Simulation of Stream Wood Source Distance for Small Streams in the Western Cascades, Oregon[1]

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Abstract

The model, STREAMWOOD, is an individual-based stochastic model designed to simulate the dynamics of wood in small streams of the Pacific Northwest. We used STREAMWOOD to examine source distance as a function of tree fall regime and stand age. Our results suggest that source distance increased with stand age for the first 400 years of stand development and then declined. Simulated source distance for mature conifer forests (81 to 200 years old) were consistent with observed data, but simulated source distances for old-growth forests (201 to 1,000 years old) were below observed data. Further information on stand ages for the forests used in the observational study would refine the compassion with simulated data.

Introduction

One consideration of riparian forest management is the long-term recruitment of wood to the stream. The chance of a riparian tree entering the channel is related to its source distance (Van Sickle and Gregory 1990). We define source distance as the slope distance between the stream bank and the base of the tree perpendicular to the stream channel. Several studies have addressed the relationship between source distance and riparian forest width in the Pacific Northwest. McDade (1987) and McDade and others (1990) surveyed 39 streams adjacent to either mature conifer (80 to 200 years old) or old-growth conifer (> 200 years old) riparian forests in western Oregon and Washington. The source distance for 90 percent of the wood inputs was found to originate within 26 m for mature conifer and 36 m for the old-growth stands. McDade and others (1990) also modeled the source distances for riparian stands composed of uniform heights. The simulated source distance for 90 percent of the trees 40 m and 50 m tall was 32 m and 40 m, respectively.

Van Sickle and Gregory (1990) developed a computer model that simulates the recruitment of stream wood from riparian forests with trees of mixed heights. They applied this model to a mixed-hardwood/conifer stand in the Oregon Cascades and found that 90 percent of the pieces originated within 18 m from the bank. The authors

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also proved mathematically that, for a forest of uniform height, approximately three times as many trees would enter the channel falling directly towards the stream bank as opposed to falling randomly.

These studies provide valuable insights into the relationship between width of the riparian zone and recruitment of wood into a stream. However, these studies give limited insight into how source distance varies with stand age. The purpose of this study was twofold: to compare the results of the simulations reported here with the results from this previous studies and to investigate changes in source distance through time as a function of stand age.

Model Description

We developed STREAMWOOD, a computer simulation model, to investigate the dynamics of wood in streams. (A brief description of STREAMWOOD is provided here; further information can be found at our Web site: http://www.fsl.orst.edu/lter/research/compplfr.htm). STREAMWOOD is an individual-based stochastic model that operates on an annual time step at the reach scale. Stream systems that can be simulated range from a single reach to a small basin. Stream wood dynamics represented in the model are tree entry, breakage, movement, and decomposition. Riparian forest inputs are generated either from a simplified forest gap model built within STREAMWOOD or from a user-specified input file. The model is run under a Monte Carlo procedure and the results are reported as average conditions per reach. The current version of STREAMWOOD was developed for fifth-order and smaller streams in the coniferous forests of the Pacific Northwest. Species considered include Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), western hemlock *(Tsuga heterophylla* [Raf.] Sarg.), western red cedar *(Thuja plicata* Donn ex D. Don), and red alder *(Alnus rubra* Bong.).

The forest model within STREAMWOOD was based largely on three existing forest–gap models: ZELIG (Pacific Northwest version by Steven Garman, Forest Science Laboratory, Corvallis Oregon), JABOWA (Botkin 1993, Botkin and others 1972), and CLIMACS (Dale and others 1986, Dale and Hemstrom 1984, Hemstrom and Dale 1982). Since the forest model adheres closely to the original design of Botkin and others (1972) and Shugart (1984), it inherits many of their limitations (Schenk 1996).

Riparian Zone Definition in STREAMWOOD

A simulated stream reach consists of a length, bankfull width, and a riparian forest adjacent to each bank. The dimensions of each riparian forest is the reach length by a width selected between 0 m to 100 m. A tree fall regime is associated with each riparian forest. In a random fall regime, trees have an equal chance of falling in any direction. In a directional fall regime, tree fall angle is normally distributed around a mean (and standard deviation) fall angle. A directional fall regime defined with a mean of 180 degrees and a standard deviation of zero forces all trees to fall directly towards the channel.

