Limits on the usefulness of erosion-hazard ratings: experiences in northwestern California

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Although erosion-hazard ratings are often used to guide forest practices, those used in California from 1974 to 1982 have been inadequate for estimating erosion potential. To improve the erosion-hazard rating procedure, separate estimating equations were used for different situations. The ratings were partitioned according to yarding method, erosional process, and both yarding method and erosional process. Partitioning by yarding method resulted in a slight improvement in the precision of erosion estimates. The other two methods resulted in fourfold increases in prediction errors. Results indicate that a single unified erosion-hazard rating procedure is the most practical way of predicting logging-related erosion in northwestern California.

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Bien que les classifications des zones susceptibles à l'érosion soient souvent utilisées pour planifier les pratiques forestières, celles utilisées en Californie, de 1974 à 1982, ont été inadéquates pour estimer le potentiel d'érosion. En vue d'améliorer ces classifications, différentes équations furent utilisées pour diverses situations. Les classifications furent divisées selon la méthode de débusquage, du processus d'érosion et des deux méthodes combinées. La précision de l'estimation de l'érosion fut quelque peu améliorée lorsque la classification, selon la méthode de débusquage, fut utilisée. Les deux autres méthodes quadruplèrent les erreurs de prédiction. Les résultats indiquent qu'une seule méthode de classification des zones susceptibles à l'érosion s'est avérée pratique pour prédire l'érosion reliée à l'exploitation forestière dans le nordouest de la Californie.

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Introduction

Logging-related erosion is the result of the interaction of weather, site, and disturbance from timber harvest. One way to control the erosion is to use information about site and climate to determine which logging practices are appropriate. The state of California has taken that approach. The Z'berg-Nejedly Forest Practice Act of 1973 prompted a complete redrafting of the state's Forest Practice Rules (Green *et al.* 1981). In each of the state's three Forest Practice Districts, the new rules contained explicit procedures for estimating erosion hazard. Some Forest Practices were modified on the basis of estimated erosion hazard. Both the erosion-hazard ratings (EHRs) and the Forest Practice Rules were modified again in 1983. These modifications were in response to the 1972 Amendments to the Federal Water Pollution Control Act, and required that "best management practices" be instituted. In the latest Rules, therefore, surface erosion hazard and mass erosion hazard are estimated separately; however, the same procedures are used throughout the state. But the mass erosion-hazard procedure has yet to be adopted.

The current surface erosion-hazard rating and the previous erosion-hazard ratings for California's Northern and Southern Forest Practice Districts were patterned after a procedure used by the United States Department of Agriculture Forest Service in the state (Anonymous 1968). The Coast Forest Practice District used a different procedure between 1974 and 1982. It was developed mainly from research of Anderson (1972, 1974). Unfortunately, none of the erosion-hazard ratings were validated before adoption. Those adopted in 1974 have since been checked against measured erosion (Datzman 1978, Dodge *et al.* 1976). The Dodge study sums up the results as follows: "Erosion-hazard rating systems presently included in the Forest Practice Rules are not adequate for estimating erosion potential on lands where timber is to be harvested." Datzman (1978) found the overall correlation between her erosion data and the Coast District's erosion-hazard rating to be 0.10, indicating that about 1% of the variance in erosion was explained by the erosion-hazard rating. She later subdivided her data by timber size and yarding methods. With that breakdown, 63% of the variance in erosion from tractor yarded old-growth redwood areas was explained by the erosion-hazard rating. This relatively good prediction capability for one type of logging was attributed to the fact that such logging was prevalent during the period from which Anderson (1972, 1974) collected his data.

Using the data collected in 1975 and 1976 to validate the Coast District's erosion-hazard rating, we attempted to develop an improved erosion-hazard rating (Rice and Datzman 1981). Our regression analysis yielded an equation having an explained variance of about 0.4. The equation was based on slope, aspect, yarding method, and rock type. The improvement in predicting capability may be misleading, however, because the equation was fitted to the data, whereas the Coast District's erosion-hazard rating was developed independently of the data with which it was validated. We question, therefore, whether it is even reasonable to expect much accuracy or precision from a single erosion-hazard rating that is expected to

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TABLE 1. Average conditions cable- and tractor-yarded plots in northwestern California compared for site condition, logging disturbance, and source of erosion

