tree, and those that relate to the harvesting system.

Bark is more easily knocked off stems, logs, and wood chips in spring, when the sap is rising, than at other times of the year (Wilcox et al. 1954, Harder et al. 1978, Neville 1997). Wilcox et al. (1954) reported that the bark–wood bond strength is very low during the active growing season, from April to August for the species they studied in the Adirondacks in the eastern United States. During the dormant season, the bonding strength of the bark increased dramatically, and the chance of bark abrasion was dramatically reduced during this time period. Moore and

The authors are, respectively, Professor and Research Forest Engineer, Oregon State Univ., Corvallis (glen.murphy@oregonstate.edu, steve.pilkerton@oregonstate.edu). This paper was received for publication in December 2010. Article no. 11-00001.

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McMahon (1986) also noted that the bark–wood bond strength varied by season for three species of eucalypts (*Eucalyptus* spp.) and radiata pine (*Pinus radiata*) grown in Australia.

Harder et al. (1978) found that, during the dormant season, wood–bark adhesion varied greatly from species to species, usually being higher for hardwoods than conifers, for the 42 species they studied. They also found that growing season wood–bark adhesion was very similar for all species tested.

Uzonovic et al. (1999) reported bark loss ranging from less than 5 percent to as high as 45 percent on Corsican pine (*Pinus nigra*) logs that had been delimbed. They also noted that bark loss appeared to be less in late spring than in midsummer. Murphy and Pilkerton (in press) reported bark loss ranging from 4 to 63 percent for five species in Oregon. They were able to show for three of the species that bark loss during late spring to early summer was threefold to fivefold greater than bark loss in late autumn to winter.

Bark acts as a barrier to moisture loss and, therefore, weight loss from solid wood. Nicholls and Brackley (2008) report that fully debarked conifer logs dry at a much faster rate than logs with all of the bark present. Defo and Brunette (2006) found that the air-drying rate of aspen logs is proportional to the percentage of bark missing. Both sets of authors note that the rate of drying also depends on the season. Logs that have been harvested and left for extended periods in the forest could be expected to lose an amount of weight proportional to the amount of bark lost during harvesting.

The objective of the study reported in this article was to quantify the seasonal effects of bark loss on truck payloads, bark delivery to mills (attached to delivered logs), and transport costs for two freshly harvested, commercial species in Oregon. This article is an extension of our earlier work (Murphy and Pilkerton, in press).

Methods and Materials

Study sites and data collection

Quantification of seasonal bark loss for Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) was conducted beginning in late October to early November 2009. Study sites for the Douglas-fir were on private industrial forestland in the Oregon Coast Range west of Corvallis. The ponderosa pine stands were located north of Sisters, Oregon, in the Deschutes National Forest.

Harvest systems for the Douglas-fir consisted of hand falling, whole tree cable yarding, and mechanized processing at the landing. The ponderosa pine stems were harvested with a cut-to-length system. All stems were mechanically delimbed with processing heads that had chain over rubber drive wheels.

Monthly site visits were timed with harvesting contractor cooperation dependent upon availability of study species, sample quantity of stems, and contractor operational considerations. Monthly sampling consisted of 25 stems for each species. A line intersect method was used to determine the presence (or absence) of bark. Additional data collected for all 25 stems included stem length, inside bark diameters at the butt and merchantable top, and bark thickness at the butt and top diameters. Extra bark thickness measurements were gathered from the ends of logs cut from a subsample of 8 of the 25 stems. Raw data were entered into Excel spreadsheets for analysis.

Data analysis

Data analysis included determining the areal extent and location of bark loss, the bark thickness along the stem, the solid wood volume and bark volume for representative sets of stems, volume–weight conversion factors for both solid wood and bark, and trucking costs.

The monthly areal bark loss figures reported in Murphy and Pilkerton (in press) were smoothed and rounded to the closest 5 percent. Monthly site visits were timed with harvesting contractor cooperation and were dependent upon availability of study species, market conditions, and contractor operational considerations. Months with missing data were interpolated to fill a full 12-month period. This meant interpolating data for 2 months (September through October) for Douglas-fir and 4 months (July through October) for ponderosa pine. As reported in Murphy and Pilkerton (in press), areal bark loss tended to be concentrated toward the top of ponderosa pine stems and evenly distributed in Douglas-fir stems. Second-order polynomial or linear regressions were fit to ponderosa pine stem data to reflect the increased bark loss toward the top of the stem.

