TEMPORAL DYNAMICS OF LARGE WOODY DEBRIS IN THE FOOTHILLS OF ALBERTA

- FINAL REPORT -



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FOR
FOOTHILLS RESEARCH INSTITUTE,
HINTON WOOD PRODUCTS, AND
ALBERTA NEWSPRINT COMPANY

TREE RING LAB at UBC

JANUARY, 2011

EXECUTIVE SUMMARY

Logs in streams, called "large woody debris" (LWD), influence the physical structure and ecological function of small, headwater streams. Our research investigated the ecological links between natural disturbances in riparian forests and temporal changes LWD, including the processes of log recruitment, persistence, decay, and transport in streams. We used multiple lines of evidence to investigate lodgepole pine- and spruce-dominated forests surrounding streams in the Rocky Mountain foothills of western Alberta. Field surveys determined the abundance, quality and function of logs in 56 streams of different sizes that had been burned by fires at different times in the past (<5, 50, 100, >150 years). A combination of data from permanent sample plots and tree-ring analysis of living and dead trees allowed us to reconstruct forest histories and LWD dynamics.

Our research revealed several new discoveries about in-stream LWD:

(1) Dead trees persist decades to centuries in the streams and forests of Alberta's foothills.
The "oldest" LWD in streams died 155 years ago, but could still be sampled and dated using tree ring analyses. Depletion curves indicated a half-life of 47 or 48 years for LWD.

(2) Recruitment from forest to stream of LWD is strongly influenced by natural disturbance.
Fires generate a pulse of dead wood that persists at least 50 years. In mature forests, LWD recruitment is relatively continuous due to competition and within-forest disturbances.

(3) LWD position relates to decay and determines log function in the stream. LWD change with time so that the least-decayed logs usually form long bridges suspended above the stream. LWD length and volume decrease with decay, making logs less stable. Highly-decayed LWD directly contact the stream and contribute to bank stability, sediment retention, debris jams and riffle and pool formations.

(4) LWD is stable in headwater streams with transport initiated in streams wider than 3.5m.
In general, log size decreased, decay increased, fewer logs originated from the adjacent forests, and more logs were loose and less associated with stream banks.

Improved understanding of the ecological links between forests and streams and the longevity and function of LWD has important implications for sustainable forest management practiced by our industrial partners, Hinton Wood Products and the Alberta Newsprint Company. Specifically, our findings: (1) emphasize the importance of natural disturbances in riparian forests as a key driver of in-stream LWD dynamics, (2) illustrate that fire and harvesting impact LWD dynamics differently, providing opportunities for innovative silviculture, (3) confirm the value of buffer zones surrounding streams, particularly as a source for LWD recruitment in harvested and burned landscapes, and (4) provide ecosystem-specific baseline data to ensure long-term success of forest management and stream restoration through action and monitoring. We continue to work with the Foothills Research Institute to develop tools to integrate this new knowledge into forest management practices and policy.

Sustainable management of renewable resources is a critical component of the Canadian economy. In forestry, sustainability is most likely to be achieved by basing management on local, ecological knowledge and by using natural processes to guide practices. By improving knowledge of riparian forest and LWD dynamics, our research has enhanced decision-making and empowered our partners to employ scientifically-based adaptive management. In doing so, our partners are better able to demonstrate sustainability and corporate citizenry, maintain a competitive advantage by achieving certification standards, and increase local-to-international market acceptability of forest products from Alberta and Canada.

INTRODUCTION

Large woody debris (LWD) significantly influences the structure and function of small headwater streams. LWD is a key link between riparian forests and streams; however, the temporal dynamics of in-stream wood remains poorly quantified. The primary objective of our research was to quantify links between natural disturbances of riparian forests and the temporal dynamics of LWD, including rates of recruitment and decay. Supporting objectives were to compare wood decay in upland and riparian forests, test for effects of wood position on decay processes, and improve the accuracy of age estimates of LWD.

This report presents our original research hypotheses and objectives and summarizes the major findings for each component, plus additional research on watershed-scale LWD dynamics and tree mortality rates.

RESEARCH HYPOTHESES (STATED AS PREDICTIONS) AND SPECIFIC OBJECTIVES:

H1. Recruitment of LWD is a function of disturbance and stand development. After stand-level disturbance, LWD input is episodic, whereas stand development processes, such as self-thinning in young forests or gap-phase dynamics in old forests, result in chronic input of LWD. Regardless of the type of input, LWD persists several decades in the stream.

(a) Determine the year of death of LWD in streams and calculate the proportional amount of LWD contributed episodically *versus* chronically.
(b) Determine the tenure of LWD in streams using a chronosequence of study sites burned at different times over the past 150 years.

H2. Accuracy of dendroecological estimates of year of death of trees and age of woody debris decreases with stage of decay. The relation is non-linear and estimates are least accurate for highly decayed samples.

(a) Develop a regression model to quantify how species, size and type (snags, wind-thrown and broken boles) of decaying wood affect the rate of ring loss.

H3. Decay rates of LWD in riparian areas are slower than those of upland coarsewood. Rate of decay depends on species, size, and position relative to the stream.

(a) Develop predictive maximum likelihood/regression models of decay based on time since death and size of riparian LWD versus terrestrial coarsewood.
(b) Determine how LWD position relative to the stream affects decay rates.

STUDY AREA AND RESEARCH APPROACH

We have assessed the abundance and dynamics of snags and logs at 56 sites in the Alberta Foothills, 46 sites in the Foothills Research Institute landbase surrounding Hinton, AB and 10 sites burned by the 2001 Dogrib fire near Sundre, AB. Using a combination of permanent sample plot (PSP) data, field surveys, and dendrochronological reconstructions, we determined residence times and rates of decay of in-stream LWD, terrestrial logs and snags. Included are analyses of riparian forest dynamics and in-stream LWD at 18 headwater streams arranged along a chronosequence from <5 years to >200 years since the last stand-replacing fire (Jones and Daniels 2008, Powell et al. 2009, Bataineh et al. in preparation), additional 14 reaches along a longitudinal profile of the Wigwam watershed (Nicoll 2011), and 10 upland forest sites (Jones 2009, Jones and Daniels submitted).

RESULTS AND DISCUSSION

I. LWD ABUNDANCE AND FUNCTION IN HEADWATER STREAMS (H1 AND H3B)

We quantified LWD abundance and tested for associations among decay, position, orientation, and function classes in 21 headwater streams near Hinton, Alberta, Canada (Jones et al. 2009). For the 21 sampled steams, bankfull width averaged 2.01±0.2 m (mean ± standard error) and stream area averaged 102.4±9.4 m^2. We sampled a total of 684 LWD, including 189 lodgepole pine, 130 black and white spruce, 27 subalpine fir, and 15 alder; species could not be determined for 323 pieces. For all species, frequency averaged 64.0±3.3 individual LWD per 100 m of active stream channel. The total LWD volume was highly variable and averaged 0.111 ± 0.011 $m^3\ m^{-1}$ of stream length, while in-stream LWD volume averaged 0.020±0.002 $m^3\ m^{-2}$ of stream area.

