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PROJECT REPORT

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Harvesting Practices - Effects on Woody Debris in Streams and Channel Bank Disturbance

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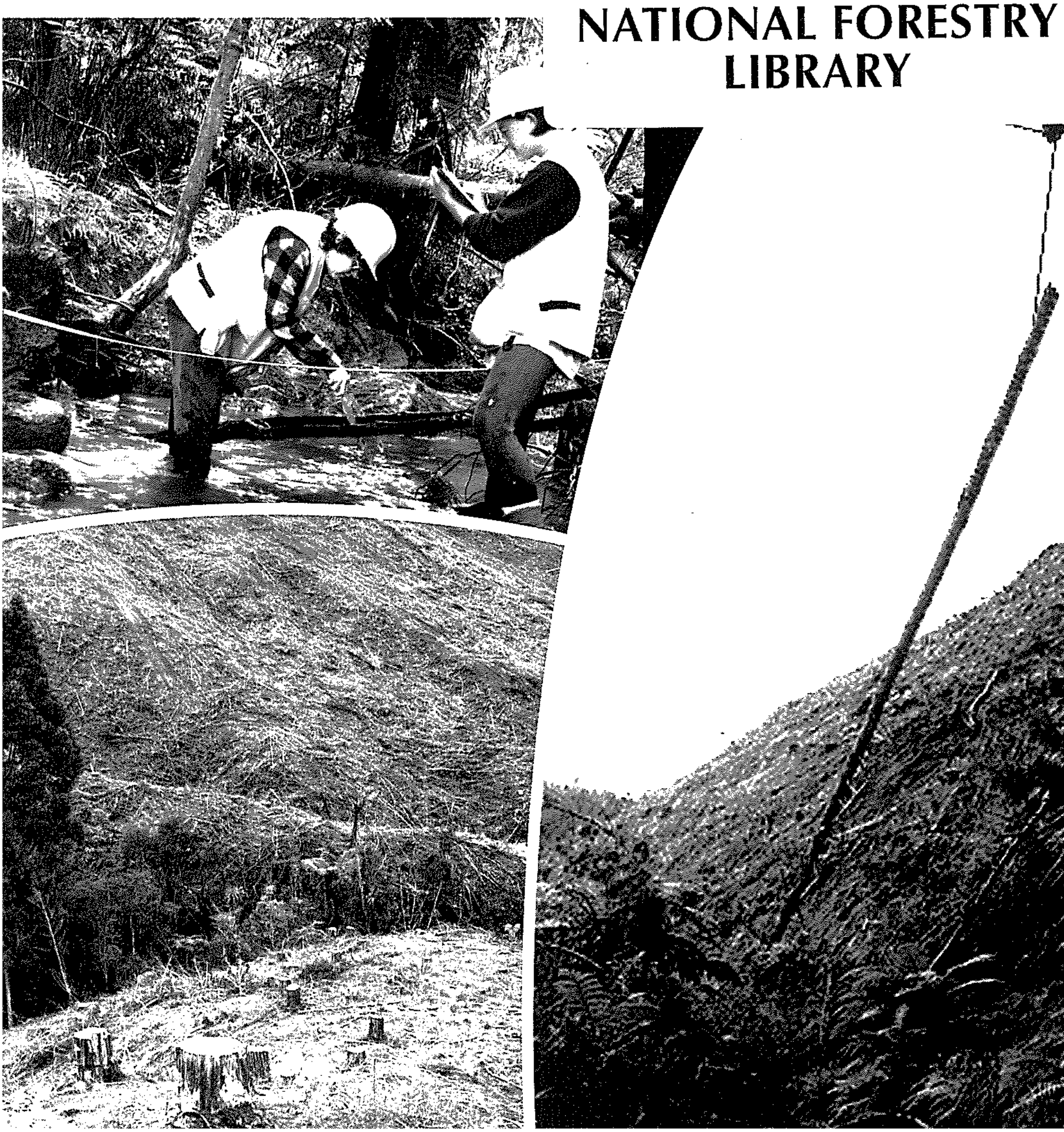

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HARVESTING PRACTICES - EFFECTS ON WOODY DEBRIS IN STREAMS AND CHANNEL BANK DISTURBANCE

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EXECUTIVE SUMMARY

Woody debris ≥ 1 cm in diameter was measured before and after harvesting, along a 100 m section of stream channel, at seventeen stream sites in New Zealand's pine plantation forests. Small streams (0.5 to 5.5 m in width) which forest companies had identified as requiring protection, were selected for the study. Main on-site reasons cited for stream protection were to: minimise sedimentation in the stream channel, maintain or protect the stream ecosystem, minimise stream bank and soil disturbance and minimise the risk of debris dams. Main down stream issues were fishery values (trout and native fish), farmland, water supply and down stream sedimentation. The most common practices used to protect the stream were directional felling back from, or parallel to, the stream edge, no delimbing close to the stream edge, and removing merchantable or large pieces of woody debris from the stream channel.
The main findings of this study were:

