AN ABSTRACT OF THE THESIS OF

Nicole Marie Czarnomski for the degree of Master of Science in Forest Science presented on October 22, 2003.
Title: Effects of Harvest and Roads on In-stream Wood Abundance in the Blue River Basin, Western Cascades, Oregon.

ABSTRACT APPROVED: ____.
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Despite many studies of large wood in streams, few landscape scale studies have been conducted. Large-scale studies can reveal how the history of forest harvest and road building has influenced wood patterns in streams of the Pacific Northwest. This study examined the relationships between wood in streams, timber harvest, and road building at large (>50 km^2) spatial and long (>25 year) temporal scales, based on longitudinal surveys of 25.2 km of stream length in five sub-basins of the Blue River Basin, Cascade Range, Oregon.

In-stream wood was surveyed in six sampling sites, ranging from 1.6 km to 14.1 km in length along 2^{nd} to 5^{th}-order channels in public forests. Wood volumes, numbers of pieces of large wood, numbers of accumulations and timing of emplacement were determined at 50-m intervals. Wood volumes and numbers of pieces were expressed per unit of channel area in order to account for variations in channel width. Wood volumes and piece numbers were related to spatial data on harvest and road building using GIS. Analysis of variance (using SAS) tested how wood volumes and piece numbers were related to the presence of a harvest or road unit within 40 m of the stream, sampling site, timing of harvest, distance harvest was from the channel, and effects of natural processes. P-values for pairwise comparisons were adjusted using a Bonferroni procedure.

Distributed patch clearcutting and road construction were concentrated in the 1950's and 1960's in the Lookout Creek basin and 1960's to the 1980's in the Upper Blue River basin. A total of 66% (Cook Creek), 55% (Mack Creek), 53% (Lower Lookout), 37% (McRae Creek and Upper Lookout), and 7% (Quentin Creek) of stream length had harvests and/or roads within 40 m of the stream.

Approximately 80% of the wood volume and 85% of the number of large pieces occurred in accumulations. Wood volumes were lower in 5th-order compared to 3rd-order streams. Lower Lookout (the only 5th-order channel) had significantly lower wood volumes (109 m^3/ha) than all other locations (200-378 m^3/ha, $p<0.05$) and significantly lower numbers of large pieces (23 large pieces/ha) compared to all other locations (39 vs. 64 large pieces/ha, $p<0.008$). All other locations had fairly similar wood volumes and numbers of large pieces

For all study sites combined, 50-m stream segments without harvests or roads had significantly higher volume (356 m^3/ha) and number of large pieces (57 pieces/ha), than stream segments with harvests or roads within 40 m (80 to 157 m^3/ha, $p<0.03$; 19 to 39 pieces/ha, $p<0.04$). Stream segments without harvests or roads (32 pieces/ha) also had significantly higher number of accumulations compared to stream segments with roads (16 pieces/ha, $p<0.004$), or compared to stream segments with harvest on one side and roads (16 pieces/ha, $p<0.004$). Distance a harvest was from the stream and timing of harvest did not appear to affect wood volume or number of large pieces.

Harvests and roads were associated with decreases in wood abundance 50 m upstream and 50 m downstream of harvest units and road crossings. The 50-m stream segments immediately upstream (171.8 m^3/ha) and downstream (191.6 m^3/ha) of a section of stream with harvest and roads had significantly lower volume than the 50-m stream segments without harvest or roads (427.7 m^3/ha, $p<0.1$).

Natural processes such as floods, windthrow, near-stream toppling, and debris flows from the last 50 years had not obscured the effects of harvest and roads on wood volume and number of pieces in stream channels of Lookout Creek and Blue River. The legacy of harvest and road activities was still apparent in in-stream wood patterns up to 50 years later in this site, which consisted of old-growth forest subjected to dispersed patch clearcutting, road construction, and salvage logging conducted in the 1950's to the 1980s. However, harvest, road, and salvage practices on public lands have changed since that period. Therefore, these results should be extrapolated to other sites only with careful consideration of site history.

EFFECTS OF HARVEST AND ROADS ON IN-STREAM WOOD ABUNDANCE IN THE BLUE RIVER BASIN, WESTERN CASCADES, OREGON

by

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A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented October 22, 2003
Commencement June 2004

Master of Science thesis of Nicole Marie Czarnomski presented on October 22, 2003.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorized release of my thesis to any reader upon request.

Nicole M. Czarnomski, Author

ACKNOWLEDGEMENTS

I greatly appreciate the time and energy that Julia Jones and Fred Swanson gave me for endless hours of discussion on the role of wood in the stream. Special thanks go to both of them – Julia, who provided wonderful encouragement and support throughout the thesis and Fred, whose big ideas always kept me on my toes.

I would especially like to thank Dave Dreher, who was in it with me every step of the way. With our two projects so closely related we were able to work together on setting up a sampling design, conducting the field surveys, processing data, assessing quality assurance of data, evaluating analyses and interpreting results. Whew!

I'd like to thank George Lienkaemper, for taking the time to walk me through GIS programs. His patience and willingness to help were a great relief from the mind-boggling world of spatial analysis.

Thanks go to Jim Kaiser and Jim Mayo who helped by lending us the appropriate equipment for our field work. Also thanks to Lisa Ganio and Manuela Huso for helpful comments regarding the statistics.

And of course, I'd like to acknowledge my partner, Cameron Bergen, for support and understanding during the entirety of my graduate experience.

Spatial data sets were provided in part by the Forest Science Data Bank, a partnership between the Department of Forest Science, Oregon State University, and the U.S. Forest Service Pacific Northwest Research Station, Corvallis, Oregon. Significant funding for these data was provided by the National Science Foundation Long-Term Ecological Research program (NSF Grant numbers BSR-90-11663 and DEB-96-32921).

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EFFECTS OF HARVEST AND ROADS ON IN-STREAM WOOD ABUNDANCE IN THE BLUE RIVER BASIN, WESTERN CASCADES, OREGON

1. INTRODUCTION

Timber harvest and roads are present in a large number of forested basins throughout the Pacific Northwest, affecting countless natural processes, including the recruitment of in-stream wood. In order to understand how harvest and roads influence stream networks, there is a need to look at larger (>50 km^2) spatial and longer (>25 years) temporal scales. Many studies have operated on small spatial scales and only a few tried to model the changes through longer periods of time or space. This may be due in part to the difficulty in examining the role they have in altering wood abundance at these scales. Their impacts are complicated by changes in management practices over time, as well as natural input and redistribution processes, such as floods and debris flows.

In this study, a longitudinal sampling of in-stream wood, coupled with an evaluation of harvest and roads on the landscape, was used to identify the relationship of harvest and roads with in-stream wood abundance. By conducting a longitudinal study, transitions between different parts of the basin and lengths of the stream could be observed. Volume, number of large pieces, and number of accumulations were evaluated and compared for segments of stream with and without the presence of harvest and/or roads within 40 m of the channel.

The purpose of this research was to understand the harvest and road legacy on in-stream wood abundance at a basin-wide scale. Current forest management in the Pacific Northwest has emphasized the need to protect wood contribution areas, but selection of appropriate areas is challenging. Research has emphasized landscape-scale natural processes, such as debris flows, as important factors in contributing in-stream wood (Reeves et al. 1995, Martin and Benda 2001). Little emphasis has been placed on understanding the legacy of past management practices. Therefore, there is a need to understand the landscape-scale effects of past harvest and road practices on the current state of in-stream wood in order to create more accurate plans for the future.

2. BACKGROUND & MOTIVATION

The relationship among roads, timber harvest practices, and aquatic health has been examined in a variety of ways, but usually in both small spatial and temporal scales. There is growing interest in providing research that scales up in both space and time. This chapter describes some key points of interest related to the landscape-scale study of in-stream wood and the effects of harvest and roads.

2.1 Function of in-stream wood

In-stream wood can influence both physical and biological elements of aquatic and riparian ecosystems at large spatial scales. Wood in the channel may increase channel stability (Keller and Swanson 1979), diversity of habitats (Bisson et al. 1987), and hydraulic complexity (Keller and Swanson 1979). Wood can trap and store sediment, creating pools and leading to the formation of gravel bars and islands (Keller and Swanson 1979, Bilby and Ward 1989, Nakamura and Swanson 1994, Massong and Montgomery 2000, Martin and Benda 2001, Lancaster and Hayes 2001). For fish and aquatic invertebrates, large wood provides critical habitat (Bisson et al. 1987, Harmon et al. 1986). They may function as refuge during high flow events or from pursuit by predators, or in the trapping and storing of fine organic material – an important energy source for aquatic invertebrates (Anderson and Sedell 1979, Cummins et al. 1989).

2.2 Abundance and distribution

The abundance of large wood in a stream is related to stream order, width, discharge, stream gradient, sinuosity, and spatial distribution of riparian forests (Harmon et al. 1986, Bisson et al. 1987, Bilby and Ward 1989, Nakamura and Swanson 1994, May 2001).

When conducting a landscape-scale study, many of these factors could obscure the effects of harvest or roads.

Spatial distribution and species of riparian trees may have a substantial impact on wood recruitment (Harmon et al. 1986, Murphy and Koski 1989, McDade et al. 1990, Van Sickle and Gregory 1990). Deciduous forests appear to produce less large wood than coniferous forests (Harmon et al. 1986, Bilby and Ward 1989, Bilby and Ward 1991, McDade et al. 1990, May 2001). Also, the successional stage of the stand and mortality rates of species can influence the amount, type and distribution of large wood (Rainville et al. 1985, Harmon et al. 1986, McDade et al. 1990, Bilby and Ward 1991, May 2001).

Volume and number of pieces of wood in streams generally decrease from small to large channels (Lienkaemper and Swanson 1987, Keller and Swanson 1989, Bilby and Ward 1991, Martin and Benda 2001, May 2001, Gurnell et al. 2002). This may be due in part to the high capacity of large channels to transport wood, especially small pieces (Lienkaemper and Swanson 1987, Bilby and Ward 1989, Haga et al. 2002, Dreher in prep). Mean diameter, length of pieces, volume, and size of accumulations increase (although frequency of accumulations decreases), as channel width and drainage area increases (Bisson et al. 1987, Bilby and Ward 1989, Bilby and Ward 1991, Nakamura and Swanson 1994).

2.3 Natural recruitment and removal processes

Wood from adjacent forests can be delivered by bank failure, windthrow, fire, insects, disease, suppression and competition, collapse of trees due to wet snow and ice loading, and soil mass movement (Keller and Swanson 1979, Harmon et al. 1986, Lienkaemper and Swanson 1987, Murphy and Koski 1989), all of which can occur extensively in landscapes. Windthrow and bank erosion are the greatest continual sources of wood in streams of the Pacific Northwest (Lienkaemper and Swanson 1987, McDade et al. 1990). Recruitment from bank undercutting and windthrow lessen as a stand ages (Bragg 2000, Rainville et al. 1985), and windthrow in forested buffers has been known to be higher the first few years after harvest (Andrus and Froehlich 1992, Hairston-Strang and Adams 1998). Debris flows are important for episodic wood recruitment and redistribution (Swanson et al. 1987, Benda and Cundy 1990, May 2001). Harvest and road building can decrease amount and/or size and volume of wood and increase frequency of debris flows, affecting both recruitment and removal of large wood in the channel (Swanson et al. 1987, Benda and Cundy 1990, Wemple et al. 1996, May 1998, A. Johnson et al. 2000, May 2001).

Source distance is highly variable and depends on stream position, input processes associated with that position, and terrestrial characteristics. In steep, montaine, old-growth forests of Oregon, 70% of the identified sources of large wood in small streams are found within 20 m of the stream, but can come from as far as 45 m from the channel (Harmon et al. 1986, McDade et al. 1990, May 2001). In lower gradient streams, 95% of large wood has been found within 20 m of the channel, and 99% within 30 m (Murphy and Koski 1989). Slope instability leads to large wood input from the farthest average distance (40 m), followed by windthrow (20 m), mortality (18 m), and bank erosion (2 m) (May 2001). Additionally, source distance is less for mature forests than old-growth (Murphy and Koski 1989).

2.4 Influence of harvest and roads

Timber harvest and roads often are a significant part of the landscape and their affects are only partially understood. The recruitment pattern of large wood can be altered by timber harvest practices (Grette 1985, Murphy and Koski 1989, Bilby and Ward 1989, Benda et al. 2002, Faustini and Jones 2003). Salvage logging out of adjacent forests and streams has been associated with timber harvest and roads, but the legacy is not well known.

The effect of roads on wood abundance is not well known, but indirect effects on wood have been suggested because they can increase slope failure (Swanson and Dyrness 1975, Beschta 1978, A. Johnson et al. 2000,Wemple et al. 2001) and increase peak flows (Jones and Grant 1996, Wemple et al. 1996, Jones et al. 2000). Older roads tend to be in more highly sensitive areas of the watershed (i.e. valley floors and along the stream) and more prone to slope failure (i.e. winding midslope stretches) (Skaugset and Wemple 1999, Jones et al. 2000). Additionally, midslope and valley bottom roads can collect sediment and wood carried by slides from the hillslope or in streams, obstructing natural pathways (Wemple et al. 2001). Improvements in road engineering and placement have led planners to place new roads on ridge tops when possible, reducing the number of stream crossings and the risk of hillslope failure (Skaugset and Wemple 1999, Wemple et al. 2001), but a legacy of older roads is still present on the landscape.

2.5 Network and patch theory

Networks (i.e. roads and streams) and patches (i.e. timber harvest units) can interact at multiple temporal and spatial scales (Swanson et al. 1997, Jones et al. 2000). Wood can persist for long periods of time (Swanson and Lienkaemper 1978, Murphy and Koski 1989, Hyatt and Naiman 2001), complicating the legacy of harvests and roads on the landscape. Many studies have suggested that depending on the type of management practice, wood abundance is negatively affected (Grette 1985, Murphy and Koski 1989, Bilby and Ward 1991, Benda et al. 2002, Faustini and Jones 2003), but these studies are conducted on selected reaches, usually no longer than half a kilometer in length. Models have been created to look at both spatial and temporal scales (Martin and Benda 2001, Lancaster and Hayes 2001, Meleason 2001), yet field data have not been collected at these scales.

3. STUDY AREA

This study was conducted in five streams – Lookout Creek, McRae Creek, Mack Creek, Quentin Creek and Cook Creek – within the Blue River basin above Blue River Reservoir in the central western Cascade Range of Oregon (Table 3.1, Figure 3.1). One long sample reach was sampled in each of the five streams, in 2^{nd} through 5^{th} order channels.

The area has deeply dissected, mountainous terrain with stream valleys that were, on occasion, terraced. Blue River Basin above Blue River Reservoir is approximately 118 km^2, and streams range from 1^{st} to 5^{th} order. Hillslope gradients range from 20 to 80%, elevations range from 400 to 1600m.

Forests are primarily Douglas-fir (*Psuedotuga menzesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*), with big-leaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*) present at lower elevations. In low and middle elevation forests, stands are mainly 400-500 and 100-200 years old, regenerated from widespread fire circa 1500, with maximum heights greater than 70 m (Swanson and Jones 2002). Fire is the predominant disturbance agent in forest stands, but debris flows and flooding also play a role in disturbance along streams and riparian corridors. The fire return interval ranges from approximately 100 to 250 years (Weisberg 1998, Cissel et al. 1999), but for riparian forests it may be longer.

Average precipitation ranges from 230 cm in lower elevations, mainly as rain, to over 355 cm at upper elevations, primarily as snow (Swanson and Jones 2002). Highest precipitation levels occur from November through March, with rain-on-snow events generally from November through February. Mean temperature range from 2.1°C in December to 17.5°C in August (Smith 2002).

Major floods have occurred either over the basin, listed here in chronological order: December 1964/January 1965, January 1972, November 1977, February 1986, and February 1996, (overall peak discharge in Lookout for these events ranged from 1.23 to 4.93 $m^3/s/km^2$). In these events riparian areas experienced disturbance from debris flows,

Table 3.1. Descriptions of the 6 sampled stream sites in 5 sub-basins of Blue River in the western Cascades of Oregon. Lookout Creek is subdivided into Upper and Lower sections. ** Land Use History includes only harvests or roads within 40 m of each sampling site. † Data from McKenzie River Ranger District, Willamette National Forest, harvest unit maps compiled during the Hankin and Reeves aquatic inventory of 1997, as well as information originally compiled for Jones and Grant (1996). ‡ Data from GIS layers originally compiled for Wemple (1994).

Stream	Sampling Site length (km)	Sampling Site Drainage Area (ha)		Elevation of the Basin (m)	Land Use History**	
		Start	End		Harvest, years†	Roads, years‡
Lookout				420-1615	1950-1985	1950-1970
Upper	8.5	405	3420		1952-1976	1950-1970
Lower	5.9	3420	6240		1950-1983	1950-1970
Mack	1.55	490	860		1965-1985	1950-1970
McRae	3.9	515	1445		1953-1981	1950-1970
U. Blue R.				400-1600	1961-1987	1960-1980
Quentin	2.1	1625	2215		1985-1987	1960-1980
Cook	3.1	985	1800		1961-1986	1960-1980

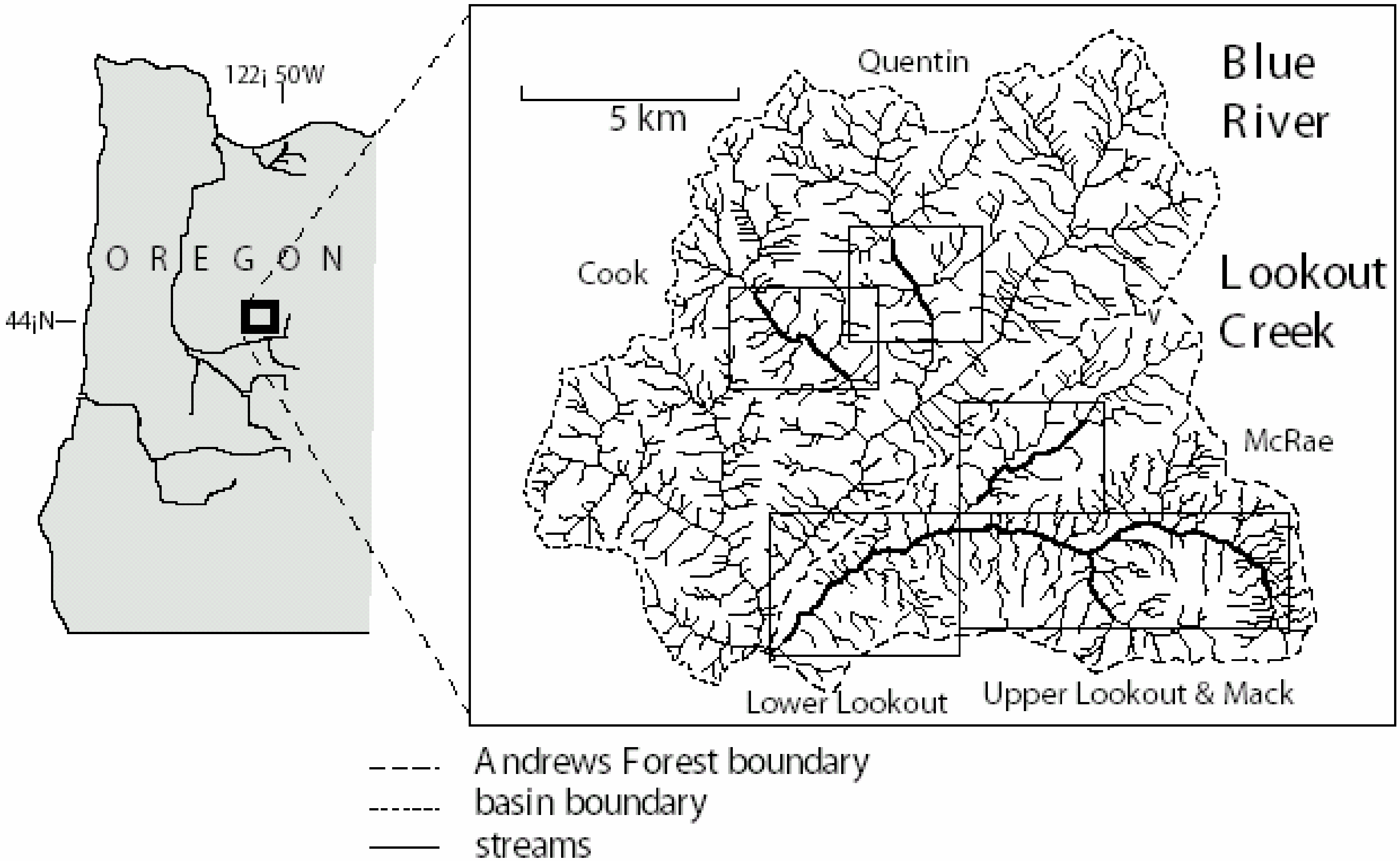


Figure 3.1. Map of Oregon showing the study area and individual sampling sites.

high peak flows and floated wood (Jones et al. 2000). Much of the February 1996 flood disturbance occurred in sites previously disturbed by 1964/65 floods (S. Johnson et al. 2000).

Like much of western Oregon, shallow, rapid mass movements (1-3 m deep failure planes, up to 10 m/s) of soil, sediment and wood are common in the Blue River basin (Swanson and Dyrness 1975, Snyder 2000). Three quarters of the inventoried debris flows in the Lookout Basin occurred during 1964/65 and 1996 floods, in lower elevations where slopes are steep, early land-use practices were most extensive, and snowmelt during warm rain events creates extreme soil water conditions (Snyder 2000). Many of the areas with unstable slopes that also had experienced disturbance from harvest or road building in the 1950's were prone to slope failure during the 1964/65 storm events (Swanson and Dyrness 1975, Snyder 2000). Subsequently, debris flow-prone areas were major sources of wood input to channels in the floods of 1964-65 and 1996 (Swanson et al. 1998, Wondzell and Swanson 1999, S. Johnson et al. 2000).

Lookout Creek was roaded and cut primarily in the 1950's to the early 1970's (Jones and Grant 1996, Skaugset and Wemple 1999). In Upper Blue River, almost all harvesting and roads were introduced in the 1960's through 1980's, with some additional road building in the 1990's to present (Jones and Grant 1996, Skaugset and Wemple 1999). In-stream salvage logging was widespread during the 1960's and early 1970's, although specific sites where salvage logging occurred have not been well documented. Common locations of salvage were in road prisms (the area around the road from below the base of the road fill to above the top of the road cut), from the stream near roads and harvest units, and in stands adjacent to harvest units. Buffer strips and riparian protection measures began to be used in the late 1960's and more specific guidelines were put into place in the mid-1970's with the passage of the National Forest Management Act (Gregory 1997).

Each of the five sampled streams is described below.

3.1 Lookout

Lookout is the largest basin in the study (Table 3.1) and includes the tributaries of Mack and McRae. Due to variation in the geomorphology of the basin, Lookout was separated into Upper and Lower Lookout for analysis.

Channels range from steep, narrow, recently scoured by debris flow chutes to wide alluvial reaches created by constrictions to the valley floor. The majority of the stream system is boulder dominated (Grant et al. 1990).

3.1.1. Upper Lookout Creek

The 8.5 km sample section of Upper Lookout starts in the headwaters and includes the confluence with Mack (Figure 3.1, Table 3.1). Transport of wood by flooding is thought to be limited (Lienkaemper and Swanson 1987) due to bankfull channel widths that are less than 12.5 meters and presence of much longer pieces of wood. The valley floor is generally U-shaped, water moves through hillslopes primarily by subsurface flow and pool-step sequences created by boulder and wood are regular features. Earthflow activity constricting the channel 2.4 km above the confluence with Mack Creek has periodically sloughed off significant amounts of sediment and wood (Swanson and James 1975). The majority of streamside management occurred on the downstream end of the reach.

3.1.2. Lower Lookout Creek

The Lower Lookout section extends 5.9 km from 200 m above the confluence with McRae to the USGS gauging station near the confluence with Blue River (Figure 3.1, Table 3.1). Significant changes in wood volume and channel geometry resulting from flooding have been documented in this portion of the stream network (Faustini 2000).

Transport of wood by flooding affects a wide range of piece sizes and lengths in this sampling site due to bankfull channel widths that are generally greater than 12.5 meters. Flood events from 1977 to 2000 significantly altered channel morphology and large wood amounts in Lower Lookout (Faustini 2000, Figure 10.12). Prior to flooding in 1996 sections of Lower Lookout had significant amounts of large wood, including channel spanning old-growth logs, but most of this wood was evacuated during the 1996 flood (Faustini 2000).

First- and second-order channels within this part of the basin produce relatively frequent debris flows attributed to steep slopes and highly weathered underlying rocks (Snyder 2000). Where these debris flows continue into the mainstem channel they are deliver "batches" of large wood (S. Johnson et. al. 2000). Additionally, the middle third of the section is constricted by a large inactive earthflow (Swanson and James 1975).

3.1.3. Mack Creek

The section sampled in Mack Creek starts 600 m above the gauging station and ends at the confluence with Lookout (Figure 3.1, Table 3.1). It has similar geomorphology to Upper Lookout, with a U-shaped valley, a predominance of subsurface flow, and pool-step sequences. Frequencies of boulders in both sections are similar to the maximum frequency of boulders found in Lookout (Faustini and Jones 2003).

Unlike the other sampling sites, the bridge and gauging station in Mack creates a definite divisor between streamside forest characteristics – an old-growth forest (above) and mixed age, highly managed landscape (below). The channel of the old-growth section of stream is wider, yet more constrained than that of the managed section of stream (Faustini and Jones 2003). Boulder frequency tends to be slightly higher in the old-growth section, yet boulder steps are four times more frequent in the managed section of stream (Faustini and Jones 2003). Larger step features, associated with large wood, are present in the old-growth section of stream (Faustini and Jones 2003).

There is a general lack of wood movement documented in Mack (Gurnell et al. 2002, Gregory et al. 2000, Dreher in prep.). In-channel movement rates are generally low (as little as <1%), but during the 1996 flood year, 11% of wood in the old-growth section and 25% of wood in the managed section moved more than 10 m (Gregory et al. 2000). Wood jam features have been known to persist for 50 to 150 years (Swanson and Lienkaemper 1978, Gregory et al. 1991).

3.1.4. McRae Creek

In McRae, the sample section extends 3.9 km beginning 500 m above Forest Service Road 325 and continuing to within 500 m of the confluence with Lookout (Figure 3.1, Table 3.1). The upper third of the McRae section has similar geomorphology to that described for Upper Lookout and Mack. The lower two thirds of the section has a terraced valley floor that is similar to the geomorphology of Lower Lookout. Streamside management influences are concentrated in the upper and lower portions of the section where roads are in close proximity to the stream.

For the lower section of McRae, flood impacts from 1996 were documented (Wondzell and Swanson 1999, S. Johnson et al. 2000). A debris flow reached the mainstem channel in 1996 and significantly affected the wood loads in the lower half of the sampled section (Wondzell and Swanson 1999, Snyder 2000). Most of the large wood was deposited on stream banks or in one large accumulation at the end of a 2-km-long disturbance track. Additionally, previously present pieces of wood spanning the channel were moved downstream or floated out of the active channel.

3.2 Upper Blue River

In Upper Blue River basin, the sampling was done in the Cook and Quentin sub-basins. In these sub-basins, channels range from low to high gradient and valleys are steeply incised. The valley floors in upper parts of the sub-basins are wider, with slope deposits that result from significant debris slide and debris flow activity (USDA 1996). In general, Cook and Quentin have not experienced the intensive, long-term study of the other sampling sites.

3.2.1. Quentin Creek

Sampling in Quentin Creek covered a section from 1.1 km above to 1.0 km below the confluence with Slipout Creek (Figure 3.1, Table 3.1). Fires occurred in Quentin in the 1800's (McKenzie River RD 2001), therefore stands in the sampling site were generally less than 200 years old. Stream surveyors in 1974 described the stream as having a steep gradient, dominated by boulders and cobbles until the lower (0.8 km) stream (USDA 1996). Although the 1994 surveys described Quentin as primarily bedrock, it has cobble and gravel at the lowest and uppermost reaches.

During the time of data collection for this study, in the sample reach, long stretches of the channel were bedrock, with steep cliffs (often bedrock) on one or both sides interspersed with occasional stretches with a wide valley floor and steep valley walls. Throughout the sample reach there is substantial fluvial transport, and signs of both debris flows and movement of large batches of wood. Most of the management activity in Quentin is not adjacent to the channel.

3.2.2. Cook Creek

In Cook Creek, 3.1 km was sampled from about 1 km above the road crossing in the middle of the basin to approximately 2 km below (Figure 3.1, Table 3.1). Past studies in Cook have noted the large amount of erosion generated by harvest and roads, in some cases the canyon bottom was filled with slash (USDA 1996). A 1994 survey described it as a moderately incised valley with low to moderate gradient, with bedrock in the lower section and cobble and small boulders upstream (with bedrock patches).

Much of the sampled section has a terraced valley floor with steep valley walls. Forest harvest units occur on one or both sides of most of the sampled section. In addition, there is a bridged road crossing and over 500 m of road within 40 m of the sampled section.

4. METHODS

4.1 Study design

The study consists of (1) an exhaustive field inventory of wood in a total of 25 km of stream length in 6 sampled stream sections; (2) GIS analysis of existing records of forest management history in the sampled basins; and (3) statistical analysis of the relationships between wood and the management status of adjacent hillslopes.

An observational study was conducted due to several motivating factors, including practicality and benefits of a broader site history. Manipulative experiments designed to examine road and harvest impacts on in-stream wood at larger spatial scales are not practical because of the impact to the landscape, limits imposed by forest regulations, and long time scales of landscape change. Additionally, with an experimental design it is difficult to observe pattern-process interactions in an entire stream network. The history of past management in these sites, followed by several floods of record, may allow expression of wood additions, removal, and redistribution. Early work on large wood in streams was conducted in some of the sampling sites, therefore in some portions of the study area there is an ability to verify changes over time (see Dreher in prep).

A longitudinal study of large in-stream wood was conducted in each of six streams to examine in-stream wood and patterns of adjacent harvest and roads. Sampling sites include Upper and Lower Lookout Creek, McRae Creek, Mack Creek, Quentin Creek and Cook Creek. The rest of the streams in the Upper Blue River basin were not selected for study due to addition of wood for habitat improvement that could obscure a harvest and road legacy. Within each stream, sampled sections were selected to include sections of stream both with and without harvest and roads within 40 m of the stream subjected to a variety of natural wood addition and redistribution processes. Starting and ending points for sampling were determined based on proximity to roads and harvest units and ease of access.

A spatial analysis of debris flows and human-induced disturbances (i.e. roads and harvest) was conducted using GIS for the landscape surrounding the sampling sites. GIS maps of road and stream networks were overlaid on site history information (disturbance such as harvest, roading or soil mass movement) and wood abundance variables sampled in this study.

4.2 Terminology

Some terms are defined below. Terms are grouped into three categories: wood related, harvest and road related, and channel related.

4.2.1 Wood related terminology

Accumulation: a grouping of 3 or more pieces of in-stream wood that had 2 or more points of contact, and are located wholly or in part within the active channel.

Single Piece: a piece of in-stream wood wholly or in-part within the active channel that is not a part of an accumulation

Large Piece: a piece of in-stream wood from ≥30 cm in diameter and ≥15 m in length, or ≥60 cm in diameter and ≥10 m in length (piece size classes 2.3, 2.4, 3.2, .3.3, and 3.4). See Table 4.1. These size limits were chosen due to the potential of a piece to trap other pieces of wood See Figure 4.1.

Volume: measure of wood in m^3/ha per 50-m stream segment. Area is calculated using the average channel width over 50 m of channel length.

Table 4.1. Size classes for pieces of wood. Those highlighted in gray are considered "large" pieces of wood. Size class is a designation given in this study. Diameter is expressed in cm, length in m. Average volume (m^3) is based on estimates derived from detailed measurements of 415 pieces of in-stream wood within the study area.

Size Class	Diameter (cm)	Length (m)	Average Volume (m^3)
1.1	10 to 30	1 to 5	0.07
1.2	10 to 30	5 to 10	0.17
1.3	10 to 30	10 to 20	0.32
1.4	10 to 30	20 +	0.70
2.1	30 to 60	1 to 5	0.40
2.2	30 to 60	5 to 10	1.01
2.3	30 to 60	10 to 20	1.87
2.4	30 to 60	20 +	4.02
3.1	60 +	1 to 5	1.33
3.2	60 +	5 to 10	3.33
3.3	60 +	10 to 20	6.19
3.4	60 +	20 +	13.28

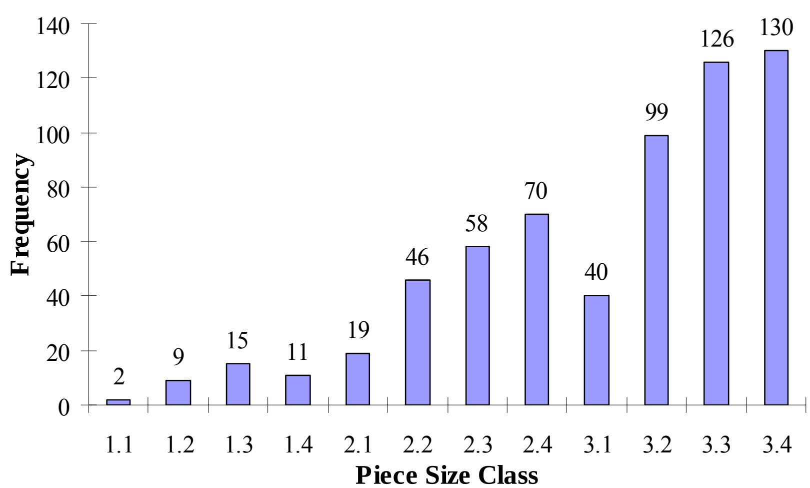


Figure 4.1. Piece sizes of wood that were found to be key to the emplacement of an accumulation, listed by piece size class. Size class is denoted by "diameter.length" where diameter 1=10-30 cm, 2 = 30-60 cm, 3 = 60+ cm, and length 1 = 1-5 m, 2 = 5-10 m, 3 = 10-20 m, and 4 = 20+ m. See Table 4.1.

4.2.2 Harvest and road related terminology

Harvest: mainly clearcuts, though some thinning has occurred in at least one of the harvest units; located on either "one side" or "two sides" of the stream, within 40 m of the channel. See Table 4.2.

Stream segments adjacent to harvest and roads: 50-m stream segments with a harvest or road within 40 m of the channel.

Management intensity: the presence of harvest and/or roads on one or two sides of the 50-m stream segment, e.g. harvest on one side versus harvest on two sides. See Table 4.2.

Neighborhood effect of harvest and roads: the wood volume, number of large pieces, or number of accumulations of upstream or downstream 50-m stream segments both immediately adjacent to and within 1 50-m stream segment of a series of 50-m stream segments with harvest and roads within 40 m.

4.2.3 Channel related terminology

Active channel: any area that would be expected to be wetted during a 50-year flood event, including those areas outside of bankfull widths.

Longitudinal position: distance from an upstream designated point to, a) the central point of a single piece, or b) the midpoint between the starting and ending points of an accumulation.

Table 4.2. Definitions of harvest and roads classes created to define the streamside influence.

Harvest and Road Class	Definition
None	No roads or harvest within 40 m of either side of the stream
H1	Harvest unit within 40 m on one side only of the stream
H2	Harvest unit within 40 m on both sides of the stream
R	Roads within 40 m on one or the other or both sides of the stream
H1&R	Harvest unit within 40 m on one side and roads on one or the other or both sides of the stream
H2&R	Harvest unit within 40 m on both sides and roads on one or the other or both sides of the stream

Stream segment: 50 m long segment of stream created during GIS analysis, based on 100-m lengths of stream measured in the field.

Stream side: one side of the channel of a 50-m stream segment, there are 2 sides for each 50-m stream segment.

Average width: five measurements were taken from bank to bank of the active channel for each 100 m field-sampled stream segment. They were averaged and each of the associated 50-m stream segments received the same average width designation.

4.3 Field sampling

Information on large in-stream wood and the status of the adjoining hillslopes was collected for each of the six sampling sites (Table 4.3). The upstream and downstream endpoints were selected to allow the inclusion of harvest and road influence. Data were collected at 100 m intervals, starting at the upstream-most point and moving downstream. Sampling in the direction of flow was conducted to reveal connections between wood sources, deposition points, and mass movement activity.

Starting and ending points of Lookout were geo-referenced using GPS. GPS points were collected only for Lookout because it was the longest continuous stretch of stream and the points were used to correct distances during field sampling. The nine points collected at locations in the stream were easily matched to existing maps and represented start and end locations for reaches within the sampling site. Reach designations were used to organize the 100 m stream segments for sampling.

Starting at the upstream end of each 100 m stream segment, data were collected for every piece of wood, whether single or in an accumulation, in the active channel (data collection sheet in Appendix A). Pieces of in-stream wood less than 10 cm in diameter or

Table 4.3. Variables measured for each single piece of wood, accumulation, or both in stream surveys. The classes used for each categorical variable are shown.