To compare LWD abundance in the Alberta foothills to other streams, we identified 24 studies in the peer-reviewed literature that report on 126 small, headwater streams in four forest types; however, directly comparing studies was difficult because the criteria for LWD vary (Jones et al. 2009, Ewan 2010). Once size criteria were taken into account, LWD appeared to be more frequent in headwater streams of the Alberta foothills than in other mountain, coastal, and mixed broadleaf streams, and it was twice as frequent as the LWD in boreal streams.

Within the Alberta foothills, stream-level LWD frequency, total volume, and total in-stream volume varied significantly by decay, position, and orientation class (Jones et al. 2009). Individual LWD morphology also changed significantly as logs decayed and transitioned to different position and orientation classes. Concurrently, the associations among LWD decay, position, orientation, and function were strong and significant. Given the limited transport capacity of our study streams, most LWD was decaying *in situ*, providing the opportunity to assess wood decay dynamics. We have integrated our findings in a conceptual model of LWD dynamics that includes multiple pathways in which logs are recruited and contribute to stream function through time (Figure 1). Key processes of the model are (a) recruitment of living trees and snags in various decay stages, (b) LWD transition into advanced decay classes, and (c) LWD function after it contacts the stream channel.

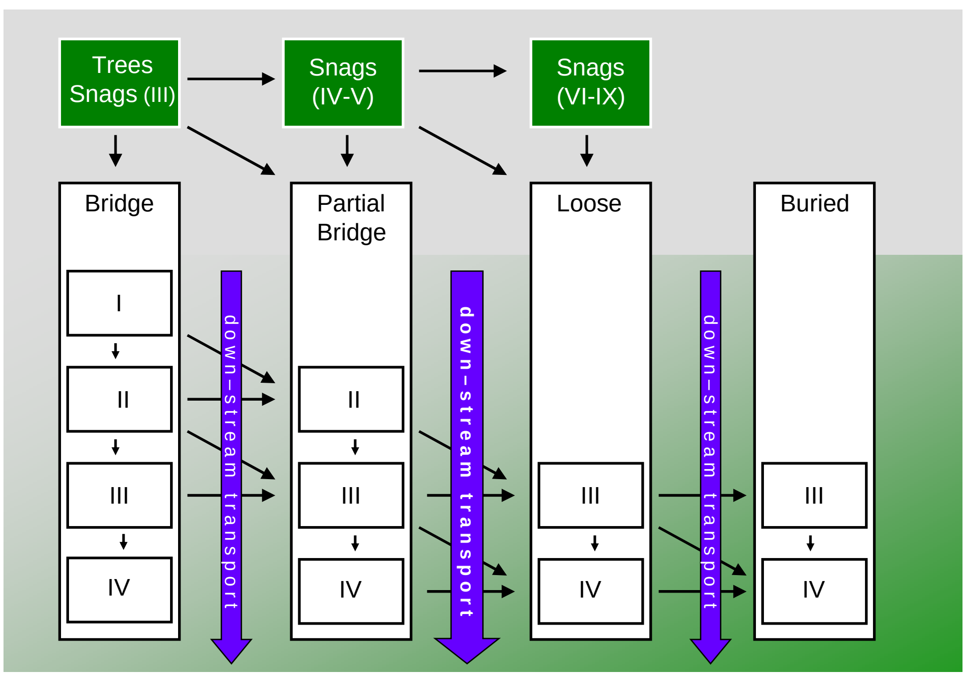

Figure 1. Conceptual model depicting multiple pathways through which large woody debris (LWD) most frequently recruits, decays, and interacts with the channel to influence stream function. Boxes depict decay classes for trees (I-II) and snags (III-VII) (top) and log (I-IV) (bottom) decay classes nested within position classes (bridge, partial bridge, loose and buried). Black arrows indicate changes in decay and position classes through time. Blue arrows indicate the risk of down-stream transport, which is greatest for loose LWD. Shading indicates the function of LWD; grey (top left) indicates no function and dark green (bottom right) indicates multiple functions per individual LWD.

Most living trees that fall and become LWD enter decay class I in the bridge position with the log spanning the stream channel. Falling snags can become bridges, partial bridges, or loose LWD. The decay stage of a snag depends on time since tree death and determines whether the resulting LWD is in decay classes I, II or III. A small proportion of bridged LWD transitions into advanced decay classes without breaking. Since these logs remain suspended above the channel, they contribute little to geomorphic function except to stabilize banks as they accumulate soil. More often, bridged LWD transition into decay classes III and IV and break, creating partial bridges and loose LWD. As the logs break, LWD length, volume, and stability decrease. When LWD contacts the stream channel and sinks, it directly influences geomorphic functions by affecting water flow, sediment movement, and channel morphology. Larger LWD that is diagonal or perpendicular to stream flow accumulates sediment upstream, burying the wood and slowing biological decay and mechanical erosion. In contrast, loose LWD is generally small, unstable, and parallel to stream flow, making them susceptible to downstream transport during peak flows.

This conceptual model provides a framework for understanding LWD distribution and dynamics at the stream reach scale. Using the results from subsequent components of this research, we are developing a model to explore management and restoration scenarios and options (Daniels et al. in prep.)

II. RESIDENCE TIMES AND DECAY OF LWD (HYPOTHESES 3A,B)

Using dendrochronology, Powell et al. (2009) successfully crossdated 113 pine and 73 spruce LWD from mature headwater streams to determine year of death and time since death. Time since death of LWD ranged from 2 to 143 years, with a maximum of 86 years for pine and 143 years for spruce. It increased significantly with increasing decay class and among position classes (Figure 2a, b). LWD in decay classes I and II died more recently those in decay classes III and IV, while those that were bridges and partial bridges died more recently than those that were loose and buried. Based on difference in mean time since death between adjacent decay and position classes, LWD was in each of decay classes I to III for about 20 years. LWD remained in the bridge position for about 30 years, but in the partial bridge and loose positions for only about 15 years. LWD in decay class IV and that in the buried position persisted up to 80 years and remained sufficiently sound to be crossdated. The depletion curve of pine was significantly