	Yarding method		
	Cable	Tractor	All plots
Plot description			
Number	55	47	102
Area (ha)	4.4	4.6	4.5
Time since logging[a] (years)	4.0	5.4	4.6
Old-growth redwood (% plots)	21.8	48.9	34.3
Site conditions			
Elevation[a] (m)	846	517	695
Slope[a] (%)	51.5	34.1	43.5
Aspect severity[a,b]	3.4	4.6	4.0
Mean annual precipitation[a] (cm)	185	168	177
Maximum 10 year-24 hour ppt[a] (mm)	178	167	173
Maximum 2 year-6 hour ppt[a] (mm)	57	54	55.4
Geologic parent material[a] (%)			
Ultramafic	10.9	6.4	8.8
Granitic	18.2	12.8	15.7
Franciscan formation	34.5	29.9	32.4
Metamorphic	27.3	14.9	21.6
Hard sediments	9.1	4.3	6.9
Soft sediments	0.0	31.9	14.7
Soil analyses (%)			
Surface sand[a]	54.8	49.9	52.5
Surface clay[a]	16.8	21.9	19.1
Aggregate stability			
Field, surface[a,c]	6.4	5.1	5.8
Field, subsurface[a,c]	6.2	5.3	5.8
Laboratory, surface[a,d]	35.0	41.3	37.9
Laboratory, subsurface[a,d]	38.1	44.7	41.1
Logging disturbance (%)			
Basal area cut	99	83	92
Slash burned[a]	67	32	51
Surface condition			
Herbaceous plants	10	9	9
Shrubs	11	12	12
Broad leaved trees	2	2	2
Coniferous trees	3	6	4
Litter[e]	19	22	20
Slash[e]	20	17	18
Wood[e]	11	9	10
Rock	5	4	4
Bare ground	20	20	20
Area in roads (%)	1.6	1.9	1.8
Area in landings (%)	3.3	2.8	3.1
Area in skid trails (%)	1.7	12.5	6.7
Remaining plot area (%)	93.3	82.7	88.4
Volume of skid trail cuts (m^3 /ha)	25.6	319.1	162.5
Volume of ruts (m^3 /ha)	7.5	1.9	4.9
Sources of erosion (m^3 /ha)			
Roads	0.9	14.6	7.2
Landings	1.8	8.1	4.7
Skid trails	0.2	10.7	5.1
Other areas	11.6	7.1	9.5
Rills	1.3	3.0	2.1
Gullies	2.2	18.6	9.7
Slides	10.6	8.4	9.6
Slumps	0.2	10.5	5.0
Total	14.4	40.6	26.4

[a]Independent variables used in analyses.
[b]Rated on a scale: N = 1, NE = 2, NW = 3, E = 4, W = 5, SE = 6, SW = 7, S = 8.
[c]Rated on a scale of decreasing stability from 1 to 10 (Anonymous 1968).
[d]Represents the ratio of the specific gravities of aggregated and dispersed suspensions (Middleton 1930).
[e]Slash is organic debris between 1.3 and 15.2 cm in diameter. Litter is smaller and wood is larger.

predict the aggregate effect of any type of disturbance on all erosional processes.

This paper reports three ways of partitioning our data, by yarding method, by erosion process, and by both, to see if any method produces an erosion-hazard estimate that is superior to those obtained from a single erosion-hazard rating.

Partitioning erosion-hazard ratings

In our earlier paper (Rice and Datzman 1981) we proposed that much of the inability of our equation to fit the data might be due to operator variability. It would be difficult to test this "Murphy's Law" hypothesis, but it seems reasonable that partitioning the data into more homogeneous subgroups could improve correlation between site conditions and erosion resulting from timber harvest. This could be done by computing separate regressions for cable- and tractor-yarded areas, or by estimating surface and mass erosion separately, or by partitioning by both yarding method and erosional process.

