Seasonal Impacts on Bark Loss for Douglas-fir and Ponderosa Pine Harvested on the Pacific Northwest Coast of the USA

Glen Murphy*
Stephen J. Pilkerton

Abstract

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. Understanding the magnitude of bark loss and the factors that affect it should lead to minimization of the costs and maximization of the benefits.

Quantification of seasonal bark loss (expressed as a percentage of the surface area of the stem) for two commercial tree species was conducted monthly over a 10-month period. All assessments were carried out on Douglas-fir and ponderosa pine harvesting operations that were using mechanized processor heads with chains over rubber feed wheels. Over 400 stems were assessed.

There was a substantial (up to five times) increase in bark loss during late spring and early summer compared with the winter season. We were also able to show that the amount of bark loss is species dependent, with Douglas-fir incurring more than twice the bark loss than found for ponderosa pine. It is possible that the distribution of bark loss along the stem is also species dependent; we found greater bark loss towards the top of the stem in ponderosa pine than towards the bottom of the stem, but no such trend for Douglas-fir.

Keywords: Seasonal impact, bark loss, Douglas-fir, ponderosa pine, mechanized log processing.

Introduction

Bark is the term used to describe all the plant tissue outside the vascular cambium where cell division occurs. It is made up of two tissue types: inner living bark, which is composed of secondary phloem, and the outer non-living bark. Bark thickness can range from a few millimeters up to 0.3 meters or more. Meyer (1946) and Philip (1994) report that bark makes up 10 to 25% of the overbark volume and weight of a tree.

Past interest in determining what factors affect bark loss has usually been related to surface damage and fungal degrade in logs. Lee and Gibbs (1996) found at two Corsican pine (*Pinus nigra*) study sites (Thetford and Inverness) in Great Britain that there was much less bark loss on logs that had been manually delimbed and processed (13% and 1%), than on logs that had been mechanically delimbed and processed with rubber rollers (29% and 6%), or with spiked rollers (39% and 8%). The authors commented that the higher bark loss at the Thetford site was likely to have been due to the thinner bark at this site.

Uzonovic et al. (1999) also reported much less bark loss with manual delimbing and processing (< 5%) than with mechanical delimbing and processing with rubber rollers (5 to 45%) in Corsican pine. Bark loss also appeared to be greater on logs delimbed in late spring than in mid-summer. Others have noted that 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).

Granlund and Hallonborg (2001) report that bark loss by five harvesters, all fitted with rubber rollers, ranged from 0 to 5%. This is considerably lower than was noted by Murphy and Amishev (2008) where processors with spiked feed wheels were used with Douglas-fir (*Pseudotsuga menziesii*) logs; up to 95% of bark was missing on some logs.

The interest in bark loss, however, is much broader than concern about it providing access for fungi that can degrade

The authors' affiliations are: College of Forestry, Oregon State University Corvallis, OR 97331, USA,
glen.murphy@oregonstate.edu; and peksaw@aol.com.

*Corresponding author

International Journal of Forest Engineering
Volume 22, No. 1

wood quality. In the 1970s pulpwood chip users were very interested in procedures for removing bark from the chips before pulping and the magnitude of the differences between different tree species in wood/bark adhesion (Harder et al. 1978). Understanding the factors affecting wood/bark adhesion is also of interest to harvesting equipment manufacturers designing equipment for debarking prior to chipping at the harvesting site (Hartsough et al. 2000).

Acoustics technologies have become widely accepted in the forest products industry for products grading and on-line quality control (Pellerin and Ross 2002). Wang et al. (2007) comment that “the precision of acoustic technology has been improved to the point where tree quality and intrinsic wood properties can be predicted and correlated to structural performance of the final products.” They summarize studies that show how acoustic technologies can be used early in the wood supply chain to sort logs for lumber, veneer, and pulp quality, to monitor moisture changes in log stocks, and to verify log supply for visually graded lumber. Recent studies in radiata pine (*Pinus radiata*) in New Zealand (Lasserre 2005) and Douglas-fir in Oregon (Murphy and Amishev 2008), however, have shown that acoustic measurements of wood properties can be affected by the amount of bark present on a log. Lasserre (2005) comments that bark adds mass to the stem without contributing much to stiffness. Understanding how time of year affects bark loss should improve the ability to monitor wood properties using acoustic technologies.

