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Channel Disturbance and Logging Slash in S5 and S6 Streams

An examination of streams in the Nitinat Lake area, Southwest Vancouver Island

by
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Research Disciplines: Ecology ~ Geology ~ Geomorphology ~ Hydrology ~ Pedology ~ Silviculture ~ Wildlife

TABLE OF CONTENTS

Cover Photo: Researcher examines a stream in the study area near Nitinat Lake, Vancouver Island.

EXECUTIVE SUMMARY

The Forest Practices Code of BC allows logging of some S5 and S6 streams (non-fish bearing streams that are not in community watersheds) without leaving a streamside reserve. During silviculture prescription development, if the decision is made to not leave a streamside reserve, then an assessment of whether to recommend removal of logging slash from the stream may be needed. An important factor in determining whether logging slash should be removed from the stream (often called stream cleaning) is whether it will lead to increased volumes of sediment or woody debris transported into downstream channel reaches, particularly fish habitat.

This study examined logged and uncleaned S5 and S6 streams in the Nitinat Lake area of Vancouver Island to assess the degree of channel disturbance that resulted from leaving logging slash in streams. Channels that have higher levels of disturbance are probably transporting elevated amounts of sediment and logging debris into downstream channel reaches, whereas channels that are not disturbed are not transporting elevated amounts of sediment and logging debris downstream.

Ninety-nine stream reaches were field assessed. Data were collected for stream location, terrain type, channel width, channel depth, channel area, gradient, bank, and bed type, and the maximum size of sediment moved in the channel. How the channel was affected by logging slash was evaluated using several specific response parameters:

· the size of logging slash transported by water

· the percentage of logging slash moving in the stream

· the size of logging debris jams

· the percentage of logging debris incorporated into debris jams

· the size of sediment wedges, and

· the amount of bed and bank erosion.

In addition to the specific response parameters, each stream reach was given an overall channel disturbance assessment, based on the presence and degree of one or more of the specific response parameters. The five classes of overall disturbance were: no disturbance, little disturbance, moderate disturbance, extensive disturbance, or severe disturbance. There were no predetermined criteria that equated set levels of specific responses to a particular overall disturbance level, and there was no requirement that any specific response must be part of the overall disturbance assessment. Therefore, part of the analysis compared the overall disturbance with each of the specific responses to determine which specific responses were strongly associated with the overall disturbance. Overall disturbance was found to be associated with the size of logging debris moving, the percentage of logging debris moving, the size of logging debris jams, and the size of sediment wedges. Bank and bed erosion were not associated with overall disturbance level.

Most streams (64%) in the study had little or no disturbance. Twenty percent of the streams were moderately disturbed, 13% extensively disturbed, and 2% severely disturbed.

The results of this study showed that overall disturbance was strongly dependent upon the size of the channel. Whether channel size was measured using width, depth, or area, the level of disturbance increased as the channel size increased. Width was statistically the most significant of these three variables, and therefore is the most useful channel parameter to identify the likelihood of a channel to become disturbed if logging slash is left in the channel. All streams in the study less than 1.5 m wide had little or no disturbance, whereas 90% of streams greater than 3.0 m had moderate or worse disturbance. Eighty-two percent of streams between 1.5 and 3.0 m wide had little or no disturbance.

Only 15% of the channels in this study had either bed or bank erosion. Bank erosion tended to increase as channel width increased, but bed erosion was not associated with any channel characteristics.

In addition to channel width, the size of sediment a channel transports, and the size of woody debris a channel transports, can be used as predictors of the likelihood of a channel to become disturbed if logging slash is left in the channel. There was usually little or no channel disturbance in streams that transported sediment <90 mm in diameter, whereas channels that transported sediment >250 mm most often had extensive or severe disturbance. If a channel transports woody debris of a particular size after logging (as was measured in this study), it is likely able to transport woody debris of that size prior to logging. Therefore, the size of woody debris transported in an unlogged stream is a useful predictor of whether the channel is likely to become disturbed after logging. Streams that transported small woody debris usually had little or no disturbance, whereas streams that transported larger woody debris were more likely to become disturbed.

KEYWORDS

channel, stream, disturbance, woody debris, logging slash, Vancouver Island

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1.0 INTRODUCTION

The Forest Practices Code of BC (FPC) defines S5 and S6 streams as non-fish bearing streams in non-community watersheds. S5 streams are >3 m wide and S6 streams are <3 m wide. The FPC permits logging of these streams without a reserve zone in some situations. If the decision is made to not leave a streamside reserve, then an assessment of whether to remove the logging slash from the stream (often called stream cleaning) may be needed. An important factor in determining whether logging slash should be removed from the stream is whether it will lead to increased volumes of sediment or woody debris transported into downstream channel reaches, particularly fish habitat.

Although stream cleaning is common, there are few studies that examine either the effect of logging slash in streams, or the benefits of stream cleaning. Tripp (1995) published a table that used channel width, channel gradient, and sidewall slope angle to assess the stream transport potential. Streams with a moderate or greater stream transport potential were judged to have the potential for affecting downstream fish reaches, and thus were candidates for cleaning.

Bovis et al (1998) measured sediment output from four types of gullied streams, including streams cleaned of logging slash as well as uncleaned streams. The uncleaned streams did not deliver any sediment, whereas the cleaned streams delivered more sediment than unlogged streams or streams that had been scoured by a debris flow a short period of time prior to the measurement period. The primary source of sediment from the cleaned streams was from bed erosion.

A study by Golder Associates (1999) supported these observations, noting many cases where stream cleaning had negative effects on channel stability. The Golder study also examined streams that were not cleaned. They found that channel width provided a good set of criteria for measuring slash transport potential. Stream less than 2 m wide were unlikely to transport debris, whereas streams greater than 4 m wide were likely to transport debris.

This study has two objectives:

1. To determine how channels respond if logging slash is left in the stream, and,

2. To identify stream parameters that can predict the likelihood of channel disturbance and downstream transport of logging debris and sediment.

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Streams were examined several years after logging, to ensure that the stream had had time to respond to the slash left in-stream and to a number of storm events. In this study, the response of the stream is defined by changes of in-reach channel morphology, as well as changes in sediment and woody debris output after logging. Channels that have higher levels of disturbance are probably transporting elevated amounts of sediment and woody debris into downstream channel reaches, whereas channels that are not disturbed are not transporting elevated amounts of sediment and woody debris downstream.

2.0 STUDY AREA

Areas near Nitinat Lake were selected for the study (Figure 1). To the south of Nitinat Lake, streams in the Haddon Creek and Upper Walbran Creek watersheds were examined. To the north of Nitinat Lake, streams in the Upper Klanawa River, Flora Lake and Hitchie Creek watersheds were examined.

The two areas are very similar. Bedrock of the volcanic Bonanza Group underlies almost all of the streams (Muller, 1977). The Island Intrusions or the West Coast Complex underlie a few of the streams in the Upper Walbran valley. The glacial history and mountainous terrain produce a variety of surficial materials, including rock, glacial till, colluvium, glaciofluvial sediments, and modern fluvial sediments. All of the streams are in the montane or submontane very wet maritime Coastal Western Hemlock biogeoclimatic zone (Nuszdorfer and Boetger, 1994).

In this area, fall and winter storms between October and February produce the majority of high runoff events in streams, either from rainstorms or from rain-on-snow events. Data from the Nitinat Hatchery weather station from 1981 to 1998 show five storm events with 24-hour precipitation greater than 200 mm. The largest of these storms was in November 1995, with 257 mm of precipitation, and in November 1998, with 205 mm (A. Chapman, pers. comm.). These two storms indicate that the streams in this study were likely subjected to very significant flood events after logging occurred. (Records for November 1990 are missing; however, the coast of British Columbia experienced widespread heavy precipitation in this period, and it is likely that this was also a large event at Nitinat Lake).