Variable	Classes
Singles & Accumulations	
Longitudinal position	Meters from upstream-most starting point
Diameter of large wood	Class: 1 (10-30cm), 2 (30-60cm), 3 (60+ cm)
Length of large wood	Class: 1 (1-5m), 2 (5-10m), 3 (10-20m), 4 (20+m)
Trapping sediment	Singles: Yes or No; Accumulations: None, None/Min, Minimum, Min/Mod, Moderate, Mod/Hi, High
Key to emplacement	Streambank, Boulder, Wood, Vegetation, Island, Bed, Rootwad
How emplaced	Fluvial, Windthrow, Near-stream Toppling, Debris Flow, Earthflow
When emplaced	Pre-1996, 1996, Post 1996
Orientation	With Flow (0-30° from thalweg), Between Flow (30-60°), Against Flow (60-90°)
Presence of cut ends	Singles: Yes or No; Accumulations: number of pieces w/cut ends
Singles Only	
Cross-sectional position in channel (zone)	% in Zone: 1-4 (Robison & Beschta 1990)
Decay of large wood	Class: 1-5 (Triska & Cromack 1980)
Conifer or hardwood	Conifer or Hardwood
Accumulations Only	
Number of pieces in accumulation	Class: 1 (3-9 pieces), 2 (10-20 pieces), 3 (21-50 pieces), 4 (51-100 pieces), 5 (100+ pieces)
Density of accumulation	Low, Low-Medium, Medium, Medium-High, High
Span across channel	0, ⅓, ⅔, 1 based on stream width of the location
Type of accumulation	Fall In, Log Levee, All in Channel, Head of Island, Mass Movement, Tributary Junction

less than 1 m in length were excluded from this study. An accumulation was defined as a grouping of 3 or more pieces of in-stream wood that had more than 2 points of contact. The active channel was defined as any area that would be expected to be wetted during a 50-year flood event.

The longitudinal position of each single piece of wood or accumulation was noted. The longitudinal position of a single piece was defined as the central point of the piece that was located within the active channel. For accumulations, both a start and an end longitudinal position were recorded, which was later averaged in order to have one point defined as the longitudinal position.

For a single piece, the following data were collected (Table 4.3): longitudinal position in the 100 m unit, cross-sectional position within the channel, diameter class, length class, decay class, whether it was a conifer or hardwood, if it trapped sediment, the process(es) and feature(s) which appeared to determine its placement in the current location, the inferred date of placement, orientation relative to flow, and whether it had cut ends.

For an accumulation, the following data were collected (Table 4.3): number of pieces, start and end longitudinal position in the unit, diameter and length of pieces in the accumulation, density of the accumulation arrangement including fine woody debris, span over the channel, the process(es) and feature(s) which appeared to determine its placement in the current location, the inferred date of placement, type of accumulation, whether it trapped sediment, orientation relative to flow, and the number of pieces with cut ends.

All of the variables are categorical variables that were estimated visually and grouped into pre-determined classes (Table 4.3). Some classes had been defined by previous studies, but the majority of classes were created for purposes of this study. An element of error is associated with each class based upon the individual collecting data and the definition of the class. Defining the classes before and having the same two data collectors throughout field sampling reduced error. In the assessment of when a piece of wood was emplaced, determining how the piece was buried in the bed and what was resting on it reduced error.

Size and length of all pieces of wood were estimated visually. Diameters were grouped into 3 classes (10-30, 30-60, and 60+ cm), and lengths were grouped into 4 classes (1-5, 5-10, 10-20, 20+ m). These classes were intersected to produce 12 "diameter.length" piece size classes denoted as follows: 1.1, 1.2, 1.3, 1.4, 2.1, … 3.4 (Table 4.1). Volume for each size class was estimated by measuring 415 pieces of large wood from several randomly chosen locations in Lookout. Two diameter measurements were taken at each end and the midpoint of each piece using calipers. Length of the piece was measured using an Impulse laser surveyor.

Observations of channel morphology and disturbance were made for each 100-m stream segment. Channel width was measured using an Impulse laser surveyor at five points within each 100-m stream segment; one near each end and three at roughly 25 m intervals. Tributaries were identified and their location and width at the confluence was noted. Boulders exceeding 1 m in diameter were counted and these counts were grouped into three boulder count classes: 0-10, 10-100, or >100 boulders per 100-m stream segment. Channel bed forms (boulders, cobble, gravel, bedrock, or sand as defined by Brady and Weil 1999) were estimated as percentage of each 100-m stream segment. Notes were taken on sinuosity, channel constraint and the locations (starting and ending points) of adjacent natural and human disturbances (e.g. windthrow, near-stream toppling, harvest units and roads) as observed from the stream.

All information collected was entered into Microsoft Excel worksheets and metadata were recorded. Each cell was evaluated for accuracy and corrections were made manually.

4.4 GIS analysis and mapping

The relationship of large wood to natural geomorphic processes, harvest and roading was evaluated using ArcView GIS mapping. Existing layers were gathered from the McKenzie Ranger District, Willamette National Forest, and the H.J. Andrews Forest online spatial database (Table 4.4). Drainage area was determined from a flow accumulation layer based on a 10 m DEM. The stream layer was dynamically segmented, a process where the stream route was segmented so that data could be associated with discrete lengths of the route (Longley et al. 2001).

Existing stream layers were segmented in ArcInfo, then field data were organized into 50-m stream segments and associated with the new layer in ArcView. A 50-m stream segment was the length chosen because a larger stream segment may not have captured the transitions in the channel width or changes in stand structure. A smaller stream segment would have created difficulties in counting pieces of wood, many which would have spanned more than one stream segment. Choosing a 50-m stream segment would not greatly influence spatial autocorrelation or independence more than choosing a larger or smaller stream segment. The smaller the stream segment the greater the sample size, therefore 50-m stream segments likely have more statistically significant results than a larger stream segment and les statistically significant results than a smaller stream segment.

Starting at the upstream position of the sampling site and moving downstream on the GIS map, the presence of an adjacent harvest unit or road within 40 m of each 50-m stream segment was noted and data were tabulated in a spreadsheet. The percentage of length of each 50-m stream segment adjacent to a harvest unit or road was calculated from GIS for the following categories of adjacent land use: immediately adjacent (0 m), 1-10 m forested buffer (10 m), 10-20 m forested buffer (20 m), and 20-40 m forested buffer (40 m). If harvest or roads were farther than 40 m, they were not considered in this study. In some cases, field observations contradicted information in the GIS layers. When a contradiction was found, corrections were made to tabular field data based upon

Table 4.4. Description of each GIS layer used in this study, where it came from, what information it was based on, and the accuracy (if known) (McKenzie River RD 2001).

Layer	Where from	Original data	Accuracy
Streams	Willamette National Forest*	Aerial photography	?
Roads	Willamette National Forest*	Aerial photography	± 40 m
Harvest units	Willamette National Forest*	Aerial photography and satellite imagery	?
Flow accumulation	This study	10 m DEM	?
Harvest and road classes	This study	This study	?
Landscape-scale natural process classes	Dreher in prep.	Swanson and James 1975	?

qualitative data, topographic maps, other GIS layers available, aerial photographs, and additional field data.

Additionally, data on the time of harvest for units within 40 m of the stream were collected for each 50-m stream segment. Each side of the stream was counted separately (i.e. if there was a cut on one side in the 1950's and on the other side in the 1980's, a mark was made for each decade category; if there was a cut on one side in the 1950's, only one mark was made, the other one was "none"). This process was used due to the complications caused by occurrences where two harvests of two different time periods were located within the same 50-m stream segment. An approach assigning just one decade per unit misrepresented the times of harvest in the sampled sites, while an approach accounting for all the possible decade combinations made comparisons difficult. Results are reported based on "50-m stream sides".

Field data on wood were resampled at 50-m intervals to match spatial data and to provide more detailed analysis. All wood data, spatial data and metadata are preserved in the Forest Service Databank, available through the H.J. Andrews website (Andrews 2003).

4.5 Data Analysis

4.5.1 ANOVA analyses

Statistical models were developed to test for spatial and temporal patterns of wood in streams. Descriptions of dependent and independent variables, and scales of comparison, are described in more detail in following sections. Seven one-way and two-way ANOVA models were run on various subsets of data to test whether wood volumes and numbers of pieces were related to management units, and localized natural processes classes. The ANOVA models were run using PROC MIXED in SAS v8.2. For each hypothesis, a dependent variable was tested using one of six general models:

Model 1 (one-way): y = f (harvest and road classes)

Model 2 (one-way): y = f (sampling site)

Model 3 (one-way): y = f (localized natural process classes)

Model 4 (one-way): y = f (landscape scale natural process classes)

Model 5 (one-way): y = f (neighborhood effects classes)

Model 6 (one-way): y = f (harvest distance from stream classes)

Model 7 (one-way): y = f (decade classes)

For the models above, the following dependent variables were tested:

y1 = ln [volume of wood (m^3)/ channel area (ha)]

y2 = ln [(number of large pieces of wood)/ channel area (ha)]

y3 = ln [(number of accumulations)/channel area(ha)]

Residuals were assessed for adherence to assumptions of normality and constant variance before results were examined. The variables volume, number of large pieces, and number of accumulations were examined for normality, independence, and equality of variance. These variables were log-normally distributed, and were natural log transformed prior to statistical analysis to produce equal variances among sub-samples. Data were back-transformed for reporting of results. When sample sizes were less than 5, they were not included in statistical analyses. A conservative Bonferroni adjustment for unplanned comparisons was used for all hypothesis testing. The Bonferroni adjustment in SAS adjusts each p-value by multiplying it by the number of comparisons, thereby creating a more conservative p-value. For example, if the p-value for one comparison was 0.01 and there were 5 comparisons, it became 0.05 (0.01 x 5).

4.5.1.1 Dependent variables

Dependent variables examined were volume, number of large pieces and number of accumulations. For all three dependent variables, values were based off of actual counts of the number of pieces and calculated on a channel area per 50-m stream segment.

Volume was created as a continuous variable by applying the estimated volume to each piece found (single or in an accumulation) and summing the volume for a 50-m stream segment. A volume estimate for each piece was found as described in Section 4.3 (Field sampling) and displayed in Table 4.1.

Number of large pieces was based on actual counts of pieces. Definition of a large piece is described in Section 4.2 and displayed in Table 4.1. Included is size class 3.2, which is shorter than the other size classes that are a part of the large pieces category, but there is reason to believe that diameter may be as or more important than length in determining stability (Braudrick and Grant 2000).

Accumulations were identified in the field and tallied for 50-m stream segments. On occasion, throughout the field survey, not all of the pieces in an accumulation were identified, therefore the number of pieces in the accumulation was also estimated. Most of the pieces that went unidentified were most likely small pieces – large pieces being more obvious and easy to find. Comparisons of actual counts and estimates yielded fairly similar results (Appendix B), therefore the actual counts were used in this study.

Volume (m^3), number of large pieces (#), and number of accumulations (#) were calculated based upon channel area per 50-m stream segment (ha) prior to transformation. Channel area was determined based upon the average width for a 50-m stream segment (found by taking the estimated average from the 5 width measurements per 100-m field sampled stream segment) multiplied by the length of the segment.

Units of channel area were used instead of units of channel length because variations in the valley width index were not entirely explained by position along the channel, and many ecologists evaluate variables of interest in units of area. Analysis of wood abundance by harvest and road class was conducted based on units of channel length, and similar results were found. Analysis of wood abundance by sampling site was conducted based on units of channel length and there were some differences between these results and those found for units of channel area. Nevertheless, units of channel area were used.

Piece numbers and numbers of accumulations could not be successfully naturally log transformed as long as 50-m stream segments with zero occurrences were included. Therefore, 50-m stream segments with zero pieces or zero accumulations were not included in ANOVA models, unless otherwise noted. For large pieces, 87% (436) of the original 501 50-m stream segments were retained (Table 4.5). McRae retained the most 50-m stream segments (99%), as compared to Quentin (95%), Upper Lookout (88%), Cook (87%), Lower Lookout (83%) and Mack (74%). No harvest or roads retained the most 50-m stream segments (96%), as compared to harvest on one side and roads (90%), harvest on one side (76%), harvest on two sides and roads (75%), roads (73%), and harvest on two sides (63%). For accumulations, 92% (463) of the original 501 50-m stream segments with accumulations were retained. McRae retained the most 50-m stream segments (97%), as compared to Cook (94%), Quentin (93%), Upper Lookout (91%), Lower Lookout (91%), and Mack (87%). Both roads with harvest on one side and two sides retained the most 50-m stream segments (100%), followed by no harvest or roads (95%), harvest on one side (89%), roads (87%), and harvest on two sides (77%).

4.5.1.2 Independent variables

Independent variables in statistical models consist of five spatial and one temporal variable: (1) sampling site, (2) harvest and roads, (3) neighborhood effect, (4) natural processes, (5) distance to nearest harvest, and (6) decade of harvest; and were tested at four spatial scales: (1) overall basin (includes all potential natural and anthropogenic effects for all sampling sites), (2) within sampling site, (3) selected sections of sampling sites, and (4) selected harvest and road effects. Designated classes for independent variables were created and modified for each of the appropriate scales.

Sampling site was defined in Chapter 3 (Study Area), consisting of Upper Lookout, Lower Lookout, Mack, McRae, Cook, and Quentin. Upper and Lower Lookout are con-

Table 4.5. Total number of 50-m stream segments and 50-m stream segments with large pieces and accumulations distinguished by sampling sites and management unit designations. A 50-m stream segment was removed from the large pieces sample set if there were no large pieces found in the 50-m stream segment. A 50-m stream segment was removed from the accumulations sample set if there were no accumulations found in the 50-m stream segment.

			50-m stream segments with Large Pieces		50-m stream segments with Accumulations	
	Total Units Sampled	% of Total	Units analyzed	Retention %	Units analyzed	Retention %
Sampling site						
Upper Lookout	170	34	150	88	156	91
Quentin	42	8	40	95	39	93
McRae	78	16	71	99	76	97
Mack	31	6	23	74	27	87
Lower Lookout	118	24	98	83	107	91
Cook	62	12	54	87	58	94
Total	501					
Harvest and Road Class						
None	285	57	274	96	272	95
Harvest one side	124	25	94	76	110	89
Harvest two sides	30	6	19	63	23	77
Roads	30	6	22	73	26	87
Harvest one side & roads	20	4	18	90	20	100
Harvest two sides & roads	12	2	9	75	12	100
Total	501					

tiguous parts of Lookout Creek, divided 8550 m from the upstream-most sampling point. This dividing point was chosen due to change in average channel width, in order to more accurately represent the two sections of stream and detect differences.

Harvest and roads designations were assigned to each 50-m stream segment and defined based on one of six land management classes of the hillslopes immediately adjacent to the 50-m stream segment (Table 4.2). Class designations were based upon the presence of a harvest unit or a road within 40 m upslope of the channel. The 40 m distance was chosen because large wood in streams is created by Douglas-fir and western hemlock trees that are commonly up to 70 m tall for trees in the old-growth age class, and so trees within 40 m of the stream may be "recruited" to form the large wood component of the stream (Harmon et al. 1986, McDade et al. 1990). Harvest and road class "none" represents sites with no harvest or roads within 40 m of the stream. Harvest and road class H1 (harvest on one side), H2 (harvest on two side), R (roads only), H1&R (harvest on one side and roads), and H2&R (harvest on two sides and roads), have harvest, roads, or both harvest and roads within 40 m of the stream. Due to the small number of occurrences of roads (12%) in 50-m stream segments, they were not broken into a "one side"/"two sides" category like harvest. Instead, where roads are present in a 50-m stream segment, they could occur on one or both sides of the stream.

For selected sampling sites, the six harvest and road classes were reorganized into two classes for analyses. All harvest and road classes were grouped into one class called "with harvest and roads", whereas those without harvest and roads remained together in the class called "none".

Tests for independence of the six harvest and road classes found that a spatial correlation was present (Figure 4.2). Spatial correlation was examined using a partial autocorrelation function on the residuals from an ANOVA in S-Plus 2000 on the following model: y (management unit designation) = f (ln [volume per ha] + lag 1 + lag 2), where lag 1 and lag 2 are the lagged variables of ln[volume per ha]. This strong lag 1 correlation suggested that adjacent 50-m stream segments are similar, implying that every other 50-m stream segment should be included in ANOVA analyses. Because adjacent

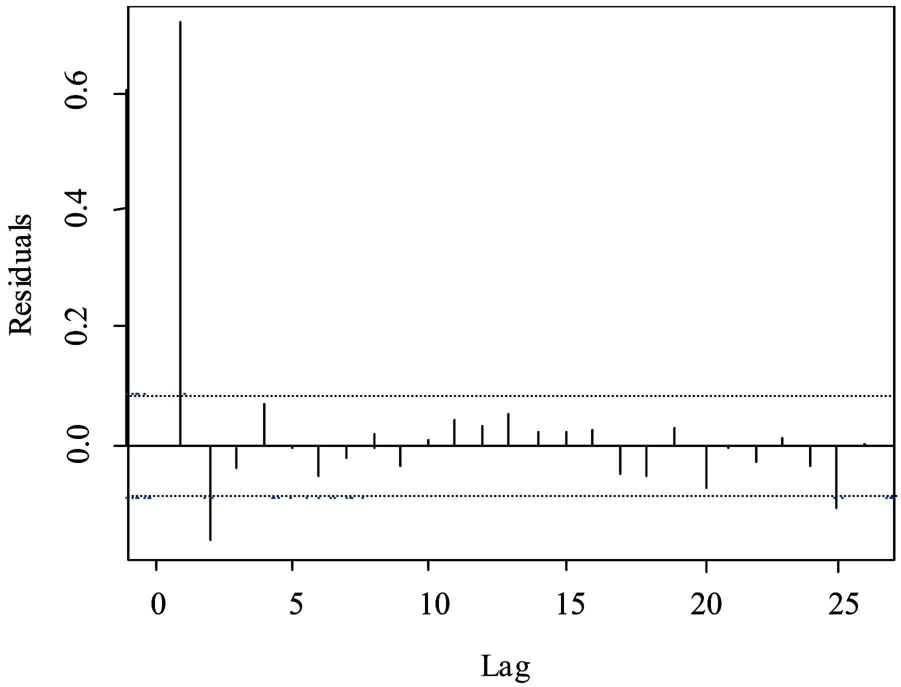


Figure 4.2. Partial autocorrelation of residuals from an ANOVA in S-Plus 2000 on the following model: y (management unit designation) = f (ln [volume per ha] + lag 1 + lag 2), where lag 1 and lag 2 are the lagged variables of ln[volume per ha]. This plot shows a lag 1 correlation.

50-m stream segments may include pairs of 50-m stream segments with and without harvest and roads, the adjustments were not made. Due to this decision, an analysis of the neighborhood effect (i.e. the relationship of 50-m stream segments to their nearest neighbors) was conducted to determine whether the significance of the ANOVA analyses might be biased. In addition, analysis of selected sections of the sampling sites were conducted to determine whether findings present in the large sample were also apparent at individual sites. Finally, analyses were conducted of sampling sites and the 50-m stream segments remaining after all harvest and roads effects and neighborhood effects were removed to determine whether there were individual site effects not explained by harvest and roads.

Sampled 50-m stream segments without adjacent harvest and roads immediately upstream and downstream a section of stream with multiple 50-m stream segments with adjacent harvest or roads were selected to create a sample set of 50-m stream segments. The first two 50-m stream segments both upstream and downstream of a continuous section of stream with adjacent harvest and roads were also separated into four independent categories for analysis (Figure 4.3). All classes of harvest and roads were grouped into one class, except the upstream- and downstream-most 50-m stream segments of a section of stream with adjacent harvest and roads. These were tested separately. All remaining 50-m stream segments had neither adjacent harvest nor roads. Overall, 22 sections of stream were found that consisted of two or more 50-m stream segments with adjacent harvest or roads, upstream of two or more 50-m stream segments lacking adjacent harvests or roads, and 26 sections of stream consisted of one or more 50-m stream segments with harvest or roads downstream of two or more 50-m stream segments lacking adjacent harvest or roads (Table 4.6).

Nevertheless, several unique combinations were created when assigning neighborhood effects classes to 50-m stream segments. Some 50-m stream segments were located both upstream and downstream of a section of stream with contiguous 50-m stream segments that are adjacent to harvests or roads. These units were arbitrarily assigned an upstream or downstream 50-m stream segment category and were not double

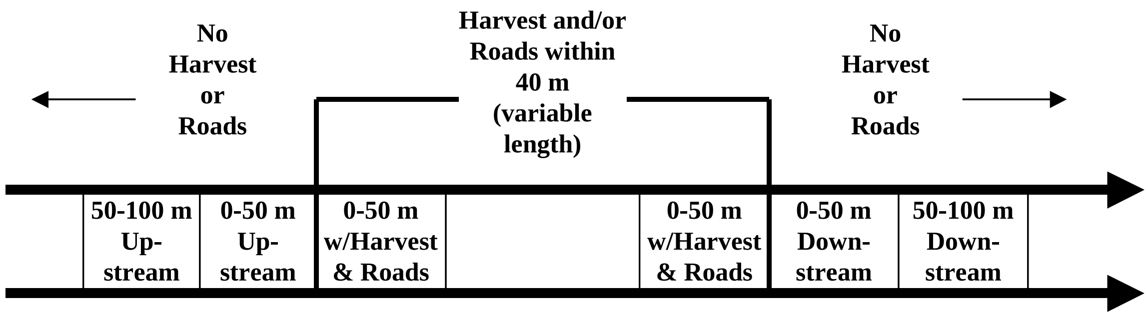


Figure 4.3. Arrangement of 50-m stream segments in the stream used for the neighborhood effects class system analysis. Rectangles individually labeled represent 50-m stream segments.

Table 4.6. Frequency and relationship of 50-m stream segments immediately upstream and downstream of sections of stream with harvest or roads. *There were some situations where a segment could be in more than one category or a managed section was either not preceded or followed by an unmanaged section. In this table, all possible combinations are displayed, even if they may appear in more than one category.

	50-m stream segments adjacent to harvests or roads upstream of 50-m stream segments lacking harvests or roads				
Downstream 50-m Segments with "None" Designation	1 with harvest or roads (0-50m)	2 with harvest or roads (51-100m)	3 with harvest or roads (101-150m)	>3 with harvest or roads (>150m)	Total
1 without harvest or roads (0-50m)	0	0	0	0	0
2 without harvest or roads (51-100 m)	0	0	1	2	3
3 without harvest or roads (101-150m)	0	0	1	1	2
> 3 without harvest or roads (>150m)	0	1	1	15	17
Total	0	1	3	18	22

	50-m stream segments adjacent to harvests or roads downstream of 50-m stream segments lacking harvests or roads				
Upstream 50-m Segments with "None" Designation	1 with harvest or roads (0-50m)	2 with harvest or roads (51-100m)	3 with harvest or roads (101-150m)	>3 with harvest or roads (>150m)	Total
1 without harvest or roads (0-50m)	0	0	0	1	1*
2 without harvest or roads (51-100 m)	0	0	1	2	3*
3 without harvest or roads (101-150m)	0	0	1	1	2
> 3 without harvest or roads (>150m)	0	1	1	18	20
Total	0	1	3	22	26

counted. There were five situations where no 51-100 m upstream 50-m stream segment without harvest or roads was above a 50-m stream segment with harvest or roads; two where the 51-100 m downstream 50-m stream segment without harvest or roads was immediately followed by a 0-50m upstream 50-m stream segment without harvest or roads; and three where the 51-100m downstream 50-m stream segment without harvest or roads was the same as the 0-50m upstream 50-m stream segment without harvest or roads (Table 4.6). In McRae, there was one case where there were no 51-100 upstream 50-m stream segments without harvest or roads because the 50-m stream segment with harvest or roads starts just below the upstream end of the sampling site. Sample sizes remain large due to Mack, McRae, Cook and Lower Lookout, where sampling sites end in 50-m stream segments with harvest or roads, leaving upstream 50-m stream segments without harvest or roads, but no downstream 50-m stream segments without harvest or roads.

Both landscape-scale and localized natural processes were examined with data from this study. Landscape-scale natural processes were created by Dreher (in prep) and used on a comparative basis in this study. Localized natural process effects classes were developed based on qualitative field observations made in this study (i.e. notes on disturbance, constraint, and general comments) (Table 4.7). Categories included evidence of (1) channel form (i.e., secondary channels, mid-channel bars or islands), (2) soil movement (i.e. slumping, significant near-stream toppling, debris flows, or earthflow activity), and (3) windthrow into the stream channel. All three or none of these processes might have been noted in a given 50-m stream segment, creating 7 possible classes.

Classes defining harvest distance from stream (5 classes) and decade of harvest (5 classes) are defined in Section 4.3. The "roads only" category had a small sample size, and were located at often variable distances from the stream, therefore not assigned an exact distance or decade. In order to have an accurate representation of the relationship between, 1) 50-m stream segments with harvest greater than 40 m distance to the stream versus those with harvest closer, and 2) 50-m stream sides harvested prior to 1950 versus those harvested in decades after, 50-m stream segments and sides with only roads were left out of analysis. In total, 30 50-m stream segments (4% of the 501) and 60 50-m

Table 4.7. Definition of localized natural process effects classes.

Localized Natural Process Classes	Definition
Channel form	Secondary channels or mid-channel bars
Windthrow	Windthrow only
Soil movement	Slumping, significant near-stream toppling, debris flows, or earthflow activity
No localized effect	None of the localized natural process effects present

stream sides (4% of the 1002) with roads were removed. All but one 50-m stream segment and two 50-m stream sides were from Lower Lookout, thereby 75% of 50-m stream segments in Lower Lookout remained for analysis.

4.5.2 Chi-square tests for independence

Chi-square analyses were conducted using SAS v8.2 PROC FREQ to test for independence of the categorical variables sampling site, harvest and road classes, distance of nearest harvest, natural processes, and decade of harvest. In most situations, the high frequency of categories with less than five 50-m stream segments or 50-m stream sides required the grouping of classes before analysis. Because results from grouped classes appeared the same as ungrouped classes, original groupings were retained.

Tests were run on the following combinations of categorical variables that were compared in ANOVA analyses:

Variable 1	Variable 2	Table in Results
Sampling site	Distance of nearest harvest class (for those with harvest)	5.2
Sampling site	Harvest and road class	5.4
Sampling site*	Decade (for 50-m stream segments with harvest)	5.5
Harvest and road class	Local natural delivery processes	5.16
Harvest and road class	Landscape-scale natural processes	5.18

(* = Combined sampling sites into two groups -- Lookout Basin vs. Blue River Basin.)

4.5.3 Comparative analysis

In selected sections of the sampling sites (Table 4.8, Figure 4.4), piece number data were sub-divided according to time periods: (1) before the 1996 flood (pre-1996), (2) during 1996 (1996), and (3) since the 1996 flood (post-1996), based on interpreted dates of placement of wood pieces from the field inventory. The timing of emplacement was

Table 4.8. Descriptions of seven selected sections 1 to 2.5 km for further examination. Described below are drainage area (km^2) at the upstream-most sampling point to the downstream-most sampling point, length (m) of the selected section, and location within the sampling site (upstream and downstream-most points in meters of the selected section within the sampling site).

Section of stream	Drainage (km^2)		Length (m)	Location Within Sampling Site (m)	
	Top	Down		Upstream	Downstream
Upper Lookout	11	17	1400	2900	4300
Lookout	33	54	2450	7550	10000
Mack	4	7.5	1100	0	1100
McRae-up	6	8	1050	250	1300
McRae-mid	8	12	1350	1300	2650
McRae-low	11.5	13.5	1100	2550	2650
Cook	10	14	2250	150	2400

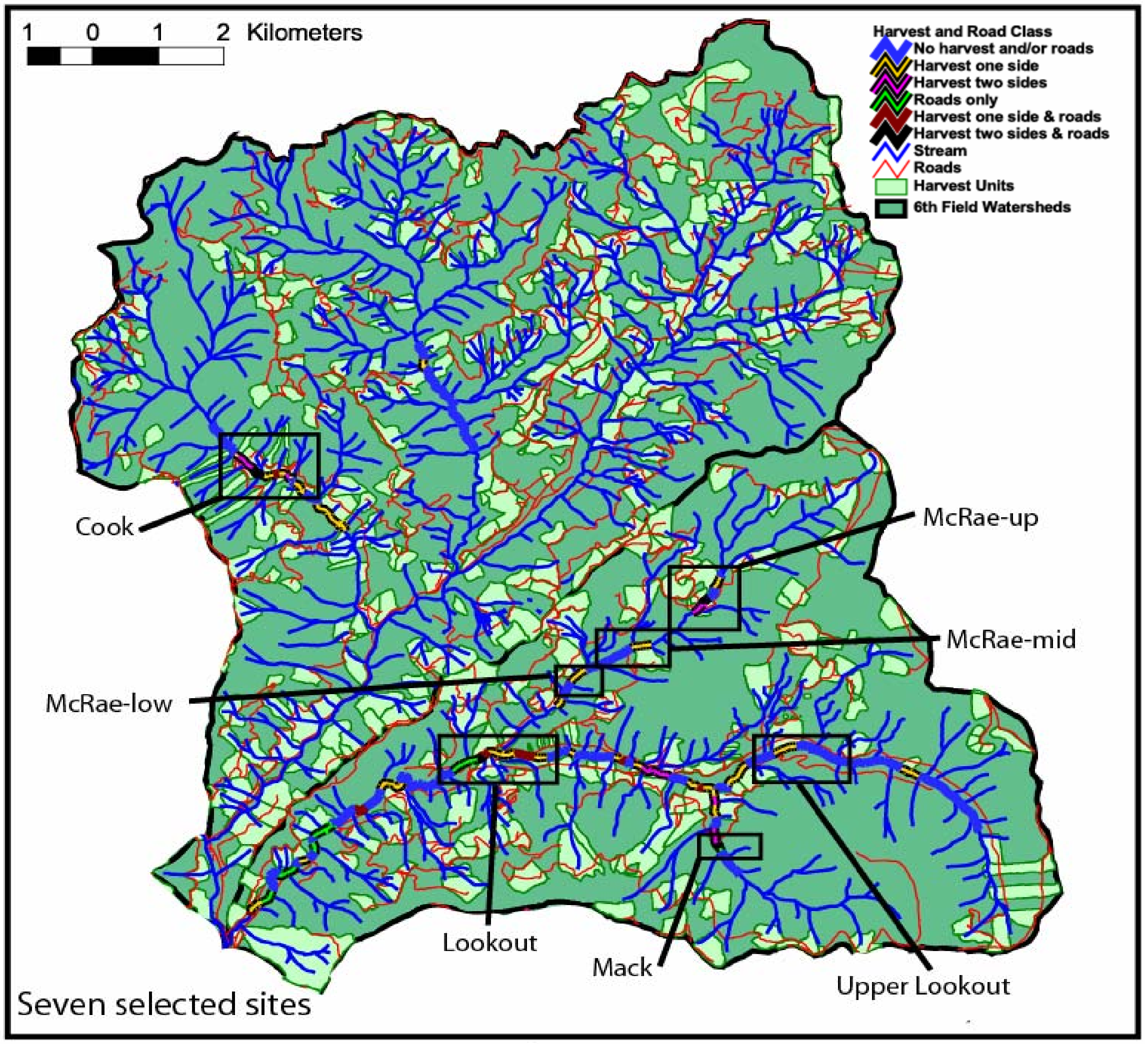


Figure 4.4. Map of seven selected sections for further examination, 1 to 2.5 km in length. See Table 4.8 for more detail of seven sites and Figure 5.3 for more detail of sampling sites.

recorded for each single piece, but for accumulations, the percentage of the accumulation emplaced in each time category was recorded in the field. In order to translate the timing of emplacement to individual pieces in an accumulation, a series of rules was established to partition pieces, which were evaluated on a case-by-case basis:

- If only one piece is large and 10% of pieces in the accumulation or greater is pre-1996, then the one large piece is interpreted as the one that was pre-1996.
- If 90% of pieces in the accumulation or was pre-1996, all large pieces were considered pre-1996.
- If less than or equal to 3 pieces were large and 50% of pieces in the accumulation or greater were pre-1996, all the large pieces were considered pre-1996, as long as there were at least 6 pieces as part of the accumulation.
- If pre-1996, 1996, and post 1996 categories have equal percentages of pieces in the accumulation and there are only three pieces, one of which is large, then the large piece is pre-1996.
- If the same conditions were true and there were two large pieces, one was pre-1996 and one was 1996.
- If 50% of pieces in the accumulation or less and 50% of pieces in the accumulation or greater was equally divided between pre-1996 and 1996, all large pieces were equally divided between the two categories.
- If 50% of pieces in the accumulation or less and 50% of pieces in the accumulation or greater was unequally divided between pre-1996 and 1996, all large pieces are divided according to the ratio of pre-1996 and 1996 pieces, with at least one piece always being pre-1996.

All results were cross-checked with field data stating what was key to the emplacement of the accumulation, and if it was wood, what was the size of the key piece. If so, and any percentage of the accumulation was pre-1996, then the key piece was considered to be pre-1996. If this same relationship was true when instead the time category was 1996 or post 1996, the key pieces would be considered to be 1996 or post 1996, respectively.

The numbers of pieces were calculated based upon channel area per 50-m stream segment (ha). Data was not natural log transformed, therefore 50-m stream segments with zero occurrences of large wood were included in this analysis. Plots were created with these data displayed by position in the stream. Additionally, averages of volumes and percentages of volume were calculated for time categories and for 50-m stream segments with and without large pieces, based upon harvest and road construction history.

5. RESULTS

5.1 Importance of large pieces and accumulations

Large pieces were a small proportion of total pieces, but they represented most of the wood volume. Large pieces contained 66.2% of the volume of all pieces found in accumulations, 72.6% of the volume of all single pieces, and 67.1% of the volume of all pieces sampled (Table 5.1, Figure 5.1). In accumulations, over 52% of the smallest pieces accounted for less than 5% of the total volume, and 1.5% of the largest pieces accounted for nearly 24% of the volume. In single pieces, over 46% of the pieces accounted for nearly 4% of the total volume, and 1.8% of the pieces accounted for nearly 24% of the volume. Overall, 51% of the smallest pieces sampled accounted for only 5% of the total volume, and 1.6% of the largest pieces accounted for 24% of the volume.

Most of the large pieces and volume were found in accumulations (Figure 5.2). Accumulations contained 86% of the total pieces, and 81.8% of the large pieces, and 83.9% of the volume of wood in this study (Table 5.1, Figure 5.1).

5.2 Spatial and temporal patterns of harvests and roads

For purposes of analysis we designated stream segments as “adjacent” to harvest or a road if a harvest unit occurred within 40 m of the stream. Stream segments with a harvest within 40 m of the stream were considered to be adjacent to a harvest because trees 70 m tall (typical height of mature and old-growth Douglas-fir) and 40 m distant from the stream could reach the stream if they fell. Timber harvests occurred anywhere from 0 to 40 m from sampled streams (Table 5.2), although two-thirds of the 50-m stream segments with harvest had been cut to the stream edge.

Table 5.1. Volume and piece size relationship for accumulations, singles, and accumulations and singles combined over all six sampling sites. Rows depict the twelve size classes of the pieces (in order of estimated volume per piece). The total and cumulative number of pieces, estimated volume per piece (m^3/piece, based on field collected data*), total and cumulative volume (m^3), and the percent and cumulative percent of total volume are shown below. *Note: estimated volume per pieces was determined by sampling 415 pieces for exact size and length.