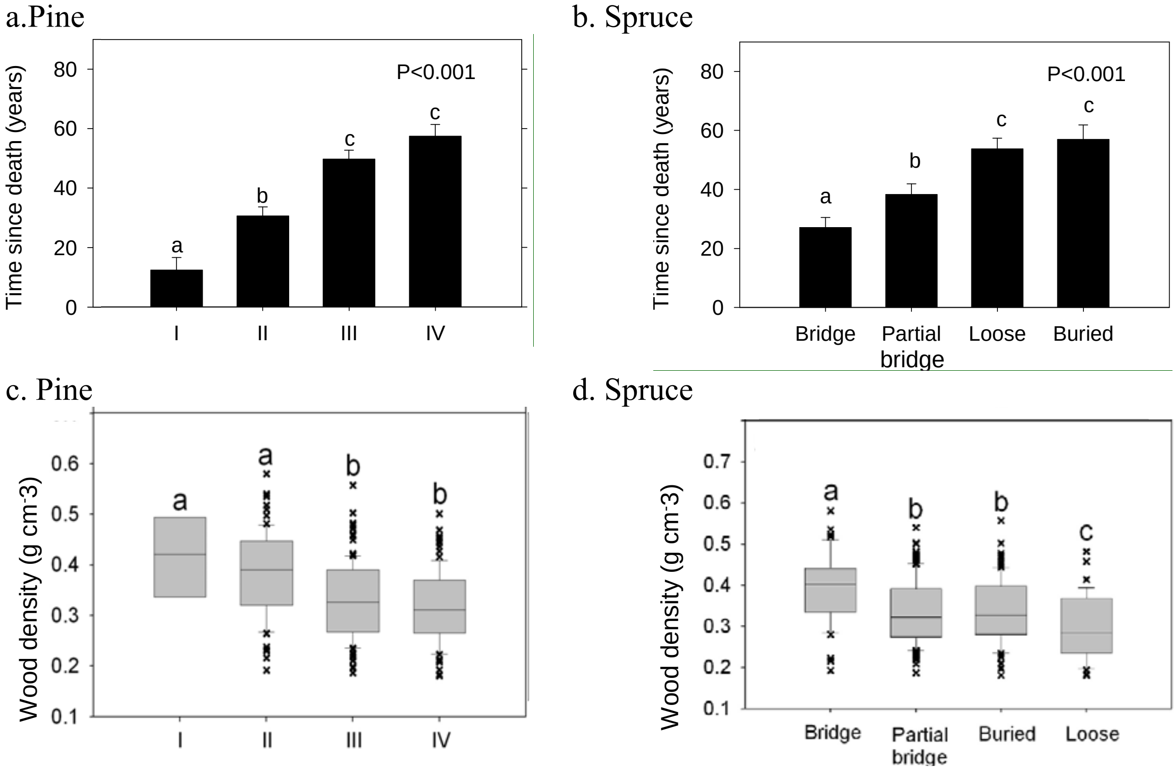

Figure 2. Comparison of large wood debris decay classes (a,c) and positions (b,d). For time since death (a, b), bars are means with standard errors. For wood density (c.d), the box plots show the median (horizontal line), 25th and 75 percentiles (boxes), 90th and 10th percentiles (lines), and outliers (crosses). Within each panel, bars and box plots with the same letter are not significantly different (α =0.05).

different from spruce. Initially, depletion rates were similar, with half (50%) of the LWD depleted in 47 years for pine and 48 years for spruce, but diverged for LWD that had been dead >50 years.

Subsequent research combined dendrochronological estimates of time since death with wood density measurements to compare 426 pine and spruce LWD in different decay and position classes (Henderson 2009, Henderson et al. in prep.). Corroborating our previous work, both pine and spruce showed a significant trend of increasing time since death along a decay class gradient from least decayed (decay class I) to most decayed (decay class IV) and from bridged, to partially bridged, to buried, to loose positions. Similarly, wood density decreased significantly along these decay and position gradients for pine and spruce (Figure 2c, d). Despite these general trends, Henderson (2009) concluded that the high variability in times since death and wood density among decay and position classes illustrated the non-linear nature of wood decay in streams.

Our comparative research on terrestrial coarsewood included two components to test the hypothesis that decay rates of in-stream LWD are slower than those of coarsewood in upland and riparian forests. Jones (2009; Jones and Daniels in prep.) assessed the decay dynamics of 322 snags and 405 logs in mature upland pine- and spruce-dominated forests. Mean densities were 403 snags/ha and 506 logs/ha. Like the LWD, coarsewood persisted for many decades after death and estimated time since death of the oldest snag and log was 180 and 175 years, respectively. Snags and logs in intermediate decay classes were the most common. Time since death varied significantly across decay class, but the range of YOD dates in each decay class was so broad that decay class was not a reliable indicator of approximate time since death. Contrary to our hypothesis, upland log depletion rates were comparable to those of LWD (Powell et al. 2009, Jones and Daniels 2008), with 50% of the spruce and pine logs depleted in 46 and 54 years, respectively (Figure 3a). Interestingly, depletion rates were greater for snags (47 and 36 years for spruce and pine snags, respectively) likely because most snags decompose to decay class 4 or 5, rot at the base and fall over, rather than decaying *in situ* (Jones 2009). In direct contrast with our original hypothesis, depletion rates were fastest for spruce logs in the riparian forest with 50% depleted in 37 years resulting in a half-life that was 9 years shorter than LWD or upland logs (Figure 3b, Amerongen-Maddison 2010, Bataineh et al. in prep.). Differences in depletion rates likely reflect subtle, but relevant, differences in site temperature and moisture regimes which affect fungi and microbial decomposition, as well as wood moisture and oxygen availability.

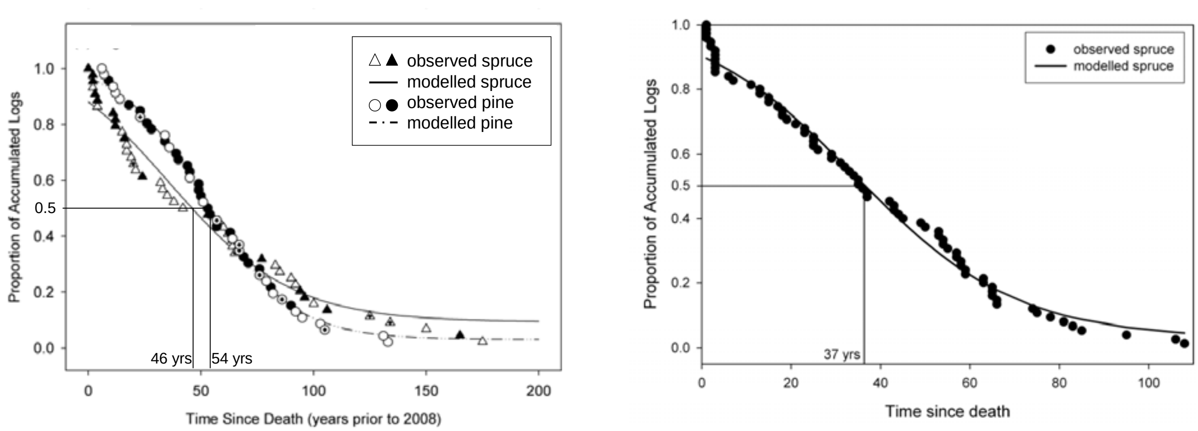

Figure 3. Depletion curves for terrestial logs in upland forests (left) and riparian forests (right), illustrating half-life values.

III. RIPARIAN STAND DYNAMICS AND LWD (HYPOTHESES 1A,B)

a. Old Pine- and Spruce-Dominated Riparian Forests

Our initial research on forest history and LWD dynamics showed that the disturbance history of riparian forests strongly influences LWD recruitment into streams (Powell et al. 2009). At the mature spruce-dominated sites, the riparian forests were in the old-growth stage of stand development in which the trees are uneven aged and mortality of canopy trees is due to fine-scale disturbances (Figure 4a). The ring widths of most trees indicated slow initial growth rates suggesting the trees established beneath an existing canopy. The LWD was primarily spruce, with some pine, and had recruited during all decades since 1866.