Inside bark diameters and bark thickness measurements were used to develop regression equations for predicting inside bark diameters as a function of over-bark diameters and length up the stem.

Two stem data sets that had been gathered external to this study in 2002 and 2006 were selected as being representative of a ponderosa pine thinning stand and a Douglas-fir clearfell stand. These data sets were selected since they included detailed estimates of over-bark stem taper at decimeter intervals along each stem. The Douglas-fir data set contained 259 trees (average butt diameter under bark = 421 mm). The average tree size of this Douglas-fir data set was slightly larger than that of the trees measured as part of the bark loss study (average butt diameter under bark = 399 mm). The ponderosa pine data set contained 110 trees (average butt diameter under bark = 242 mm). The average tree size of this ponderosa pine data set was smaller than that of the trees measured as part of the bark loss study (average butt diameter under bark = 317 mm).

Two small programs were written in Visual Basic. The first program ''removed'' bark from each stem in the representative data sets. Bark was assumed to be absent or present, in segments of 1 dm along each stem, based on the smoothed bark loss percentages and distribution of bark loss. Twelve sets of stem descriptions, one for each month of the year, were created for each species. The second program determined the volumes of solid wood and bark, before and after bark loss, for each stem.

Solid wood metric volumes were converted to green weights using a conversion factor of 956 kg/m^3 for Douglas-fir and 867 kg/m^3 for ponderosa pine. Bark volumes were converted to green weights by first multiplying by a factor of 0.73 (Krier and River [1968] noted that voids and fissures made up 25% to 28% of the volume of three conifer species) and then multiplying by kilograms per cubic meter average values reported by Smith and Kozak (1971) and Harder et al. (1978). Bark conversion factors, which included voids and fissures, as used in the analyses, were 615 kg/m^3 for Douglas-fir and 320 kg/m^3 for ponderosa pine.

Monthly delivery of bark, attached to logs, was based on an assumed daily delivery of solid wood of 750 m^3 (~180,000 m^3 input per year) to a medium-sized mill. The energy potential of the bark delivered was based on ovendry fuel values reported by Harder et al. (1978) and moisture contents reported by Smith and Kozak (1971). Fuel values of 11.78 and 17.77 GJ per green metric ton were used in the analyses for Douglas-fir and ponderosa pine, respectively (Harder et al. 1978).

In calculating transport costs, we assumed a net payload of 25,000 kg (this includes both bark and solid wood), a daily truck owning and operating cost of $850 (Mason et al. 2008), and an average of 3.5 loads per day.

Results

A total of 450 Douglas-fir and ponderosa pine stems were assessed for bark loss over the 10-month study period. Douglas-fir bark loss ranged from 10 to 63 percent, with an average loss of 34 percent. Ponderosa pine bark loss ranged from 4 to 37 percent for the monitoring period, with an average bark loss of 13 percent. More detail on areal bark loss is provided in Murphy and Pilkerton (in press).

Examination of profiles of the probability of bark loss along each stem showed no apparent trend for the Douglas-fir samples for all months in which data were gathered, all points along the stem having similar probability of losing bark. For the ponderosa pine samples, there did appear to be a trend for greater bark loss toward the top of the tree than at the base of the tree (Fig. 1). This was strongly evident in the samples from November through April, but less evident in the May and June samples.

Table 1 shows the smoothed bark loss percentages that were used in the following analyses for Douglas-fir and ponderosa pine. We also include the equations used to determine the profile of the probability of bark loss for ponderosa pine.

The bark thickness equations were initially developed using the ratio of under-bark diameter to over-bark diameter as the dependent variable. A distance-dependent regression model was built for Douglas-fir, and an average ratio was calculated for ponderosa pine. These have been rearranged for the two species to provide the equations shown below.

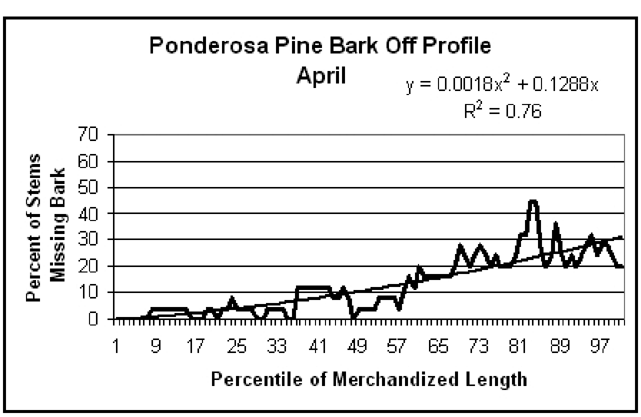

Figure 1.—Percentage of ponderosa pine stems missing bark along the stem profile for April 2010 (beginning of the "sap-rise" season). Zero percentile of merchandized length occurs at the butt of the stem.