Initial Conditions

We conducted two simulations with STREAMWOOD using the forest model to grow identical riparian forests. Both simulations were run for 1,000 years and 200 iterations. In the first simulation, trees could fall in any direction (random fall), and in the second all trees were forced to fall directly across the channel (directional fall). Both simulations represented riparian forests in the Oregon Cascades at an elevation of 300 m. Soil moisture content was set such that the growth of red alder was negligible, but supported Douglas-fir, western hemlock, and western red cedar. The reach dimensions were 100 m long and 15 m wide. The thermal growth index was set at 1,500 growing degree-days (5.5ºC base) with a standard deviation of 100 growing degree-days.

The simulated riparian forests were 75 m wide and started with no trees. The riparian forest was divided into 31 intervals, or source distances, parallel to the stream bank. The first 30 intervals were 2 m wide, and the last interval was for recruitment of all pieces $\geq$ 60 m from the bank. For each source distance, the mean number of input events that entered the channel during each 10-year period was calculated. An input event included any tree that contributed a piece at least 10 cm top diameter and 1 m in length to the stream.

Results and Discussion

Comparison with Previous Studies

The first purpose of this study was to compare the results from the simulations with the results of previously published studies. Van Sickle and Gregory (1990) proved mathematically that, given a stand composed of trees of the same height, exactly 1/л less input events would result from trees falling randomly as opposed to falling directly across the channel. We extend this proof to stands composed of mixed heights. Consider a riparian forest containing trees of two different heights. The ratio of input events between random and directional fall would be identical (1/л) for both heights. The ratio for the entire stand would also be 1/л since it is the sum of all random fall inputs over the sum of directional fall inputs. Extending this argument, the ratio of 1/л would hold for any number of height classes.

The input ratio described by Van Sickle and Gregory (1990) provided a simple test for evaluating STREAMWOOD's performance. The two simulations reported had identical initial conditions except for the fall regime used. The ratio of the number of input events from the two simulations was determined *(fig. 1).* The mean ratio between the number of input events from random and directional fall was 0.307 with a standard deviation of 0.018. The mean input ratio from the simulations was 3.6 percent lower than the predicted value and could be due to small differences between the two simulated forests. The coefficient of variation was 5.8 percent and most likely could be reduced with an increase in the number of iterations. Thus, the performance of the model was consistent with the predictions of Van Sickle and Gregory (1990).

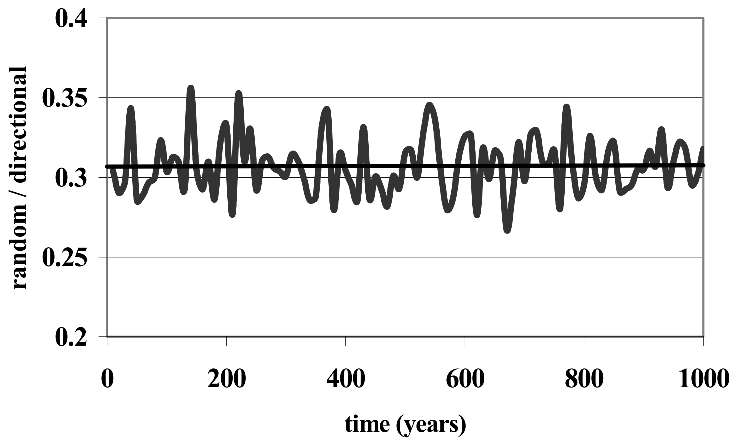

Figure 1—Ratio of input events from random and directional fall. The mean ratio of input events for each 10-year period was determined using the two simulations. The global mean obtained over the 1,000-year simulation was 0.31 (solid line). This value is consistent with the expected value of 0.32 (Van Sickle and Gregory 1990).

The second comparison with previous work was with the source distance estimates presented in McDade and others (1990) *(fig. 2, table 1).* The old-growth curve from McDade and others (1990) lies entirely below both source distance curves from this study, while the majority of the mature conifer curve lies between the source distance curves from this simulation. In addition, both source distance curves from McDade and others (1990) were very similar for the first 5 meters and below either of the simulated source distance curves.

