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Windthrow and recruitment of large woody debris in riparian stands

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ABSTRACT

To document the impacts of windthrow in riparian leave strips and identify the components needed for small stream large woody debris (LWD) recruitment modeling, we monitored nine small streams at a temperate rainforest site in coastal British Columbia. This study was a component of a larger integrated study of forest management impacts on small streams. A series of small clearcuts were harvested in 1998 in a 70-year-old second growth stand that had regenerated naturally following logging and wildfire. Three cutblocks each were assigned to 10 m and 30 m buffer width treatments and three areas were assigned as unharvested controls. Seven years after the 1998 logging, all logs greater than 10 cm diameter that spanned at least part of stream channel width were measured. A total of 179 logs were recorded. Post-harvest windthrow was higher in the 10 m buffer treatment, while competition-related standing tree mortality was higher in the controls. The major windthrow events had occurred in the first and second years after logging of adjacent stands. There was no significant difference in the number of spanning and in-stream logs in the 10 m, 30 m buffer and control treatments. More than 90% of the LWD was in the 10–30 cm diameter classes. The majority of logs were oriented perpendicular to the stream channel. At the time of measurement, the majority of these trees were still suspended above the stream channel, indicating that the recruitment of logs into the stream channel is a long-term process. Time to recruitment into the channel is dependent on log and valley geometry, log size, species, and log condition prior to toppling. Log height above stream was negatively correlated with log decay class and valley width. Log length was negatively correlated with state of decay, and many windthrown logs were in an advanced state of decay before they entered the stream.

1. Introduction

Changes in forest practice regulations in British Columbia and the northwest United States in the past two decades have lead to greater protection of small streams during timber harvesting. Forest policies require retention of treed buffer strips along relatively small stream channels if they have fish populations (Wang et al., 2002). These unharvested strips are intended to minimize impacts of forest management activities on water quality, aquatic ecosystems and riparian community diversity (BCMOF, 1995). In-stream large woody debris (LWD) helps to structure fish habitat (Bisson et al., 1987), shape channels (Swanson et al., 1976), and trap sediments (Swanson and Lienkaemper, 1978; Gurnell et al., 2005). Larger wood pieces tend to remain where they are delivered in small streams, providing long-term benefits (Gurnell et al., 2002). The transfer of LWD from streamside forests to the stream and river systems creates a strong linkage between terrestrial and aquatic ecosystems (Lienkaemper and Swanson, 1987). The process of transfer of LWD from forests to streams is complex, and occurs in phases, starting with tree fall.

In riparian buffer strips, post-harvest windthrow is a major source of tree falls. Approximately 15% of cutblock boundary segments in wind exposed areas of coastal BC are partially windthrown following harvesting (Lanquaye-Opoku and Mitchell, 2005; Scott and Mitchell, 2005), and riparian buffers are particularly susceptible (e.g. Steinblums et al., 1984; Rollerson and McGourlick, 2001). To design effective riparian prescriptions, we need to understand the ecological impacts of windthrow in both the short and longer term. Potential impacts include loss of overstory, introduction of LWD into the streams, pulse introduction of foliage and fine branch materials, loss of bank stability and exposure of sediment sources (Lewis, 1998; MacDonald et al., 2003).

There are a number of models that aim to characterize the input, storage and loss of LWD in stream systems (e.g. STREAMWOOD, Meleason, 2001; RAIS, Welty et al., 2002; AQUAWOOD, Wei, 2005b). In these models, tree fall rates are usually tied to standing tree mortality rates. Tree fall direction is either treated as random or is conditioned by the user based on expert knowledge or empirically derived data. If it is explicitly dealt with at all, windthrow in newly exposed riparian buffers is often viewed as a pulse source of LWD input (e.g. RAIS, Welty et al., 2002). Given the geometry of

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Table 1
Description of variables.