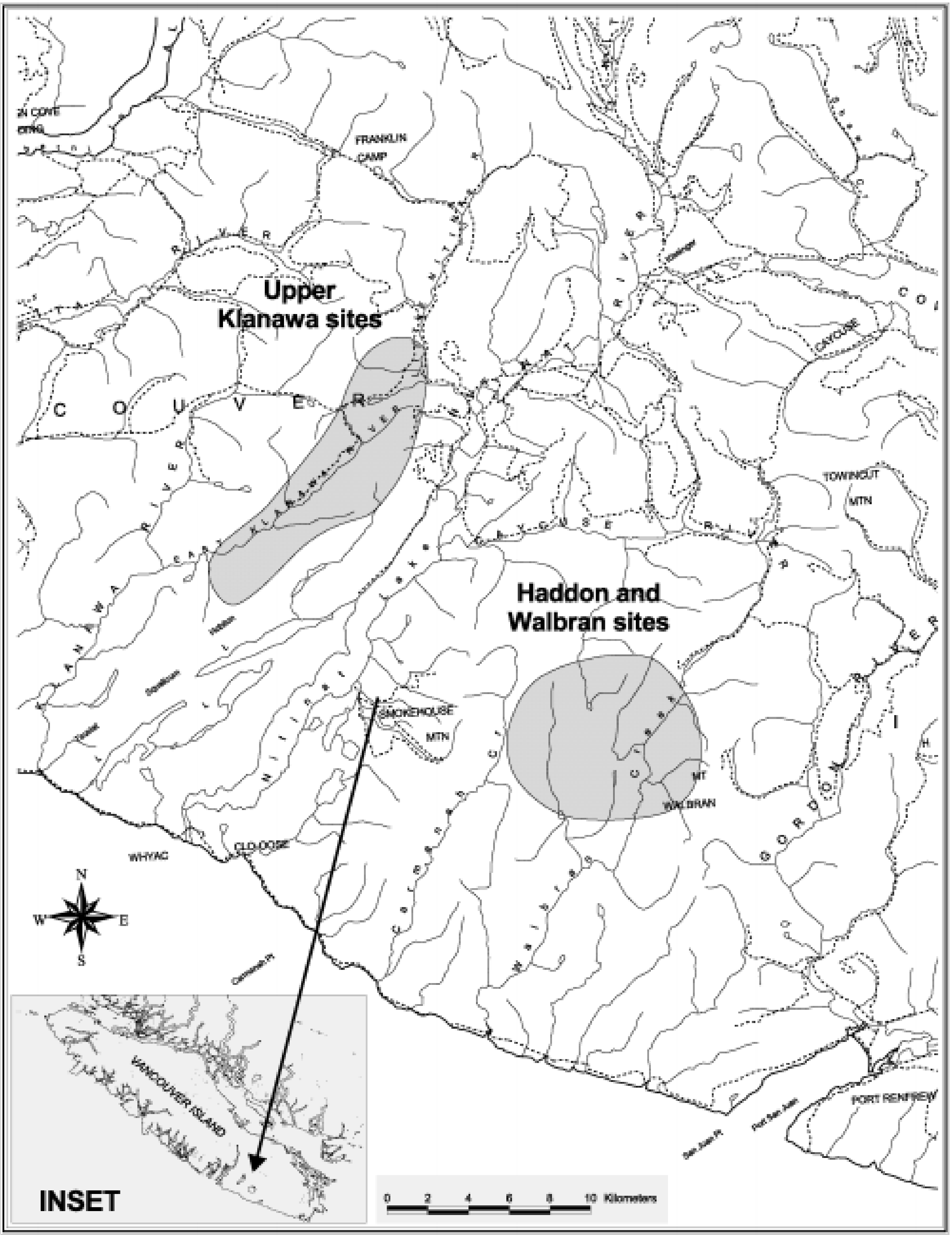
3.0 STUDY DESIGN AND DATA COLLECTION

3.1 STUDY DESIGN

Streams selected for the study met the following criteria:

- Logging occurred between about 1985 and 1991. This allowed time for the stream to respond to several winters of storm events.
- The stream was less than 6 m wide. This upper limit was chosen because it seemed evident that if logging slash was retained in streams larger than this, there were negative effects.

Figure 1. Location map of study area



● There was relatively easy access to the stream, and usually there were a number of suitable streams close to one another.

A stream reach was defined on the basis of general uniformity of channel gradient, bed and bank materials, amount and distribution of logging debris, and volume of flow. If a significant change in any of these attributes occurred, a new stream reach was declared.

About 40 stream reaches in the Haddon Creek and Upper Walbran watersheds were sampled using these criteria. Most of these streams had been logged when the Coastal Fish Forestry Guidelines (CFFG) were in effect. In some of these streams it appeared that the stream was recovering from disturbance, and therefore the full extent of disturbance may not have been accurately assessed. A second set of streams was selected that were logged between about 1992 and 1996. These were the streams to the north of Nitinat Lake. These streams had been logged when either the CFFG or the Forest Practices Code was in effect.

A total of 139 stream reaches were assessed. Of these, 37 reaches had been cleaned of logging debris (based on evidence in the field and confirmed in most cases with logging records). An additional three stream reaches were deleted from the database as examination of air photographs indicated that a post-logging debris flow had occurred. The remaining 99 stream reaches were analyzed.

It is believed that most streams in each specific area fitting the selection criteria were assessed, and that the selection process was not biased. Because some streams had more than one reach assessed, each case is not strictly independent. However, it is believed that this is not a serious restriction for analysis as in-reach effects were usually much greater than observed effects from upstream reaches. Statistical analysis of the data is therefore appropriate.

3.2 DATA COLLECTION

Three types of data were collected in this study:

1. Predictor variables that may provide criteria to determine whether retention of logging slash in the channel will lead to negative effects.

2. Response variables that measured the extent to which the logging slash affected the channel morphology within that specific stream reach.

3. Additional information that did not fit into predictor or response categories. This category of data was not analyzed, but was occasionally used to clarify conditions noted in the channel.

3.2.1 PREDICTOR VARIABLES

Data for the several predictor variables were collected. Many of the measurement procedures followed or were similar to those specified in the Channel Assessment Procedure Field Guidebook (Anonymous, 1996).

● Location: choices were open slope, gully, fan, valley flat, and canyon.

● Average channel gradient, measured with a clinometer over most of the reach length.

● Bankfull width: width and depth measurements were taken an average of three times.

● Bankfull maximum depth: measured from the thalweg to the top of the bank. Bankfull average depth was also measured for about half of the streams.

● Bankfull maximum area: the product of bankfull width and bankfull maximum depth.

● Largest size of sediment moved.

● Surficial material type: grouped into colluvial and fluvial fans, fluvial plains and glaciofluvial terraces, deep tills, till veneers, combinations of till and rock, and rock dominated.

● Channel bed type, grouped into:
1. Cobble or boulder dominated
2. Pebble dominated
3. Sand dominated, or
4. Vegetation dominated.

● Channel bank type, grouped into:
1. Bedrock with boulder or cobble dominated sediments
2. Vegetated banks with bedrock
3. Vegetated banks with sand or pebbles
4. Pebble and cobble combinations, or
5. Sand and pebble combinations.

● For gullies, sidewall distance, sidewall gradient, gully bottom width, and confinement, defined as channel width/gully bottom width.

3.2.2 RESPONSE VARIABLES

There are several response variables that can be used to characterize how a stream responds to logging slash. In this study, several specific response variables that measure or estimate a specific stream characteristic were used. In addition, an overall response variable was used to integrate the effects of the specific response variables. Data for the following response variables were collected:

● Largest size of woody debris moved, grouped into three categories. Logs were >0.5 m diameter and >3 m length, or >0.3 m diameter and >5 m length. Large woody debris (LWD) was >0.1 m diameter and >3 m length. Small woody debris (SWD) was anything smaller than LWD.