- Pre-harvest woody debris volumes in the stream channel averaged 105 ± 42 m^3 ha^{-1} (95% CI). Windthrown stems and residual native woody debris contributed to most of the woody debris volumes.
- Post-harvest woody debris volumes in the stream channel (pre-harvest + harvest) excluding the stream-cleaned sites, averaged 289 ± 100 m^3 ha^{-1}, a three-fold increase on pre-harvest levels.
- Woody debris volumes from harvest averaged 147 ± 84 m^3 ha^{-1} . Stream-cleaned sites had the lowest average woody debris volumes (15 m^3 ha^{-1}), followed by ground-based operations (48 m^3 ha^{-1}). Hauling back from the stream edge averaged 104 m^3 ha^{-1} and the highest volumes were recorded when hauling across the stream channel (287 m^3 ha^{-1}).
- Harvest method had the greatest influence on woody debris volumes in the stream channel and over rode the influence of riparian buffers.
- Both small woody debris 1 - 9 cm diameter class (SWD) and large woody debris ≥ 10 cm in diameter (LWD) volumes increased after harvest. However, the proportion of SWD increased from 13% of woody debris volumes at pre-harvest to 38% of the woody debris volumes at post-harvest. This was due to small material (branches, broken tops) entering the stream channel during harvesting operations and the prescription requirements to remove larger merchantable wood from the stream channel.
- The length of the LWD pieces from harvesting, was significantly shorter than pre-harvest LWD. Windthrown stems contributed to the longer LWD pieces at pre-harvest. The requirement to remove merchantable timber from the stream channel was the main reason for smaller LWD lengths at post-harvest.
- Most of the woody debris in the stream channel was positioned above the stream at pre-harvest, harvest and post-harvest, 69%, 64% and 66%, respectively. The remainder of the woody debris volumes lay either in-stream or on the floodplain.
- Bank collapse was the most common type of channel bank disturbance (69%) prior to harvest, accounting for 83% of the soil lost from the channel bank. Bank scuffing was the most common type of channel bank disturbance after harvest (47%), accounting for 63% of the soil lost.
- Most forest companies are re-planting the stream sites 5 to 10 m back from the stream edge or along the geomorphic boundary of the stream.

INTRODUCTION

In New Zealand's pine plantations, timber is being harvested along stream edges using a variety of systems and practices. In some cases, a riparian buffer exists, but in most instances trees have been planted up to the stream edge.

Harvest operations have the potential to change the amounts and characteristics of woody debris in streams and increase channel bank disturbance. In a number of North American studies, harvesting tended to decrease wood volumes in the stream channel. Woody debris piece size distribution also changed after harvest, piece size was smaller, the number of pieces increased and the woody debris was less stable (Froehlich 1977; Toews and Moore 1982a).

Harvesting operations can also increase the amount of channel bank disturbance. Toews and Moore (1982b) recorded significant increases in channel bank erosion in harvested sites in comparison to sites where unharvested riparian buffers remained.

In the plantation forests of New Zealand, harvesting residue is usually the main source of woody debris in the stream channel. However, some additional woody debris enters the stream channel from thinning operations and windthrow. Woody debris from harvesting operations can provide shade, temperature control, and a habitat and food source for aquatic animals (Collier *et al.* 1997; Baillie *et al.* 1998). However, high levels of woody debris can impact on water quality (Pruden and Coker 1990;

Table 1- Description of study sites

Site Number	Region	Catchment area (ha)	Av stream width (m)	Av stream depth (mm)	Stream Order
1	Auckland/ Coromandel (A/C)	16.4	1.4	68	1
2	A/C	65.0	3.6	155	1
3	A/C	68.5	3.2	36	1
4	A/C	20.0	1.7	107	1
5	A/C	26.3	1.5	49	2
6	Central North Island (CNI)	297	2.5	159	2
7	CNI	268.5	2.5	171	2
8	CNI	2200	5.5	351	3
9	CNI	865	1.4	479	2
10	CNI	28.3	1.1	44	1
11	Hawke's Bay	280	2.4	190	2
12	Nelson	33.5	1.7	48	1
13	Nelson	16.7	2.6	6	1
14	Nelson	26.5	3.0	45	1
15	Nelson	9.3	2.6	46	1
16	Southland	84	2.2	75	2
17	Southland	18.5	0.5	15	1

Table 2 - Reasons for stream protection

On-site issues	No*
Minimise sedimentation	8
Maintain/protect stream ecosystem	6
Minimise stream bank/soil disturbance	5
Minimise risk of debris dams	4
Flooding	2
Protect native fauna	1
Protect native riparian vegetaion	1
Down stream issues	
Fish values (trout and native fish)	8
Farmland	5
Water supply	4
Sedimentation	4
Water recreation	3
Woody debris	2
Harbour	1
Maintain/protect stream ecosystem	1
Protect native fauna	1

* As there was usually more than one reason per stream site for protecting the stream, the total in the No column is greater than seventeen.