Transporting logs from the forest to the mill is becoming the largest single component 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 USA. Since transportation costs make up a large proportion of the overall costs, even small increases in efficiency can significantly reduce costs (Ronnqvist et al. 1998). There is, therefore, considerable interest by forest industries worldwide in new work procedures, decision support systems, payloads and equipment configurations, and road-truck interactions that can lead to reductions in overall transport costs and improve the utilization of wood. Understanding how time of year affects bark loss, when it can affect log weights by up to 25%, should improve the ability to manage truck payloads and transport costs.

Bark has gone from being a waste product to a by-product of wood utilization. For example, Murphy et al. (2007) report that all bark residues produced in Pennsylvania in 2003 (estimated to be 19 million cubic feet) were utilized, either as mulch for agricultural/horticultural purposes (83%) or as industrial fuels (17%). Interest in bark as fuel for energy/steam production is expanding rapidly in the Pacific Northwest. Understanding how time of year affects bark loss, should improve the ability to manage supply and utilization of this by-product.

Many modern harvesters/processors are fitted with measurement and optimization systems which help the logger to cut the right products for the right customers and to maximize value capture for the forest owner. The measurement systems measure stem diameter overbark and estimate underbark diameters using bark thickness functions. There is a move in some parts of the world to reduce log scaling costs, particularly in some parts of Europe, and to utilize harvester information on log volumes as the basis of payment by the mills to the logger and to the forest owner. Marshall et al. (2006) have shown that using the wrong bark thickness model can result in more than 30% of the logs cut being out-of-specification, volume estimates being incorrect, and a loss of value to forest owner of up to 11%. Understanding how time of year affects bark loss should lead to more logs meeting specification, better estimates of log volumes and improved value recovery.

Harder et al. (1978) evaluated the bark and wood properties of 42 pulpwood species in the mid-1970s. They reported differences in bark/wood adhesion between different species and between different seasons which they labelled “growing season” and “dormant” season. Selected data from their report is shown in Table 1. The higher the bark/wood adhesion value the more difficult it is to remove bark.

Table 1. Effect of season and species on bark/wood adhesion for samples gathered at breast height on a stem.*

Species	Bark/Wood Adhesion ($kg\ cm^{-2}$) Growing Season	Bark/Wood Adhesion ($kg\ cm^{-2}$) Dormant Season
Douglas-fir	3.4	8.0
Ponderosa Pine	5.0	9.6

* Source: Harder et al. (1978) Bark and wood properties of pulpwood species as related to separation and segregation of chip/bark mixtures.

Wilcox et al. (1954) noted 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 USA. 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 McMahon (1986) also noted that the bark/wood bond strength varied by season for three species of eucalypts (*Eucalyptus spp.*) and radiata pine grown in Australia.

The objective of the study reported in this paper is to quantify the effects of time of year on bark loss, expressed as a percent of the surface area of the stem, during mechanized harvesting and processing of two commercial species in Oregon. A separate paper will address the potential impacts of bark loss on truck payloads, transport costs and bioenergy supply.

Materials and Methods

Study Site Description

Quantification of seasonal bark loss for two Pacific Northwest coast (USA) commercial tree species was conducted beginning in late October/early November 2009. The species of interest were: Douglas-fir and ponderosa pine (*Pinus ponderosa*). Study sites for the Douglas-fir were on private industrial forestland in the Oregon Coast Range west of Corvallis, Oregon. The ponderosa pine stands were located north of Sisters, Oregon, in the Deschutes National Forest, United States Department of Agriculture, Forest Service (USDA-FS).