● Percentage of logging debris moving, visually estimated. Logging debris that had moved tended to be clustered against larger pieces, and was often aligned across the channel. In contrast, logging debris that had not moved was usually randomly orientated and not clustered.

- Average volume of logging debris jams in stream reach. Jam volume was estimated using measurements of the length, width, and height of the jam.
- Percentage of logging debris in jams, visually estimated.
- Bed and bank erosion volumes, estimated with length, width, and depth estimates where recent erosion was apparent.
- Average sediment wedge volume, estimated with length and width measurements and an estimate of average depth.
- Overall disturbance assessment, classified as no disturbance, little disturbance, moderate disturbance, extensive disturbance or severe disturbance. Overall disturbance was determined after recording all the other stream data, and was based on the presence and degree of one or more of the specific response variables. There were no predetermined criteria that equated set levels of specific responses to a specific overall disturbance level, and in addition, there was no requirement that any specific response must be part of the overall disturbance assessment. Photographs showing examples of streams at each level of disturbance are included in this report.

3.2.3 ADDITIONAL INFORMATION

These variables either did not fit into the predictor or response variable categories, or were not used in formal analysis. In some cases they were used to clarify the causes of disturbance in the channel. As an example, stream reaches that were supplied with large amounts of sediment from roads often developed larger sediment wedges than channels not influenced by roads. Information on the following attributes was collected:

- Minimum and maximum gradients. These were recorded for reaches that had varying gradients, but the variation was not great enough to declare a new channel reach.
- Percentage of channel covered by logging debris. This may have been affected by the original amount of logging debris deposited in the channel as well as whether the channel had transported the debris out of the channel.
- Proportions of SWD, LWD, and logs of the logging debris that was in the channel.
- Proportions of SWD, LWD, and logs in the jams.
- Number and size of slope failures affecting the channel.
- Size of sediment supplied by the reach immediately upstream of the study reach, as well as supplied by tributaries and road sources. This was noted as sand, pebbles, cobbles, or boulders.
- Deposition sites other than sediment wedges. These were noted as in-channel, pool filling, or overbank deposition.

4.0 ANALYSIS

4.1 METHODS

Summary statistics of all the predictor and response variables were completed to provide an overall description of the range and average values of each variable. There were several response variables, and therefore the analysis first examined which of the individual response variables were associated with the overall disturbance assessment. Next, the predictor variables were compared to the overall disturbance assessment to determine whether they had any effect on the level of disturbance in the channel. Multivariate analysis was used to determine the relative importance of each predictor variable. Each specific response was evaluated using multivariate analysis to determine whether the results of the analysis for overall disturbance were equivalent to the results for specific responses. In all statistical tests, a p-value less than 0.05 was considered a significant result.

The primary multivariate analysis method used in this study was CHAID (Chi-square Automatic Interaction Detection; Anonymous, 1998). This method of analysis uses a classifying procedure to group cases into different groups, and then determines the significance by applying a series of Chi-square tests to the groupings. The most significant classification is selected, and then the process is repeated for each sub-group. CHAID produces classification trees that effectively present results and are easily understood. CHAID does not rely on normally distributed variables.

In addition to CHAID, multiple regression and logistic regression where used to provide additional analysis.

4.2 SUMMARY STATISTICS

Streams were sampled from 16 logging blocks. The 99 stream reaches analyzed were sampled from 55 streams, so each stream had an average of 1.8 reaches sampled. Average reach length was 65 m, or an average of 29 bankfull widths in length. Histograms of the predictor and response variables are presented in Figures 2 and 3. Many variables have a skewed distribution. As a result, the median values are presented for the continuous variables.

Most stream reaches were located in gullies or on open slopes (location histogram, Figure 2). Gradients ranged from about 1% to over 60%, but streams with gradients between 10% and 30% accounted for about half of the cases. The median channel width was 2.3 m, and the median depth was 0.36 m. Just over half the streams transported sediment that was 64 to 181 mm in size.

Most of the streams transported small woody debris (size of logging debris moving histogram, Figure 3). A general pattern seems to be present where streams either transported a relatively low percentage of the logging slash in the stream (<30%), or else transported a high percentage of the logging slash in the stream (>80%). Only 12% of the streams transported 40% to 80% of the logging slash in the streams. Just over half the streams had an average jam size of less than 1 m^3, and most of the streams had an average sediment wedge size of less than 1 m^3 as well. Only about 15% of the streams had bed or bank erosion. Most of the

