Response of fish to cumulative effects of suction dredge and hydraulic mining in the Illinois subbasin, Siskiyou National Forest, Oregon*

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EXHIBIT A-63

Contents

"Truth, like gold, is to be obtained not by its growth, but by washing away from it all that is not gold."

- Leo Tolstoy

Abstract:

Potential cumulative effects of suction dredge mining (SDM) was assessed in combination with early hydraulic mining and other independent variables reflecting land-uses on fish in the Illinois subbasin. Fish response data were from 59 reaches sampled by summer snorkeling under the SMART program. Responses utilized were pool densities of salmonids over one year old, of young-of-the-year salmonids, and a stream habitat measure, width-to-depth ratio. Intensity of suction dredge mining was estimated from a directed survey that censused the quantity of sediment proposed to be moved per unit stream length in each 640-acre Section. The potential cumulative effect for each explanatory variable was estimated by summing the inverse distance of each corresponding pixel in each drainage defined by the location of each fish sample. Cumulative SDM was found to be non-significant (tested at P=0.05, with significance of coefficient always >0.5) for each of the three response variables tested in a general linear model. However, early hydraulic mining was found to have a significant negative effect (P=0.03) on observed density of salmonids over one year old.

1. Introduction

The activities of suction dredge mining (SDM) in streams of the Siskiyou National Forest have attracted the attention of environmental organizations, many of whom oppose such activity in the Forest, particularly in the Kalmiopsis Wilderness. This opposition has been met with similarly well-organized miners who wish to retain their claims. The U.S. Forest Service has responded with a set of guidelines for miners to minimize environment effects of their activities, and an EIS has been prepared.

The ingredient that is lacking in this process is scientific information and analysis that accounts for suction dredge mining and other potential confounding effects on stream biota, including early hydraulic mining (HM). This report describes a first analysis of existing, recent data which accounts for cumulative effects of suction dredge mining, early hydraulic mining, and other activities as reflected by land-use on measures of fish populations and habitat in the Illinois subbasin (Fig. 1).

1.1 Acknowledgements

The following colleagues are thanked for their help during this project: John Bolte, Randall Frick, Steve Jacobs, Kevin Johnson, John Nolan, Tom Atzet, Bonnie Howell, Karen Honeycutt, Edmund Hall, Margaret McHugh, Dan Delany, Roger Mendenhall.

1.2 Background

Suction dredge mining (SDM) involves pumping streambed material via a pipe, passing it over a sluice box to sort out any gold, and discarding the tailings downstream (Fig. 1).

There have been several studies on local effects on stream biota of SDM that have been reviewed from scientific (Harvey and Lisle 1998) and policy (Bernell et al. 2003) points of view. Rather than repeat the details of these excellent reviews, I summarize here the key issues as they may pertain to the area of study.

There have been several localized effects of SDM documented depending on where and at what time of the year it is carried out. These have included entrainment and subsequent mortality of fish larvae, fish eggs, or invertebrates and the use of unstable tailings for spawning by some salmonids (Harvey and Lisle 1998). There are potential effects due to a plume of suspended fine sediment downstream that does not normally occur during summer flows, due to the physical disturbance of riparian habitat or stream banks, effects due to site access by vehicles, and to the inevitable spills of fuel or oil. Harvey and Lisle (1998) opine that "effects of dredging commonly appear to be minor and local", but stress that cumulative effects of several operations at larger scales have not been investigated. This is one reason this study has been undertaken.

In a comprehensive policy review of recreational placer mining in Oregon Scenic Waterways, Bernell et al. (2003) deduce from the literature, stakeholders, and government agencies that the most effective control to prevent potential effects of poor mining practice is self-control, which requires more investment in education and compliance.

Because most SDM activity (e.g., Fig. 1) in the Rogue basin and the Siskiyou National Forest was concentrated in the Illinois River drainage, the study described here was limited to the drainage of that subbasin (Fig. 2).

2. Approach

Designing and executing a study specifically for this purpose would not only require fish sampling during several years, but also a parallel labor-intensive process of tracking and measuring current mining activities in an extensive and challenging landscape. Existing mining claims provide an unreliable measure of potential impact because most claims are not active during any one season, and those that are vary considerably in mining intensity. Therefore, a study based on a new sampling design was beyond the resources available and would not be timely for required management decisions.

Fortunately, two factors coincided to make this study possible. First, a survey of SDM was completed in 1999 (Kevin L. Johnson, Area Mining Geologist, USFS, Grants Pass, OR) that included a measure of the intensity of mining as quantity of sediment moved. Secondly, independent fish survey data were available from the SMART program of USFS (USFS 2001), and ODFW salmon spawning survey data (provided by Steven Jacobs, ODFW Hwy 34 lab., Corvallis, pers. comm.) described in www.streamnet.org.

However, merely combining fish and suction dredge mining data sets alone would not provide sufficient information for a valid analysis, because the study was observational rather than a fully controlled experiment (Diamond 1986). In order to account for any significant influence of other differences among riverscapes and avoid potential confounding with any SDM effects, other 'nuisance' variables were required to represent those potential effects.

Rationales for determining the response and potential effects for the derivation of explanatory variables are described below.

3. Methods: Response variables

For the purposes of this study, a response variable representing fish or fish habitat in a stream needs to (1) be sensitive to habitat change that includes potential effects of SDM, (2) have a sufficient range of values, (3) not be dominated by zero values to prove statistically intractable, (4) be measurable with consistent bias among sample sites, (5) be from a survey with independent and random - or at least representative - samples of consistent protocol, and (6) be from samples that are independent.