Piece Size Class									
Class	Diameter (cm)	Length (m)	Number of Pieces	Cumulative Number of Pieces	Estimated Volume/ Piece	Volume in Size Class	Cumulative Volume	Percent Volume	Cumulative Percent Volume
				Accumulations					
1.1	10-30	5-10	7850	7850	0.07	548	548	3.7	3.7
1.2	10-30	10-15	1283	9133	0.17	224	772	1.5	5.2
1.3	10-30	15-20	398	9531	0.32	129	901	0.9	6.1
2.1	30-60	5-10	3705	13236	0.40	1492	2393	10.1	16.1
1.4	10-30	>20	70	13306	0.70	49	2442	0.3	16.5
2.2	30-60	10-15	1295	14601	1.01	1306	3748	8.8	25.3
3.1	>60	5-10	956	15557	1.33	1272	5020	8.6	33.8
2.3	30-60	15-20	523	16080	1.87	980	6000	6.6	40.4
3.2	>60	10-15	564	16644	3.33	1879	7879	12.7	53.1
2.4	30-60	>20	251	16895	4.02	1009	8888	6.8	59.9
3.3	>60	15-20	384	17279	6.19	2378	11266	16.0	75.9
3.4	>60	>20	269	17548	13.28	3572	14838	24.1	100.0
	Total		17548	17548	N/A	14838	14838	100.0	100.0

Singles

1.1	10-30	5-10	970	970	0.07	68	68	2.4	2.4
1.2	10-30	10-15	305	1275	0.17	53	121	1.9	4.2
1.3	10-30	15-20	162	1437	0.32	53	174	1.8	6.1
2.1	30-60	5-10	493	1930	0.40	199	372	7.0	13.1
1.4	10-30	>20	23	1953	0.70	16	388	0.6	13.6
2.2	30-60	10-15	232	2185	1.01	234	622	8.2	21.8
3.1	>60	5-10	122	2307	1.33	162	784	5.7	27.5
2.3	30-60	15-20	150	2457	1.87	281	1066	9.9	37.4
3.2	>60	10-15	95	2552	3.33	317	1382	11.1	48.5
2.4	30-60	>20	58	2610	4.02	233	1615	8.2	56.7
3.3	>60	15-20	90	2700	6.19	557	2172	19.6	76.2
3.4	>60	>20	51	2751	13.28	677	2850	23.8	100.0
	Total		2751	2751	N/A	2850	2850	100.0	100.0

Accumulations & Singles Combined

1.1	10-30	5-10	8820	8820	0.07	615	615	3.5	3.5
1.2	10-30	10-15	1588	10408	0.17	277	893	1.6	5.0
1.3	10-30	15-20	560	10968	0.32	182	1075	1.0	6.1
2.1	30-60	5-10	4198	15166	0.40	1691	2765	9.6	15.6
1.4	10-30	>20	93	15259	0.70	65	2830	0.4	16.0
2.2	30-60	10-15	1527	16786	1.01	1540	4370	8.7	24.7
3.1	>60	5-10	1078	17864	1.33	1434	5804	8.1	32.8
2.3	30-60	15-20	673	18537	1.87	1261	7066	7.1	39.9
3.2	>60	10-15	659	19196	3.33	2196	9261	12.4	52.4
2.4	30-60	>20	309	19505	4.02	1242	10503	7.0	59.4
3.3	>60	15-20	474	19979	6.19	2935	13438	16.6	76.0
3.4	>60	>20	320	20299	13.28	4249	17688	24.0	100.0
	Total		20299	20299	N/A	17688	17688	100.0	100.0

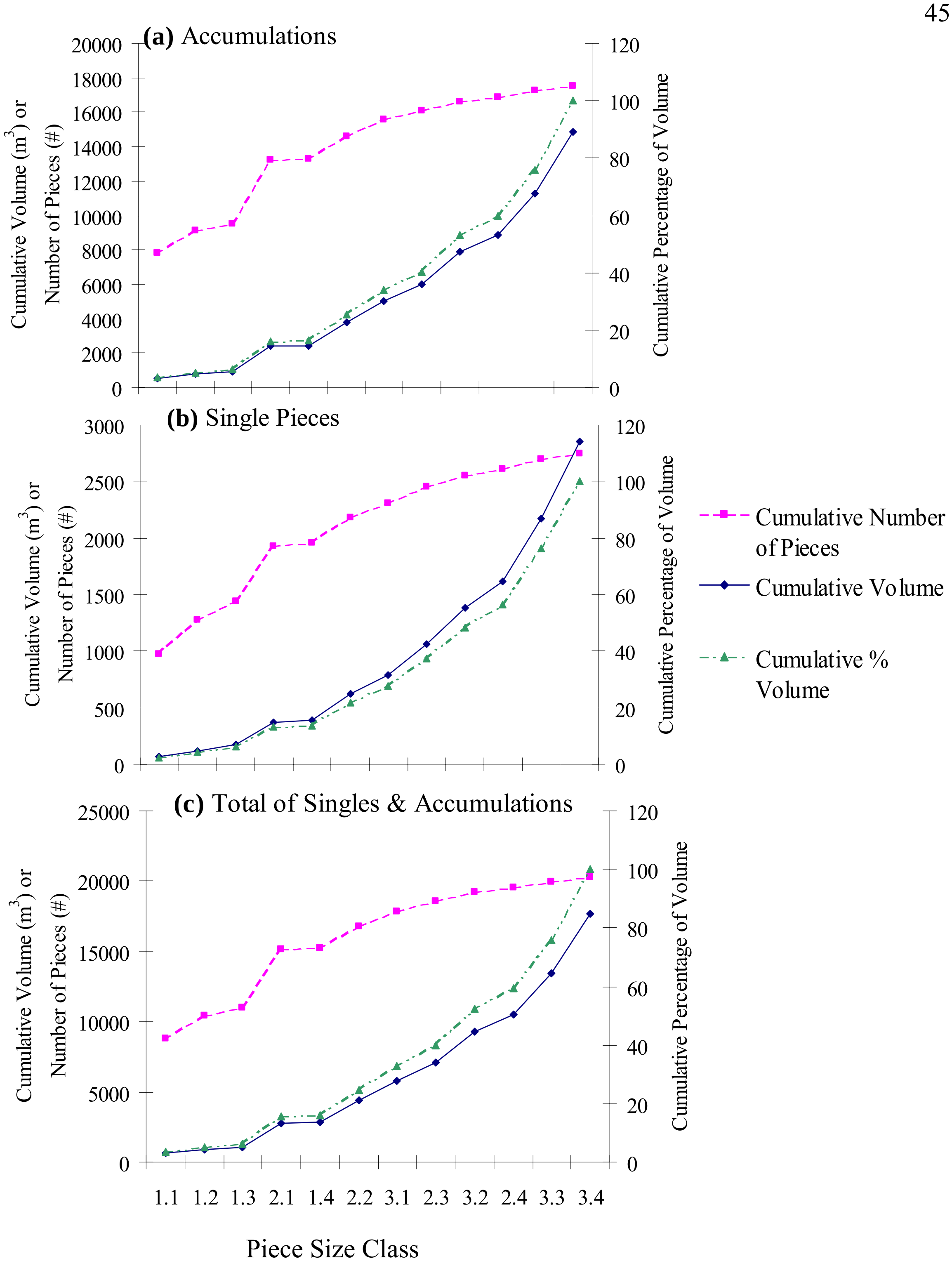


Figure 5.1. Volume and piece size relationship over all six sampling sites. Relationships expressed by percentage of volume contained in all pieces, cumulative volume (m^3), and cumulative number of pieces for: (a) accumulations, (b) singles, and (c) accumulations and singles combined. See Table 5.1 for piece size classes.

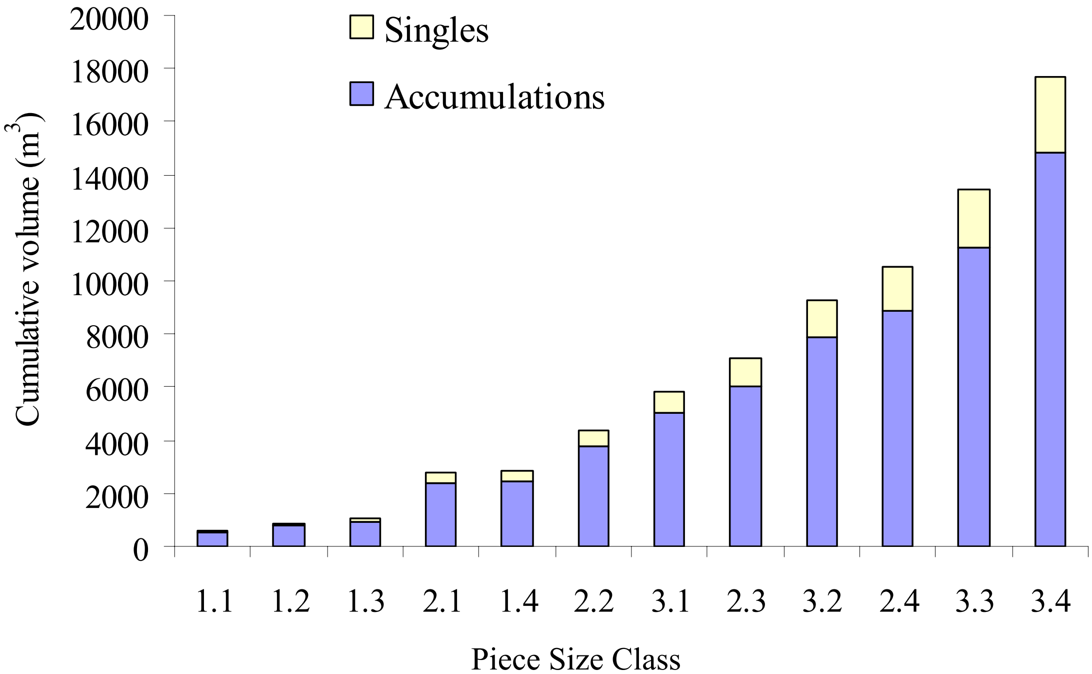


Figure 5.2. Relationship of volume in accumulations vs. singles for all six sampling sites. Shown as a comparison of the cumulative volumes of total pieces, pieces in accumulations and pieces that are singles. See Table 5.1 for piece size classes.

Table 5.2. Numbers of sampled 50-m stream segments by distance to nearest harvest for each sampling site. Segments with no harvest within 40 m were considered to have no adjacent harvest.

	Distance to Nearest Harvest Unit					
	0 m	0-10m	10-20m	20-40m	> 40m	Total
Lower Lookout	9	7	2	16	84	118
Upper Lookout	39	1	2	21	107	170
Mack	14	2	0	0	15	31
McRae	24	1	1	3	49	78
Cook	34	2	0	5	21	62
Quentin	0	0	0	3	39	42
Total	120	13	5	48	315	501
% of Total	24	2	1	10	63	100

Chi-square analysis of categorical variables suggests that distance of harvest and roads to the stream is correlated with sampling site ($p<0.001$). Four out of six sampling sites were dominated by 50-m stream segments where harvest was adjacent to the stream, the highest was Mack (92%), followed by Cook (87%), McRae (86%), and Upper Lookout (67%) (Table 5.2). Lower Lookout had only 25% of its adjacent to harvest 50-m stream segments, while 50% had harvest 40 m from the stream. Quentin had only 50-m stream segments with harvest 20-40 m from the stream. Those 50-m stream segments with harvest greater than 0 and less than 40 m had low numbers in each of the sampling sites (0% to 20%).

Stream segments with no harvest or roads within 40 m had significantly more wood volume and large pieces than 50-m stream segments with harvest immediately adjacent to (0 m) the stream and those with harvest 20-40 m from the stream ($p<0.0001$) (Table 5.3). Stream segments with harvest >0 to 20 m from the stream had intermediate levels of wood.

Stream segments adjacent to harvests or roads (i.e. within 40 m) had varying combinations of harvest on one or both sides and roads on one or both sides. Overall, nearly 57% (285) of the 501 sampled 50-m stream segments have no harvest or roads (Table 5.4, Figure 5.3). Of the 216 50-m stream segments with either harvest or roads, over half (57%) of the segments had harvest on only one side of the stream. Nearly 29% of the 216 50-m stream segments had a road. Of the nearly two-thirds of 50-m stream segments with roads, half have only roads and nearly one-third also have harvest on one side. Comparatively, there are very few cases of harvest on both sides of the stream, with or without roads. Regardless, in all six sample sites there were contiguous 50-m stream segments within 40 m of harvest or roads, ranging from less than one 50-m stream segment (50 m) to over 30 50-m stream segments in a row (1.5 km) (Figure 5.3).

Table 5.3. Volume of wood in 50-m stream segments based on distance to nearest harvest unit. Volume (m^3/ha) is expressed per channel area for a 50-m stream segment for all sampling sites combined in Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making non-independent comparisons (10 for volume and 6 for large pieces)).

Distance to Nearest Harvest	N	Mean		95% CI
Volume (m^3/ha) ($p<0.0001$, $F_{4, 466}=16.85$)				
0 m	120	144.3	a	116.3, 179.1
10 m	13	202.4	ab	105.0, 390.0
20 m	5	249.1	ab	86.5, 717.5
40 m	48	120.6	a	85.7, 169.7
>40 m	285	355.6	b	309.1, 409.1
Number of Large Pieces (#/ha) ($p<0.0001$, $F_{3, 409}=12.58$)				
0 m	88	32	a	27, 39
10 m	13	43	ab	26, 70
40 m	38	29	a	22, 38
>40 m	274	57	b	51, 63

Table 5.4. Number of 50-m stream segments harvest and road class for each of the 6 sample sites. All harvest and road classes refer to the presence or absence of harvest or roads within 40 m of the stream.

	None	Harvest One Side	Harvest Two Sides	Roads Only	Harvest One Side & Roads	Harvest Two Sides & Roads	Total
Lower Lookout	55	25	0	29	7	2	118
Upper Lookout	107	42	10	0	11	0	170
Mack	14	6	8	1	0	2	31
McRae	49	22	4	0	0	3	78
Cook	21	26	8	0	2	5	62
Quentin	39	3	0	0	0	0	42
Total	285	124	30	30	20	12	501

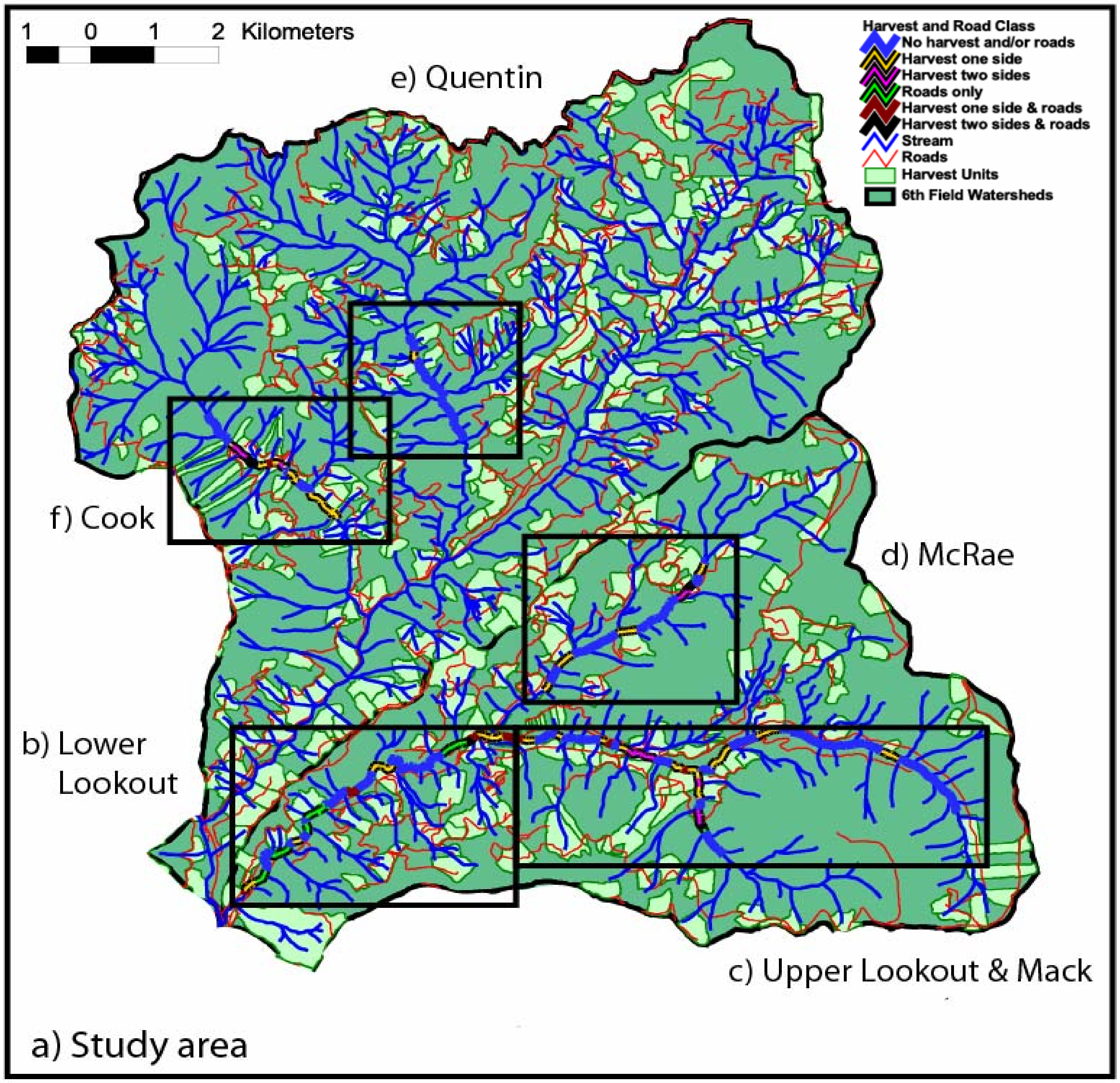


Figure 5.3. Maps of harvest and road classes for all six sampling sites in Blue River Basin. Maps include (a) an overview of the entire study area and (b-f) enlargements of each sampling site. The area included in enlargements are displayed above on overall map; starting from the lower left and going counter-clockwise are (b) Lower Lookout, (c) Upper Lookout and Mack, (d) McRae, (e) Quentin, and (f) Cook. Note: occasionally harvest units or roads layers do not correspond directly with harvest and road class. This is due to errors in GIS layers. The most accurate representations of harvest and road proximity are found in the harvest and road classes.

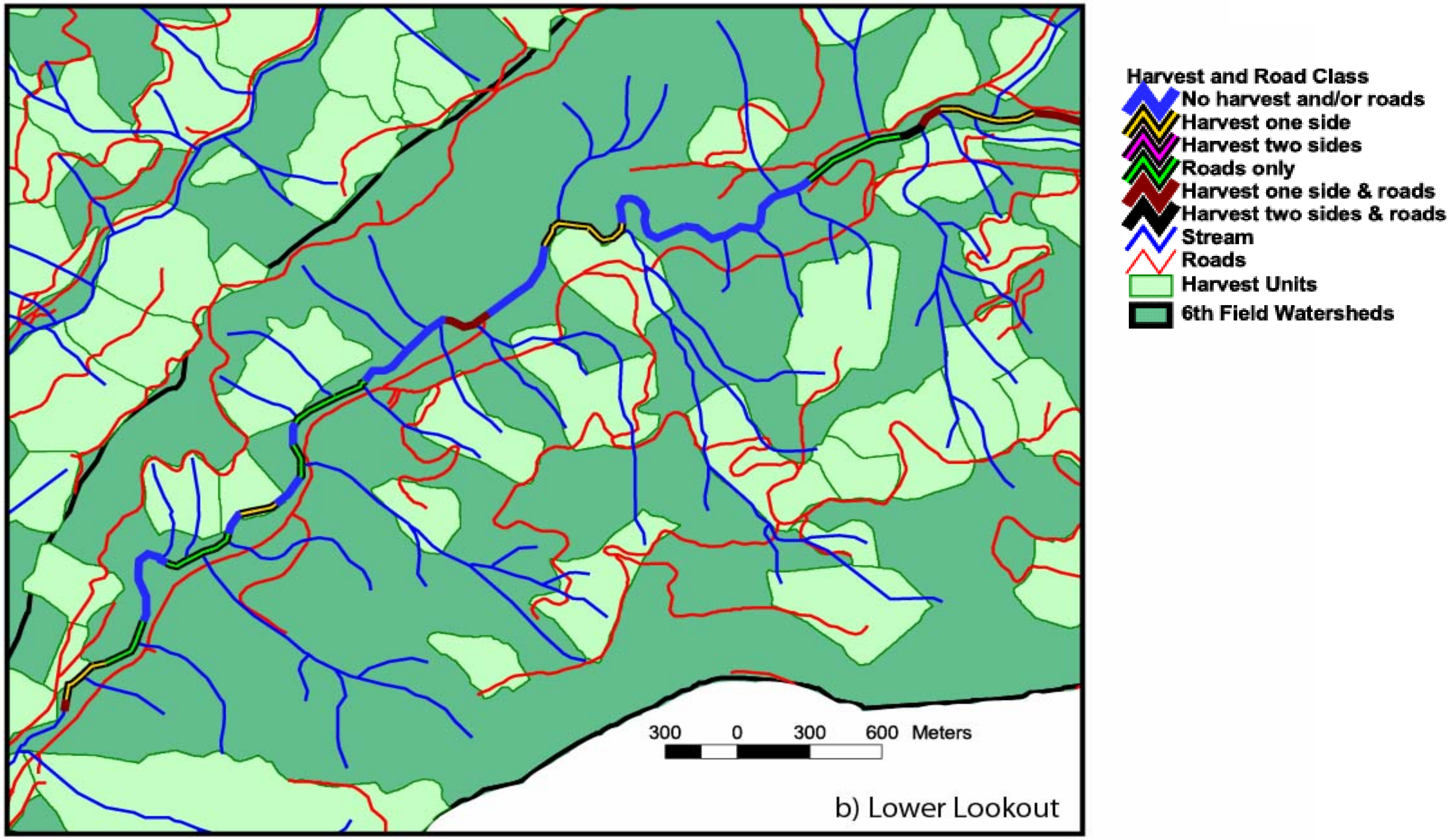
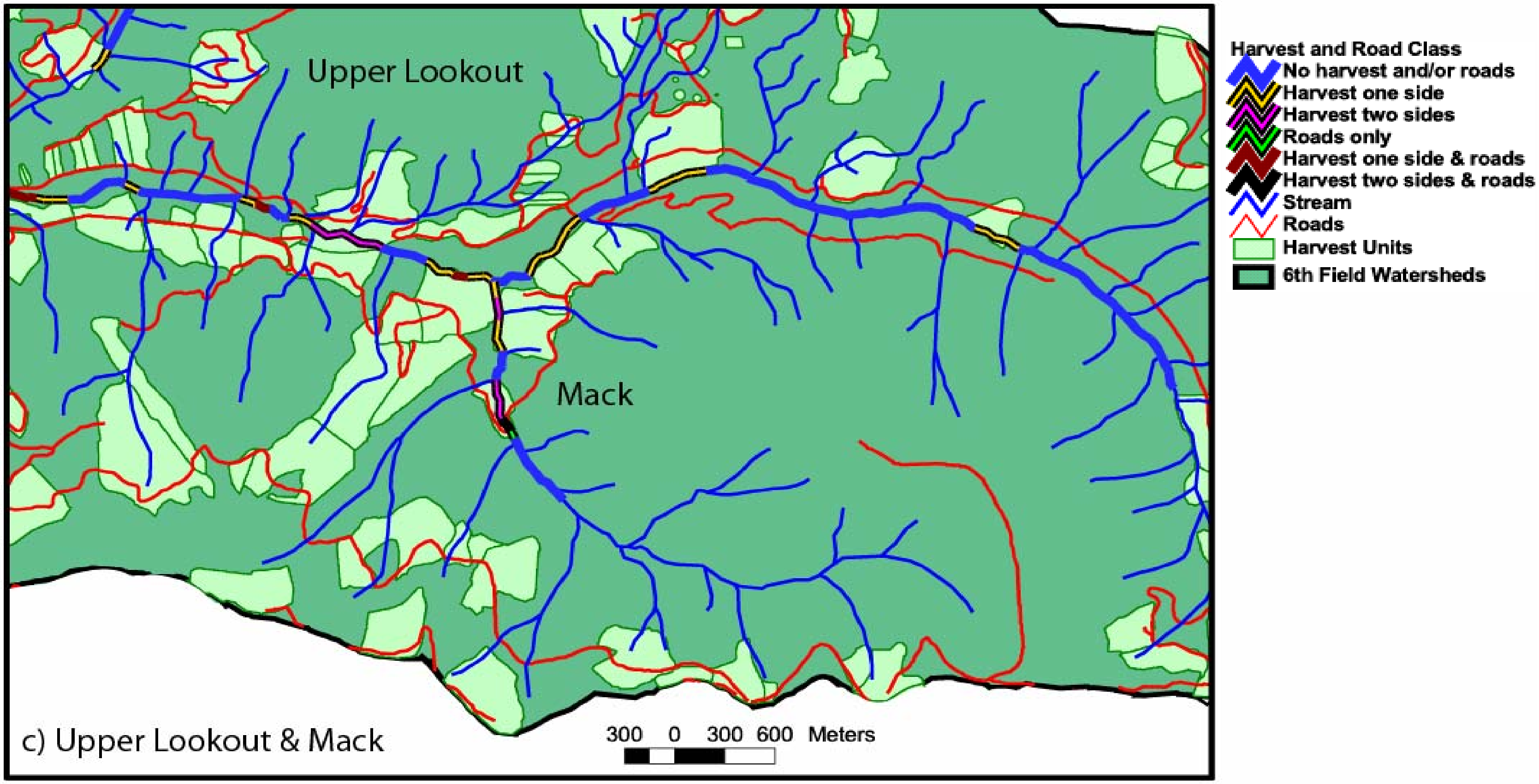


Figure 5.3. (continued)



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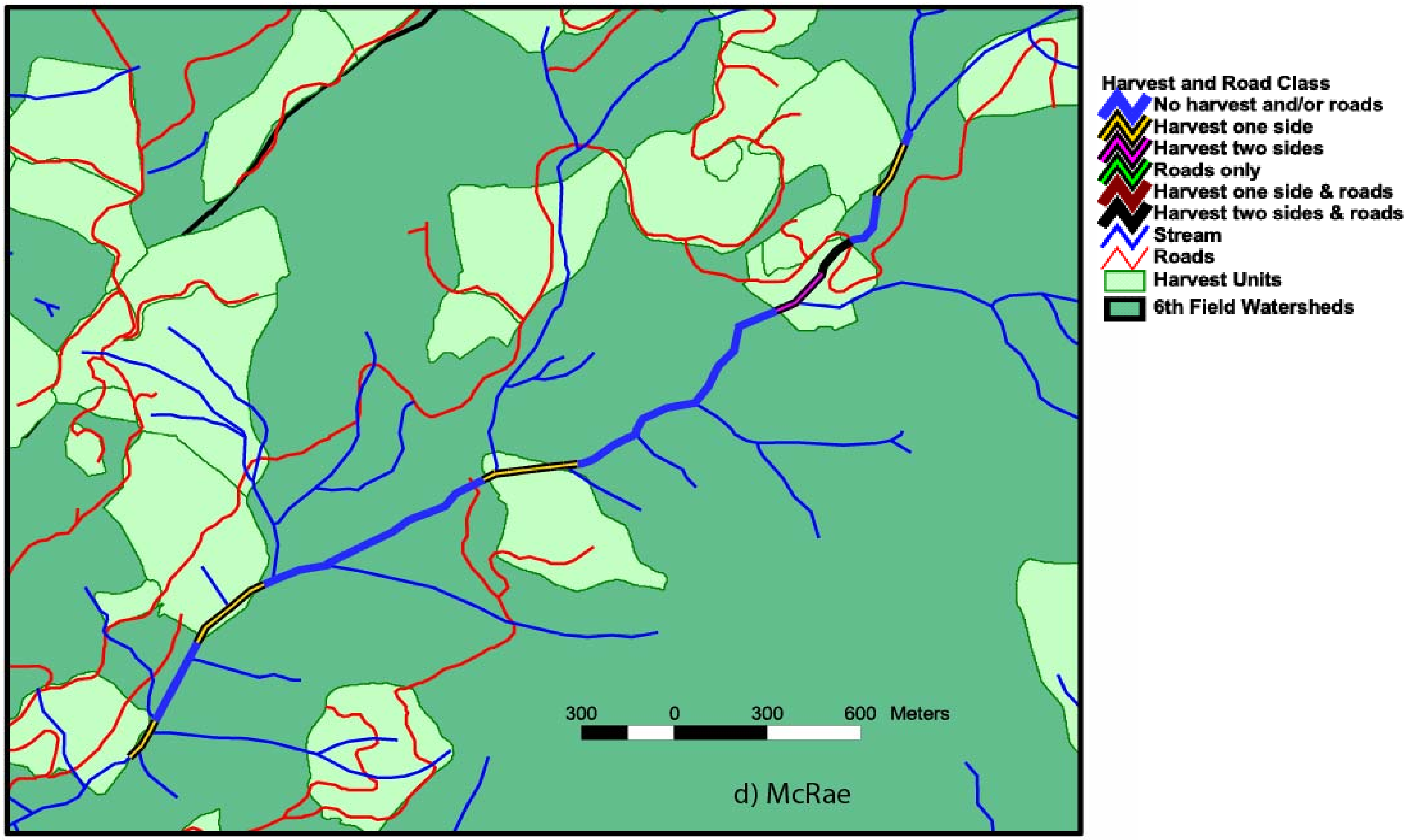

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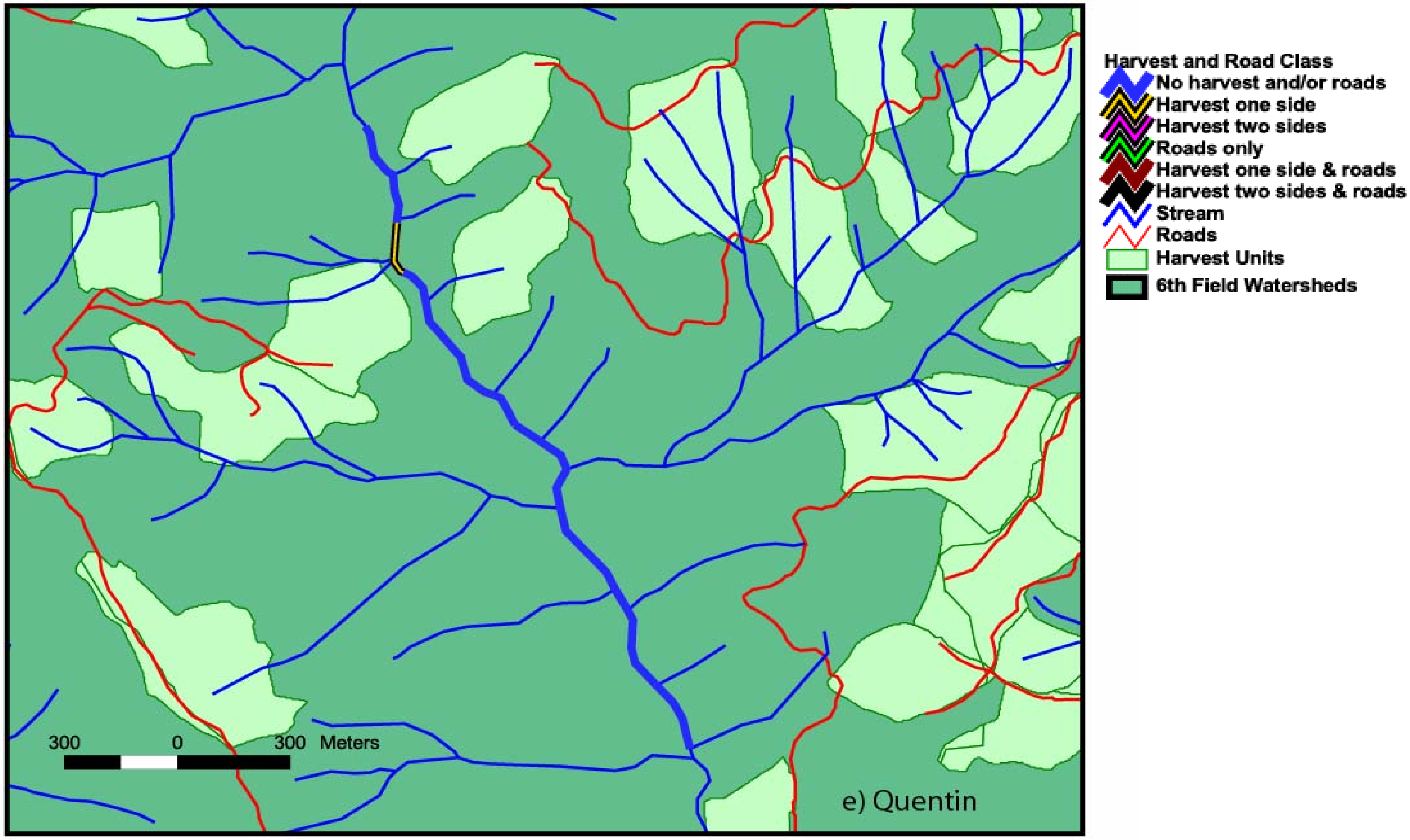

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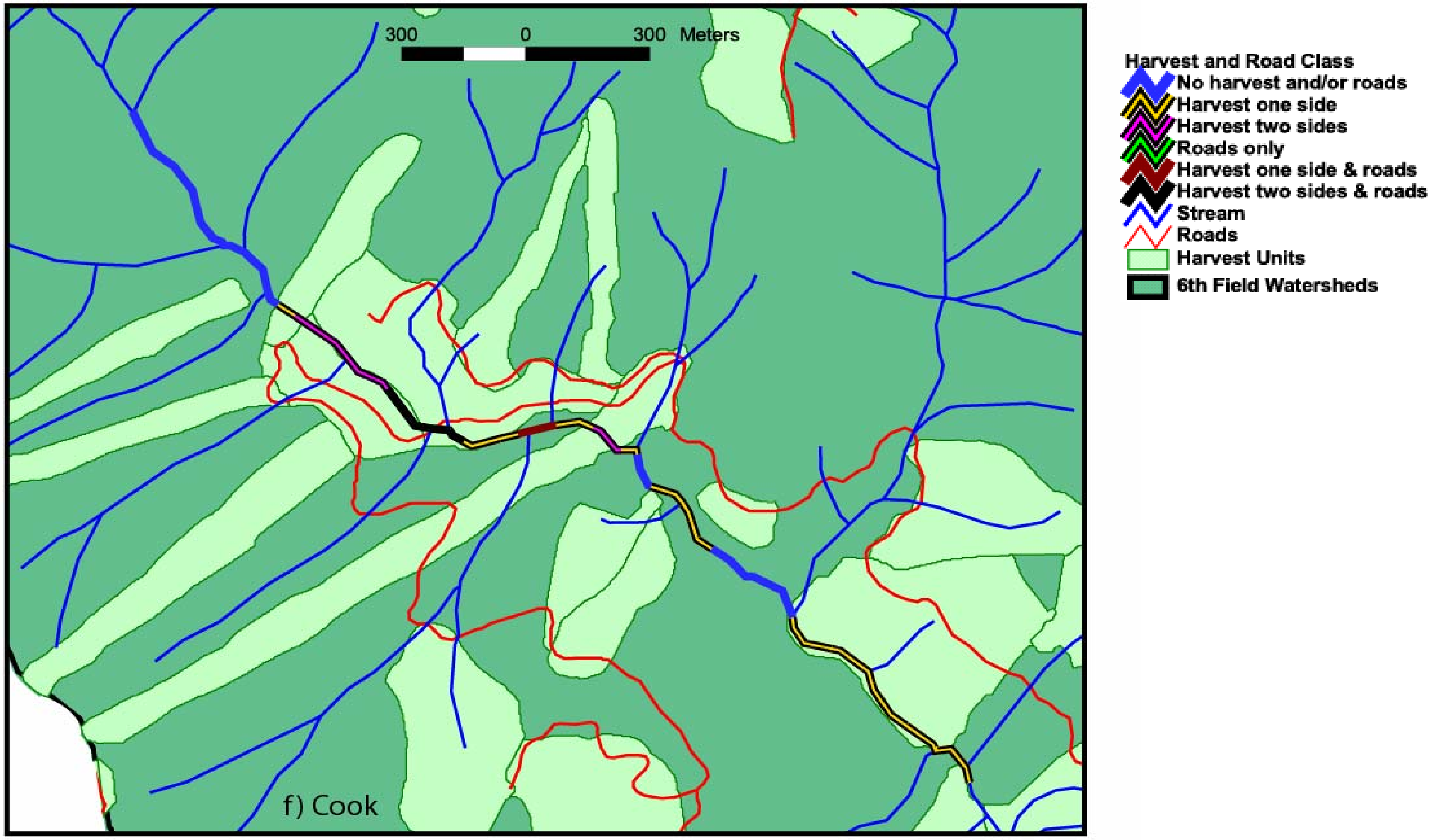


Figure 5.3. (continued)

The length of stream in sampling sites affected by harvests and roads is disproportionately larger than the upslope area of landscape affected by harvests and roads (Figure 5.3). In all of the basins studied, less than or approximately one-quarter of the total landscape has harvest and roads (USDA 1996, McKenzie River RD 2001). Along the stream, in every sampling site except Quentin, two-fifths to two-thirds of the 50-m stream segments had harvest or roads near the stream. Cook has the highest ratio of 50-m stream segments with roads or harvest (66%), followed by Upper Lookout (37%), Lower Lookout (53%), Mack (55%), McRae (37%), and Quentin (7%). Chi-square analyses suggest that 50-m stream segments with harvest and roads area correlated with sampling site ($p<0.0001$). Over 57% of 50-m stream segments are in Upper and Lower Lookout. Over 61% of the 50-m stream segments with roads are located in Lower Lookout.

Over three-quarters of the harvests adjacent to streams occurred in the 1950's and 1960's, and a majority of the remaining quarter was cut in the 1970's (Table 5.5, Figure 5.4). In Upper Lookout 35 of the 73 50-m stream sides with harvest were harvested in the 1950's (48%), 24 in the 1960's (33%), and 14 in the 1970's (19%). In Lower Lookout, 23 of the 36 50-m stream sides with harvest were harvested in the 1950's (64%), 8 in the 1960's (22%), 4 in the 1970's (11%), and 1 in the 1980's (3%). In Mack, 5 of the 26 50-m stream sides with harvest were harvested in the 1950's (19%), 19 in the 1960's (73%), and 2 in the 1980's (8%). In McRae, all 36 of 50-m stream sides with harvest were harvested in the 1950's (100%). In Cook, 30 of the 54 50-m stream sides with harvest were harvested in the 1960's (56%), 11 in the 1970's (20%), and 13 in the 1980's (24%). In Quentin, all 3 of the 50-m stream sides with harvest were harvested in the 1980's (100%). The timing of road building was similar (Jones and Grant 1996).

Chi-square analyses suggest timing of harvest is correlated with sampling site ($p<0.0001$). Lookout Creek basin (Upper and Lower Lookout, Mack and McRae combined) had 58% of the 50-m stream sides harvested in the 1950's, 30% in the 1960's, 10% in the 70's and only 2% in the 1980's. In the Blue River basin (Cook and Quentin combined), 0% of 50-m stream sides were harvested in the 1950's, 53% in the 1960's, 19% in the 1970's, and 28% in the 1980's.

Table 5.5. Timing of harvest by decade expressed in number of 50-m stream sides and the percentage of total 50-m stream sides.

