Testing Indices of Cold Water Fish Habitat.

Final Report for

Development of Techniques for Measuring Beneficial Use Protection and Inclusion into the North Coast Region's Basin Plan by Amendment of the "Guidelines for Implementing and Enforcement of Discharge Prohibitions Relating to Logging, Construction and Associated Activities"
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North Coast Regional Water Quality Control Board in cooperation with the California Department of Forestry

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Executive Summary

Water quality regulations normally are promulgated to provide quality water for domestic consumption or for the protection of other dependent resources (fish and wildlife for example). Regulations for domestic quality such as turbidity, alkalinity or hardness, are easily measured and conclusions regarding the suitability of water for drinking are unambiguous. However, regulations established to protect fish have been problematic because:

1) the most common problems affecting fish in forested watersheds are changes in habitat, not changes in the chemical constituents or physical attributes of the water'. Therefore, most of our current regulations which are based on water quality variables, are ineffective in protecting fish.

2) Very little information exists that can be directly applied to the establishment of new regulations based on habitat variables. Changes in habitat (usually additional sand in the channel or removal of instream logs) affect fish habitat by reducing areas where fish can hide from predators and adverse environmental conditions, and by reducing the quality of gravels the fish need to spawn in. While much is known about habitat and fisheries relationships, little is known regarding which habitat elements can be reliably measured and what those measurements mean in the context of natural habitat conditions.

The objective of this study was to determine which components of cold water fish habitat could serve as future regulatory tools and provide a means to achieve effective fisheries protection.

Specifically, this project sought to determine:

1) Which physical elements of instream habitat are affected by human activity in the upslope watershed?
2) What is the current range of values for those elements?
3) What is the range of values that represents undisturbed habitat conditions and,
4) How the results from this study might be used in a regulatory framework?

This study measured a range of habitat variables in 60 streams within the North Coast Planning Basin of California. Sampling was limited to the Franciscan geologic formation. The variables used in this study were selected following consultation with over 30 scientists throughout the Western United States. Sample locations and measurement methods were designed to provide a statistically reliable assessment. Sampling sites were divided into three descriptive categories of increasing upslope erosion potential to assess whether the variables selected for this study were affected by that activity. Sample locations for the Index group included all available streams (18), while reaches in the other two categories were selected randomly from a pool of over 120 watersheds **(21** streams in each category). Sampling occurred without regard to ownership boundaries.

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[1]Temperature is a notable exception. However, temperature was not a variable measured in this study.

The results from this study indicate that “V*", the amount of fine sediment collected in the bottom of stream pools, "RASI" or Riffle Armour Stability Index, a measure of the composition of riffle gravels and “D50”, the median particle size of the riffle gravels all showed significant differences between reaches with different levels of upslope disturbance. An important finding of this study is that these three variables can be used to identify habitat condition in similar streams. Options are presented for using this study’s results in a regulatory framework. This study did not evaluate how the observed differences in habitat affect fish populations.

The importance of this study is:

1) It identifies variables and sampling methods which can be expanded into other geologic formations which will improve our ability to regulate upslope activities and protect fisheries resources.

2) It provides baseline data for habitat variables that makes meaningful rankings of instream habitat condition possible. This may influence instream restoration priorities and upslope management techniques.

3) The indices (variables) verified in this study provide a way to assess the cumulative effects of all upslope activities and to concurrently monitor the aggregate effectiveness of upslope protection measures.

4) It provides new data suggesting that the consequences of historical forest management are still adversely affecting instream habitat. This new information may have far reaching effects on how restoration priorities are established.

Overview

Aquatic habitat can be conceptualized as being composed of structural elements such as the amount and distribution of cover associated with large wood, the volume and configuration of pools, or the quantity and particle size distribution of spawning gravels. To understand what aquatic habitat condition is, we must know 1) Which structural elements of aquatic and riparian ecosystems affect productivity of the beneficial uses, 2) which structural elements are quantifiable (in a practical way) and 3) what characteristics reflect "good" habitat. The ongoing shift in forest management towards managing ecosystems, will require a process for identifying the structural elements of aquatic ecosystems to allow the establishment of meaningful goals, provide a basis for setting restoration priorities and design objectives, and provide a framework for monitoring management actions. Agencies charged with protecting water quality are ultimately trying to maintain and protect the water-associated beneficial uses. Because biotic populations are often difficult to quantify and are naturally variable (for reasons unrelated to habitat quality), measurement of quantifiable physical attributes are attractive to researchers. The determination of habitat condition, as identified by its structural elements, should provide a practical alternative for evaluating the beneficial uses directly.

On the Northern Coast of California, streams drain into the Pacific Ocean and have historically supported large populations of anadromous fish which in turn, have supported significant commercial, sport and Native American fisheries. The North Coast's soils and moist climate have also produced one of the most prolific timber growing regions in the world. Historically, log removal involved dragging logs downhill to the streams. Railroad grades, roads and dams were constructed in stream channels to transport logs to local mills. The results were massive modification of fish habitat. The fish resource was also impacted directly by commercial harvest as canneries were established at the mouths of many large rivers, commercial fishing fleets grew into national enterprises and the technology for ocean harvesting improved.

Fish numbers continue to decline today, long after the practices of the past have given way. to new forest practices, fish quotas, habitat restoration efforts and fish rearing programs. Whether the decline is the result of overfishing, loss of habitat or other factors is still hotly debated. Clearly, all have played their parts; less clear is which had(s) the lead.

The study provides a first step in defining a process to assess the condition of cold water fish habitat. By knowing the relative condition of instream habitat within a watershed, restoration efforts can be prioritized, forest management plans can establish quantifiable goals, and the aggregate effect of forest practices can be evaluated. This will improve future forest management, which in turn will benefit both the timber and fisheries resources.

Objective

The objective of this study was to test several indices of cold water fish habitat to determine their relevance to upslope disturbance and determine the range of associated values[2]. If this could be accomplished, the variables and methods developed might eventually be used in a broader regulatory framework.

Specifically, this study sought to determine;

1) Which variables selected to represent habitat condition vary with respect to upslope forest management, and therefore reflect a management issue?
2) What is the current range of values for those variables?
3) Which values represent unmanaged conditions ("good" habitat) and,
4) How might the results from this study be used in a regulatory framework?

Location

The study area was the northern coastal region of California, 60 miles north of the San Francisco Bay to the Oregon border (Map 1). Most sample sites were within 10 miles of the coast, predominantly within the Redwood - Douglas Fir vegetation type. The remainder were within 25 miles, in Douglas Fir. Only watersheds within the Franciscan Formation were evaluated. Precipitation occurs primarily as rain from November through May, with quantities increasing with elevation and with proximity to the coast. Average annual precipitation ranged from 35 to 100 inches along the coast, diminishing to 30 to 55 inches at the inland locations.

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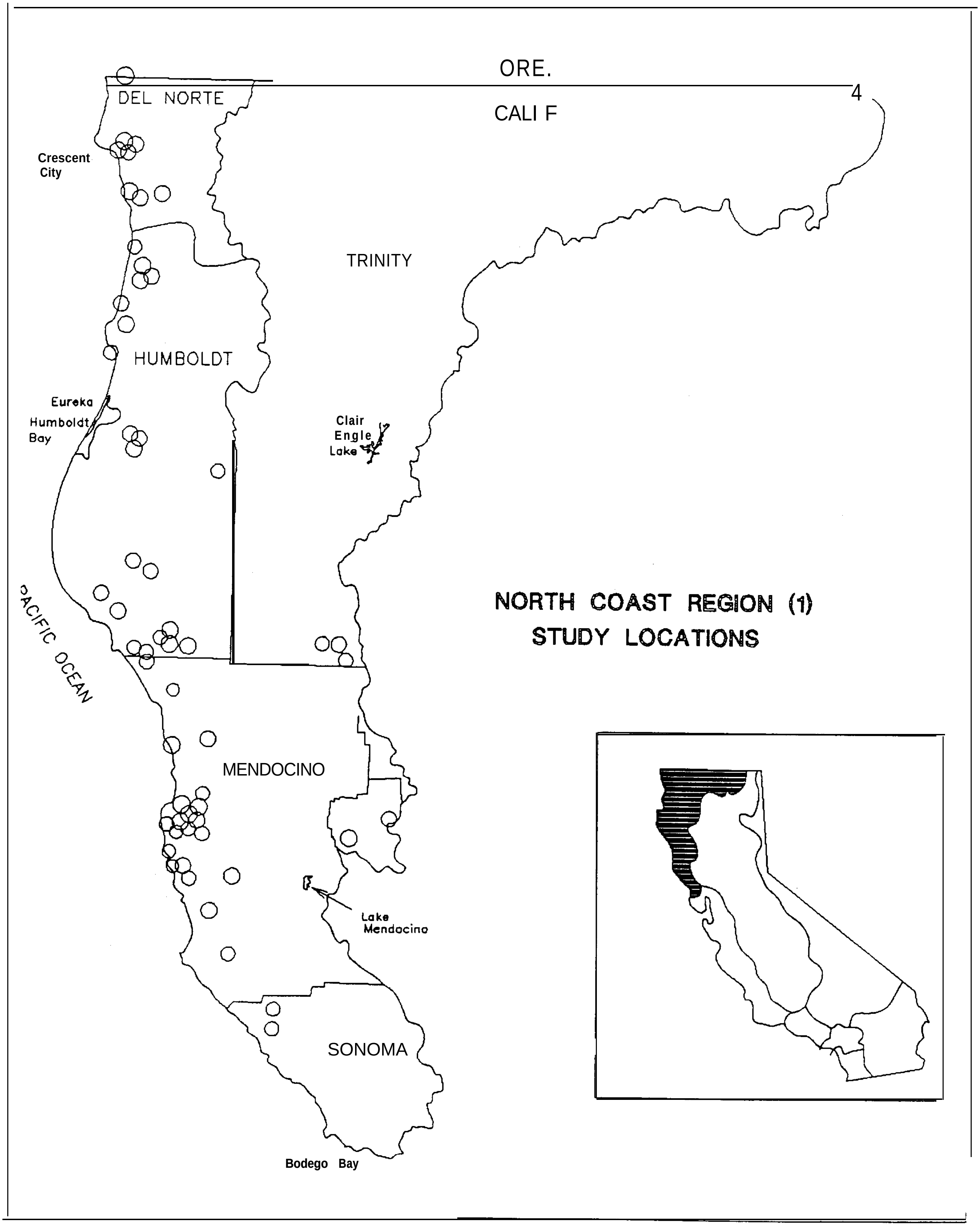
*Most of the indices evaluated by this study do not distinguish between impacts associated with grazing, subdivision development, or timber management. The results reflect all impacts in the upslope watershed. In all cases, the primary activity was timber management.

Map 1. Sampling locations with the North Coast Planning Basin.



Methodology

Study Design

The sample design, site selection criteria and the indices to be monitored were selected to limit the natural variability and to identify those components of habitat that are both important and quantifiable. To accomplish this, sampling locations were selected based on geology and channel type. Only the Franciscan Formation and channels exhibiting small cobble substrates and slopes between 1 and 4 percent (B-2 channels, Rosgen, 1985) were sampled. (These correspond to Rosgen B-3 and C-3 channels under the current, unpublished classification.) The study area and sampling locations are shown on Map 1. Sampling occurred during the summer low flow period, from June 1, 1992, through September 1992. However, a few channels were sampled as late as November 8, following rain, to allow the flows to rise enough to permit sampling. The sampled period followed 5 to 7 years of below normal precipitation, and study results may represent habitat conditions affected by below normal flows.

Sixty reaches, each 1000 meters long, were sampled for 3 primary variables. Several other variables necessary to quantify the primary variables were also measured and were included in the analysis (For example, D50, median particle size of the riffles, was collected as part of the RASI values, but was also evaluated separately). Upslope disturbance was accounted for by dividing the sixty reaches into three descriptive categories. The purpose of the categories was to determine if the measured variables (instream) were affected by upslope disturbance. They were not intended as a means to describe erosion and deposition processes associated with forest management practices. The utility of the categories was to establish the range of conditions characteristic of undisturbed watersheds, and to identify the range of values associated with disturbed watersheds. The range could then be used as a baseline for future comparisons (within the limitations imposed by the study design).

Three Disturbance Conditions:

Index **watersheds,** drainages with no human disturbance history or little disturbance within the past 40 years and no evidence of residual erosion or instability due to past human activity. The term “Index” was used instead of “control” to distinguish these reaches from truely undisturbed watersheds. The Index category represented the least disturbed watersheds available.and are believed to exhibit similar habitat structure to true controls in most instances. Exceptions became apparent and are noted in the report.

Open roads normally disqualified a reach for inclusion in the Index category, however, exceptions were made on a case by case basis, if the road was unlikely to affect fish habitat. Index reaches were additionally split into Index reaches with no previous management (Index No), and reaches with historic management, greater than 40 years old (Index Yes). This subdivision was not part of the original design. The Results Section displays the two subdivisions, as well as the three original categories. The Index category was composed of 18 reaches; 12 'Index No' and 6 'Index Yes'.

Moderately Disturbed **watersheds,** drainages with recent management but with good protection of stream courses, (predominantly undisturbed buffers approximately 100 feet or more wide on each side of perennial water courses, minimal road encroachment on the riparian area), high and mid-slope road locations, and avoidance of unstable areas. Timber harvest operations reflected predominantly cable systems. Twenty one 'Moderate' reaches were sampled.

Highly Disturbed **watersheds,** drainages that exhibited large areas of disturbed soil, unpaved, low slope roads, inconsistent or poor stream course protection, and inconsistent avoidance of unstable terrain. Twenty one 'High' reaches were sampled.

Selection of Variables

Variables selected for inclusion in this study were identified following consultations with over 30 scientists from management agencies, research, achedemia and industry in 5 Western States. The preliminary list included V*, Q*, habitat typing, channel stability ratings, stream width/depth ratios, temperature, intragravel dissolved oxygen, macro-invertebrates, fish populations, riparian canopy age class distribution and recruitment volumes, woody debris, woody debris complexity, suspended sediment, bedload, stream discharge, various pool parameters (maximum depth, volume, pool frequency), RASI, DSO, embeddedness, McNiel core samples and numerous others. The methods and variables described above were evaluated for their 1) applicability to a routine sampling program, 2) their relavence to known physical processes within the North Coast Planning Basin, 3) the opinions of the scientists on each parameter's likelyhood of providing useful separation between unmanaged and disturbed reaches, (repeatablility, minimal natural variation) and 4) for their applicability to the financial and time constraints placed upon the project.

The list described in the following section represent those variables that we felt best met these criteria. Other variables are likely to be effective in other geographic areas or given different financial situations. Also, variables that did not vary with different levels of upslope disturbance in this study, should not be discounted from consideration for different areas.

Data Collection Methods

V*

V* represents the proportion of fine sediments that occupy the scoured residual volume of a pool (Lisle and Hilton 1992). As the quantity of sediment being transported increases, the percentage of the total pool volume occupied by fine sediments should increase. The primary selection criteria for V* pools was a maximum depth of at least 4 times the riffle crest depth (at low flows). (The riffle crest is the depth of the water as it flows over the downstream lip of the pool.) V* was measured by probing the sediment of a pool with a steel rod until an armored layer was encountered. The depth of water to both the top of the sediment and to the armor layer was recorded. Transects were distributed perpendicular to a longitudinal tape line to define the pool's morphology. A minimum of 4 transects per pool were measured. Analysis of the transect data provided an estimate of the total volume of the pool and the sediment contained in the pool. Six pools per 1000 meter reach were sampled. A three person crew would measure 6 pools in about 4 hours. Large or complicated pools would take up to an hour or more each.

