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Identifying Trees in Riparian Areas That Can Provide Coarse Woody Debris to Streams

E. GEORGE ROBISON
ROBERT L. BESCHTA

ABSTRACT. The natural fall of trees into mountain streams provides coarse woody debris that can improve fish habitat and influence stream morphology. Geometric and empirical equations, based on tree size and distance from the stream, were used to determine the conditional probability of a tree's adding coarse woody debris to a stream. Additional equations were developed to relate this probability to basal area factor. For conditions in the Pacific Northwest, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) was selected to illustrate how the equations can be used for varying tree sizes and probabilities. After selecting a probability and determining basal area factor by these equations, resource managers can use prisms or wedge devices before timber harvesting in riparian areas to identify specific trees that can potentially add woody debris to the stream. FOR. SCI. 36(3):790–801.

ADDITIONAL KEY WORDS. Debris recruitment, large woody debris, streamside management, forest practice rules.

COARSE WOODY DEBRIS is an important component of forest streams in the Pacific Northwest (Harmon et al. 1986, Bisson et al. 1987). Although management practices in the past have often been directed at removing coarse woody debris from streams, recent studies have shown that debris removal can alter fish habitat (Murphy et al. 1986, Bisson et al. 1987, Sedell et al. 1988), channel morphology (Robison 1988) and sediment routing (Sedell and Beschta, in press). Thus, forest managers are currently attempting to retain, or even increase, coarse woody debris in streams.

Directional felling of trees into streams at harvest time is one method to enhance debris recruitment. Although debris would enter streams from this operation, this method would also increase harvesting costs, produce instream debris that would not have rootwads attached, and place the trees in the stream all at once instead of allowing them to fall in over time. Blasting has been used to fell trees with rootwads, but this method is generally cost-prohibitive. Transporting logs from other areas of a forest to a stream channel is another alternative to leaving trees for future debris recruitment. This type of operation is currently being widely used by fisheries biologists to enhance fish habitat, but the procedure is costly, and often can also damage or alter streambanks and beds. Like naturally occurring woody debris, this added material will ultimately decay or be removed by high flows. To have a continual supply of wood in a stream system requires a sustainable supply of coarse woody debris from the forest along the stream.

To ensure a continual supply of coarse woody debris in mountain streams, many states and provinces in the Pacific Northwest have recently adopted forest practice rules that call for setting aside standing live trees in riparian areas to provide future debris recruitment (Adams et al. 1988). These rules designate a certain number of conifers to be left along streams. However, within the existing forest practices rules it is possible to leave conifers that have little chance of providing large wood to a stream, and at the same time take conifers that would provide large wood to the stream. This possibility of leaving or taking the wrong trees suggests that a method to select trees based on their potential to provide coarse woody debris to a stream needs to be developed.

The purpose of this paper is (1) to present a method for determining the probability that a tree, upon falling, will provide coarse woody debris to a stream and (2) to relate this probability to the basal area factor (BAF) obtained by a wedge device or prism so that specific leave trees can be easily and consistently selected in the field.

METHOD DEVELOPMENT

General Assumptions

The development of the following equations and methodology required several assumptions. First, a tree was assumed to have an equal chance of falling in any direction. No literature was found that identified the direction of tree fall near streams or on hillsides. Although the general direction of tree blowdown may be associated with prevailing wind direction, the interaction of wind patterns with topography is complex (Steinblums et al. 1984). Trees may also exhibit greater growth and biomass towards the stream because of greater light availability, causing them to lean toward the stream. Soil creep, streambank erosion, or some other factor might also cause a tendency for trees to fall toward or away from the water. Analyses of down timber on 17–70% hillslopes in the Oregon Cascades (R. L. Beschta, unpubl. data) indicated that the probability of a tree falling downslope was greater than 75%. If a similar condition exists for trees in riparian areas, the probabilities presented later in this paper would underestimate actual values for streams with sideslopes. More information on the direction of tree fall in riparian zones is needed to allow refinement of the probabilities given.