Sampling site	Number of 50-m Stream sides				Total Number Stream sides	Percentage of Total 50-m Stream sides			
	50's	60's	70's	80's		50's	60's	70's	80's
Lower Lookout	23	8	4	1	36	64	22	11	3
Upper Lookout	35	24	14	0	73	48	33	19	0
Mack	5	19	0	2	26	19	73	0	8
McRae	36	0	0	0	36	100	0	0	0
Quentin	0	0	0	3	3	0	0	0	100
Cook	0	30	11	13	54	0	56	20	24

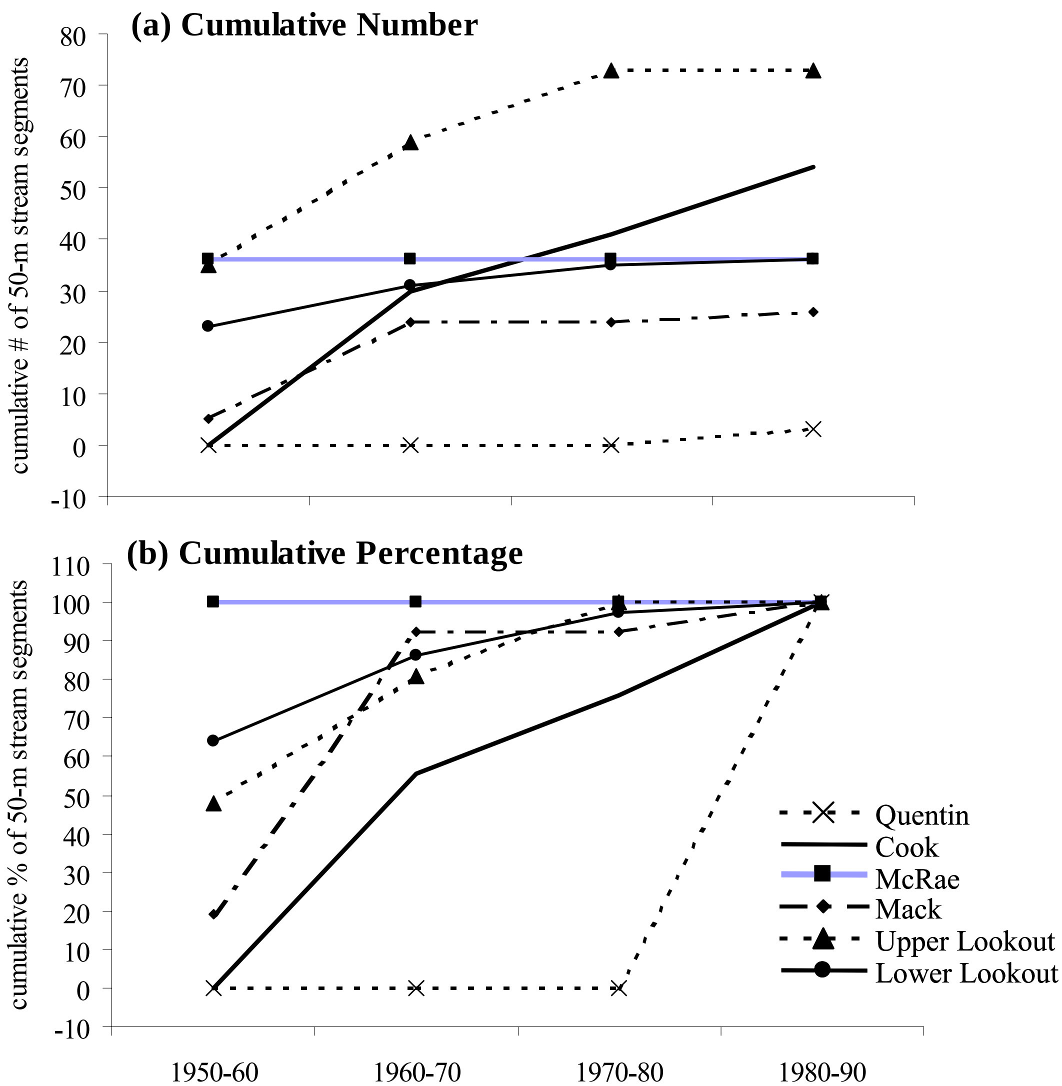


Figure 5.4. Timing of riparian harvest for each sampling site expressed as (a) cumulative number of one-sided 50-m stream segments with harvest within 40 m of the stream by decade and sampling site (b) cumulative percentage of one-sided 50-m stream segments within 40 m of the stream by decade and sampling site. Percentages are calculated out of total number of one-sided 50-m stream segments in the sampling site.

5.3 Site-scale spatial and temporal patterns of wood in streams

Wood volumes, numbers of large pieces, and numbers of accumulations varied significantly among sites. Lower Lookout had significantly lower wood volumes (109.1 m^3/ha, $p<0.05$), numbers of large pieces (23 pieces/ha, $p<0.02$), and numbers of accumulations (16 accumulations/ha, $p<0.0001$) than all other sampling sites (Table 5.6, Figure 5.5). McRae (377.7 m^3/ha, 64 pieces/ha) had significantly higher wood volumes and large pieces than Cook (200.0 m^3/ha, $p<0.04$; 39 pieces/ha, $p<0.03$; 29 accumulations/ha, $p<0.04$). Cook also had a significantly lower number of large pieces than Upper Lookout (60 pieces/ha, $p<0.04$). McRae (41 accumulations/ha) also had more accumulations than Lower Lookout and Quentin (16-28 accumulations/ha, $p<0.04$).

Controlling for local harvest and road effects, unharvested and unroaded 50-m stream segments in Lower Lookout had a significantly lower wood volume (143.1 m^3/ha, $p<0.02$), number of large pieces (24 pieces/ha, $p<0.002$), and number of accumulations (16 accumulations/ha, $p<0.0001$) than all other sampling sites (Table 5.7, Figure 5.6). When 50-m stream segments with harvest on one side of the stream were evaluated, Lower Lookout had significantly lower wood volume (80.9 m^3/ha, $p<0.09$) and number of large pieces (24 pieces/ha, $p<0.06$) than only Upper Lookout (205.7 m^3/ha, 47 pieces/ha) (Table 5.8, Figure 5.7). Also, Lower Lookout (20 accumulations/ha) had fewer accumulations than McRae (35 accumulations/ha, $p<0.05$) when harvest occurred on just one side of the stream.

When controlling for local harvest and road effects, Quentin had lower wood abundance than other sites in the Blue River basin. Unharvested and unroaded 50-m stream segments of Quentin (29 accumulations/ha; 284.8 m^3/ha) had significantly fewer accumulations than Mack (53 accumulations/ha, $p<0.02$) and accumulations and volume than McRae (43 accumulations/ha, $p<0.03$; 548.7 m^3/ha, $p<0.05$) (Table 5.7, Figure 5.6).

Table 5.6. Patterns of wood in all 50-m stream segments. Volume (m^3), large pieces, and accumulations are expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 15 non-independent comparisons). See Figure 5.5.

Sampling Site	N	Mean	95% CI
Volume (m^3/ha) ($p<0.05$, $F_{5,495}=13.30$)			
Lower Lookout	118	109.1 a	87.0, 136.9
Cook	62	200.0 b	146.3, 273.4
Mack	31	229.5 bc	147.5, 357.2
McRae	78	377.7 c	285.8, 499.2
Quentin	42	291.2 bc	199.1, 425.8
Upper Lookout	170	313.1 bc	259.2, 378.2
Number of Large Pieces (#/ha) ($p<0.04$, $F_{5,430}=17.19$)			
Lower Lookout	98	23 a	19, 28
Cook	54	39 b	31, 49
Mack	23	45 bc	32, 65
McRae	71	64 c	53, 79
Quentin	40	51 bc	39, 67
Upper Lookout	150	60 c	52, 69
Number of Accumulations (#/ha) ($p<0.04$, $F_{5,457}=30.05$)			
Lower Lookout	107	16 a	14, 17
Cook	58	29 b	25, 34
Mack	27	41 bc	32, 51
McRae	76	41 c	35, 47
Quentin	39	28 b	23, 34
Upper Lookout	156	33 bc	30, 37

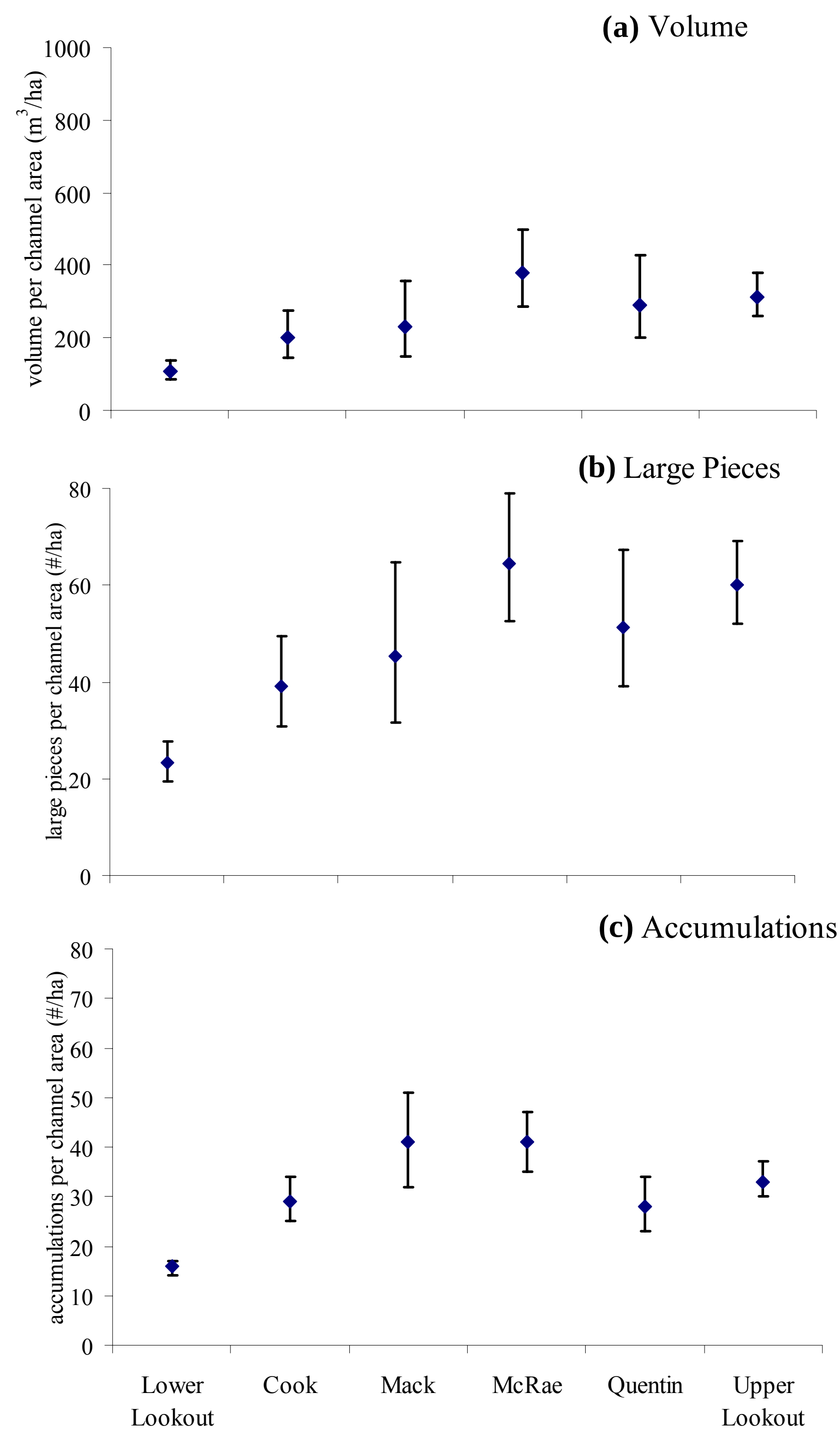


Figure 5.5. Site-scale patterns of wood in streams. Expressed as (a) estimate of volume (m^3), (b) number of large pieces, and (c) number of accumulations, along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See Table 5.6.

Table 5.7. Site-scale patterns of wood in 50-m stream segments with no adjacent harvest or roads. Volume (m^3), large pieces, and accumulations are expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 15 non-independent comparisons). See Figure 5.6.

Sampling Site	N	Mean	95% CI
Volume (m^3/ha) ($p<0.02$, $F_{5,279}=12.67$)			
Lower Lookout	55	143.1 a	108.9, 187.8
Cook	21	437.1 bc	281.3, 679.2
Mack	14	473.9 bc	276.2, 813.2
McRae	49	548.7 c	411.2, 732.3
Quentin	39	284.8 b	206.1, 393.6
Upper Lookout	107	466.9 bc	384.1, 567.6
Number of Large Pieces (#/ha) ($p<0.002$, $F_{5,268}=15.40$)			
Lower Lookout	52	24 a	19, 30
Cook	21	59 b	41, 84
Mack	13	66 b	42, 103
McRae	49	81 b	64, 102
Quentin	37	51 b	39, 67
Upper Lookout	102	75 b	64, 88
Number of Accumulations (#/ha) ($p<0.03$, $F_{5,266}=22.31$)			
Lower Lookout	52	16 a	13, 18
Cook	20	37 bc	29, 48
Mack	13	53 b	39, 73
McRae	49	43 b	36, 51
Quentin	35	29 c	23, 35
Upper Lookout	102	37 bc	33, 42

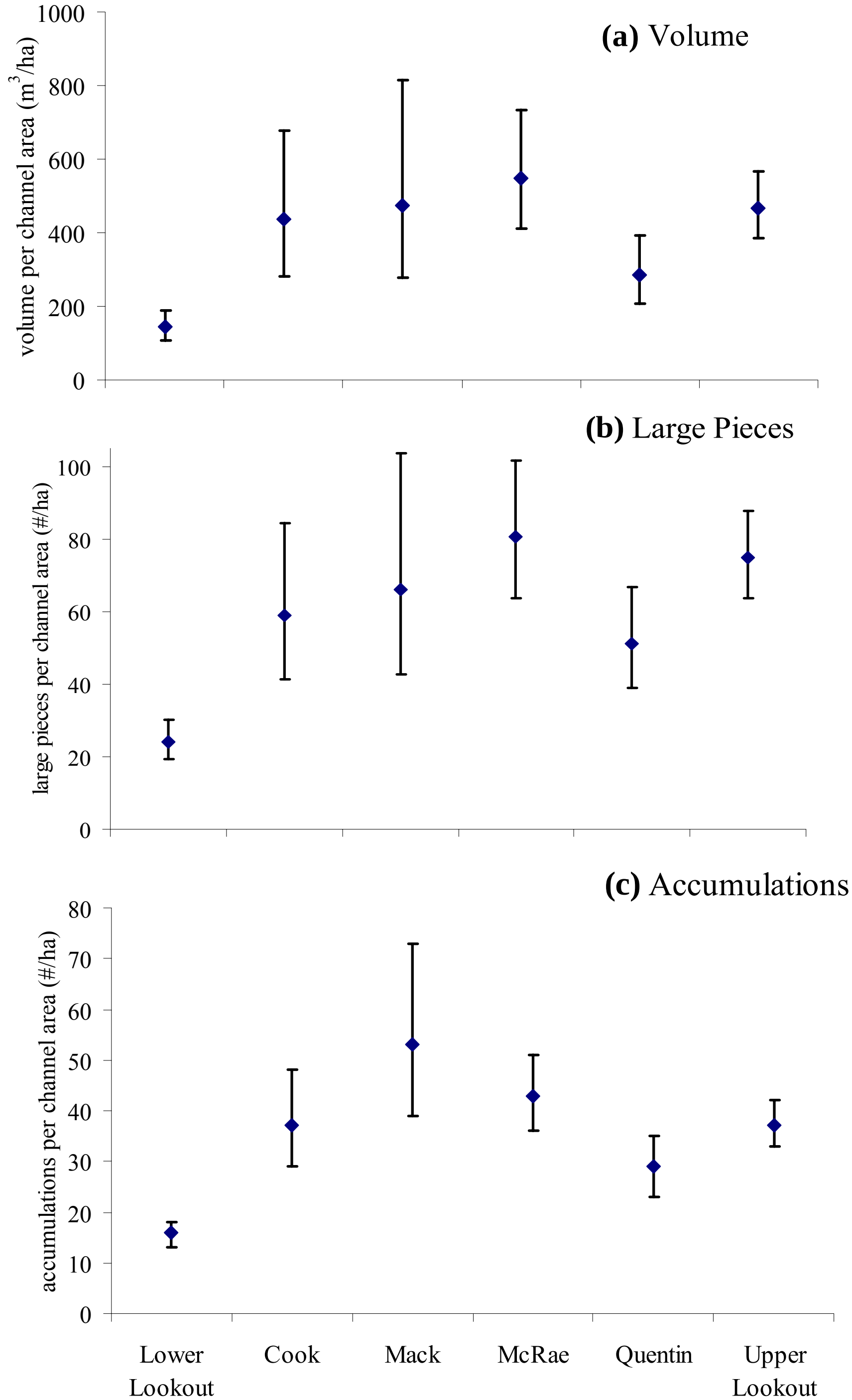


Figure 5.6. Site-scale patterns of wood in 50-m stream segments with no adjacent harvest. Expressed as (a) estimate of volume (m^3), (b) number of large pieces, and (c) number of accumulations, along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See Table 5.7.

Table 5.8. Site-scale patterns of wood in 50-m stream segments with harvest on one side of the stream. Volume (m^3), large pieces, and accumulations are expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making non-independent comparisons (10 for volume and accumulations and 6 for large pieces)). See Figure 5.7.

Sampling Site	N	Mean	95% CI
Volume (m^3/ha) ($p<0.05$, $F_{4,116}=1.91$)			
Lower Lookout	25	80.9 a	46.9, 140.1
Cook	26	149.7 ab	87.4, 256.6
Mack	6	158.1 ab	51.5, 485.1
McRae	22	185.6 ab	103.3, 333.4
Upper Lookout	42	205.7 b	134.6, 314.2
Number of Large Pieces (#/ha) ($p<0.06$, $F_{3,83}=2.52$)			
Lower Lookout	16	24 a	16, 36
Cook	20	44 ab	31, 63
McRae	17	38 ab	26, 57
Upper Lookout	34	46 b	35, 61
Number of Accumulations (#/ha) ($p<0.05$, $F_{4,102}=2.35$)			
Lower Lookout	21	20 a	15, 26
Cook	25	29 ab	23, 38
Mack	6	30 ab	18, 50
McRae	20	35 b	26, 46
Upper Lookout	35	31 ab	25, 38

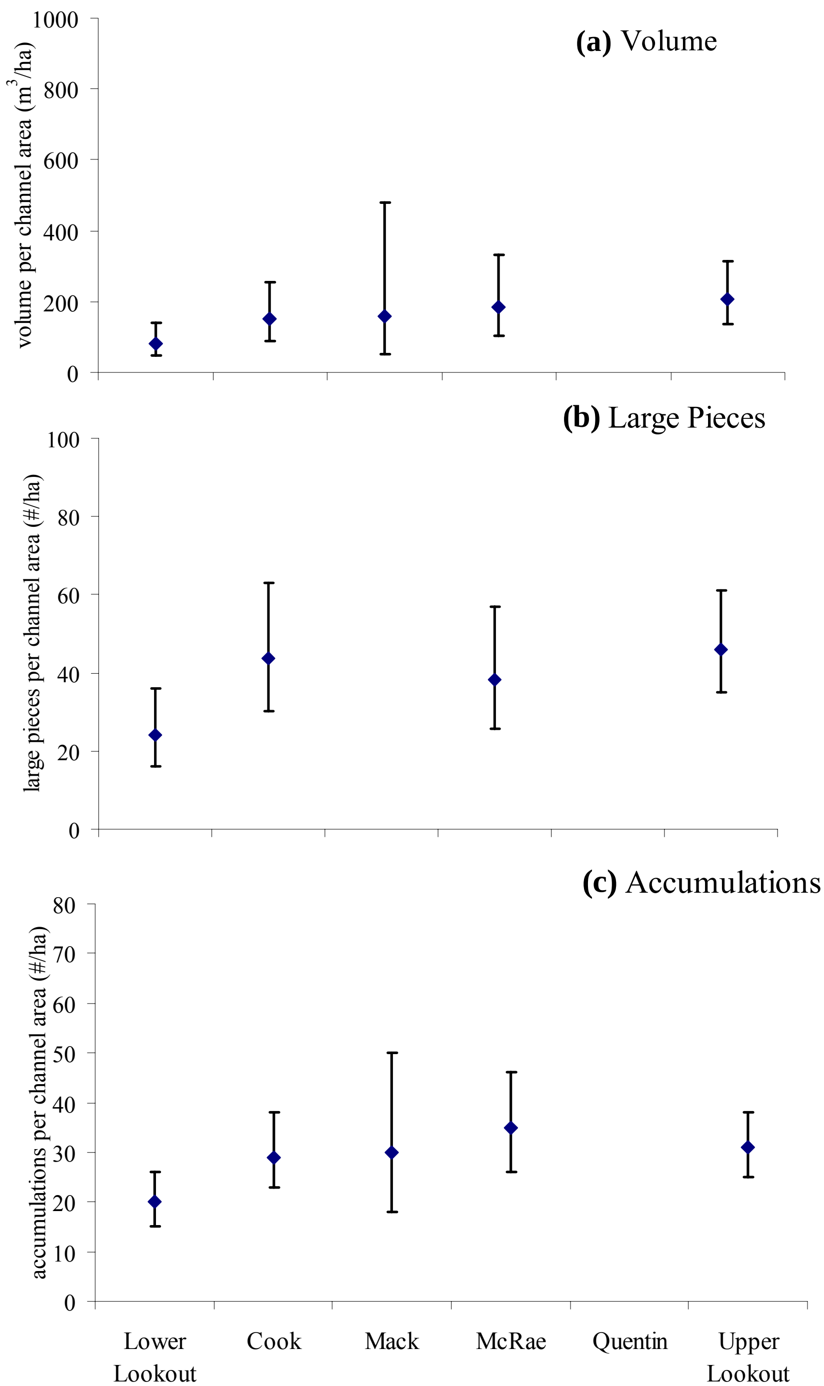


Figure 5.7. Site-scale patterns of wood in 50-m stream segments with harvest on one side of the stream. Expressed as (a) estimate of volume (m^3), (b) number of large pieces, and (c) number of accumulations, along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See Table 5.8.

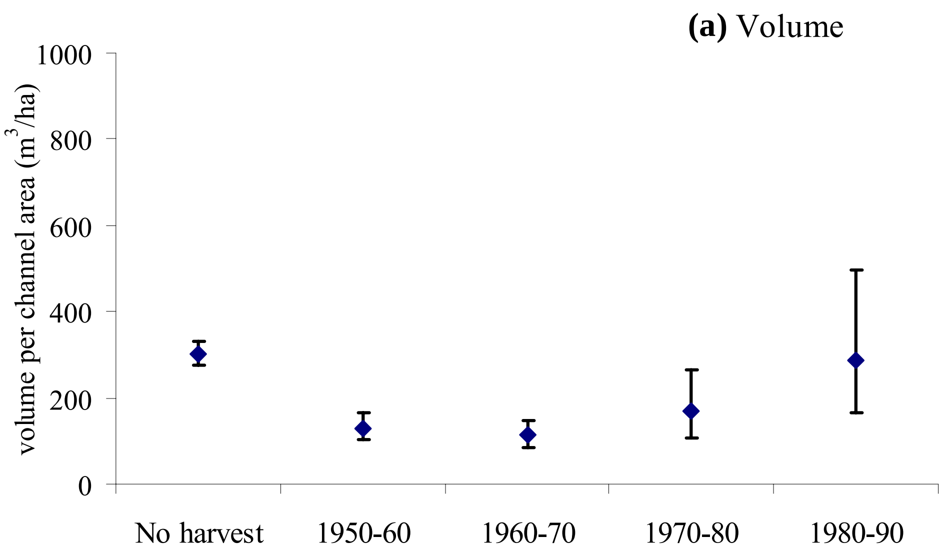
When using units of channel length and controlling for local effects of harvest and roads, there were some different relationships found between sampling sites than when wood abundance was evaluated by units of channel width. Lower Lookout (n=55) had less volume than Cook ($p<0.06$, n=21) and McRae ($p<0.007$, n=49), but only less large pieces than Mack ($p<0.007$, n=14). Cook (n=21), Mack (n=14), and McRae (n=49) had fewer accumulations than Lower Lookout ($p<0.006$, n=55) and Upper Lookout ($p<0.06$, n=107). Also, Mack (n=14) had more accumulations than Quentin ($p<0.09$, n=39).

Stream segments adjacent to harvests from the 1950's and 1960's had significantly lower wood volumes and fewer large pieces of wood then 50-m stream segments with no harvest. The 50-m stream sides with no harvest had significantly higher wood volume (300.6 m^3/ha) than 50-m stream segments with harvests from the 1950's (130.5 m^3/ha, $p<0.0001$) and 1960's (112.3 m^3/ha, $p<0.0001$) (Table 5.9, Figure 5.8). Additionally, harvest in the 1960's (112.3 m^3/ha) had significantly lower wood volume than harvest in the 1980's (286.0 m^3/ha, $p<0.03$). The 50-m stream sides with no harvest (52 pieces/ha) had significantly higher numbers of large pieces than all others (24-37 pieces/ha), but there were no significant between decade differences ($p<0.002$). Earlier harvests tend to be closer to the channel than later harvests (Figure 5.9), but because distance does not greatly influence wood abundance, it likely does not influence these results.

Chi-square analysis suggests that time of harvest is correlated with basin position ($p<0.0001$) (Table 5.10). In the 1950's, more 50-m stream sides (23%) than overall (18%) were associated with lower parts, while less (49%) than overall (57%) were in intermediate parts of the basin. In the 1960's, less 50-m stream sides (10%) than overall (18%) were associated with lower parts, more (59%) than overall (57%) in intermediate, and more (31%) than overall (25%) in higher parts of the basin. In the 1970's, less 50-m stream sides (3%) than overall (18%) were associated with lower parts, more (97%) than overall (57%) in intermediate, and less (0%) than overall (25%) in higher parts of the basin. In the 1980's, less 50-m stream sides (5%) than overall (18%) were associated with lower parts, more (84%) than overall (57%) in intermediate, and less (11%) than overall (25%) in higher parts of the basin.

Table 5.9. Volume and number of large pieces in streams adjacent to harvest units, by decade of harvest. Volume (m^3) and large pieces are expressed per channel area of 50-m stream sides (ha) for all six sampling sites combined with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 10 non-independent comparisons). See Figure 5.8.

Decade	N	Mean	95% CI
Volume (m^3/ha) ($p<0.03$, $F_{4,937}=20.22$)			
No harvest	714	300.6 a	274.6, 329.1
1950's	99	130.5 bcd	102.3, 166.4
1960's	81	112.3 bc	85.9, 147.0
1970's	29	168.3 ac	107.4, 263.7
1980's	19	286.0 ad	164.2, 498.1
Number of Large Pieces (#/ha) ($p<0.002$, $F_{4,823}=12.01$)			
No harvest	660	52 a	49, 56
1950's	68	34 b	27, 42
1960's	54	29 b	23, 37
1970's	28	24 b	17, 34
1980's	18	37 ab	24, 56



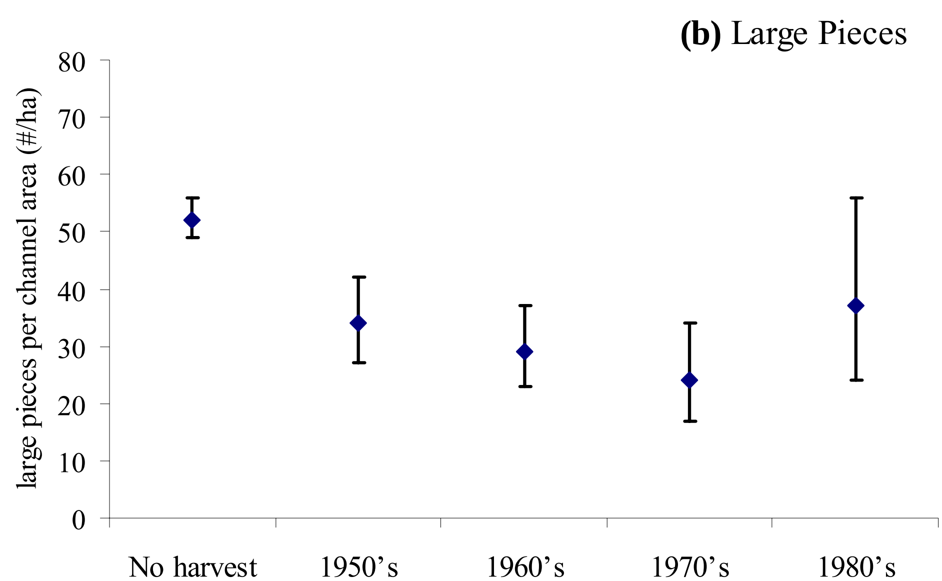


Figure 5.8. Differences among time of harvest for volume and number of large pieces. Expressed as (a) estimate of volume (m^3) and (b) number of large pieces, along with 95% confidence intervals, expressed per channel area of 50-m stream sides (ha) for all six sampling sites combined with sample sizes >5 in the Blue River Basin. See Table 5.9.

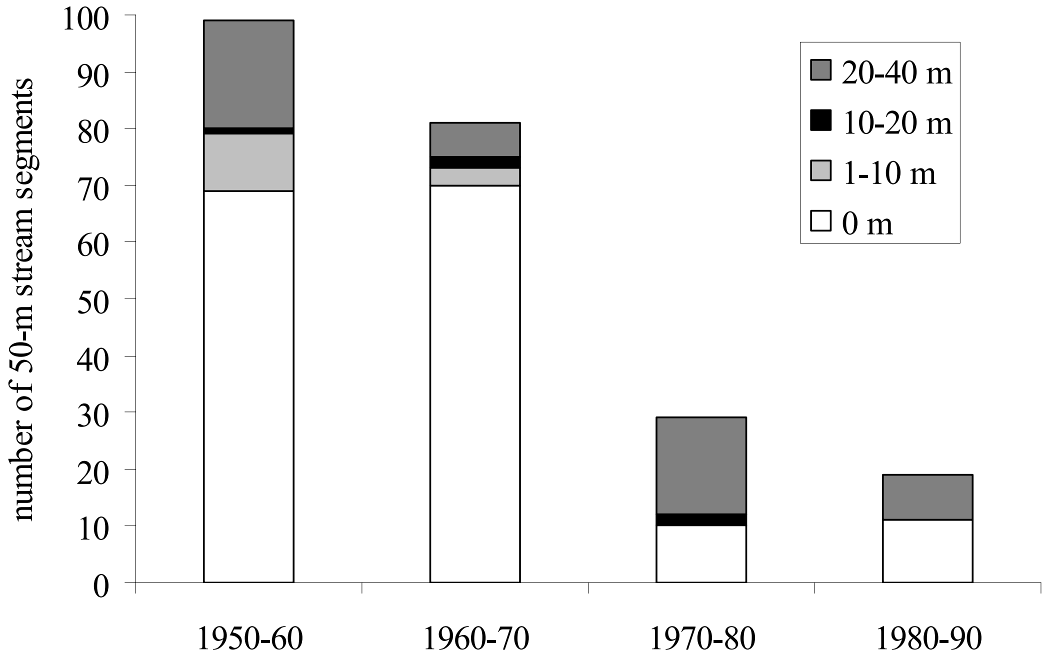


Figure 5.9. Number of 50-m stream segments with harvest present at varied distances from the stream, shown by decade of harvest.

Table 5.10. Degree of association between time of harvest and drainage area. Expressed as number of 50-m stream sides with percentage of total in parentheses.

Time of Harvest	1-10 km^2	10-49 km^2	49+ km^2	Total
0	181 (25)	394 (55)	139 (20)	714
1950	28 (28)	48 (49)	23 (23)	99
1960	25 (31)	48 (59)	8 (10)	81
1970	0 (0)	28 (97)	1 (3)	29
1980	2 (11)	16 (84)	1 (5)	19
Total	236 (25)	534 (57)	172 (18)	942

5.4 Spatial patterns of wood in streams by adjacent harvest and road treatments

Stream segments with no adjacent harvest or roads had higher wood volumes and numbers of large pieces than segments with harvest and/or roads. For all sites pooled, 50-m stream segments with neither road nor harvest adjoining them had significantly higher wood volumes (355.6 m^3/ha) and number of large pieces (57 pieces/ha) than all other treatments (79.7 to 156.9 m^3/ha, $p<0.03$; 18 to 39 pieces/ha, $p<0.01$) (Table 5.11, Figure 5.10). For individual sites, the same trend was true for both volume and number of large pieces for Upper Lookout, Mack, McRae, and Cook, but not for Lower Lookout or Quentin (because Quentin has a small sample size of harvest and roads). In Lower Lookout, wood volume and large pieces was generally lower than the other sampling sites and did not differ by harvest and road classes (Table 5.12, 5.13, Figure 5.11, 5.12).

- In Upper Lookout, 50-m stream segments without adjacent roads or harvests (466.9 m^3/ha, 75 pieces/ha) had significantly higher volume and number of large pieces than harvest on one side (205.7 m^3/ha, 46 pieces/ha) and harvest on two sides (55.2 m^3/ha, 19 pieces/ha), and higher volume than harvest on one side with roads (154.4 m^3/ha, $p<0.03$) (Table 5.12, 5.13, Figure 5.11, 5.12).
- In Mack Creek, 50-m stream segments without adjacent roads or harvests (473.9 m^3/ha, 67 pieces/ha) had significantly higher wood volumes and number of large pieces than harvests on both sides (163.3 m^3/ha, $p<0.06$; 32 pieces/ha, $p<0.03$) and volume than harvest on one side (158.1 m^3/ha, $p<0.08$) (Table 5.12, 5.13, Figure 5.11, 5.12).
- In McRae Creek, 50-m stream segments without adjacent roads or harvest (548.7 m^3/ha, 81 pieces/ha) had significantly higher volume and large pieces than 50-m stream segments with roads and harvests on one side of the stream (185.6 m^3/ha, adjusted $p < 0.0001$; 39 pieces/ha, $p<0.0001$) (Table 5.12, 5.13, Figure 5.11, 5.12).

Table 5.11. Local pattern of wood on streams (for all sites pooled) by adjacent harvest and road treatment. Volume (m^3), large pieces, and accumulations are expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 15 non-independent comparisons). See Figure 5.10.

Harvest and Road Class	N	Mean	95% CI
Volume (m^3/ha) ($p<0.03$, $F_{5, 495}=17.65$)			
None	285	355.6 a	308.2, 410.3
Harvest, one side	124	156.9 b	126.3, 195.0
Harvest, two sides	30	108.5 b	69.8, 168.6
Roads	30	79.7 b	51.3, 124.0
Harvest, one side & roads	20	140.8 b	82.0, 241.7
Harvest, two sides & roads	12	114.3 b	56.9, 229.7
Number of Large Pieces (#/ha) ($p<0.04$, $F_{5,430}=13.07$)			
None	274	57 a	51, 63
Harvest, one side	94	39 b	32, 46
Harvest, two sides	19	28 bc	19, 42
Roads	22	22 bc	15, 33
Harvest, one side & roads	18	19 c	13, 29
Harvest, two sides & roads	9	18 bc	10, 33
Number of Accumulations (#/ha) ($p<0.004$, $F_{5,457}=8.41$)			
None	272	32 a	29, 34
Harvest, one side	110	28 a	25, 32
Harvest, two sides	23	25 a	19, 33
Roads	26	16 b	13, 21
Harvest, one side & roads	20	16 b	12, 21
Harvest, two sides & roads	12	26 ab	18, 38

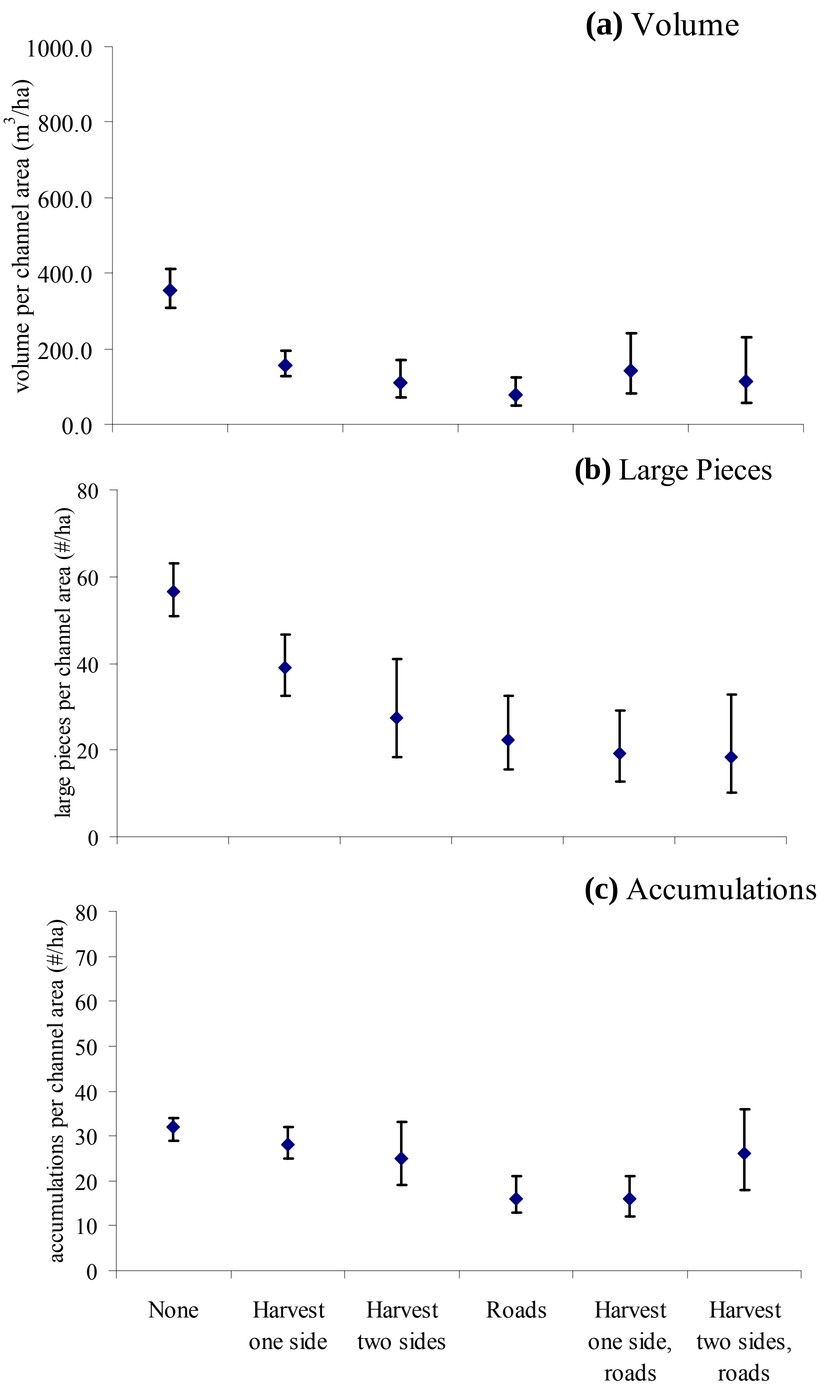


Figure 5.10. Local patterns of wood in streams by adjacent harvest and road treatments. Expressed as (a) estimate of volume (m^3), (b) number of large pieces, and (c) number of accumulations, along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See Table 5.11.