Collier *et al.* 1998) and, in areas which are subject to frequent flooding, woody debris can be a potential hazard.

The objective of this study was to quantify the effect of different harvesting systems and practices on woody debris characteristics in streams of pine plantations. In addition, this study measured the impact of harvesting practices on channel bank disturbance.

SITE DESCRIPTION

Seventeen sites were selected from around New Zealand, covering a range of hauler and ground-based harvesting operations along stream edges. Characteristics of the sites are summarised in Table 1.

The study focused on smaller sized streams 0.5 - 5.5 m in width, which required some degree of protection during harvest, depending on on-site and down stream issues identified by the forest companies (Table 2).

Table 3 - Prescription requirements for harvesting along stream edge

Prescription standard	No*
Felling direction back from/parallel to stream edge	5
Felling direction back from or across stream	2
No delimbing within 20 m or close to stream	3
Merchantable timber/large debris removed from stream channel	3
Stream-clean (material removed from water table)	2
Whole stem extraction	2
Logging slash and debris removed from the stream channel	2
Maximum suspension across the stream channel	2
No machinery within 5 m of stream	2
No trees/slash/soil to be felled/deposited in stream	1

* As there was usually more than one prescription standard per stream site for protecting the stream, the total in the No column is greater than seventeen.

Table 4 - Description of harvesting and stand characteristics

Site Number	Harvest System	Harvest Method*	Stand vol (m^3ha^{-1})	Ground Slope(°)
1	Motor-manual, TMY 70, Northbend, motorised slack pulling carriage	1	579	26
2	Motor-manual, TY 80 Northbend	1	690	28
3	Motor-manual, TY 80 Northbend	1	690	20
4	Motor-manual, TY 80 Northbend	4	649	29
5	Motor-manual, TMY 70 Northbend	3	466	16
6	Motor manual, Madill 071 standing skyline motorised slack pulling carriage	4	749	32
7	Motor-manual, Madill 071 standing skyline motorised slack pulling carriage	3	749	29
8	Motor-manual, Thunderbird 738 excavator, John Deere 640E skidder	2	720	3
9	Timbco T445, John Deere skidder	2	937	3
10	Motor-manual, D65 Komatsu, Cat 518	2	358	5
11	Motor-manual, Bellis Northbend	4	571	13
12	Motor-manual, John Deere 640E	2	412	19
13	Motor-manual, Madill 071 motorised slack pulling carriage	4	241	31
14	Motor-manual, Bellis BE 70	4	522	29
15	Motor-manual, Dispatch shotgun	4	516	20
16	Motor-manual, Cat 518, John Deere 640	2	663	3
17	Motor-manual, TY45 modified slackline system	4	561	15

* Method 1 - hauler system, stream cleaned
Method 2 - ground-based system, extraction direction away from the stream channel
Method 3 - hauler system, extraction direction away from the stream channel
Method 4 - hauler system, extraction direction across the stream channel

Company prescription requirements to harvest in the stream area are summarised in Table 3. Sixteen sites were in stands of *Pinus radiata* ranging in age from 22 to 34 years. One site was in a *Pinus nigra* stand aged 68 years. Four sites (Sites 4, 5, 13 and 16) had riparian areas of native trees, shrubs and ground ferns, ranging from one to 30 m in width along the stream edge. Twelve sites were harvested using hauler systems (Table 4), the remaining five sites were harvested with ground-based systems. The systems and practices used to harvest the 17 sites were categorised into four methods (Table 4).