Oregon's climate is considered to be mild and is largely influenced by the Pacific Ocean. Precipitation is higher in areas to the west of the Cascade Range (~1200 mm) than to the east of the Cascade Range (~350 mm); most precipitation falls as rain. Temperatures in the study area usually fall between -5 and +35 ^{o}C.

Operational Systems Employed

Monthly site visits were timed with harvesting contractor cooperation dependent upon availability of study species, sample quantity of stems, and contractor operational considerations. Harvest systems for the Douglas-fir consisted of hand falling, whole tree cable yarding, and mechanized processing at the landing. Steep slopes and cable yarding limited the number of sampled stems which retained their tops to the minimum merchantable limit. Processing heads for these operations included LogMax models 7000 and 10000XT (Log Max Inc., Vancouver, Washington, USA). All heads used chain over rubber feed wheels. The ponderosa pine stems were harvested with a Cut-To-Length (CTL) system – Timberjack 1270D harvester (John Deere, Moline, Illinois, USA) with 7620 processing head (chain over rubber drive wheels). Ten and eight monthly observations were made for Douglas-fir and ponderosa pine, respectively. Depressed lumber and log markets limited availability of operations in some months. The ponderosa pine harvesting contractor moved operations to coastal Oregon operations for the final months of the study.

Measurement Procedure

Monthly sampling consisted of 25 stems, of which eight were randomly selected for additional bark retention measurements. The stems were delimbed and topped at the merchantable top diameter. The stem lengths were then set aside for evaluation. The evaluator would first estimate the percent of bark loss on the top (upward facing) quadrant of the stem to the nearest 5%; this was done to see if a machine operator might be able to correctly assess bark loss under normal operating conditions. Each of the 25 stems was then assessed along the top quadrant for absence of bark, using the following line intersect methodology. A tape was laid out on top of the stem. Then, starting at the butt of the stem (distance = 0), bark presence (or absence) was noted and recorded. The evaluator traversed the stem until the current bark presence/absence condition changed. The distance to this point was recorded. The bark presence/absence condition was then changed to reflect the condition from this point to the next condition reversal. Traversing, recording distance and presence/absence condition continued to the merchantable top realized. For the eight randomly selected stems, this process was repeated for the right (evaluator's right, looking from stem butt to top) and left side quadrants. 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.

Data Analysis

Data were entered into a spreadsheet. For each stem, the percent of bark loss (by surface area) was calculated for the top quadrant (and side quadrants for the eight random stems). The average areal percent bark loss was then calculated for each month's sample. The right and left side quadrant data was similarly averaged, individually and aggregated for both sides to compare with the top quadrant data. A t-test (two-sample assuming equal variances) was performed for the null hypothesis that the means for the top quadrant and aggregated side quadrants were the same.

In order to further identify any tendencies in bark loss as a function of stem position, the stem distance location of bark loss was converted to presence (0) or absence (1) at 1-foot (0.3 meter) increments for each stem (top quadrant only). These locations were then standardized to a percentile location of merchantable stem length by dividing incremental locations by the merchantable stem length. The resulting percentile locations (0 = butt, 100 = top) were summed at 1% steps for all 25 stems. The summed value at each percentile location was then divided by 25 to calculate the percent of stems with bark loss at that location. This data set then creates a bark loss profile for that month's sample of stems.

Results

A total of 450 stems were assessed for bark loss over the 10-month study period. Summary statistics for butt diameter and stem length are presented in Table 2 for the Douglas-fir

Table 2. Average inside bark butt diameter and merchandized stem length by species and month (average of n = 8 stems).

Month	Douglas-fir		Ponderosa Pine	
	Butt Diameter (mm)	Length (m)	Butt Diameter (mm)	Length (m)
November	361	18.9	322	16.2
December	409	18.0	320	13.5
January	345	16.5	312	13.2
February	439	18.9	307	13.5
March	439	19.8	322	13.5
April	386	16.8	315	16.2
May	409	18.9	330	15.0
June	389	17.7	297	17.4
July	376	22.8		
August	432	21.9		
Average	400	19.0	315	14.8

and for ponderosa pine stems. The average butt diameter for these two species was 400 mm (15.7 inches) and 315 mm (12.4 inches), respectively. The average stem length for these two species was 19.0 m (63.3 feet) and 14.8 m (49.4 feet), respectively.