Figure 2. Distribution of predictor variables

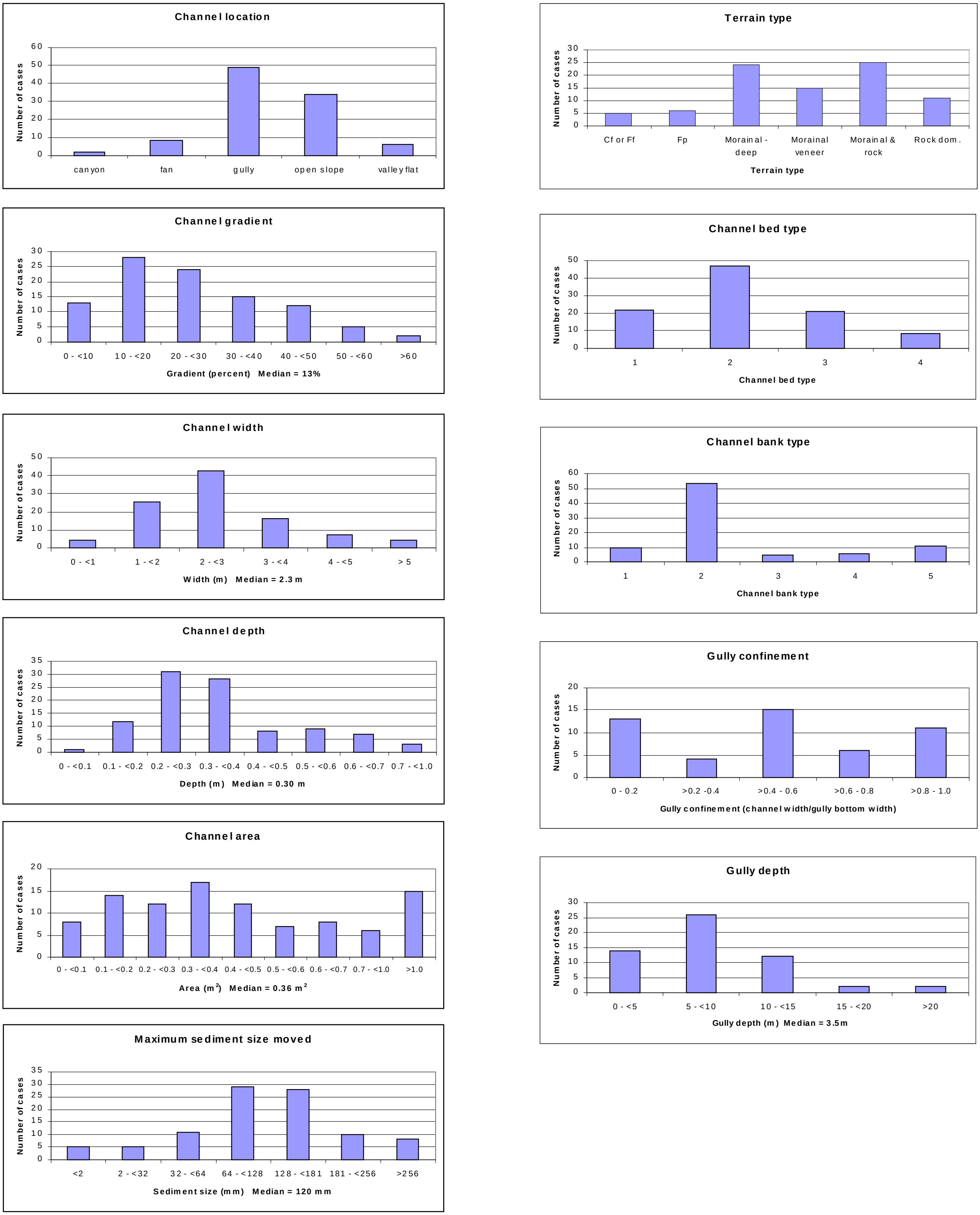
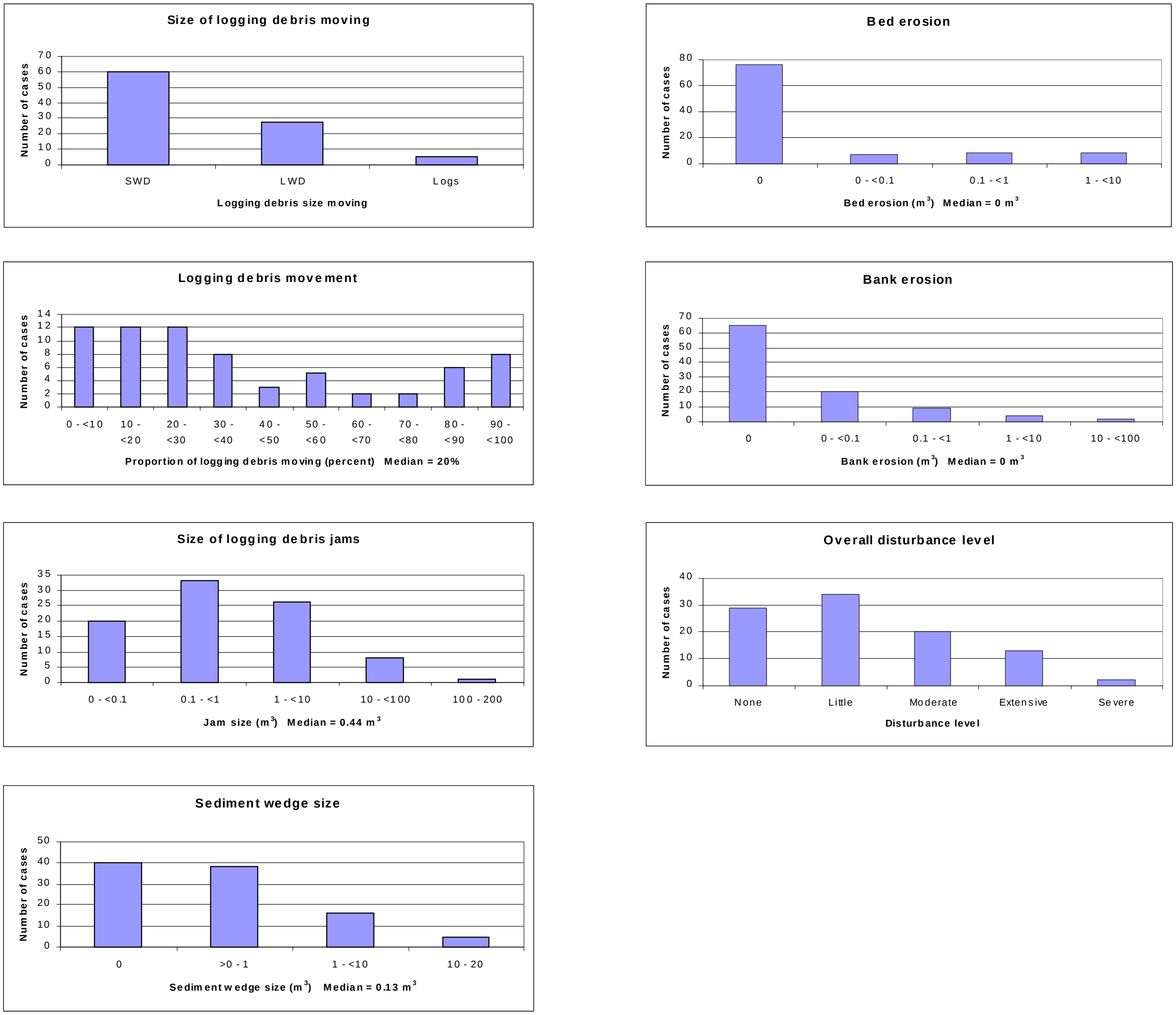


Figure 3. Distribution of response variables



streams had little or no disturbance, and one-third of the streams had moderate or extensive disturbance. Only two streams were classified as having severe disturbance.

4.3 OVERALL DISTURBANCE AND SPECIFIC RESPONSE VARIABLE ASSOCIATIONS

Although the overall disturbance assessment was based on the presence and extent of the specific response variables, no set criteria were used to classify overall disturbance. This was because in some streams the overall disturbance might be based on the presence of several of the specific response variables, whereas in another stream it might be based on the presence of only one or two specific response variables. To clarify how overall disturbance was affected by specific response variables, overall disturbance was compared with the specific response variables. Table 1 shows how the specific response variables affect the overall disturbance assessment.

The relationships between overall disturbance and specific responses are quite evident in Table 1. Overall disturbance is strongly associated with the size of logging debris moved in the stream. Almost all channels with no or little overall disturbance did not move LWD or logs, whereas almost all the channels with extensive or severe disturbance moved LWD or logs. The median percentage of logging debris that is moving increased from 10% for streams with no disturbance to 40-100% for streams with moderate or greater disturbance. Streams with no

Photo 1:

Stream 9 Reach 1	
Overall disturbance: None	
Width (m)	1.9
Depth (m)	0.50
Gradient (%)	9
Sediment size moved (mm)	80
Size of logging debris moved	SWD
% of logging debris moved	n/a
Logging debris jams size (m^3)	2
Sediment wedge size (m^3)	0
Comments: This channel has had little change post-logging. Only 2 jams were present, and no sediment wedges were behind these jams (n/a = not available)	

Photo 2:

Stream 2 Reach 1	
Overall disturbance: None	
Width (m)	0.9
Depth (m)	0.25
Gradient (%)	42
Sediment size moved (mm)	190
Size of logging debris moved	SWD
% of logging debris moved	Trace
Logging debris jams size (m^3)	0
Sediment wedge size (m^3)	0.1
Comments: This channel moved very little logging debris, had no jam development, and had very little sediment wedge development.	

Photo 3:

Stream 12 Reach 3	
Overall disturbance: Little	
Width (m)	2.3
Depth (m)	0.27
Gradient (%)	18
Sediment size moved (mm)	150
Size of logging debris moved	SWD
% of logging debris moved	n/a
Logging debris jams size (m^3)	0.2
Sediment wedge size (m^3)	0.3
Comments: A few small jams with small sediment wedges were in this channel.	

Photo 4:

Stream 64 Reach 2		Overall disturbance: Little	
Width (m)	1.9	Size of logging debris moved	SWD
Depth (m)	0.23	Percent of logging debris moved	30
Gradient (%)	23	Logging debris jams size (m^3)	0.3
Sediment size moved (mm)	20	Sediment wedge size (m^3)	0.7
Comments: Several small jams with some sediment wedges were in this channel. Traces of bed and bank erosion were present.			

Photo 5:

Stream 16 Reach 3	
Overall disturbance: Moderate	
Width (m)	3.4
Depth (m)	0.25
Gradient (%)	25
Sediment size moved (mm)	45
Size of logging debris moved	LWD
% of logging debris moved	50
Logging debris jams size (m^3)	1.4
Sediment wedge size (m^3)	1.4
Comments: This channel had several jams and sediment wedges developed. The road was noted as the main source of sediment.	

Photo 6:

Stream 6 Reach 1	
Overall disturbance: Extensive	
Width (m)	4.0
Depth (m)	0.40
Gradient (%)	16
Sediment size moved (mm)	n/a
Size of logging debris moved	LWD
% of logging debris moved	n/a
Logging debris jams size (m^3)	15
Sediment wedge size (m^3)	20
Comments: This channel developed large jams and sediment wedges. The area was logged in 1989 and the channel appeared to be recovering when it was assessed.	