At sites dominated by mature pine, LWD recruitment was influenced by stand development processes following stand-replacing disturbances in the late 19th century (Figure 4b). The even-aged structure and fast initial growth rates of the dominant canopy trees indicated these riparian forests initiated following stand-replacing fires. Inter-tree competition due to crown closure occurred when these stands were about 40 years old. The oldest datable pieces of LWD were generated at that time, consistent with accumulation of snags and logs in sub-boreal and boreal spruce forests about 40 to 50 years after fire. Tree death and LWD recruitment continued to the time of sampling and were likely caused by both self-thinning of the even-aged stands as they matured, as well as within-stand disturbances.

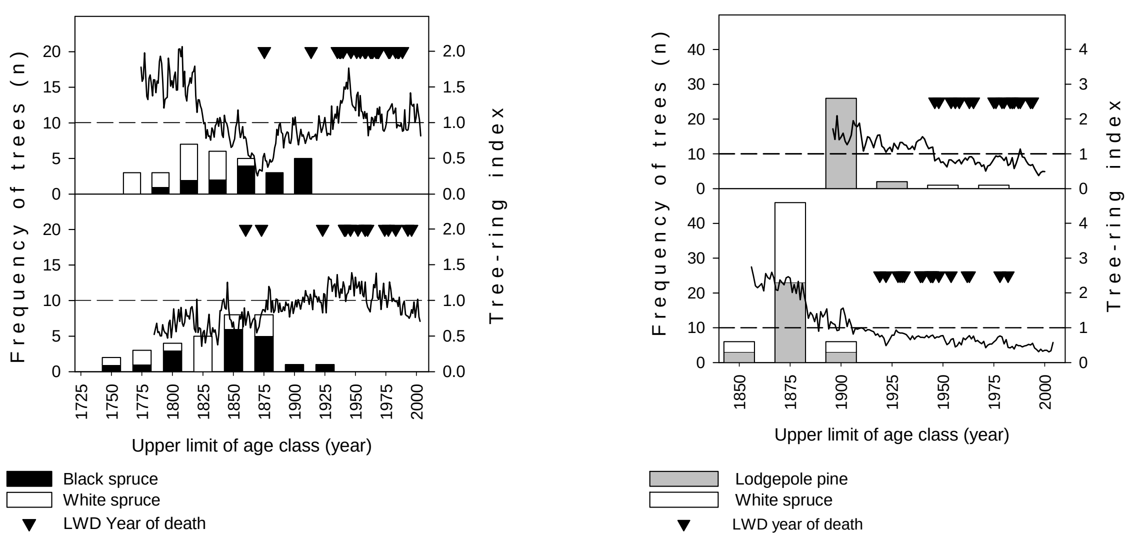

Figure 4. Examples of riparian forest dynamics and year of death of large woody debris (LWD) at spruce- (left) and pine-dominated (right) sites. Bars represent the age structure of canopy dominant trees. Solid lines chronologies standardized to depict trends in tree growth and dashed lines indicate a tree-ring index value of 1.0. Triangles indicate years of death of LWD in streams.

We had expected to find that some LWD at the pine sites had originated before or during the last stand-replacing fire. The lack of old (time since death > 85 years) pine LWD at our study sites could be due to limitations of our research and sampling designs or due to LWD depletion. Since we used a stratified-random sampling design, the oldest LWD could have been missed by chance or it may have been too decayed to crossdate. Alternately, the pine LWD may have been depleted due to decay, transport and burial in sediments. Two subsequent studies were designed to quantify wood dynamics following fires.

b. Initial Post-fire LWD Dynamics

To determine the short-term impacts of fire on LWD abundance and dynamics, we reconstructed LWD dynamics in five headwater streams burned by the 2001 Dogrib fire near Sundre, AB (Jones and Daniels 2008). The density, morphology, decay, position and function of in-stream wood were comparable to that reported by Jones et al. (2010) and Powell et al. (2009).

Using dendroecological methods, we estimated the year of death of 108 of 115 spruce logs. LWD resulted from tree deaths that occurred between 1874 and 2001, so that time since death ranged from 5 to 132 years. The majority of LWD was a legacy of pre-fire forest dynamics and had a similar time since death distribution as the spruce LWD documented by Powell et al. (2009). The depletion rate of this old LWD were exponential, such that 50% of LWD would be lost to decay, erosion or down-stream transport within 30 years of tree death and <12% of LWD would persist more than 100 years. Superimposed on the relatively continuous recruitment of LWD prior to 2001, was a clear episode of recruitment. After fire, 16.5% of the LWD recruited between 2001 and 2006, most of which were bridges or partial bridges in decay class II.

c. Chronosequence of Post-fire LWD Dynamics

In addition to the Dogrib sites, our chronosequence study included 13 new fixed-area permanent sample plots in post-fire riparian forests that were 50-years old (n = 3 pine and n = 3 spruce at sites that burned in 1957), 100 years old (n = 3 pine) and >150 years old (n = 4 spruce) (Bataineh et al. in prep). Live trees (3539), snags (480), terrestrial downed woody debris (DWD; 810), and in-stream LWD (629) were measured and identified. Increment cores and cross sections were used to determine age or year of death for 520 live trees, 353 snags, 345 DWD, and 347 LWD. As expected, tree densities were greater in the young forests but basal areas were lower than in the mature/old forests. We had expected less LWD in the streams surrounded by young forests but the frequencies and distributions of among decay classes were similar. At the young pine and spruce forest sites, the diameters of most LWD exceeded those of the surrounding living trees (Figure 5). Crossdated time since death dates ranged from 1854 to 2006, with a strong modal class during the 1950 caused by the fire and few LWD recruits since then (Figure 6). LWD with years of death preceding the fire was in decay classes 3 and 4; more recently recruited LWD was in decay classes 1 and 2. We conclude that most LWD in streams surrounded by young forests was a persistent legacy of the pre-fire forest. A comparison of LWD in streams surrounded by 50-, 100- and >150-year old forests suggests that, between 50 and 100 years after fire, much of that LWD will decompose to the point it cannot be crossdated or be depleted from the system by decay, transport and burial in sediments. In mature and old forests, the range of diameters of LWD corresponds to those of the surrounding living trees and snags. Although some LWD is high decayed and persistent, most is the result of recent within-stand processes such as self-thinning and disturbance.