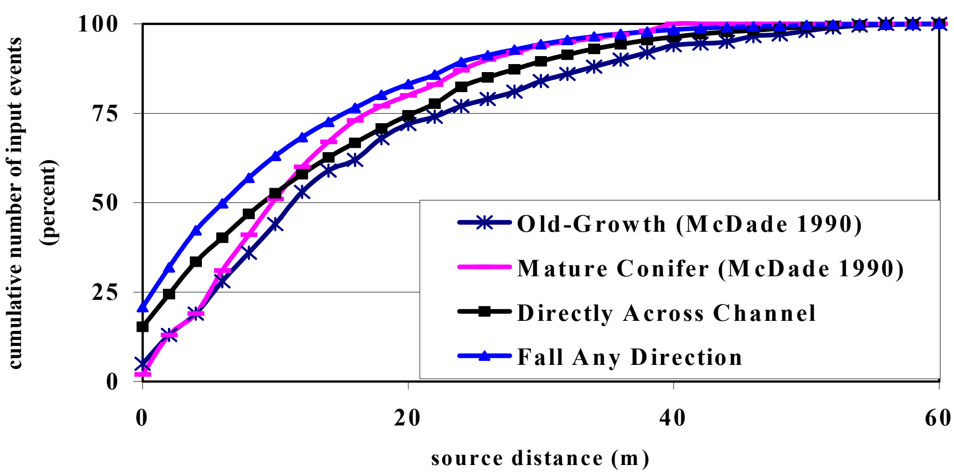

Figure 2—Comparison of source distances, western Cascades, Oregon. The two source distance curves from this study are compared with those presented in McDade and others (1990). The simulated source distance curves include all input events over a 1,000-year period. The simulated random fall curve is consistent with observed mature conifer curve, but the observed old-growth curve is greater than both simulations.

Table 1—*Comparison of source distances between the two simulations and data in McDade and others (1990). Two source distances are reported for each forest age class. These distances represent 50 and 90 percent of the input events associated with a forest age class.*

Study	Forest age class (years)	Source distance (m)	
		50 percent	90 percent
McDade (1990)	81 – 200	10	26
	> 200	12	36
Random fall	All Ages	6	26
(this study)	≤ 80	3	14
	81 – 200	8	26
	201 – 400	6	30
	> 400	6	24
Directional fall	All Ages	10	31
(this study)	≤ 80	4	20
	81 – 200	12	32
	201 – 400	10	36
	> 400	9	30

Possible explanations for the discrepancies in source distance between the results of McDade and others (1990) and the simulations may be related to the biases inherent in each approach. The tree fall regimes in the study sites surveyed may not be completely random. Thus, it would be expected that the source distance curve for the old-growth would lie between the random and directional source curves. In the simulations, the density of trees within the plot was assumed uniform. However, tree densities in the field plots surveyed by McDade and others (1990) may not be uniform, especially within the first few meters from the stream bank. The region adjacent to the stream bank is more susceptible to disturbance from high flows and typically has higher light levels reaching the forest floor—conditions favoring the establishment of early successional species.

The cumulative percent of input events for the first 2 meters was substantially less in the field study (2 and 5 percent) than in the simulations (15 and 21 percent). This difference suggests that the number of input events close to the stream bank was overestimated by STREAMWOOD. However, the simulations accounted for all input events that occurred over a 1,000-year period. In contrast, since the persistence of input events is not equal, larger and more recent events would be favored in the field surveys. Most likely, the cumulative percent of inputs 2 m and less from the channel are between the field and simulation estimates.

Source Distance and Stand Age

The second objective of this study was to investigate how cumulative input of wood into a stream varies through time as a riparian forest matures. Maximum source distance is equivalent to the maximum effective height (height to 10 cm top diameter) for a given species. In STREAMWOOD, the maximum effective height for the three species used in the simulation are approximately 80 m for Douglas-fir, 60 m for western hemlock, and 55 m for western red cedar. As noted previously, the riparian zone was divided into 30 source distance sub-zones 2 m wide, and one additional category for all input events occurring > 60 m from the stream bank. In our simulations, trees obtained sufficient height in approximately 450 years to contribute stream wood 60 m from the channel.

