Effect of harvests, road construction, and channel morphology on in stream wood – A statistical approach to predicting wood volume from network to segment scale

Peter A. Duin
Humboldt State University
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Abstract

Although a conceptual framework is well developed for understanding the processes that influence the abundance of large woody debris (LWD) in streams, which of these influences has greater impact on the presence or absence of LWD at specific locations throughout a river network is less understood. A statistical regression model that predicts LWD volume per 50-meter reach is constructed using 215 observations of 50-meter reaches gathered from 7 geographically separate locations in a Western Cascades Watershed. The model is used to investigate the effects of historical harvests, roads, and channel morphology on LWD at the network, half network, and segment scales. The model predictions of LWD volume are based on predictor variable estimates of width, slope, proximal area of historic harvest, proximal length of road, percent slope of surrounding hillslopes, and elevation. When applied at the network scale, results indicate that historic harvests and roads are negatively correlated with LWD. Upon dividing the network into upper and lower portions, the magnitude of the impact of harvests declines in the lower portion and the correlation switches signs, possibly a result of fluvial wood transport altering the legacy of that disturbance. The predictor variables used to form the regression equation are more suited to predict wood in the upper portions of the network than the lower, likely a result of the inability of the predictor variables to account for fluvial transport and accumulation potential of LWD in the higher order streams that develop toward the lower portion of the watershed. A positive correlation between the goodness of fit of the model and average elevation of a segment confirms its ability to better predict wood in the high locations in the network suggesting that the predictor variables are significant in supplying LWD to streams in locations and orientations that allow it to remain in place.

Introduction

Historically, large woody debris (LWD) has been removed from Pacific Northwest streams by logging practices, for increased navigability, and for general "stream cleaning" (Bisson et al., 1987). Since the late 1970's, the value of LWD in streams has become known and its important role in creating complex heterogeneous habitats has been acknowledged (Swanson and Lienkaemper, 1978). Increased channel complexity, hydraulic variability, sediment storage, pool scouring, and hydraulic roughness are amongst many ecological benefits provided by LWD (Montgomery and Buffington, 1997).

Many considerations are required to conceptualize the input and redistribution processes responsible for the presence of LWD throughout a river network. LWD sources, fluvial redistribution, and anthropogenic influences each play an important role on the presence or absence of LWD at a particular location. Snow avalanches, hillslope debris slides, windthrow, bank erosion, and earthflows are amongst many processes that contribute to the inputs of LWD into a stream (Swanson, 2003). Once wood has entered the channel, the potential for fluvial transport downstream begins to have influence, governed by a balance of the forces acting upon the wood (Cramer, 2012; Knudson and Fealko, 2014). Transport processes have been observed to have differing effects dependent on stream network location, commonly having a more notable effect at downstream locations due to increases in channel width and stream power (Dreher, 2004). In terms of anthropogenic influence, logging and road construction occurring in proximity to streams have been correlated with decreased volumes of LWD (Czarnomski et al., 2008). While LWD input and redistribution processes have been conceptualized, further investigation into the magnitude of various LWD influences as a function of location within the river network is needed.

Study area:

Lookout Creek Watershed is a small watershed consisting of 1st through 5th order streams located in the HJ Andrews Experimental Forest, 45 Miles east of Eugene, Oregon (Figure 1). The drainage area of the Lookout Creek Watershed is 62 km^2 and the mean annual precipitation in the region is 227 cm (USGS, 2012). The mean basin elevation is 985 meters, and the watershed is 97.5% forested with vegetative cover including: Douglas-fir, western hemlock, western red cedar, sword fern, dwarf Oregon grape, and vine maple (USDA, 2013). Prominent geologic makeup in the watershed includes: andesite, tuff, landslide deposits, and glacial and glaciofluvial deposits (Hull, 1988). Forest harvest began in the Lookout Creek Watershed in 1950’s and although it has left the watershed with approximately 30% of plantation, 40% of the watershed remains old growth forest (Andrews Forest, 2017). For the purpose of this research, 10.7 km of stream within the Lookout Creek Watershed was surveyed for general channel morphology and wood presence to investigate the potential impacts of forest harvests, road networks, and channel morphology on wood in geographically separate locations within the network.