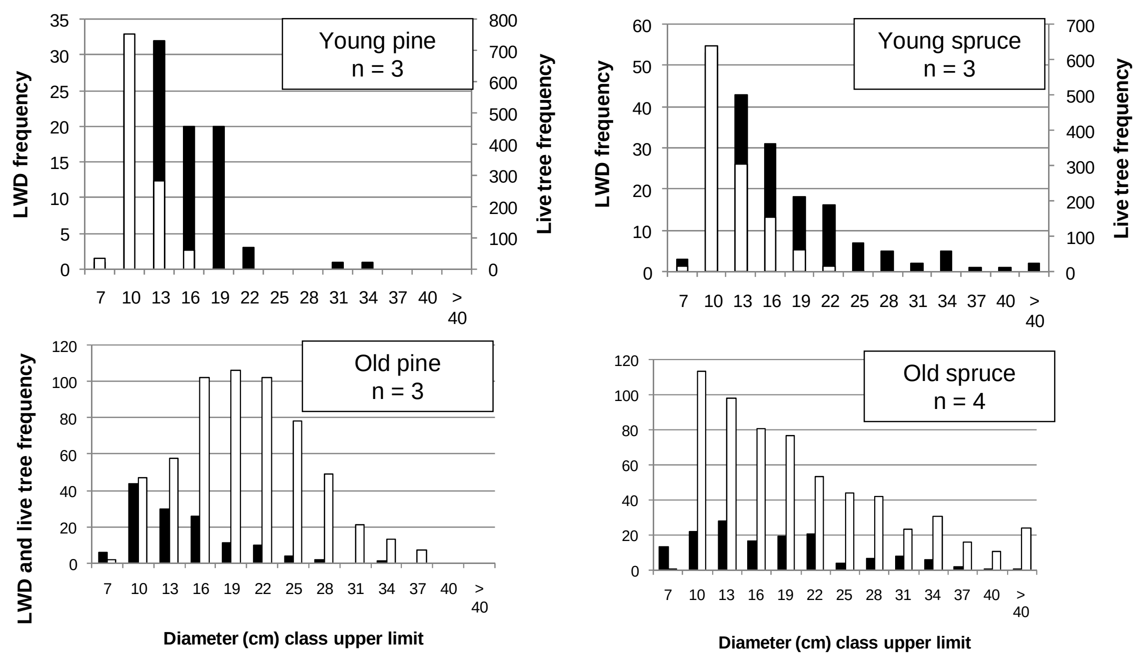

Figure 5. Diameter distributions of living trees (black) and large woody debris (LWD, white) at young and old pine and spruce sites. In young forests, the frequency of living trees greatly exceeded LWD.

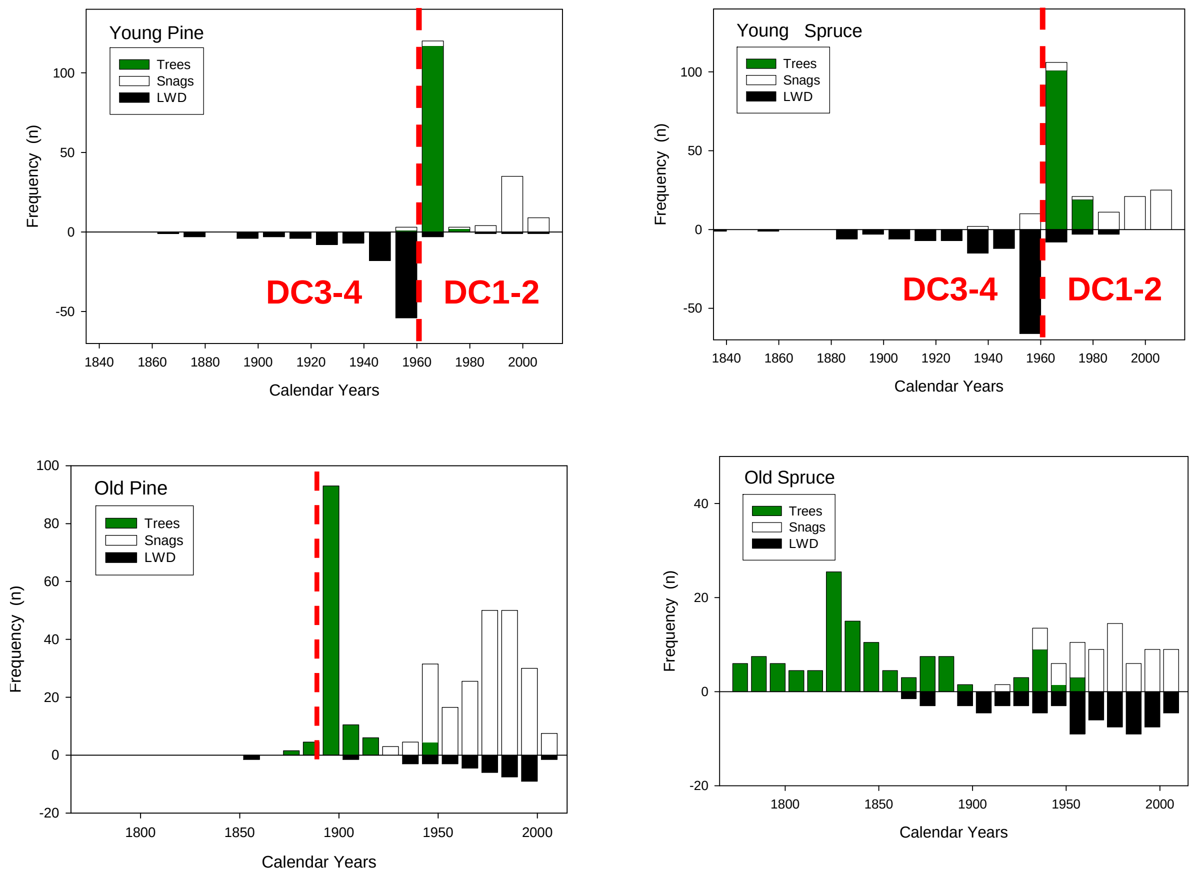

Figure 6. Forest dynamics at young and old pine and spruce sites. Green bars depict establishment dates of living trees. White bars depict the year of death of snags. Black bars depict year of death of large woody debris. Red dashed lines indicate when fires burned in young and old pine forests. In young forests, most LWD originated before fire and were in decay classes (DC) 3 and 4; LWD that originated after fire were in DC 1 and 2.

d. Implications of LWD Research Findings for Sustainable Forest Management

Given that individual logs can persist in streams for more than a century, management decisions that alter LWD abundance and dynamics could have long-term implications for the structure and function of riparian forests and in-stream habitat, and biodiversity. We are concerned about management decisions that reduce the amount of LWD. Indirectly, fire exclusion in the foothills of Alberta may significantly alter LWD dynamics since fire and post-fire stand development contribute LWD into streams. Directly, harvesting removes wood from riparian zones and can have negative impacts on biophysical processes, habitat, and biodiversity of streams. Therefore, our findings support creating buffer zones around headwater streams to protect them from direct impacts of logging and to provide a source of LWD for streams over time. Specifically, our chronosequence research showed that following a stand-replacing disturbance (fire or logging), recruitment of new LWD is delayed by c. 40 years while new trees establish and stands develop. We anticipate a further delay of 30 to 45 years before newly recruited logs decay and change in position so that they contribute to stream morphology and function. Therefore, there is a period of about 70 years between stand-replacing disturbance and recruitment of new, functional LWD into stream channels. During this time, trees and snags in riparian buffers are an important source of LWD to small streams. For headwater streams in environments susceptible to floods and erosion, we recommend that buffer zones be created in areas that have burned and where salvage logging is underway as burned snags are an important source of in-stream LWD as the forest regenerates.