Second, for a given "average" tree diameter, there are assumed to be equal numbers of trees both larger and smaller. Whether such size distribution occurs for trees in a riparian forest is not known.

Third, this method evaluates the potential for a tree of a given size to provide debris at the time that it was evaluated. However, this potential will change over time because of diameter and height growth. Also, channel adjustments may move a stream closer to or farther away from a tree, thus altering its probability of providing coarse woody debris to the channel. Stand dynamics and channel adjustments were not incorporated into this study.

Fourth, these probabilities also assume that the entire tree, rootwad, and bole will fall. Breakage was not considered.

DETERMINING PROBABILITY

When a tree falls in a forest, the probability of its falling into a stream is primarily a function of tree height and distance from the stream. If a tree is assumed to have an equal chance of falling in any direction, the possible surface area that could be impacted can be represented by the area of a circle whose radius is equal to the total tree height (H_t) (Figure 1). However, the upper crown of a tree does not normally have wood of sufficient size to be considered coarse woody debris (pieces large enough to influence stream hydraulics, stream morphology, and/or fish habitat). Coarse woody debris usually consists of pieces of wood or tree boles that exceed a specific diameter and/or length (Bisson et al. 1987). Thus, an "effective tree height" (H_e), which is the height to the minimum diameter and length necessary for the wood to qualify as coarse woody debris (assumed here to be at least 8 in. in diameter and 5 ft in length), would be a more appropriate standard to use for assessing the potential fall area (Figure 1). This effective tree height can be adjusted on the basis of management needs. For instance, if larger wood was desired for larger streams, the minimum diameter and length could be increased.

If a tree is located at the edge of a stream and has an equal chance of falling in any direction, the probability of its falling into the stream is 50% (Figure 2A). As distance (D) away from the stream increases, the probability (P) of a tree's falling into the stream decreases (Figure 2B). Therefore, the probability of a tree's falling so that coarse woody debris is supplied to the channel is proportional to the arc distance (AD) along the stream divided by the total arc distance (circumference) of the circle or

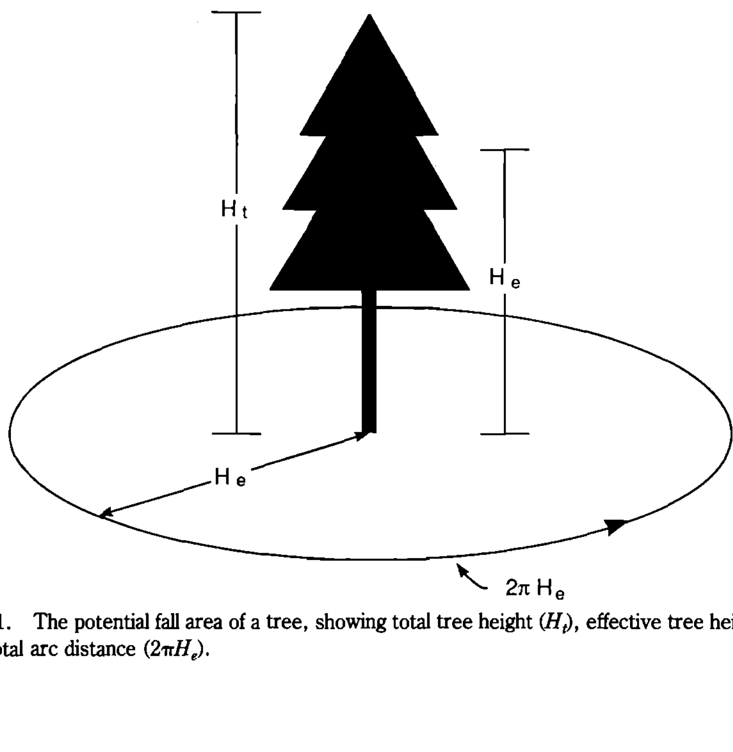

FIGURE 1. The potential fall area of a tree, showing total tree height (H_t), effective tree height (H_e), and total arc distance ($2\pi H_e$).