Photo 7:

Stream 3 Reach 2		**Overall disturbance: Extensive**	
Width (m)	5.8	Size of logging debris moved	Logs
Depth (m)	0.40	Percent of logging debris moved	100
Gradient (%)	38	Logging debris jams size (m^3)	n/a
Sediment size moved (mm)	360	Sediment wedge size (m^3)	25
Comments: This channel had large sediment wedges, bank erosion, and an aggraded channel. The stream reach immediately downstream was classified as severely disturbed.			

Photo 8:

Stream 23 Reach 2		**Overall disturbance: Severe**	
Width (m)	3.5	Size of logging debris moved	Logs
Depth (m)	0.63	Percent of logging debris moved	100
Gradient (%)	18	Logging debris jams size (m^3)	70
Sediment size moved (mm)	260	Sediment wedge size (m^3)	50
Comments: This channel had large, regularly spaced jams with large sediment wedges stored behind each jam.			

Table 1. Comparison of overall disturbance with specific response variables.

Specific response variable	p-value[1]	Overall disturbance				
		None	Little	Moderate	Extensive	Severe
Number of cases		29	34	20	13	2
Modal size of logging debris moving	0.0001	SWD	SWD	LWD	LWD	Logs
Median % of logging debris moving	0.0001	10	25	50	40	100
Median jam volume (m^3)	0.001	0.1	0.3	1.0	7.0	70
Median % of logging debris in jams	0.002	0	17	30	80	n/a
Median sediment wedge volume (m^3)	0.0002	0	0.3	0.38	1.1	37
Median bank erosion (m^3)	0.19	0	0	0	0	11
Median bed erosion (m^3)	0.32	0	0	0	0	0

1) Kruskal - Wallis test, except for a likelihood ratio Chi-square test for the size of logging debris moving.

Table 2. Comparison of overall disturbance with continuous predictor variables

Median value	Overall disturbance				
	None	Little	Moderate	Extensive	Severe
Number of cases	28	33	20	12	2
Width (m)	1.9	2.2	3.2	3.3	4.6
Max depth (m)	0.23	0.28	0.40	0.40	0.52
Area (m^2)	0.18	0.34	0.65	0.59	1.3
Sediment size (mm)	75	110	150	145	310

disturbance had very small jams (a median of 0.1 m^3), compared with 7 m^3 for extensively disturbed streams. In addition, streams with little or no disturbance had a small percentage (<20%) of logging debris incorporated into jams, whereas extensively disturbed streams had a median of 80% of the logging debris incorporated into jams. Similar to jams, the median sediment wedge volume increased from 0 m^3 for no disturbance streams to over 1 m^3 for extensively disturbed streams. However, both bank and bed erosion were not strongly associated with the overall disturbance level. This was most likely because only about 15% of the stream reaches had either bed or bank erosion.

In summary, the evaluation of overall disturbance level usually incorporated the size and amount of logging debris moving, jam size, the percent of logging debris in jams, and the size of sediment wedges. As such, it was a useful surrogate variable for all of these variables combined. Instead of a separate and detailed analysis of each specific response, the analysis focussed on the overall disturbance assessment. Bank and bed erosion were analyzed separately.

4.4 ANALYSIS OF OVERALL DISTURBANCE AND PREDICTOR VARIABLES

Overall disturbance was compared with the predictor variables to determine which predictor variables affect overall disturbance. Of the continuous predictor variables (gradient, width, maximum depth, channel area, sediment size), highly significant differences ($p < 0.0001$, using Kruskal-Wallis tests) were shown for width, depth, area, and sediment size when individually compared with overall disturbance. Table 2 shows the median values of width, depth, area, and sediment size for each class of overall disturbance. Gradient was not significant with a p-value of 0.38.

The nominal or ordinal variables (terrain, location, bank type, and bed type) were tested against overall disturbance using a likelihood ratio chi-square test. Only terrain did not show a significant effect.

Stream location was a significant factor in the amount of disturbance ($p < 0.02$). The most notable influence of stream locations is that of gullied streams. Eighty percent

Table 3. Stream location and overall disturbance contingency table

Stream location	Overall disturbance (number of cases in each group)				
	None	Little	Moderate	Extensive/ Severe	Total
fan	2	3	2	1	8
gully	11	18	7	12	48
open slope	16	12	5	1	34
valley flat	0	1	4	1	6
Total	29	34	18	15	96

Table 4. Bank type and overall disturbance contingency table

Bank type	Overall disturbance assessment (number of cases in each group)				
	None	Little	Moderate	Extensive/Severe	Total
1) rock, coarse	1	5	0	4	10
2) rock, veg.	23	15	7	7	52
3) veg., sand	0	2	2	1	5
4) pebble, cobble	0	2	4	0	6
5) pebble, sand	2	4	2	3	11
Total	26	28	15	15	84

Table 5. Bed type and overall disturbance contingency table

Dominant bed type	Overall disturbance assessment (number of cases in each group)				
	None	Little	Moderate	Extensive/ Severe	Total
1) Cobble, boulder	3	5	8	6	22
2) Pebble	12	18	10	6	46
3) Pebble sand	8	8	2	3	21
4) Sandy veg.	6	3	0	0	9

of the streams that had extensive or severe disturbance were gullies, even though only 50% of the total number of streams sampled were gullies (Table 3). The two severe disturbance cases were grouped with the extensive disturbance case, and the two canyon cases were excluded in the likelihood ratio Chi-square test.

Bank type was shown to be significant (p <0.01). However, no clear pattern of bank type and disturbance level is shown (Table 4). Over half the cases had bank type 2. Although the likelihood ratio test shows significance, the low numbers of cases in each cell makes the test suspect. Extensive and severe disturbance cases were combined for the likelihood ratio Chi-square test.

Bed type was shown to be significant (p <0.03). The coarser sediment beds (boulders, cobbles, and to some degree pebble beds) had a greater proportion of streams with moderate, extensive or severe damage. The beds dominated by vegetation or sand generally had no or little disturbance (Table 5). Extensive and severe disturbance cases were combined for the likelihood ratio Chi-square test.

CHAID was used to determine which combination of predictor variables affected channel disturbance. The following variables were included in the analysis: width, maximum depth, channel area, sediment size, location, bank type, and bed type. Although gradient showed no effect on its own, it was included since it is generally thought to be an important factor in a stream's transport capability. Figure 4 shows the results of the CHAID analysis. The response variable is titled Assess (overall disturbance assessment), with 1 = no disturbance, 2 = little disturbance, 3 = moderate disturbance, 4 = extensive disturbance, and 5 = severe disturbance.

Figure 4 shows width was the most important predictor variable, and highly significant (p <.00001). Three width classes are identified:

1. Streams <1.4 m wide. All of these streams had either no or little disturbance (categories 1 and 2).

2. Streams 1.4 m wide to 2.8 m wide. Eighty-three percent of these streams had no or little disturbance, but there were some streams with moderate or extensive disturbance.