IV. LONGITUDINAL PROFILE OF LWD TO IDENTIFY WOOD TRANSPORT THRESHOLDS

Downstream transport is a component of LWD dynamics not addressed in our original proposal. To better understand this process, Nicoll (2011) examined downstream trends in several indicators, including time since death of in-stream wood, as part of a watershed-scale study. Starting at headwater streams, 14 first to fourth-order reaches in the Wigwam Creek watershed were surveyed. Riparian forests consisted of mature spruce. In each reach, all woody debris (diameter≥5cm, n=1816) was assessed for position, geomorphic size, decay class, function and origin and 20 LWD in five reaches (n=100) were randomly sampled to determine time since death. Wood was stable at three headwater reaches and transport was significant in two downstream reaches. In general, log size decreased downstream, logs were more decayed downstream, less wood originated from the adjacent forests, and log positions were increasingly loose and less associated with stream banks. Time since death ranged from 2-129 years. Time since death distributions and medians were similar among both transporting and non-transporting streams; however, the oldest age classes were absent in the largest stream reach. Although distribution was not a direct indicator of transport, it was strongly related to decay class and position in the channel, which have established relationships to transport. Highly decayed logs were older, and bridges and partial bridges were younger than loose and buried logs (Nicoll 2011). Our findings improve understanding of the relative importance of wood transport versus in-situ decay and will refine models of in-stream LWD dynamics (Daniels et al. in prep.).

V. LONG-TERM TRENDS IN TREE MORTALITY RATES IN THE ALBERTA FOOTHILLS

A number of recent studies indicate that background rates of tree mortality are increasing in forests that appear undisturbed. This phenomenon has been linked to warming temperatures and associated water deficits. We sought to determine whether long-term trends in tree mortality rates were increasing in the forests of northwestern Alberta, Canada using data from an extensive permanent sample plot network established in the 1950s (Thorpe et al in prep). Of the approximately 3000 plots in the network, 192 met our inclusion criteria and were included in our analysis. These plots originated following fire; at least 50 trees were sampled during the first census; and at least three censuses had been completed, the last of which occurred no earlier than 1990. Across the study period from 1962 to 2007, average annual mortality rates varied widely, from 0.49% in the 1960s, to 0.24% and 0.26% in the 1970s and 1980s, up to 0.84% and 0.82% in the 1990s and 2000s.

We developed species-specific statistical models for lodgepole pine, black spruce and white spruce to predict annual mortality risk at the level of the individual tree using tree diameter, stand basal area and calendar year as predictors. In models that used calendar year, a proxy for warming temperatures, as the sole predictor, we found a significant positive association between mortality risk and year. However, once tree diameter at breast height (dbh) and stand basal area (BA) were included as predictors in the model, there was no association between mortality risk and year, indicating that increasing tree mortality rates were a result of successional processes alone. For all three species, the selected best models included effects of tree size and stand basal area, a proxy for competition, with predicted mortality risk declining with increasing dbh and increasing with BA. Black spruce, the most shade tolerant species, showed the least variation in predicted mortality rates across ranges of dbh and BA. In contrast, predicted mortality rates for lodgepole pine, the least shade tolerant species, varied widely across the observed ranges of dbh and BA.

Our results indicate no evidence for climate-related increases in tree mortality in the Alberta foothills. This may be a result of the relatively cool, moist climate found in our study sites. However, results from this study do provide important information on tree mortality rates and their correlates and may be useful in modeling studies and for assessing future changes in tree mortality.

VI. COARSEWOOD FUNCTION AS WILDLIFE HABITAT

As snags and logs decay, morphological structural changes correspond to changes in habitat function and thus affect the long-term availability of wildlife habitat (Jones 2009; Jones and Daniels in prep.). We observed 151 instances of snag habitat function and 706 instances of log habitat function. Eight of 11 possible snag habitat functions were observed, with substrates for cavity excavation and trunks with cracks or loose or furrowed bark most common. All six potential log habitat functions were observed. Only 33% of snags but 94% of logs functional and <10% of snags but 50% of logs served multiple functions. Wildlife habitat function was provided by snags 9-142 years since death and logs 0-175 years since death. Mean time since death did not vary across habitat function type nor between stand types for both snags and logs. However, snags appear to increase in habitat value as they decay. Snags with the highest wildlife value (≥4 functions) were from decay classes 4 and 5. Logs in decay class 3 were most common and had the greatest habitat value. Generally, these logs were not elevated above the ground, but were solid enough to provide overhead cover. They served as exposed, raised travel lanes and provided small concealed spaces. As logs collapsed and began to incorporate into the soil, their value as wildlife habitat generally decreased. Large concealed spaces were most common in uprooted trees while small concealed spaces and exposed, raised travel lanes were most commonly associated with snapped trees. Given the longevity of coarsewood in these stands, management plans must take a long-term view in order to maintain levels of coarsewood that are within the natural range of variability.

VII. CONTRIBUTIONS TO RESEARCH METHODS

a) Assessment of year-of-death estimates using permanent sample plot data (Hypothesis 2a)

In Jones and Daniels (in revision), we used permanent sample plot (PSP) data to assess the precision and accuracy of year-of-death (YOD) estimates obtained by crossdating white spruce and lodgepole pine snags (n = 71) and logs (n = 54). Precision was assessed by comparing YOD estimates from pairs of cores (snags) or radii (logs). Overall, pairs were highly correlated. Mismatches (imprecision) in YOD dates were attributed to highly decayed sapwood, suppressed outer rings, asymmetrical cambial death, and missing bark. Accuracy was assessed by comparing the crossdated YOD of 100 trees with their interval of death (IOD) recorded in PSPs. Most YOD estimates occurred within the observed IOD or preceded it by <10 years. YOD dates preceded the IOD midpoint by 4.2±11.7 (mean ± standard deviation) years for spruce snags, 11.9±10.2 years for pine snags, 3.3±14.1 years for spruce logs, and 10.0±13.8 years for pine logs, indicating an overestimation of time since death. We recommend YOD estimates are better represented by a range of dates rather than a single calendar year. Error estimates derived from the accuracy assessment can be applied to individual trees or to select class widths when grouping YOD dates to represent mortality during multiple years.

b) Incorporating time into stage-based decay classification systems (Hypothesis 3a)

Stage-based classification systems provide a qualitative measure of decay. In these classifications, coarse wood is assigned a decay class that reflects its morphology and wood integrity, which are assumed to change through time in predictable ways and at relatively constant rates. However, few studies have measured the strength of the relationship between decay classes and processes and time since tree death to test these assumptions. The inclusion of a time measure provides assessment of dead wood residency within each decay class and its consequent habitat value implications. In this study, we have developed a new, objective classification index and related it to time since death estimates (Bataineh et al. in prep).