The source distance associated with 90 percent of the input events as a function of stand age was determined for both simulations *(fig. 3)*. The maximum value for both simulations occurred between stand ages of 200 to 400 years: 40 m for directional and 34 m for random fall. The source distances reflect the initial dominance of Douglas-fir (200 to 400 years) followed by the eventual dominance of western hemlock *(fig. 3)*.

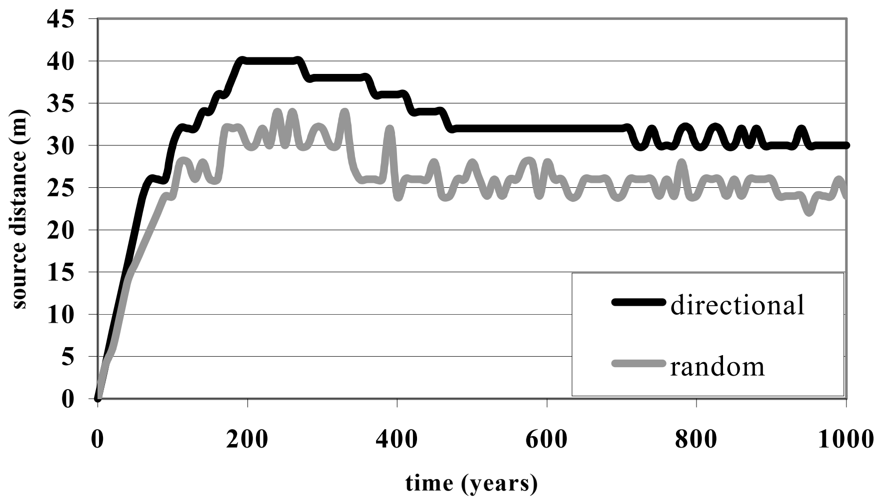

Figure 3—Source distance for 90 percent of the input events from directional and random fall through time. The greatest source distance is associated with a riparian forest dominated by the tree species with the greatest height, Douglas-fir. As the stand matures, Douglas-fir is eventually replaced by western hemlock.

To investigate how source distance varies by stand age, cumulative input events were determined for each of four riparian forest age classes: young conifer (0 to 80 years old), mature conifer (81 to 200 years old), Douglas-fir dominated old-growth (201 to 400 years old), and hemlock dominated conifer (> 400 years old) *(figs. 4, 5; table 1)*. Results were similar for both runs *(figs. 4, 5),* with young conifer stands having the shortest source distance, Douglas-fir dominated old-growth stands having the longest source distance, and the mature conifer and western hemlock dominated old-growth having almost identical source distances. The difference between the two runs can be illustrated by comparing the source distance at the 50 percent and 90 percent cumulative input levels *(table 1)*. At the 50 percent level, the source distances for all forest age classes, save for the young conifer, were within 3 meters. For the 90 percent level, the three older forest age classes were within 6 meters.

Finally, comparisons were made between the simulation results of the mature conifer *(fig. 6)* and old-growth stands *(fig. 7, table 1)* with those of McDade and others (1990) *(fig. 2)*. For the mature conifer age class, source distances ≥ 14 m were almost identical between the field survey and the random fall simulation *(fig. 6, table 1)*. This suggests that trees tend to fall randomly in the interior of the stand. This warrants further testing.