Pool volume has consistently been identified as an important aspect of pool habitat and one that appears to be vulnerable to increased sediment loads caused by watershed disturbance. Bjornn et al. (1977) found that introducing fine sand into a natural 3rd order stream pool reduced its volume by half (V* of OS), and caused fish numbers to decline by two thirds. Pool size has also been described as a direct relationship with suitability and fish size (Allen 1969, Heiffetz et al. 1986). It is not surprising that the effect of adding fine sediment, which reduces pool volume and substrate diversity should have an adverse effect on the overall suitability of the pool as habitat. If pool habitat is a limiting factor in fish production, the reduction of pool volume will translate into an adverse impact on overall fish survival.

RASI

RASI is believed to reflect the amount of sediment in transport relative to a stream's capacity to transport it. RASI is an acronym for Riffle Armor Stability Index. Its a measure of the cumulative percent of the riffle particles (measured using a modified Wolman pebble count) that are less than or equal to the size of the largest annually mobile particles on the riffle. Numbers greater than 80 are believed to indicate unnaturally high sediment loads. Values range from less than 20 to 100. As sediment loads increase, the surface of a riffle exhibits a greater proportion of smaller particle sizes (Platts and Megahan 1975, Lisle 1982, Dietrich et. al. 1989). The size of the largest mobile particles stay constant (or possibly increase if upslope disturbance changes the flow regime). The result is that the proportion of the riffle's surface particles smaller than the largest mobile particles increases. The advantage of RASI over a standard D50 measurement is that it allows direct comparison of streams with dissimilar hydraulic properties. (Kappesser 1992). A detailed discussion of the sampling methods are included in Appendix A.

The effects that increases in fine sediments have on fish have been studied for decades, although the results remain controversial when applied to a natural streams (Chapman 1988, Hicks et al. 1991). The conflicts within the literature probably result from the inherent complexity associated with differences in the morphology of streams, the different requirements of species, and the changing habitat requirements of individuals at various life stages. Much information exists which suggests that high proportions of fine sediments are adverse to fish. Excessive sedimentation has been shown to reduce pool volumes, reduce the oxygen inflow or limit the diffusion of metabolic wastes from redds, and can physically impair the emergence of fry from the gravel (Gangmark and Bakkala 1960, Coble 1961, Koski 1966, Bjomn et al. 1977, Meehan and Swanston 1977, Crouse et al. 198 1, Everest et al. 1987, Chapman 1988, Scrivener and Brownlee 1989). Reductions in intragravel space can also influence the micro habitat for aquatic insects (considered as a primary food source for fish or as a component of biodiversity), or can reduce the diversity of cover for juveniles by burying coarse cobbles (Cordone and Kelley 1961, Bjornn et al. 1977). Therefore, the composition of stream gravels is an important factor in assessing habitat condition.

Wood Volume, Wood Cover, Pool Volume and associated **Substrate Change.**

All four variables associated with woody debris were selected to address not only the quantity of woody debris in a channel, but also its utility as habitat. Wood Volume was measured within the active channel (the area of annually scoured gravels). Cover was measured as the area of a shadow cast on the stream bed by an overhead light source. It was estimated within the bankfull channel. Both Pool Volume and Substrate Change were also measured within the active channel. Pool Volume was measured by estimating an average depth for a pool and multiplying it times the pool's surface area. Only wet pools were included. Substrate Change measured the surface area of deposited or scour-exposed gravels and was intended to reflect diversity of substrates associated with woody debris.

Woody debris benefits all life stages of salmonids (Bisson et al. 1987, Sullivan et al. 1987), by creating pools which aid in migration, serving to retain spawning gravels, create slack water areas which provide opportunities for juveniles to feed on drift and by providing essential cover from predators and freshets (Murphy and Meehan 1991). Woody debris in streams also increases the frequency and diversity of pool types (Bilby and Ward 1991). Since structure and function of stream ecosystems are significantly influenced by woody debris (Murphy and Meehan 199 l), its presence, configuration and effects on channel morphology were judged to be important elements of habitat condition for fish.

Secondary variables

Secondary variables were collected in the course of measuring the primary variables. In some cases these secondary variables were components of other variables such as D50, which was a component of the RASI variable. Others, like the Pool variables, were measured in the course of identifying pools which met the V* selection criteria. These data were analysed to the same extent as the primary variables.

Number of Pools per Reach:

All pools that occupied 50 percent or more of the active channel, and whose surface did not show turbulence were included. No criteria were included for depth for this variable.

Total Length of Pools per Reach/ Pool Average Length/ Pool Maximum Length/ Pool Maximum Depth:

Distance measures were taken along the pool's thalweg. The number, length and depths were measured in all pools for the entire 1000 meter reach. Pool depths for this variable were not corrected by subtracting the riffle crest. The measures are self explanatory.

D50:

The D50 was determined using a modified Wolman Pebble Count within the bankfull channel, The count used 200 points per riffle, and included 3 riffles per reach. The value used in the analysis was the reach average. The D50 was collected as a component of the RASI variable.

Additional information regarding the sampling design and variables selected is available in the project's assessment plan, titled "Testing Three Indices for Measuring; the Condition of Cold Water Fish Habitat," California North Coast Regional Water Quality Control Board, July 3, 1992. Sampling methods are included in Appendix A of this document.

Data Analysis Methods

Data was analysed using an Analysis of Variance (AOV). The AOV determined if significant differences existed between descriptive categories. Differences were evaluated at the 80 percent and 95 percent confidence levels. The test determined if the variables used in the study were affected by upslope soil disturbance, and therefore, demonstrated the variable's relevance to forest management issues.
Also, a sediment budget was done to validate the assumptions used to define the descriptive categories. The sediment budget was designed to provide 'order of magnitudes' level information quickly. Sixty reaches were evaluated for three periods, 1960-1970, 1970-1980, 1980-1990. All data was collected from topographic maps, Timber Harvest Plan maps and air photos. This information was subsequently included in the AOV.

The design for the analysis of variance was as follows:

Table 1. Sampling design.

Variable	Number of samples / reach	Reaches / Category	Categories
V*	6 pools/reach	18 Index reaches	3 descriptive
RASI	3 riffles/reach	(12 Index No, 6 Yes)	Categories
Woody Debris (Volume, Cover, Substrate, Pool volume)	All / 1000 m reach	21 Moderate **21** High	(Disturbance Conditions)
All Pools (depth, length, volume)	All pools / 1000m		
D50,	See RASI		
Cover/Volume	Composite from Wood Cover and Volume. See Woody Debris.		
Substrate/Volume	Composite from Wood Substrate and Volume. See Woody Debris.		

NOTE: Primary variables identified in the ***assessment plan*** *are boldfaced.*

Habitat Quality Assumptions

The study assumed that native populations of cold water fish evolved in response to environmental conditions, and that the mean condition represented by undisturbed reaches (Index No) represents the mix of habitat elements best able to maintain viable populations. Good quality habitat (relative to a specific geologic formation and channel type), is therefore defined as the mean condition existing under undisturbed conditions. Changes in habitat condition are assumed to translate into changes in utility of the habitat for cold water fish and consequently, into changes in fish numbers. However, this study does not establish the relationship between changes in physical habitat to changes in fish numbers.

The mean condition is not a true optimum, but only an approximation. Undisturbed habitat also exhibits a range of habitat conditions. Actual differences in results between true optimum conditions and the range of values measured from the descriptive categories are assumed to be somewhat greater than the differences shown in the results.

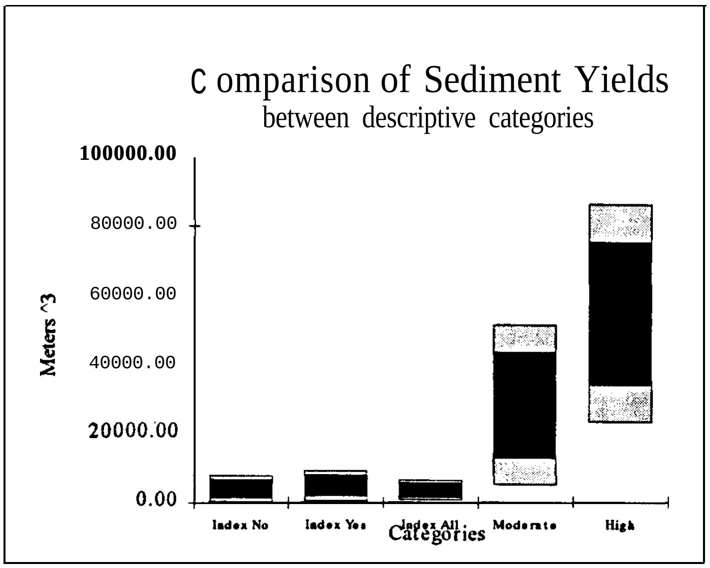
Results and Discussion

This section first discusses the assumptions associated with the descriptive categories, then presents the results of the analysis of individual variables.

Evaluation of disturbance categories

Sediment yields were estimated with a general sediment budget using data from air photos and available maps (Appendix C). Figure 1 shows the 80 and 95 percent confidence bands around the mean sediment yields for each upslope disturbance category. All of the Index groups are significantly different from the High category at the 80 and 95 percent level. Although a trend is evident between the Moderate and High categories, the differences are not statistically significant at the 80 percent level. The subjective groupings of stream reaches into levels of upslope disturbance compare favorably with results generated from the sediment budget. Increased levels of disturbance based on subjective criteria were similarly reflected by increased levels of sediment. The results from the sediment budget confirm (within the limitations of the budget) the descriptive categories and their utility as indicators of upslope disturbance.

Figure 1. Sediment yields grouped by descriptive categories.



Based on the sediment budget results (Figure I), the initial three descriptive categories represent a reasonable separation between watersheds with different levels of upslope soil disturbance. The Index No and Yes categories do not show significant differences based upon sediment sources observable in 1960 and later air photographs. This suggests that most of the disturbance that is know to have occurred in the Index Yes category watersheds had revegetated by 1960.

Evaluation of the 3 Disturbance Categories for Bias

The Index Categories were composed of all available reaches and were not selected on a random basis. The "Moderate" and "High" reaches were randomly selected. Therefore, a logical question is; Are there fundamental differences between categories with respect to area or channel slope caused by the selection procedure?

Area measurements were taken from the project's sediment maps, which were based on USGS topographic sheets. Stream channel slopes were also taken from the topographic maps. The slope measurements provide a good comparison, but at the higher ranges they overestimate the actual slopes in the monitored reach (due to adjustments in reach locations to avoid steep channel sections).

Evaluation of differences in Watershed Size between categories:

In all of the following figures, the dark band represents the 80 percent confidence interval around the mean for each category. The gray bands above and below the 80 percent band represents the 95 percent confidence interval about the mean. The 'Index No' category represents Index reaches with little or no previous management. The 'Index Yes' group represents Index reaches that had been managed at least 40 years ago. No effort was made to uncover the exact harvest dates for these reaches but most of them had not been disturbed for 80 years. The 'Index All' group is the combination of the No and Yes groups and reflects the original intent of the index category. The 'Moderate' and 'High' categories reflect increasing levels of upslope disturbance based on recent activity.

Figure 2. Comparison of watershed sizes.

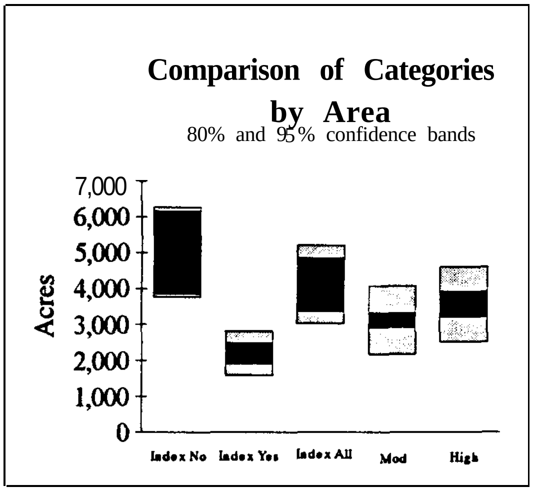
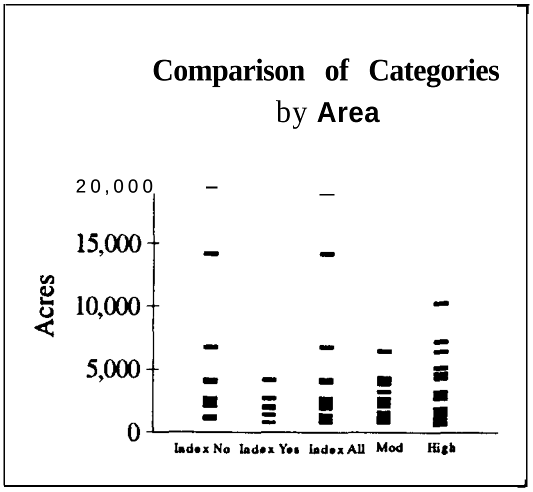


Figure 3. Total plot of sizes by category.



There are significant differences between the Index No and Yes categories with respect to area. Figure 3 shows the distribution of watershed sizes for each reach by category. The Index No group (Index reaches with no previous management) has 2 outlyers which are larger than all other watersheds sampled. However, if they are ignored, the sizes of the watersheds in each category are comparable. An additional analysis was done by selecting reaches in the Moderate and High categories that matched the areas and slopes found in the Index No category. The purpose of this analysis was to eliminate any possible effect of area and slope. The subset (27 reaches), was then analysed in the same manner as the entire data set, with an Analysis of Variance. The results from the slope and area corrected data were compared to the results from the entire data set. The results are discussed in the context of the individual variables, later in this section.

Evaluation of differences in Slopes between categories:

Reaches that met the 1 to 4 percent slope requirements were initially identified based on the USGS maps. Actual reaches were sited in the field using a clinometer to measure the slope. Several reaches were discontinuous to avoid steep sections that exceeded the selection criteria. Three reaches were terminated short of 1000 meters (with the pool frequency and woody debris data adjusted to a 1000 meter reference), also to avoid slope irregularities. Records of reach slopes were made using a clinometer and an altimeter (there was insufficient time available to survey a channel profile). However, the altimeter proved to be unreliable, and the clinometer somewhat inaccurate, especially at the 1 and 2 percent level. Therefore, slopes shown in this comparison of categories are taken from the USGS topographic maps. They have not been corrected to reflect the adjustments made in the field for slopes outside of the target range. As such, they represent a broader range in slopes between steep and shallow reaches than were actually present.

Figure 4. Comparison of slopes by groups.

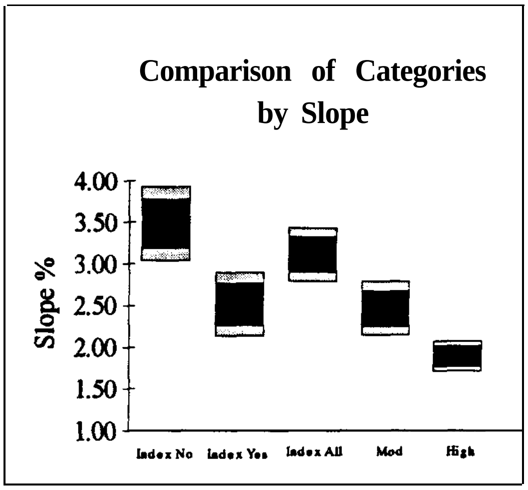


Figure 5. Total plot of slopes by group.