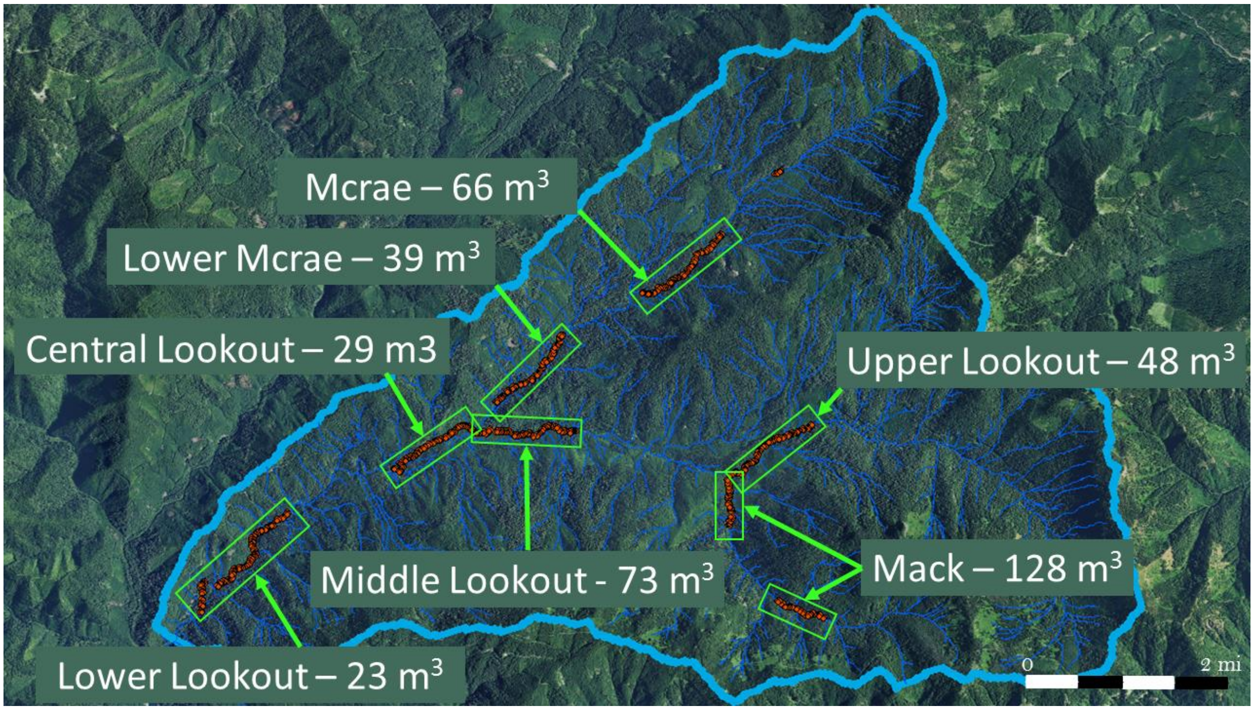

Figure 1 - Lookout Creek Watershed with seven sampling sites and their average wood volume per 50-meter segment.

Methods

Field Data Collection

Data were collected across seven segments of the Lookout Creek Watershed, each separated geographically and by geomorphic characteristics. The surveyed segments include Mcrae Creek, Lower Mcrae Creek, Mack Creek, Upper Lookout Creek, Middle Lookout Creek, Central Lookout Creek, and Lower Lookout Creek (Figure 1). Measurements were taken every 50-meters, measured using a meter tape and tracking the flow path of the channel. The data collected every 50-meters in each location includes active channel width, channel slope, LWD number and size, and channel unit. The procedures and definitions used to obtain these data are as follows:

Width - Active channel width was measured by meter tape. Width measurements included mid-channel bars and side channels when present.

Slope – Slope was measured in the thalweg of the main-stem channel using a clinometer and stadia rod. 50-meter distances were partitioned into two or three sections when visual obstructions were present.

Large Woody Debris – Length and diameter were visually estimated and placed into predetermined size classes. The entirety of pieces partially in the active channel were counted. Size classes used are consistent with standard procedures for LWD analysis (Dreher, 2004; Czarnomski et al., 2008; Wohl et al., 2010). LWD accumulations were defined by having at least three logs that meet the criteria inside the active channel connected by at least two points, and their occurrence was recorded separately than individual pieces. Individual pieces composing LWD accumulations elevated above the active channel were counted, as long as the piece was within the lateral boundaries of the active channel. In LWD accumulations with logs outside of the active channel, connected logs that are entirely laterally outside of the active channel were not counted.

Channel Unit – Channel unit was determined visually in accordance with long standing morphological categorizations (Montgomery and Buffington, 1997).

A cellular GPS was used in conjunction with the Avenza Maps application to record the GPS locations of the cross sections for measurement as well as the locations of LWD accumulations.