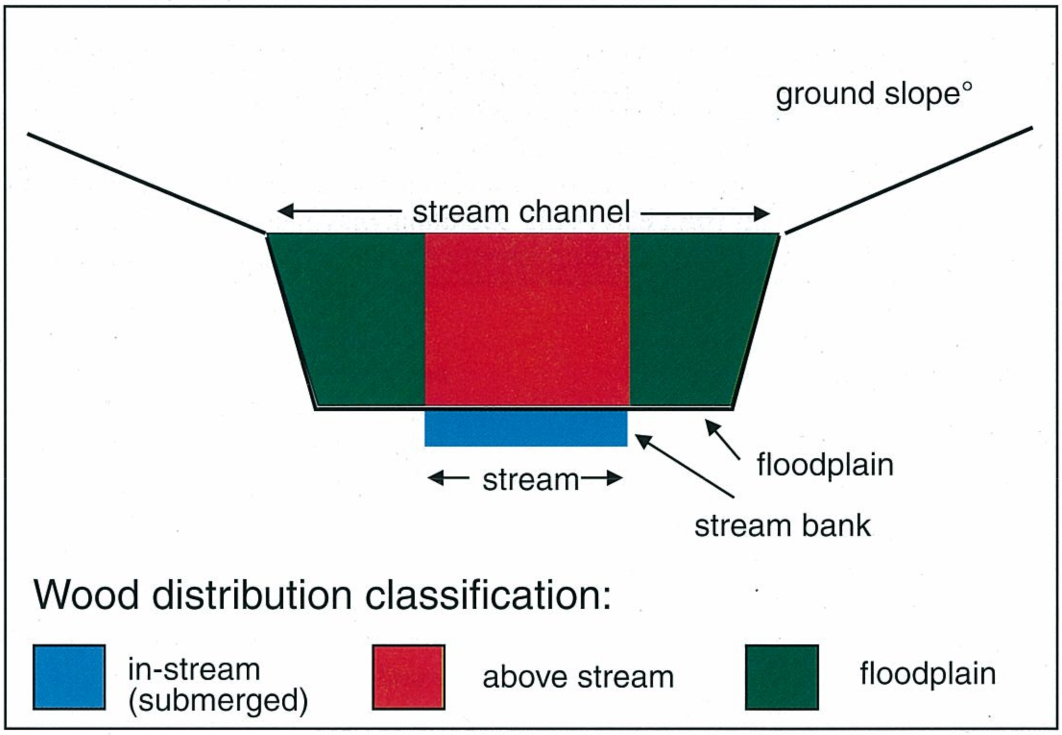

Figure 1 - Channel morphology measurements and classification of wood distribution in the stream channel

METHOD

At each site, a representative 100 m section of stream channel was selected for the study. Prior to harvest, measurements were taken of the channel morphology (Figure 1) and used to calculate the area of stream channel for the woody debris volume calculations. Reference photo points were established along the 100 m section of stream channel to provide a visual record of pre- and post-harvest changes in the stream channel.

Woody debris measurements

Transects based on the Van Wagner (1968) method were used to measure small woody debris in the 1 to 9 cm classes (SWD). To reduce the error from orientation bias of the wood, transects angles were randomly selected in 15° steps from 0 to 165° and spaced 5 m apart along the 100m section. SWD pieces were tallied in 1 cm diameter classes, and classified as in-stream, above stream or on the floodplain (Figure 1). Tallying rules followed those outlined in Van Wagner (1968).

All large woody debris ≥ 10 cm (LWD) was measured for small end diameter (SED), large end diameter (LED) and length, and was classified as either in-stream, above stream or on the floodplain (Figure 1).

Woody debris measurements were repeated after harvest, and measured the additional woody debris in the stream channel from harvesting operations.

Table 5 - Classification of channel bank disturbances

Code	Channel bank disturbance description
BC	Bank collapse (discrete volume loss)
SL	Bank slump (no discrete volume loss)
LS	Lateral scour, stream flow has cut into bank, includes undercut banks
BS	Bank scuff from harvesting operation, may include discrete volume loss
R	Rut caused by harvesting operation, includes discrete volume loss

Channel bank disturbance assessments

Both sides of the 100 m section of stream were assessed for fresh channel bank disturbances prior to, and after harvest, and were categorised according to the classifications in Table 5. The location of the channel bank disturbance along the 100 m section of stream channel was recorded. The length and height of each channel bank disturbance was measured, and where volume losses had occurred, depth measurements were also taken to estimate volume losses. These records were used to ensure fresh channel bank disturbances at pre-harvest were not confused with those caused during harvesting.

RESULTS AND DISCUSSION

Pre-harvest/post-harvest woody debris comparison

Table 6 shows the changes in woody debris volumes before and after harvest for the seventeen sites. The pre-harvest woody debris volumes were added to the woody debris volumes from harvest to calculate post-harvest woody debris volumes (excluding the stream-cleaned sites).

Pre-harvest woody debris volumes averaged 105 ± 42 m^3 ha^{-1} (95% CI) and ranged from 2 - 345 m^3 ha^{-1} (Table 6). Windthrown stems from surrounding stands, were the main contributors to high woody debris volumes in the stream channels of most sites (60%). In the Southland sites, remnant native hardwoods were the main contributors to pre-harvest woody debris volumes.

Pre-harvest woody debris volumes were similar to those in streams of mature and 15 year-old pine plantations and old-growth native forests (Evans *et al.* 1993; Collier *et al.* 1998; Quinn *et al.* 1997) and higher than the woody debris volumes found in the streams of regenerating native forest and 10 year old pine plantations. (Evans *et al.* 1993).