Table 1.—Monthly smoothed bark loss (BL) percentages (to the closest 5%) and equations for determining the probability of loss along a stem profile.[a]

Month	Douglas-fir BL (%)	Ponderosa pine BL (%)	Ponderosa pine: Probability of BL (%) as a function of HP[b]
Jan	10	5	$BL\% = -0.0006HP^2 + 0.0972HP + 0.3$
Feb	15	5	$BL\% = -0.0006HP^2 + 0.0972HP + 0.3$
Mar	20	5	$BL\% = 0.0033HP^2 - 0.1169HP - 0.5$
Apr	45	10	$BL\% = 0.0018HP^2 + 0.1288HP - 2.6$
May	50	40	$BL\% = 0.2826HP + 25.3$
Jun	60	25	$BL\% = 0.0026HP^2 - 0.0869HP + 20.5$
Jul	50	**20**	$\mathbf{BL\% = 0.0026HP^2 - 0.0869HP + 15.7}$
Aug	45	**15**	$\mathbf{BL\% = 0.0018HP^2 + 0.1288HP + 2.4}$
Sep	**20**	**10**	$\mathbf{BL\% = 0.0018HP^2 + 0.1288HP - 2.6}$
Oct	**15**	**5**	$\mathbf{BL\% = -0.0006HP^2 + 0.0972HP + 0.3}$
Nov	15	5	$BL\% = -0.0006HP^2 + 0.0972HP + 0.3$
Dec	15	5	$BL\% = -0.0006HP^2 + 0.0972HP + 0.3$

[a] Values for months where data have been interpolated are in boldface type.
[b] HP = height percentile.

$$\text{Douglas-fir:}\quad \text{DIB (mm)} = 0.942 \times \text{DOB} - 0.0033 \times \text{Dist} \times \text{DOB} \qquad (1)$$

$$n = 307, \qquad r^2 = 0.05$$

$$\text{Ponderosa pine:}\quad \text{DIB (mm)} = 0.868 \times \text{DOB} \qquad (2)$$

$$n = 237$$

where DIB = diameter inside bark (mm), DOB = diameter outside bark (mm), and Dist = distance from the butt of the stem (m).

After bark loss, the percentage of the stem by volume and by weight that would be bark is shown in Table 2 for each species for the representative stands. Figure 2 shows the amount of bark delivered monthly to a mill receiving 750 m^3 of solid wood per day. Table 3 shows the energy content of the delivered bark.

The impact that bark loss has on transportation costs is shown in Figure 3. These costs assume that the solid wood content carries all of the costs and the bark gets a "free ride" to the mill. For both species there is a drop of about

Table 2.—Percentage of stem (over-bark) that is bark, before and after bark loss, due to harvesting and time of year.

Month	Douglas-fir Volume (%)	Douglas-fir Weight (%)	Ponderosa pine Volume (%)	Ponderosa pine Weight (%)
Before bark loss	11.9	8.0	25.3	11.1
Jan	10.8	7.2	24.3	10.6
Feb	10.3	6.9	24.3	10.6
Mar	9.7	6.5	24.6	10.7
Apr	6.9	4.5	24.0	10.4
May	6.3	4.1	17.6	7.3
Jun	5.1	3.3	20.5	8.7
Jul	6.3	4.1	21.5	9.2
Aug	6.9	4.5	23.2	10.0
Sep	9.7	6.5	24.0	10.4
Oct	10.3	6.9	24.3	10.6
Nov	10.3	6.9	24.3	10.6
Dec	10.3	6.9	24.3	10.6

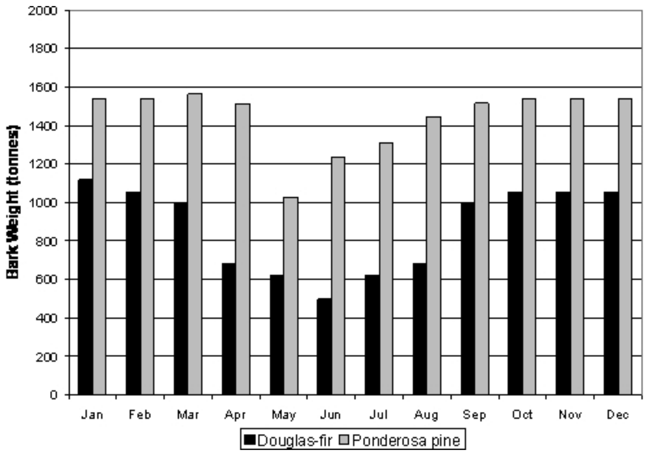

Figure 2.—Amount of bark delivered monthly to a mill receiving 750 m^3 of solid wood per day from a clearfell Douglas-fir stand and a thinning ponderosa pine stand.