A fish habitat variable was used that satisfied the relevant conditions. Regarding fish responses and (4), all fish sampling methods are biased, but the important issue here is that the protocol and sampling conditions beyond the protocol do not produce a variable bias that may be related to the potential causal effects being tested. Two existing surveys satisfied the foregoing conditions:

3.1 ODFW Spawning anadromous salmonid surveys:

In a given stream and year, replicate counts of visible spawning or spawned anadromous salmonids are made by trained personnel during the spawning season, producing "Adult Return-Peak" and "Adult Return-Estimates of Spawning Population" estimates by species, stream reach and year. The "Adult Return-Estimates of Spawning Population" estimates are made by an integration of all counts during the season ('area-under-the-curve' method, English et al. 1992)) over a defined length of stream. These spawning population totals, estimated by ODFW, were expressed as number of adults on a per-stream-kilometer basis for coho salmon, chinook salmon, and all anadromous species combined (that also includes some steelhead).

Data from 1995 through 2000 were obtained from 53 sites (stream reaches) that had been randomly selected in the Illinois subbasin (Fig. 3), in which a subset of those sites had been sampled each year.

3.2 Summer snorkeling counts by SMART program

USFS's SMART (Stream Management, Analysis, Reporting, and Tracking database) has included sampling of reaches in the system during two phases: 1989-1995 and 1996 to the present. Data from the second phase, in which training and recording were more rigorous, were utilized from 1996-1999. Ranger District biologists were required to sample all fish bearing streams within 10 years, and the design protocol required that each stream was to be randomly selected for sampling in a given year.

Summer, daytime snorkel counts by species, with breakdowns for salmonids into size or age groups, were made in a reach from successive pools and riffles progressing upstream. Considerably fewer fish were observed in riffles than in pools. Riffle counts were not included because in summer it is difficult to obtain representative snorkel counts in many riffles due to shallow, turbulent water and coarse substrates.

Sixty-one samples were taken from reaches during the second phase which began in 1996. Of these, two samples were taken from one reach in different years. One of these was eliminated by coin toss. A second reach was eliminated because only one riffle was sampled for fish. Therefore 59 independent reaches were retained for the analysis (Fig. 4). These reaches averaged 3.3 km (range 0.8 - 9.4) long. A mean of 10 pools per reach (range 1-23) was sampled for fish.

Physical measurements of pools and riffles were taken directly every 10th pool (minimum of 10 pool-riffles measured when available).

Mean pool width varied between 5.6 ft (1.7 m) and 37.4 ft (11.4 m), and averaged 17.7 ft (5.4 m). Measurements of remaining habitat units were estimated by identified crew members, estimates that were calibrated with measurements every 10th pool (Appendix 1). Basin drainage areas corresponding to each sample (downstream end of reach) varied from 584 to 51,500 acres (236 to 20,840 Ha).

Only fish data from pool observations were included because it is difficult to maintain consistency when attempting quantitative observations in riffle and other habitat types during low summer conditions. The species breakdown of fish taxa observed in pools in shown in Fig. 5, along with the frequency of presence in all pools and reaches sampled. A total of 610 pools were sampled among the 59 reaches. All reaches contained fish, and a zero fish count was only record for one pool. Sampled pool frequencies (every 10th pool) varied from 1 to 27 pools per reach. Total reach lengths varied from 0.6 to 6.3 miles. Young-of-the-Year (YOY or O+) salmonids were observed in 502 pools and 58 reaches, while older salmonids were observed in 434 pools and 58 reaches.

Only Rainbow trout (which may have included juvenile steelhead which are the same species), occurred consistently throughout the reaches. Statistical analysis would be difficult for other species because of large numbers of zero observations. Because all salmonids are sensitive to higher temperature and restricted habitats during summer and low flows, it was decided to represent all native salmonid species in response variables. However, because of different behaviors and habitat preferences among YOY and older salmonids, these were analyzed as two separate responses. It is easy for trained snorkelers to distinguish between YOY and older salmonids because of their size difference.

The response variable was expressed in density form as the number of a defined fish group (young-of-year or older salmonids) observed per 1000 m^2 of pool area. The number of fish are summed over all pools snorkeled:

Fish Response = S(# fish observed in pool, i)/S(surface area of pool, i)

Methods and results of corrected estimates of pool dimensions, based on SMART calibration data, used to estimate pool area are described in Appendix 1.

3.3 Fish habitat

One of the most useful measures of fish habitat is the dimensionless variable, width-to-depth ratio, based on wetted stream habitat dimensions. Streams that are deep for their width (i.e., low width-to-depth ratio) tend to provide more habitat for fish, especially salmonids during summer (Scarnecchia and Bergersen 1987; Kozel and Hubert 1989). Natural differences in the ratio do exist due to differences in sediment type, transport, and deposition, and also whether the reach channel is constrained geomorphically. However, degradation of streams through riparian forest removal, changes in hydrology, and transport of sediment generally tends to widen streams at the cost of mean depth, a process that is consistent with reduction of overhanging bank habitat and bankside vegetation. Maximum depth of pool or riffle was measured for all sampled habitats, therefore this depth measure was used instead of the strongly correlated mean depth that was estimated for less than half of sampled habitats. The mean ratio for a reach was estimated by calculating the mean of all pool and riffle width-to-depth ratios.

Width-to-depth ratio averaged 9.2, and ranged from 5.4 to 15.5 for the same 59 reaches sampled in the SMART program that contributed to the fish response data (Fig. 4).

All response variables were checked for quality and internal consistency, but were not compared to explanatory variables until an independent set had been derived from the latter as described in Sections 4, 5.1, and 5.2.

4. Methods: Potential effects on fish populations

The primary potential effect represents the object of this study, suction dredge mining (SDM). The 1999 survey of SDM included (1) a census of the proposed amount of sediment that miners were anticipating that they would transfer downstream during the summer season, and (2) an extensive field sample of the mining activity in which the actual amount of sediment moved was measured. Notwithstanding some individual differences in between expected and actual quantities moved, there was a good correlation from 48 samples ($r = 0.600$, $P<0.00001$, Fig. 6). Because it was essential to have a measure of cumulative effects from all SDM operations, the measure of the estimated (proposed) amount to be moved was adopted, because this resulted from a census during the 1999 season. This was also considered to be more appropriate because fish responses were measured over a 5-year period, and proposed SDM that did not occur during 1999 could have occurred during other years.