Harvesting contributed on average 147 ± 84 m^3 ha^{-1} of woody debris to the stream channel, ranging from 2 -528 m^3 ha^{-1} (Table 6). At the four sites which had native riparian vegetation (Sites 4, 5, 13 and 16) riparian vegetation made up 29%, 51%, 58% and 35%, respectively, of the harvest volumes.

Post-harvest woody debris volumes averaged 289 ± 100 m^3 ha^{-1} (Sites 4 to 17 only), range was from 66 - 596 m^3 ha^{-1} (Table 6). This was a three-fold increase on pre-harvest levels, a similar increase to Collier *et al.* (1998). The amounts of SWD and

Table 6 - Woody debris volumes (vol) before and after harvest (m^3 ha^{-1})

Site	Pre-harvest vol (m^3ha^{-1})	Harvest vol (m^3ha^{-1})	Post-harvest vol (m^3ha^{-1})	% increase on pre-harvest vol
Method 1 - stream cleaned				
1	145	38	*	*
2	2	6	*	*
3	54	2	*	*
Mean	67	15		
Method 2 - ground-based				
8	144	22	167	15
9	97	13	111	14
10	108	9	117	8
12	345	177	522	51
16	152	20	172	13
Mean	169	48	218	20
Method 3 - haul back from stream edge				
5	28	38	66	138
7	145	169	315	116
Mean	87	104	191	127
Method 4 - haul across stream channel				
4	53	344	397	651
6	68	528*f*	596	781
11	10	147	157	1457
13	182	86	269	47
14	40	356*f*	396	899
15	75	154	229	206
17	140	391*f*	531	279
Mean	81	287	368	617
Total Mean ±95% CI)	105 ± 42	147 ± 84	289 ± 100	334

* Sites 1 - 3 were stream-cleaned removing most of the pre-harvest and harvest material so pre-harvest plus harvest volumes do not equal post-harvest volumes.

f volumes underestimated, unable to reach all the harvest woody debris in the stream channel.

NB: due to rounding conventions pre- harvest plus harvest volume does not always equal post-harvest volume.

LWD in the stream channel also increased significantly on pre- harvest levels ($P< 0.05$). Average SWD woody debris volumes increased from 13 to 109 m^3 ha^{-1} and LWD volumes increased from 92 to 180 m^3 ha^{-1}, respectively.

Harvesting also changed the proportions of SWD and LWD in the stream channel (Figure 2), significantly increasing the proportion of SWD. Thirteen percent of woody debris volumes at pre-harvest were composed of SWD. This increased to 38% of

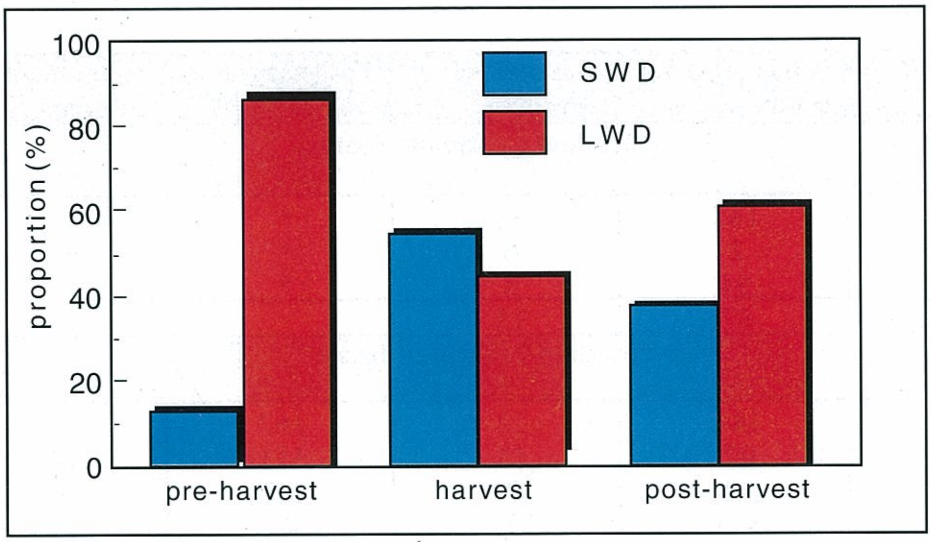

Figure 2 - Changes in composition of woody debris before and after harvest

woody debris volumes at post-harvest. This was due to smaller material such as branches and broken tops falling, or being swept into the stream channel during harvesting operations. It also reflected the prescription requirements to fell and extract trees away from the stream edge and to remove the larger merchantable wood from the stream channel.

Although harvesting changed the size distribution of woody debris, it did not influence the position of the woody debris in the stream channel. The proportion of wood positioned above the stream channel was similar for pre-harvest, harvest and post-harvest woody debris volumes (69%, 64% and66%, respectively. The remainder of the woody debris lay in the stream or on the floodplain (Figure 3).