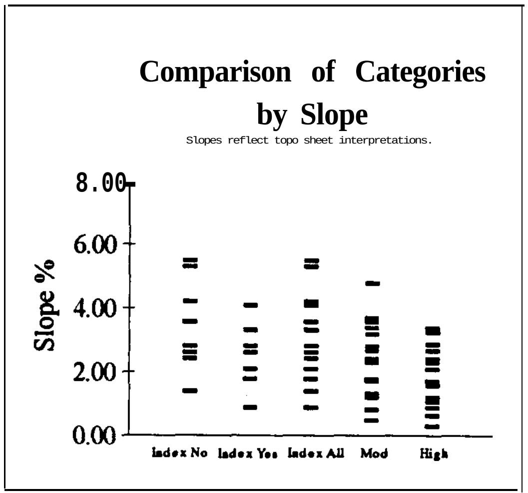


Figure 4. Slopes are significantly different between the Index All category and the High category and between the Index No and High categories.

Figure 5. The reaches that show slopes in excess of 4 percent were either broken into 2 shorter sections to avoid steeper cascades or were completed with lengths less than 1000 meters to avoid exceeding the 4 percent limit. However, since average slopes are not available for each reach based on field measurements, the topographic map slopes are used. The general relationships shown in Figures 3 and 4 do reflect differences between categories, although, the ranges of the differences should be compressed to reflect adjustments made in the field. The implications of these differences were evaluated with a correlation matrix to determine which variables vary as a result of slope.

Table 2. Correlation coefficients, for variables with Area and Slope compared in two descriptive categories. Only the Index No and High categories were evaluated for slope and area correlations. Based on these results, which suggest some interaction between selected variables with drainage area or slope, an additional analysis to eliminate bias and reevaluate disturbance effects was performed.

	Index No		**High**	
Variable	**Acres**	**Slope**	**Acres**	**Slope**
RASI	-0.33	.08	**.08**	**-.16**
D50	0.41	-.15	**.20**	**.lO**
V*	-0.42	-.01	**.28**	**-.43**
COVNOL	0.84	.07	**.33**	**-.24**
WdCOV	-.59	-.02	**.04**	**.01**
PNum	-.61	.02	**-.17**	**-.17**
PFreq	.04	.32	**.26**	**-.47**
WdSUB	-0.24	-.48	.01	**.43**

A separate analysis of matched areas and slopes was done to determine if differences observed between categories would still be present if no significant differences in either area or slope were present. The subset consisted of 10 Index No, 10 Moderate, and 9 High for the area evaluation, and 8 Index No, 8 Moderate, and 8 High reaches for the slope evaluation. These were the largest sample sizes possible in order to have reaches with similar slopes and watershed areas. An Analysis of Variance was used to test if the means of individual variables were significantly different between categories. The results were as follows:

Table 3. Results of Area and Slope corrected categories. A subset of the complete data set was analysed with matched reaches to eliminate possible bias between categories with respect to Area or Slope. All comparisons are between the 'Index No' category and the 'Moderate' (M), and 'High' (H),categories. Differences between categories are evaluated at the 80 and 95 percent level.

	Differences ***from 'Index No'***				
AOV Variables	Area Corrected		Slope Corrected		**Conclusions**
	80%	95%	80%	95%	
RASI	M,H	M,H	M,H	M,H	Differences not result of area or slope
D50	M, H	H	M, H	M, H	Differences not result of area or slope
V*	M, H	H	M, H	M	Differences not result of area or slope
Wood Cover	M, H	H	H		*Slope responsible for some of effect*
Cov/Vol			M,H		*Area responsible for much* of effect
PNum			M		*Area responsible for much of effect*
PFreq	M,H	H			*Slope responsible for much of effect*
Wd Substrate	M, H				*Slope responsible for much of effect*
Subst/Vol					*Slope and Area responsible for effect*

Where M = Moderate and H=High

Individual variables were compared between groups at the 80 and 95 percent confidence level. The table displays which variables in the Index No category were different with respect to Area or Slope from the Moderate (M) or High (H) categories based on the corrected data set. Differences between the corrected data set and the complete, uncorrected data set are discussed with respect to the influence of Area and Slope.

In summary, as a result of the site selection procedure, significant differences were observed between watershed areas and slopes between descriptive categories. An evaluation of individual variables determined that several of the variables were affected by these differences. A separate analysis with area and slope matched reaches was done which showed that some of the differences between descriptive categories were probably the result of sampling bias. These results are discussed as part of the evaluation of individual variables.

Evaluation of Upslope Disturbance on Variables

An Analysis of Variance was used to determine if differences existed between descriptive categories, which would answer the first question of whether the variables were affected by upslope disturbance and were therefore relevant to the overlying regulatory issues. Each variable's analysis is displayed, then discussed relative to the percieved sampling bias. The range of values and the category means are also displayed to answer the second and third questions, regarding the range of values that existed during the study period and what values are reflective of average, undisturbed (assumed to be good habitat) conditions?

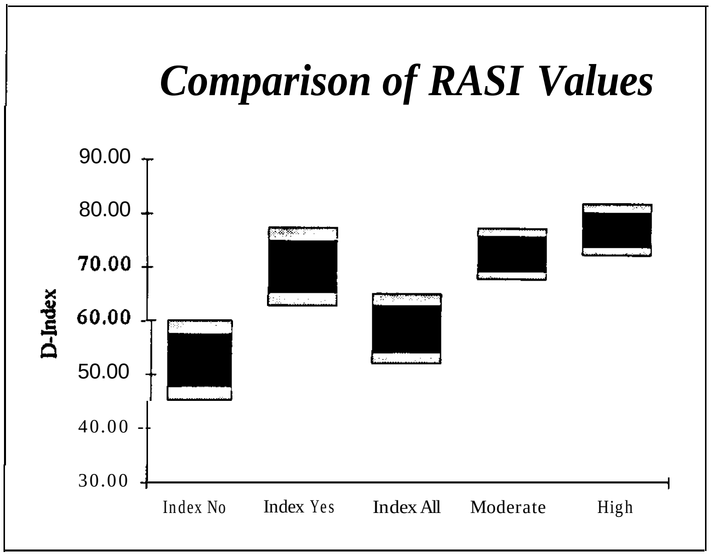
RASI

Table 4. RASI values by disturbance category. Table 4 displays the differences between categories and the ranges of RASI values within each category. RASI represents the cumulative percent of the riffle substrates that are smaller or equal in size to the largest mobile particle on the riffle surface.

	Disturbance Category				
RASI	**Index No**	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**52.61**	**69.81**	**58.34**	**72.38**	**77.02**
Median	**52.64**	**70.89**	**57.55**	**69.67**	**76.73**
Std Deviation	**12.89**	**9.14**	**14.20**	**11.26**	**11.34**
Minimum	**24.1**	**53.57**	**24.10**	**53.93**	**55.40**
Maximum	**75**	**80.00**	**80.00**	**92.10**	**97.20**
Count	**12**	**6**	**18**	**21**	**21**

The following graphs represent 80 percent (the dark band) and 95 percent (the light band plus the dark band) confidence bands around the sample means. The greater the separation between category bands, the more likely that the variable was sensitive to impacts related to upslope disturbance. The 'Index Yes' category was composed of 6 reaches. They represented reaches with historical management, but with no disturbance within the past 40 years (several have not been disturbed for at least 80 years). The Index All category is the composite of the Index No and Yes categories.

Figure 6. RASI values by category. The graph displays 80 and 95% confidence bands around the category means. The higher the RASI value, the greater the proportion of fines on the riffle surface.



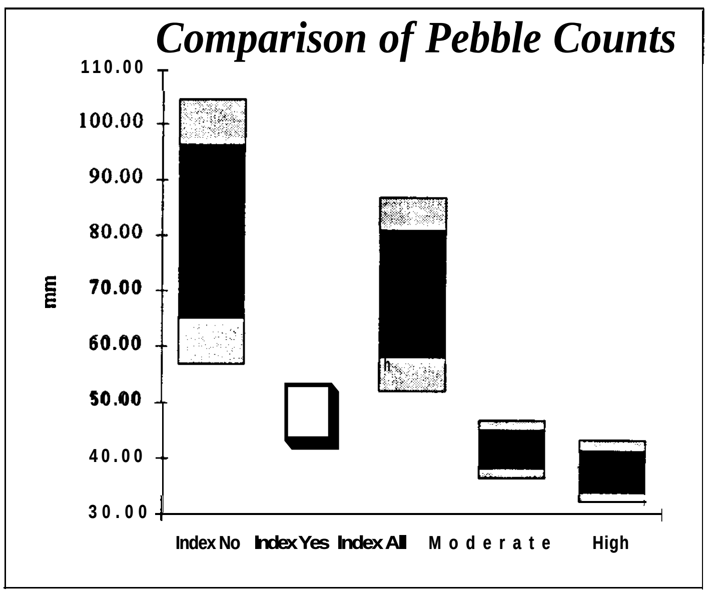
RASI values show a clear trend with increasing upslope disturbance. Very little recovery (relative to the High category) is evident based on differences between the 'Index No' and 'Index Yes' groups. The difference between 'Index Yes' and 'No' groups is significant at 80 and 95%. The 'Index All' category is significantly different from both the 'Moderate' and 'High' categories (at 80 and 95%), while the 'Moderate' category is not significantly different from the 'High' category. The 'Index No' category is also significantly different (at 80 and 95%) from the 'Moderate' and 'High' groups, while the 'Index Yes' group is not. RASI values exhibited a weak (r = -0.33), relationship with drainage area in undisturbed watersheds (RASI decreasing with increasing watershed size), but no significant relationship in disturbed reaches. With respect to slope, RASI values exhibited no discemable relationship in undisturbed watersheds and a weak (r = -0.24), relationship in highly disturbed conditions (Table 2). When a subset of reaches was tested to eliminate any possible bias between categories with respect to area or slope (Table 3), RASI values continued to show distinct, significant differences. Therefore, the differences we observed between categories with respect to RASI values appear to have resulted from differences in the level of upslope disturbance. High RASI values exhibited by the 'Index Yes' category are likely to be residual effects from historic, turn of the century, timber removal operations.

D50

Table 5. D50s by category. D50s reflect pebble count data collected to characterize RASI values in riffles. Values represent median particle sizes in millimeters.

	Disturbance Category				
***D50* of Riffle**	**Index No**	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**80.66**	**47.07**	**69.46**	**41.46**	**37.61**
Median	**73.62**	**47.37**	**51.47**	**37.23**	**36.87**
Std Deviation	**42.17**	**6.97**	**37.82**	**12.20**	**13.20**
Minimum	**37.43**	**38.43**	**37.43**	**17.03**	**10.20**
Maximum	**183.13**	**57.70**	**183.13**	**61.93**	**60.83**
Count	12	**6**	**18.00**	**21**	**21**

Figure 7. D50s by category. A D50 value of 65 millimeters (mm), means that 50 percent of the substrates were smaller than 65 mm, and 50 percent were larger. Figure 7 represents the 80 and 95 percent confidence bands around the category means.



Each reach was represented by (3) 200 count riffles. The data was collected as a component of the RASI evaluation. A clear trend of decreasing particle sizes in the riffles was evident with increasing upslope disturbance. Again, the 'Index Yes' reaches were not different from the 'Moderate or 'High' reaches, although both appear to exhibit smaller particle sizes. The 'Index No' reaches were significantly different from the 'Index Yes', 'Moderate' and 'High' categories at 80 and 95 percent. The 'Index All' category was significantly different from the 'Moderate' and 'High' category at 80 and 95 percent. The 'Moderate' category was not different from the 'High' category.

The distribution of particle sizes in riffles showed a weak trend of increasing particle sizes with increasing drainage Area (Table 2). Generally, as flows increase, the channel bed displays a coarser texture as fine material is transported. If sediment loads increase, however, flow alone will not determine substrate sizes. Watersheds with variable sediment loads would be expected to display an inconsistent relationship between drainage Area and riffle substrates (D50), because increases in sediment supply have been shown to increase the proportion of fine sediments on the riffle's surface (Dietrich et.al. 1989). The poor relationship between watershed Area and D50 suggests that other factors (sediment) influenced particle sizes.

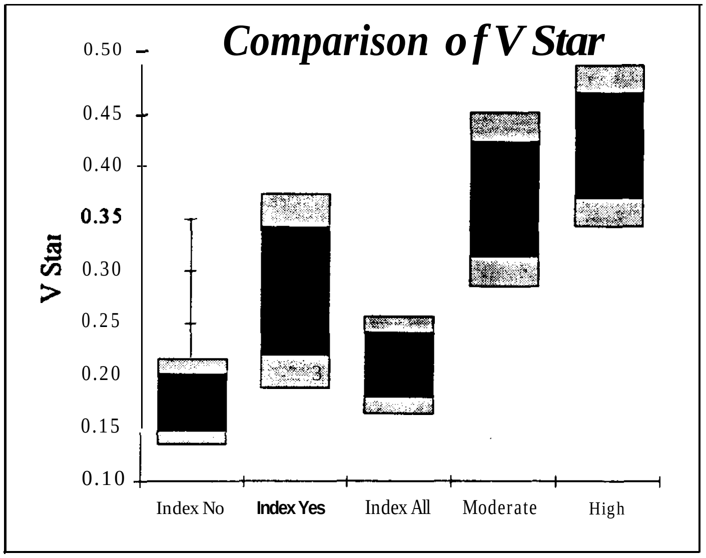
D50 values displayed no correlation with slope in undisturbed watersheds (within the limited range tested), and a very weak relationship in disturbed conditions (Table2). Analysis of a subset of reaches to eliminate area and slope bias, resulted in significant differences between categories with respect to D50 values (Table 3). The differences between categories in the corrected data set implies that the consequences of upslope disturbance exceeded the effects of area and slope differences between categories. Therefore, differences between categories in D50 values were the result of upslope disturbance.

V*

Table 6. V* values by category. V* values represent the proportion of total scoured pool volume that's occupied by fine sediments. Proportions are shown in decimal form.

	Disturbance Category				
V*	**Index No**	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**0.17**	**0.28**	**0.21**	**0.37**	**0.42**
Median	**0.18**	**0.28**	**0.22**	0.31	0.39
Std Deviation	**0.07**	**0.12**	**0.10**	**0.20**	**0.18**
Minimum	**0.07**	**0.14**	**0.07**	**0.12**	**0.12**
Maximum	**0.27**	**0.45**	**0.45**	**0.91**	**0.77**
Count	**12**	**6**	**18**	**21**	**21**

Figure 8. V* values by category. 80 and 95 percent confidence bands around the means are depicted.



Individual reach V* values represented the average of six separate pools. Each category's number of reaches is shown in Table 6. V* measurements exhibited a trend of increasing accumulations of fine sediments with increasing upslope disturbance, indicating that V* was affected by upslope disturbance. 'Index No' and 'Yes' were significantly different from each other at 80 and 95 percent (t-test). 'Index No' and 'Index All' were significantly different from the 'Moderate' and 'High' categories at 80 and 95 percent. The 'Moderate' category was not statistically different from the 'High' category (AOV).

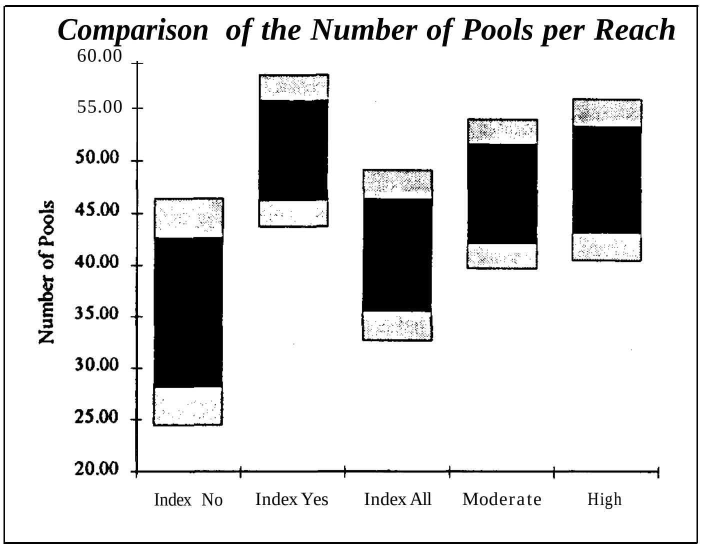
V* values showed a weak relationship with watershed size (Area), in undisturbed conditions and with Slope in disturbed conditions (Table 2). Because differences between categories were apparent with respect to Area and Slope, a separate analysis was done on a subset of reaches that were matched to eliminate bias. The results of that analysis are shown in Table 3. V* values continued to reflect significant differences between categories, which implies that V* values were affected by upslope disturbance and not by differences in Area or Slope between categories.