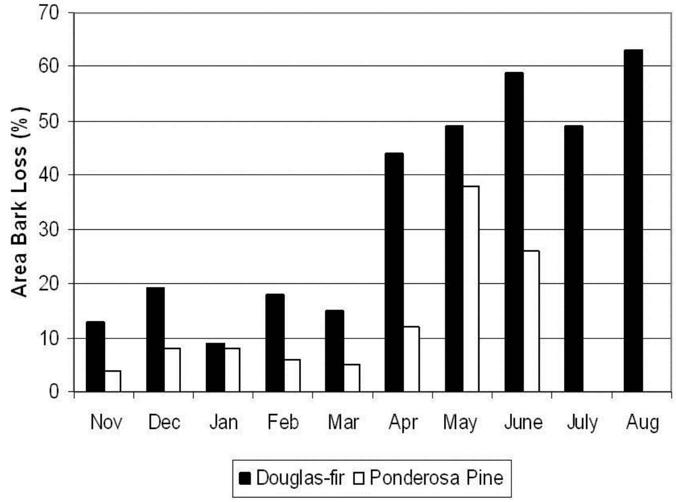
The evaluator was able to estimate the percent of bark loss, on average, within 5% of average actual values (Table 3). There was an initial adjustment period having a short learning curve. The evaluator's average overestimated bark loss in the first month for Douglas-fir. Subsequently the evaluator tended to consistently underestimate these two species due to decreased visual acuity, as these longer-stemmed species tended to curve downward out of sight. The evaluator felt the increased actual bark loss occurred in the upper stem as recognized when traversing to the top. Subsequent average differences were smaller. With the shorter ponderosa pine stems, the evaluator was able to visualize and estimate bark loss with higher accuracy. The exception was month two, when 75-100 mm of snow was present on the ground and tree tops. Occasionally stem canopy snow would settle on the bark after felling, giving the appearance of cambial wood (bark loss), resulting in an overestimate of bark loss (by 5%).

Table 3. Difference (%) between estimated and actual bark loss by month and species (top quadrant, average for n = 25).

Month	Species	
	Douglas-fir	Ponderosa Pine
November	7	0
December	-1	5
January	0	1
February	-4	0
March	-3	0
April	-4	0
May	-2	-1
June	-2	-3
July	-3	
August	3	

Seasonal effects of bark loss are seen for both Douglas-fir and ponderosa pine. Douglas-fir bark loss ranged from about 10% to 63% (Figure 1, Table 4) with an average loss of 34%. It should be noted the harvesting system changed to ground-based shovel logging for months 9 and 10 of the study (July and August 2010). Additionally, the sample stems were likely run through the processing head a second time prior to data collection for month 10. The stems were transferred from one side of the roadside landing to the other between researcher visits. This may be a reason for the unexpected increase in bark loss in this month. The increase in months 6-8 (April-June 2010) corresponds with traditional "sap flow" season and increased bark slippage.

Figure 1. Percent bark loss, as a function of stem surface area, for Douglas-fir and Ponderosa pine stems by month.



Ponderosa pine bark loss ranged from 4% to 37% for the monitoring period (Figure 1, Table 4) with an average bark loss of 13%. The peak occurred in month 7 (May 2010). It should be noted the data for ponderosa pine was collected immediately after felling and delimbing by the harvester. This is operationally different from the other species (operations) where the stems likely had bark loss prior to processing due to felling (striking and being struck) and yarding/skidding (stumps, logs, banging logs during inhaul, log loader from chute to processor). For this reason, these percents and trends should be viewed as specific to a CTL harvesting system. Alternative harvesting systems for ponderosa pine ecotypes include cable systems on steeper terrain in northeastern Oregon and the intermountain region.

Side quadrant bark loss averages were generally larger than the measured top quadrant. The side quadrants, as presented during data collection, were generally the sides associ-

Table 4. Percent areal bark loss by species and month (top quadrant, average for n = 25).