Analysis

Once data were collected and processed a statistical model was developed to predict the presence of LWD using multiple regression in R programming. The model was constructed using forward selection, with a basic multiple linear regression model of six predictor variables as a base (Table 1). Each variable was first assessed for normality by generating histograms of the data and inspecting their symmetry. The variables with the least normal distributions were transformed in order to more closely meet the assumption of normality in regression. Square root, common log, and natural log transformations were applied to all 215 survey points that composed our whole-network dataset. Once the model was constructed, it was tested for collinearity by calculating variance inflation factors in R and insuring they result in values less than two. The variables not measured in the field were collected from ArcMAP using shape files of harvests and roads as well as the 10-meter digital elevation model (DEM) (Table 1). A scatterplot of each data set revealed the polynomial nature of the surrounding hillslope input and as a result this variable was included using a second order polynomial term. The response variable considered in this analysis is wood volume per 50-meters. Wood data was converted to wood volume by assuming a cylindrical shape and using the mean values of each size class to represent all logs within that size range.

Table 1 - Response and predictor variables used in multiple regression analysis of LWD volume for the Lookout Creek Watershed, Western Cascades, Oregon.

Type	Symbol	Description	Source
Response	WV	Wood volume per 50m stretch	Field data
Predictor	W	Active channel width averaged at upstream and downstream boundaries of 50m stretch	Field data
Predictor	E	Elevation averaged at upstream and downstream boundaries of 50m stretch	HJA 10M DEM (ArcMAP 10.4.1)
Predictor	G	Channel gradient retrieved for 50m stretch	Field data
Predictor	S	Hillslope surrounding upstream boundary of x-section (average of four point intersections between 10m stream buffer and 15m x-section point buffer)	HJA 10M DEM (ArcMAP 10.4.1)
Predictor	H	Area of harvest in 100-meter radial buffer from upstream boundary	HJA Historic Harvest Units (ArcMAP 10.4.1)
Predictor	R	Length of road in 100-meter buffer from upstream boundary	HJA road network map (ArcMAP 10.4.1)

Once the model was refined, with an optimal R^2 value resulting from the improvements made by the transformations and polynomial fitting it was applied to data on two finer scales. First, the data for the entire network was divided into two portions, upstream and downstream. The upstream portion consisted of all data points for Mack, Mcrae, and Upper Lookout while the downstream portion consisted of Lower, Central, and Middle Lookout. The regression coefficients and statistics resulting from the two regressions were analyzed to determine how well the model fit each data set and what changes can be observed between the upstream and downstream sections. The scope of analysis was then magnified further to the individual segment scale, where trends and quality of fit were also assessed. The ability of the predictor variables included in the model to accurately simulate LWD abundance is used as an indicator of the role of those variables in the LWD input and redistribution processes at each location in the network. Finally, the regression equations were used to calculate simulated LWD volumes for each segment and plotted against observed LWD volumes in order to test their accuracy at various spatially and morphologically heterogeneous segments.

Results

The refined numerical model that best fit the data for all 7 segments and 215 observations taken across the basin is shown (Equation 1).

$$\sqrt{WV} = 2.57\ln(W) + 8.49\sqrt{G} + 0.0151\,E - 0.00588\,R - 0.000104\,H + 3.17\sqrt{S} + 9.98\,S - 10.5 \quad (1)$$

Assuming a significance level of 0.05, the regression parameters of Equation 1 indicate that all variables can be deemed statistically significant ($p < 5\%$) (Table 2). The R^2 value of 0.403 demonstrates that about 40% of the variance in the data can be described by the model. The collinearity test verified that none of the variables in the model were dependent on each other. The negative signs on the coefficients for the harvest and road variables indicates that there is a negative correlation with LWD volume and its proximity to these variables. All other variables were found to be positively correlated with LWD volume.

Table 2 - Regression parameters resulting from a multiple regression analysis performed on 215 observed data points collected from the Lookout Creek Watershed, Western Cascades, Oregon.

			Overall Model Fit Statistics			
Variable	**Coefficient Estimate**	**p-value**	**R^2**	**Adjusted R^2**	**p-value**	**F-stat**
(Intercept)	-1.05E+01	7.54E-05	0.403	0.382	2.2E-16	19.92
Harvest	-1.04E-04	2.42E-03				
Road	-5.88E-03	2.97E-02				
Ln(Width)	2.57E+00	9.10E-07				
Sqrt(Gradient)	8.49E+00	9.40E-02				
Elevation	1.51E-02	6.08E-05				
Sqrt(Slope)	3.17E+00	4.39E-01				
Sqrt(Slope)	9.98E+00	1.04E-02				

To further investigate the accuracy of the regression equation, Equation 1 was applied to data at the upper and lower portions of the network. The number of observations for the upper and lower portions of the network are 91 and 97, respectively. Wood in the upper section was much more accurately estimated than that of the lower section, with an R^2 in the upper section of 0.597, while that of the lower section was 0.209 (Tables 3 & 4). Furthermore, the low p-values, and high f-statistics of the upper portion of the network support that the correlation of the upper portion and model fit was more significant.