Number of Pools

Table 7. Number of pools per reach by category.

	Disturbance Category				
No. **of Pools**	**Index No**	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**35.36**	**51.00**	**40.88**	**46.86**	**48.24**
Median	**38.00**	**50.00**	**45.00**	**44.00**	**45.00**
Std Deviation	**18.58**	**9.30**	**17.38**	**17.02**	**18.38**
Minimum	**7**	**39**	**7**	**22**	**23**
Maximum	**64**	**64**	**64**	**86**	**85**
Count	**11**	**6**	**17**	**21**	**21**

Figure 9. Number of pools per reach by category.



The number of pools per 1000 meter reach showed an increasing trend as upslope disturbance increased. The lowest number of pools was recorded in the 'Index No' category (Index reaches with no previous management). There was a significant difference between the 'Index No' and 'Index Yes' groups at 80 and 95 percent. Only the 'Index No' group was significantly different from the 'Moderate' and 'High' categories (at 80 percent). Other possible combinations were not significantly different. These results are unusual and conflict with much of the literature. Part of the results may be explained by the similarity between categories with respect to Woody Debris volumes (discussed later). However, most of these results appear to be explainable by evaluating the effects of differences in Areas between the categories. The Number of Pools per reach correlated strongly with watershed size (Area, r = -0.87). No correlation was evident between Slope and the Number of Pools. When a subset of Area - matched reaches was analysed, no significant differences between categories were noted. Therefore, the observed differences between categories in the complete data set were probably the result of differences in watershed size.

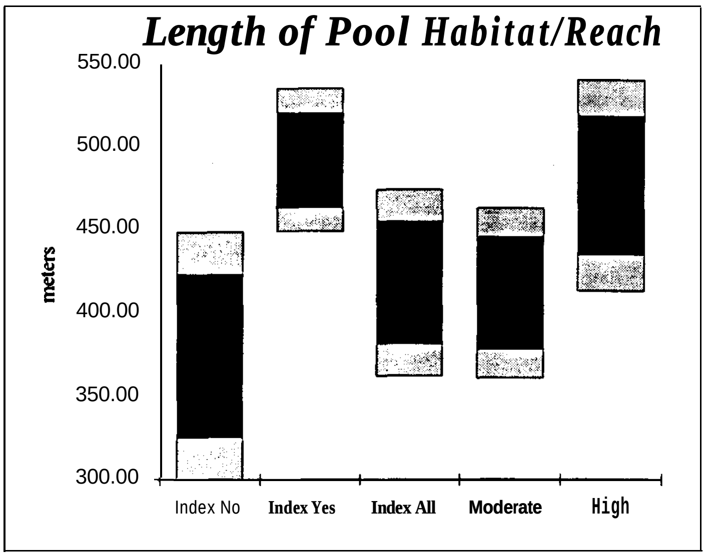
Length of all Pools

Table 8. Comparison of the length of all pools per reach by category. Values are in meters.

Pool Habitat /1000M

	Disturbance Category				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**373.59**	**491.40**	**417.77**	**411.55**	**476.14**
Median	**348.50**	**495.55**	**465.05**	**436.80**	**488.35**
Std Deviation	**120.24**	**54.34**	**114.58**	**119.43**	**145.77**
Minimum	**166.90**	**400.80**	**166.90**	**149.40**	**219.30**
Maximum	**520.20**	**557.70**	**557.70**	**659.10**	**848.00**
Count	**10**	**6**	**16**	**21**	**20**

Figure 10. Comparison of the length of all pools per reach by category. The 80 and 95 percent confidence bands are depicted.



The Length of Pool Habitat, is the summation of the individual pool lengths in a reach. A trend of increased pool lengths with increasing upslope disturbance was evident. The differences displayed in figure 10 between 'Index No' and 'Index Yes' were significant at 80 and 95 percent (t-test). 'Index No' and 'Index All' were both significantly different from 'High' at 80 percent. No other combinations were significant.

Differences in slopes between the descriptive categories were probably responsible for the differences displayed in Figure 10. A moderate correlation existed between Pool

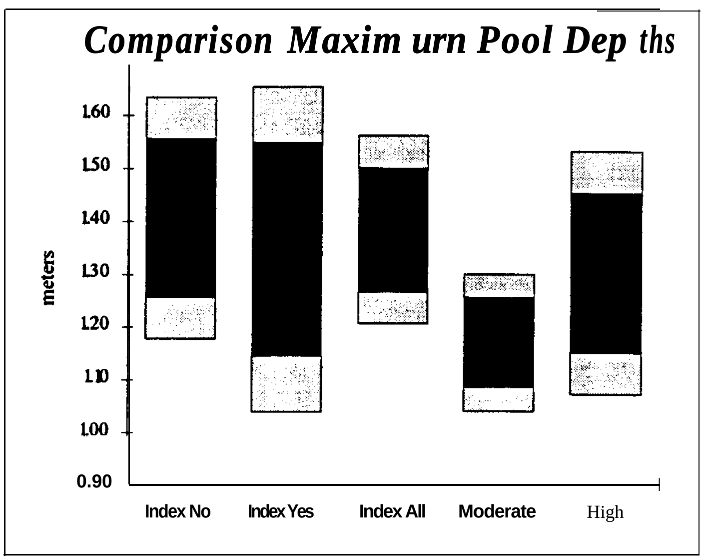
Frequency and Area in undisturbed reaches (r = -0.60), and with Slope in disturbed reaches (r = -0.54). When the Slope - matched reaches were analyzed, no significant differences were observed between categories. Therefore, the differences observed in the complete data set between categories were probably the result of differences in Slopes.

Maximum Pool Depth

Figure 9. Comparison of the maximum depth of pools per reach by category. Values are in meters.

Pool Max Depth	*Disturbance Category*				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	1.41	1.35	1.38	1.17	1.30
Median	1.50	1.19	1.30	1.30	1.25
Std Deviation	0.39	0.39	0.38	0.30	0.54
Minimum	0.70	1.08	0.70	0.62	0.60
Maximum	2.00	2.10	2.10	1.80	3.00
Count	11	6	17	21	21

Figure 11. Maximum depth of pools per reach by category. 80 and 95 percent confidence bands around the category means are depicted.



This graph compares the maximum pool depth from each reach by category. None of the categories were significantly different at 80 percent.

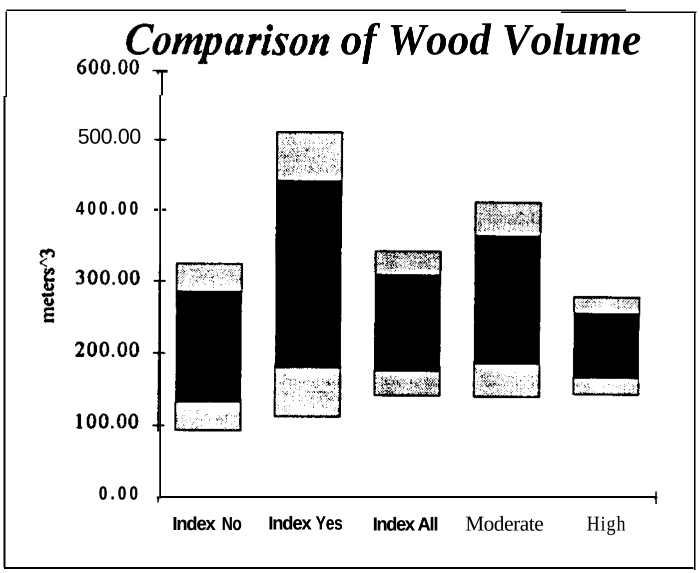
Maximum Wood Volume

Table 10. Wood Volume by category. Values are in cubic meters per 1000 meter reach.

Channel Wood Volume

	Disturbance Category				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**209.42**	**311.64**	**243.50**	**277.78**	**213.72**
Median	**227.06**	**297.90**	**239.70**	**168.58**	**174.50**
Std Deviation	**206.3 1**	**250.17**	**220.01**	**320.13**	**158.65**
Minimum	**9.83**	**46.04**	**9.83**	**13.42**	**41.68**
Maximum	**776.52**	**735.60**	**776.52**	**1244.26**	**639.46**
Count	**12**	**6**	**18**	**21**	**21**

Figure 12. Wood Volume by category. 80 and 95 percent confidence bands around the category means are depicted.



This graph compares the volume of wood within the active low flow channel by category. No statistically significant relationships between categories were evident. Historically, wood had been removed from North Coast streams to improve fish migration (including this studies' Index reaches) and had been added to streams where management or floods have removed it. The result is a fairly uniform distribution of Wood Volume between categories that was less than would occur naturally. Current Wood Volumes averaged about 225 cubic meters per 1000 meters of stream. In several reaches that had not had channel clearing work, the values for wood volume ranged from 800 to 1200 cubic meters per 1000 meters of stream.

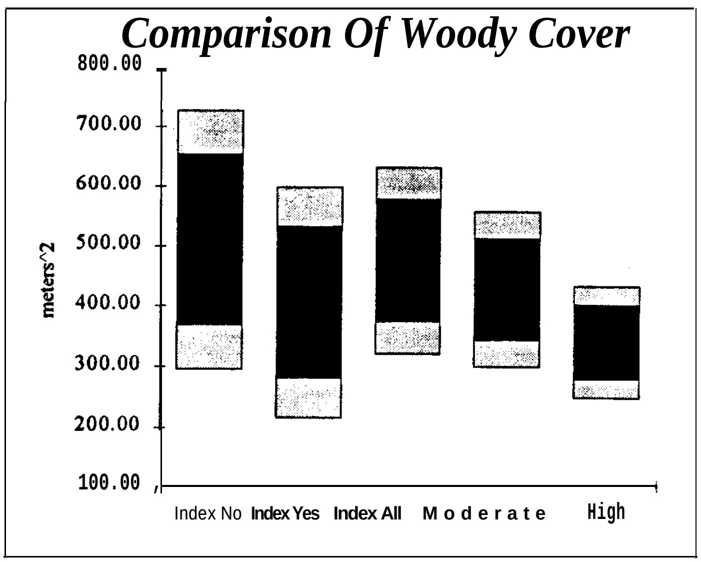
Wood related Cover

Table 11. Cover by category Values are in square meters

Channel Wood Cover

	Disturbance Category				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**511.21**	**406.85**	**476.42**	**428.71**	**341.64**
Median	**434.98**	**399.82**	**424.36**	**385.36**	**286.83**
Std Deviation	**383.68**	**239.76**	**338.71**	**302.83**	**217.47**
Minimum	**82.91**	**96.35**	**82.91**	**86.18**	**73.78**
Maximum	**1300.29**	**724.70**	**1300.29**	**1248.18**	**906.10**
Count	**12**	**6**	**18**	**21**	**21**

Figure 13. Total area of Cover provided by woody debris, by category. 80 and 95 percent confidence bands around the category means are depicted.



Cover associated with in-channel woody debris was determined by measuring the hypothetical shadow cast on the channel by the wood from an overhead light source. It was reported as a total for each 1000 meter reach. Although a trend of decreasing cover with increasing upslope disturbance was evident, none of the differences are statistically significant at 80 percent. The variable Cov/Vol (Cover divided by Wood Volume) is discussed to address Cover independently from differences in Wood Volume between categories.

Wood related Maximum Pool Depth

Table **12.** Maximum depth of Pools associated with woody debris, by category. Values are in meters.

Depth Wood Debris Pools

	Disturbance Category				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High'**
Mean	**1.25**	**0.90**	**1.11**	**1.04**	**1.00**
Median	**0.95**	**0.93**	**0.95**	**0.88**	**1.00**
Std Deviation	**0.74**	**0.20**	**0.60**	**0.57**	**0.32**
Minimum	**0.60**	**0.60**	**0.60**	**0.42**	**0.33**
Maximum	**2.95**	**1.10**	**2.95**	**3.00**	**1.50**
Count	**9**	**6**	**15**	**20**	19

Figure 14. Comparison of the Maximum Depths of Pools associated with woody debris by category. 80 and 95 percent confidence bands around the category means are depicted.

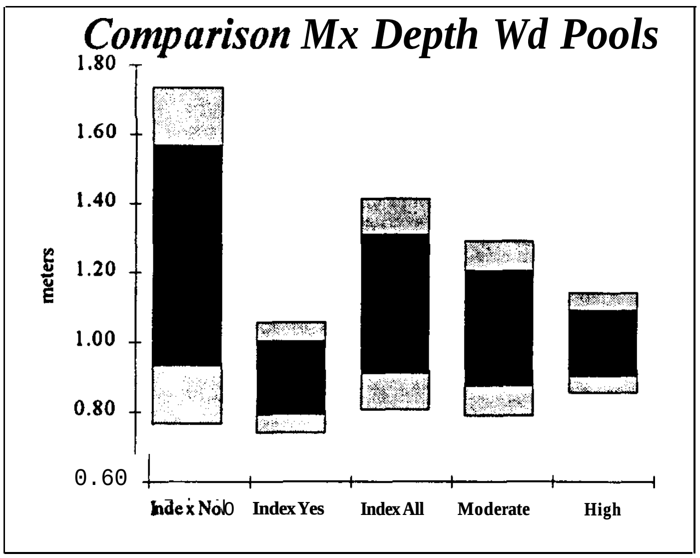


Figure 14 compares the Maximum Depth per reach of pools associated with woody debris. There are no statistically significant differences between the means, but a trend of decreasing variability was evident as upslope disturbance increased. Other variations, (not shown), such as Depth of the 85th percentile pool, were also evaluated with similar results.

Wood related Pool Volume

Table 13. Volume of Pools associated with woody debris, by category. Values are in cubic meters.

Pool Volume Wood Debris

Disturbance Category

	Index No	Index Yes	Index All	Moderate	High
Mean	**104.09**	**136.79**	**117.17**	**67.00**	**91.47**
Median	**87.10**	**120.28**	**106.40**	**52.16**	**55.90**
Std Deviation	**74.80**	**103.93**	**85.61**	**55.02**	**90.86**
Minimum	**4.80**	**33.74**	**4.80**	**3.64**	**1.20**
Maximum	**260.18**	**328.35**	**328.35**	**176.43**	**3 16.50**
Count	**9**	**6**	**15**	**20**	**18**

Figure 15. Comparison of the **average Volume** of Pools associated with woody debris by category. 80 and 95 percent confidence bands around the category means are depicted.