Month	Species	
	Douglas-fir	Ponderosa Pine
November	13	4
December	19	8
January	9	8
February	18	6
March	15	5
April	44	12
May	49	38
June	59	26
July	49	
August	63	
Average	34	13

ated with the processor drive wheels. Observational impressions suggest side quadrant bark loss was greater than top quadrant bark loss. However, the statistical test performed failed to reject the null hypothesis. Statistically side quadrant bark loss was not significantly greater than top quadrant bark loss.

Profiles of the probability of bark loss along each stem are shown in Figures 2a and 2b for Douglas-fir and in Figures 3a and 4b for ponderosa pine for the months of December and May. These months were selected because they were in the slow growing (or dormant) season and the sap-rise season, respectively. It can be seen that there was no apparent trend for bark loss along the length of a stem for the Douglas-fir samples for either of the months shown in Figure 3; all points along the stem having similar probability of losing bark. Graphs of the other 8 months also show no trend. For the ponderosa pine samples, there did appear to be a trend for greater bark loss towards the top of the tree than at the base of the tree. This was strongly evident in the samples from November through to April, but less evident in the May and June samples.

Figure 2. Percent of Douglas-fir stems missing bark along the stem profile for two sampling periods: (a) December 2009 ("dormant" season), (b) May 2010 ("sap-rise" season).

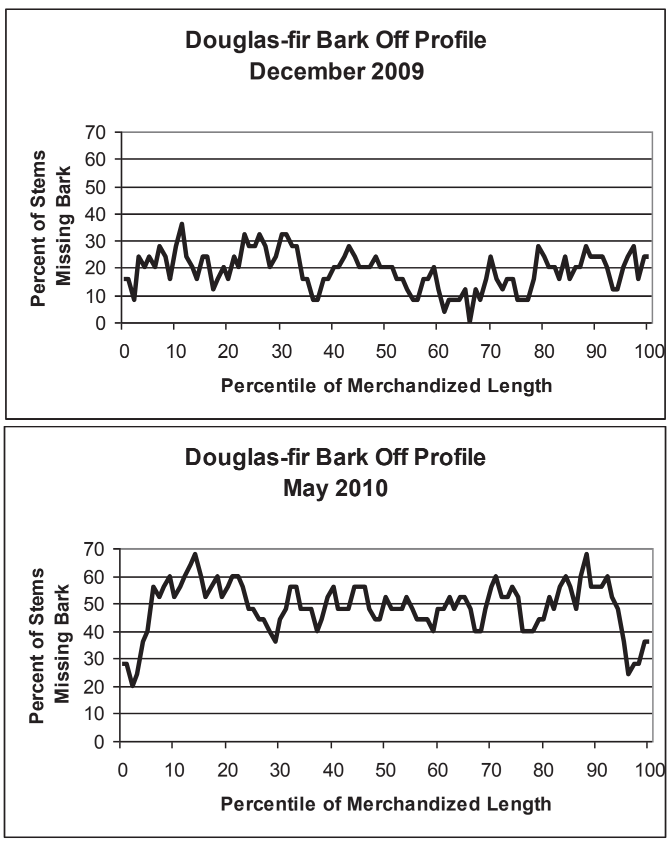
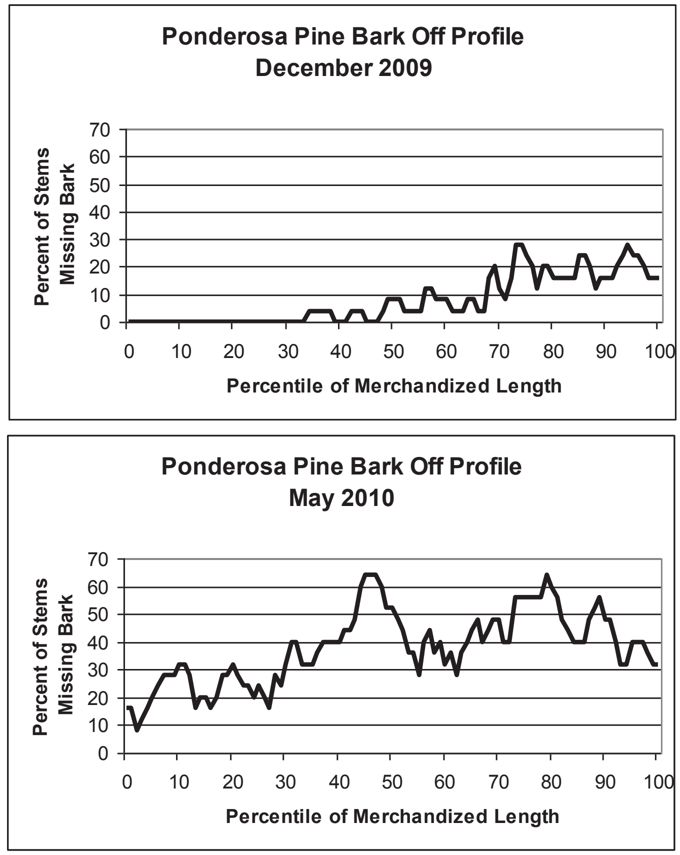