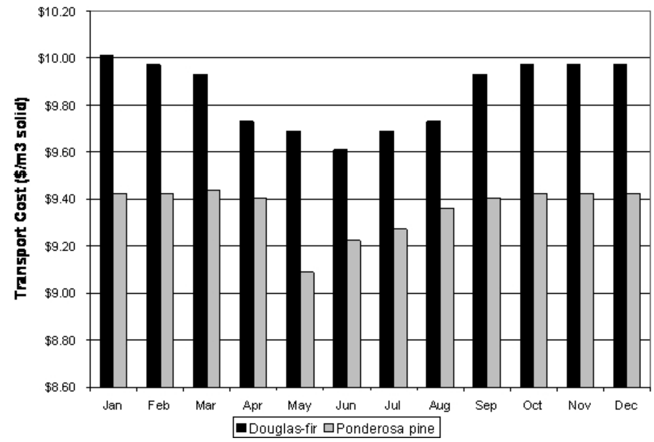

Figure 3.—Solid wood transportation costs after bark loss due to harvesting and time of year for Douglas-fir and ponderosa pine. Unit volume costs are based on an average daily transport cost of $850 and an average of 3.5 trips per day.

$0.35 to $0.40/m^3 (or $5,500/mo for a mill receiving 750 m^3 of solid wood per day) between winter and the height of the sap-rise season in late spring to early summer. The main reason for lower overall calculated costs in ponderosa pine than in Douglas-fir relates to the lower green densities of ponderosa pine solid wood and bark.

Discussion and Conclusions

Our study measured seasonal bark losses for two commercial species in Oregon and, using publically available information, quantified the potential impact of this bark loss on truck payloads, bark delivery, and transport costs.

Areal bark loss in ponderosa pine was less than half that found for Douglas-fir. This finding would be supported by the bark adhesion figures reported by Harder et al. (1978), which showed that bark adhesion was greater for ponderosa pine than for Douglas-fir during both dormant and growing seasons. For both species there was a substantial (up to five times) increase in areal bark loss during late spring and early summer compared with the winter season. Areal bark loss tended to be concentrated toward the tip of the tree in ponderosa pine but evenly dispersed along the stem in Douglas-fir.

Table 3.—Energy content in green bark delivered monthly to a mill receiving 750 m^3 of solid wood per day.

Month	Energy delivery (GJ/mo)	
	Douglas-fir	Ponderosa pine
Before bark loss	14,627	28,815
Jan	13,165	27,378
Feb	12,433	27,378
Mar	11,702	27,809
Apr	8,045	26,917
May	7,314	18,261
Jun	5,851	21,971
Jul	7,314	23,294
Aug	8,045	25,710
Sep	11,702	26,946
Oct	12,433	27,378
Nov	12,433	27,378
Dec	12,433	27,378

Transporting logs from the forest to the mill is one of the largest single components of wood supply costs for many suppliers around the world. For example, McDonald et al. (2001) comment that log transport represents nearly half the delivered cost of wood fiber in the southern United States. Small increases in transportation efficiency, through such actions as increasing truck payloads, can significantly reduce costs (Ronnqvist et al. 1998).

Prior to bark loss, bark accounted for about 8 percent of the weight (12% of the volume) of Douglas-fir stems and 11 percent of the weight (25% of the volume) of ponderosa pine stems for our representative stands. In late spring to early summer, bark would account for 3 to 4 percent less of a stem's weight than in the winter season for the two species studied. This has implications for log transport costs. Less bark means that more solid wood can be carried per trip. Transport costs per unit of solid wood volume could be expected to be 3 to 4 percent less ($0.35 to $0.40/m^3 less) at the period of greatest bark loss than at midwinter. Fonseca (2005) reported that weight–volume conversion factors for Douglas-fir and ponderosa pine were 4.6 and 4.0 percent greater, respectively, in the November to June period than the July to October period. Part of this difference may be due to bark loss during harvesting operations. Coulter (1959), however, reported no seasonal differences in weight–volume conversion factors for radiata pine.