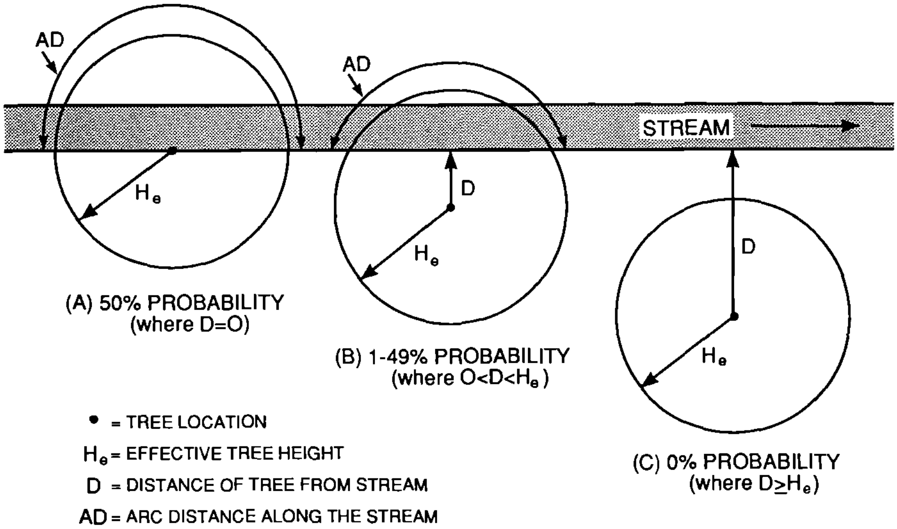

FIGURE 2. Schematic view illustrating the probability of coarse woody debris falling into a mountain stream from a tree located (A) at the edge of the stream, (B) at a distance less than the effective tree height, and (C) at a distance greater than the effective tree height.

$$P = \frac{AD}{2\,\pi\,H_e} \tag{1}$$

An equation for calculating the arc distance along the stream is the same as that for determining the wetted perimeter of circular pipes in hydraulic equations (Beschta 1981):

$$AD = \frac{2\,\pi\,H_e\,[\cos^{-1}(1 - 2d/2\,H_e)]}{180°} \tag{2}$$

where

AD = arc distance of stream within the circle of influence ($0 \leqslant AD \leqslant \pi\,H_e$ (ft))

H_e = effective tree height (ft)

D = distance of tree away from stream ($0 \leqslant D \leqslant H_e$ (ft))

$d = H_e - D$ (ft).

This can be simplified to:

$$P = \frac{\cos^{-1}(D/H_e))}{180°} \tag{3}$$

When distance from the stream equals or exceeds the effective tree height, the probability of coarse woody debris entering the stream by direct fall becomes zero (Figure 2C).

CALCULATING EFFECTIVE TREE HEIGHT

In this study, we assumed that a tree bole must be ≥8 in. in top diameter *and* ≥5 ft long for it to be considered as coarse woody debris. To calculate the effective tree height that meets these minimum criteria, we adapted Biging's (1984) taper equation for six conifer tree species in northern California:

$$T_d = DBH\ (b_1 + b_2) \ln(1 - \lambda\ (H_e/H_t)^{1/3}))) \tag{4}$$

Solving for H_e and subtracting 5 ft,

$$H_e = H_t\ ((1 - \exp(T_d - DBH(b_1))/DBH(b_2))/\lambda)^3 - 5 \tag{5}$$

where

H_e = effective tree height (ft)
H_t = total tree height (ft)
T_d = top diameter (in.)
DBH = diameter at breast height, including outside bark (in.)
b_1 and b_2 = coefficients that vary with tree species (see Table 1)
$\lambda = 1 - \exp(-b_1/b_2)$

These taper equations are based on data from second-growth forests in California and thus can provide only rough estimates for relatively large trees or trees from other regions. Other published (e.g., Walters and Hann 1986) and unpublished taper equations could have been used.