Figure 3. Percent of ponderosa pine stems missing bark along the stem profile for two sampling periods: (a) December 2009 ("dormant" season), (b) May 2010 ("sap-rise" season).



Discussion and Conclusion

Bark loss ranged from as low as 4% to as high as 63% and averaged 25% for both species and all sampling periods. The range in bark loss for these two species brackets values found for three other species (western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), and red alder (*Alnus rubra*)) measured by the authors but where there were insufficient data points to establish seasonal trends; bark loss for these three species combined ranged from 20% to 61%.

There was a four- to five-fold increase in bark loss during late spring/early summer than was found for late autumn/winter seasons for Douglas-fir (4X) and ponderosa pine (5X). For these species there was a sudden increase in bark loss after five or six months of relatively low loss. For ponderosa pine the sudden increase occurred one month later, in May, than was found for Douglas-fir; possibly due to elevational and temperature differences.

Other differences between species were evident as well. Bark loss in ponderosa pine (13%) was less than half that found for Douglas-fir (28%) when comparisons were made over the same eight-month sampling period. This finding would be supported by the bark adhesion figures reported by Harder et al. (1978) and shown in Table 1; these suggest that bark loss would be less for ponderosa pine than for Douglas-fir for both "dormant" and "growing" seasons. As noted in the

"Results" section, however, different extraction systems were used in these two species which may have accounted for some of the differences in bark loss; namely a CTL system in the ponderosa pine and cable yarding or shovel logging in the Douglas-fir.

The areal distribution of bark loss along a stem is important for volume calculations for loss. We found that areal bark loss was evenly distributed along a stem for the Douglas -fir stems but tended to be concentrated towards the tops for the ponderosa pine stems. The different patterns of distribution could be either species-related (i.e., compared with the butt of the stem, ponderosa pine has relatively lower bark adhesion towards the top of the stem) or harvesting system related or a combination of these.

If operators are to make allowance for bark loss in determining truck payloads or assessing wood quality using acoustic measurement tools they will need to be able to rapidly assess how much bark has been lost. This study showed that an evaluator could estimate the percent of areal bark loss, on average, within 5% of average actual values.

As with most studies there are limits on how far the results of this study can be extended; limits relate to sample size, species, locations and harvesting systems.

All of the measurements were collected in stands within Oregon. The same species in different locations could have different growing conditions, e.g., timing of onset of sap-rise, which could affect the amount of bark loss in any month.