Table 5.12. Local patterns of wood volume for each individual sampling site, distinguished by adjacent harvest and road treatment. Volume is expressed per channel area (m^3/ha) of 50-m stream segments for forestry treatments with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making non-independent comparisons (6 for Upper and Lower Lookout and Cook, 3 for Mack and 1 for McRae and Quentin)). See associated Figure 5.11.

Harvest and Road Class	N	Mean	95% CI
Lower Lookout ($p>0.1$, $F_{3,112}=1.54$)			
None	55	143.1 a	98.0, 208.7
Harvest, one side	25	80.9 a	46.2, 141.6
Roads	29	80.1 a	47.6, 134.7
Harvest, one side & roads	7	129.6 a	44.9, 373.8
Upper Lookout ($p<0.02$, $F_{3,166}=14.64$)			
None	107	466.9 a	373.5, 583.7
Harvest, one side	42	205.7 b	144.0, 293.7
Harvest, two sides	10	55.2 c	26.6, 114.7
Harvest, one side & roads	11	154.4 bc	77.0, 309.7
Mack ($p<0.08$, $F_{2,25}=4.38$)			
None	14	473.9 a	278.6, 806.1
Harvest, one side	6	158.1 b	70.2, 355.8
Harvest, two sides	8	163.3 b	80.9, 329.6
McRae ($p<0.0001$, $F_{1,69}=28.59$)			
None	49	548.7 a	438.1, 687.3
Harvest, one side	22	185.6 b	132.6, 259.7
Cook ($p<0.01$, $F_{3,56}=5.79$)			
None	21	437.1 a	271.1, 704.8
Harvest, one side	26	149.7 b	97.4, 230.0
Harvest, two sides	8	87.2 b	40.2, 189.2
Harvest, two sides & roads	5	160.0 ab	60.1, 426.1
Quentin ($p>0.1$, $F_{1,40}=0.19$)			
None	39	284.8 a	194.7, 416.7
Harvest, one side	3	387.9 a	98.4, 1528.8

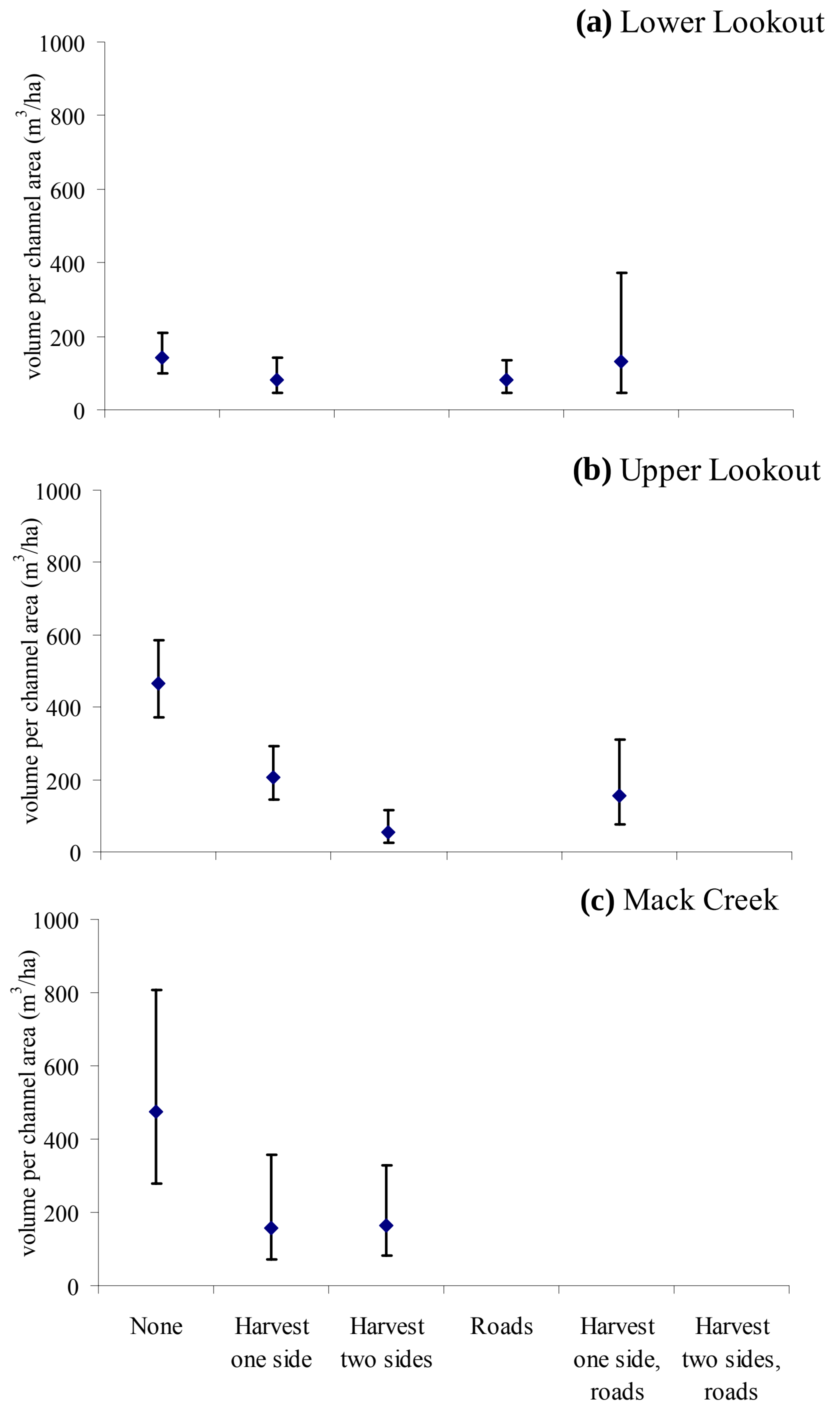


Figure 5.11. Local patterns of wood volume for each individual sampling site, by adjacent harvest and road treatment. Volume and 95% confidence intervals expressed per unit of channel area for a 50-m stream segment (m^3/ha) for Lower Lookout (a), Upper Lookout (b), Mack (c), McRae (d), Cook (e) and Quentin (f). See associated Table 5.12.

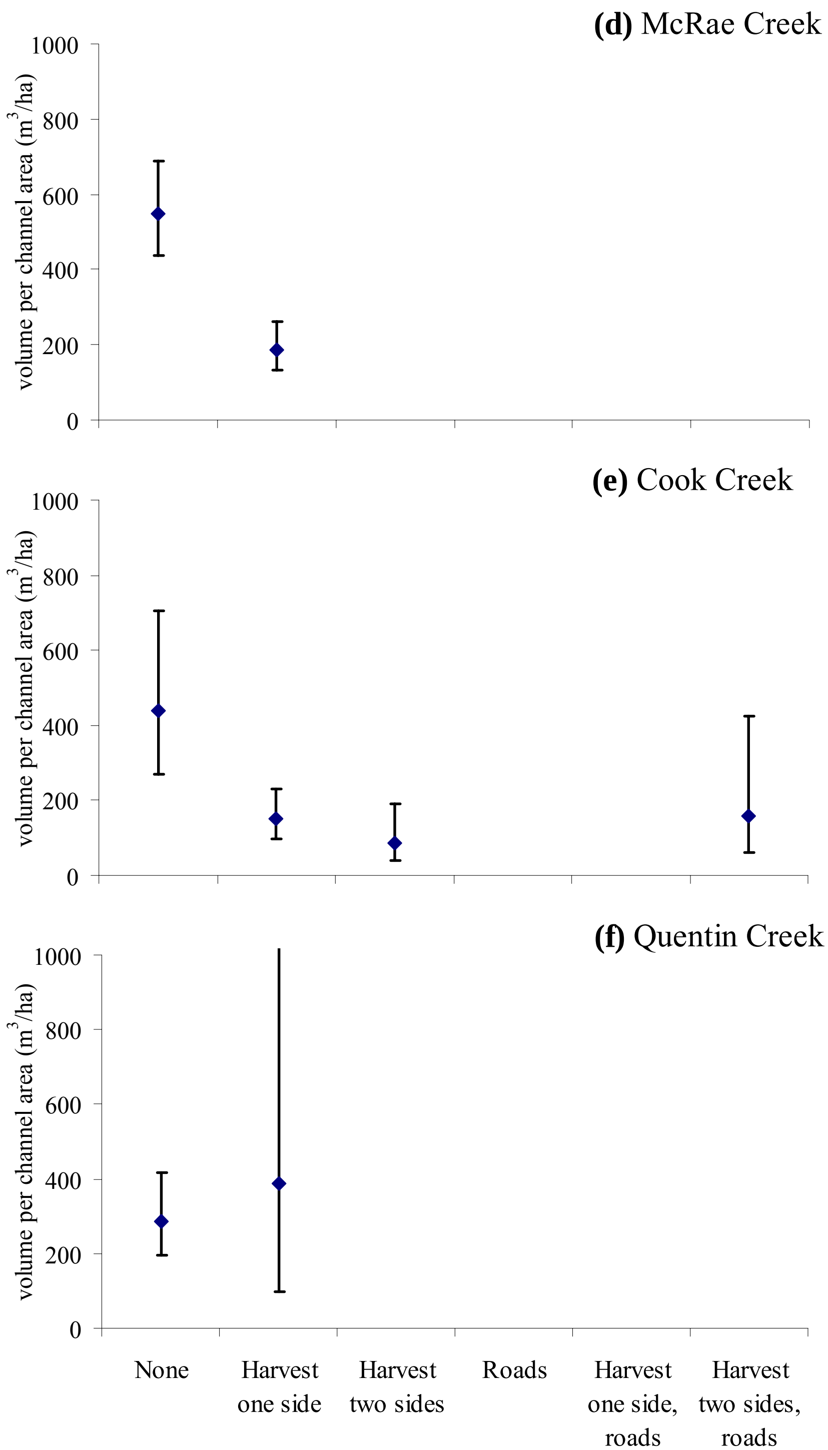


Figure 5.11. (continued)

Table 5.13. Local patterns of number of large pieces for each individual sampling site, distinguished by adjacent harvest and road treatments. Number of large pieces is expressed per channel area of a 50 m segment (#/ha) for forestry treatments with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making non-independent comparisons (6 for Lower Lookout and Cook, 3 for Upper Lookout and 1 for Mack, McRae and Quentin)). See associated Figure 5.12.

Harvest and Road Class	N	Mean	95% CI
Lower Lookout ($p>0.1$, $F_{3,92}=0.12$)			
None	52	24 a	19, 30
Harvest, one side	16	24 a	16, 36
Roads	22	22 a	16, 32
Harvest, one side & roads	6	20 a	10, 39
Upper Lookout ($p<0.03$, $F_{2,144}=12.97$)			
None	102	75 a	62, 90
Harvest, one side	34	46 b	34, 63
Harvest, one side & roads	11	19 c	11, 32
Mack ($p<0.03$, $F_{1,17}=5.50$)			
None	13	67 a	46, 97
Harvest, two sides	6	32 b	18, 55
McRae ($p<0.0001$, $F_{1,64}=18.05$)			
None	49	81 a	67, 96
Harvest, one side	17	39 b	29, 53
Cook ($p<0.02$, $F_{3,49}=7.70$)			
None	21	59 a	43, 82
Harvest, one side	20	44 ab	31, 61
Harvest, two sides	7	15 c	9, 27
Harvest, two sides & roads	5	19 bc	10, 37
Quentin ($p>0.1$, $F_{1,38}=0.02$)			
None	37	51 a	39.0, 66.4
Harvest, one side	3	55 a	21.4, 139.1

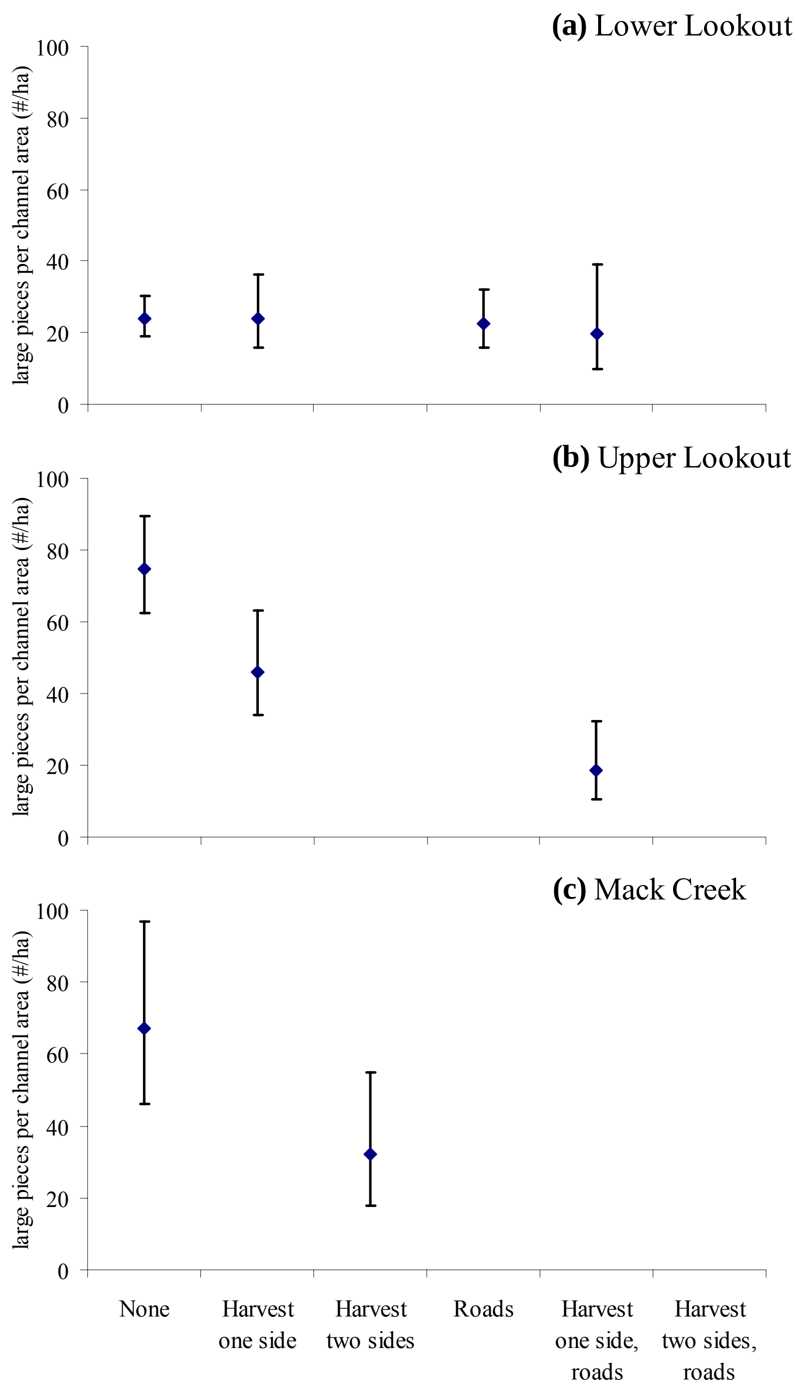


Figure 5.12. Local patterns of number of large pieces for each individual sampling site, by adjacent harvest and road treatments. Number of large pieces and 95% confidence intervals expressed per unit of channel area for a 50-m segment of stream (#/ha) for Lower Lookout (a), Upper Lookout (b), Mack (c), McRae (d), Cook (e) and Quentin (upper CI for harvest, two sides:139 pieces/ha)(f). See associated Table 5.13.

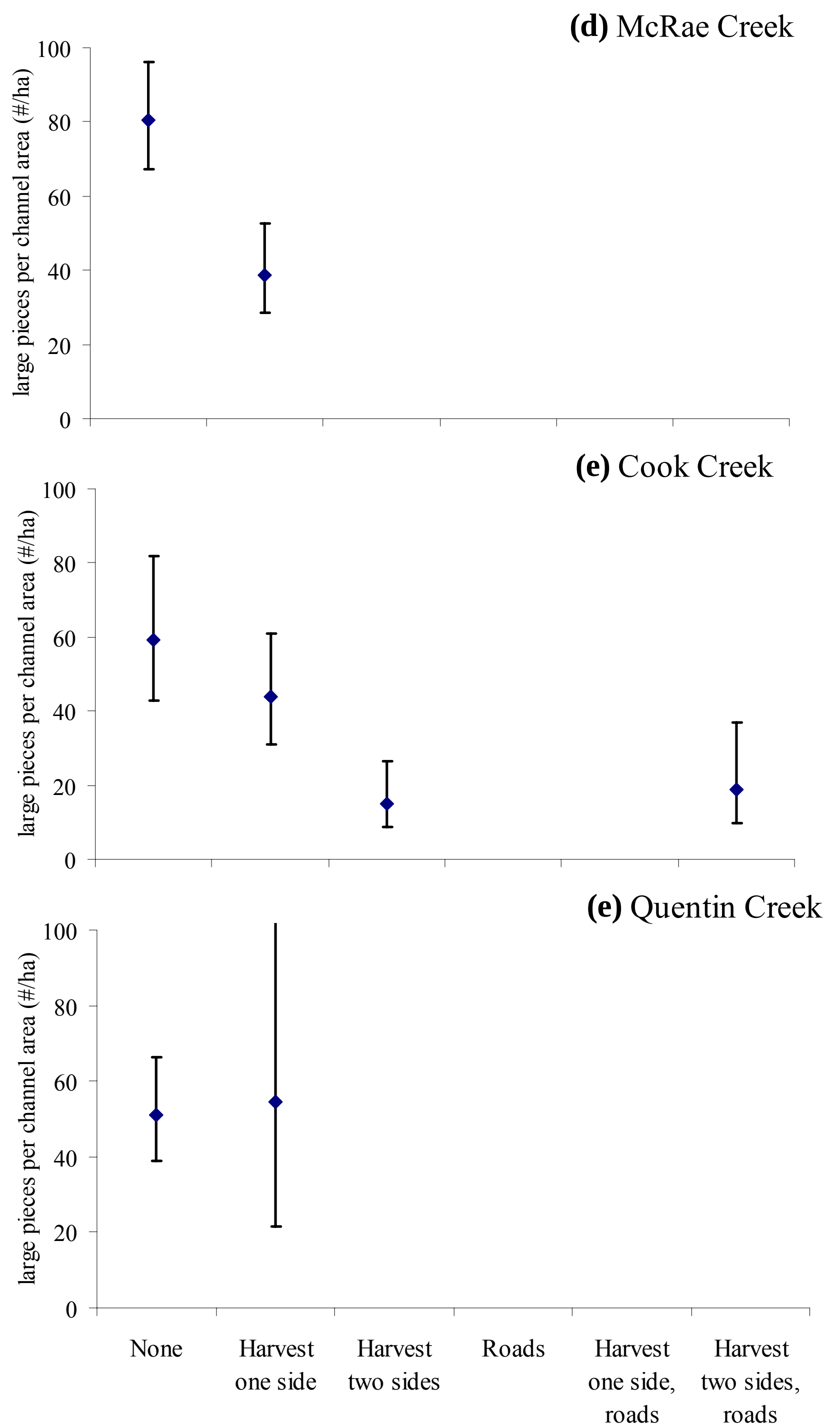


Figure 5.12. (continued)

- In Cook Creek, 50-m stream segments without adjacent roads or harvest (437.1 m^3/ha; 59 pieces/ha) had significantly higher volume and large pieces than harvests on both sides (87.2 m^3/ha, Bonferroni adjusted $p < 0.005$; 15 pieces/ha, $p<0.0007$), volume than harvest on one side (149.7 m^3/ha, Bonferroni adjusted $p < 0.009$), and significantly higher number of large pieces than 50-m stream segments with both roads and harvest on two sides of the stream (19 pieces/ha $p<0.02$) (Table 5.12, 5.13, Figure 5.11, 5.12).

More intensive harvest and road treatments were associated with fewer large pieces of stream wood. For all sites pooled, 50-m stream segments with harvest on one side of the stream (39 pieces/ha) had a significantly higher number of large pieces than 50-m stream segments with both harvest on one side and roads (18 pieces/ha, $p<0.04$) (Table 5.11, Figure 5.10). A similar effect on volume and accumulations is apparent, but not statistically significant, potentially due to small sample sizes. However, in Upper Lookout 50-m stream segments with harvest on one side had significantly higher wood volumes (205.7 m^3/ha) than 50-m stream segments with harvests on both sides (55.2 m^3/ha, $p<0.01$) (Table 5.12, Figure 5.11). For McRae and Quentin, the effects on volume cannot be tested due to small sample sizes; Lower Lookout, Mack and Cook do not show consistent trends. The effect on large pieces is true for Upper Lookout and Cook, but not Lower Lookout, and it cannot be tested at Mack, McRae or Quentin due to small sample sizes. In Upper Lookout, 50-m stream segments with roads and harvest on one side of the stream (19 pieces/ha) had a significantly lower number of large pieces than 50-m stream segments harvest on one side (46 pieces/ha, $p<0.02$) (Table 5.13, Figure 5.12). In Cook, 50-m stream segments with harvest on one side of the stream (44 pieces/ha) had a significant higher number of large pieces than 50-m stream segments with harvest on two sides of the stream (15 pieces/ha, $p<0.01$).

Similar trends were found when examining the impact of roads on the number of accumulations. For all sites pooled, both roads and harvest on one side with roads (both 16 accumulations/ha) were significant less than all other harvest and road designations (25-32 accumulations/ha, $p<0.004$) (Table 5.11, Figure 5.10). No harvest and roads was greater in Cook (37 accumulations/ha) and Mack (53 accumulations/ha) than harvest on two sides (17 accumulations/ha, $p<0.04$; 29 accumulations/ha, $p<0.03$) (Table 5.14, Figure 5.13). In addition, in Mack 50-m stream segments with no harvest and roads were greater than harvest on one side (30 accumulations/ha, $p<0.03$), and in Upper Lookout, no harvest and roads (37 accumulations/ha) was greater than roads with harvest on one side (20 accumulations/ha, $p<0.01$).

Chi-square analysis suggests that harvest and road class is correlated with basin position ($p<0.0001$) (Table 5.15). When there are no harvest or roads, less 50-m stream segments (19%) than overall (23%) were associated with lower, and more (28%) than overall (24%) in higher parts of the basin. When harvest on one side, less 50-m stream segments (18%) than overall (23%) were associated with lower, more (65%) than overall (53%) in intermediate, and less (17%) than overall (24%) in higher parts of the basin. When harvest on two sides, less 50-m stream segments (0%) than overall (23%) were associated with lower, more (60%) than overall (53%) in intermediate, and more (40%) than overall (24%) in higher parts of the basin. When there were only roads, more 50-m stream segments (97%) than overall (23%) were associated with lower, less (0%) than overall (53%) in intermediate, and less (3%) than overall (23%) in higher parts of the basin. When there were harvest on one side and roads, more 50-m stream segments (35%) than overall (23%) were associated with lower, more (65%) than overall (53%) in intermediate, and less (0%) than overall (23%) in higher parts of the basin. When there were harvest on two sides and roads, less 50-m stream segments (16%) than overall (23%) were associated with lower, less (42%) than overall (53%) in intermediate, and more (42%) than overall (23%) in higher parts of the basin.

When evaluated based on units of channel length, similar results to those conducted by units of channel area were found for volume, number of large pieces and number of accumulations. No harvest or roads ($n=285$) had significantly greater volume than all classes of harvest or roads except harvest on one side with roads ($p>0.1$, $n=12$-124), greater number of large pieces than all other classes ($p<0.08$, $n=12$-124) and no difference in number of accumulations than any of the other classes ($p>0.1$, $n=12$-124).

Table 5.14. Local patterns of number of accumulations for each individual sampling site, distinguished by adjacent harvest and road treatments. Number of accumulations is expressed per channel area of 50-m stream segments (#/ha) for forestry treatments with sample sizes >5 in Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making non-independent comparisons (6 for Upper and Lower Lookout and Cook, 3 for Mack and 1 for McRae and Quentin)). See associated Figure 5.13.

Harvest and Road Class	N	Mean	95% CI
Lower Lookout ($p>0.1$, $F_{3, 101}=2.05$)			
None	52	15 a	13, 18
Harvest, one side	21	20 a	15, 25
Roads	25	15 a	12, 20
Harvest, one side & roads	7	11 a	7, 17
Upper Lookout ($p<0.01$, $F_{3,152}=4.27$)			
None	102	37 a	33, 42
Harvest, one side	35	31 ab	25, 38
Harvest, two sides	8	25 ab	16, 39
Harvest, one side & roads	11	20 b	13, 29
Mack ($p<0.03$, $F_{2, 21}=6.41$)			
None	13	53 a	42, 67
Harvest, one side	6	30 b	21, 42
Harvest, two sides	5	29 b	20, 42
McRae ($p>0.1$, $F_{1, 67}=1.86$)			
None	49	43 a	36, 50
Harvest, one side	20	35 a	27, 45
Cook ($p<0.04$, $F_{3, 52}=2.76$)			
None	20	37 a	29, 48
Harvest, one side	25	29 ab	23, 37
Harvest, two sides	6	17 b	11, 28
Harvest, two sides & roads	5	28 ab	17, 48
Quentin ($p>0.1$, $F_{1,37}=0.00$)			
None	36	28 a	23, 34
Harvest, one side	3	28 a	14, 54

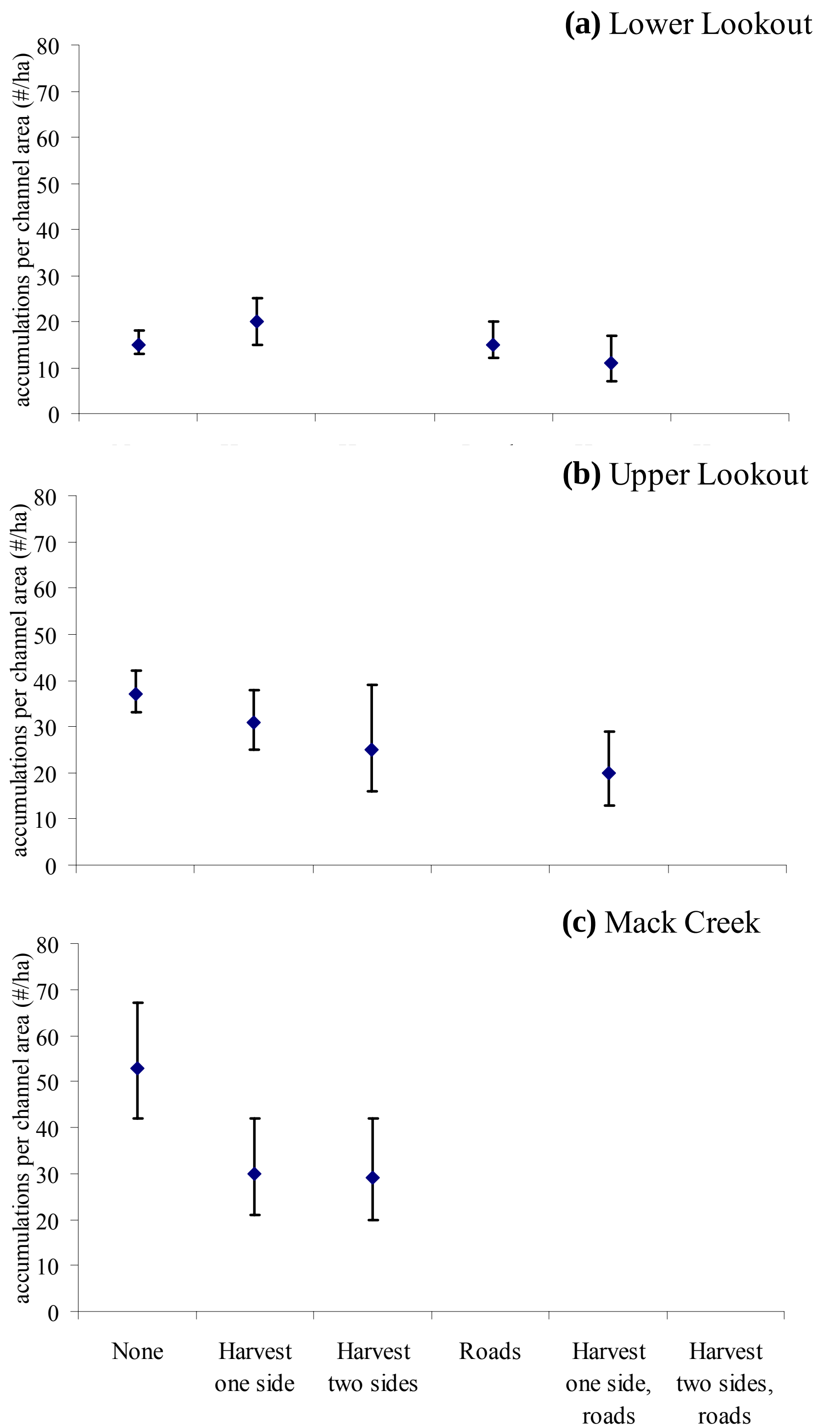


Figure 5.13. Local patterns of number of accumulations for each individual sampling site, by adjacent harvest and road treatments. Number of accumulations and 95% confidence intervals expressed per unit of channel area for a 50-m segment of stream (accumulation/ha) for Lower Lookout (a), Upper Lookout (b), Mack (c), McRae (d), Cook (e) and Quentin (f). See associated Table 5.14.

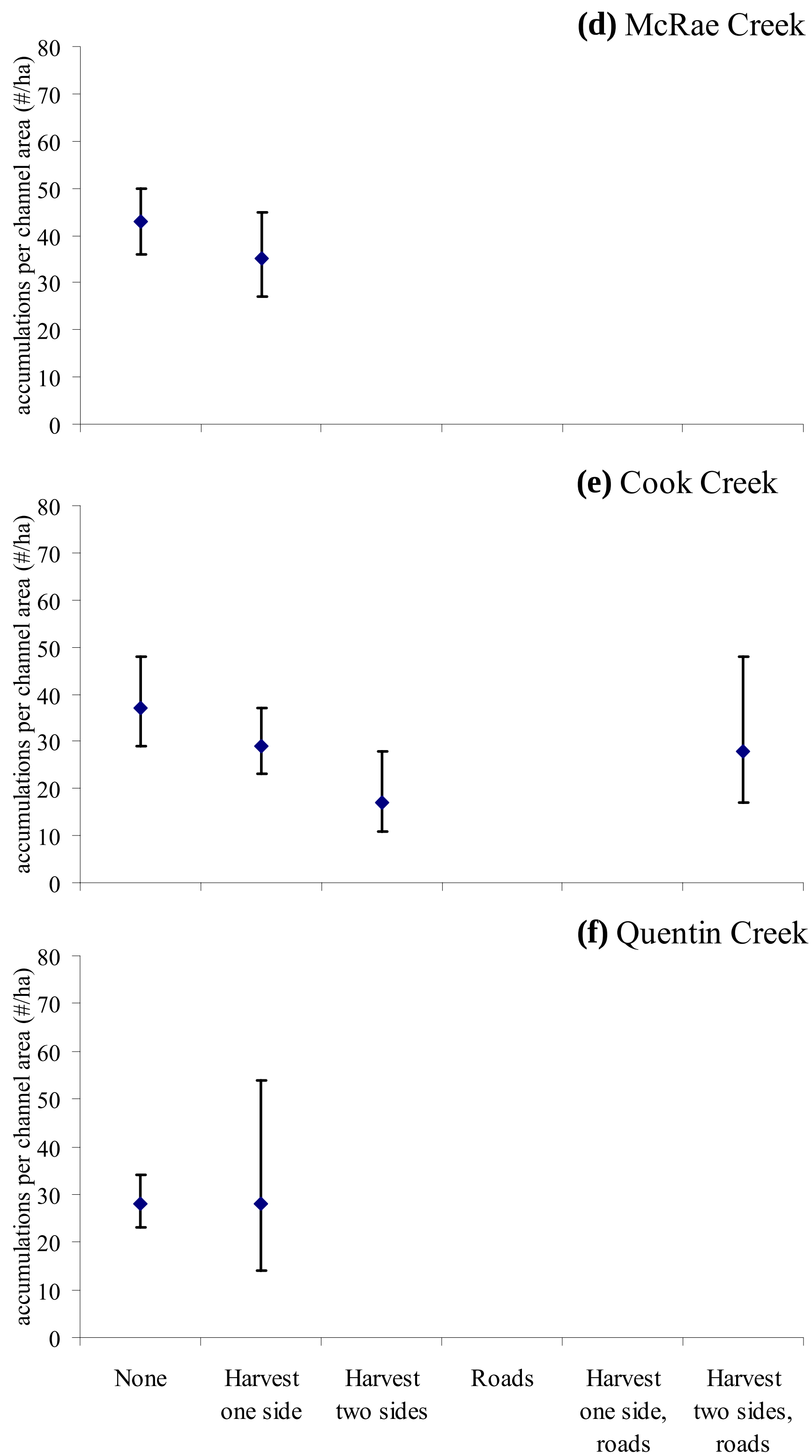


Figure 5.13. (continued)

Table 5.15. Degree of association between time of harvest and drainage area. Expressed as number of 50-m stream segments with percentage of total in parentheses.

	1-10 km^2	10-49 km^2	49+ km^2	Total
None	80 (28)	150 (53)	55 (19)	285
Harvest, one side	21 (17)	81 (65)	22 (18)	124
Harvest, two sides	12 (40)	18 (60)	0 (0)	30
Roads	1 (3)	0 (0)	29 (97)	30
Harvest, one side & roads	0 (0)	13 (65)	7 (35)	20
Harvest, two sides & roads	5 (42)	5 (42)	2 (16)	12
Total	119 (24)	267 (53)	115 (23)	501

5.5 Neighborhood-scale patterns of wood in streams by harvest and road treatments

Compared to 50-m stream segments lacking harvests or roads, 50-m stream segments within 50 m upstream and downstream of 50-m stream segments adjacent to harvests and roads had reduced wood volumes and numbers of large pieces. When all harvest and road designations are combined into one category, 50-m stream segments with no harvest or roads (427.7 m^3/ha) had significantly higher wood volume than the 0-50 m stream segments upstream of a 50-m stream segment adjacent to harvests or roads (171.8 m^3/ha, $p<0.02$), and weakly significantly higher volume than 0-50-m stream segments downstream of a 50-m stream segments adjacent to harvests or roads (191.6 m^3/ha, $p<0.1$) (Table 5.16, Figure 5.14). Stream segments 51-100 m upstream and downstream of a 50- m stream segment adjacent to harvest or roads did not have significantly different wood volumes than 50-m stream segments without harvest or roads. Although the 51-100 m 50-m stream segment upstream of the managed section (341.4 m^3/ha) is not significantly different than 50-m segments without harvest and roads, it is significantly higher than 50- m segments with harvest and roads (130.5 m^3/ha, $p<0.03$).

Relationships between the 50-m stream segments at the upstream and downstream side of a section of stream with 50-m stream segments with harvest or roads and the adjacent 50-m stream segments without harvest or roads shows the close relationship of contiguous 50-m stream segments. Upstream and downstream most 50-m stream segments without adjacent harvest or roads were not significantly different than the 50-m stream segments with them (Table 5.16, Figure 5.14). In addition, there were no significant differences between the upstream and downstream most ends of a 50-m stream segment adjacent to sections of stream with harvests or roads and the two 50-m stream segments lacking harvest or roads upstream or downstream of these 50-m stream segments. The 50-m stream segments with no harvest or roads had a significantly higher volume of wood (427.7 m^3/ha) than 50-m stream segments with harvest or roads (130.5 m^3/ha, $p<0.0001$), the first 50 m on the upstream end of a 50-m stream segments adjacent to harvests or roads (125.0 m^3/ha, $p<0.0002$) and the last 50 m on the downstream end of a 50-m stream segments adjacent to harvests or roads (149.1 m^3/ha, $p<0.001$).

Table 5.16. Neighborhood scale patterns of wood in streams by adjacent harvest and road treatments. Volume (m^3), large pieces, and accumulations are expressed per channel area of 50-m stream segments (ha) for all six sampling sites combined with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 28 non-independent comparisons). See Figure 5.14.