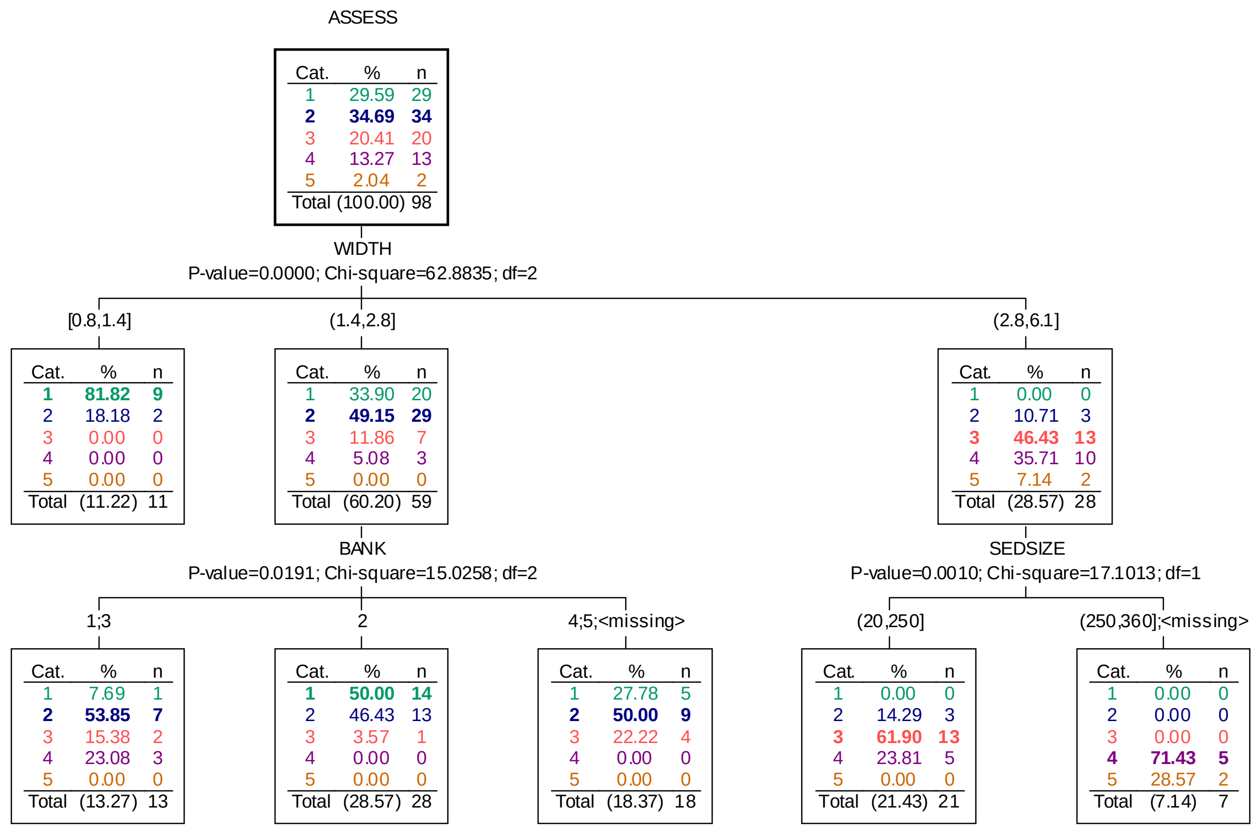
3. Streams >2.8 m wide. None of these had no disturbance, and almost 90% had at least moderate disturbance.

The streams between 1.4 and 2.8 m wide were further broken down by CHAID on the basis of bank type. All but one of the bank type 2 (vegetated banks with bedrock) streams had no or little disturbance. Bank types 1 and 3 were combined, as were bank types 4 and 5. All of these bank types had a range of stream disturbance levels, although bank types 1 and 3 were somewhat worse in their typical outcome.

Streams >2.8 m wide were split on the basis of the largest sediment transported in the stream (SEDSIZE in Figure 4). All streams >2.8 m wide that transported sediment >250 mm had extensive or severe disturbance. Streams that transported sediment <250 mm tended to have moderate disturbance.

Although both depth and channel area were individually significant to overall outcome, they were not as significant as width. In addition, they provided no additional improvement to the fit of the data, and thus were not

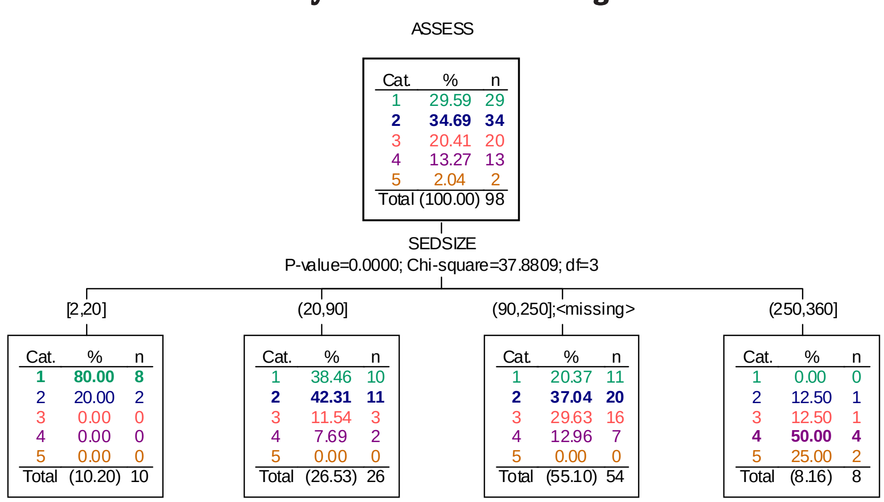
Figure 4. Overall disturbance analysis using CHAID



identified as significant in conjunction with width in the CHAID analysis. However, when width was eliminated from the data set, CHAID selected channel area as the most significant variable, and when both width and area were eliminated from the data set, CHAID selected depth as the most important variable.

Logistic regression was used to test whether another multivariate statistical method yielded the same results as CHAID. It confirmed width as the most significant factor affecting overall disturbance (p <.0000). The maximum sediment size transported was also shown to be significant (p = .026), and bank type was shown as just significant (p = .041). Logistic regression did not show any other variables to be significant. Therefore logistic regression confirmed the CHAID selection of predictor variables. However, logistic regression ranks bank type some-

Figure 5. Overall disturbance classified by sediment size using CHAID



what differently from CHAID. CHAID identified bank types 1 (bedrock and boulder or cobble dominated sediments) and 3 (vegetated banks with sand or pebbles) as the most likely to be disturbed, and bank type 2 (vegetated banks with bedrock) as the least likely to be disturbed. Logistic regression ranked bank type 3 as most sensitive to disturbance and bank type 4 (pebble and cobble combinations) as least sensitive to disturbance. The low number of cases with either bank type 3 or 4 suggests these results should not be relied upon.

In addition to channel dimension measurements, the size of sediment transported was an effective univariate predictor of channel disturbance. Figure 5 shows the results when sediment size transported was selected as the initial variable. CHAID did not select further variables to subdivide categories.

Although increased sediment size was clearly associated with an increased risk of channel disturbance, it was not as useful a predictor as width. Most streams that transported sediment less than 90 mm in size had little or no disturbance; however, there were a few cases where moderate or extensive damage was present. Streams that transported sediment larger than 250 mm most often had extensive or severe disturbance.

4.4.1 GULLY STREAMS -EFFECTS OF CONFINEMENT AND SIDEWALL PARAMETERS

Although the CHAID analysis did not indicate stream location to be a significant factor in the overall disturbance response, the univariate analysis indicated that gullied streams may have had greater disturbance than non-gullied streams. As well, confinement and gully sidewall data were collected to determine whether gully characteristics affected stream disturbance. In order to test whether these factors affected overall response, the gully streams were analyzed separately with CHAID. The results are shown in Figure 6.