It should be noted that our analyses relate to freshly felled, delimbed, and transported wood. Delays between felling and delimbing can reduce bark loss due to increases in bark adhesion as stems dry out (Kubler 1990, Duchesne and Nylander 1996). We saw that freshly felled Douglas-fir stems were more likely to lose bark than stems that had been left to sit for a few weeks after felling during the sap-rise season. Delays between delimbing and transport are also likely to contribute to potential variability in payloads. Logs with bark missing lose moisture at up to five times the rate of logs with no bark missing (Defo and Brunette 2006, Nicholls and Brackley 2008). Another key assumption in our analyses is that the standing trees have not been chemically treated prior to harvesting to lower green density of both the solid wood and bark and to encourage bark loss (Holt 1971).

A medium-sized mill, receiving about 30 truckloads of logs per day, will have more than 17,000 metric tons of ponderosa pine bark, or 10,000 metric tons of Douglas-fir bark, delivered per year attached to logs. Because of seasonal variation in bark loss due to harvesting, delivery will not be evenly distributed throughout the year. If the mill was receiving Douglas-fir logs, more than 1,100 metric tons of bark would be delivered in January, falling to about 500 metric tons in June. If the mill was receiving ponderosa pine logs, the bark deliveries would be as high as 1,500 metric tons in January and as low as 1,000 metric tons in May. If these mills were using the bark to meet some of their energy needs, there would be a supply variation of up to 7,300 GJ/mo for the Douglas-fir mill and 9,500 GJ/mo for the ponderosa pine mill.

There are a number of limitations to this study. First, and foremost, the results are based on simulations of the effects of bark loss for two stands (one for each of the two species included in the study), one mill size, and one transport scenario. Insufficient stems were measured monthly to follow logs through the forest-to-mill supply chain. Second, bark thickness functions based on the measured stems were used in the simulations. Marshall et al. (2006) have shown that variations in bark thickness between stands for the same species can account for a difference of up to 7 percent in solid wood volume estimates and a difference of up to 65 percent in bark volume estimates. Maguire and Hann (1990), for example, report bark volume estimates for Douglas-fir stands in southern Oregon that were 50 percent greater than found in our study. Finally, the study was restricted to bark loss from delimbing and bucking machines, which had rubber feed wheels with chains over them. There is evidence in the literature that greater bark loss could be expected from delimbing machines with spiked feed wheels (Lee and Gibbs 1996). A site visit by the senior author of this article to a ponderosa pine harvesting operation suggests that there may also be greater bark loss when using a stroke delimber than when using rubber feed wheels with chains.

Notwithstanding these limitations, we have been able to quantify the seasonal impacts of bark loss on selected forest-to-mill supply chain variables for two commercial species, Douglas-fir and ponderosa, that have been delimbed and bucked by mechanized processors with rubber feed wheels and chains. We have been able to show that seasonal variation in bark loss could lead to large variations on a monthly basis in the delivery of bark (and energy from bark) and to small differences in transport costs for solid wood.

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Literature Cited

Coulter, F. A. 1959. Density of *Pinus radiata* logs. *N. Z. J. Forestry* 8(1): 143–147.

Defo, M. and G. Brunette. 2006. A log drying model and its application to the simulation of the impact of bark loss. *Forest Prod. J.* 56(5): 71–77.

Duchesne, I. and M. Nylander. 1996. Measurement of the bark/wood shear strength: Practical methods to evaluate debarking resistance of Norway Spruce and Scots pine pulpwood. *Forest Prod. J.* 33(5): 21.

Fonseca, M. A. 2005. The Measurement of Roundwood: Methodologies and Conversion Ratios. CABI Publishing, Cambridge, Massachusetts. 246 pp.

Granlund, P. and U. Hallonborg. 2001. Latest harvesters are gentle on the wood. Results No 5. Skogforsk, Uppsala. 4 pp.

Harder, M. L., J. D. Hankey, D. W. Einspahr, and J. W. Swanson. 1978. Bark and wood properties of pulpwood species as related to separation and segregation of chip/bark mixtures. Project 3212, Report Eleven: A summary report to members of Group Project 3212. http://smartech.gatech.edu/bitstream/handle/1853/1064/3212_001_11011974.pdf. Accessed April 7, 2011.