RELATING TREE DIAMETER TO HEIGHT

Because resource managers seldom have both tree diameter and height information available to them, we calculated height and diameter values using equations from Larsen and Hann (1987) for several coniferous and hardwood species in southwest Oregon:

$$Ht = 4.5 + \exp(b_3 + b_4\ DBH^{b_5}) \tag{6}$$

By solving for DBH, diameter can be related to height:

$$DBH = (\ln((Ht - 4.5) - b_3)/b_4)^{1/b_5} \tag{7}$$

TABLE 1.

Arithmetic values of coefficients for taper equations (Biging, 1984).

	Coefficients	
Tree species	b_1	b_2
Ponderosa pine	1.016215	0.332529
Douglas-fir	1.027763	0.333721
White fir	1.093343	0.364280
Sugar pine	1.067508	0.411978
Incense-cedar	1.077913	0.482610

where

b_3, b_4, b_5 = coefficients that vary with tree species (see Table 2)

Errors due to the use of nonlocal equations could be avoided by measuring all tree heights; or, if a sample of heights representing the range of diameters is measured, a linear regression equation can be used to predict tree heights at a particular site (Curtis 1967).

Relating Probability to Basal Area Factor

The probability of a tree providing coarse woody debris to a stream and the determination of a tree being "in" or "out" as determined by a prism (Husch et al. 1972, Bell and Dilworth 1988) are both based on tree size and distance relationships. Therefore, variable plot methodologies can be used to select trees in the field that have a given probability of providing coarse woody debris to a stream.

To calculate the basal area factor (*BAF*) of a prism, the diameter (*DBH*) and plot radius (*PR*) of a borderline tree need to be known. A "borderline tree" is a tree in which the wedge angle lines for a given plot radius are at the exact outer edges of the tree diameter at breast height (Husch et al. 1972). By manipulating equation (3), the plot radius (*PR*) from the streambank to a borderline tree can be determined:

$$PR = H_e - H_e[1 - \cos(180°P)] \qquad (8)$$

The basal area factor is calculated by the equation:

$$BAF = 10{,}890\ (DBH/12\ PR)^2 \qquad (9)$$

The *BAF* calculated in Equation (9) is for a given tree species, tree size, and the probability (*P*) of a portion of that tree to provide coarse woody debris to the stream. For a particular *BAF*, large trees or trees relatively close to a stream would be more likely to be identified as "in" trees.

COMPUTATIONS FOR DOUGLAS-FIR

We selected Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) as a representative tree species to show relationships between probability, basal area factor, tree

TABLE 2.

Arithmetic values of coefficients for height/diameter equations (Larsen and Hann 1987).

	Coefficients		
Tree species	b_3	b_4	b_5
Douglas-fir	7.12760	−5.36420	−0.261749
Grand/white fir	6.74974	−5.49823	−0.327093
Ponderosa pine	8.18646	−6.65322	−0.203531
Sugar pine	6.58804	−5.50568	−0.321050
Incense-cedar	8.90359	−7.53667	−0.163019

size, and distance to the stream for various conditions. Relationships for other tree species, including hardwoods, would differ because of different tree taper and form.

The probability of a tree's falling into a stream and providing coarse woody debris (e.g., ≥8 in. in diameter and ≥5 ft long) decreases rapidly with increasing distance from the stream (Figure 3A). Over an intermediate-tree size range (20 in. ≤ *DBH* ≤ 50 in.) and for low-to-intermediate probabilities (*P* ≤ 40%), the relationship between *BAF* and probability is similar for Douglas-fir, regardless of tree size (Figure 3B). Therefore, a particular BAF may be appropriate for determining "in" trees over a 20- to 50-in. *DBH* size range. Differences in *BAF* for a given probability are due primarily to the direct relationship between diameter and effective height. At diameters greater than 50 in., the rate of increase in effective height decreases, causing changes in the relationship between probability and *BAF*.