As with all the streams, width was the most important factor. The splits were at somewhat higher values of width (1.8 and 3.4 m, compared with 1.4 and 2.8 m for all streams), however the pattern was the same, with wider streams more likely to have a higher degree of disturbance. The greater width values for the splits were likely not significant - more

Figure 6. Overall disturbance for gullies using CHAID

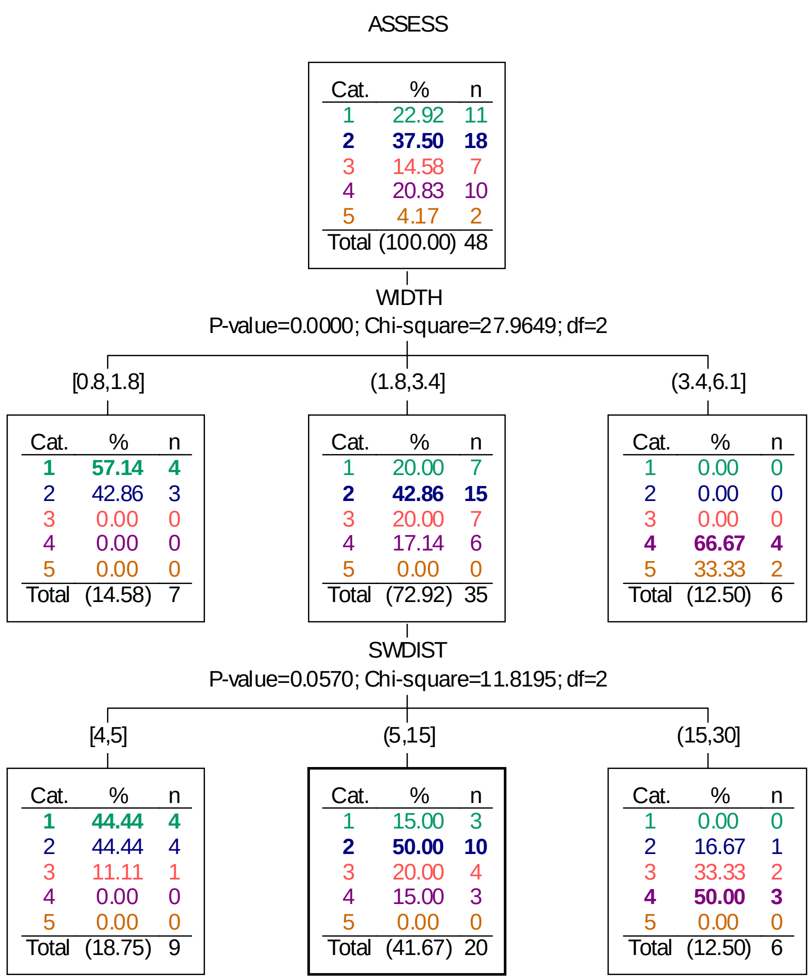


Table 6. Predictor variables with significant effects using multivariate analysis

Specific response variable	Predictor variable (Y = significant at *p*=0.05)							
	Location	Sed size	Gradient	Width	Depth	Area	Bed type	Bank type
% of WD moving				Y			Y	
Size of WD moving				Y		Y		
Jam volume				Y				
% WD in jams				Y		Y		
Sediment wedge volume	Y			Y				

likely they were a product of a lower number of samples.

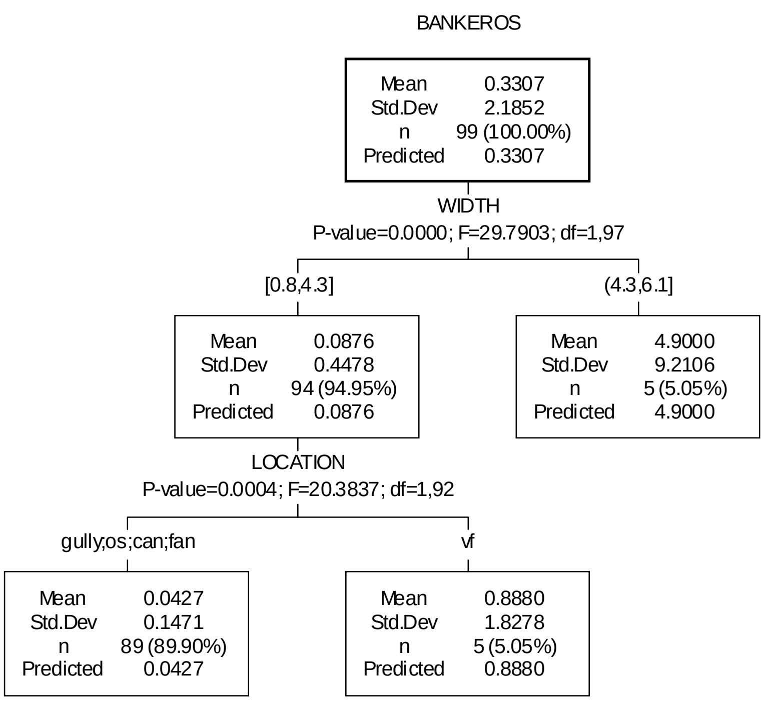
The CHAID tree also showed that streams between 1.8 and 3.4 m wide could be subdivided on the basis of sidewall distance (SWDIST in Figure 6), and that the degree of disturbance increased as sidewall distance increased. However, this result was not significant at the 0.05 level, so it should be treated cautiously.

4.5 SPECIFIC RESPONSES AND PREDICTOR VARIABLES ANALYSIS

In order to clarify whether the same predictor variables affected specific response variables as affected overall disturbance, multivariate statistical tests were done for each specific response variable that was correlated with overall disturbance. Table 6 shows the results. Ordinal responses were evaluated using logistic regression and continuous responses were evaluated using multiple regression. For the highly skewed continuous responses, log (base 10) transformations were used in the multiple regressions.

The results show that width was a significant predictor to all of the specific response variables. Most of the specific response variables have an additional predictor identified as significant. In two of these cases, the additional predictor variable is channel area - a measurement similar to width. In all the cases where another predictor variable in addition to width was identified as significant, width was the more significant variable. This confirms that width is the best predictor of channel disturbance,

Figure 7. Bank erosion results using CHAID



whether channel disturbance is evaluated using a set of specific response variables, or whether it is evaluated using the overall disturbance assessment.

4.6 BANK AND BED EROSION

Although most of the individual predictors of channel disturbance were associated with the overall disturbance assessment, bank and bed erosion were not associated with overall disturbance. CHAID analysis was done to determine whether bank or bed erosion was affected by any of the predictor variables. Bed erosion was not associated with any of the predictor variables. Figure 7 shows the results for bank erosion.

Width was the most important variable affecting bank erosion; however the split in this case only produced two categories: streams greater or less than 4.3 m wide. The wider streams had much greater bank erosion; however there were only five streams in this category. Streams less than 4.3 m wide were separated by location, with valley flat streams having greater erosion than other streams.

5.0 DISCUSSION

This study examines the degree of channel disturbance that occurs when logging slash is deposited into a channel. Disturbance is defined as changes in channel morphology, as well as changes in sediment and woody debris output after logging. Several measurements were available to indicate the degree of disturbance. In this study, the overall disturbance assessment was used as an integrated assessment of five channel disturbance measurements:

- The size of logging debris moved in the stream
- The percentage of logging debris moved in the stream
- The size of logging debris jams in the stream
- The percentage of logging debris in jams, and
- The size of sediment wedges in the stream.

Two other specific response variables, bed and bank erosion, were examined separately.

The extent of disturbance is likely dependent upon the size of flood flows a stream has experienced after logging. Almost all streams in this study were logged prior to November 1995, when the highest recorded precipitation event at Nitinat Lake occurred. In addition, another very large rainstorm occurred in 1998 at Nitinat Lake. Thus all of the streams in this study were likely subject to high flood flows after logging.

The degree of disturbance in a logging slash-full channel depends on the capability of the stream to transport the slash. Stream power (a measure of the potential energy available in a stream) is the product of stream discharge, gradient, and the specific weight of water (Knighton, 1984). Measures of channel size - width, depth, or area - approximate stream discharge. The strongest result in this study shows that small streams - whether measured using channel width, depth, or area - are much less likely to be disturbed after deposition of logging slash than larger streams, indicating that channel disturbance is related to stream power. The analysis shows that channel width is the most effective measurement of stream size; however the result is consistent whether the measurement of channel size is width, depth, or area. The size of sediment transported, another indicator of a stream's transport capability, is also an effective predictor of whether a channel is likely to become disturbed if slash is left in the channel after logging.