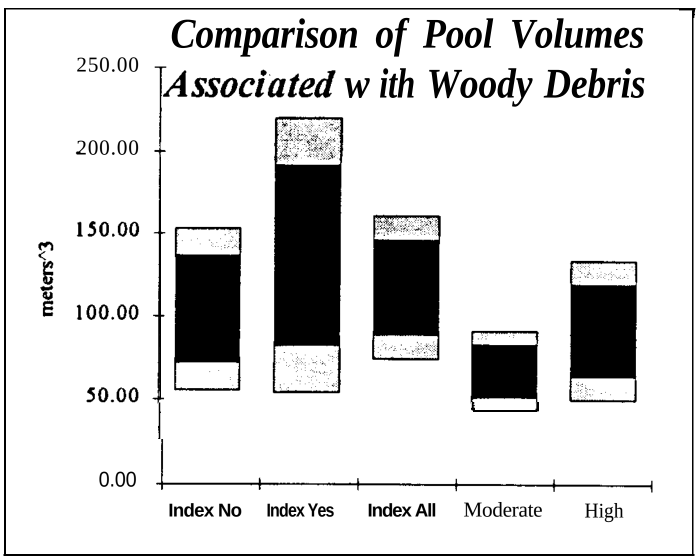


Figure 15 displays the average Volume of Pools associated with woody debris, by category. A slight trend of decreasing volume with increasing upslope disturbance may be reflected. None of the differences are statistically significant at 80 percent. Woody debris pools were excluded from the V* sample.

Wood related Substrate Change

Table **14.** Substrate Change associated with woody debris by category. Values are in square meters.

Substrate Change Wood Debris

	Disturbance Category				
	Index No	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	**750.44**	419.00	617.87	216.24	153.83
Median	**486.00**	**429.58**	**458.50**	**134.10**	**143.46**
Std Deviation	**1029.95**	**298.21**	**816.20**	**197.90**	**101.45**
Minimum	**0.00**	**39.00**	**0.00**	**0.00**	**0.00**
Maximum	**3403 .00**	**839.00**	**3403 .00**	**704.00**	**377.00**
Count	**9**	**6**	**15**	**20**	**18**

Figure 16. Comparison of the change in substrate associated with woody debris by category. 80 and 95 percent confidence bands around the category means are depicted.

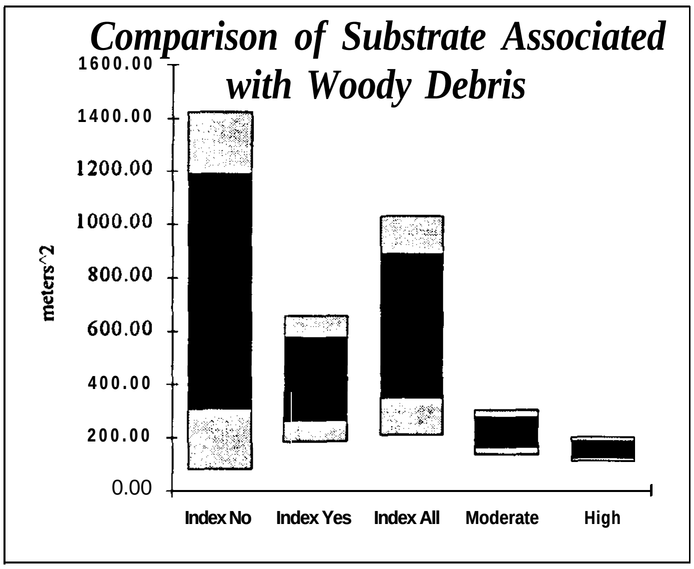


Figure 16 reflects changes in channel substrate associated with woody debris. Both deposition and coarse substrate revealed by scour were included. A trend of decreasing variability with increasing upslope disturbance was evident. The 'Index All' category was significantly different from the 'Moderate' and the 'High' category at **80** percent and from the 'High' at 95 percent. 'Index All' was significantly different from the 'High' category at 80 and 95 percent. The variable Sub / Vol (Substrate change divided by Wood Volume) was discussed to evaluate substrate differences independently of wood volume.

When Substrate Change was evaluated in the Slope corrected reaches, no significant differences were observed, therefore the differences discussed above are assumed to have resulted from unintentional differences in Slopes between categories.

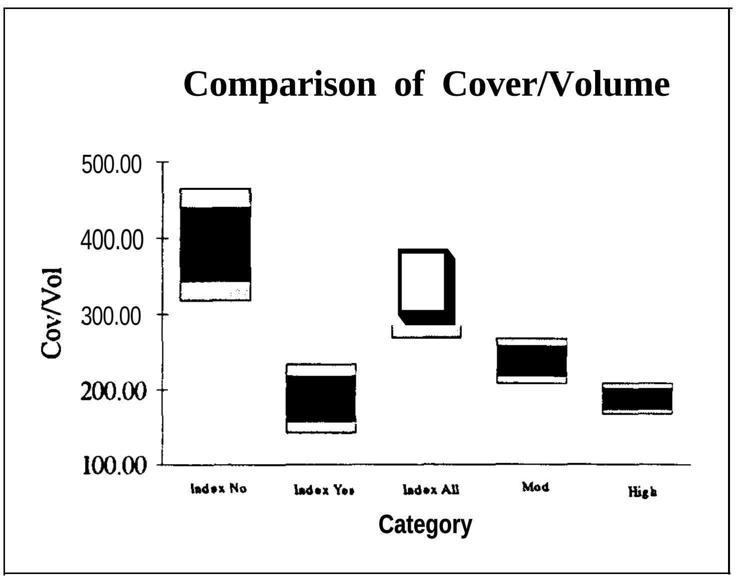
Wood related Cover/Volume

Table 15. Cover associated woody debris divided by Wood Volume per reach multiplied by 1000 (m^2/m^3 * 1000).

	Category			
Cover/ Volume	**Index No**	**Index Yes**	**Mod**	**High**
Mean	391.48	187.38	237.05	187.35
Median	**339.38**	185.92	**208.50**	168.89
Standard Deviation	263.08	115.23	142.67	99.00
Minimum	140.64	54.05	82.51	64.63
Maximum	925.67	367.42	642.18	557.52
Count	12	6	21	21

Cover/Volume is a composite variable Wood Cover divided by Wood Volume (Cov/Vol). The 'Index No group is significantly different from the 'High' group at 95 percent. At 80 percent confidence, the 'Index No' group is significantly different from the 'Index Yes', 'Moderate' and 'High' groups.

Figure 17. Wood associated Cover divided by Wood Volume, by category.



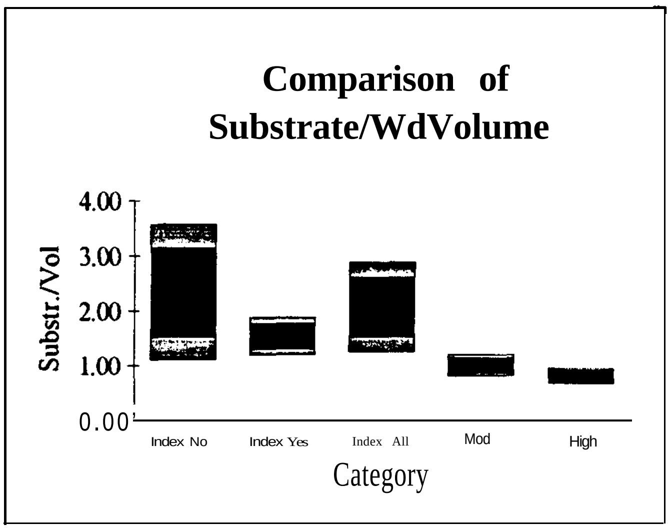
The ratio of the Cover / Wood Volume decreased as the amount of upslope disturbance increased (Figure 17). Increased sediment may reduce the natural variability with respect to the Cover / Volume ratio, while lowering the overall quantity of Cover that any given volume of wood in a channel provides. However, when Cov / Volume was compared in the Area - corrected data set, no statistically significant relationships were evident. Therefore, it was assumed that the differences shown in Figure 17 were primarily the result of differences in watershed size between categories and not as a result of differences in upslope disturbance.

Wood related Substrate Change/Volume

Table 16. Substrate Change associated with woody debris divided by the Volume of woody debris, per category (m^2/m^3).

Substrate/Volume	Category				
	Index No	Index Yes	Index All	Mod	High
Mean	2.33	1.53	2.06	1.00	0.81
Median	0.93	1.43	1.23	0.61	0.74
Standard Dev	4.38	0.88	3.57	0.94	0.71
Minimum	0.00	0.47	0.00	0.00	0.00
Maximum	15.77	3.11	15.77	3.3 1	2.41
Count	12	6	18	21	21

Figure 18. Comparison of Substrate Change divided by reach Wood Volume. 80 and 95 percent confidence bands around the category means are depicted.



This data provided a comparison of changes in Substrate associated with Woody Debris independent of the total Volume of wood in each reach. Differences in Substrate caused by woody debris appear to have decreased as the sediment supply to the channel increased.

No significant differences between categories were evident in the Area - Slope corrected data sets with respect to Substrate / Volume. Therefore, the differences shown in Figure 18 between categories were due to differences in Slopes or Areas between the categories and not as a result of upslope disturbance.

Effect of Historical Management on Background

The 'Index' category was intended to identify the most natural conditions available. Streams with management at least 40 years old were included only after all unmanaged reaches had been sampled. Six reaches were used that did exhibit past management and 12 mostly undisturbed reaches were used[3]. Even to the experienced observer, these six streams appeared to be in good condition. However, we were surprised to find that significant differences existed between the Index reaches with no previous management (Index No) and the six with prior management (Index Yes). The relative recovery between the 'High' reaches and the 'Index Yes' reaches as compared to the 'Index No' reaches were as follows: RASI 30% recovery, D50 22% recovery, and V* 56% recovery.[4] The high background (Index Yes), was probably the result of historical practices that produced massive changes to the morphology of most North Coast rivers. Current practices as a group (either the 'Moderate' or the 'High' category) were not normally distinguishable from the background as evidenced by the finding that the 'Index Yes' group was not significantly different from the 'Moderate' or 'High' groups for any variable. However, individual reaches that exhibited poor implementation of current Forest Practice Rules or BMPs tended to exhibit values at the extreme end of the observed range. The separation of individual reaches into meaningful groups is discussed further in the section "Determination of Habitat Condition".

Summary of the utility of variables to reflect upslope disturbance related habitat condition.

Three variables displayed significant differences between upslope disturbance categories that were attributable soley to differences in disturbance. They were, in order of their ability to detect differences between categories (based on the discriminate analysis), RASI, V* and D50. Other variables evaluated here may still eventually prove to be useful, however greater resolution in local slopes and attention to matching watershed sizes between controls and affected reaches will be necessary.

3Several reaches initially classified as Index were found to have had management in them that required that their classification be changed to 'Moderate'. Therefore, only 18 reaches were included in the Index Category. One Index No reach was retained in that category despite several cable logged units, while others with ***old*** harvest evidence were shifted to the Index Yes category. The decision point for which index category a reach belonged in was evidence of historic logging practices.

4The term 'recovery' does not imply recovery from past impact, rather recovery relative to the High category. Past impacts, such as using stream channels for road beds, etc. created devastating disturbances from a habitat perspective, that probably would yield results considerably more severe than what we measure today.

Determination of Habitat Condition

This section strives to answer the last question posed in the objectives; How could these results be applied in a regulatory framework? A discriminate analysis uses the range of variation in multiple habitat variables to differentiate groups of similar values. The number of groups is specified by the user. The first question to be answered with a discriminate analysis was can the data from the 'Index No' category (index reaches with little previous management) be delineated from the 'High' category based on the data. Use of these two groups seeks to differentiate between *unaffected* and *affected* reaches. The analysis did not try to analyze three groups because the premise for the 'Moderate' category, that reaches were available that exhibited effects from current practices only, was clearly not realistic given the high background associated with historic harvest activity. The 'Moderate' category reflects an unknown blend of current practice impacts, and past, continuing impacts.

Affected vrs Unaffected

The discriminate function for the differentiation of *affected* vrs *unaffected* reaches was based on V*, (the volume of fine sediments per the total scoured pool volume), and RASI or Riffle Armor Stability Index. V*, RASI and D50 were available for the analysis, but only V* and RASI met the analysis' selection criteria. A "Discriminate Score" combines the data from two variables (in this instance), into a continuous linear function. A separation between categories is defined which serves to distinguish "Unaffected" from "Affected" reaches. The equation that defines the Discriminate Function is shown in Equation 1.

Equation 1. Linear discriminate function for the identification of Affected and Unaffected fish habitat.

$$\text{Discriminate Score} = 2.36 * (V^*) + 0.064 * \text{RASI} - 5.17 \quad r = .73$$

Where V* is in decimal form (V* = 0.23, represents 23 % of the total scoured pool occupied by fine sediment for example), and RASI is used in a percent form (RASI values range from approximately 50 to 95).

Discriminate scores smaller than -0.294 represent membership in the Unaffected group, while scores greater than -0.294 belong in the affected group.

This discriminate function correctly classified 88 percent of the 33 reaches in the 'Index No' and 'High' groups, based upon their initial subjective classification. Of the 27 reaches in the 'Moderate' and 'Index Yes' groups that were not used to determine the discriminate function, 8 were classified as unaffected (3 'Index Yes' and 5 'Moderate'), and 19 affected.

This procedure is applicable to headwater, coastal Californian streams within the Franciscan Geology, exhibiting slopes from 1 to 4 percent (reach averages) with channel substrates of coarse gravel to small cobbles. By measuring V*, RASI and D50s, new reaches can be categorized in the context of this data. The discriminate function offered in this study is not a complete answer to the question of whether a given stream reach has been adversely affected or not. These results must be applied in the context of a thorough understanding of all relevant processes that might affect habitat condition. Only then should professional judgement be used to evaluate the relevance of the habitat's structural configuration.

A simpler assessment is possible by comparing the data from new reaches with the baseline developed here. The following graphs, (Figure 19 - 27) are the cumulative frequency distributions for each of the variables measured in this study. New sample data can be directly compared against the distribution to determine the relative position of the data to yield a semi quantitative comparison. Determinations of habitat condition should be restricted to V*, RASI and D50. The other variables are included to provide context. Test data should be evaluated in the context of baseline slope and drainage area when evaluating pool and woody debris variables.

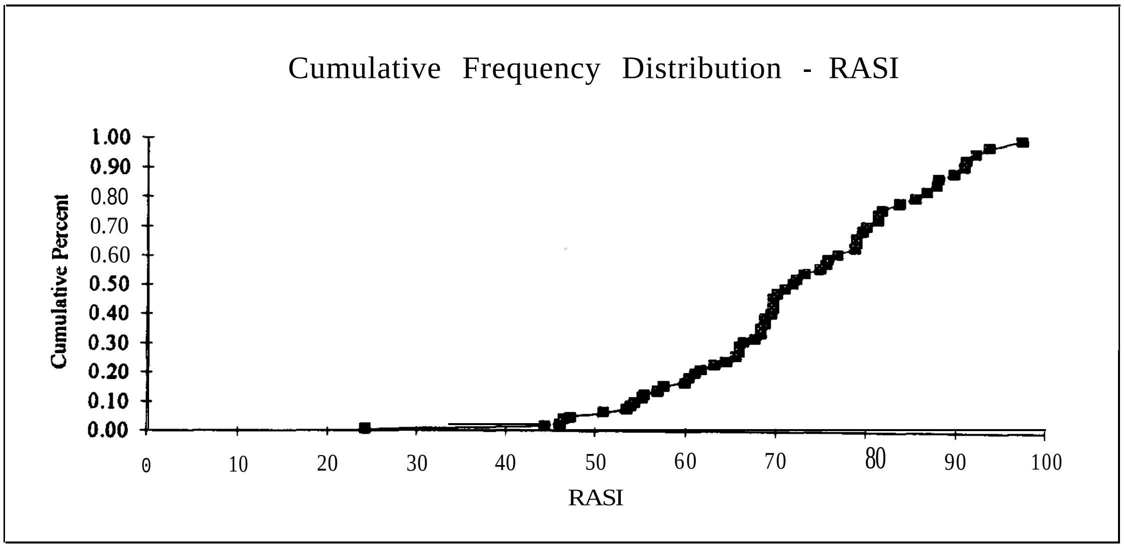


Figure 19.