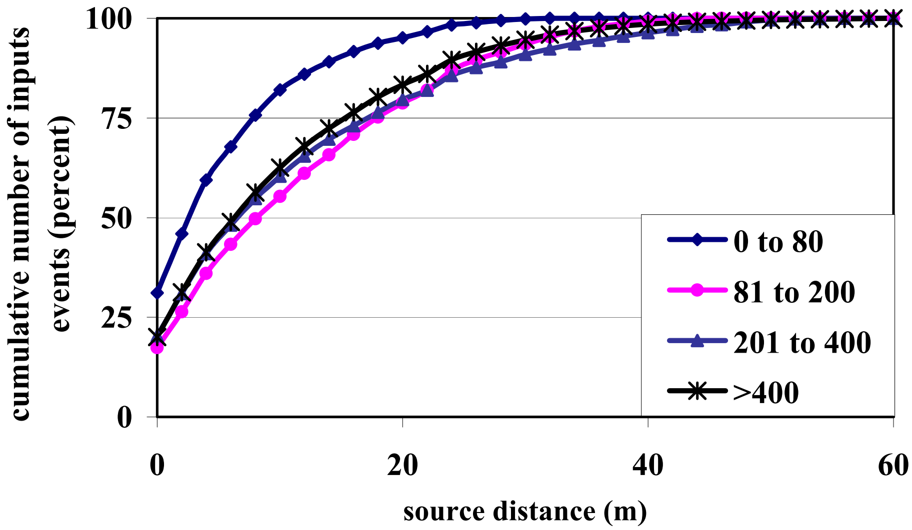

Figure 4—Cumulative number of input events from random fall as a function of the riparian forest age class. The four forest age classes represent young conifer, mature conifer, old-growth dominated by Douglas-fir, and old-growth dominated by western hemlock.

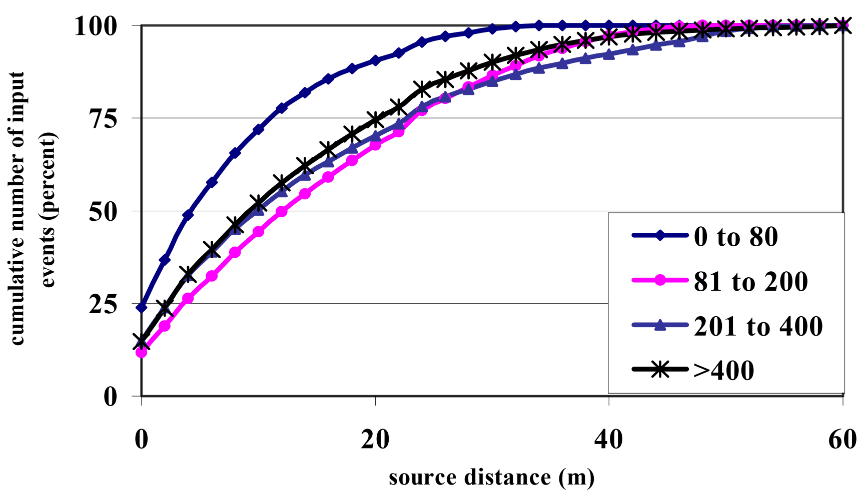

Figure 5—Source distance for the directional fall simulation as a function of the riparian forest age class. The four forest age classes represent young conifer, mature conifer, old-growth dominated by Douglas-fir, and old-growth dominated by western hemlock.

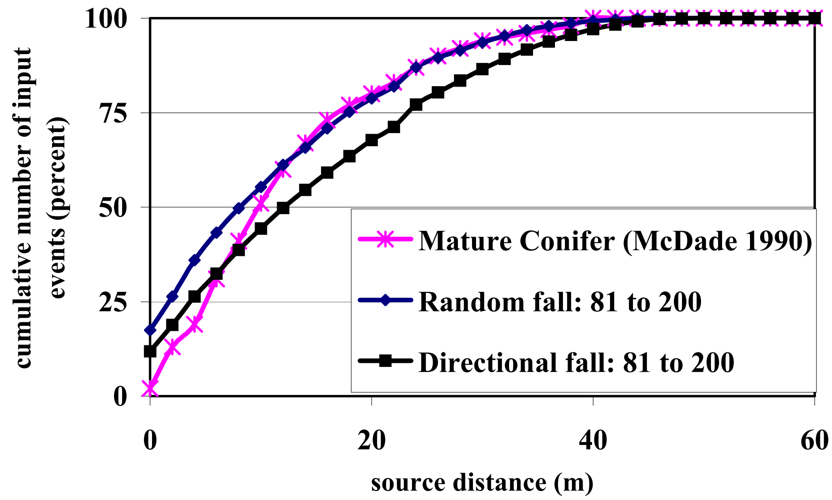

Figure 6—Comparison of source distance estimates for mature conifer, western Cascades, Oregon. Comparison of mature conifer source distance curves from the two simulations and McDade and others (1990). Each simulated source distance curve includes only those input events from stand ages between 81 to 200 years. The random fall source distance is consistent with the observed for source distances ≥ 14 m. This suggests that in the surveyed plots, trees ≥ 14 m from the stream bank tended to fall in any direction.