Because our previous analysis showed erosion associated with cable-yarded areas to be only one fourth of that associated with areas where tractor skidding was used, stratifying data according to yarding method appeared promising. Apart from the statistical properties of the data, physical considerations also suggested that such a breakdown could be useful. Disturbance from tractor yarding differs from disturbance caused by cable yarding in pattern and severity (Table 1). Tractor yarding usually requires construction of skid trails that are nearly absent on cable-yarded settings. These skid trails create cutbanks that are susceptible to slumping. A high-lead system was used on most of our cable-yarded plots. Because full suspension was rarely achieved, the cable-yarded plots had nearly four times the volume of ruts as did the tractor-yarded plots. Roads leading to cable-yarded plots tend to be located on more stable ground near ridges, whereas, roads leading to tractor-yarded plots frequently traverse less stable ground lower on the slopes. These geomorphic differences may explain why substantially more road-related erosion was associated with our tractor-yarded plots. As a result of these many differences, the relationship between the resulting erosion and site conditions may also differ according to yarding system.

Partitioning the measured erosion between surface and mass processes also may be beneficial. Surface erosion represents a continuum ranging from the smallest rill to the largest gully. Mass erosion, however, is composed mainly of large discrete events. Surface erosion can occur on all slopes, but logging-related mass movements occur almost exclusively on slopes steeper than 30°. Ground cover prevents the start of surface erosion but, by promoting infiltration, it may increase the risk of mass movements. Differences in the two processes argue strongly for separate estimates of the hazard from surface and mass erosion.

It also seems reasonable to expect that yarding methods and erosional processes might interact so that four different erosion-hazard rating equations would be necessary to obtain the most accurate procedure: separate equations for surface erosion from tractor-yarded areas, mass erosion from tractor-yarded areas, surface erosion from cable-yarded areas, and mass erosion from cable-yarded areas. In our previous study, for example, rill erosion was only 13% of the surface erosion on tractor-yarded plots but it was 38% of the surface erosion on cable-yarded plots. Mass erosion accounted for 48% of the total erosion on tractor-yarded plots and 76% of the total erosion on cable-yarded plots. Within mass movements, slides (all translational, as opposed to rotational, mass movements) made up 59% of the mass erosion on tractor-yarded plots, whereas they accounted for virtually all the mass movement erosion on cable-yarded plots. These differences suggest that yarding method and erosion processes may interact and thereby affect the linkage between erosion and site conditions.

FIG. 1. Location of study areas used to develop erosion-hazard ratings.

Methods

Sampling scheme

Our analyses will use the data (Table 1) we used in the earlier study (Rice and Datzman 1981). A stratified sampling scheme was used to obtain maximum utility from the data we collected. It reduced the correlations that naturally occur among some of the variables. The strata included four slope classes, five annual precipitation classes, five geologic types (later expanded to six), three lengths of time-since-logging, and two yarding methods. When sampling from these strata, we tried to get a uniform distribution of plots among the 720 possible cells in the complete data matrix. Data were collected from 102 plots in northwestern California (Fig. 1). The stratification yielded a well-distributed sampling of conditions. The only exception was our inability to find any cable-yarded plots on soft sedimentary parent material (Table 1). The highest individual correlation, between slope and yarding method, was 0.51. The multiple correlations between yarding method and the geologic types was 0.68, as was the multiple correlation between mean annual precipitation and the geologic types. These values indicate that some of the naturally occurring correlations among these variables has persisted in our data. The correlations are low enough, however, that it is unlikely that they could adversely affect our regression analyses.

The plots were rectangular, about 201 m wide, and extended up or down a slope to include all area yarded to a particular landing. Logs were skidded downhill on almost all the tractor-yarded plots. All cable-yarded plots were yarded uphill. About 100 variables were measured on each plot to describe the site, its spatial variability, and the amount and location of erosion resulting from various mech-

TABLE 2. Exponents and multipliers of erosion-hazard rating (EHR) on the basis of various partitionings, by erosional processes and yarding methods