Neighborhood Class	N	Mean	95% CI
Volume ($p<0.1$, $F_{7,493} = 14.41$)			
None	198	427.7 a	360.8, 507.1
Upstream 51-100m	20	341.4 ac	199.9, 583.3
Upstream 0-50m	23	171.8 bc	104.3, 283.0
Upstream 50m Segment with Harvest or Roads	26	149.1 bc	93.2, 238.4
50m Segments with Harvest or Roads	168	130.5 b	108.5, 157.0
Downstream 50m Segment with Harvest or Roads	22	125.0 bc	75.0, 208.3
Downstream 0-50m	22	191.6 bc	115.0, 319.3
Downstream 51-100m	22	278.1 abc	166.9, 463.3
Large pieces ($p<0.0001$, $F_{7,428} = 9.73$)			
None	191	66 a	58, 74
Upstream 51-100m	20	41 ab	30, 65
Upstream 0-50m	21	38 ab	26, 57
Upstream 50m Segment with Harvest or Roads	18	39 ab	26, 59
50m Segments with Harvest or Roads	128	29 b	25, 34
Downstream 50m Segment with Harvest or Roads	16	36 ab	23, 56
Downstream 0-50m	20	39 ab	26, 56
Downstream 51-100m	22	44 ab	28, 60
Accumulations ($p<0.05$, $F_{7,455} = 4.71$)			
None	190	35 a	32, 38
Upstream 51-100m	20	25 ab	18, 34
Upstream 0-50m	21	30 ab	22, 39
Upstream 50m Segment with Harvest or Roads	23	30 ab	22, 40
50m Segments with Harvest or Roads	150	24 b	21, 27
Downstream 50m Segment with Harvest or Roads	19	21 b	15, 28
Downstream 0-50m	21	25 ab	19, 34
Downstream 51-100m	20	24 ab	18, 32

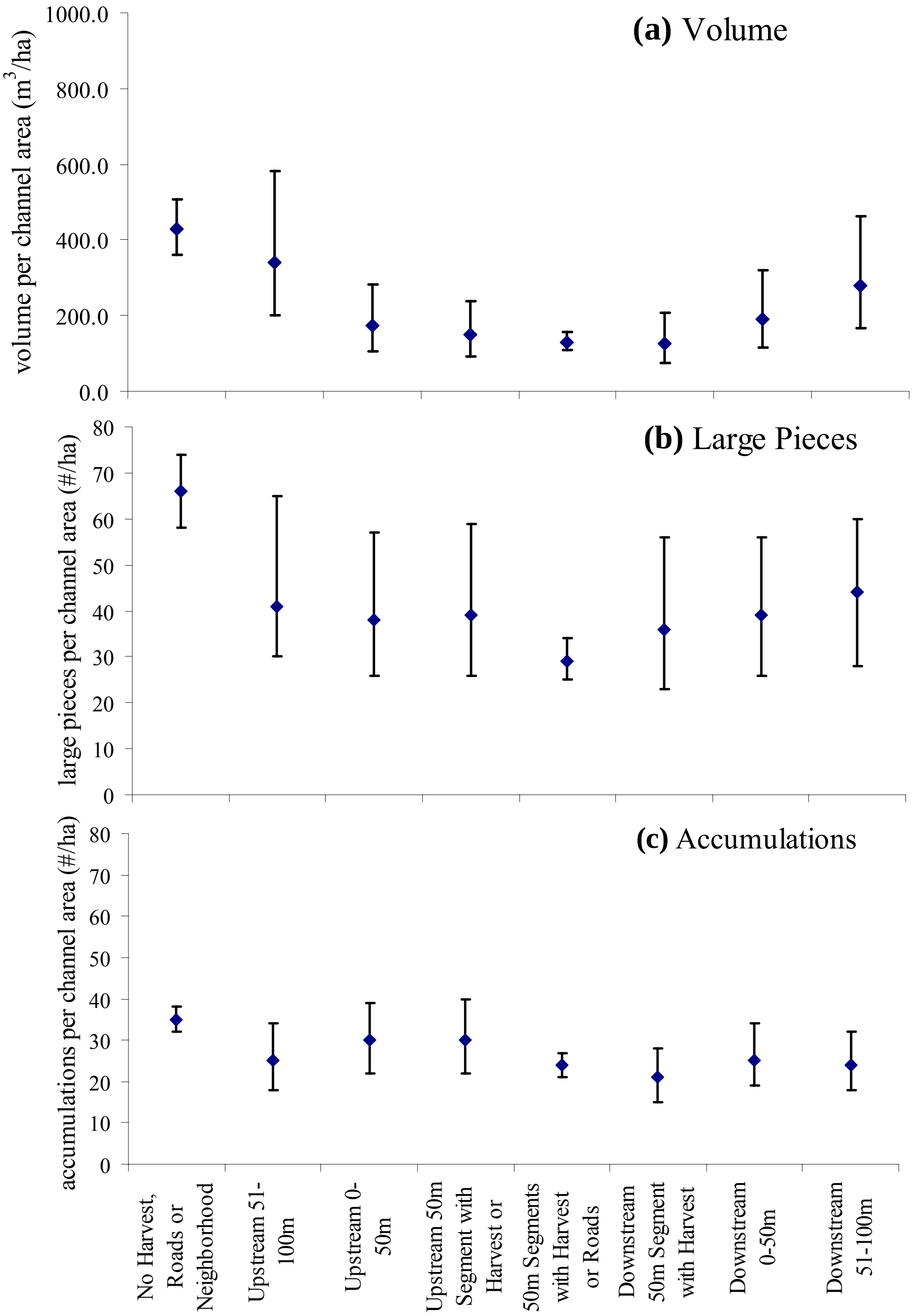


Figure 5.14. Neighborhood scale patterns of wood in streams by adjacent harvest and road treatments. Expressed as (a) estimate of volume (m^3), (b) number of large pieces, and (c) number of accumulations where large wood is key, along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See associated Table 5.16.

Except for the similar conclusion of a significantly higher number of pieces and accumulations of 50-m stream segments without harvest or roads (66 pieces/ha, 24 accumulations/ha) to 50-m stream segments with harvest and roads (29 pieces/ha, $p<0.0001$; 35 accumulations/ha, $p<0.05$), evaluation of the number of large pieces and accumulations did not result in the same relationship found for wood volume (Table 5.16, Figure 5.14). The 50-m stream segments with no harvest or roads had significantly higher number of accumulations (35 accumulations/ha) than the 50-m downstream segment with harvest and roads (21 accumulations, $p<0.05$). Generally, 50-m stream segments with harvest and roads had lower numbers of large pieces and accumulations than those lacking harvest or roads, but results do not show statistically significant differences.

When all effects of harvest and roads, including the 100 m upstream and downstream of 50-m stream segments with harvest and roads, were removed there were still significant differences in volume between sampling sites (Table 5.17, Figure 5.15). Quentin (291.6 m^3/ha) was significantly lower than both McRae ($p<0.08$) and Upper Lookout ($p<0.003$). Additionally, Lower Lookout had significantly lower wood volume (195 m^3/ha) than Cook (550.7 m^3/ha, $p<0.01$), McRae (553.8 m^3/ha, $p<0.0002$), and Upper Lookout (603.7 m^3/ha, $p<0.0001$). Nevertheless, when examined independently, 50-m stream segments with harvest, roads, or a neighborhood effect in Lower Lookout (87.8 m^3/ha, n=86) had significantly lower wood volume than those without (195.4 m^3/ha, $p<0.006$) (Table 5.18, Figure 5.16). For all other sites except Quentin, the same relationship was found.

5.6 Confounding effects

Analysis of natural process effects in all 50-m stream segments show that wood volume was highest in areas where significant windthrow and soil movement (i.e. near-stream toppling) were observed, as well as where channels were smaller. Stream segments with windthrow (480.2 m^3/ha) and soil movement (398.7 m^3/ha) had signif-

Table 5.17. Comparison of mean volume of wood by site once harvest, road and neighborhood effects were removed. Neighborhood effects are the 100 m upstream and downstream of 50-m stream segments with harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (p<0.08, p-values Bonferroni adjusted for making 15 non-independent comparisons). See Figure 5.15.

Sampling Site	N	Mean	95% CI
Lower Lookout	32	195.4 a	141.1, 270.5
Cook	13	550.7 bc	330.6, 917.3
Mack	8	430.6 ab	224.7, 825.2
McRae	32	553.8 b	400.1, 766.7
Quentin	35	291.6 ac	213.7, 397.9
Upper Lookout	78	603.7 b	490.1, 743.5

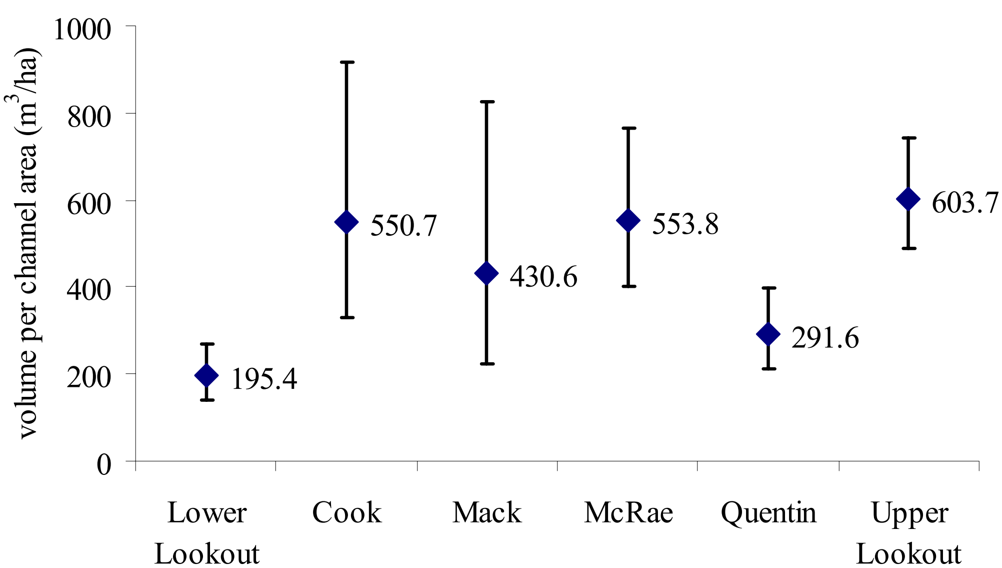


Figure 5.15. Site-scale patterns of wood in 50-m stream segments with harvest, road and neighborhood effects removed. Neighborhood effects are the 100 m upstream and downstream of 50-m stream segments with harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha), along with 95% confidence intervals, for all six sampling sites with sample sizes >5 in Blue River Basin. See Table 5.17.

Table 5.18. Comparison of mean volume of wood by site for 50-m stream segments without and with harvest, road and neighborhood effects. Neighborhood effects are the 100 m upstream and downstream of 50-m stream segments with harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. Differences in group means stated in table. See Table 5.16.

	Harvest, Road or Neighborhood Effects							
Sampling Site	N Without	N With	Mean Without	Mean With	95% CI Without	95% CI With	F-stat	p-value
Lower Lookout	32	86	195.4	87.8	120.7, 316.4	65.5, 117.8	7.88	0.006
Cook	13	49	550.7	152.9	300.6, 1009.0	111.9, 208.8	14.16	0.0004
Mack	8	23	430.6	184.4	188.8, 982.0	113.4, 299.9	3.28	0.08
McRae	32	46	553.8	289.4	402.8, 761.5	221.9, 377.4	9.72	0.003
Quentin	35	7	291.6	289.3	195.0, 436.1	117.6, 711.5	0.00	1.0
Upper Lookout	78	92	603.7	179.4	466.1, 781.9	141.4, 227.7	46.40	0.0001

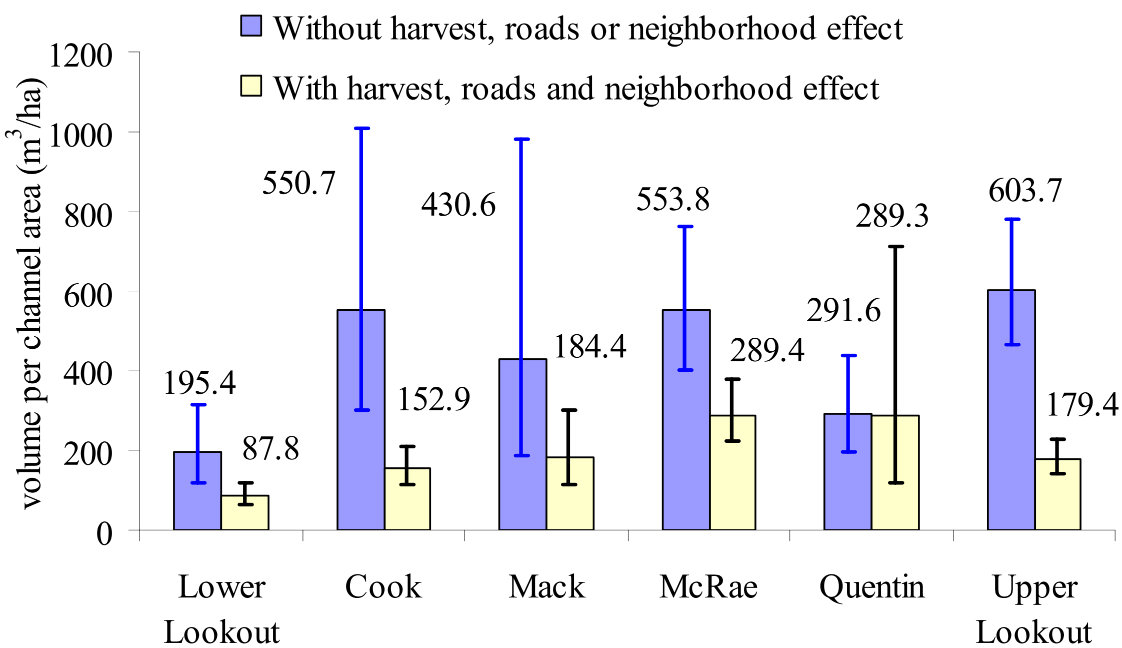


Figure 5.16. Comparison of mean volume of wood by site for 50-m stream segments without and with harvest, road and neighborhood effects. Neighborhood effects are the 100 m upstream and downstream of 50-m stream segments with harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for all six sampling sites with sample sizes >5 in the Blue River Basin. See Table 5.18.

icantly higher wood volume than when there was no observable local effect (192.3 m^3/ha), channel form change (200.4 m^3/ha), or when channel form and soil movement occurred together (121.3 m^3/ha) ($p<0.04$) (Table 5.19, Figure 5.17). Sample size was too small for strong comparison of the effect of soil movement and windthrow occurring simultaneously. When categories of landscape-scale natural process class were compared to each other for Upper and Lower Lookout, Mack, and McRae, 50-m stream segments in small channels (718.6 m^3/ha) had significantly higher wood volume than all other landscape-scale natural process classes (101.3 to 448.3 m^3/ha, $p<0.02$) (Table 5.20, Figure 5.18; also see Dreher in prep). Large channels (101.3 m^3/ha) had lower volume than all other categories except those with debris flows (128.1 to 210.7 m^3/ha).

When the effect of harvest and roads is controlled for, there were no differences in wood volume among the localized natural process classes (Table 5.19, Figure 5.17). Therefore, it appears that the effects of harvest and roads may explain some of the differences between classifications, and they likely have a stronger effect than localized natural processes.

Designation of localized natural processes effects and the adjacency of harvest and roads are correlated (Chi-square $p<0.0001$). Comparisons of the localized natural process effects classes and harvest and road classes showed that of the total 50-m stream segments, 43.1% had a harvest or road designation and 48.7% had a localized effect designation (Table 5.21). Nearly 39% of the 244 localized effects units also had a harvest or road designation, and nearly 44% of the 216 harvest or road 50-m stream segments had a localized effect class.

When the effects of harvest and roads were controlled for, large channels (144.2 m^3/ha) still had lower volume than intermediate (450.9 m^3/ha, $p<0.0001$) or small channels (718.6 m^3/ha, $p<0.01$) (Table 5.20, Figure 5.19). In addition, large channels (144.2 m^3/ha) had lower volume than intermediate channels with earthflows (599.1 m^3/ha, $p<0.0001$).

Most of the channel size relationships have been controlled for in this study by the separation of sampling sites. Chi-square analysis suggests that sampling site and land-

Table 5.19. Effect of localized natural wood input and redistribution processes on wood volume in streams, with and without the effects of harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for 3 localized process effects and 3 combinations of localized process effects in all sampling sites combined for sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in table, p-values Bonferroni adjusted for making 15 non-independent comparisons). See associated Figure 5.17.

Localized Effect	N	Mean	95% CI
Overall ($p<0.04$, $F_{5,490}=8.17$)			
None	257	192.3 a	164.3, 225.1
Channel form	87	200.4 a	152.9, 262.7
Soil movement	87	398.7 b	304.2, 522.7
Channel form and Soil movement	26	121.3 a	73.9, 199.0
Windthrow	30	480.2 b	302.9, 761.4
Soil movement and Windthrow	9	459.6 ab	198.1, 1066.4
No Harvest or Roads ($p>0.09$, $F_{5,276}=3.09$)			
None	135	302.7 a	250.9, 365.2
Channel form	38	326.6 a	229.3, 465.2
Soil movement	67	477.6 a	365.9, 623.4
Channel form and Soil movement	9	160.7 a	77.7, 332.5
Windthrow	26	483.3 a	315.1, 741.2
Soil movement and Windthrow	7	542.3 a	237.9, 1236.4

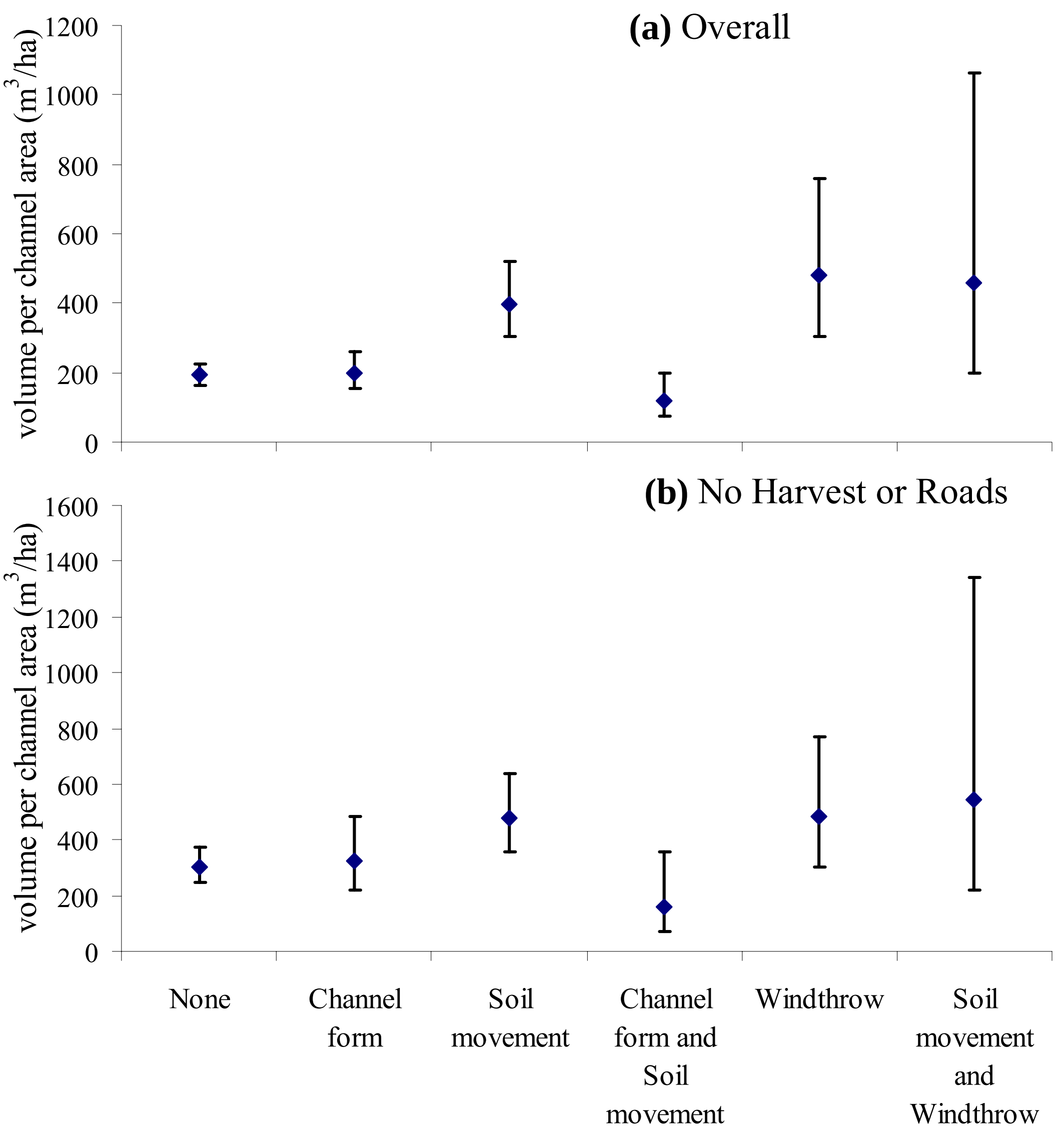


Figure 5.17. Effect of localized natural wood input and redistribution processes on wood volume in streams, with and without the effects of harvest and roads. Volume and 95% confidence intervals expressed per unit of channel area for a 50-m stream segment (m^3/ha). See associated Table 5.19.

Table 5.20. Effect of landscape scale natural wood input and redistribution processes on wood volume in streams, with and without the effects of harvest and roads. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for 5 landscape scale natural process effects in Upper and Lower Lookout, McRae and Mack combined for sample sizes >5 in the Blue River Basin. Group means in the same column followed by the same letter are not significantly different from each other (overall protection level stated in the table, p-values Bonferroni adjusted for making 15 non-independent comparisons). See Figure 5.18.

Landscape Scale Effect	N	Mean		95% CI
Overall ($p<0.02$, $F_{5,319}=16.27$)				
Large channel, flood	98	101.3	a	79.0, 129.7
Large channel, flood and debris flow	16	128.1	ab	69.4, 236.4
Intermediate channel, flood	209	290.4	bc	245.1, 344.0
Intermediate channel, flood and debris flow	22	210.7	ac	124.9, 355.3
Intermediate channel, flood and earthflow	28	448.3	cd	282.1, 712.6
Small channel, flood	24	718.6	d	435.7, 1185.5
No Harvest or Roads ($p<0.05$, $F_{5,219}=13.51$)				
Large channel, flood	50	144.2	a	108.7, 191.3
Large channel, flood and debris flow	5	132.0	ab	54.1, 322.5
Intermediate channel, flood	115	450.9	bc	374.3, 543.1
Intermediate channel, flood and debris flow	11	349.2	ac	191.3, 637.7
Intermediate channel, flood and earthflow	20	599.1	cd	383.3, 936.3
Small channel, flood	24	718.6	d	478.1, 1080.3

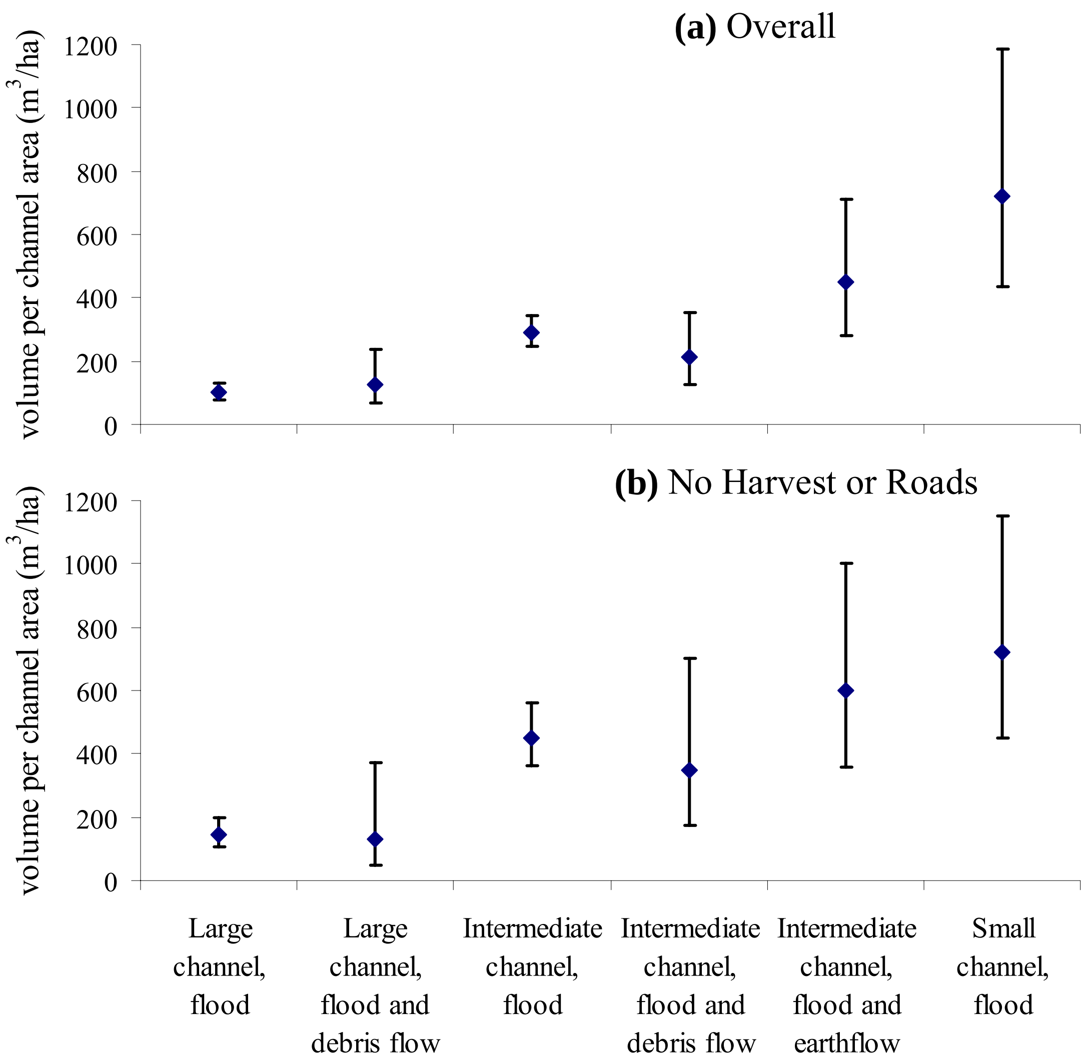


Figure 5.18. Effect of landscape scale natural wood input and redistribution processes on wood volume in streams, with and without the effects of harvest and roads. Volume and 95% confidence intervals expressed per unit of channel area for a 50-m stream segment (m^3/ha). See associated Table 5.20.

Table 5.21. Degree of association between harvests and roads and localized wood input and redistribution processes. Expressed as number of 50-m stream segments.

	None	Harvest one side	Harvest two sides	Roads	Harvest one side, Roads	Harvest two sides, Roads	Total
No localized effect	135	72	11	19	16	4	257
Channel form	38	25	12	5	4	3	87
Soil movement	67	13	3	3	0	1	87
Channel form & Soil movement	9	8	4	1	0	4	26
Windthrow	26	4	0	0	0	0	30
Channel form & Windthrow	3	0	0	0	0	0	3
Soil movement & Windthrow	7	2	0	0	0	0	9
Channel form, Soil movement & Windthrow	0	0	0	2	0	0	2
Total	285	124	30	30	20	12	501

scape natural process class are correlated ($p<0.0001$). All of the 50-m stream segments found in large channels are in Lower Lookout & all of the segments in small channels are in Upper Lookout (Table 5.22). Nearly 90% of the intermediate, earthflow 50-m stream segments are also found in Upper Lookout.

Designation of landscape-scale natural process effects and the adjacency of harvest and roads are also correlated (Chi-square $p<0.0001$). Comparisons of the landscape-scale natural process effects class and harvest and road class showed that of the total 50-m stream segments, 43% had a management designation and 17% had a debris flow or earthflow designation (Table 5.23). Forty-five percent of the 66 50-m stream segments with earthflow or debris flow also had a harvest or road class, yet only 17% of the 172 harvest and road classes had an earthflow or debris flow effect. By harvest and road class, 23% of harvest on one side and 27% of roads only 50-m stream segments also had an earthflow or debris flow effect.

5.7 Detailed study of seven 1 to 2.5 km stream sections

Evaluation of seven selected sites for closer study largely reconfirmed that 50-m stream segments with harvest and roads have lower volume and number of large pieces than those without. The 50-m stream segments without harvest or roads were significantly higher in wood volume (397.0 to 828.0) and large pieces (59 to 167 pieces/ha) than 50-m stream segments with harvest or roads (96.3 to 257.8, $p<0.007$; 21 to 87 pieces/ha, $p<0.006$) in nearly all of the sections of stream examined except Upper Lookout and the combined Lookout (Table 5.24, Figures 5.19 to 5.25). Significant differences were not found between 50-m stream segments with and without harvest and roads for both volume and number of large pieces in Lookout, and number of large pieces in Upper Lookout. The Lookout section spans both Lower and Upper Lookout, although over half of the 50-m stream segments are from Lower Lookout, where harvest and road influences were not easy to discern. Additionally, this section of stream includes the confluence with McRae and is unique in the Lookout drainage, where the stream meanders across a relatively broad, terraced valley bottom.

Table 5.22. Degree of association between landscape-scale wood input and redistribution processes and sampling sites Upper and Lower Lookout, Mack and McRae. Expressed as number of 50-m stream segments.

	Lower Lookout	Upper Lookout	Mack	McRae	Total
Large channel, flood	98	0	0	0	98
Large channel, flood and debris flow	16	0	0	0	16
Intermediate channel, flood	4	121	28	56	209
Intermediate channel, flood and debris flow	0	0	0	22	22
Intermediate channel, flood and earthflow	0	25	3	0	28
Small channel, flood	0	24	0	0	24
Total	118	170	31	78	397

Table 5.23. Degree of association between harvests and roads and landscape-scale wood input and redistribution processes in Upper and Lower Lookout, Mack and McRae. Expressed as number of 50-m stream segments.

	None	Harvest one side	Harvest two sides	Roads	Harvest one side, Roads	Harvest two sides, Roads	Total
Large channel, flood	50	18	0	21	7	2	98
Large channel, flood and debris flow	5	3	0	8	0	0	16
Intermediate channel, flood	115	55	22	1	11	5	209
Intermediate channel, flood and debris flow	11	11	0	0	0	0	22
Intermediate channel, flood and earthflow	20	8	0	0	0	0	28
Small channel, flood	24	0	0	0	0	0	24
Total	225	95	22	30	18	7	397

Table 5.24. Detailed analysis of patterns of wood volume and large pieces in seven 1 to 2.5 km stream sections. Estimates of volume (m^3) and large pieces are expressed per channel area of 50-m stream segments (ha) for seven selected sections of stream in the Blue River Basin. Differences in group means in the same row stated in table. See associated Figures 5.19 to 5.25.

Section of stream	# 50-m Segments Without Harvest or Roads	# 50-m Segments With Harvest or Roads	Estimate Without Harvest or Roads	Estimate With Harvest or Roads	Bonferroni Adjusted P-value
Volume			*(m^3/ha)*	*(m^3/ha)*	
All seven cases	120	94	471.4	143.4	0.0001
Up. Lookout	20	8	776.3	217.2	0.007
Lookout	18	31	193.4	106.5	>0.1
Mack	14	8	473.9	96.3	0.0002
McRae-up	14	7	828.0	257.8	0.006
McRae-mid	20	7	538.7	249.6	0.002
McRae-low	16	6	397.0	89.0	0.001
Cook	18	27	425.9	166.0	0.002
Large Pieces			*(pcs/ha)*	*(pcs/ha)*	
All seven cases	119	75	67	28	0.0001
Up. Lookout	20	5	105	102	>0.1
Lookout	18	28	29	21	>0.1
Mack	13	4	66	21	0.005
McRae-up	14	5	167	87	0.03
McRae-mid	20	6	76	37	0.01
McRae-low	16	3	68	26	0.006
Cook	18	24	59	30	0.02

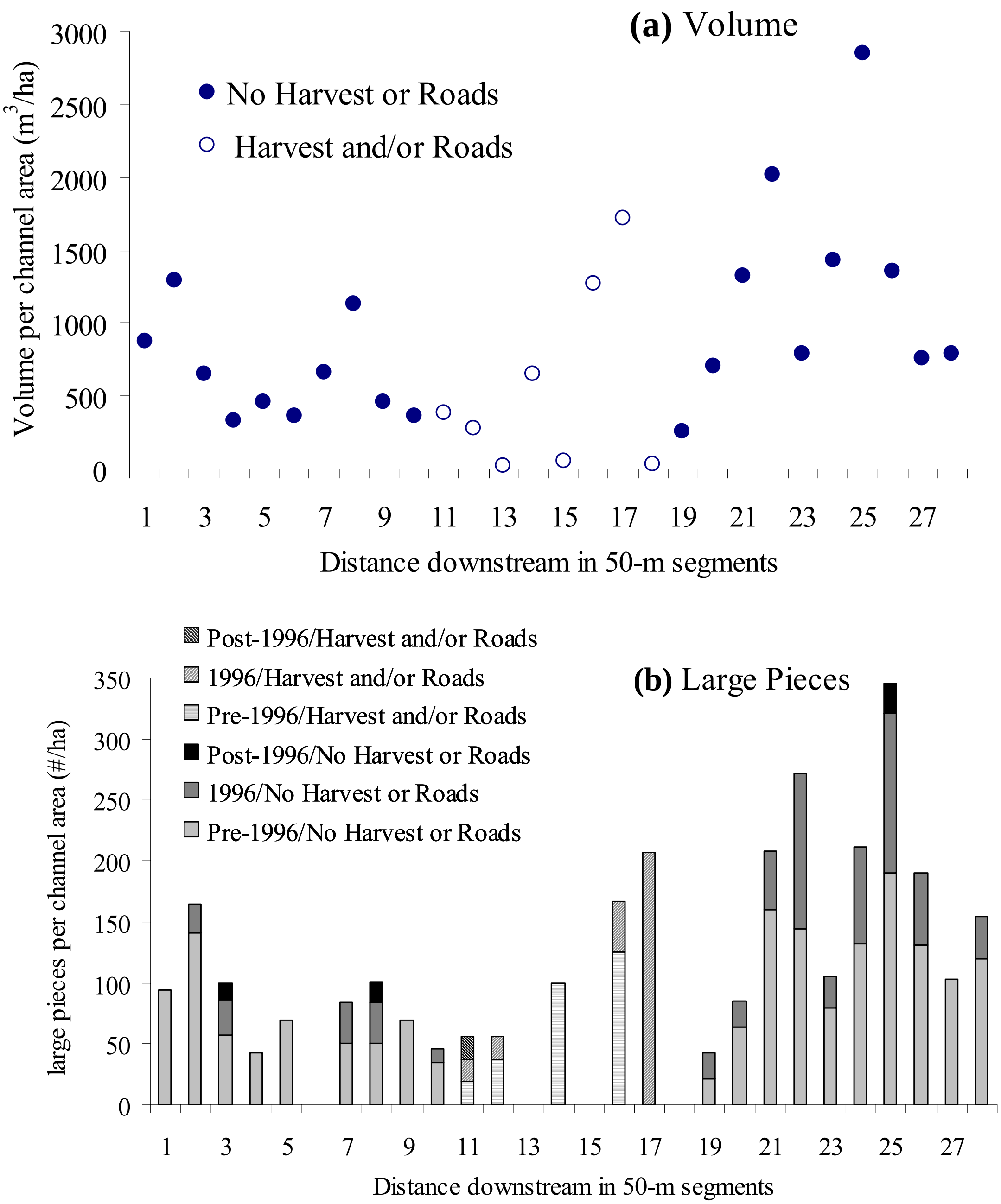


Figure 5.19. Upper Lookout – along-stream pattern of the effect of harvest and roads on volume and number of large pieces in a section of stream. Section covers 1400m, from the upstream point 2900 to 4300 m of the sampled site, a drainage area of 11 to 17 km^2. Expressed as volume (m^3) and number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). Displayed above include: (a) volume, (b) breakdown of number of large pieces by category of time: pre-1996, 1996, and post 1996. See associated Tables 5.24 & 4.8.

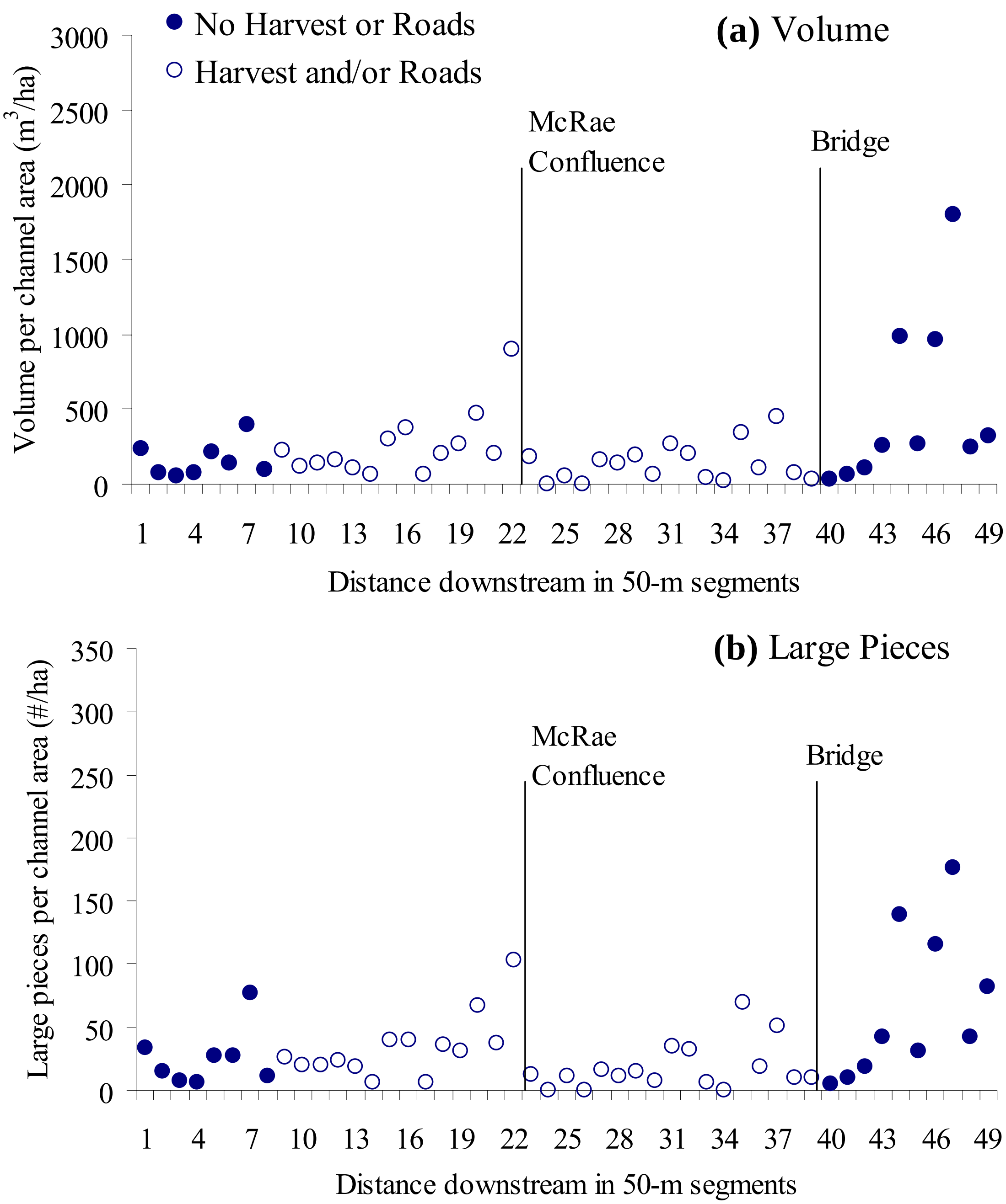


Figure 5.20. Lookout -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces in a section of stream. Section covers 2450m, from the upstream point 7550 to 10000 m of the sampled site, a drainage area of 33 to 54 km^2. Expressed as (a) volume (m^3), and (b) number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). See associated Tables 5.24 & 4.8.