The proposed measure adopted was expressed as the quantity of sediment moved per unit length of stream in segments that were contained in 640-acre (close to 1-mile square) Sections. Derivation of potential cumulative effect of several processes in a given drainage is described below under Cumulative Effects.

Any effect on the fish response from causes other than SDM could potentially confound interpretation. These 'nuisance' variables include early hydraulic mining (HM) and several land-use effects.

HM mostly occurred in 1860-1910 (Fig. 7), but was included because it had a long-lasting visible effect on the surface geology, soils, and vegetation of riparian zones (e.g., Fig. 8). HM peaked in the early 1900's but continued to occur sporadically until as recently as a single operation on Althouse Creek in the mid 1980's (John R. Nolan, USFS, Pers. comm.).

Also land use varied, with forest type, degree of deforestation, urban, and agriculture uses differing among drainage areas sampled for fish. For quantifying the relative effect of these land uses, the best available source covering the whole basin was the Western Oregon Digital Imagery Project (WODIP: Nighbert et al. 2000). That project classified the region into 25-by-25-m pixels representing 49 land-use types, largely on the basis of satellite imagery and ground truth information. Their very detailed forest classification included estimates of mixed or single stands of hardwoods and conifers, four tree size classes, and canopy cover down to 10% intervals. These distinctions were far too fine to indicate differences among basins statistically in this study, so a reduced set of forest and other land-use components was derived that did not involve the elimination of pixels (Fig. 9). In addition a road cover image was obtained through U.S. Forest Service, Grants Pass, which was merged with the simplified WODIP land-use cover .

Water-use effects on hydrology from dams is negligible in the basin, and water abstraction effects would be related to the potential agricultural and urban influence already being measured. The foregoing data sources were analyzed as follows.

5. Analysis and results:

Before performing a definitive statistical analysis (5.3), an appropriate method for encoding potential influence to derive explanatory variables is described (5.1), followed by the process to derive an independent set of those explanatory variables (5.2).

5.1 Rating potential influence of explanatory variables

The fish sampled at a given location are mostly influenced by habitats in their home range, which is roughly of the same order as the reach lengths sampled. However, these habitats are primarily influenced by natural and anthropomorphic activities upstream. What is the most rational way of measuring potential influence stream and land-use types?

The traditional approach is simply to sum the number of pixels corresponding to each classification, with each sum being the explanatory variable representing the potential influence of each classification (Fig. 10 A). This process provided equal weights to each pixel, so a land-use at the periphery of the drainage basin would be deemed equally influential as one of similar area adjacent to the sample point. This scoring procedure was unrealistic for assessing effects on a stream reach. Given the importance of riparian zones on streams, a stream buffer zone approach (Fig. 10B) became popular, but the distance from the stream (buffer width) beyond which land-use effects were rated at zero has become a controversial issue. Moreover, a land or stream use in the buffer zone was still considered to have the same effect whether it was close or distant from the sampled reach.

A solution to the foregoing problems is to weight each land-use (including mining use) according to some inverse function of its distance, as the water flows, to the sample location ('pour point'). A rationale for utilizing an inverse-distance weighting method is derived (Appendix 2) and illustrated (Fig. 11). This process produces an explanatory variable datum that represents a cumulative measure of the potential impact on each sampled reach from all sources of each candidate effect in the drainage associated with that sample.

Explanatory variables for all land-use types, including SDM and hydraulic mining (HM) activities along the stream corridor, were converted where necessary to raster (25-m pixel) images. A recent 10-m resolution DEM was used to develop a 25-m raster image indicating flow path directions over the entire landscape, a process that also defines the drainages basins corresponding to each fish sample. The process, developed by John Bolte (Department of Bioresources, Oregon State University), utilizes a program (ZOI) that interfaces with the flow direction cover map to derive sums of inverse-distance weighted values for each classification in each drainage basin ARC-INFO GIS software (Bayley et al. 2001; Kehmeier et al. in submission).

The two mining activities were coded as follows. The proposed cubic yards of sediment to be moved (see above) by Suction dredge mining (SDM) in 1999 was expressed on a per unit stream length (cu. yds/1000 ft of stream) in each Section where this mining was involved. This measure of intensity of mining was converted to classes and assigned to pixels in a rasterized GIS image (Figs. 2,3). The process outlined above weighted each pixel by the measure of mining intensity in addition to its inverse distance from the sampled reach.

The stream reaches where early hydraulic mining (HM) occurred was mapped by John Nolan and Roger Mendenhall (USFS, Grants Pass, OR). They assigned one of four ranks to each reach to describe the visual effects (e.g. see Fig. 8) that reflected the intensity of this mining activity independently of other activities. These rankings were assigned intensities of 1 through 4 that were applied to classes in a similar manner as SDM. Different units for different mining effects do not matter in a linear statistical analysis; what is important is to reflect the relative intensity and cumulative effect of each mining activity in each drainage.

Figure 12 provides an example of a combined image with drainage basins corresponding to three SMART fish samples, with corresponding calculations of inverse distance weights of aggregated land-uses (see next section). This process does not eliminate any land or water use in the drainage, but weights each pixel of each classification according to the inverse of its distance to the fish response measured.

5.2 Deriving a set of independent explanatory variables

Any statistical analysis that investigates the significance and magnitude of a potential influence requires that the explanatory variable representing that influence is independent of potentially confounding variables. A fair assessment of whether correlations are insufficiently correlated among a set of candidate variables must account for the multiple testing effect. Consequently Bonferroni adjustments were made to the overall alpha value of 0.05 used as a rejection criterion.

Because the response variables involved two surveys with separate sets of drainages that required separate statistical modeling, a multiple correlation test was performed on the explanatory variables of each data set. Fig. 13 shows the Pearson correlation matrix for all cumulative-effect, explanatory variables for the 53 drainages corresponding to the ODFW salmon spawning samples. Even though Bonferroni corrections (at $P=0.05$) were used, there is a serious problem because of the highly significant correlation between the SDM and HM cumulative effects (Fig. 14). Because subsets of the sites were sampled during different years, the explanatory variables of those subsets were separately analyzed. However, the significant correlation among the mining types persisted. Although there is some overlap between the types, this persistence was partly attributed to lack of proximity to upstream mining of a large proportion of the sites (Fig. 3).