Holt, H. A. 1971. Internal moisture relations of standing Douglas-fir trees injected with organic arsenicals. PhD thesis. Oregon State University, Corvallis. 150 pp.

Krier, J. P. and B. H. River. 1968. Bark residues: A model study for quantitative determination. Bulletin 35. University of Montana, School of Forestry, Missoula.

Kubler, H. H. 1990. Natural loosening of the wood/bark bond: A review and synthesis. *Forest Prod. J.* 40(4):25–31.

Lee, K. and J. N. Gibbs. 1996. An investigation of the influence of harvesting practice on the development of blue-stain in Corsican pine logs. *Forestry* 69(2):137–141.

Lowell, E. C., D. Dykstra, and G. McFadden. 2010. Effects of bear damage on Douglas-fir lumber recovery. *Western J. Appl. Forestry* 25(2):73–80.

Maguire, D. A. and D. W. Hann. 1990. Bark thickness and bark volume in southwestern Oregon Douglas-fir. *Western J. Appl. Forestry* 5: 5–8.

Marshall, H. D., G. E. Murphy, and B. Gartner. 2006. Effects of bark thickness on optimal log merchandizing. *Forest Prod. J.* 56(11/12): 87–92.

Mason, C. L., K. L. Casavant, B. R. Lippke, D. K. Nguyen, and E. Jessup. 2008. The Washington log trucking industry: Costs and safety analysis. Report to the Washington State Legislature. University of Washington, College of Forest Resources, Seattle. Washington State University, School of Economic Sciences, Pullman. 109 pp. http://www.ruraltech.org/pubs/reports/2008/log_trucks/log_truck_report.pdf.

McDonald, T., B. Rummer, S. Taylor, and J. Valenzuela. 2001. Potential for shared log transport services. *In:* Proceedings of the 24th Annual Council on Forest Engineering Meeting, J. Wang, M. Wolford, and J. McNeel (Eds.), July 15–19, 2001, Snowshoe Mountain, West Virginia; Council on Forest Engineering, Corvallis, Oregon. pp. 115–120.

Meyer, H. A. 1946. Bark volume determination in trees. *J. Forestry* 44(12):1067–1070.

Moore, G. A. and T. A. McMahon. 1986. Bark/wood bond strength and its association with material and environmental variables. *Wood Fiber Sci.* 18(4):526–536.

Murphy, G. E. and D. Amishev. 2008. Effects of bark removal on acoustic velocity of Douglas-fir logs. *N. Z. J. Forestry Sci.* 38(2/3): 247–252.

Murphy, G. E. and S. J. Pilkerton. Seasonal impacts on bark loss for Douglas-fir and ponderosa pine harvested on the Pacific Northwest coast of USA. *Int. J. Forest Eng.* (in press).

Neville, R. J. 1997. A review of tree wounding. Technology Transfer Notes Number 3. Pacific Forestry Centre, Canadian Forest Service, Victoria, British Columbia. 4 pp.

Nicholls, D. and A. Brackley. 2008. House log drying rates in Southeast Alaska for covered and uncovered softwood logs. General Technical Report PNW-GTR-782. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 18 pp.

Ohman, J. H. 1970. Value loss from skidding wound in sugar maple and yellow birch. *J. Forestry* 68(4):226–230.

Oregon Forest Resources Institute. 2006. Biomass energy and biofuels from Oregon's forests. Report prepared for Oregon Forest Resources Institute. http://www.oregonforests.org/assets/uploads/Biomass_Full_Report.pdf. Accessed April 7, 2011.

Philip, M. S. 1994. Measuring Trees and Forests. 2nd ed. CAB International, Wallingford, Oxfordshire, UK. 310 pp.

Ronnqvist, M., H. Sahlin, and D. Carlsson. 1998. Operative planning and dispatching of forestry transportation. Report LiTH-MAT-R-1998-18. Linkoping Institute of Technology, Linkoping, Sweden. 31 pp.

Smith, J. H. G. and A. Kozak. 1971. Thickness, moisture content, and specific gravity of inner and outer bark of some Pacific Northwest trees. *Forest Prod. J*. 21(2):38–40.

Uzonovic, A., J. F. Webber, A. J. Pearce, and D. J. Dickinson. 1999. The role of mechanized harvesting in the development of bluestain in pine. *Can. J. Forestry Res*. 29:242–251.

Wilcox, H., F. Czabator, and G. Girolami. 1954. Seasonal variation in bark-peeling characteristics of some Adirondack pulpwood species. *J. Forestry* 52(5):338–342.