BAF prisms greater than 60 *BAF* are needed to identify trees associated with probabilities of 40% or larger. For instance, at a probability of 45% the calculated *BAF* in Table 3 is ≥210, regardless of tree diameter. These high BAF's occur because Douglas-fir trees with 40–50% probabilities of providing coarse woody debris must either be close to the streambank or very large. Only an extremely large BAF prism or wedge, with an angle approaching 180° would be able to identify such trees as "out."

At relatively high probabilities, BAF becomes more sensitive to changes in tree size (Figure 4). Also, as tree DBH becomes small and approaches the effective top diameter, the calculated BAF increases rapidly and approaches infinity (Figure 4).

APPLICATIONS

Designing Riparian Buffer Strips

The design of an effective riparian buffer strip requires an estimate of average tree size and choice of a probability level of coarse-woody-debris deposition. Selecting a low probability level will result in a relatively wide buffer strip. For instance, a buffer strip with a probability of 10% would have as "in" trees all those with a greater than 10% chance of providing coarse woody debris to the stream. Next, the appropriate BAF can be calculated from Equations (5), (8), and (9). For example, in a riparian forest dominated by Douglas-fir with average diameters of 30 inches, Table 3 indicates an 11 BAF prism would select trees as "in" that had a ≥25% probability of providing coarse woody debris to a stream.

To lay out a buffer strip in the field, a person needs to walk along the banks of a stream with the appropriate prism or wedge and identify trees that are "in" or "out" (Husch et al. 1972 or Bell and Dilworth 1988). The prism (or equivalent BAF device) should be held perpendicular to the streambank as each tree is encountered along the stream. A tree observed as "in" from any point on the streambank would represent a leave tree for a buffer strip, whereas an "out" tree would be available for harvest. There is no need to adjust for slope as is the case