Variable	Label	Description
Channel form	ChFrm	A category to classify the channel as narrow or broad based on valley width index
Narrow channel type	CB	Constrained by bedrock
	CH	Constrained by hill slope
	CF	Constrained by alluvial fan
Broad channel type	US	Unconstrained predominantly single channel
	UA	Unconstrained anastomosing several complex interconnecting channels
	UB	Unconstrained braided channel (numerous, small channels often flowing over alluvial deposits)
	CT	Constraining terrace
	CA	Constrained by alternating terraces
	CL	Constrained by land use
Valley form	VFrm	General description of the valley cross-section with emphasis on the configuration of valley floor and classify into narrow or broad based on valley width index
Narrow valley type	SV	Steep V-shaped valley or bed rock gorge (side slope ≥ 60°)
	MV	Moderate V-shaped valley (side slope >30°, <60°)
	OV	Open V-shaped valley (side slope ≤ 30°)
Broad valley type	CT	Constraining terraces. Terraces high and close to active channel
	MT	Multiple terraces. Surface with varying height and distance from the channel
	WF	Wide active flood plain. Significant portion of valley floor influenced by annual floods
Bankfull channel width	BCW	Distance across channel at bankfull flow
Valley floor width	VFW	Distance of valley across channel
Valley floor index	VFI	It is a ratio of VFW to BCW
Distance along	Dist_along	Distance of log from point of commencement
Status		SL: standing live; LL: live leaning; DB: dead broken; SD: standing dead; DL: dead leaning; UR: uprooted
Species	Spp	Hw: western hemlock; Cw: western redcedar; Fd: Douglas-fir; Ss: sitka spruce; Ep: Paper birch; Dr: red alder; Mb: Maple
Decay class	Deccls	Classification system for logs based on decay (Table 2) (Bartels et al., 1985)
Orientation	Brg	Orientation to the top of log and orientation of stream measured with compass in degrees
Diameter at breast height	DBH	Diameter at breast height measured with diameter tape
Diameter at mid-stream	DMC	Diameter of log measured at middle of stream
Bankfull channel width length	BCWL	The portion of log in active channel measured with tape
Total length	TL	The total length of log
Debris type		RN: rootwad attached to ends; N: broken ends; C: cut ends
Base diameter	Base_dia	Diameter at base of the downed logs
Length mid-stream	Len_midcreek	Distance of log from mid-stream to the base of the tree
Span length	Span_leng	Distance between two suspending points of log
Height above stream	HAS	Height of log from bankfull height of stream

small stream valleys, it is more likely that downed trees, whether from standing tree mortality or from pulses of windthrow will be suspended above small streams rather than immediately entering the channel. The process by which these spanning logs enter the channel, and log condition at the time of channel entry is not well understood or modeled. The objectives of this research project were to:

(1) Evaluate the effect of riparian buffer width on windthrow and LWD recruitment and contrast this with unharvested controls.
(2) Investigate the condition of LWD.
(3) Document the geometry of post-harvest windthrow in riparian buffers of different widths.
(4) Develop the framework for a process model that simulates the supply of LWD of windthrow origin to streams within riparian buffers.

2. Methods

This study is a component of a larger integrated study of forest management impacts on small streams in second growth forests. The riparian areas investigated in this study are in dense young-mature conifer-dominated forests that have developed following harvest and wildfire. This is a common forest type in the low elevation areas of the north west coast of North America and small, fish bearing streams are abundant in these forests. The small streams riparian buffers experiment is located in the foothills of the Coast Mountains, approximately 60 km east of Vancouver, British Columbia (Feller and Sanders, 1999; Moore and Richardson, 2003). The climate is maritime and characterized by dry, warm summers and wet, cool winters. Total precipitation ranges between 2200 mm and 3000 mm per year. Snow falls only occasionally at these low elevations (120–450 m). Soils are shallow and are derived from glacial till and glacio-marine deposits. The topography varies from flat to hilly and gently rolling, with some bedrock knolls. The underlying geology of the study site is quartz diorite, diorite and granodiorite. The stands in the study area naturally regenerated following logging and wildfire in the 1930s and are dense and uniform in structure. The tree species include western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), paper birch (*Betula papyrifera* Marsh.), and red alder (*Alnus rubra* Bong.).

2.1. Experimental design

Two buffer width treatments (10 m and 30 m on each side of the stream), and unharvested controls were each replicated three times within the riparian buffers experiment. There were also three fully harvested blocks (0 m buffers), but these treatment units were not included in the LWD study since they had no post-harvest LWD recruitment. Harvesting commenced in the fall of 1998. Overstory vegetation plots were measured annually. These vegetation