Model	Constant multiplier (m^3/ha)	Yarding method multipliers		Geologic parent material multipliers						Exponents		Standard error of estimate (m^3/ha)
		Tractor	Cable	Soft sediment	Granite	Metamorphic	Hard sediment	Franciscan formation	Ultramafic	Slope (%)	Aspect[a] (%)	
Unified EHR	1.428×10^{-2}	2.02	0.50	3.45	0.48	1.56	1.78	0.55	0.40	1.30	0.70	8.34
Yarding method partitioned EHR												8.23
Tractor	5.036×10^{-3}	—	—	4.04	1.39	0.90	1.29	0.88	0.17	1.79	0.60	
Cable	4.265×10^{-3}	—	—	—	0.42	2.56	2.31	0.52	0.78	1.21	0.72	
Erosional process partitioned EHR												36.33
Mass	1.360×10^{-5}	2.70	0.37	12.38	0.16	1.06	4.18	0.54	0.21	2.40	0.73	
Surface	1.910×10^{-2}	2.00	0.50	1.58	0.76	2.16	0.90	0.74	0.58	1.15	0.51	
Yarding method and erosional process partitioned EHR												38.68
Tractor/surface	5.007×10^{-3}	—	—	1.76	2.34	1.26	0.74	1.10	0.24	1.78	0.29	
Tractor/mass	1.819×10^{-5}	—	—	12.54	0.15	0.65	10.34	0.56	0.15	2.45	1.18	
Cable/surface	2.782×10^{-2}	—	—	—	0.58	2.94	0.94	0.64	0.87	0.84	0.60	
Cable/mass	4.961×10^{-6}	—	—	—	0.26	2.06	5.37	0.83	0.42	2.33	0.55	

[a]Arbitrary code approximating the radiation balance: N = 1, NE = 2, NW = 3, E = 4, W = 5, SE = 6, SW = 7, S = 8.

anisms. Mass movements appearing to have displaced more than about 0.76 m^3 of soil were individually surveyed. Those portions of all gullies having cross-sectional areas greater than about 930 cm^2 were also surveyed. Ground conditions and rill erosion were estimated from transects running across the slope at 40-m intervals. Rill volume was estimated from the product of its cross-sectional area on the transect and 40 m.

Regression analyses

As a result of what was learned in our earlier study (Rice and Datzman 1981), all of the erosion-hazard ratings that we compare are based on regression analysis of logarithmically transformed variables. The regression models had untransformed forms such as:

$$[1] \quad Y = b_0 \cdot x_1^{b_1} \cdot x_2^{b_2} \cdot b_{3i} \cdot b_{4j} \cdots$$

where x_1 and x_2 are continuous variables and b_3; and b_{4j} are multipliers for the ith and j^{th} states of categorical variables 3 and 4, respectively. We presume that a logarithmic model is a closer approximation to how site variables interact naturally than is a linear model. Regardless of the validity of that assumption, we found the logarithmic model to provide a better fit to the data. Our analyses differ from the earlier one in that the categorical variables, yarding method and geologic parent material, were not weighted according to the relative frequency of each category. This change resulted in somewhat different regression coefficients, however, the statistical properties of the equations were identical. We began our analyses with a set of 15 independent variables (Table 1). They were variables which, on the basis of our previous analyses, seemed to promise some utility in the partitioned erosion-hazard rating procedures we are developing. From other analyses (Rice and Furbish 1981) of the same data set, it was concluded that no measures of logging-related site disturbance were better predictors of erosion than a simple dichotomous yarding method variable. We also think that it is unwise to base an erosion-hazard rating on the *expectation* of the amount of future site disturbance. Rather, it is preferable to base an EHR on site conditions that can be verified prior to logging.

Mallows' C_p (Daniel and Wood 1971) was the principal criterion by which we compared competing regression equations. It is computed by first dividing the residual sum of squares by an estimate of the population variance. This quotient is then adjusted by subtracting the number of observations and adding two times the number of variables. C_p is used to guard against adding unnecessary variables to a regression equation. The "best" equation is the one yielding the smallest C_p. Some variables, however, were not retained if the reduction in C_p that they produced was deemed to be insignificant compared with the difficulty or ambiguity associated with measuring them in the field. Others were rejected because they appeared to be artifacts of our data set. For example, the mass erosion equations contained precipitation variables with negative coefficients. We presume this resulted from the fact that the two plots having the largest amount of mass movement erosion happen to be in very low rainfall areas. Within the range of our data, we do not believe that a plausible hydrologic explanation exists for a negative correlation between erosion and precipitation.

As a result of the preliminary screening just described, we found that all of the equations that we had tentatively selected included slope, all but one included aspect, two thirds included the rock-type variables, and yarding method was present in the three equations where it was appropriate. Because of the pervasiveness of these variables, we decided to compare partitioning using slope, method, aspect, and geologic parent material in all equations (Table 2).