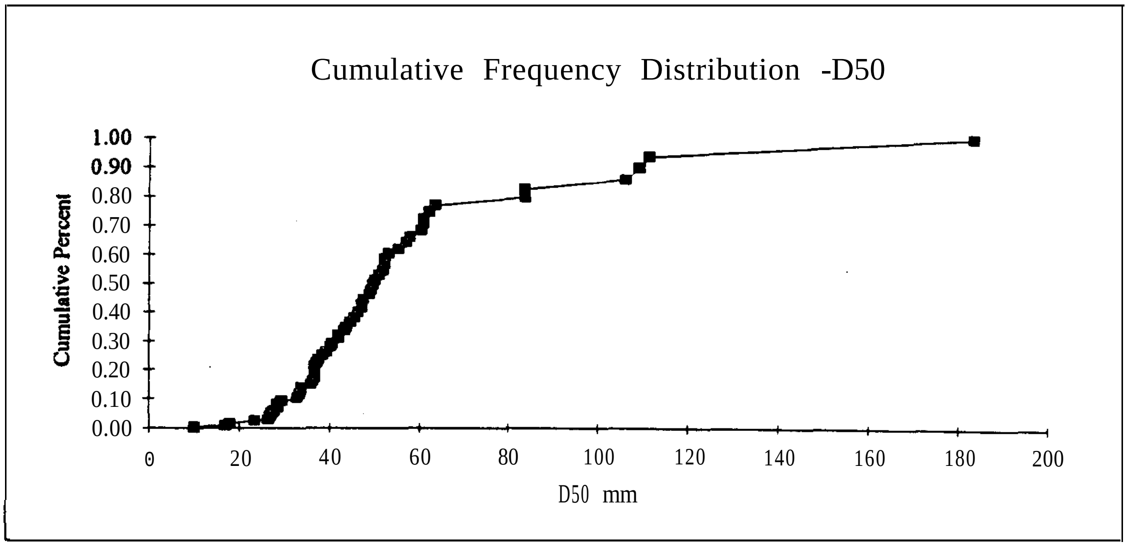
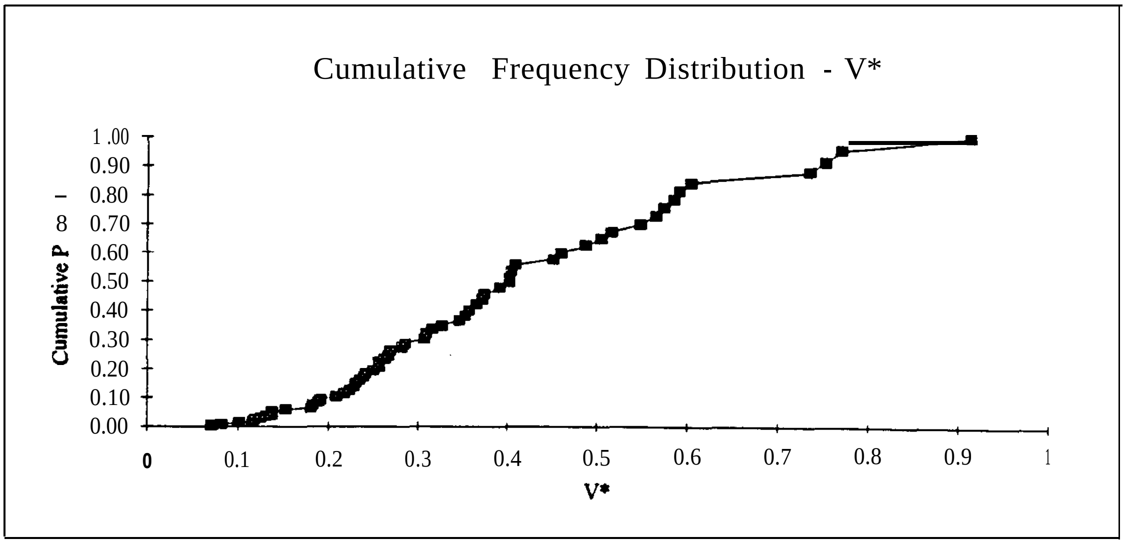


Figure 20.



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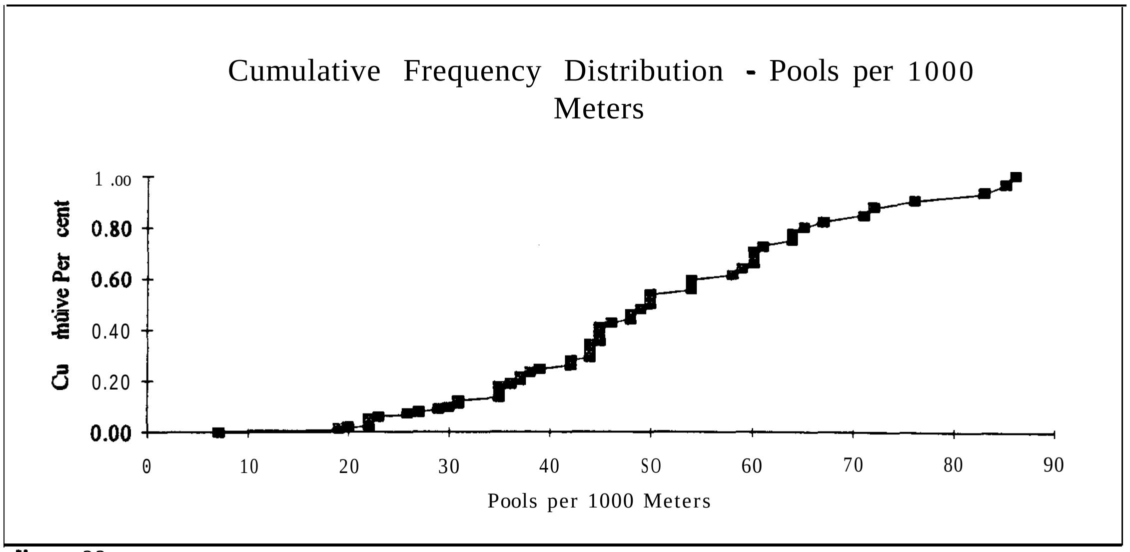

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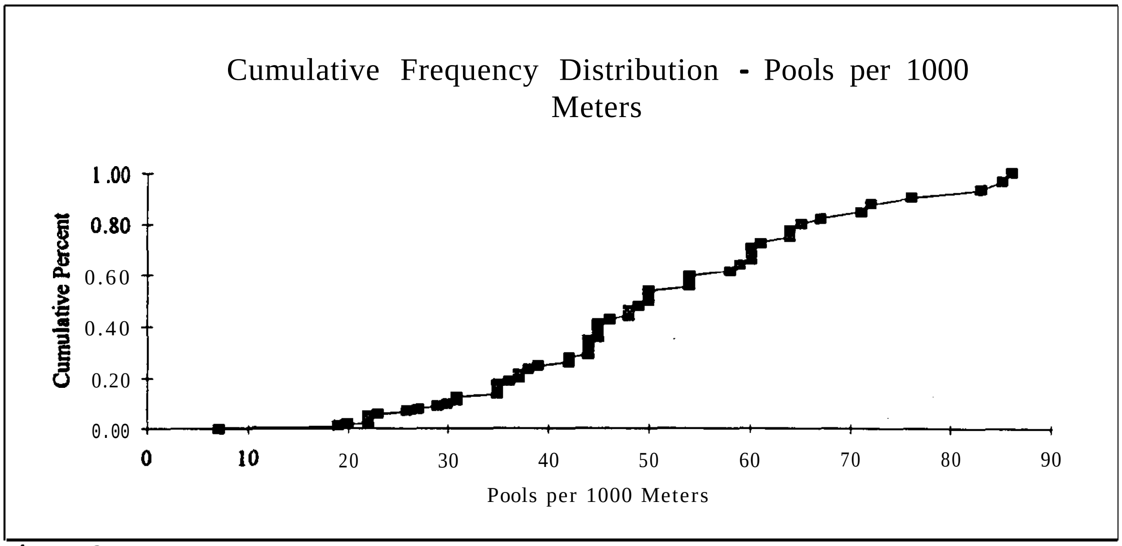

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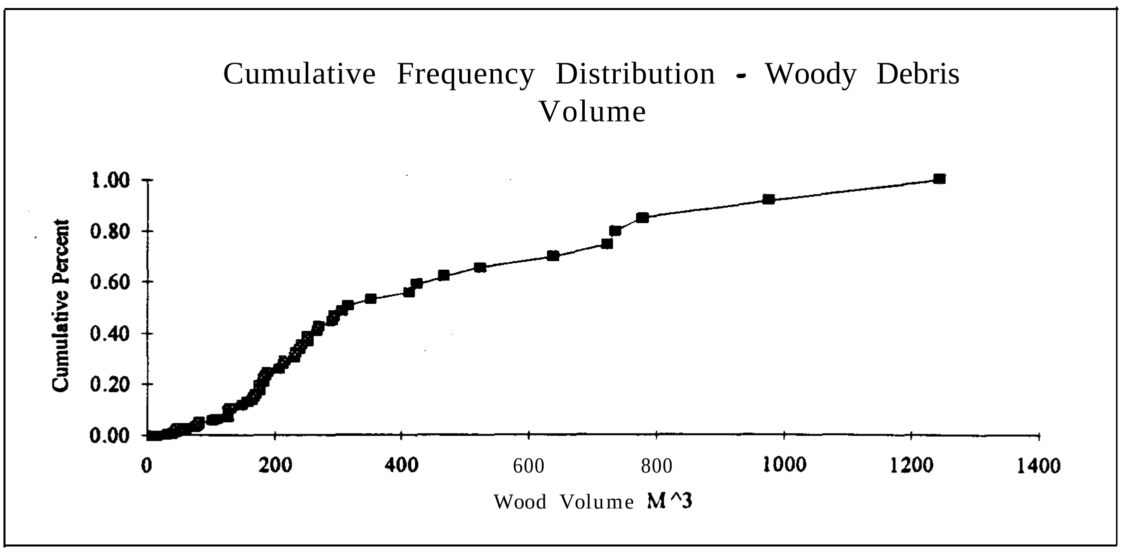
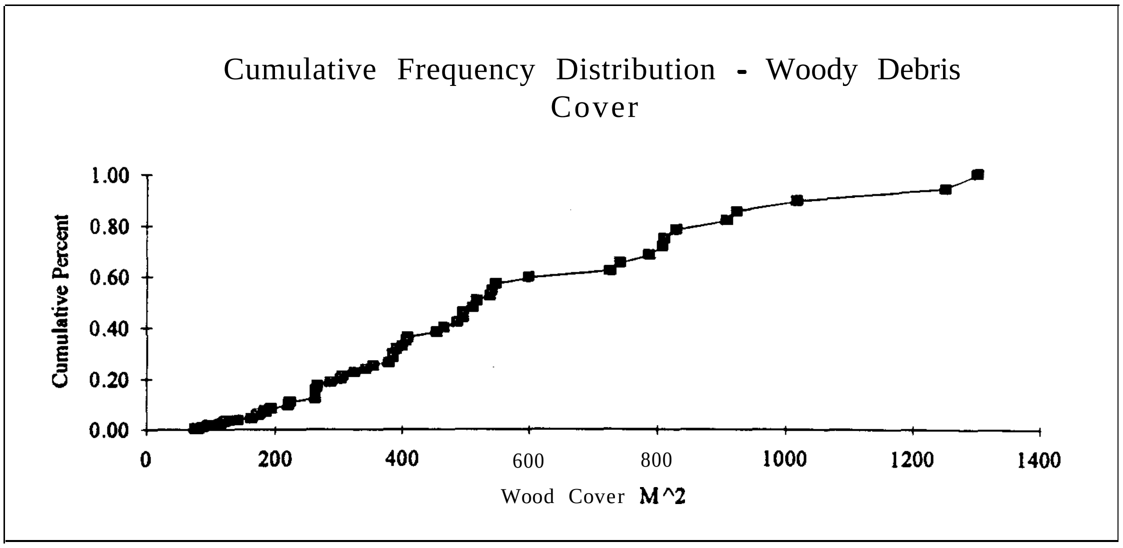


Figure 24.



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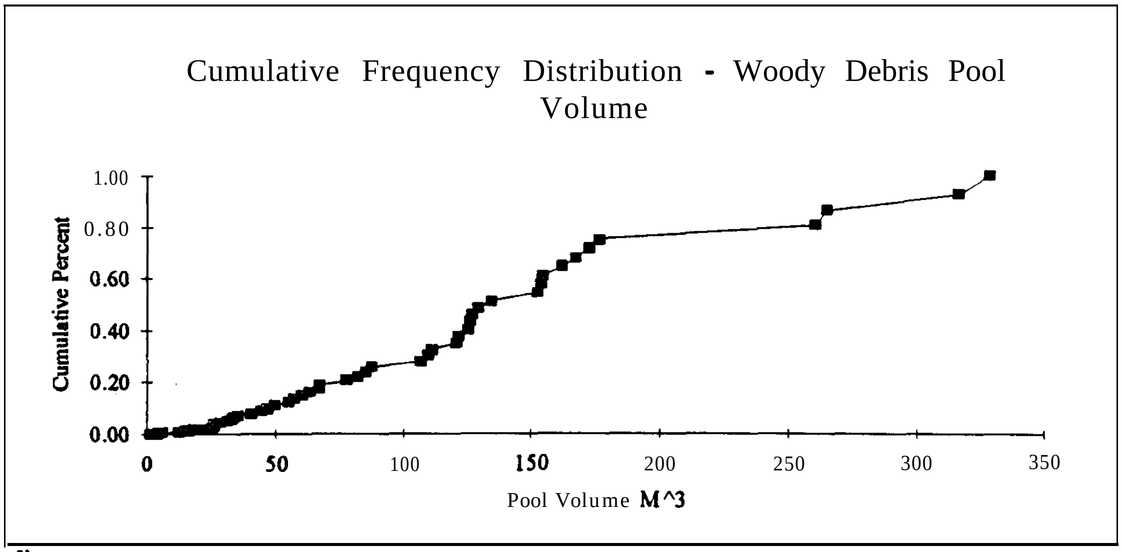

'igure 26.

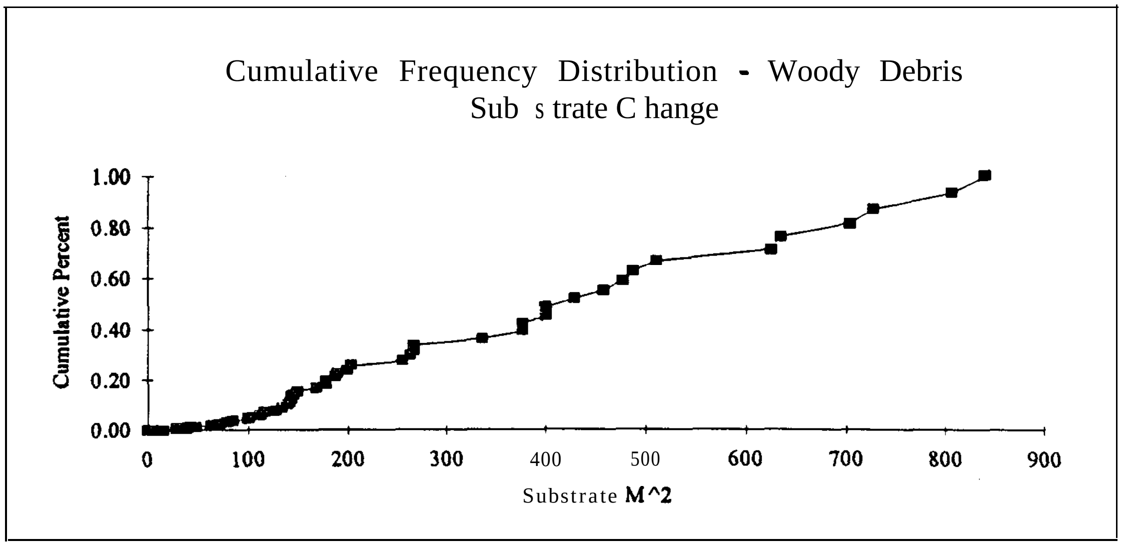

Figure 27.