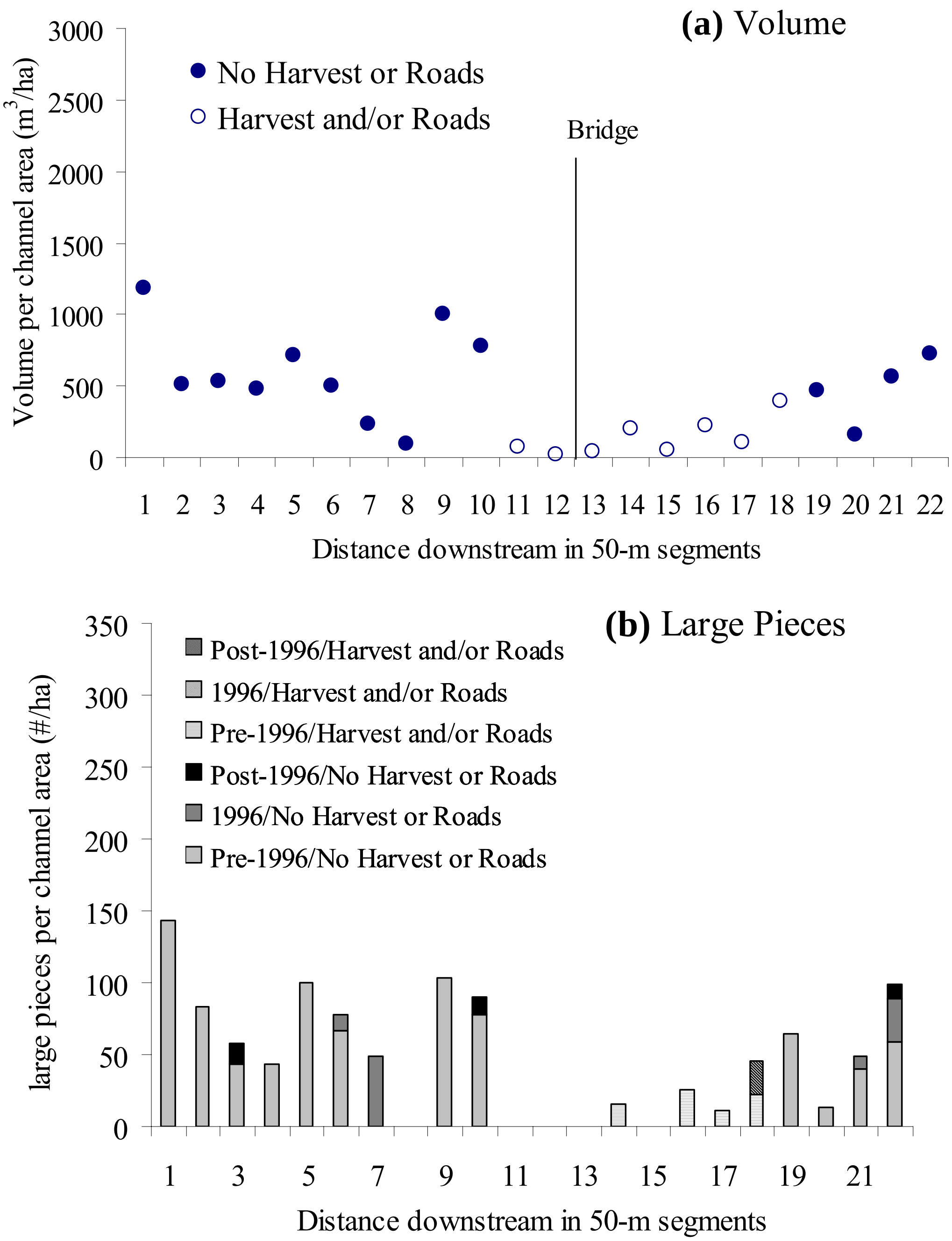
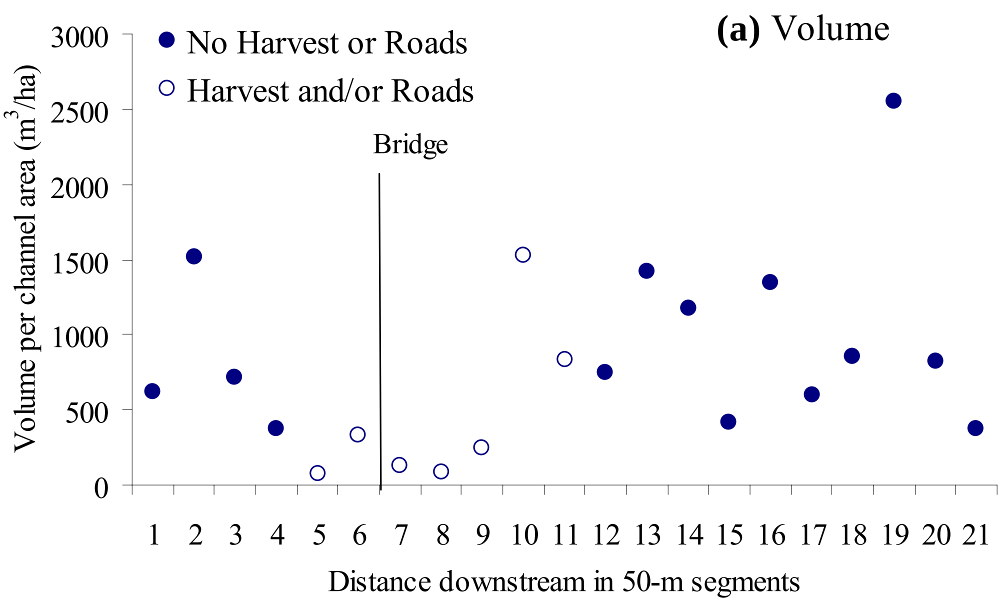


Figure 5.21. Mack -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces through time in a section of stream. Section covers 1100m, from the upstream point 0 to 1100 m of the sampled site, a drainage area of 4 to 7.5 km^2. Expressed as volume (m^3) and number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). Displayed above include: (a) volume, (b) breakdown of number of large pieces by category of time: pre-1996, 1996, and post 1996. See associated Tables 5.24 & 4.8.



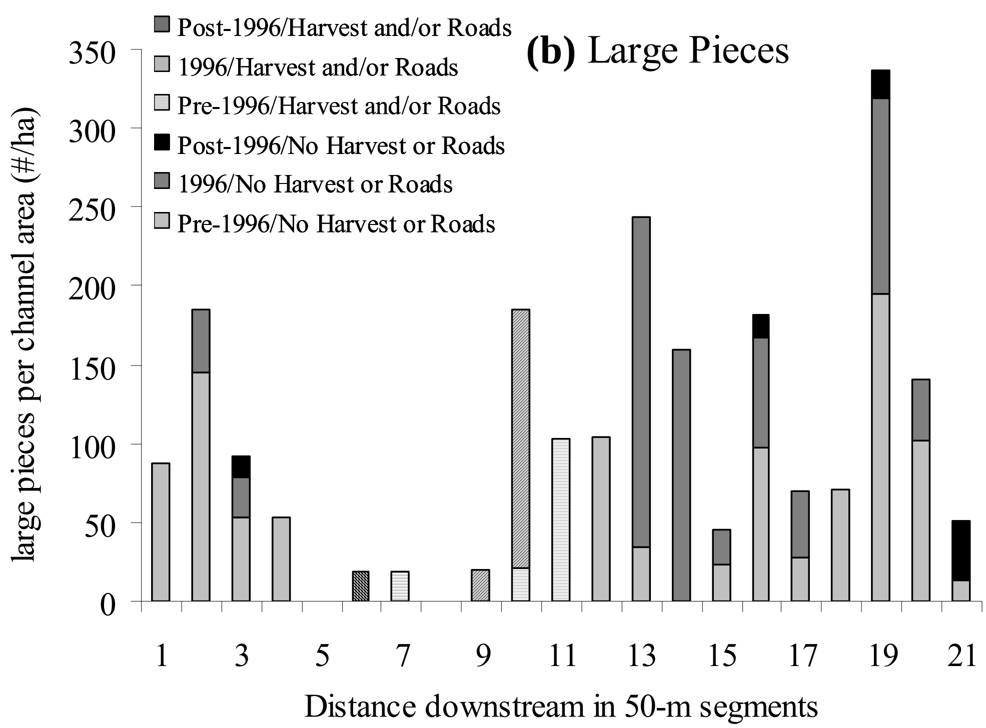


Figure 5.22. McRae-up -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces through time in a section of stream. Section covers 1050m, from the upstream point 250 to 1300 m of the sampled site, a drainage area of 6 to 8 km^2. Expressed as volume (m^3) and number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). Displayed above include: (a) volume, (b) breakdown of number of large pieces by category of time: pre-1996, 1996, and post 1996. See associated Tables 5.24 & 4.8.

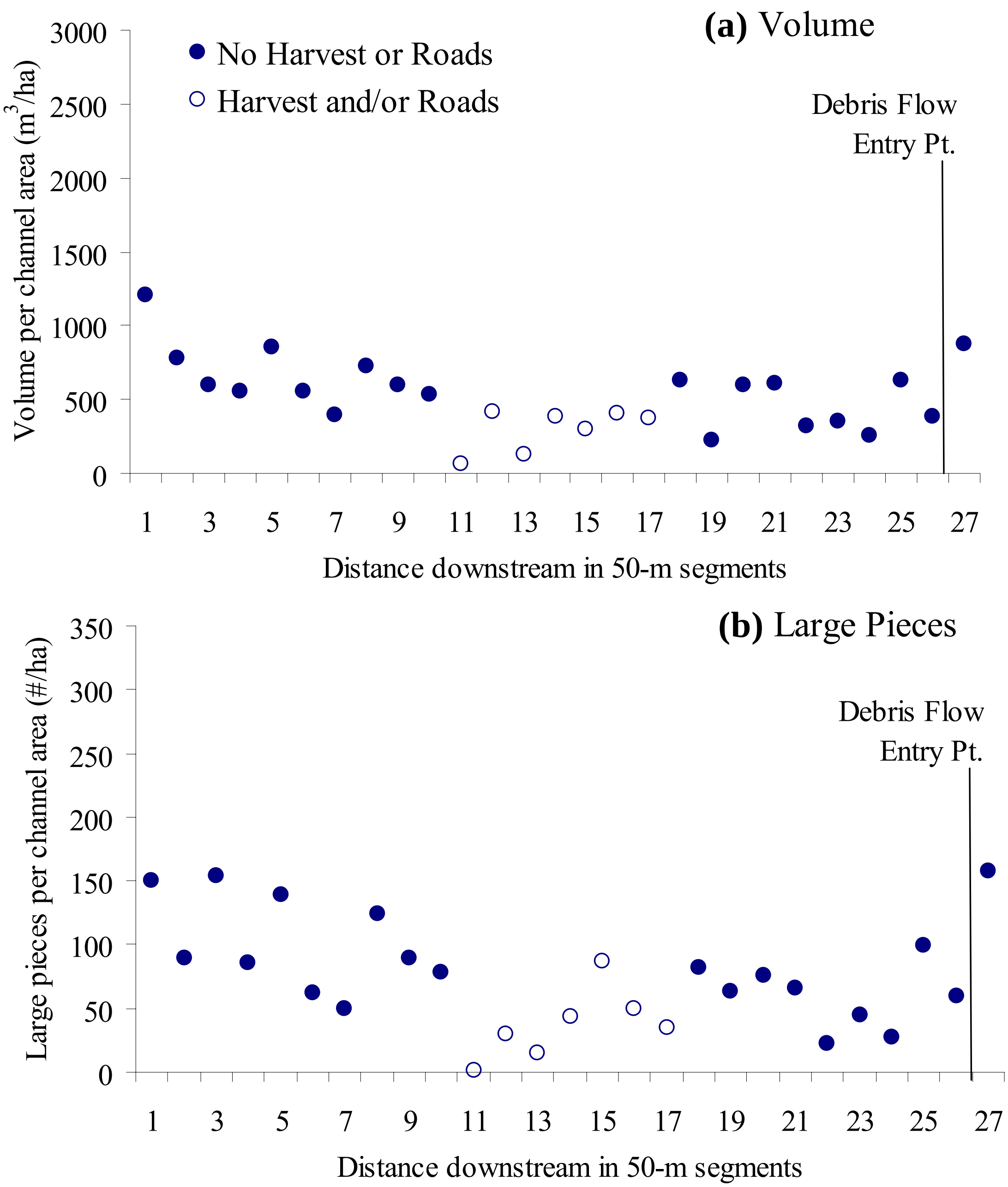


Figure 5.23. McRae-mid -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces in a section of stream. Section covers 1350m, from the upstream point 1300 to 2650 m of the sampled site, a drainage area of 8 to 12 km^2. Expressed as (a) volume (m^3), and (b) number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). See associated Tables 5.24 & 4.8.

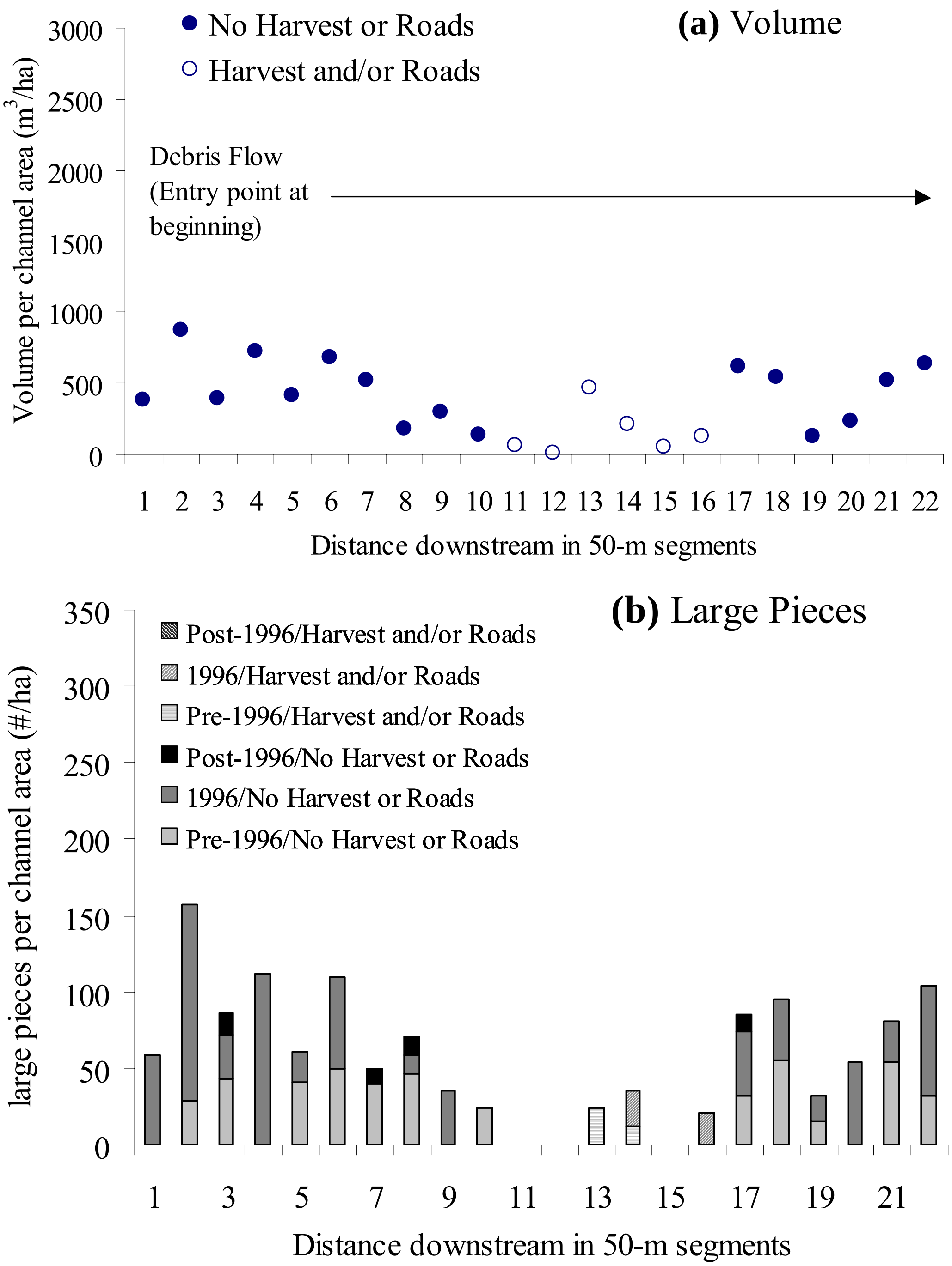
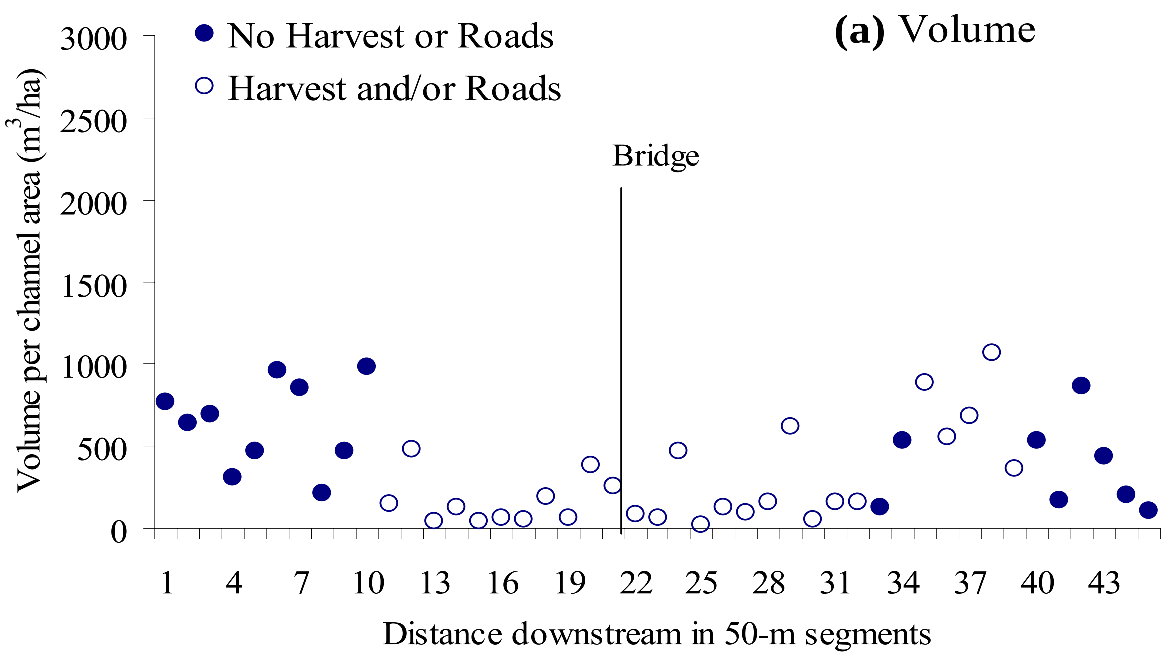


Figure 5.24. McRae-low -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces through time in a section of stream. Section covers 1100m, from the upstream point 2550 to 3650 m of the sampled site, a drainage area of 11.5 to 13.5 km^2. Expressed as volume (m^3) and number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). Displayed above include: (a) volume, (b) breakdown of number of large pieces by category of time: pre-1996, 1996, and post 1996. See associated Tables 5.24 & 4.8.



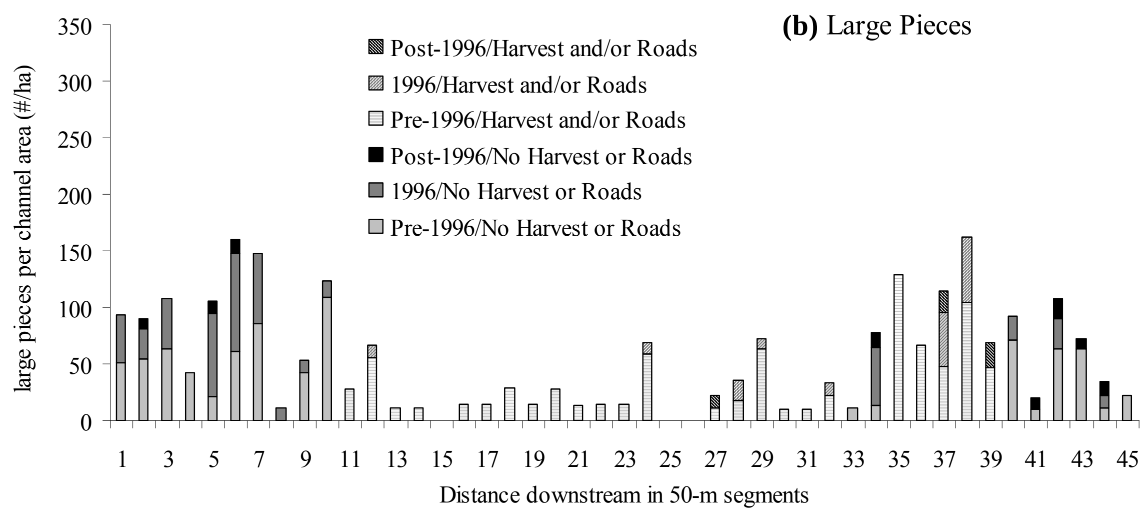


Figure 5.25. Cook -- along-stream pattern of the effect of harvest and roads on volume and number of large pieces through time in a section of stream. Section covers 2250m, from the upstream point 150 to 2400 m of the sampled site, a drainage area of 10 to 14 km^2. Expressed as volume (m^3) and number of large pieces along with 95% confidence intervals, expressed per channel area of 50-m stream segments (ha). Displayed above include: (a) volume, (b) breakdown of number of large pieces by category of time: pre-1996, 1996, and post 1996. See associated Tables 5.24 & 4.8.

Overall, evaluation of the volume found in 50-m stream segments differed according to the selected section of stream (Table 5.25, Figure 5.26). In Upper Lookout, 66% of volume was pre-1996, 31% was from 1996, and 3% was post 1996. In Mack, 85% of volume was pre-1996, 9% was from 1996, and 6% was post 1996. In McRae-up, 53% of volume was pre-1996, 42% was from 1996, and 5% was post 1996. In McRae-low, 38% of volume was pre-1996, 58% was from 1996, and 4% was post 1996. In Cook, 67% of volume was pre-1996, 27% was from 1996, and 6% was post 1996.

Based upon the seven selected sites, 50-m stream segments with harvest and roads had a higher frequency and percentage of segments with zero pieces of large wood, yet differences in volume and number of large pieces could still be distinguished when these were excluded from analysis (Table 5.26). Only one out of seven sites with 50-m stream segments without harvest and roads had no large pieces, whereas six out of seven sites with harvest and roads had no large pieces. In the analysis of the number of large pieces in seven sites (Table 5.24), where there were adjacent harvest and roads, up to 50% of the 50-m stream segments were eliminated prior to analysis and only up to 7% of those without harvest and roads were eliminated, yet still the effects of harvest and roads could be seen (Table 5.26).

Overall, 50-m stream segments with no large pieces, no accumulations, or no volume are found largely in locations where there are harvests and/or roads within 40 m of the channel, although proportional to the overall number of 50-m stream segments in a particular drainage area. Of 50-m stream segments with no occurrences of a wood variable, 100% of volume, 89% of large pieces (Tables 5.27), and 79% of accumulations (Tables 5.28) were in 50-m stream segments with harvest and/or roads. For all 50-m stream segments in the study, 24% are found in 1-10 km^2 drainage areas, 53% in 10-49 km^2, and 23% in 49+ km^2. All of the occurrences with no volume were in 49+ km^2 drainage areas. For occurrences with no large pieces, 23% were found in 1-10 km^2, 46% in 10-49 km^2, and 31% in 49+ km^2 drainage areas. For occurrences with no accumulations, 21% were found in 1-10 km^2, 50% in 10-49 km^2, and 29% in 49+ km^2 drainage areas.

Table 5.25. Descriptions of mean number of large pieces for five selected sections 1 to 2.5 km in length, regardless of harvest and road history. Mean number of large pieces expressed in area of 50-m stream segment. See related Figure 5.26.

Section of stream	Mean Number of Large Pieces (#/ha)		
	Pre-1996	1996	Post 1996
Upper Lookout	73	34	3
Mack	42	5	3
McRae-up	55	44	5
McRae-low	23	34	2
Cook	36	14	3

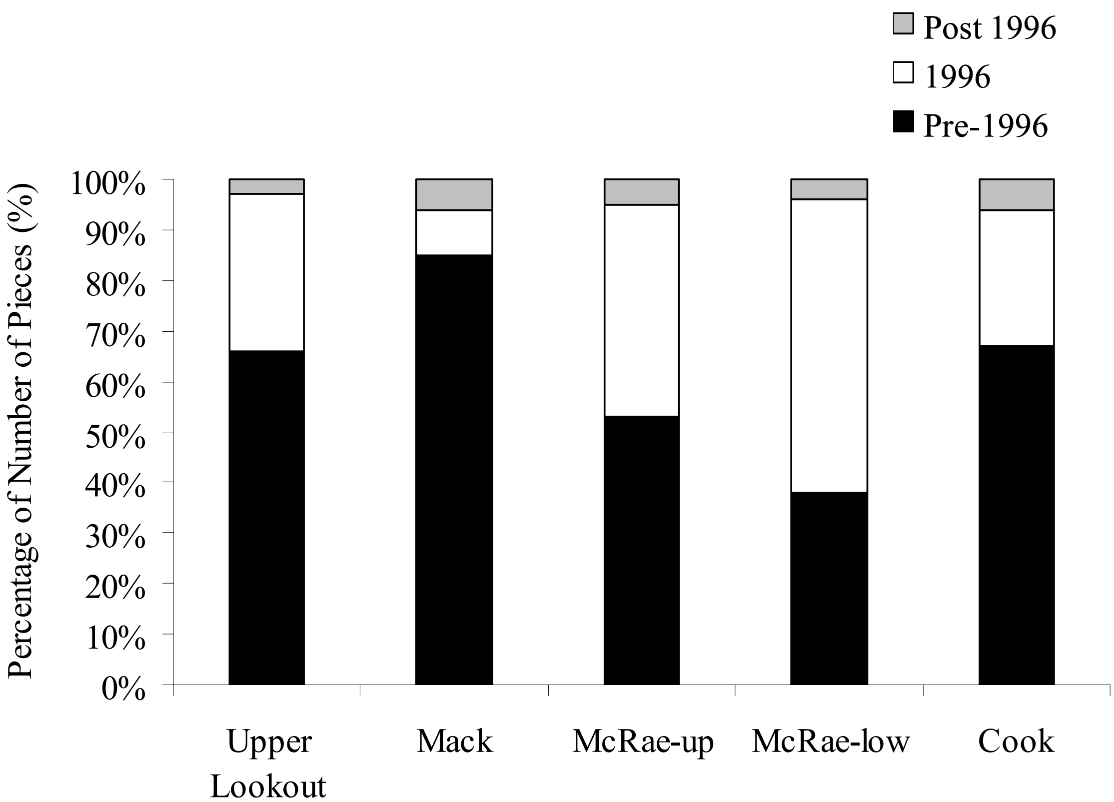


Figure 5.26. Comparison of percentages of volume found in 50-m stream segments for pre-1996, 1996, and post 1996 in five selected sections of stream. Percentage is taken of the number of pieces per channel area (ha). See related Table 5.25.

Table 5.26. Detailed evaluation of 50-m stream segments with and without large pieces of wood and with and without harvest and roads in seven 1 to 2.5 km stream sections. Volume is expressed per channel area of 50-m stream segments (m^3/ha) for seven selected sections of stream in the Blue River basin.

Section of stream	# of 50-m Segments: With Large Pieces		# of 50-m Segments: Without Large Pieces		Percentage of 50-m Segments Without Large Pieces based on the Total…		Mean Volume (m^3/ha): With Large Pieces		Mean Volume (m^3/ha): Without Large Pieces	
	Without Harvest or Roads	With Harvest or Roads	Without Harvest or Roads	With Harvest or Roads	Without Harvest or Roads	With Harvest or Roads	Without Harvest or Roads	With Harvest or Roads	Without Harvest or Roads	With Harvest or Roads
Upper Lookout	20	5	0	3	0	38	942.6	861.0	n/a	34.0
Lookout	18	28	0	3	0	10	350.9	211.7	n/a	16.8
Mack	13	4	1	4	7	50	604.0	232.8	92.1	47.8
McRae-up	14	5	0	2	0	29	967.0	613.4	n/a	75.9
McRae-mid	20	7	0	0	0	0	584.4	296.1	n/a	n/a
McRae-low	16	3	0	3	0	50	457.5	269.1	n/a	43.9
Cook	18	24	0	3	0	11	518.2	302.3	n/a	62.8

Table 5.27. Location of 50-m stream segments without any large pieces. Harvest and Road Classes defined as: None = no harvest and/or roads, H1 = harvest one side, H2 = harvest two sides, R = roads, H1&R = harvest one side and roads, and H2&R = harvest two sides and roads. All Harvest and Road Classes from within 40 m of channel.

		Harvest and Road Class							
Drainage Area	Sampling Site	None	H1	H2	R	H1&R	H2&R	N	Total
1-10 km^2	Upper Lookout	3	0	0	0	0	0	0	3
	Mack	1	2	2	1	0	2	0	8
	McRae	0	2	1	0	0	1	0	4
Total		4	4	3	1	0	3	0	15
10-49 km^2	Cook	0	6	1	0	1	0	0	8
	Upper Lookout	0	8	7	0	0	0	2	17
	McRae	0	3	0	0	0	0	0	3
	Quentin	2	0	0	0	0	0	0	2
Total		2	17	8	0	1	0	2	30
49+ km^2	Lower Lookout	1	9	0	7	1	0	2	20
Total		1	9	0	7	1	0	2	20
Overall Total		7	30	11	8	2	3	4	65
Overall Percentage		11	46	17	12	3	5	6	

Table 5.28. Location of 50-m stream segments without any accumulations. Harvest and Road Classes defined as: None = no harvest and/or roads, H1 = harvest one side, H2 = harvest two sides, R = roads, H1&R = harvest one side and roads, and H2&R = harvest two sides and roads. All Harvest and Road Classes from within 40 m of channel.

		Harvest and Road Class							
Drainage Area	Sampling Site	None	H1	H2	R	H1&R	H2&R	N	Total
1-10 km^2	Upper Lookout	1	1	0	0	0	0	0	2
	Mack	1	0	2	0	0	1	0	4
	McRae	0	2	0	0	0	0	0	2
Total		2	3	2	0	0	1	0	8
10-49 km^2	Cook	0	1	2	0	0	0	1	4
	Upper Lookout	2	6	2	0	0	0	2	12
	Quentin	3	0	0	0	0	0	0	3
Total		5	7	4	0	0	0	3	19
49+ km^2	Lower Lookout	1	4	0	4	0	0	2	11
Total		1	4	0	4	0	0	2	11
Overall Total		8	14	6	4	0	1	5	38
Overall Percentage		21	37	16	10	0	3	13	

6. DISCUSSION

This observational study was conducted in the Upper Blue River basin, which has a harvest and road building history that is in some ways unique to the western Cascades, but a spatially heterogeneous natural history that resembles other parts of the region. Despite natural disturbances, observations argue that the presence of harvest and roads near the stream was reduced in-stream wood abundance.

6.1 Limitations of this study

6.1.1 Observational nature of the study

Due to the observational nature of this study, it is limited to the determination of weak, rather than strong, causal relationships. Nonetheless, results of statistical analyses indicated strong trends.

6.1.2 Natural wood input and redistribution processes in sampling sites

All sampling sites are affected by a range of natural wood input and redistribution processes that are spatially heterogeneous, including earthflows, debris flows, windthrow, and wood and channel restructuring by floods (Swanson and Lienkaemper 1978, Lienkaemper and Swanson 1987, Swanson et al. 1998, Snyder 2000, S. Johnson et al. 2000, Faustini 2000), which may have effects that were not taken into consideration in this study. Each event or process acts at distinctive spatial and temporal scales (Keller and Swanson 1979) and has the potential to recruit, redistribute, and remove pieces of wood in the stream.

6.1.3. Harvest and road history in the sampling sites

Due to the specific harvest and road history of the study area, conclusions should not be taken out of context. Previously compiled site history for the entire basin shows that harvest and road building was mainly conducted in Lookout from 1950 to 1970, whereas in Upper Blue River it started approximately 10 years later, from 1960 to the 1990's (Jones and Grant 1996). Timber harvest intensity was higher in the Lookout Creek watershed than Blue River, but this situation reversed in the 1970's. Road construction occurred mainly between 1950 and 1970 in Lookout, and 1960 and 1980 in Blue River (Wemple et al. 1996). In both basins together, 32% of the road network was constructed before 1960, 34% in the 1960's, 25% in the 1970's, and 8% after 1980 (Wemple et al. 1996).

In-stream salvage was known to have occurred throughout the Blue River basin, but the extent is not well known. In only a few places salvage could be detected in the stream (e.g. cut ends of tree boles and skid roads), most related to streamside harvest and roads (Appendix C).

6.1.4. Limitations of Lookout Creek basin

Both natural and human factors distinguish Lookout Creek from other neighboring portions of the central western Cascades, thereby limiting the scope of inference from this study. The natural landscape of Lookout Creek contains a larger proportion of forest stands 450-500 years old than in the Upper Blue River basin. Also, Lookout Creek has unique features such as a wide, terraced valley with subsequent alluvial fans in Middle Lookout (Swanson and James 1975). Harvest and roading occurred earlier (1950's and 1960's) than in neighboring basins and at times different techniques were used for experimental purposes (Silen 1955, Jones and Grant 1996). Since the preponderance of the samples in this study were taken from Lookout Creek (especially of roads), they are only partly representative of other neighboring basins. These differences in timing of management may be significant because practices had variable effects on streams over time.

6.1.5 Sample size

In many cases the number of 50-m stream segments was dominated by one or two categories of harvest or road intensity, decade of harvest, or sampling site while remaining categories have a fairly small sample size. Results for 50-m stream segments may be low because a majority of those segments are in lower parts of the basin where wood abundance was found to be lower. Therefore, more confidence is given to results relating to harvest on one side of the stream, harvest in the 1950's and 1960's, and patterns observed in Lookout Creek. Most biases have been addressed by examining individual sites for harvest and road effects.

6.1.6 Evaluation per unit channel area vs. unit channel length

Differences between sampling sites were sensitive to whether channel area or channel length was the unit chosen for evaluation. Using units of channel area enables accountability for differences in channel width between sampling sites and locations within a sampling site. Channel length is a more one-dimensional unit and does not always capture these differences. For instance, Upper Lookout, which had highly variable average widths (ranging from under 5 m to nearly 40 m), did not have significantly higher volume, number of large pieces or number of accumulations than Lower Lookout when evaluated by units of channel length, but did when evaluated by channel area. Whereas Cook, with less variable average widths (ranging from 13.5 m to approximately 26 m), had a similar relationship with Lower Lookout despite the unit of comparison.

6.2 Relationship of volume and large pieces

Large pieces area a small proportion of total sampled pieces of wood, but they contain the largest proportion of volume, therefore often determining differences in wood volume between 50-m stream segments. Over half of the total pieces accounted for a very small proportion of the volume, suggesting that the total number of pieces may fluctuate, but volume changes significantly only with the addition or subtraction of large pieces of wood. Due to these associations, results of analyses of volume and large pieces were often similar.

This pattern remains true for accumulations, where the majority of total pieces of wood, large pieces and volume are found in similar proportions. The abundance of wood found in accumulations suggests that the results from analysis of accumulations may be similar to that of large pieces, which was in large part true.

6.3 Harvest and road effects on stream vs. landscape

Earlier harvest and road building practices were different than later practices, thereby creating different patterns of in-stream wood. Lookout harvests were earlier than Blue River, but not so much earlier that harvesting methods included splash damming ad log jam removal that was occurring on federal, state and private lands prior to the 1950's (Sedell and Luchessa 1982). Because the Andrews Forest (Lookout Creek basin) was established as an experimental forest in 1948, road construction and harvesting occurred earlier (i.e. 1950's and 1960's) than neighboring basins such as Blue River (Silen 1955), but not earlier than some other basins in the Willamette Valley (Jones and Grant 1996).