The standard error of estimate (SEE) was our measure of the expected efficacy of the four approaches to estimating erosion hazard. The SEE for the model using a single equation was computed in the conventional fashion. For the erosion hazard rating procedure based on partitioning the plots according to yarding method the SEE was computed by summing the squared residuals for both cable and tractor plots and dividing by the total number of plots minus the number of parameters fitted. For the EHR based on partitioning the data according to erosional process, the SEE was computed by first summing the residuals for the estimates of surface and mass erosion,

summing the squares of that computation, and dividing by the number of observations minus the average number of parameters in the two equations. The SEE for the model based on partitioning both according to yarding method and erosion process was computed using both procedures just described. First the residuals were aggregated for both erosional processes within each yarding method and then the squared residuals for the two yarding methods were combined.

Discussion

The results of regression analyses are disappointing (Table 2). Our best EHRs have SEES which, although only 0.3 times the mean, are approximately 2.5 times the median amount of erosion on the plots. The great increase in the SEE that accompanied partitioning schemes based on erosional processes is particularly discouraging. Before discussing the inferences that we draw from the study, we will investigate the possible sources of weakness in our regression analyses. Three seem most important: the sample was defective, the independent variables were defective, or the model was inappropriate.

The sample

Our sample could have been defective because it was too small, or because it was biased, or because of collinearities among the independent variables. It would be easy to blame all of our difficulties on the sample size. Considering the many sources of variation with which we were trying to deal, 102 plots do not constitute a large source of information. The sample, however, was stratified with considerable care to collect as little redundant information as possible. Even so, only a small fraction of the cells in our stratification matrix were filled.

Two sources of bias caused us concern. We first discovered that the data contained a few (four) plots with large amounts of erosion. We questioned if our regression was merely a function relating four outliers with a cluster of low values of erosion. This particular concern lessened when we inspected our residuals and reviewed the results of two other studies. A similar study dealing with roads (McCashion and Rice 1983) and a companion study conducted by the state of California (Dodge *et al.* 1976) showed the same tendency for most of the total erosion measured to be found on a small number of plots. From this we concluded that logging-related erosion is approximately lognormally distributed. We believe that we countered much of the difficulty presented by the distribution of our sample by using regressions on logarithms of the measured values.

When we came to suspect that differences in how each timber harvest was planned and executed could be as important as site characteristics in determining subsequent erosion, we considered another possible source of bias (Rice and Datzman 1981). Timber operators may be responding to perceived erosion hazard in a manner than tends to destroy the correlation between erodibility and erosion; that is, by being more careful on hazardous sites and less careful on less hazardous sites. Short of a designed experiment where erosional effects are held constant or strictly controlled, we see no way of evaluating or diminishing this possible source of bias.

It was expected that the stratification used for sample plot selection would also reduce collinearities among the variables. We conducted a number of tests that indicated that we were generally successful in this regard (Rice and Datzman 1981).

Independent variables

Because colinearity was not a problem does not mean that our independent variables were not deficient in some other way. They could be measuring the wrong things, they could be poorly expressing what they are measuring, or we could have neglected to include an important variable. Any data set must include these three defects to a certain degree. The geologic variables, for example, are surrogates for the physical characteristics of soil and rock that affect both surface and mass erosion. We attempted to measure some of these properties (Table 1) and found that the theoretically more relevant measurements offered little or no improvement to the EHRs. There are probably several explanations for the ineffectiveness of our precipitation variables. The spurious negative correlation between erosion and precipitation was discussed earlier. Another is that the isohyetal maps, upon which the variables were based, were derived from a very sparse rain-gage network. The variables themselves, however, may have been poor expressions of the effect that meteorological conditions have on erosion. For mass erosion, a function of Caine's (1980) threshold, such as has been proposed (Rice *et al.* 1981), may be a better expression of the landslide producing capabilities of a storm.

A dichotomous variable indicating whether cable or tractor systems are used is a crude index of yarding disturbance. Subdivisions of disturbance within each of these classes of yarding methods exist and the disturbance resulting from any system is governed, in part, by the topography on which yarding is taking place. In spite of the reality of these physical interactions, there seems to be no superior way, within our database, to describe qualitative differences in yarding disturbances (Rice and Furbish 1981).

Missing variables may represent another source of weakness in our analyses. One category of such variables contains those related to subsurface hydrology. Such parameters are difficult or prohibitively expensive to measure in the field, even assuming we know precisely the relevant measurements to make. As mentioned previously, our equation lacked precipitation variables as a result of poor estimates and unfortunate random correlations that turned up in our data. Presumably, the omission of meteorological variables is an important lack. It may be, however, that the influence of climate is slight compared with the other factors influencing erosion.