Table 3 - Regression parameters resulting from application of Equation 1 to data for three segments in the upper half of the network (Mack, Upper Mcrae, Upper Lookout).

Variable	Coefficient Estimate	p-value	Overall Model Fit Statistics: R^2	Adjusted R^2	p-value	F-stat
(Intercept)	-2.11E+01	2.03E-04	0.597	0.562	1.56E-13	16.94
Harvest	-1.08E-04	1.74E-02				
Road	-6.92E-03	2.87E-01				
Ln(Width)	3.45E+00	2.04E-05				
Sqrt(Gradient)	-3.62E-01	9.54E-01				
Elevation	2.93E-02	1.56E-04				
Sqrt(Slope)	1.13E+01	9.63E-03				
Sqrt(Slope)	2.55E-01	9.38E-01				

The significant change in R^2 values demonstrates a clear difference in the ability of the model to accurately predict LWD between these two portions of the network. It should also be noted that the upper portion maintained the negative coefficient signs on the road and harvest variables while the lower portion presented a change in sign for harvest (Table 4).

Table 4 – Regression parameters resulting from application of Equation 1 to data for three segments in the lower half of the network (Middle Lookout, Central Lookout, Lower Lookout).

Variable	Coefficient Estimate	p-value	Overall Model Fit Statistics: R^2	Adjusted R^2	p-value	F-stat
(Intercept)	-9.04E+00	1.31E-01	0.209	0.147	0.003	3.357
Harvest	9.96E-06	9.09E-01				
Road	-8.34E-03	4.71E-02				
Ln(Width)	2.11E+00	1.60E-02				
Sqrt(Gradient)	1.58E+01	1.08E-01				
Elevation	1.25E-02	2.25E-01				
Sqrt(Slope)	-1.43E+00	7.94E-01				
Sqrt(Slope)	1.89E+00	6.60E-01				

When Equation 1 was applied to each of the seven segments, segments with higher elevation yielded significantly better model fit than others (Figure 2). The R^2 value of each of the segments was plotted against its average elevation and it was revealed that the ability of the regression to predict wood in the channel decreases longitudinally downstream. A simple linear regression was performed on the R^2 vs elevation plots and a p-value of 0.042 indicates that there is a significant correlation between R^2 or goodness of fit of the model to each segment and the average elevation at that segment.