There has been a large shift in delimbing and bucking practices in the Pacific Northwest coast region of the USA over the last two decades. Where once manual delimbing and bucking were common, now mechanized delimbing and bucking are the norm. This change in systems has implications for bark loss. The delimbing and bucking machines selected for this study all had rubber feed wheels with chains over them. Bark losses reported by others (Lee and Gibbs 1996, Uzonovic et al. 1999) indicate that these type of systems are likely to have greater bark losses than manual felling and delimbing systems but smaller bark losses than processor heads fitted with spiked feed wheels. Some harvesting contractors in the Pacific Northwest also use stroke delimbers. It is unknown how these processors compare with other systems with respect to bark loss. Further research should be undertaken on a wider range of processing systems and log handling systems.

Finally it was noted during the study that freshly felled and delimbed Douglas-fir stems were more likely to lose bark than stems which had been left to sit for a few weeks after felling during the "sap-rise" season. Others have found that bark adhesion increases as stems dry out after felling (Duchesne and Nylander 1996, Kubler 1990). Further work is needed to determine how much bark is lost after different levels of drying time during different seasons of the year.

Despite these limitations we have been able to quantify the level of bark loss for two commercial species, Douglas-fir and ponderosa pine, for mechanized processors with rubber feed wheels and chains. We have also been able to show that there is a substantial (up to 10 times) increase in bark loss during late spring and early summer compared with winter season. We were also able to show that the amount of bark loss is species dependent, with Douglas-fir incurring more bark loss than ponderosa pine.

Acknowledgements

Funding for this project was provided through a USDA Special Project Grant, Wood Utilization Research. The authors would like to acknowledge the assistance of the following logging contractors and forest companies: Giustina Land and Timber Co., Shiloh Forestry, Regrowth Enterprises; USFS Deschutes Ranger District, Scott Melcher, Melcher Logging, Derek Starbuck, Quicksilver Logging; Starker Forests, Inc., Roy Parks – Ramco Logging; and, Thompson Timber, Bill Wischnofski Logging. Without their support this project would not have been possible.

References

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

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

Harder, M.L., Hankey, J.D., Einspahr, D.W., Swanson, J.W., and others (7 named organizations). 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. Available from http://smartech.gatech.edu/handle/1853/882/3212_011_06231978.pdf [accessed November 4, 2010].

Hartsough, B., Spinelli, R., Pottle, S. and Klepac, J. 2000. Fiber recovery with chain flail delimbing/debarking and chipping of hybrid poplar. *International Journal of Forest Engineering.* 11(2):59-68.

Kranzuch, E. 2010. Personal communication, email dated June 7, 2010.

Kubler, H.H. 1990. Natural loosening of the wood/bark bond: a review and synthesis. *Forest Products Journal.* 40(4):25-31.

Lasserre, J.P. 2005. Influence of initial stand spacing and genotype on Pinus radiata corewood properties. Master of Forestry Science thesis, University of Canterbury, Christchurch, New Zealand. 107 pp.

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

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

McDonald, T., Rummer, B., Taylor, S., and Valenzuela, J. 2001. Potential for shared log transport services. Pp.115-120. Proceedings of the 24th Annual Council on Forest Engineering Meeting. Snowshoe Mountain, West Virginia. Wang, J. et al. (eds.). Council on Forest Engineering, Corvallis, OR.

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

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

Murphy, G.E., and Amishev, D. 2008. Effects of bark removal on acoustic velocity of Douglas-fir logs. *New Zealand Journal of Forestry Science.* 38(2/3):247-252.

Murphy, J.A., Smith, P.M., and Wiedenbeck, J. 2007. Wood residue utilization in Pennsylvania: 1988 vs 2003. *Forest Products Journal.* 57(4):101-106.

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

Pellerin, R., and Ross, R.J. 2002. Nondestructive evaluation of wood. Forest Products Society, Madison, Wisconsin. 210 pp.

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

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

Uzonovic, A., Webber, J.F., Pearce, A.J., and Dickinson, D.J. 1999. The role of mechanized harvesting in the development of bluestain in pine. *Canadian Journal of Forestry Research.* 29(2):242-251.

Wang, X., Carter, P., Ross, R.J., and Brashaw, B.K. 2007. Acoustic assessment of wood quality of raw forest materials – a path to increased profitability. *Forest Products Journal.* 57(5):6-14.

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