Road construction techniques differed by the 1970's and 1980's. Recognition of slope stability concerns and mass failure of midslope roads, led to the construction of a higher proportion of ridgetop roads (Wemple et al. 1996). In addition, technological improvements to harvest techniques allowed for longer hillslope yarding distances, reducing the need for midslope roads and landings (Wemple 1994). Basins such as upper Blue River, with a majority of road building and harvest post 1970 would be expected to have different road construction patterns than those in Lookout Creek basin.

Although studies in these sampling sites suggest that harvesting and roading occurred in lower portions of the basin first then moved to higher parts of the basin (Wemple 1994, Wemple et al. 1996, Jones and Grant 1996), it appears that riparian forests did not follow the same patterns but there is a similar trend (Table 5.10). Forest harvest practices consisted of small dispersed clear-cuts (eventually creating a patchwork landscape) that gradually increased since the 1950's, with approximately 85% of the cuts below 1200 m elevation (Jones and Grant 1996). Reduced cutting near the stream began in the early 1970's, due in part to the growing recognition in forestry of the importance of protecting riparian corridors for aquatic species, especially fish populations (Gregory 1997).

6.4 Reduced wood abundance where harvest and roads occur

6.4.1. No harvest and roads vs. harvest and roads

Large wood may be lacking in harvested and roaded sections due to a variety of wood removal events, combined with reduced subsequent recruitment. Wood recruitment can be highly variable through time (Lienkaemper and Swanson 1987, Van Sickle and Gregory 1990, May 2001). No new wood may enter the study area for several years at a time, allowing for only a single or a couple large trees to account for a large proportion of the total volume that enters (Lienkaemper and Swanson 1987). During the 1996 floods, in areas adjacent-to-harvest, wood removed may not have been replaced, whereas it might have in adjacent-to-unharvested areas.

As roads were built and timber harvested, trees may have been removed from the road right-of-way and salvaged from adjacent forest and streams, reducing wood abundance. Salvage reduces wood abundance immediately during harvest. Also a gradual decrease is expected as large wood in the channel after harvest decays (Bilby and Ward 1991). Stream salvage probably occurred along roads constructed adjacent to streams in the 1950's and 1960's in Lookout and Blue River (Wemple et al. 1996). Also, there may have been other effects, like the bucking up of wood in streams to see if it was solid enough to remove, or for fish passage, thereby increasing its mobility (Sedell and

Luchessa 1982). Therefore, the earlier the harvest and roading was conducted, the higher the chance of relatively low wood abundance.

Differences between harvested and unharvested sections of stream have been found in previous studies (Grette 1985, Murphy and Koski 1989, Bilby and Ward 1991, Bragg 2000, Faustini and Jones 2003), but none have also looked at the impact of roads on the amount of in-stream wood or examined these relationships at this length of stream. The difference between harvest and roads along a stream is that a stand will become reforested and a road, as long as it is present, will not. Similar reductions in wood would be expected for both harvest and roads in the first decades after a harvest. After a clearcut, there may be an increase in pieces of large wood due to harvesting technique, but this would drop off relatively rapidly and then stay near zero while the stand grows (Bilby and Ward 1991, Bragg 2000). Fifty years after logging, large wood volume in channels can still be substantially lower than that of old-growth forests (Grette 1985, Bilby and Ward 1991, Bragg 2000), yet for roads the legacy can last as long as the road remains. In these sampling sites, not enough time has passed for differences to emerge in wood volume. In addition, streams in mature conifer stands tend to have higher wood abundance and larger piece size than streams running through younger forests, especially those dominated by hardwoods (Grette 1985, Bilby and Ward 1991).

Comparisons of accumulations can easily be confounded. In any given section of stream a variety of characteristics (i.e. floods, land management practices) involved with emplacement and retention of accumulations can create a highly variable number of accumulations. Many accumulations consisting of large pieces can remain for longer than 50 years (Swanson and Lienkaemper 1978, Hyatt and Naiman 2002, Dreher in prep), further confounding the relationship of the number of accumulations and the presence of harvest and roads. Additionally, the length of the channel with a harvest or road influence was often too short relative to the length needed to have an adequate sample of large accumulations.

6.4.2. Differences between harvest and road treatments

Differences between harvest and road intensities could not be well tested due to the small sample sizes in individual sites. Only three individual sampling sites had enough 50-m stream segments for comparison of volume, large pieces, or accumulations -- Upper Lookout, Lower Lookout and Cook, although sample sizes were still low. Even when all sites were combined, variability in samples was often too great to compare harvest and road intensities.

Nonetheless, two trends were observed. Harvest on one side of the stream tended to have higher wood abundance than harvest on two sides of the stream. Additionally, harvest tended to have higher wood abundance than 50-m stream segments that had roads.

6.5 Spatial lags/neighborhood effects

Due to wood removal processes, lower wood abundance was expected downstream of a harvest or road. Fluvial transport is more common in larger channels (Keller and Swanson 1979, Braudrick and Grant 2000, Haga et al. 2002), yet small pieces can be moved in smaller channels, and high flow events can impact a larger number of low-order streams. Nevertheless, large wood is not as prone to fluvial movement since coniferous large wood can persist for long periods of time, often over 100 or 200 years, and is more stable, slower to decay, and less likely to be transported out of the system than hardwoods (Swanson and Lienkaemper 1978, Murphy and Koski 1989, Hyatt and Naiman 2002).

Despite expectations, there was a neighborhood effect on wood volume not only downstream, but also upstream of a harvested and roaded section of stream. A reduction in volume of the 50-m stream segments downstream of a section of stream with harvest and/or roads could be expected due to in-stream wood movement, but the similar results for the 50-m stream segment upstream suggests that this may not be the most influential reason.

Potentially, this could be due, in part, to stream cleaning and salvage practices that were more commonplace during the 1960's and early 1970's (Sedell and Luchessa 1982, Bilby 1984) when most of the streamside, unbuffered harvests occurred. Wood reduction created by stream cleaning, salvage, and the removal of hazard trees from the adjacent stands and streams within 100 m from cut unit boundary may create a neighborhood effect, like that seen upstream and downstream of harvested and roaded sections of stream.

On the edges of any given harvest unit, increased windthrow might be expected (Steinblums 1977, Sinton et al. 2000), which could increase wood abundance in the channel both upstream and downstream. If increased windthrow did occur, it did not appear significant enough to outweigh factors causing reduced amounts of in-stream wood.

A neighborhood effect was not observed when the number of large pieces and accumulations where large wood was key were evaluated, which may in part be due to the number of 50-m stream segments without large pieces removed from the dataset (in order to adhere to statistical assumptions). By removing 50-m stream segments without large pieces, sample sizes became reduced and variability increased.

By accounting for the neighborhood effects combined with the harvest and road effects, differences in volume between 50-m stream segments with harvest and roads and those without could be accounted for in the sampling sites. Additionally, this suggests that once neighborhood effects are accounted for, harvest and road effects can be found even in Lower Lookout, where there is substantial fluvial transport.

6.6 Effects of natural processes

Natural wood input and redistribution processes have not obscured the patterns imposed by roads and harvests decades ago, even after large wood recruitment and removal events. The majority of the study area was harvested and roaded less than 60 years ago, but more than 30 in Lookout Creek and more than 20 in Blue River, during and prior to sizable floods and windthrow events.

Natural wood input and redistribution processes can have a measurable effect on wood in streams, therefore it was considered a potentially confounding variable in this study. Windthrow is the more dominant force of input in first through fifth-order streams in Cascade mountain channels in Oregon (Lienkaemper and Swanson 1987), although near-stream toppling, tree lean, debris flows, and other factors can contribute. Debris flows, can make significant contributions to in-stream wood abundance, especially during large storm events (Swanson and Dyrness 1975, Wemple et al. 1996, Wondzell and Swanson 1999, Snyder 2000). They can occur in first through third stream orders and consist of significant amounts of large wood (300-1000+ m^3), which can be in direct contact with the active channel of the mainstem and account for over half of the total large wood volume within a disturbed stretch of the mainstem (Swanson et al. 1987, Benda and Cundy 1990, Nakamura and Swanson 1994, May 1998, S. Johnson et al. 2000, Snyder 2000, May 2001). Floods can engage pieces of wood, moving them downstream or out of the channel and creating new accumulations (S. Johnson et al. 2000).

In Lookout and Upper Blue River basins, natural events have occurred that could obscure the effects of harvest and roads. Several 50-year return-period floods have occurred since 1960 (floods in 1964, early 1970's, 1996), significantly re-arranging wood and channel form in many portions of the stream channel (Swanson and Dyrness 1975; Nakamura and Swanson 1993, 1994; Swanson et al. 1998; Wondzell and Swanson 1999; Snyder 2000; S. Johnson et al. 2000; Faustini and Jones 2003). Two major windthrow events in 1962 and 1990, as well as ice storms and snow events that create localized patches of windthrow have affected the basin (Powers et al. 1999). Debris slides and debris flows are fairly common in Upper Blue River, with nearly 90 inventoried in Lookout, McRae and the mainstem of Blue River over a fifty year period (Dyrness 1967, Swanson and Dyrness 1975, Swanson and James 1975, Snyder 2000), three-quarters which occurred during flood years 1964-65 and 1996 (Snyder 2000). Debris flow history is not as well known for Cook and Quentin with only a few noted (USDA 1996), additionally some were found during field surveys. Active earthflows may not play a large role in wood recruitment if the rate of movement is slow, but have been found in Mack and both Upper and Lower Lookout (Swanson and James 1975).

Windthrow, near-stream toppling and channel meander did influence wood volume in ways that would be expected, although their effects were not stronger than the harvest and road effects. Higher volume was expected where a significant degree of windthrow and near-stream toppling occurred (Lienkaemper and Swanson 1987, Murphy and Koski 1989, McDade et al. 1990). Lower volume was expected where braiding and meander of the channel were found, if channel change has affected the age of the adjacent stands (Gurnell et al. 2002). Yet, when the effect of harvest and roads was accounted for, these natural processes effects could not be seen.

After applying the wood volume estimates from this study to a landscape-scale natural processes designation system, Dreher (in prep) found that channel size was a good explanation of wood volume. The confounding effects of channel size found in the natural process designation system were captured by the designation of different sampling sites. All of the small channel effects were within Upper Lookout, all of the large channel effects were in Lower Lookout, and all of the intermediate/earthflow effects were in Upper Lookout.

Dreher also found that debris flows were not a good explanation of wood volume. This is consistent with other recent findings (Fox 2001). To examine this relationship further, see Dreher (in prep).

6.7 Landscape and network results

Significant between-site differences in wood volumes, numbers of large pieces, and numbers of accumulations are most likely attributable to differences in harvest and road frequency, but actual effects depend upon the natural setting of the basin and the combined effects of harvest and roads on wood. A landscape is composed of a combination of patches and network structures that can be distinguished by vegetation or other properties that reflect evolution, disturbances or management (Swanson et al. 1997). Types of networks include both road and stream systems (Jones et al. 2000). Patches can be created on the landscape by natural disturbance events, such as flooding, or by management practices, such as timber harvest (Swanson et al. 1997).

Harvest patches and road networks, some of which were created simultaneously, create a management history that is distinguishable at both spatial and temporal scales for individual sampling sites. Timing of harvest and road building in McRae, Mack and Upper and Lower Lookout (1950-60's) tended to be earlier than Cook and Quentin (1960-80's), yet few differences were found between the two harvest and roading histories. The effects of time on wood abundance can be related not only to the harvest and road history, but also the ability for wood to decompose and be moved out of its original location in the channel. In addition, few differences were found between-sites of differing harvest and roading histories when harvest and roads were removed.

There is a sampling site effect that is not accounted for by this study, shown by the differences in sampling sites despite harvest, road, and neighborhood effects being removed. After removing all stream segments next to, or within 100 m up and downstream of a road or clearcut, Lower Lookout still had less wood than most sites except Quentin. Lower Lookout has the largest drainage area in the study with the highest stream orders and flow, allowing fluvial arrangement to play a more significant role and contributing to lower wood volumes (Bilby 1985, Keller and Swanson 1979, Lienkaemper and Swanson 1987, Bilby and Ward 1991, Martin and

Benda 2001, and May 2001). The 1996 floods significantly changed wood arrangement in Lower Lookout (Faustini 2000), which may have blurred the distinction between harvested, roaded, and unmanaged sections of the stream. Potentially, after a significant amount of time with no major fluvial rearrangement, difference between harvested and roaded sections and untreated sections would be seen. For differences between harvested and unharvested reaches to persist there must be little longitudinal transport of large wood in channels draining areas less than about 1000 ha (10 km^2).

Reduced wood levels in Quentin could be due to higher transport capacities or reduced recruitment. Less is known about the flood history of Quentin, but the channel was unique in this study with a larger proportion of bedrock and more highly constrained reaches than other sampling sites. Constrained channels have lower amounts of wood trapped than unconstrained channels due to the dissipation of flow energy that moves pieces (Nakamura and Swanson 1994). Fires in the 1800's affected areas all the way down to the channel (McKenzie River RD 2001), therefore not enough time may have passed for recruitment to return to natural levels.

6.8 Between-site differences not explained by this study

Controlling for harvests and roads, and for natural input and redistribution process evidence noted in the 2002 survey, there were still between-site differences in wood volumes and numbers of large pieces that were not explained by this study. This can be due to 1) the timing of wood emplacement is largely speculative, and 2) a number of 50-m stream segments had no large pieces or accumulations, which varied by sampling site and harvest and road effect.

It is important to consider that patterns of wood recruitment prior to, during and after the 1996 flood are largely speculative due to the difficulty in placing a piece of wood in the appropriate category. Despite efforts to avoid error, the course-scale nature of this study did not allow for rigorous timing determinations. In addition, a piece was given a recruitment category based upon when it was emplaced at the location found, but it could have entered upstream and had been transferred to the location during a later recruitment category.

Nevertheless, by examining selected sites in more detail, temporal differences could be seen between sites that were not necessarily related to the presence of harvest or roads. There was very little new recruitment of wood post 1996 with or without harvest and roads; and greater variability of both pre-1996 and 1996 was due to two sites – Mack and Cook. Mack did experience greater than average peak flows in the 1996 flood event, yet only 11% of pieces moved more than 10 m (Gurnell et al. 2002), which may explain the low 1996 emplacement. On the other hand, McRae-low, with the highest 1996 emplacement of the sites may have been more greatly influenced by the 1996 floods than the others. Mack was higher in the Lookout Creek basin, therefore a larger snowpack than lower elevation stream reaches limited the peak flow in 1996 (Swanson, personal communication).

The re-visitation of 1975 mapped reaches of wood in Lookout and Mack suggest that, although pieces are lost to decay and movement, a similar number and size of pieces are recruited into the section over time (Dreher in prep). This suggests that other natural processes are involved over short time scales and can be a significant factor in determining wood abundance. Further study must be conducted to understand the relationship of harvest and roads to the potential collection of wood and the natural processes that would influence this collection process.

Although the removal of 50-m stream segments without large pieces allowed for a more conservative analysis of the effects harvest and roads have on the stream, no analysis was conducted to determine the overall frequency of 50-m stream segments with zero occurrences of wood. Differences between in the number of 50-m stream segments without large pieces not affected by harvest and roads could potentially explain some between-site differences.

6.9 Management Implications

Findings from this study can be used to understand the legacy of past management practices, as well as to make speculations about effects of current management policies and practices. Most of the harvesting and road building in this study were conducted in the 1950's through 1970's, when the impact on the land and channel were more intensive than prescribed by recent management policies and practices. Few harvests had been conducted in the Blue River basin during the late 1970's through the early 1990's, a time when policies and practices had begun to be implemented to protect aquatic resources. Since the introduction of the Northwest Forest Plan in 1994, very few harvests have been conducted in the Blue River basin, with none near enough to the mainstem streams to be inventoried in this study.

In a study such as this, with a management legacy that is more intensive than recent management practices, a high degree of contrast in wood abundance between channels adjacent to managed and unmanaged stands would be expected because natural stands are primarily old growth. In other basins with differing fire and management histories, post-wildfire streamside stands may be younger and smaller and management may have had lower impact, leading to smaller differences in wood abundance. Contrast between management practices in other basins could differ if more recent management policies and practices have been implemented or different combinations of management policies and practices have been implemented than those in this study.

Some modeling and chronosequence studies suggest that minimal wood abundance may occur in the when wood from pre-fire stands has decomposed and before the post-fire stands begin producing at a higher rate (Bragg 2000). Low wood levels in Quentin Creek, for example, suggest that it takes longer than 150 years after wildfire before wood levels more typical of old growth are achieved.

Additionally, the impact of management practices must be examined with respect to fluvial transport capabilities. In smaller channels, where fluvial transport is low, the effects of harvest and roads can stay in place for a long period of time with persistence determined by rates of wood input and decomposition. Wood pieces placed in channels for restoration may also stay in place, as long as they are as stable as the native material. In zones of substantial fluvial redistribution, the effects of harvest and roads are still present, but may be reflected significant distances downstream as reduced wood abundance. In these sites wood placed in channels for habitat restoration may last for a time (until the next flood of sufficient magnitude to move the key pieces), but should not be expected to have the same longevity as in channels with low fluvial redistribution.

6. CONCLUSIONS

Results of this study show that the impact of harvest and roads on wood abundance can still be seen after up to 50 years post-harvest and roading in highly localized sections of stream, despite large flood events and other subsequent natural disturbance processes. These results may be due in part to the longevity of pieces in many of the sampling sites, riparian stand conditions, and the very limited fluvial rearrangement in channels draining less than about 1000 ha (10 km^2).

Differences between basins are in part attributable to the differences in harvest and road impacts on the entire basin, especially the impact on the riparian environment. Timber harvest and road building in riparian areas of the Lookout Creek basin began in the 1950's and largely ended by the 1970's. In the Upper Blue River basin, riparian harvest and road building occurred largely between 1960 and 1990. In sampling sites in Lookout Creek basin, volume was higher than those of Upper Blue River, but there was no difference in the number of large pieces of wood, despite the close correlation of volume and large pieces of wood.

Analysis of volume, number of large pieces, and accumulations of wood showed that 50-m stream segments with harvest or roads had depressed amounts of wood compared to those with no harvest or roads present. Not only was this pattern found for all sampling sites together, but also for each individual sampling site except Lower Lookout, where fluvial movement has blurred the response. Most importantly, this study shows that not only harvest, but also roads reduce in-stream wood amounts.

Additionally, a very localized effect of harvest and roads was seen in streams with limited fluvial movement, even after large flood events. Lower wood volume was found not only in 50-m stream segments with harvest and roads within 40 m of the stream, but also the 50-m stream segment directly upstream and downstream of the harvested and roaded area.

Despite naturally occurring events, reduced wood volume was observed in 50-m stream segments with harvest or roads. Examination of localized natural processes, such as windthrow, near-stream toppling, and channel meander, suggested that none was successful in obscuring the effects of harvest and roads. Corresponding work conducted by Dreher (in prep) suggests that flooding, debris flow, and earthflow activity within the last 50 years also did not conceal the harvest and roads effects. Additionally, results suggest that even a large flood event such as that experienced in 1996 did not obscure the effects of harvest and roads in the majority of sampling sites.

The nature of this landscape-scale sampling design gave a perspective on the whole basin and allowed for examination of thresholds of change. A landscape-scale perspective has allowed for insights into the extent and magnitude of the legacy of harvest and roads after up to 50 years.

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APPENDICIES

Appendix A. Field collection data sheets. Two-sides. Description of data collected in Methods and Table 4.3 p. 20.

SIDE ONE

Basin	Seg	Unit

Date: ____________

Data Collectors: ____________

CHANNEL INFORMATION

D(m)	W(m)

Range		Grad.

Trib @ (m)	Width (m)

Boulders	
0-10	
10-100	
>100	

	B	C	G	BR	S
Bedform (%)					

Constraint:

Sinuosity:

Disturbance:

Comments:

Singles

	Location in channel:											Empl. By			
D (m)	Zone (%) 1	2	3	4	SC	LC	DC	C / HW/?	Cut end Y/N	Trapping Y/N	Resting on?	F/DF/WT/BE/?	Dir of Orien	Date of Empl	Comments:

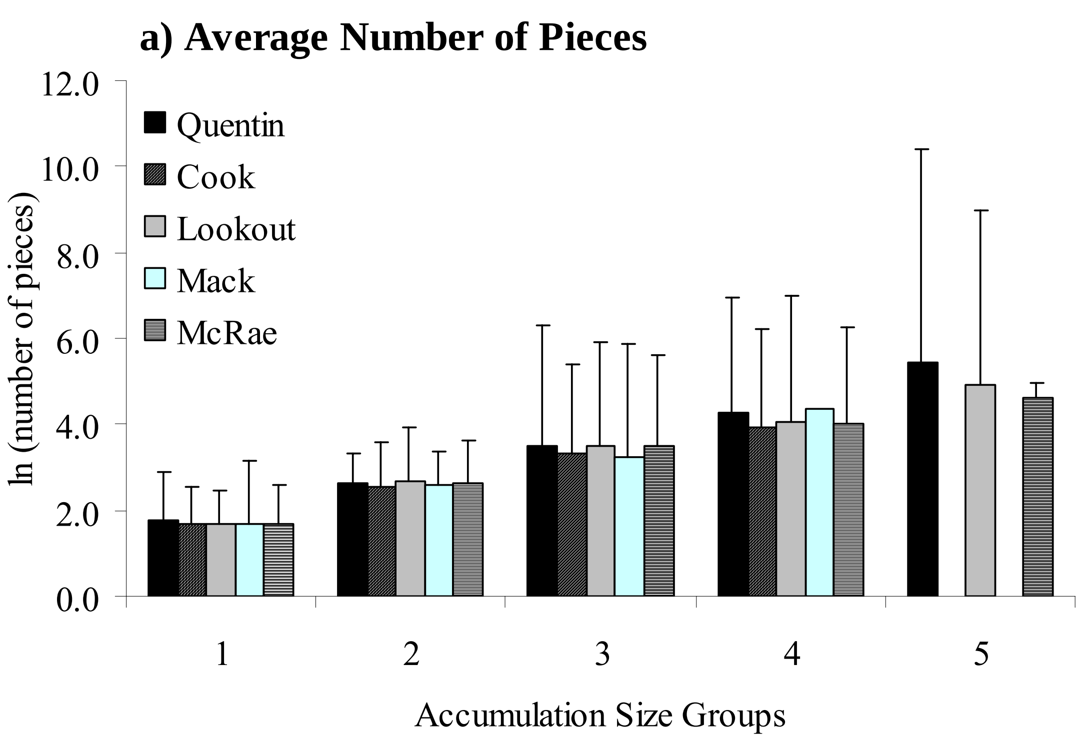
SIDE TWO

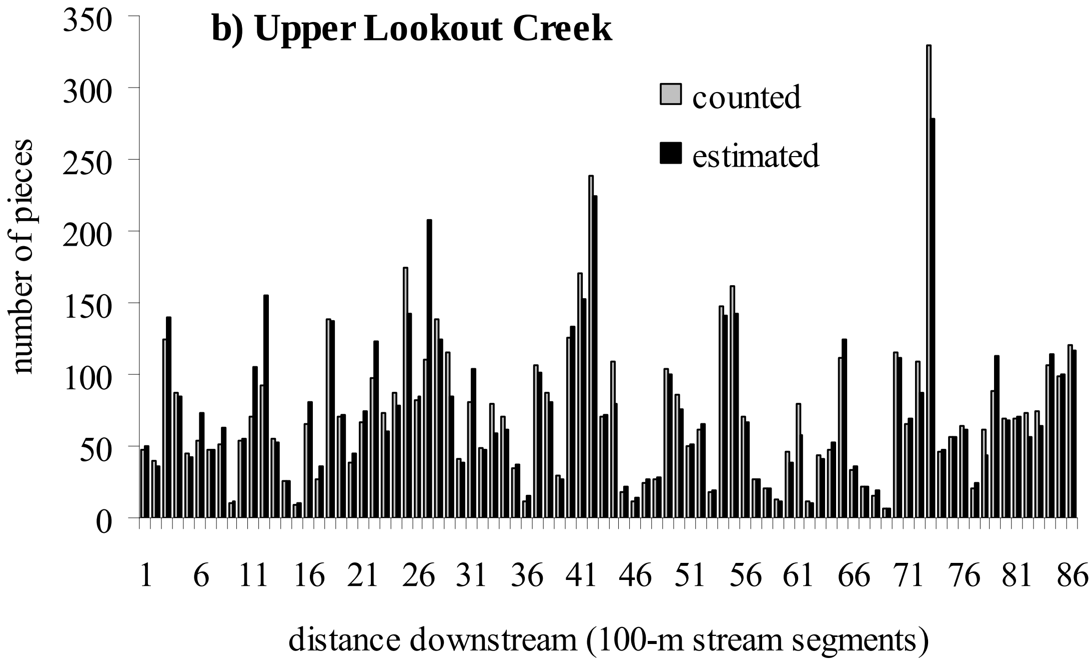
Accumulations (3-10 pieces) and Jams (>10)

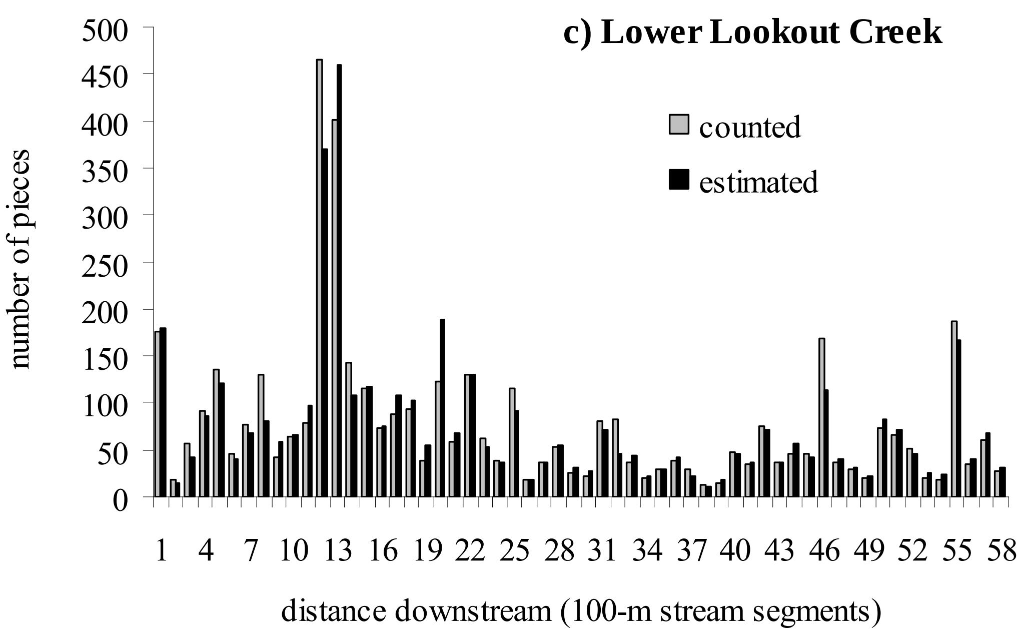
# of pieces	Do (m)	Df (m)	# in each SC.LC 1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4

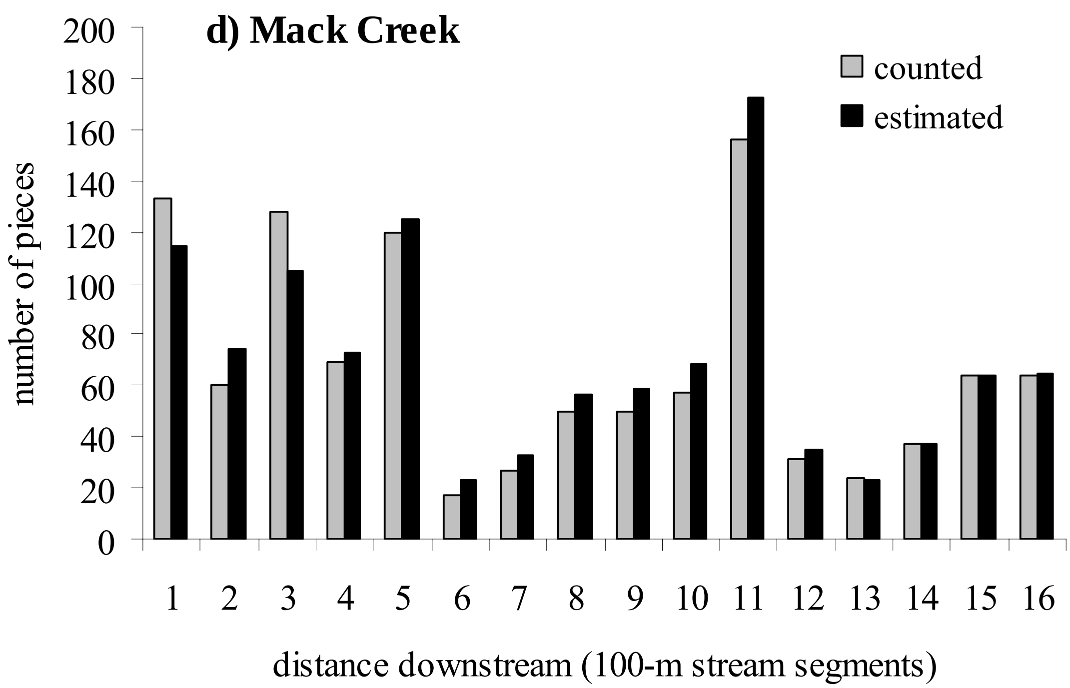
				Emplacement mechanism					When Emplaced								
Density	% span	What's Key?	If wood, S.L	F	BE	EF	DF	WT	Pre	96	Post	Unk	Type of accum	Eff of trap	Orient of feature	Cut Ends	Comment

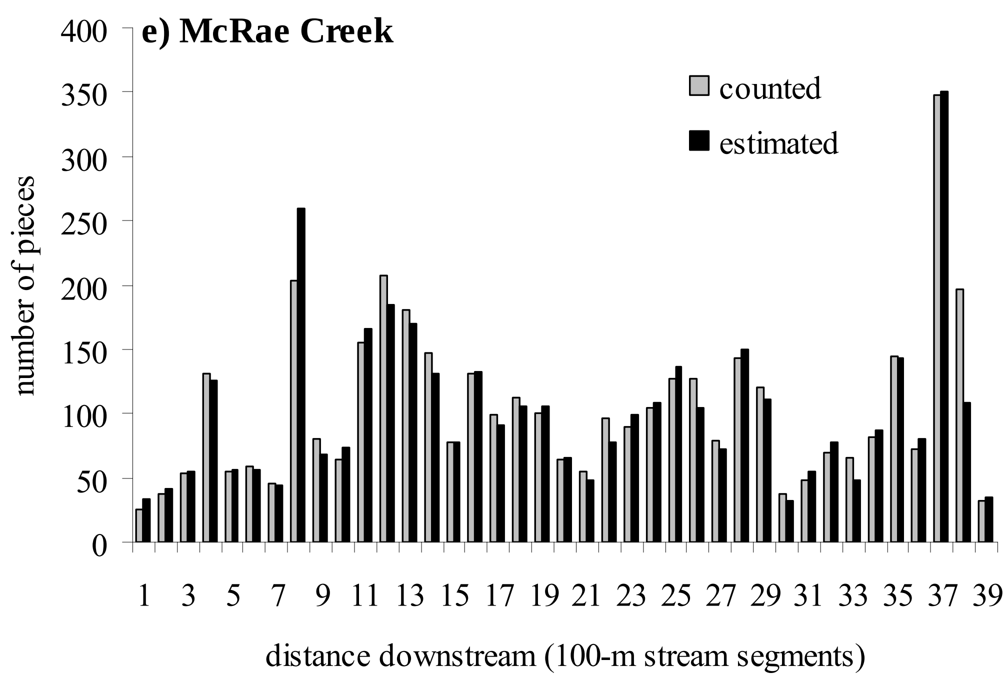
Appendix B. Actual vs. estimated number of pieces. Comparisons of actual counts and estimates yielded fairly similar results, therefore the actual counts were used in this study. Estimates are based off of an accumulation size classification collected during field surveys. A mean value of the number of pieces in each size class actually counted, for all six sampling sites, was computed. For each 100-m stream segment, the number of accumulations in each size class was tallied then multiplied by the mean to get the total number of pieces. Comparisons are first presented as a) average number of pieces in each of 5 accumulation size class categories (1 = 3-9 pieces, 2 = 10-20 pieces, 3 = 20-50 pieces, 4 = 50-100 pieces, and 5 = 100 + pieces) for all sites. Next, the total number of pieces per 100-m stream segment counted during field surveys versus those estimated by accumulation size class for b) Upper Lookout, c) Lower Lookout, d) Mack, e) McRae, f) Cook, and g) Quentin.

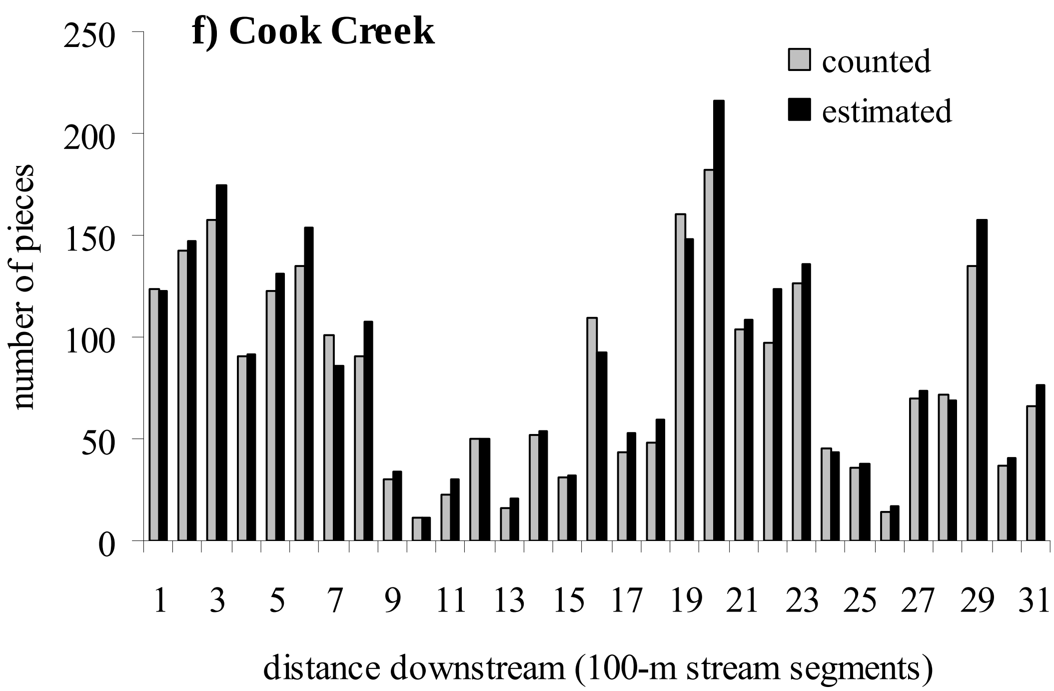


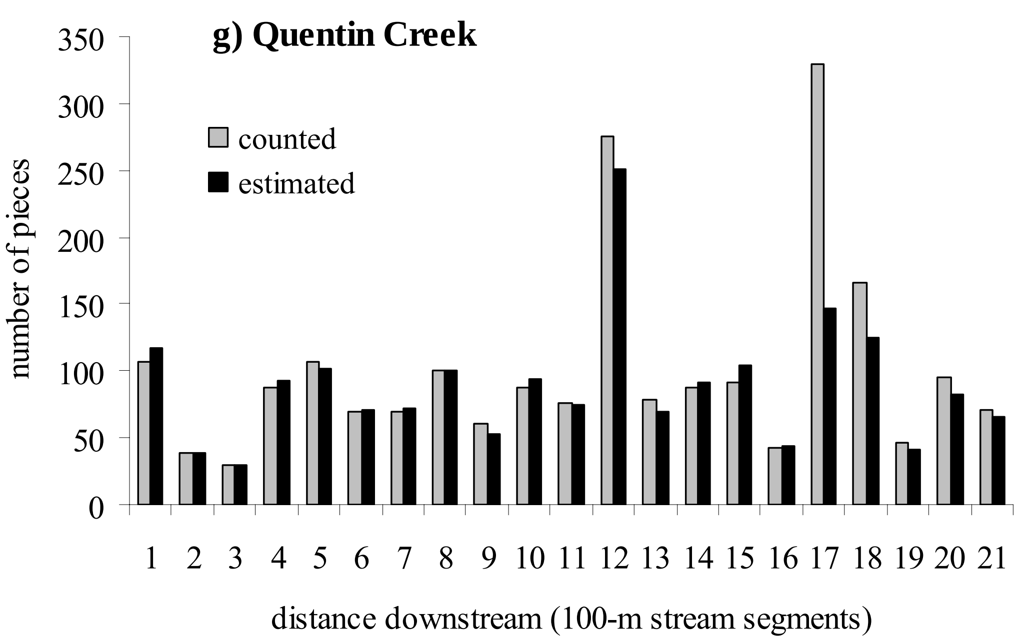

b) Upper Lookout Creek
counted
estimated
number of pieces
0
50
100
150
200
250
300
350
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86
distance downstream (100-m stream segments)


c) Lower Lookout Creek
counted
estimated
number of pieces
0
50
100
150
200
250
300
350
400
450
500
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
distance downstream (100-m stream segments)


d) Mack Creek
counted
estimated
number of pieces
0
20
40
60
80
100
120
140
160
180
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
distance downstream (100-m stream segments)


e) McRae Creek
counted
estimated
number of pieces
0
50
100
150
200
250
300
350
400
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
distance downstream (100-m stream segments)


f) Cook Creek
counted
estimated
number of pieces
0
50
100
150
200
250
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
distance downstream (100-m stream segments)


g) Quentin Creek
counted
estimated
number of pieces
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
distance downstream (100-m stream segments)

Appendix C. Map of in-stream salvage noted during field surveys.