VIII. FUTURE RESEARCH

Two follow-up projects resulting from this research have been identified:

(1) During the 2010 workshop and field tour, we identified two additional research needs: (a) assessment of existing steam buffers to determine their effectiveness and impacts on LWD abundance and dynamics, and (b) interdisciplinary collaboration to directly assess the role of LWD in creating in-stream microhabitats suitable for various fish species. These projects would involve additional graduate students and will require funding potentially from the Alberta Conservation Association or a subsequent application to the NSERC-CRD program.

(2) Integration of LWD outcomes, linking riparian forest and LWD dynamics to stream geomorphology and fist habitat, and development of a decision-support system for managers. We are developing an empirically-based prediction model that can be used to project the effects of current and proposed, new management policies on the spatial and temporal dynamics of large

woody debris. Modelled outcomes can be compared with results from our completed field studies to identify management approaches that are consistent with the natural range of variation of LWD or to identify previously unknown trigger points for compromising versus sustaining LWD. They can also be used for testing management scenarios and potential new options for generating large woody debris, such as prescribed burning, girdling, or even transportation of downed logs. Dr. David Andison of the Foothills Research Institute Natural Disturbance Program will host and fund a workshop to establish the framework for integration of our results with those of the FRI Natural Disturbance and Fish and Watershed Programs in order to develop a management support tool for industrial partners. Potentially, a PDF could be recruited who is eligible for funding from the NSERC-Industrial R&D Fellowships program to achieve this objective.

IX. Benefits of Research Outcomes to Our Industrial Partners

Sustainable management of renewable resources is a critical component of the Canadian economy. In forestry, sustainability is most likely to be achieved by basing management on local, ecological knowledge and by using natural processes to guide practices. Management of large woody debris in streams and riparian forests at stand-to-landscape scales is one of the most compelling and controversial issues of adopting a natural disturbance forest management strategy that aims to extract renewable resources while maintaining biodiversity. We have advocated that sustainable conservation and management of riparian forests and in-stream habitats requires ecosystem-specific understanding riparian forest dynamics as well as the links between upland terrestrial and riparian forests and the adjacent aquatic environment. The best possibility for a sustainable solution lies in a better understanding of the natural range of variation of wood dynamics, specifically the processes and mechanisms of woody debris generation, combined with knowledge of decay processes as well as how LWD function changes over time.

Improved knowledge of LWD processes allows us to assess current practices, policies and regulations and recommend changes and improvements. For example, in response to damage to streams caused by industrial forestry and other resource extraction, Canadian governments and industries have erred on the side of caution when managing riparian zones and have developed guidelines which protect most aquatic ecosystems from significant changes to water quality or stream function. Consequently, the current management strategy is to protect most riparian zones from all forms of disturbance, either by applying buffers during harvesting and through fire, insect, and disease control policies. Although our research supports the used of buffer zones to ensure a long-term supply of in-stream LWD, we have also shown that periodic fires and other natural disturbances are key processes contributing woody debris into streams and riparian forests. We caution that policies that attempt to eliminate natural disturbances from riparian forests can have unintended negative consequences at landscape scales over the long term. This example illustrates the importance of understanding the variation in magnitude and frequency of different types of disturbances and their impacts on ecosystem functions and biodiversity. We continue to work with our partners to integrate the new knowledge on riparian forests and LWD dynamics into conservation and management plans for the Alberta foothills.

Integration of our research into management practices helps our industrial partners compete in the market place. By improving knowledge of riparian forest and LWD dynamics, our research has enhanced decision-making and empowered our partners to employ scientifically-based adaptive management. In doing so, our partners are better able to demonstrate sustainability and corporate citizenry, maintain a competitive advantage by achieving certification standards, and increase local-to-international market acceptability of forest products from Alberta and Canada.

ACKNOWLEDGEMENTS

This research was funded by the NSERC Collaborative Research Development Program, Foothills Research Institute Natural Disturbance Program, Hinton Wood Products (a division of West Fraser Mills Ltd.), and the Alberta Newsprint Company (ANC) Timber Ltd. Thanks to D. Andison and T. Archibald of the Foothills Research Institute, R. Bonar of Hinton Wood Products, G. Branton of Alberta Newsprint Company, and E. Wassink of Sundre Forest Products Ltd. for technical support; and to our many field and lab assistants for their hard work and dedication: R. Chavardes, K. Terry, K. Werner, J. Trau, S. Wilson, C. Bambrick, L. Parsons, B. Sawiz, V. Yan, A. Parjulee, O. Freeman, A. Hussain, S. DesRoches, N. Barrett and I. Nicoll.

DISSEMINATION OF RESEARCH RESULTS

1. Refereed Journal Articles, Published

Jones, T.A., L.D. Daniels and S.R.E. Powell. 2010. Abundance and function of large woody debris in small, headwater streams in the foothills of the Rocky Mountains, Alberta, Canada. *River Research and Applications,* DOI: 10.1002/rra.1353

Powell, S.R.E., L.D. Daniels and T.A. Jones. 2009. Temporal dynamics of large woody debris in small streams in the Alberta foothills, Canada. *Canadian Journal of Forest Research* 39:1159-1170.

Jones, T.A. and L.D. Daniels. 2008. Dynamics of large woody debris in small streams disturbed by the 2001 Dogrib fire in the Alberta foothills. *Forest Ecology and Management 256: 1751-1759*.

2. Refereed Journal Articles, Submitted

Jones, E.L. and L.D. Daniels. In Revision. Assessment of dendrochronological year-of-death estimates using permanent sample plot data. Under revision for *Tree Ring Research*, December 2010.

3. Articles in Preparation for Submission to Journals

Bataineh, M. and L.D. Daniels. In Prep. An expert system for classifying in-stream large wood. To be submitted to *Canadian Journal of Forest Research*

Bataineh, M., E. Jones, J. Amerongen-Maddison, L.D. Daniels, T.A. Jones, R. Chavardez and D.W. Andison. In Prep. Coarsewood dynamics: a comparison of upland and riparian forests with in-stream wood. To be submitted to *Ecoscience*

Daniels, L.D., M. Bataineh, T.A. Jones and D.W. Andison. In Prep. In-stream large wood dynamics: a long-term perspective. To be submitted to *Ecological Applications*

Henderson, E., T.A. Jones and L.D. Daniels. In Prep. Decay of large woody debris in small streams in the Alberta Foothills. To be submitted to *Forest Ecology and Management*

Jones, E.A. and L.D. Daniels. In Prep. Coarse wood dynamics and value as wildlife habitat. To be submitted to *Conservation Ecology*

Thorpe, H., L.D. Daniels, R. Briand and G. Buckmaster. In Prep. Long-term trends in tree mortality rates in the Alberta Foothills. To be submitted to *Forest Ecology and Management*

4. Student Theses and Directed Studies

Amerongen-Maddison, J. 2010. Dynamics and decay of downed wood in old riparian forests. B.Sc. Directed Study, Department of Geography, University of British Columbia, Vancouver, Canada.