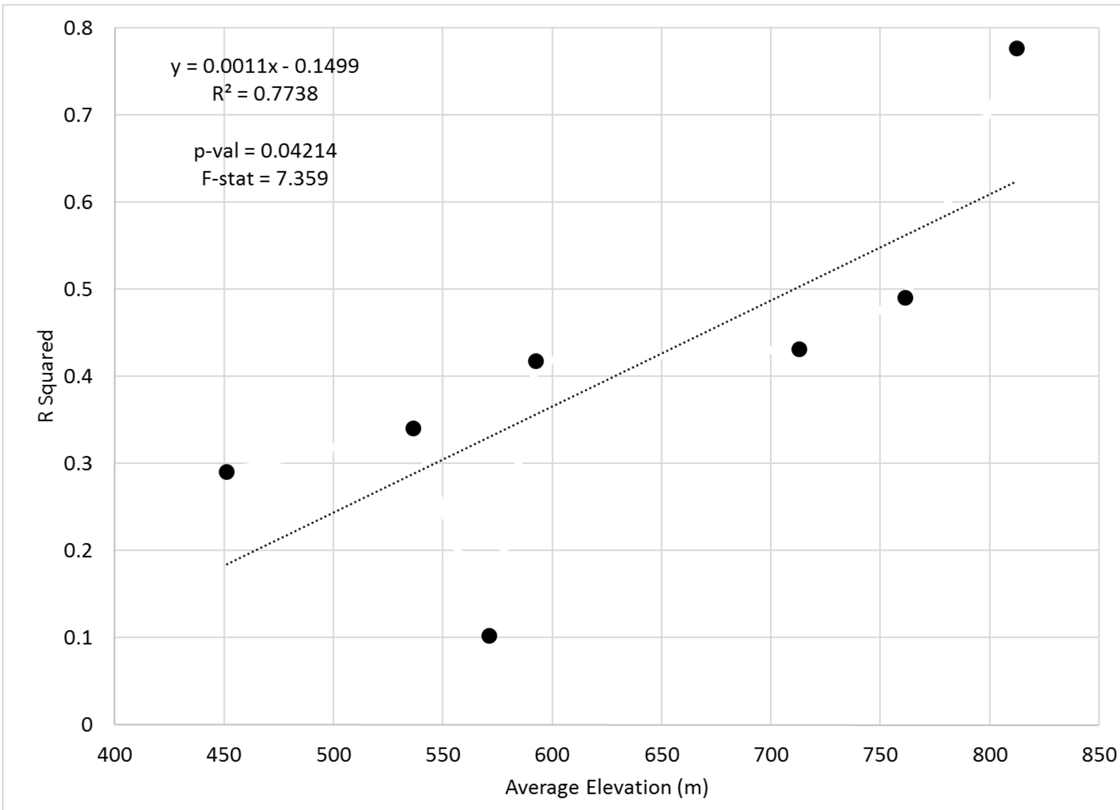

Figure 2- Simple linear regression performed on R^2 vs average elevation indicates that the ability of this model to predict LWD decreased longitudinally downstream throughout the network.

Average segment elevation was used to represent the location within the network, indicating that the ability of Equation 1 to predict LWD volume decreases as the order of the stream and distance downstream increase.

Testing the model

To further investigate the trend in declined model accuracy as a function of distance downstream, the observed LWD volumes (observed) were plotted against those estimated by the regression (simulated). Two plots are shown for Lower Lookout Creek and Mack Creek, representative of the lowest elevated segment (Figure 3) and the highest elevated segment (Figure 4) in the network, respectively.

The simulated values for Lower Lookout Creek were generally similar to the observed except for the prominent outliers exhibiting $60m^3$ or more of LWD volume. These outliers are aligned with recorded locations of LWD accumulations throughout the segment and were not accurately predicted by the model equation.