Therefore, an analysis of the salmon spawning response could not proceed, because it would not be possible to distinguish between the mining activities any effects that may be indicated statistically. Impasses such as this are not uncommon when trying to impose a sampling design on existing data, and do not reflect the quality of the information in the data set.

The Pearson correlation matrix for all explanatory, cumulative-effect variables for the 59 SMART drainages is shown in Fig. 15. Here, fortunately, there were no significant (again, Bonferroni at P=0.05) correlations between SDM and any other explanatory variables. While it is not incorrect to proceed with analyses relating this set to the fish response, there are redundancies among several of the remaining 'nuisance' variables that will unnecessarily consume degrees of freedom. Also, some cover types were sparse and did not vary much among drainages (Fig. 16). There were three clusters of strongly interrelated variables that generally represented decreasing degrees of vegetation cover and, to a large extent, human disturbance: (1) agriculture, urbanization, and roads, (2) forest with less than 50% canopy, non-forest vegetation, and barren, and (3) forest with greater than 50% canopy.

The cumulative-effect variables representing these three land-use cover types, and those for the two mining activities, produced a much cleaner correlation matrix (Fig. 17). Because no land-use types from WODIP have been eliminated, and all their areas add to 100% in each drainage, there will clearly not be independence in any set. In this case, a strong negative correlation exists between set (2) and (3) (Fig. 18), indicating that one cumulative variable should be dropped. In this case, a weak correlation was indicated between variable (2) and (1), so variable (2) was eliminated, leaving a set of four variables (Urban-Ag-Roads (1), Forest >50% (3), HM (4), and SDM (5)) that were uncorrelated at the Bonferroni-corrected 5% level. This set of explanatory variables was used in the statistical analyses described below.

5.3 Linear statistical analyses

The response variable is a count of fish in a given sampled area. The fish may or may not be randomly distributed in that area. Expressing the error distribution according to the negative binomial model (White and Bennetts 1996), accounts for any additional variance, μ^2/θ , (μ = mean, θ = constant) to that corresponding to a random error as in a Poisson distribution.

The linear statistical model fit to the SMART data set was:

$$(1) \qquad Y = exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 \; \ldots\ldots \; + \beta_{34} x_3 x_4)$$

where Y = number of fish per 1000 m^2 of total pool area sampled in the reach (juvenile + adult native salmonids greater than 1 year old or YOY salmonids),

β_0 = fitted constant,

β = fitted coefficients with non-zero subscripts corresponding to the following variables:

x_1 = 'Urban-Ag-Roads' cumulative effect,

x_2 = 'Forest >50%' cumulative effect,

x_3 = Hydraulic mining (HM) cumulative effect,

x_4 = Suction dredge mining (SDM) cumulative effect,

$x_i x_j$ = all first order interaction terms between ith and jth variables ($i \neq j$),

with the error corresponding to the variance function of the negative binomial distribution:

(2) $var\ (Y) = \mu + \mu^2/\theta$

where μ = mean of count, Y

μ^2/θ = variance additional to Poisson (random) variance

θ = fitted constant

An S-Plus routine that fits the θ constant in the negative binomial model jointly with the model coefficients with an iterative procedure (Venables and Ripley 1999) was used to compute the general linear models. In the case of the stream width-to-depth ratio response, a simple Normal linear statistical model (regression) was applied.

In this study the principal interest is in whether the coefficient, β_4, that estimates the magnitude and sign of any effect of Suction dredge mining (SDM), is significantly different from zero, providing that the SDM variable, x_4, is not part of a significant interaction with another explanatory variable. Other explanatory variables need to be included because interactions with them may confound our interpretation. If the model does not indicate significant interactions, those terms are removed and the reduced model is refitted. The modelling process was repeated after dropping non-significant ($P > 0.05$) interactions. Non-significant main effects (β_i) were not dropped if they were part of a significant interaction.

5.4 Results

With the models on native salmonids greater than one year old, no significant first order interactions remained after the elimination procedure. Fig 19A illustrates a later model run with an interaction term between the two mining activities, Fig. 19B show a run with only main effects, and Fig. 19C shows a model with the least significant ($P > 0.5$) effect, suction dredge mining, removed. Only the cumulative effect of hydraulic mining (HM) indicated a modest significance (at

P = 0.03) among the main effects. It's sign was negative, indicating that the greater the severity of this activity had been, the greater the reduction in salmonids over 1 year old.

Model diagnostics are critical to assess the appropriateness of the statistical procedure and assumptions. Theoretically, deviance residuals are expected to be approximately normal (Pierce and Schafer 1986), so models producing large departures should be viewed with suspicion. A normal probability plot of the deviance residuals suggested reasonable conformity (Fig. 20). A second issue is the independence of the data used. Although the inverse distance weighting effect gave more emphasis to land-uses occurring closer to the sample site, drainage areas of several sample points overlapped to varying degrees. Also the longitudinal movement of fish populations among adjacent sites sampled in the same year may be sufficient to render the samples non-independent statistically. Therefore, spatial autocorrelation among samples could occur to a degree that the key assumption of independence of samples would be questioned. To this end, the SMART samples were ordered according to proximity 'as the fish swims' and the corresponding deviance residuals from the model (Fig. 19C) tested for spatial autocorrelation. The mean correlation among the consecutively placed samples was 0.14 with a standard error of 0.13, so autocorrelation was not close to being significant.

As a matter of interest, Fig. 21 indicates through examples the predicted increase in salmonid density in summer pools that would be expected to occur if the prevailing negative effects on habitat of hydraulic mining did not exist.

Testing the Salmonid young-of-the year (YOY) response with similar models did not produce any significant coefficients of explanatory variables or their interactions. Similarly the stream width-to-depth ratio response using simple linear models produced no significant effects. In both cases SDM coefficients were in fact positive but not remotely significant at P>0.5.