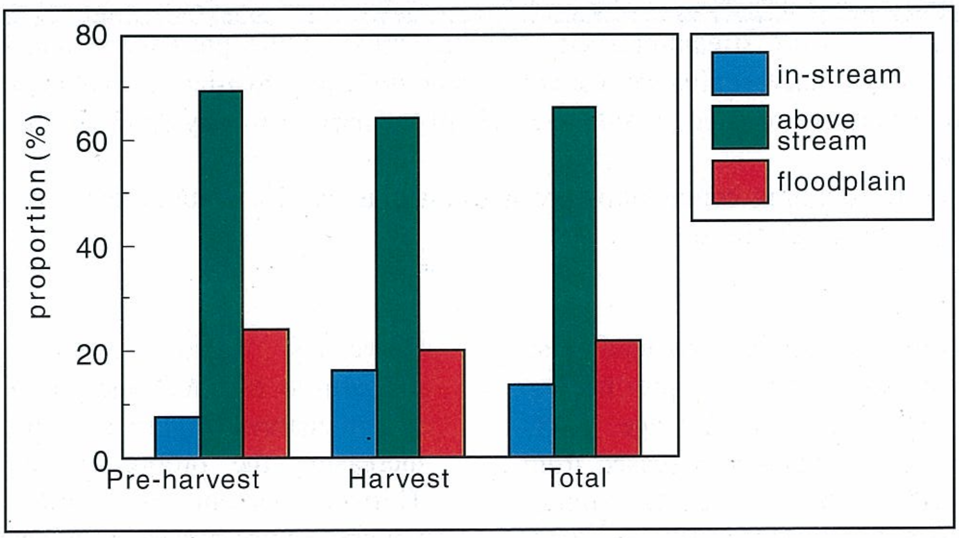

Figure 3 - Distribution of woody debris volumes in the stream channel,(pre-harvest, harvest and post-harvest).

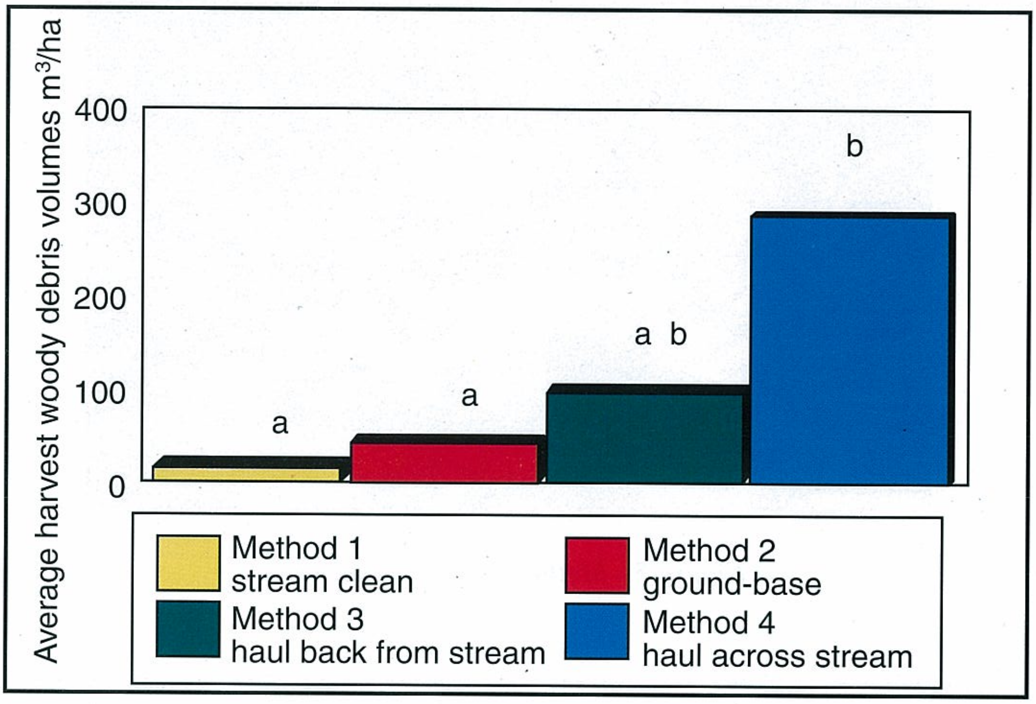

Figure 4 - Average harvest woody debris levels for the four streamside harvesting methods. Bars with different letters are significantly different (P< 0.05).

LWD diameters were similar for both pre-harvest and harvest, averaging 22 cm and 21 cm, respectively. The average length of the LWD pieces from harvesting (1.8 m) was significantly shorter than at pre-harvest (3.2 m), (P< 0.05). Windthrown stems contributed to the longer LWD pieces at pre-harvest. The requirement to remove merchantable timber from the stream channel was the main reason for smaller LWD lengths at post-harvest.