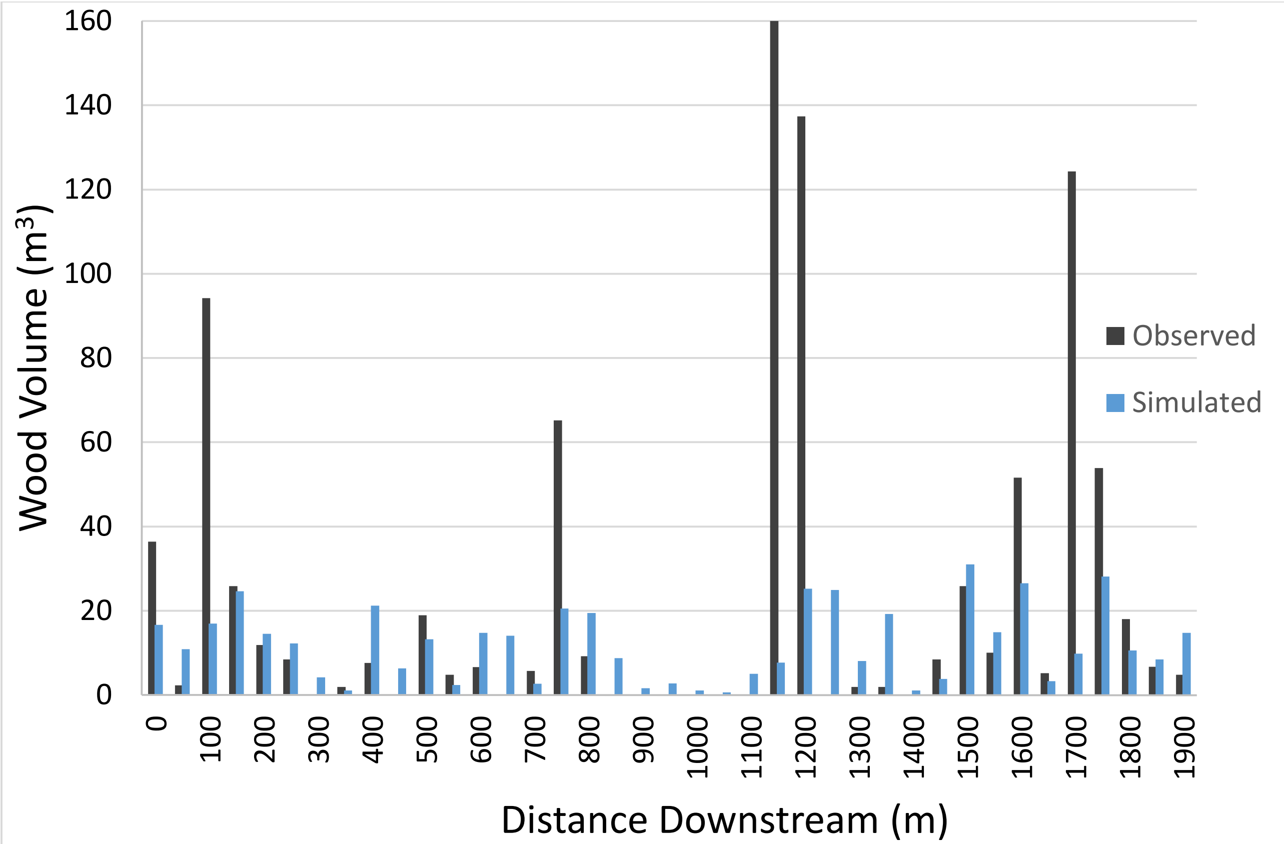

Figure 3- Simulated vs observed LWD volumes in the lowest point of the network, Lower Lookout Creek. Large spikes in observed LWD volume represent locations of accumulations.

The model was able to track wood volume much more closely in Mack Creek. Toward the lower end of the Mack Creek segment, where the LWD volume decreased drastically, the simulation was able to adjust its estimates according to its inputs and continue to accurately predict LWD volumes despite the change.

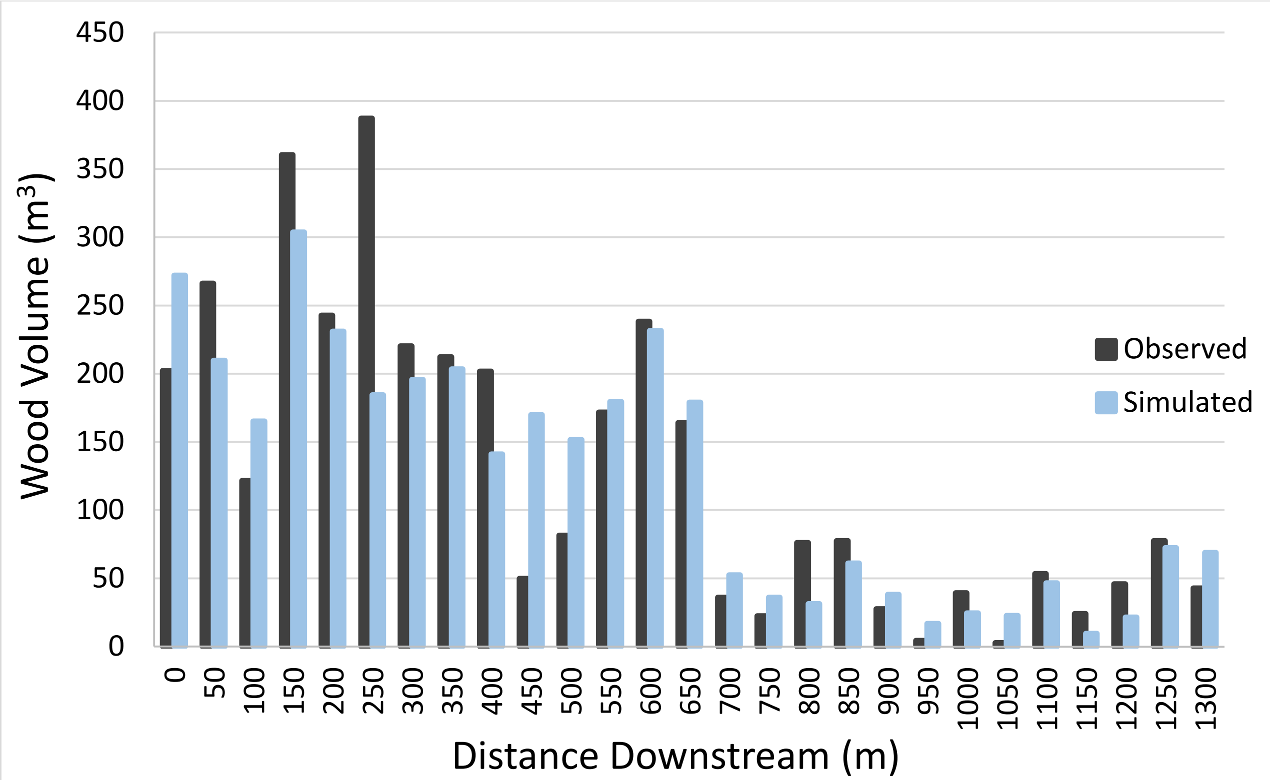

Figure 4 - Simulated vs observed LWD volumes in Mack Creek, Lookout Creek Watershed, Oregon. The model closely simulated volumes based on the six input parameters provided.