6. Discussion and Conclusions

Analyses of observational field data sets can never be expected to produce strong results compared with laboratory or field experiments (Diamond 1986; Rose 2000). This is particularly true when the sampling study has not been designed to test the specific variable of interest. However, there are not realistic alternatives because this variable, suction dredge mining, cannot be controlled or easily measured over a sufficiently larger number of drainages to provide a design robust enough to account for confounding factors and provide enough statistical power.

The statistical analyses did not indicate that suction dredge mining has no effect on the three responses measured, but rather any effect that may exist could not be detected at the commonly used Type I error rate of 0.05. The fact that the analysis was able to detect a negative effect of another mining process, HM, on native salmonids, is an indication of the long-lasting effect that hydraulic mining has had on the environment, particularly on riparian zones and floodplain sections in geomorphically unconstrained reaches (Fig. 8).

The reader is reminded of the effect of scale. Localized, short-term effects of suction dredge mining have been documented in a qualitative sense. However, on the scales occupied by fish populations such local disturbances would need a strong cumulative intensity of many operations to have a measurable effect. Local information reveals that most suction dredge miners more or less adhere to guidelines that have recently been formalized by the Forest Service (Kevin L. Johnson and John Nolan, pers. comm.) and generally in the Oregon (Bernell et al. 2003), but there are individual cases where egregious mismanagement of the immediate environment has occurred, particularly with respect to damaging river banks in various ways. This analysis cannot account for individual transgressions, and a study to do so at an appropriate scale would be very expensive if feasible.

Given that this analysis could not detect an effect averaged over good and bad miners and that a more powerful study would be very expensive, it would seem that public money would be better spent on encouraging compliance with current guidelines than on further study.

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Appendix 1. Estimation of pool dimensions from SMART calibrations.

Each set below is a regression result for habitat length and width from a specific MasterKey (stream) and observer combination. The linear regression models are:
Ln(HAB_LEN) = LHAB_LEN = CONSTANT + LEST_LEN*(Ln(EST_LEN))
Ln(HAB_WID) = LHAB_WID = CONSTANT + LEST_WID*(Ln(EST_WID))
where HAB_LEN = measured habitat length at water surface,
EST_LEN = independent visual estimate of habitat length at water surface,
CONSTANT, LEST_LEN, LEST_WID = fitted coefficients
HAB_WID = measured mean habitat width at water surface,
EST_WID = independent visual estimate of mean habitat width at water surface.