Ewan, M.A. 2010.Spatial Patterns of Large Woody Debris in the Northern Interior of British Columbia. MSc Thesis, Department of Geography, University of British Columbia, Vancouver, BC.

Henderson, E. 2008. Temporal dynamics of decay and position class transitions of large woody debris in small streams in the Alberta foothills. BSc. Thesis, Natural Resources Conservation, Faculty of Forestry, University of British Columbia, Vancouver, BC.

Jones, E.L. 2009. Decay dynamics of coarsewood habitat in old-growth spruce and pine stands in the Rocky Mountain Foothills. MSc Thesis, Department of Geography, University of British Columbia, Vancouver, BC.

Nicoll, A. Longitudinal change in woody debris over a forested channel network. M.Sc. Thesis, Department of Geography, University of British Columbia, Vancouver, Canada. (Expected March 2011)

Powell, S.R.P. 2006. A Wood Inventory and Dendroecological Analysis of Large Woody Debris in Small Streams in the Foothills Model Forest, Hinton, Alberta. M.Sc. Thesis, Department of Geography, University of British Columbia, Vancouver, BC.

5. Unpublished Reports

Daniels, L.D., T.A. Jones, M. Bataineh, H. Thorpe, E.L. Jones, A. Nicoll, S.R.E. Powell, E. Henderson, J. Amerongen-Maddison, R. Chavardes, D.W. Andison. 2011. Temporal dynamics of large woody debris in the Foothills of Alberta. Final Report to the Foothills Research Institute, Hinton Wood Products and Alberta Newsprint Company Timber Ltd. January, 2011. 23p.

Daniels, L.D. and D.W. Andison. 2011. Foothills Research Institute - Natural Disturbance Program Quick Note Series No. 47 - 50.

Daniels, L.D., M. Bataineh, T. Jones, S. Powell, E.L. Jones, and A. Nicoll. 2010. *Large Woody Debris: A Field Tour in Alberta's Foothills.* Handout, Foothills Research Institute’s Natural Disturbance Program Large Woody Debris Field Tour, September 2010. 3p.

Jones, T.A. and L.D. Daniels. 2007. LARGE woody debris in small streams of Alberta's foothills. Report to Alberta Conservation Association, Edmonton, AB. March 2007. 3p.

6. Workshop and Conference Presentations

Large Woody Debris: Connecting Forests and Streams. Presented by L.D. Daniels, Co-authors: M. Bataineh, T. Jones, S. Powell, E. Jones, A. Nicoll, E. Henderson, J. Amerongen-Maddison and D. Andison. Presented at the Foothills Research Institute’s Natural Disturbance Program Large Woody Debris Field Tour, September 2010.

The 3 R’s of In-Stream Large Wood: Recruitment, Residence Times, and Rates of Decay. Presented by L.D. Daniels, Co-authors: M. Bataineh, T. Jones, S. Powell, E. Jones, E. Henderson, J. Amerongen-Maddison and D. Andison. 2010 Canadian Institute of Forestry National Electronic Lecture Series - Foothills Research Institute’s Natural Disturbance Program: Solutions Not Just Answers, March 2010

Spatial and Temporal Dynamics of Large Woody Debris in Streams of the Alberta Foothills, Presented by L.D. Daniels, Co-authors: M. Bataineh, T. Jones, S. Powell, E. Henderson, and D. Andison. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

The Dynamics of In-Stream Large Woody Debris Presented by M. Bataineh, Co-authors: L.D. Daniels, T. Jones, S. Powell, E. Henderson, and D. Andison. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

Where Does the River Transport Wood? Longitudinal Change in Woody Debris over a Forested Channel Network Presented by A. Nicoll, Co-authors: L.D. Daniels and M. Hassan. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

Decay Dynamics of Coarsewood Habitat in Old-growth Spruce and Pine Stands. Presented by E. Jones, Co-author: L.D.Daniels. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

Long-term Trends in Tree Mortality Rates in the Alberta Foothills Presented by H. Thorpe, Co-author: L.D.Daniels. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

Evidence of Mixed-Severity Fire Regimes in the Foothills of Alberta: A Pilot Study. Presented by M. Amoroso, Co-author: L.D.Daniels. Presented at the 2009 Foothills Research Institute, Natural Disturbance Program Information Session, December 2009, Edmonton AB

Decay dynamics of snag habitat in old-growth spruce and pine stands in the Rocky Mountain Foothills Presented by E. Jones, Co-author: L.D. Daniels. Presented at the Annual Meeting of the Association of American Geographers, Las Vegas, NV, March 2009.

Abundance and function of large woody debris in small, headwater streams in the foothills of the Rocky Mountains, Alberta, Canada. Presented by T.A. Jones, Co-author: L.D. Daniels. Daniels. Presented at the Annual Meeting of the Association of American Geographers, Las Vegas, NV, March 2009.

Large woody debris research update. Presented by L.D. Daniels at the Integrating Foothills Watershed Research Workshop, University of British Columbia, Vancouver, BC, February 2009.

Water is part of an ecosystem. Presented by D.W. Andison to the Alberta Water Council tour. Hinton, Alberta, September, 2008.

Lessons Learned in the Rocky Mountain Foothills: Verifying Year of Death of Upland Lodgepole Pine Snags Using Multiple Lines of Evidence. Poster presented by E.L. Jones, Co-Author: L.D. Daniels. Presented at AmeriDendro 2008: The First American Dendrochronology Converence, University of British Columbia, Vancouver, BC, June 2008

Dendroecological analysis of in-stream large woody debris. Presented by L.D. Daniels, Co-Authors: S.R.E. Powell and T.A. Jones. Presented at the 6th North American Forest Ecology Workshop, Vancouver, BC, June 2007.

Spatial and temporal dynamics of large woody debris in first order streams from the Alberta foothills. Presented by T.A. Jones. Co-Author: L.D. Daniels. Presented at the 6th North American Forest Ecology Workshop, Vancouver, BC, June 2007.

A wood inventory and dendroecological analysis of large woody debris in small streams in the Foothills Model Forest, Hinton, Alberta. Presented by S.R.E. Powell. Co-Author: L.D. Daniels. Presented at Northwest Scientific Association Meeting, Victoria, BC, February 2007.

7. Field Tour

Large Woody Debris: A Field Tour in Alberta's Foothills. Presented by L.D. Daniels, Co-authors: M. Bataineh, T. Jones, S. Powell, E. Jones, and A. Nicoll. Presented at the Foothills Research Institute's Natural Disturbance Program Large Woody Debris Field Tour, September 2010.

8. Canadian Dendrochronology Network (CANDENDRO) Chronology Submissions

14 new ring-width chronologies (5 lodgepole pine, 5 white spruce and 4 black spruce) submitted by S.R. Powell and L.D Daniels in May 2008.

9. Websites

http://www.geog.ubc.ca/~ldaniels/index.php?content=Projects&type=project&id=17

http://www.geog.ubc.ca/~ldaniels/index.php?content=Projects&type=projects&proCat=Student Theses

http://foothillsresearchinstitute.ca/pages/ProgramsNatural_Disturbance/LWD_Project.aspx