One of the possible weaknesses in the whole idea of empirically derived erosion-hazard ratings may be that they are based on average conditions in the harvest area. Most harvest areas in northwestern California are quite complex geomorphically, vegetatively, and edaphically. By attempting to lump such diversity into a single expression of hazard we may have “averaged out" important site indicators of hazard. This certainly seems to be true with respect to mass erosion. Studies in the area (Furbish and Rice 1983; Rice and Pillsbury 1982) have found that even when dealing with notoriously unstable portions of the landscape, only a small fraction of the area (less than 3%) was actually involved in debris avalanches. If this phenomenon is also true for gully erosion, our data would indicate that an excess of 90% of the volume of logging-related erosion is confined to a relatively small portion of most harvest areas. That being the situation, an EHR indexing the prevalence of such extremely hazardous areas might be more effecttive than one that is based on average conditions.

Analytical models

A linear regression is obviously a crude approximation of the interaction of forces and conditions that regulate the amount of

postlogging erosion. But for some time to come it appears likely that it is the best we can do. Even if we knew the correct form of the equation, it is likely that it would be impractical to include some elements of it in an EHR-subsurface hydrology, for example. The regression approach to an EHR is explicit about what is being predicted. This is important, because precision and accuracy can be, and generally are, estimated. A regression analysis also provides a framework for conducting verifying experiments. Precision and accuracy of qualitatively derived EHRs could be estimated and verified by experiments, if some observable consequence were attached to the rating. Our previous test (Rice and Datzman 1981) of the Coast District EHR is the only example of such verification of which we are aware. Because forest harvesting technology is continually changing, all EHRs must be suspect until some sort of routine verification is instituted.

Future EHRs

We have just enumerated weaknesses that we perceive in the development of our EHRs. Poor as they are, our EHRs are based on *some* data. Other EHRs are usually merely codified professional opinion. These subjective EHRs may have an advantage in that they treat *all* of the presumed important variables. Their coefficients or weights, however, are suspect if they are untested and their model structures offer no improvement over regression analysis.

What are the prospects for the immediate future? The economic and political circumstances in California will probably militate against carrying out a study of the size necessary to develop and verify an EHR in which much confidence could be placed. Undoubtedly, the study would still have to be correlative in nature and be built on a relatively simple model using easily measured variables. The reasons for these constraints are that, in the model structure, Ave lack the scientific insights to develop a useable model which, based on empirical data, closely mimics the actual physical processes. With respect to the variables in any model, we are limited by the fact that EHRs are used as management tools and must be based on measurements that are accessible and economical to collect.

Even if we could develop an EHR that accurately reflected physical processes and could be practically applied, we would still face two imponderables. One would be the weather; an EHR can only predict some particular response to logging. In actuality, because of the multiplicity of possible weather patterns after logging, a spectrum of possible outcomes exists. The best we can hope for is that, on the average, the EHR is closely related to subsequent erosion. The other imponderable is the human portion of the equation. If, as we hypothesized, differences in how logging operations are laid out and executed have major effect on subsequent erosion, the variability resulting from differences in human nature will always exist.

Conclusions and recommendations

On the basis of our analyses, we conclude that the unified EHR is the most practical predictor of erosion related to logging in northwestern California that we can develop from our data. Partitioning according to yarding method produced slight improvements in the standard error of estimate and partitioning according to erosional processes inflated the standard error of estimate. We do not foresee any major improvement in erosion-hazard ratings in the immediate future. Steps can be taken, however, to improve how we deal with logging-related erosion. If our hypothesis concerning the role of operator behavior is correct, the use of an EHR can be a valuable educational tool, regardless of its accuracy or precision. The mere computation of an EHR and the modification of practices that results will tend to remind operators of competing resources that are at risk in a logging operation.

To improve the variables and models by which we attempt to estimate erosion hazard, mechanisms need to be set up by which the efficacy of current erosion-hazard ratings can be confirmed or refuted. Responses to EHRs often carry economic costs and should not be perpetuated if they are not justified. To direct the emphasis of future research and management responses to the problem of logging-related erosion, the relative magnitude of operator-related factors and site-related factors needs to be investigated.

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