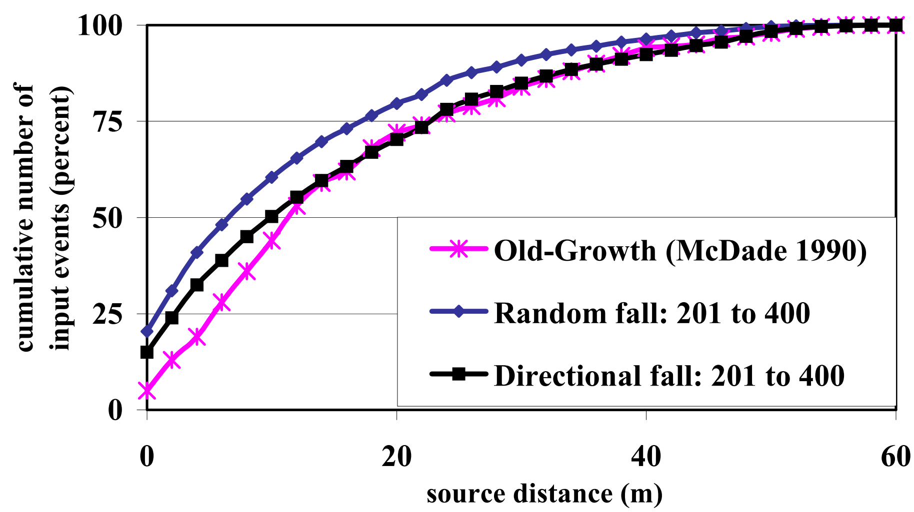

Figure 7—Comparison of source distance estimates for old-growth conifer, western Cascades, Oregon. Comparison of old-growth source distance curves from the two simulations and McDade and others (1990). Each simulated source distance curve includes only those input events from stand ages between 201 and 400 years. The directional fall source distance is consistent with the observed for source distances ≥ 14 m. This suggests that in the surveyed plots, trees ≥ 14 m from the stream bank tended to fall directly towards the channel, which is unlikely. The forest age-class of 201 to 400 years old may not be the appropriate age class for this comparison. Further information on stand ages of the surveyed plots is needed to construct an appropriate comparison.

For the old-growth age class between 201 and 400 years, source distances ≥ 14 m were almost identical to the field surveys and the directional fall simulation *(fig. 7, table 1).* This would suggest that trees of this age class tend to fall directly towards the channel, which is highly unlikely. However, the source distance curves appear to be sensitive to the definitions used for the forest age classes. Evidence for this can be found by comparing the simulation results *(fig. 2),* which includes all input events over the 1,000-year period, with the simulation results divided by forest age class *(figs. 6, 7).* Note that both the directional and random source curves have shifted down with respect to the mature and old-growth curves from McDade and others (1990).

The majority of input events identified in a field survey may be associated with the recent history of the forest stand. The close agreement with the mature conifer age class may be attributed in part to a well-defined forest age class. In contrast, the old-growth age classes used to classify the simulation results may not be equivalent to the old-growth stands surveyed by McDade and others (1990). Further information on stand age of surveyed sites would be necessary to define appropriate forest age class to use in this comparison.

Conclusion

Van Sickle and Gregory (1990) provided a mathematical proof that approximately one-third as many trees would enter the stream falling in any direction than falling directly across the channel. The results of this study were found to be consistent with this ratio. McDade and others (1990) found that 90 percent of the input events occurred within 26 m and 36 m from the stream bank for mature conifer and old-growth respectively. Over the entire 1,000-year simulation, 90 percent of the input events occur within 26 m and 31 m for the random and directional fall, respectively. A closer agreement between the two studies was found after accounting for stand age *(table 1).*

Large wood in streams is an important component in a stream ecosystem. One goal in managing riparian forests is to ensure the long-term supply of wood to the stream. The results from this study suggest that source distance varies with stand age. Based on a 1,000-year simulation, the largest source distance occurred with stand ages between 200 and 400 years old *(fig. 3).* These results may be useful in determining the appropriate riparian buffer width to ensure an adequate supply of wood to a stream. However, the recruitment of wood to streams is only one of many criteria that should be considered when developing management plans for riparian forests and the protection of the stream ecosystems.

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