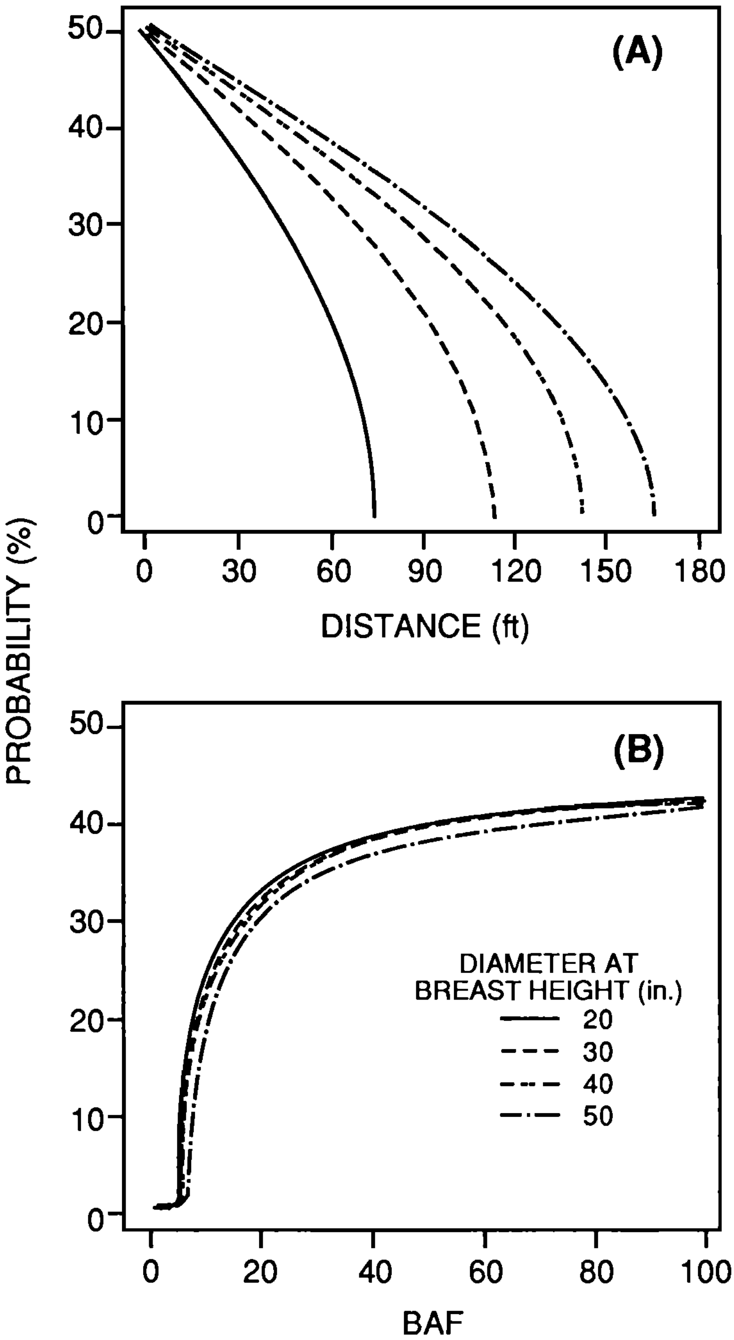

FIGURE 3. Probability of coarse woody debris from a Douglas-fir tree entering a mountain stream in relation to: (A) distance from stream and (B) basal area factor (*BAF*) for selected diameters at breast height (*DBH*).

TABLE 3.

Basal area factor (ft^2) for identifying Douglas-fir leave trees, which, on blowdown, will provide coarse woody debris[1] to a mountain stream.

Tree size			Probability (%)								
DBH (in.)	H_t (ft)	H_e (ft)	≥5	≥10	≥15	≥20	≥25	≥30	≥35	≥40	≥45
10	71	5	330	360	410	490	>500	>500	>500	>500	>500
15	93	45	9	10	11	13	17	25	42	90	350
20	112	74	6	6	7	9	11	16	27	58	230
25	128	96	5	6	7	8	10	15	25	54	210
30	142	114	5	6	7	8	11	15	26	55	220
35	155	129	6	6	7	8	11	16	27	58	230
40	166	142	6	7	8	9	12	17	29	63	250
45	176	154	7	7	8	10	13	19	31	68	260
50	186	165	7	8	9	11	14	20	34	73	280
55	195	175	8	8	9	11	15	22	36	78	310
60	203	184	8	9	10	12	16	23	39	84	330
65	210	192	9	10	11	13	17	25	42	90	350
70	217	200	10	10	12	14	18	27	45	97	380

[1] Bole ≥ 8 in. in diameter and ≥ 5 ft long.
[2] H_t = total tree height; H_e = effective tree height.