Therefore, Pool area = HAB_LEN*HAB_WID.

```
"Observer ID_Masterkey"
VARIABLE       COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T    P(2 TAIL)

"B16110300055"
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DEP VAR:LHAB_LEN      N:       39  MULTIPLE R: 0.985  SQUARED MULTIPLE R: 0.971
CONSTANT            0.160        0.132        0.000         .      1.213     0.233
LEST_LEN            0.986        0.028        0.985     1.000     35.269     0.000
DEP VAR:LHAB_WID      N:       39  MULTIPLE R: 0.931  SQUARED MULTIPLE R: 0.867
CONSTANT            0.437        0.193        0.000         .      2.266     0.029
LEST_WID            0.886        0.057        0.931     1.000     15.523     0.000

"C13110300057"
DEP VAR:LHAB_LEN      N:       20  MULTIPLE R: 0.991  SQUARED MULTIPLE R: 0.982
CONSTANT            0.043        0.141        0.000         .      0.307     0.763
LEST_LEN            1.011        0.032        0.991     1.000     31.201     0.000
DEP VAR:LHAB_WID      N:       20  MULTIPLE R: 0.753  SQUARED MULTIPLE R: 0.566
CONSTANT            0.924        0.419        0.000         .      2.205     0.041
LEST_WID            0.704        0.145        0.753     1.000      4.850     0.000

"C13110300058"
DEP VAR:LHAB_LEN      N:       20  MULTIPLE R: 0.991  SQUARED MULTIPLE R: 0.982
CONSTANT            0.043        0.141        0.000         .      0.307     0.763
LEST_LEN            1.011        0.032        0.991     1.000     31.201     0.000
DEP VAR:LHAB_WID      N:       20  MULTIPLE R: 0.753  SQUARED MULTIPLE R: 0.566
CONSTANT            0.924        0.419        0.000         .      2.205     0.041
LEST_WID            0.704        0.145        0.753     1.000      4.850     0.000

"C13110300059"
DEP VAR:LHAB_LEN      N:       20  MULTIPLE R: 0.991  SQUARED MULTIPLE R: 0.982
CONSTANT            0.043        0.141        0.000         .      0.307     0.763
LEST_LEN            1.011        0.032        0.991     1.000     31.201     0.000
DEP VAR:LHAB_WID      N:       20  MULTIPLE R: 0.753  SQUARED MULTIPLE R: 0.566
CONSTANT            0.924        0.419        0.000         .      2.205     0.041
LEST_WID            0.704        0.145        0.753     1.000      4.850     0.000

"D05110500019"
DEP VAR:LHAB_LEN      N:       44  MULTIPLE R: 0.995  SQUARED MULTIPLE R: 0.989
CONSTANT           -0.100        0.066        0.000         .     -1.515     0.137
LEST_LEN            1.037        0.017        0.995     1.000     62.325     0.000
DEP VAR:LHAB_WID      N:       44  MULTIPLE R: 0.970  SQUARED MULTIPLE R: 0.941
CONSTANT           -0.082        0.113        0.000         .     -0.722     0.474
LEST_WID            1.028        0.040        0.970     1.000     25.768     0.000

"D06110500022"
DEP VAR:LHAB_LEN      N:       18  MULTIPLE R: 0.995  SQUARED MULTIPLE R: 0.991
CONSTANT           -0.011        0.100        0.000         .     -0.107     0.917
LEST_LEN            1.001        0.024        0.995     1.000     41.996     0.000
DEP VAR:LHAB_WID      N:       18  MULTIPLE R: 0.983  SQUARED MULTIPLE R: 0.966
CONSTANT            0.175        0.108        0.000         .      1.626     0.123
LEST_WID            0.939        0.044        0.983     1.000     21.381     0.000

"D06110500023"
DEP VAR:LHAB_LEN      N:       47  MULTIPLE R: 0.991  SQUARED MULTIPLE R: 0.981
CONSTANT            0.103        0.091        0.000         .      1.135     0.262
LEST_LEN            0.979        0.020        0.991     1.000     48.780     0.000
DEP VAR:LHAB_WID      N:       47  MULTIPLE R: 0.981  SQUARED MULTIPLE R: 0.963
CONSTANT           -0.028        0.092        0.000         .     -0.308     0.760
```

```
LEST_WID             1.013        0.030         0.981      1.000   34.104      0.000

"B16110500024"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT             0.050        0.031         0.000       .        1.608     0.109
LEST_WID             0.984        0.011         0.974      1.000   86.759      0.000

"B16110500025"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT             0.050        0.031         0.000       .        1.608     0.109
LEST_WID             0.984        0.011         0.974      1.000   86.759      0.000

"B16110500026"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:      20  MULTIPLE R: 0.999  SQUARED MULTIPLE R: 0.999
CONSTANT             0.021        0.021         0.000       .        0.998     0.331
LEST_WID             0.991        0.008         0.999      1.000  119.981      0.000

"B16110500027"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT             0.050        0.031         0.000       .        1.608     0.109
LEST_WID             0.984        0.011         0.974      1.000   86.759      0.000

"B16110500043"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:      35  MULTIPLE R: 0.943  SQUARED MULTIPLE R: 0.889
CONSTANT             0.231        0.203         0.000       .        1.143     0.261
LEST_WID             0.945        0.058         0.943      1.000   16.285      0.000

"B17110500030"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
LEST_LEN             0.996        0.006         0.994      1.000  177.376      0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT             0.050        0.031         0.000       .        1.608     0.109
LEST_WID             0.984        0.011         0.974      1.000   86.759      0.000

"B17110500033"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT             0.053        0.024         0.000       .        2.239     0.026
```

```
LEST_LEN            0.996       0.006       0.994    1.000  177.376    0.000
DEP VAR:LHAB_WID     N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT            0.050       0.031       0.000      .      1.608    0.109
LEST_WID            0.984       0.011       0.974    1.000   86.759    0.000

"B17110500034"
DEP VAR:LHAB_LEN     N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT            0.053       0.024       0.000      .      2.239    0.026
LEST_LEN            0.996       0.006       0.994    1.000  177.376    0.000
DEP VAR:LHAB_WID     N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT            0.050       0.031       0.000      .      1.608    0.109
LEST_WID            0.984       0.011       0.974    1.000   86.759    0.000

"B17110500055"
DEP VAR:LHAB_LEN     N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT            0.053       0.024       0.000      .      2.239    0.026
LEST_LEN            0.996       0.006       0.994    1.000  177.376    0.000
DEP VAR:LHAB_WID     N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT            0.050       0.031       0.000      .      1.608    0.109
LEST_WID            0.984       0.011       0.974    1.000   86.759    0.000

"B18110500043"
DEP VAR:LHAB_LEN     N:      21  MULTIPLE R: 0.995  SQUARED MULTIPLE R: 0.990
CONSTANT            0.065       0.102       0.000      .      0.644    0.527
LEST_LEN            1.002       0.023       0.995    1.000   43.145    0.000
DEP VAR:LHAB_WID     N:      21  MULTIPLE R: 0.897  SQUARED MULTIPLE R: 0.804
CONSTANT            0.043       0.340       0.000      .      0.127    0.900
LEST_WID            0.979       0.111       0.897    1.000    8.822    0.000

"B19110500046"