Both Harmon *et al.* (1986) and Sedell *et al.* (1988) found piece size and length of woody debris, were two important factors affecting the stability of woody debris in the stream channel. The smaller, shorter pieces of wood left in the channel from harvest are likely to be unstable and more mobile than pre-harvest woody debris.

Influence of harvesting method on mean woody debris volumes

Method 1 had the lowest harvest volumes followed by Methods 2, 3 and 4 (Table 6). The four methods are shown in Figures 5 to 8. The harvest volumes in Methods 1, 2 and 3 did not differ significantly, but harvest volumes in Methods 1 and 2 were significantly lower (P< 0.05) when compared to harvest volumes in Method 4. (Figure 4). Post-harvest volumes in Method 3 were also lower than Method 4, but the difference was not significant.

A multivariate analysis of site characteristics was carried out to determine whether they had any influence on the amounts of woody in the stream channel from harvesting. No relationship was found between

Figure 5 - Method 1 Stream-cleaned

site characteristics and the amount of harvest woody debris in the stream channel, except for stand volume. Although stand volume did not influence harvest woody debris volumes in Methods 1, 2 and 3, there was a relationship between stand volume and harvest volume for Method 4. This is expressed by the equation:

$\log^{e}$ (post-harvest volume) = 1.57 + 0.0015 stand volume (R^2= 0.67)

where $\log^{e\ =\ \text{natural log}}$

In North American studies, riparian buffers reduced the amount of woody debris reaching the channel system during harvesting (Froehlich 1977; Toews and Moore 1982a). In this study, the harvest method influenced woody debris volumes more than the presence or absence of riparian vegetation. At Sites 5 and 16, where harvest volumes were low, felling and extraction were away from the stream edge (Method 3 and 2 respectively). The slightly higher volumes at Site 13 were a result of extracting the timber through two corridors in the riparian buffer. At Site 4, which had the highest post-harvest volumes, timber was extracted across the stream channel (Method 4). The sample sizes were too small to statistically test these differences.

Influence of harvest prescription

The standards underlying the harvest prescriptions differed between ground-based and hauler systems, this being reflected in the harvest volumes in the stream channel. Excluding the stream-

Figure 6 - Method 2 Ground-based

Figure 7 - Method 3 Haul back from stream edge

cleaned sites, harvest woody debris volumes were generally higher in the hauler sites.

Implications of woody debris on the stream ecosystem

When determining harvesting impacts on the stream ecosystem, it is not just the total volumes of woody debris in the stream that need to be considered, but the relative position of the woody debris in the stream channel.

The in-stream (submerged) wood is immediately available to biological processing. It is these volumes which can affect water quality, particularly dissolved oxygen levels (Pruden and Coker 1990; Collier *et al.* 1998).

However, where some woody debris is positioned above the stream, it can provide shade, and has been effective in regulating water temperatures in some streams, particularly during the summer months (Collier *et al.* 1997). The wood lying above the stream or on the floodplain can provide additional sources of wood to the stream channel over time as a result of high water or flooding events, or from gradual decay.

Removing all the wood from the stream channel can raise water temperatures to levels that can be stressful to some aquatic animals, especially in the warmer streams which are fed mainly by overland flow (Quinn *et al.* 1994; Collier *et al.* 1997). However, in areas of high episodic rainfall and frequent flood events, possible ecological benefits of leaving some woody debris in the stream channel have to be balanced against the risk of debris dams blowing out and adversely impacting on down stream users.

Figure 8 - Method 4 Haul across stream channel

Long term effects of woody debris

Short term effects of woody debris on the stream ecosystem also need to be kept in perspective with long term effects. Most of the woody debris in this study was suspended above the stream and will break down over time, falling into the water column.

In stable streams, woody debris can provide a long term source of food and habitat (Collier *et al.* 1997; Baillie *et al.* 1998). In particular, the LWD component has been shown to last in stable streams for more than 20 years and can be beneficial to aquatic invertebrates in streams with mobile substrates.

Channel bank disturbance

The types of channel bank disturbances recorded at pre- and post-harvest are identified in Figure 9. Bank collapses were the most common disturbance before harvest (69%). These accounted for 83% of the soil lost from the channel bank. Remaining soil losses were due to lateral scouring of the stream channel. Sites 1 and 5 had the highest amounts of disturbance (36% and 16%) (Table 7). This was due in part to disturbance from two cyclones, one in December 1996 and the other in January 1997, especially at Site 5. Six sites recorded channel bank disturbances resulting in soil loss from the channel bank, ranging from 1 to 33 m^3.

Bank scuffing was the most common type of channel bank disturbance after harvest (47%), accounting for 63% of the soil lost. The remaining soil was lost from bank collapses and ruts. There were two sites with no channel bank disturbance (Sites 1 and 10). At the remaining sites, the proportion of channel bank disturbance varied from 1 to 39% (Table 7).