Conclusions

The results from this study demonstrate that three aspects of habitat are influenced by upslope disturbance, are quantifiable, and can serve as a basis for assessing habitat condition. Based on the results of a point in time measurement of 60 forested watersheds, sediment generated from upslope disturbance has had a measurable effect on the structure of the aquatic habitat with respect to the following:

1) The variables RASI, D50, and V* show statistically significant differences between descriptive categories of upslope disturbance. RASI and V* can serve to distinguish between *affected* and *unaffected* habitat when applied in a discriminate equation (Equation 1). The discriminate analysis, used with professional judgement, could serve as a regulatory tool to a) prioritize restoration projects b) define sensitive watersheds, or c) evaluate the aggregate effectiveness of forest management rules. Simple comparisons between target reaches and the baselines (cumulative frequency distributions) associated with individual variables may serve the same purpose.

2) The ranked order of variables, relative to their utility to define differences in habitat condition were; RASI, V* and D50, (Based on the discriminate analysis which selects variables that maximize the (Between-groups sum of squares/Within-group sum of squares)).

3) Higher levels of upslope disturbance correlated with increased volumes of fine sediments deposited in pools, with a corresponding reduction in pool volume, from 17 percent fines in undisturbed reaches to 42 percent in reaches where the watershed was classified as having a 'high' level of upslope disturbance.(V*).

4) Higher subjective ratings of upslope disturbance correlated with a finer composition of riffle substrates, from a mean D50 of 81 mm in undisturbed reaches (Index No) to a mean of 38 mm in reaches with a 'High' level of upslope disturbance. RASI values also reflected significant changes with different levels of upslope disturbance ranging from a mean of 53 in 'Index No' reaches to a mean of 77 in 'High' reaches.

5) Recovery rates (relative to the High category, true recovery from historic impacts are unknown), are different for different aspects of habitat condition. The relative recovery for the 3 useful variables was; V* 56%, RASI 30% and D50 22%. (This is based on a comparison between 12 'Index No' reaches and 6 'Index Yes' reaches).

6) Index reaches with historic logging in the contributing watershed exhibited habitat values that were statistically indistinguishable from the reaches in the High category, and were significantly different from Index reaches with no previous management. It is likely that the effect was due to residual sediment generated from the initial logging, which in most cases occurred 40 to 80 years earlier. Fish habitat within reaches categorized by the 'Moderate' and 'High' groups was not statistically different from the background of historical logging (Index Yes). Decreased habitat quality in the 'High' category compared

to the ‘Moderate’ category, may be due to poor individual applications, reuse of low slope roads constructed during the initial logging or as a result of erosion associated with current practices. Based on the assumptions used to separate the categories, the most likely explanation for the differences are a combination of poor individual applications (mistakes) and the reuse of old, low slope roads on second entries. This conclusion should be viewed in the context of a small sample size (6 ‘Index Yes’ reaches).

The type of management that caused widespread modification of instream habitat prior to passage of the Forest Practices Act is history now. Roads are not built up stream channels or logs transported downstream with splash dams. Yet as evidenced by the differences between the Index reaches with old management and Index reaches with no prior management, those effects appear to be still influencing habitat quality today. Also, the data presented here is discussed in terms of averages. Not all reaches selected for inclusion in the ‘High’ category exhibited values that suggest adverse impacts. Conversely, several Index reaches in the no prior management category, do exhibit values that imply low quality habitat.

Recommendations

The results form this study demonstrate that three aspects of habitat are influenced by upslope disturbance, are quantifiable, and can serve as a basis for assessing habitat condition. The structural variables evaluated here are likely to be applicable throughout the North Coast Region in different geologies, although new baselines will need to be established. Within other geologies, where climatic regimes and vegetation are different from this study, additional variables should be investigated that best fit the circumstances. Utilization of this information could serve to focus habitat restoration needs, determine sensitive watersheds, monitor watershed recovery or evaluate the aggregate effectiveness of forest management practices.

Some specific recommendations are:

Future studies should initially concentrate on identifying the Index reaches without prior management before measuring any reaches in disturbed watersheds. Reaches in managed watersheds should be matched to the Index reaches to eliminate unwanted variability in slopes or areas. More accurate and precise measurements of slope would serve to expand these conclusions to dissimilar reaches.

Additional work is needed to evaluate the effects of historic logging on current habitat condition. The ‘Moderate’ category should be dropped and replaced with the ‘Index Yes’ objectives. Future studies should have the following categories; ‘Index’ reaches without previous extensive disturbance, reaches with only ‘Historic’ disturbance and no recent (40 years) disturbance, and ‘High’ reaches with very high upslope disturbance. The purpose should be to define the range of instream conditions and the residual effects of historic management.

State agencies should combine their expertise to define the relationships between structural habitat characteristics discussed here, and their influence on aquatic productivity. The immediate needs are:

1) Continue to evaluate habitat conditions in the remaining geologies within the Region (Granitics and Metasediments).

2) Determine the extent of change that short term climatic variation has had on the range of values measured in this study. (Has the recent wet winter affected the balance between categories, since the measurements in this study represent conditions after 5 to 7 years of drought).

3) Determine what effect changes in the structural elements of aquatic and riparian habitat have upon dependent aquatic populations. (Do the differences in habitat condition translate into differences in productivity?) Are the structural variables measured in this study, true indices of fish habitat condition?

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APPENDIX A
Sampling Methods

Sample Stratification

Sample locations were stratified by geology, channel slope and channel substrate. In this study, sample sites were limited to areas of Franciscan geology, slopes from 1 to 4 percent and coarse gravel to small cobble substrates. Different variables are possible in different geologies. If variations are contemplated, they should be selected to better reflect areas of local importance to fish and areas susceptible to sedimentation. Coordination with the North Coast Water Quality Control Board is recommended to allow compilation of an integrated data base (707-576-2220). Slopes should be determined with a level or transit and not with a clinometer or altimiter (as was done here). When multiple reaches met our selection criteria, priority for selection was given to the headward reach. If these occured too high in the drainage to yield good fish habitat, then reaches were selected to maintain approximately 3 to 5 square mile drainages. Some flexibility for access considerations was necessary, but generally the headward reach can be identified on the U.S.G.S. Quad sheets.

Temporal Variability

This project was designed to allow sampling during the summer low flow period. On the North Coast, the sampling period normally extends from late may through October. Variables included in this study were expected to remain stable during this period and not require further temporal stratification.

Changes may be expected to occur in V* or RASI over a longer time frame of several years as normal dry and wet cycles occur. Some reference testing should be anticipated following a runoff event with a 5 to 10 year return interval to evaluate the effect of climatic cycles on these habitat indices. Ideally, if these indices do show variability with climatic trends, then a resampling during a wet cycle would serve to define the range of likely conditions.

Sample collection

The following section discusses each of the variables selected for this study and the methods used to measure them. Many other variables were considered but were eliminated for a variety of reasons which included a lack of relevancy to anadromous fish, unresolved problems with sample collection, sampling at a time when access was poor, the number of samples required was too great, or for cost considerations. Finally, the list was ultimately reduced by the need to keep the project manageable. It is likely that in circumstances other than those present in the North Coast Planning Basin of California, that different variables would serve equally or better than the ones displayed here. However, these variables represent our best estimate of how to quantify the condition of instream cold water fish habitat on the North Coast of California.

V*, Fine Sediment Vol./Total Pool Vol.

V*, the volume of fine sediment in pools divided by the total scoured volume of a pool was developed to assess the supply of fine sediments being transported in a stream system (Lisle and Hilton, 1992). The volume of fines deposited in a pool are believed to reflect the total sediment transport occurring, because as high flows subside, fine sediments are selectively transported from zones of high shear stress and deposited in zones of low shear stress, such as pools (Lisle and Madej, in press). Increases in the amount of fines deposited in a pool can occur as a result of a change in the particle size of the load normally transported to one exhibiting finer grain size, or as a result of an increase in total sediment supply (Dietrich et al., 1989). In this study, the importance of V* was viewed in relation to changes in pool volume and its effects on aquatic productivity.

The quantity of fines in a pool were determined easily with an incremented probe applied over several transacts to represent the morphology of the pool.

Sampling Technique

Pools tmonitored were identified as follows: 1) locate the upstream extent of perennial channel exhibiting the desired slope characteristics. 2) Moving downstream, select the first 6 pools that meet the selection requirements. Residual pool volume would be determined from 15 to 50 soundings along 4 to 8 taped transacts aligned perpendicular to a tape stretched along the pool axis. Riffle-crest depth was determined by averaging several samples in the thalweg. This is necessary since the crest was often indistinct.

Selection Criteria

Pools were selected in order from the top of the reach moving downstream. The first 6 pools that met the selection criteria were measured. Pools were defined as a water volume which:

1) has a nearly horizontal water surface (slope $< .0005$ during low flow, (a smooth water surface will suffice),
2) occupies the main part of the channel,
3) has a maximum residual pool depth equal to at least four times the water depth at the downstream riffle crest during low flows. Lisle used 2 times the riffle crest depth, but this was increased for this study to a) reduce the variability Lisle found in small pools and, b) to better reflect the larger pools which are more important as fish habitat. [5]
4) The pool could not be formed as a result of woody debris.[6]

The volume of fine sediment, water depth and maximum pool depth were measured with a 0.5 in. diameter, graduated steel rod. Abrupt changes in resistance as the rod penetrated the gravel indicated larger bed material and the interface with the coarser substrate. Only sediment located at equal or lower channel elevations than the riffle crest was included in the calculated volumes.

RASI

RASI represents the surface particle size distribution within a riffle relative to the size of material normally transported by bankful flows (Kappesser 1993). It is the cumulative percent of the riffle substrate that's less than or equal to the size of the largest mobile particle on the riffle's surface. Increased quantities of fine particles on a streambed's surface are thought to represent a channel that is transporting a high sediment load (Platts and Megahan 1975, Lisle 1982). Dietrich reported that the surface layer may increase its percent of fine sediments solely as a result of an increased supply of sediment, even when the particle sizes being transported remain constant. Therefore, the amount of fines in the riffle bed compared to the largest mobile particle in the stream is believed to represent the current dynamics of a channel's sediment transport process, providing a sensitive, quantitative evaluation of whether the stream is agradding or degrading (Kappasser 1993).

Reviewers have pointed out that use of a pool's riffle crest depth is an inconsistent criteria for pool selection. Changes in flow levels will result in different riffle crest depths which, will in turn, affect whether an individual pool is selected. A better choice would be residual scoured pool depths based on flow, or watershed area as a proxy for flow. An estimate of sampling criteria might be watersheds < 1280 acres, residual scour depth should be greater than 30 cm. Watersheds from 1280 acres to 3200 acres, scour depths must exceed 40 cm before a pool is included in the measurements. Streams with contributing areas exceeding 3200 acres should exhibit a residual scoured depth greater than 50 cm. These estimates should provide consistency with the data collected for this study, however, time limitations don't allow a more accurate assessment.

[6] Since woody debris was a primary variable, we sought to maintain as much independence between variables as possible, and as a result did not sample V* in pools formed by woody debris.

Site selection:

Riffles should be selected to represent a section of stream a minimum of 3 channel widths long with a uniform bed slope, composition and channel width. Riffle sections with depositional features from dammed pools or mass failures should be avoided.
Three riffles per reach were measured.

Sampling:

The RASI number was determined with two separate measurements:

1) Surface composition is estimated with a modified Wolman pebble count. A riffle transact is established within the bankfull channel and 200 individual measurements of the size of the bed material are made. The particle size data is tallied by Udden-Wentworth size classes. A 200 count is used instead of the more usual 100 count, because the RASI method interpolates between categories, which requires a greater reliability within individual classes.
2) The largest particles available for seasonal transport are determined by measuring the 30 largest cobbles found on an adjoining point bar or by measuring the largest mobile particles directly from the riffle. The geometric mean of the sample collected to determine the largest mobile particle is then compared to the riffle distribution to determine what cumulative percent of the riffle is equal to or finer then the largest mobile particle. The percent of the bed that is finer than the bar count's geometric mean is the RASI number. RASI values normally range from 50 to 100, with high range numbers reflecting a riffle with a high surface fine composition (normally considered adverse) and low numbers indicating a bed with few fines. It has been postulated by Kappesser, that the bar count represents the largest size transported at bankfull, and that it reflects a unique hydraulic characteristic of the watershed's streams. However, little impirical evidence exists to support or discredit this theory. Data collected in Idaho and in California (from this study) do result in values that vary with upslope disturbance so as to suggest that this approach is measuring an aspect of the riffle composition that does vary with sediment loads. Additional work is needed to explain this.

The RASI method is sensitive to the determination of the largest mobile particle size. Two methods are presented here for it's determination; 1) to quantify in reaches with recent alluvial deposits and 2) to allow quantification in channels with few recent deposits.

1) Determination of the largest mobile substrates from depositional features:

The largest mobile particle size should be collected in a recent depositional feature that is proximate to the riffle used for the pebble counts, Features adjacent to the riffle are ideal. Care must be taken to ensure that the feature contains a blend of size classes in order to allow a meaningful selection of the largest particles available for annual transport. Features that exhibit a confined range of size classes, such as sand bars, should be avoided.

Measure the intermediate axis of the 30 largest sized particles that are clearly part of the recent deposition. In shallow deposits, care must be taken to avoid sampling cobbles that are part of the less mobile bed, or features deposited as a result of major flood events. If 30 particles of approximately the same size class are not present in a deposit, select another proximate feature and continue there. Do not start selecting successively smaller sizes as the largest class is measured. Particles with a flat or platy profile should also be avoided.

2) Determination of the largest mobile substrates from the riffle:

This approach should be used when fresh depositional features are not present in a reach. The objective is to select the *largestparticles that are annually mobile.* Selection of rocks to represent the largest annually mobile substrates should be based upon the following:

- Riffles in Rosgen B or C channels are desirable for sampling. Alluvial reaches with cobble - gravel substrates. Slopes from 1 to 4 percent.
- Sample only within that portion of the riffle that exhibits a uniform slope. Use the same reach sampled for the pebble counts.
- Rocks should be free on the bed surface and not embedded within the substrate. This is best determined by wiggling the rocks by hand. The largest loose rocks are assumed to be annually mobile.
- If some of the substrate are relatively free of algae, moss or lichens, while others are not, select only those rocks that are relatively clean.
- Avoid selecting any unusual rocks that are uncommon in the bed.
- Avoid flat or platy substrate.

Normally the sample should be collected from within the entire riffle and should be fairly uniform in size. Care must be taken to avoid sampling substrate that is too small. A wide variation in sizes indicates inconsistancy in your sampling, (100mm to 50 mm is probably too large a range, while 100mm to 80mm is acceptable or 80% of your largest sample). The alternate problem is sampling substrate that's too large. Often, in healthy streams large material will exist on the bed which is not mobile during average annual flows. The material is the result of large flood deposits or as the result of the stream cutting through old features, winnowing away the tines, leaving material too large for the stream to transport. These pieces are normally embedded and not loose to the touch. If they can not be easily distinguished by the method mentioned previously, then select another reach. Also, reaches that exhibit an unusually confined geometry (fast runs, rectangular channel cross section, large cobble to small boulder substrates) should also be avoided.