DEP VAR:LHAB_LEN     N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT            0.053       0.024       0.000      .      2.239    0.026
LEST_LEN            0.996       0.006       0.994    1.000  177.376    0.000
DEP VAR:LHAB_WID     N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT            0.050       0.031       0.000      .      1.608    0.109
LEST_WID            0.984       0.011       0.974    1.000   86.759    0.000

"D05110500028"
DEP VAR:LHAB_LEN     N:      21  MULTIPLE R: 0.990  SQUARED MULTIPLE R: 0.981
CONSTANT           -0.175       0.115       0.000      .     -1.526    0.143
LEST_LEN            1.063       0.034       0.990    1.000   31.362    0.000
DEP VAR:LHAB_WID     N:      21  MULTIPLE R: 0.940  SQUARED MULTIPLE R: 0.883
CONSTANT            0.380       0.140       0.000      .      2.718    0.014
LEST_WID            0.811       0.068       0.940    1.000   11.981    0.000

"D06110500029"
DEP VAR:LHAB_LEN     N:      24  MULTIPLE R: 0.997  SQUARED MULTIPLE R: 0.994
CONSTANT           -0.060       0.073       0.000      .     -0.824    0.419
LEST_LEN            1.019       0.018       0.997    1.000   58.080    0.000
DEP VAR:LHAB_WID     N:      24  MULTIPLE R: 0.945  SQUARED MULTIPLE R: 0.892
CONSTANT           -0.370       0.242       0.000      .     -1.527    0.141
LEST_WID            1.106       0.082       0.945    1.000   13.502    0.000
```

```
"D06110500031"
DEP VAR:LHAB_LEN     N:      23  MULTIPLE R: 0.997  SQUARED MULTIPLE R: 0.994
CONSTANT            0.040      0.066        0.000        .      0.597     0.557
LEST_LEN            1.001      0.016        0.997     1.000    61.503     0.000
DEP VAR:LHAB_WID     N:      23  MULTIPLE R: 0.968  SQUARED MULTIPLE R: 0.938
CONSTANT            0.038      0.143        0.000        .      0.268     0.791
LEST_WID            0.989      0.056        0.968     1.000    17.793     0.000

"D06110500032"
DEP VAR:LHAB_LEN     N:      20  MULTIPLE R: 0.998  SQUARED MULTIPLE R: 0.996
CONSTANT           -0.026      0.058        0.000        .     -0.444     0.663
LEST_LEN            1.008      0.014        0.998     1.000    71.231     0.000
DEP VAR:LHAB_WID     N:      20  MULTIPLE R: 0.954  SQUARED MULTIPLE R: 0.910
CONSTANT           -0.117      0.198        0.000        .     -0.594     0.560
LEST_WID            1.044      0.077        0.954     1.000    13.503     0.000

"D06110500060"
DEP VAR:LHAB_LEN     N:      22  MULTIPLE R: 0.982  SQUARED MULTIPLE R: 0.965
CONSTANT            0.028      0.170        0.000        .      0.164     0.871
LEST_LEN            1.002      0.043        0.982     1.000    23.580     0.000
DEP VAR:LHAB_WID     N:      22  MULTIPLE R: 0.922  SQUARED MULTIPLE R: 0.851
CONSTANT            0.277      0.218        0.000        .      1.269     0.219
LEST_WID            0.891      0.083        0.922     1.000    10.673     0.000

"D06110500061"
DEP VAR:LHAB_LEN     N:      22  MULTIPLE R: 0.997  SQUARED MULTIPLE R: 0.995
CONSTANT            0.024      0.063        0.000        .      0.378     0.710
LEST_LEN            0.998      0.016        0.997     1.000    61.761     0.000
DEP VAR:LHAB_WID     N:      22  MULTIPLE R: 0.971  SQUARED MULTIPLE R: 0.944
CONSTANT            0.077      0.129        0.000        .      0.595     0.558
LEST_WID            0.968      0.053        0.971     1.000    18.297     0.000

"D06110500062"
DEP VAR:LHAB_LEN     N:      22  MULTIPLE R: 0.986  SQUARED MULTIPLE R: 0.972
CONSTANT            0.162      0.141        0.000        .      1.147     0.265
LEST_LEN            0.973      0.037        0.986     1.000    26.459     0.000
DEP VAR:LHAB_WID     N:      22  MULTIPLE R: 0.986  SQUARED MULTIPLE R: 0.972
CONSTANT           -0.013      0.094        0.000        .     -0.143     0.888
LEST_WID            1.006      0.038        0.986     1.000    26.320     0.000

"D06110500063"
DEP VAR:LHAB_LEN     N:      20  MULTIPLE R: 0.980  SQUARED MULTIPLE R: 0.961
CONSTANT            0.243      0.168        0.000        .      1.447     0.165
LEST_LEN            0.952      0.045        0.980     1.000    21.088     0.000
DEP VAR:LHAB_WID     N:      19  MULTIPLE R: 0.897  SQUARED MULTIPLE R: 0.804
CONSTANT            0.370      0.221        0.000        .      1.670     0.113
LEST_WID            0.820      0.098        0.897     1.000     8.350     0.000

"D06110500064"
DEP VAR:LHAB_LEN     N:      26  MULTIPLE R: 0.997  SQUARED MULTIPLE R: 0.994
CONSTANT            0.017      0.062        0.000        .      0.278     0.783
LEST_LEN            1.002      0.016        0.997     1.000    62.348     0.000
DEP VAR:LHAB_WID     N:      26  MULTIPLE R: 0.911  SQUARED MULTIPLE R: 0.830
```

```
CONSTANT              0.017        0.188        0.000       .        0.090     0.929
LEST_WID              0.986        0.091        0.911     1.000     10.820     0.000

"D06110500065"
DEP VAR:LHAB_LEN       N:      28  MULTIPLE R: 0.992  SQUARED MULTIPLE R: 0.985
CONSTANT              0.094        0.092        0.000       .        1.029     0.313
LEST_LEN              0.991        0.024        0.992     1.000     41.150     0.000
DEP VAR:LHAB_WID       N:      28  MULTIPLE R: 0.962  SQUARED MULTIPLE R: 0.926CONSTANT
0.024        0.144        0.000        .        0.170      0.866
LEST_WID              0.998        0.055        0.962     1.000     18.048     0.000

"D07110500056"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT              0.053        0.024        0.000       .        2.239     0.026
LEST_LEN              0.996        0.006        0.994     1.000    177.376     0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT              0.050        0.031        0.000       .        1.608     0.109
LEST_WID              0.984        0.011        0.974     1.000     86.759     0.000

"D08110500066"
DEP VAR:LHAB_LEN       N:      39  MULTIPLE R: 0.998  SQUARED MULTIPLE R: 0.996
CONSTANT             -0.019        0.049        0.000       .       -0.393     0.696
LEST_LEN              1.000        0.010        0.998     1.000     97.917     0.000
DEP VAR:LHAB_WID       N:      39  MULTIPLE R: 0.969  SQUARED MULTIPLE R: 0.939
CONSTANT              0.469        0.108        0.000       .        4.355     0.000
LEST_WID              0.853        0.036        0.969     1.000     23.924     0.000

"D10110500085"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT              0.053        0.024        0.000       .        2.239     0.026
LEST_LEN              0.996        0.006        0.994     1.000    177.376     0.000
DEP VAR:LHAB_WID       N:     411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT              0.050        0.031        0.000       .        1.608     0.109
LEST_WID              0.984        0.011        0.974     1.000     86.759     0.000

"D10110500086"
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT              0.053        0.024        0.000       .        2.239     0.026
LEST_LEN              0.996        0.006        0.994     1.000    177.376     0.000
DEP VAR:LHAB_WID       N:      38  MULTIPLE R: 0.995  SQUARED MULTIPLE R: 0.990
CONSTANT              0.028        0.041        0.000       .        0.685     0.498
LEST_WID              0.987        0.016        0.995     1.000     60.364     0.000
```