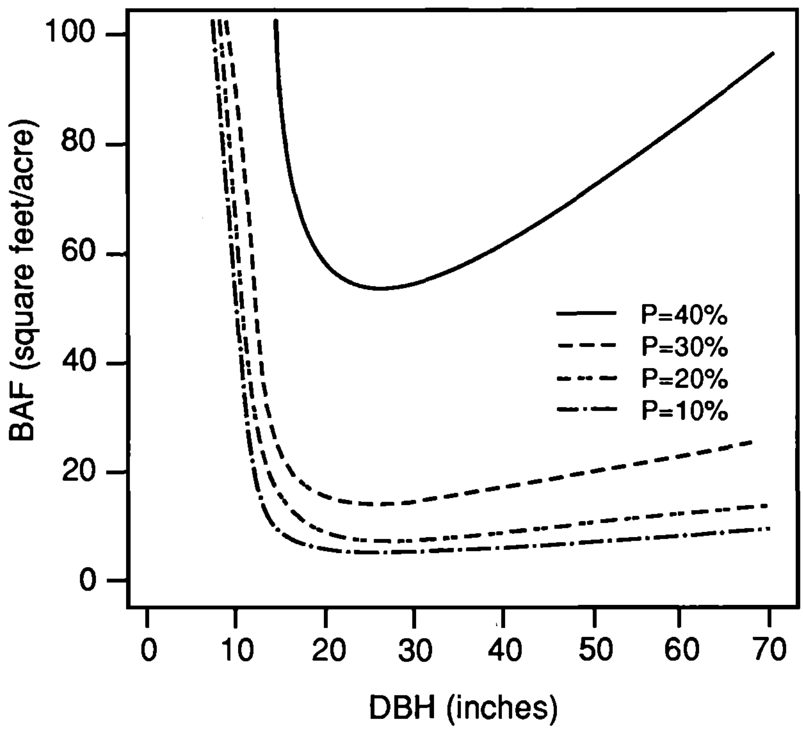

FIGURE 4. Relationship of basal area factor (*BAF*) to diameter at breast height (*DBH*) of Douglas-fir for four selected probabilities (*P*).

for timber cruising; slope distances are desired. In some riparian areas, brush may make it difficult to observe certain trees. In this case, slope distance to the tree can be measured and compared to a calculated plot radius (PR') (Bell and Dilworth 1988, p. 146–147):

$$PR' = \frac{(10{,}890/BAF)^{0.5}\ (DBH)}{12} \tag{10}$$

If the measured plot radius (from the streambank to the middle of the tree) is less than the calculated plot radius, the tree is "in."

Although this methodology can be consistently used in any particular riparian stand, flexibility in application may be appropriate. For example, a riparian area could have numerous "low-value" hardwoods that are technically "out" trees for coarse-woody-debris recruitment, but these trees may provide wildlife habitat and shade. In such instances, they might be marked as "in." For trees that are barely "in" or barely "out," the amount of lean toward or away from the stream could further influence the decision whether to leave or harvest. A large conifer that is far from the stream may barely be an "in" tree. Yet, because of its high monetary value and the likelihood that only a small portion of the tree will provide wood to the stream, the tree might be marked as "out." Trees that are too small today to be "in" represent future sources of coarse woody debris. Hence, removing all "out" trees from a second-growth stand or one with relatively small size classes will delay any "in" trees from developing in the future. Reducing the *BAF* factor would allow some of these smaller trees to be designated as "in" trees.

Other Uses

The integration of tree-growth and "fall-down" (risk-rating) models with the technique described here may be useful for identifying trees that will have a high probability of providing coarse woody debris to a stream in later years. By incorporating growth and mortality models, resource managers could determine the distance from a stream that they would plant tree species for future recruitment of coarse woody debris. That distance would be based on the probability of trees eventually providing valuable material to the stream. Similarly, in combination with risk-rating systems (Ferrell 1980), this methodology could be used to help evaluate the chance of trees falling onto highways, campgrounds, and other man-made developments.

The effects of tree canopy for shade and litter inputs, as well as roots for streambank stability, are also related to tree size and its position in relation to the stream (Meehan et al. 1977). Therefore, tree selection for coarse-woody-debris inputs inherently includes those trees that are also most likely to provide shade, litter, and streambank stability with their root systems. Models could also be developed for these specific factors, providing further insights into how the spatial distribution of trees can influence forest streams.

Current guidelines for debris recruitment for streams in most states indicate a given number of trees per unit stream length need to be left (e.g., Oregon Department of Forestry 1987). Which trees to leave is dependent primarily upon the judgment, experience, and values of the person designing the buffer strip. Hence, the composition of a buffer strip can vary greatly. Trees that may have a great potential of improving stream characteristics may be removed, while trees of lesser potential may be left standing. In contrast, using prisms or wedge devices in combination with the probability of a tree's providing coarse woody debris to a stream gives managers an objective new tool to help design riparian buffer strips.

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AUTHORS AND ACKNOWLEDGMENTS

The authors are, respectively, Hydrologist, Oregon Water Resources Dept., 3850 Portland Road N.E., Salem, OR 97310 (formerly Faculty Research Assistant, Oregon State University), and Professor of Forest Hydrology, Forest Engineering Department, Oregon State University, Corvallis, OR 97331. Review comments by J. Tappeiner, D. Paine, D. Marshall, T. Pearsons, and J. Van Sickle are acknowledged and appreciated. This is Paper 2450, Forest Research Laboratory, Oregon State University.