Discussion:

The results indicate that location in the network impacted the ability to predict LWD volume based on the model inputs, suggesting that dominant influences vary throughout the network. Higher elevated segments contained higher LWD volumes on average, a finding consistent with the work of others (Czarnomski et al., 2008; Dreher, 2004; Mealson et al., 2003). The higher elevated segments often have steeper side slopes, less drainage area, and less accessibility, each factors that are a potential cause for their high LWD volumes. The sign of the coefficient for harvest changed from negative to positive between the upper and lower portions of the network. Given the decline in model accuracy in the lower portion and the whole network and upper network models having a negative harvest coefficient, there is indication that these results support a growing body of evidence suggesting that in general roads and harvests have potential to decrease LWD volume (Czarnomski et al., 2008). The higher transport capacity of the lower streams is a possible explanation for the change in harvest sign, as wood may have been deposited near harvests from locations upstream. The surrounding hillslopes and elevation were positively correllated with instream wood, which suggests these variables are related to processes that supply LWD to streams such as hillslope debris slides and avalanches. Similar results consistent with these findings exist in previously developed conceptual models of LWD inputs (Swanson F.J., 2003). A stochastic model for predicting in-stream wood constructed and calibrated using long term LWD surveys in Mack Creek suggests that although in-stream wood movement affects small sized wood in Mack Creek, overall, transport has little affect on the in-stream wood volume (Mealson et al., 2003). This further supports that variables included in this model are related to wood inputs and not transport because of the models ability to more accurately predict wood in Mack Creek where transport is less prominent.

This study broadens the scope for the interaction between the supply, transport, and accumulation of LWD throughout the Lookout Creek Watershed by assessing the accuracy of the model on a variety of scales. Due to a lack of spatially varied data, many studies are focused on a specific segment of a watershed when predicting wood and identifying its controlling factors, but this study suggests that bias can be introduced to LWD volume analyses by limited scope. Modelling LWD volume in higher locations of the watershed can be done with relatively high accuracy and the input variables necessary to do so are included in this model. On the other hand, predicting LWD volume in the lower portions of a watershed requires consideration of more complex processes such as fluvial transport and accumulation potential. Variables that might improve the ability of the model to predict wood in the lower network include flow depth, channel sinuosity, area of floodplain, and channel debris roughness, all variables related to the potential of wood to transport or accumulate (Braudrick and Grant, 2001).

Providing a quantifiable measure of processes controlling LWD change throughout the river network has potential to improve understanding of how anthropogenic impacts are propagated through a river network for use in forest management guidance. Roads can be constructed at a specified distance from streams to allow for a riparian buffer zone as has been a regulation implemented on harvest practices. The introduction of a riparian buffer for harvests has contributed significantly to preservation of in-stream habitat (Richardson et al., 2012) and this study suggests that LWD volumes can be increased if similar regulations are implemented for road networks. When realizing that the upstream locations in the network are a driving source of LWD input, those locations can be preserved in order to ensure a sufficient supply of LWD in the network for support of a diverse and heterogeneous riverine and riparian habitat. If the goal of management is to increase or maintain LWD inputs to the entire network, and if it is true that locations with steeper side slopes increase LWD inputs as shown by their positive correlation, then there is potentially an optimal region in the network where LWD input is high due to steep hillslopes but also the stream is wide enough and with enough stream power that it can transport wood from this location to be distributed throughout the network. Upstream of this optimal location, wood inputted to the stream remains in place and is not distributed throughout the system due to narrow widths and minimal stream power, and downstream of this optimal location less steep hillslopes are less productive in terms of LWD input to the stream. From this analysis, it is proposed that the confluence of two 3rd order streams is a location of high volume wood input to the stream and the widening of the stream due to the confluence provides enough power to distribute the inputted wood throughout the system. The confluence between Upper Lookout Creek and Mack Creek for example, is likely a highly productive zone for LWD input, and may be the reason that a high amount of LWD accumulations were observed just downstream in the Middle Lookout location. This implies that in Middle Lookout (just below the confluence of two 3rd order streams) there is enough stream power for high volumes of LWD input to be transported and accumulated. Therefore, old growth forests near the Upper Lookout and Mack Creek confluence is encouraged to be preserved and roads should maintain distance from the stream near this location. Stream crossings in these locations or just below are discouraged for their potential to block wood redistribution, or be negatively impacted by wood moving through the system.