Large Woody Debris

Large woody debris volume and 3 aspects of habitat complexity produced by the wood are included in this measure. The 3 complexity measures are: 1) pool volume caused by the debris, 2) the surface area of exposed or deposited substrate caused by the debris, and 3) an estimate of the cover provided by the wood. Each will be discussed in additional detail.

Woody Debris Volume. The average diameter and length of individual pieces of wood within the annually scoured channel should be recorded for a 1000 meter reach. A minimum size limit is related to channel width.

Pool volume. Scour caused by the deposition of wood in a channel creates pool habitat. Only pools clearly caused by the woody debris should be measured. Ambiguous cases such as debris in stable meanders or debris against rock outcrops should not be counted. Pool volume should be estimated with an average depth multiplied by the pool's surface area. Riffle crest adjustments were not done for this study, although a more rigorous evaluation of pools associated with woody debris should consider more elaborate volume measures that include compensation for measuring scoured volume only.

Surface substrate. Woody debris often causes the exposure or deposition of substrate material distinct from the rest of a channel's substrate. Differences in substrate affect the diversity of habitat. The surface area of deposited or scour-exposed substrates clearly resulting from the velocity gradients caused by woody debris should be measured. Surface areas should be measured using geometric shape approximations.

Cover. is estimated by measuring the area of a "shadow "cast by a light source directly over the debris on the channel bottom. Area estimates should use geometric shape approximations.

Sampling Technique

Since the influence of woody debris upon the channel varies with the size of the debris and the size of the channel, the minimum size of material monitored should vary with channel width. In an attempt to simplify the data collection, no effort should be made to determine species composition of the debris. The following table defines the minimum size of debris to be measured.

Channel Width	Min. Debris Diameter	Debris Length
0 to 3 meters	10 cm	.5 channel widths
3 to 6 meters	20 cm	.5 channel widths
6 to 12 meters	30 cm	3 meters
> 12 meters	40 cm	4 meters

Woody debris should be characterized for the same reaches used for location of V* pools and sediment sampling. Woody debris volumes within the channel should be measured from the upstream start of the selected reach, downstream 1000 meters.

Appendix B
Data Collection Forms

Pool Frequency, Depth and Volume measures

Stream: ________________ Reach Number: ______

Category: ______________

Crew: ____

Crew: ____

Comments: ____

Page __ of __

Date: / /

Elev @ 0 ________

Elev @ 1000 ______

< 1 Meter3	1-2 Meter3	2-4 Meter3	4-8 Meter3	>8 Meter3	Max Depth	End Pool	NOTES

RASI "D" Index

Stream: ____________________

Date: ____________________ Crew Members: ____________________

Reach Number: __________ ____________________

Riffle Number: __________ Dist. _______ ____________________

Depositional Measurements (30), Use fresh depositional feature.

Pebble counts accros Riffle (200)

<2mm	2 - 4mm	5 - 8mm	9 - 16mm	17 - 32mm	33 - 64mm	65 - 128mm	129 - 256mm	257 - 512mm	513 - 1024mm

Column Totals

V* Pool Measurements

Stream: ____________ Page ____ OF ____

Date: ____________ Crew Members: ____________________

Reach Number: __________ ____________________

Pool Number: ________ Pool Length ________ Pool distance from start rcaclt: _____

Riffle Crest Measuremcnts:

_____

Transect No. __

Distance frottt head of Pool ______ Transect Intersect @ ______

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance frottt head of Pool ______ Trattscct Intersect @ ______

Dist. front bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool ______ Transect Intersect @ ______

Dist. from bank															
Water Depth (cttt)															
Pool Dcptlt (cttt)															

Transect No. __

Distance from head of Pool ______ Transect Intersect @ ______

Dist. front bank															
Water Dcptlt (cm)															
Pool Dcptlt (cttr)															

Transect No. __

Distance frottt head of Pool ______ Trattscct Intersect @ ______

Dist. front bank															
Water Depth (cttt)															
Pool Depth (cttt)															

Transect No __

Distance frottt head of Pool ______ Transect Intersect @ ______

Dist. frottt bank															
Water Depth (cm)															
Pool Depth (cm)															

V* Pool Measurements

Date: ____________________

Reach Number: __________

Pool Number: ___________

Crew Members: ________________________________

____

____

Woody Debris

Stream: ______________ Channel Width _______ Page _____ of _____

Date: / / Min Debris Size ________

Reach______________ Crew Members: ______________________________________

____

Volume		Cover		Pool attributes (low Q)				Substrate	
Active Channel		Bankfull Ch		Active Channel				Bankfull	
Diameter	Length	W	L	D max	D ave	D Rif Cr.	Area	Change	Notes:
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Appendix C
Sediment Budget Coefficients

Sediment Budget Analysis

The sediment budget used in this analysis evaluated 3 separate periods for each of 60 watersheds. The intent of the budget was to develop an ‘order of magnitudes’ resolution only. All data was derived by digitizing in roads, harvest units, stream crossings and landslides directly from air photos and topographic maps into a CAD program. The data was separated by 3 slope positions and in some cases by relative impact levels. No field checking was done. The analysis was done by a member of the Water Board’s Staff, who was not familiar with the subjective analysis already underway so as to avoid bias. Once sediment sources were entered, the CAD files were simply analyzed by layers to determine the extent, by source, in each watershed. The analysis produced a data file which could be read into a spreadsheet, which in turn allowed, many different trials of recovery assumptions and source relationships with the dependent variables. The initial data entry was accomplished in approximately 2 months, and once the bugs were worked out of the analysis program, all sixty reaches and each of 3 time periods (180 maps) could be analyzed in about an hour. The results from the sediment budget were used to validate the descriptive categories. The sediment figures shown in Appendix D could be refined further, however there was insufficient time to continue that work. Given the results of this study, a shortcoming of the sediment budget as designed was that impacts prior to 1960 were not quantified. Given the longgevity of historical impacts, future budgets should attempt to account for them. Values shown are in cubic meters delivered to the stream.

Table 17. Coefficients used to estimate sediment yields.

	Sediment Yield
Main Roads	
High slope	50 m^3/ hectare
Mid Slope	125 m^3/ hectare
Low Slope	500 m^3/ hectare
Secondary Roads	
High Slope	30 m^3/ hectare
Mid Slope	75 m^3/ hectare
Low Slope	300 m^3/ hectare
Spur Roads	
High Slope	10 m^3/ hectare
Mid Slope	25 m^3/ hectare
Low Slope	100 m^3/ hectare
Tractor Units, High Site Impact	

High Slope	5 m^3/ hectare
Mid Slope	65 m^3/ hectare
Low Slope	260 m^3/ hectare

Tractor Units, Moderate Site Impact

High Slope	2.5 m^3/ hectare
Mid Slope	30 m^3/ hectare
Low Slope	130 m^3/ hectare

Cable Units

High Slope	1 m^3/ hectare
Mid Slope	4 m^3/ hectare
Low Slope	15 m^3/ hectare

Stream Crossings, Cubic meters per Crossing.

High Impact	300 m^3/ crossing
Moderate	50 m^3/ crossing
Low Impact	5 m^3/ crossing

Streamside Landslides, volume per point digitized.

High Impact	1000 m^3
Mod Impact	100 m^3
Low Impact	10 m^3

Upslope Landslides, volume per point digitized.

High Impact	100 m^3
Mod Impact	10 m^3
Low Impact	1 m^3

The values shown in table 17 were synthesized from the following sources:

Best et al. 1982, Ried and Dunne 1984, Hagens and Weaver 1987, Kelsey et al. 1989, Raines and Kelsey 1991, Leslie 1993, Redwood National Park 1993.

Appendix D
Data Summary

Reach	Category	Acres	Rch Slope	Sediment	RASI	D50	V*	PNum	PFreq	Max Depth	WdVol	WdCov	Cov/Vol	WdPVol	WdMxD	WdSubst	Subst/Vol
1	Index No	2,323	5.5	5,971	55.1	42.0	0.26				175	265	152	49	0.9	267	1.52
2	Index Yes	2,008	2.8	67,770	68.8	40.7	0.33	46	490	2.1	410	222	54	106	1	633	1.55
3	Index Yes	1,972	0.9	0	53.6	47.6	0.22	58	531	1.2	46	96	209	134	0.75	143	3.11
4	Mod	803	2.4	878,961	69.7	27.3	0.55	50	149	0.7	130	306	236	127	0.65	429	3.31
5	Mod	931	2.3	4,883	57.0	33.1	0.40	86	456	1	181	488	270	44	1.5	377	2.09
6	Index No	2,015	1.4	76,606	50.9	52.1	0.27	60	503	0.7	250	352	141	46	0.7	266	1.06
7	Mod	1,096	2.4	3,122	69.6	36.9	0.22	44	474	1	75	220	294	40	0.7	128	1.71
8	Index No	3,987	3.6	1,701	24.1	183.1	0.07	19		1.3	45	262	586				0.00
9	High	1,643	1.6	124,148	72.2	28.5	0.38	42	520	1.2	158	263	166	154	1.2	377	2.38
10	High	663	2.9	79,532	81.6	26.4	0.41	60		1.1	128	222	174	85	1.2	143	1.12
11	Mod	1,117	1.7	10,519	86.7	29.3	0.37	49	492	1.3	164	184	112	26	0.7	100	0.61
12	Mod	4,070	0.8	56,281	68.3	35.9	0.35	35	452	1.3	148	510	346	127	1.5	255	1.73
13	High	926	1.1	2,076	65.6	36.3	0.18	26	219	0.95	127	177	139	55	0.85	140	1.10
14	Mod	2,782	1.3	5,343	69.7	37.2	0.31	44	410	1.1	81	262	323	67	1.15	101	1.25
15	Mod	2,342	7.1	18,858	69.7	46.4	0.14	48	353	0.99	212	404	191	67	1.05	168	0.79
17	Mod	1,470	3.7	103,625	60.2	40.3	0.18	50	210	0.63	174	807	464	23	0.6	86	0.49
18	High	959	2.1	19,341	64.4	49.3	0.29	72	496	0.9	183	453	248	317	1.2	177	0.97
19	High	1,482	1.7	21,953	66.5	44.6	0.39	61	493	1.1	423	906	214	121	1.1	337	0.80
20	High	926	2.9	23,610	61.6	49.5	0.40	48	370	2	639	787	123	25	0.77	144	0.23
21	Index No	2,479	2.8	0	46.6	83.7	0.24	42	322	1.5	250	830	331	82	1.7	178	0.71
22	Mod	2,633	2.7	73,423	53.9	61.9	0.25	22	330	1.8	13	86	642				0.00
23	Index No	6,743	4.2	0	54.4	63.5	0.24	22	245	1.2	241	518	215	87	1.2	806	3.34
24	Index No	4,173	2.4	203,478	46.1	105.9	0.10	7	167	1.7	32	124	385				0.00
25	High	919	1.2	68,986	93.6	28.7	0.51	60	553	1	128	342	267	77	1.1	202	1.58
26	Mod	1,553	1.8	4,057	68.4	51.7	0.24	45	515	1.3	167	409	244	111	1.3	189	1.13
27	Index Yes	820	2.6	2,309	67.8	47.2	0.45	64	501	1.13	83	303	367	34	0.6	39	0.47
28	Mod	2,126	3.4	42,092	81.2	43.8	0.23	36	439	1.4	467	385	83	60	0.85	140	0.30
29	Mod	3,976	1.3	73,259	63.1	53.1	0.12	22	322	1.4	169	141	83	4	0.42	40	0.24
30	Mod	3,122	1.7	24,823	57.5	60.3	0.26	27	232	1.3	39	163	418	12	0.85	80	2.05
31	High	3,208	2.1	20,766	74.7	48.7	0.12	31	441	1.3	229	377	165	33	1	148	0.65
32	High	4,399	1.6	71,929	81.2	39.5	0.28	30	410	1.25	315	537	170	265	1.5	264	0.84
33	High	7,172	1.6	192,947	55.4	60.8	0.36	23	250	1.85	206	541	263	31	0.8	133	0.65
34	Index No	19,357	5.3	28,104	47.2	109.3	0.13	20	462	1.9	10	83	843	5	0.6	0	0.00
35	Index No	14,142	2.6	0	44.4	111.4	0.08	22	339	2	13	120	926				0.00
36	Index No	2,645	3.3	5,887	66.0	50.2	0.21	45	358	1.2	238	547	229	130	2.95	486	2.04
37	Mod	1,120	3.6	14,658	78.7	32.7	0.57	71	331	0.62	232	389	168	15	0.65	5	0.02
38	Mod	3,792	1.3	74,784	83.7	36.5	0.49	44	659	1.1	104	262	253	26	0.9	71	0.69
39	Mod	6,357	0.5	636,629	78.9	41.8	0.58	35	501	1	60	100	165	6	0.55	0	0.00
40	High	6,491	0.6	109,410	89.6	23.5	0.75	85	645	1.3	48	267	558	57	0.82	116	2.41
41	High	10,269	0.9	116,308	70.9	52.1	0.27	35	615	3	109	184	169		1.2		0.00
42	High	1,437	2.1	78,241	71.8	36.9	0.60	54	413	0.72	78	116	149	1	0.33	15	0.19
43	High	5,086	0.3	288,126	97.2	17.8	0.77	45	848	1.85	269	174	65	173	1.5	198	0.74
44	High	2,791	1.7	36,156	90.8	27.7	0.73	83	635	0.95	126	193	153	29	0.95	187	1.48
45	High	2,832	3.4	527,739	79.5	43.2	0.37	35	491	1.3	42	74	177	18	0.85	29	0.70
46	High	1,226	2.4	157,700	87.7	36.8	0.59	65	454	0.72	46	89	195	35	0.7	48	1.05
47	High	4,605	2.3	324,434	79.0	55.3	0.40	29	525	1.5	351	398	114				0.00
48	High	1,907	2.7	273,415	76.7	26.7	0.32	31	329	1.3	188	287	153				0.00
49	Mod	1,003	4.8	786	92.1	17.0	0.91	59	427	0.99	724	741	102	109	1	401	0.55
50	Mod	2726	3.2	39,164	66.1	57.0	0.31	37	437	1.58	293	497	170	16	0.6	65	0.22
51	Mod	3,229	1.2	39,620	69.4	47.1	0.46	44	485	1.5	522	465	89	167	1.4	113	0.22
52	Mod	2,075	1.7	44,783	91.0	33.8	0.57	67	468	1.3	1244	1248	100	163	1.3	704	0.57
53	Mod	4,377	1.2	29,014	68.7	61.0	0.19	37	435	1.5	974	1018	105	176	1.5	477	0.49
54	Index Yes	1,473	4.1	86,681	80.0	38.4	0.35	54	401	1.17	305	497	163	63	0.85	401	1.31
55	Mod	2,014	2.8	0	85.3	33.8	0.52	76	551	1.3	184	383	208	121	3	510	2.77
56	Index Yes	4,204	1.8	9,611	75.7	50.9	0.19	39	468	1.4	736	599	81	155	1.08	839	1.14
57	Index No	2,714	1.4	9,122	60.0	83.8	0.15	38	315	1.5	216	810	375	152	0.95	3403	15.77
58	Index No	1,096	5.5	606	61.0	45.4	0.13	64	505	0.96	266	923	347	125	0.7	727	2.73
59	Index No	1,229	3.6	0	75.5	37.4	0.23	50	520	1.5	777	1300	167	260	1.54	623	0.80
60	Index Yes	845	2.1	0	73.0	57.7	0.14	45	558	1.08	290	725	250	328	1.1	459	1.58
61	High	1,418	3.3	20,205	88.0	10.2	0.26	54	330	0.6	175	322	185	4	0.45	0	0.00