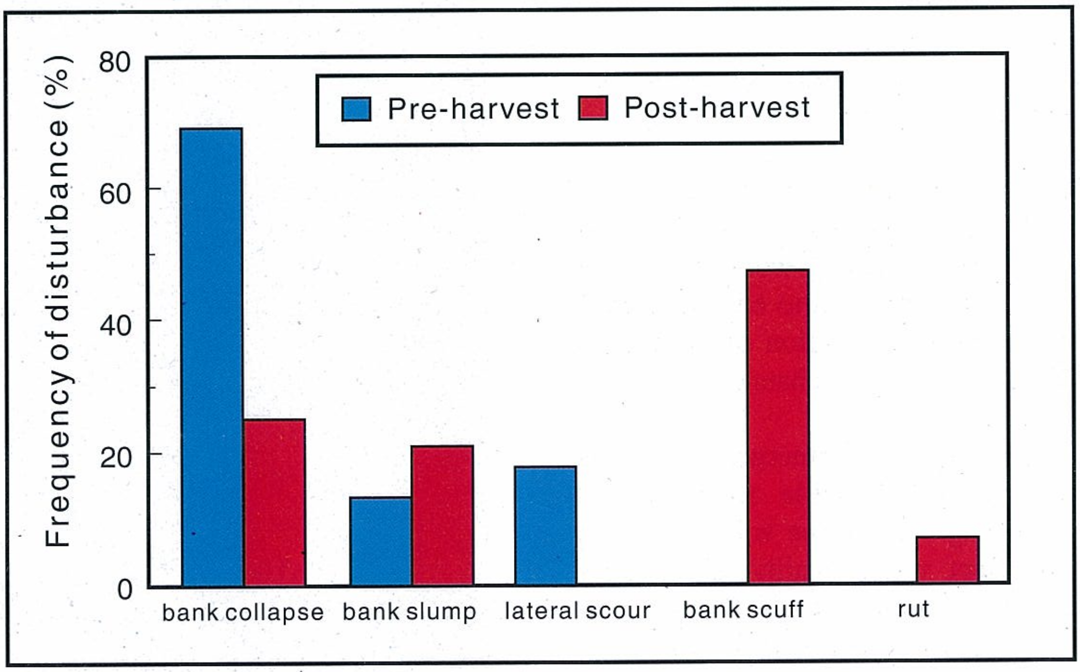

Figure 9 - Pre- and post-harvest channel bank disturbances.

Table 7 - Pre- and post-harvest channel bank disturbance

Site	Channel bank disturbances (%)* Pre-harvest	Post-harvest	Post-harvest scuffs & ruts only	Soil loss (m^3) Pre-harvest	Post-harvest
1	36	0	0	4	0
2	1	6	5	2	5
3	6	2	0	0	2
4	0	39	37	0	44
5	16	2	1	9	1
6	0	19	5	0	7
7	0	4	0	0	1
8	0	1	1	0	1
9	0	1	0	0	0
10	0	0	0	0	0
11	5	13	13	33	1
12	3	3	3	1	0
13	5	1	0	22	1
14	0	1	1	0	0
15	8	6	6	18	4
16	0	2	1	0	0
17	0	9	3	0	15
Mean	5	6	4	5	5

* channel bank disturbance - length of channel bank disturbed expressed as a percentage of the total channel bank length (200 m, both sides of channel).

Although harvesting accounted for most of the post-harvest channel bank disturbances, there was no relationship between the harvesting method and the proportion of channel bank disturbed.

The short term channel bank disturbances from harvesting in this study were minor. Determining the long term influence of harvesting on channel bank disturbances was outside

Table 8 - Re-establishment practices along stream edges

Re-establishment Practice	Number
Planting boundary 5 m from stream edge or to bank edge/drop-off into stream	7
Planting boundary not closer than 10 m watercourse	4
Planting boundary no closer than 8 m from perennial streams	2
Planting boundary 10 - 30 m back from stream edge	2
Planting site specific, up to significant change in slope between the stream and the hill slope	2
Planting boundary not less than 10 m from stream in catchments greater than 50 ha taking into account practical topographic boundaries	1
Planting boundary to edge of ground slope above floodplain	1
Planting boundary dictated by harvesting constraints including safety and without damage to the stream	1

the scope of this study, as the seventeen harvested sites lacked unharvested or riparian buffer control sites to compare long term changes.

Re-establishment along stream edges

The most common practices were to plant 5 to 10 m back from the stream edge or to a geomorphic boundary (Table 8). Re-establishment boundaries have shifted back from the stream edge, mainly because of the difficulties and costs of extracting trees without damaging the stream or channel banks (pers. com. forest company personnel).

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