Field measurements, as well as digital estimates are main sources of uncertainty in the model. Each of these measurements has some degree of uncertainty associated with them, so it is suggested that this study be repeated with different data in order to confirm and support the hypothesis listed.

Conclusion

The influence of six predictor variables on LWD volume was investigated at various locations throughout the Lookout Creek Watershed. The location in the network had an apparent influence on LWD volume mostly due to the influence of fluvial transport and accumulation in lower portions. The key findings of this study are:

- Greater LWD volumes exist in the higher elevated locations of the network.
- Harvests and roads have a negative correlation with LWD volume.
- Elevation and surrounding hillslope steepness have positive correlation with LWD volume.
- Considering the input variables used in this regression (mostly related to LWD sources) LWD volumes were much more accurately predicted at higher locations in the network.
- Prediction of LWD volume in the lower locations within the network requires consideration of fluvial transport and accumulation potential for more accurate results.

These findings provide insight to the challenges of modeling LWD volume across an entire network and the potential biases of predicting LWD volume in small segments within the network. Further work is needed in establishing a set of input variables that attempt to predict fluvial transport capacity and accumulation potential for the lower sections of the network to be more accurately predicted. Consideration should be given to areas surrounding the confluence of two third order streams by management. Characteristics of these areas suggest high potential to be more productive as LWD input zones, including their relatively steep hillslopes and sudden expansions in stream width and transport capacity. Also, implementation of riparian buffer regulations for roads in proximity to the stream should be considered. The importance of LWD in stream has become apparent in recent years, so preservation of input locations and existing LWD is essential in maintaining a heterogeneous and diverse aquatic habitat throughout the watershed.

Citations

"About the Andrews Forest." (2017). H.J. Andrews Experimental Forest - Oregon State University, https://andrewsforest.oregonstate.edu/about.

Bisson P.A., Bilby R.E., Bryant M.D., Dolloff A.C., Grette G.B., House R.A., Murphy M.L., Koski V.K., Sedell J.R. (1987). "Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future."

Braudrick C. A., Grant G. E. (2001). "Transport and deposition of large woody debris in streams: a flume experiment." Geomorphology 41, p. 263-283.

Cramer, M.L. (2012). "Stream Habitat Restoration Guidelines." Washington Departments of Fish and Wildlife. http://wdfw.wa.gov/publications/01374/wdfw01374.pdf.

Czarnomski, N. M., Dreher, D. M., Snyder, K. U., Jones, J. A., and Swanson, F. J. (2008). "Dynamics of wood in stream networks of the western Cascades Range, Oregon." NRC Research Press.

Dreher D.M. (2004). "Effects of input and redistribution processes on in-stream wood abundance and arrangement in Lookout Creek, western Cascade Range, Oregon." "Master's Thesis."

Hull, D. A. (1988). "Geologic map of the McKenzie Bridge quadrangle, Lane County, Oregon." Oregon State Employee Information Center, Department of Geology and Mineral Industries, http://digital.osl.state.or.us/islandora/object/osl:231.

Knudson, M., Fealko, J. (2014). Pacific Northwest Region Resource & Technical Services Large Woody Material Risk Based Design Guidelines. Managing water in the West. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region. Boise, Idaho.

Mealson, M.A., Gregory, S.V., Bolte, J.P., (2003). "Implications of Riparian Management Strategies on Wood in Streams of the Pacific Northwest." Ecological Society of America. 13(5) p. 1212–1221.

Montgomery D.R., Buffington J.M., (1997). "Channel-reach morphology in mountain drainage basins." Geological Society of America Bulletin v. 109, no 5, p. 596-611.

Richardson J.S., Naiman R.J., Bisson P.A., (2012). "How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices?" The society for Freshwater Science.

Swanson, F.J. (2003). Wood in rivers: A landscape perspective. American Fisheries Society Symposium. 2003. 299-313.

Swanson F.J., Lienkaemper G.W. (1978). "Physical Consequences of Large Organic Debris in Pacific Northwest Streams." United States Department of Agriculture.

United States Department of Agriculture (USDA), (2013). Web Soil Survey. http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

United States Geological Survey (USGS), (2012). Stream Stats. https://water.usgs.gov/osw/streamstats/.

Wohl E., Cenderelli D.A., Dwire K.A., Ryan-Burkett A.E., Young M.K., Fausch K.D. (2010). "Large in-stream wood studies: a call for common metrics." Earth Surface Processes and Landforms. p. 618-625.