An artefact of the CHAID analysis is the grouping of continuous variables into classes. Channel width is a continuous variable, and CHAID produces three width classes in the analysis of overall disturbance. Although these are useful breaks, it should be recognized that there is no particular threshold value of width. In general, an increase in width or channel size will bring an increased likelihood of disturbance.

Bank type was shown in both the CHAID and logistic regression analysis to be significant. Both CHAID and logistic regression identified bank type 3 (vegetated banks with sand or pebbles) as having the greatest disturbance levels. However, the two methods of analysis resulted in different rankings of the other bank types. Both bed and bank types were difficult to define. In the field, bed and bank types were classified by listing the sediment sizes (as well as vegetation and bedrock) from least common to most common. In order to reduce the large number of variations that result from this method, bank and bed classes were constructed. Given the difficulty of defining bank type, and the low number of sample numbers of most bank types, the use of bank type for channel disturbance assessment should be approached cautiously.

Surprisingly, gradient was not shown to be significant. Given that channel size was shown to be very significant for all of the specific response outcomes, as well as overall disturbance, one would expect the other variable in stream power - gradient - would also have been significant. However, this was not shown in this study. When sediment size was treated as a dependent variable, then gradient, in combination with channel width and depth, was shown to significantly affect the maximum size of sediment transported. This indicates that stream power likely does increase in the steeper streams of this study. However, most of the specific response variables measure the response of logging slash, and the lack of significance of gradient to these responses suggests that logging slash does not respond to stream power in the same way as sediment transport.

Gullied streams were analyzed separately for two reasons. A greater than expected number of gullies had extensive and severe disturbance, and additional data were collected for gullies. The analysis showed that channel size (most importantly width) was still the most significant factor, and that sidewall length may have affected the degree of disturbance. It is not clear why sidewall length might affect disturbance. Overall disturbance included the development of sediment wedges in the channel, and it may be that gullies with larger sidewalls were delivering more sediment and thus developing larger sediment wedges.

Bed and bank erosion occurred in only about 15% of the streams in this study. Bed erosion was not associated with any predictor variable, but bank erosion was dependent upon channel width. In addition, bank erosion appeared to be more common on valley flat streams, which may be a result of the erodible sediments that are often on floodplains.

An important aspect of this study is how to predict which streams with logging slash are likely to become significantly disturbed. The analysis shows that channel size is the most important factor in stream disturbance, and that channel width is the best variable to measure for channel size. This study used maximum channel depth, and channel area was the product of bankfull width and maximum channel depth. The fact that channel area did not yield better results than width suggests that average bankfull depth may be a better measurement to use than maximum depth.

A few other predictor variables are useful for assessing the likelihood of channel disturbance. In addition to channel size, the size of sediment transported in the stream is a useful indicator of the likelihood of a channel to become disturbed. Bank type may be useful, but should be used cautiously. In this study, the size of logging debris moved in the channel was used as an indicator of the degree of channel disturbance. However, in an unlogged stream, the size of natural woody debris moving can be used as an indicator of the likelihood of channel disturbance after logging.

The definition of small woody debris in this study was too broad - any piece of wood that was not <0.1 m in diameter and <3 m in length was considered small woody debris. This could include pieces of wood 1 m in diameter and just under 3 m long. A more inclusive definition of large woody debris is needed to account for these short, but large volume pieces.

6.0 CONCLUSION AND RECOMMENDATIONS

Harvesting plans for blocks that contain S5 and S6 streams should consider the effects that harvesting will have upon the stability of the stream, and whether sediment or logging debris will be transported downstream into fish-bearing waters. Each stream should be considered individually, and an appropriate harvesting strategy determined. If the assessment shows that harvesting along the channel banks is acceptable, then an assessment needs to be made whether logging slash will disturb the channel if it is left in the channel after logging. For streams that are suitable for logging to the banks, this study addresses the question of whether cleaning the logging debris from the stream is necessary to avoid channel disturbance.

The most useful predictors of channel disturbance in this study are channel width, and the sizes of sediment and woody debris transported by the stream. Assessment of the likelihood of disturbance should use all of these predictors. The Gully Assessment Procedure (1995) uses a method of assessing water transport potential using channel size, gradient, and the sizes of woody debris and sediment transported. This method can be modified using the results of this study. It is important to note that in this method, the highest ranking evaluation of any of the channel disturbance predictors determines the overall channel disturbance assessment.

Table 7 uses a modified Gully Assessment Procedure method to assess water transport potential. Table 8 contains logging debris cleaning recommendations. The use

Table 7. Assessment of water transport potential

Water transport potential	Low	Moderate	High
Bankfull channel width (m)	≤ 2	> 2 - ≤ 3.5	> 3.5
Size of water transported woody debris	SWD	LWD	Logs
Largest sediment transported (mm)	≤ 100	> 100 - ≤ 200	> 200

Logs: > 0.5m in diameter and > 3m long, or > 0.3m in diameter and > 5 m long. **Large woody debris (LWD):** >0.1m in diameter and >3 m in length, or > 0.2 m in diameter and >1 m in length, up to the size of logs. **Small woody debris (SWD):** any woody debris smaller than LWD

Table 8. Recommended cleaning strategies

Water transport potential	Cleaning strategy
Low	Do not clean
Moderate	Clean all introduced SWD and most LWD
High	Clean all logging debris except larger logs

of Tables 7 and 8 is recommended for open slope or gullied S5 and S6 streams in relatively erosion resistant surficial materials (most tills and colluvial sediments, as well as bedrock) that are connected to a fish stream. If the S5 or S6 stream is not connected to a fish stream, then leaving slash in the stream will not affect fish habitat. A qualified registered professional should be consulted in cases that do not meet the criteria specified above. In addition, it may be possible that streams in other geographic areas respond differently, and therefore local calibration should be done before using these results.

If any of the criteria in Table 7 are evaluated as high, then the overall water transport assessment is high. If there are no criteria ranked as high, then one or more moderate evaluations results in an overall water transport potential as moderate.

This study examined streams several years after harvesting, and the decision of whether to remove logging debris should be made prior to harvesting. Therefore a question that should be addressed is whether the streams will have the same characteristics prior to logging as they do after logging. Harvesting of a large portion of the basin area may have the potential to increase the discharge of a stream, and therefore channel width, sediment size transported, and size of woody debris transported may increase as well. In most cases, bed and bank erosion were not observed, and therefore stream width measurements made prior to logging would likely have been equivalent to measurements made after logging. This indicates that pre-harvest transport capability should be similar to post-harvest transport capability.

If a road crosses the stream, the water delivered to the stream from the ditch may increase the stream discharge. Roads that have a long length of ditchline that drains into a stream can significantly increase flow volumes, and therefore the transport capability, of the stream. If a stream assessment is made prior to road building, and a road crossing of the stream is expected, the transport capability assessment for the portion of the stream below the road should err on the cautious side.

The decision to clean or not clean logging slash from a channel should also consider the potential effects of cleaning slash. Slash cleaning can result in channel bed erosion and increased amounts of sediment transported from the cleaned channel, a negative effect (Bovis et al, 1998; Golder, 1999). Unwanted impacts may not occur to all streams subject to cleaning, particularly if the cleaning is done carefully. However, there has been little evaluation of the effectiveness of various cleaning techniques, or whether careful cleaning of a stream results in less impact than leaving the slash in the stream. Therefore stream cleaning should be done carefully.

An additional concern with leaving logging slash in channels is its effect on debris flows. Debris flow initiation is rarely affected by the amount of slash in a channel, and therefore removing the slash will not prevent a debris flow from starting. A debris flow that has already started may incorporate logging slash into the debris flow, and so may increase the volume of the debris flow as a result. In these cases, removal of logging debris could be considered.

The decision to clean logging debris from channels should be done on the basis of a channel's likelihood to become disturbed. This study shows that leaving logging slash in streams does not necessarily lead to channel disturbance. The recommendations contained in this report should provide useful assistance in assessing a stream's likelihood of disturbance.

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