The following bias corrections, based on observers who had consistently valid calibrations across streams, were used in reaches where unsatisfactory calibration data sets were encountered. Those were deemed unsatisfactory because they had identical values for estimates and measurements of pool length and depth, and comprised 42% of all data.

```
DEP VAR:LHAB_LEN       N:     411  MULTIPLE R: 0.994  SQUARED MULTIPLE R: 0.987
CONSTANT              0.053        0.024        0.000       .        2.239     0.026
LEST_LEN              0.996        0.006        0.994     1.000    177.376     0.000
```

```
DEP VAR:LHAB_WID       N:       411  MULTIPLE R: 0.974  SQUARED MULTIPLE R: 0.948
CONSTANT             0.050        0.031        0.000          .        1.608    0.109
LEST_WID             0.984        0.011        0.974      1.000    86.759    0.000
```

Appendix 2. Rationale for representing the effect of a land-use on a stream reach.

It is intuitive that the greater the distance a land-use is from the location of a measured response, the lesser will be its potential impact. An analogy is provided by the simple inverse square distance law of light intensity: The intensity from a point source of light is inversely related to the distance from the source. The intensity, I_1, at distance r_1 changes to I_2 at greater distance r_2 according to the increasing surface area of a sphere of radius r with the light source at the center:

$$I_1 4\pi r_1{}^2 = I_2 4\pi r_2{}^2$$

If the inner sphere 1 is unit distance (say one pixel from the source) , then the intensity I_2 at distance r_2 is reduced relative to I_1 thus:

$I_2 / I_1 = 1/r_2{}^2$; hence the inverse square law.

However, this represents a decay in energy intensity in three dimensions. While at that extreme one could envisage loss in the effect of intensity of a land-use in three dimensions (e.g., a pollution effect dissipating outwards and downwards into the water table), one can also envisage some effects (e.g. the distribution of large wood, which decays very slowly, down a stream from a riparian source) as being one-dimensional. Between these extremes, the predominantly two-dimensional nature of landscapes at the scale of drainages containing 2nd to 4th order streams probably mediates the decay of most processes over distance, even when considering the relatively shallow layers of groundwater or hyporheic zones. Therefore, the decay of intensity in two dimensions would be equivalent to that of a light source in a circle of perimeter $2\pi r$:

$$I_1 2\pi r_1 = I_2 2\pi r_2$$

or $$I_2 / I_1 = 1/r_2$$

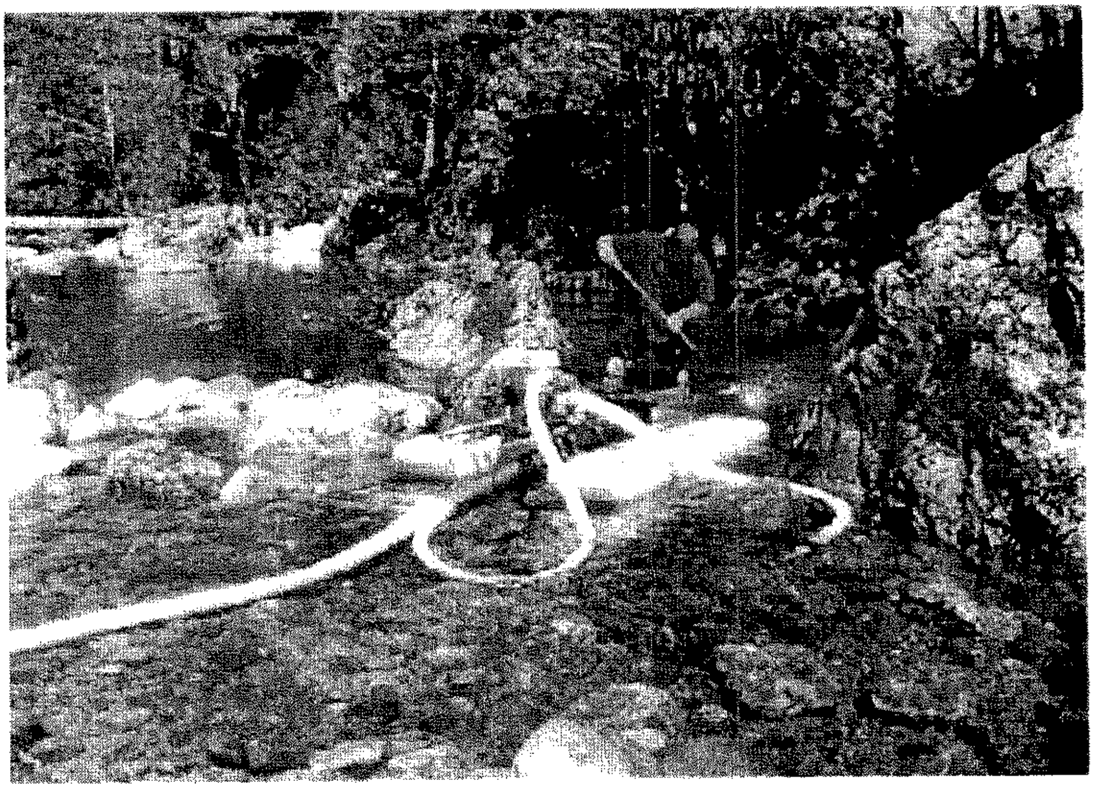
Hence the inverse rule that has been adopted in this analysis (Fig. 11).

The software, ZOI, produces inverse and inverse square measures. It also produces separate measures for instream and out-of-stream distance components from each pixel. While theoretical arguments can be made for combinations of these alternatives there are statistical limitations.

First, splitting the distance into instream and out-of-stream components doubles the number of coefficients that need to be fitted in the statistical analysis. This reduces degrees of freedom, and therefore power, and also increases the probability of lack of independence among variables or significant interactions between them. To attempt to resolve these issues a designed, stratified study covering many more drainages than in this study would be necessary.

Second, while it is tempting to repeat the statistical analysis using alternative derivations of effects (such as inverse and inverse squared variables), this compromises the meaning of the adopted error rate (e.g., the conventional 5% alpha level). In other words, unless one takes the required penalty of lowering the effective significance level to account for multiple testing, one can be accused of undertaking a 'fishing expedition' with the data set.

Fig. 1. Typical suction dredge mining activities.
(photographs by Kevin L. Johnson)



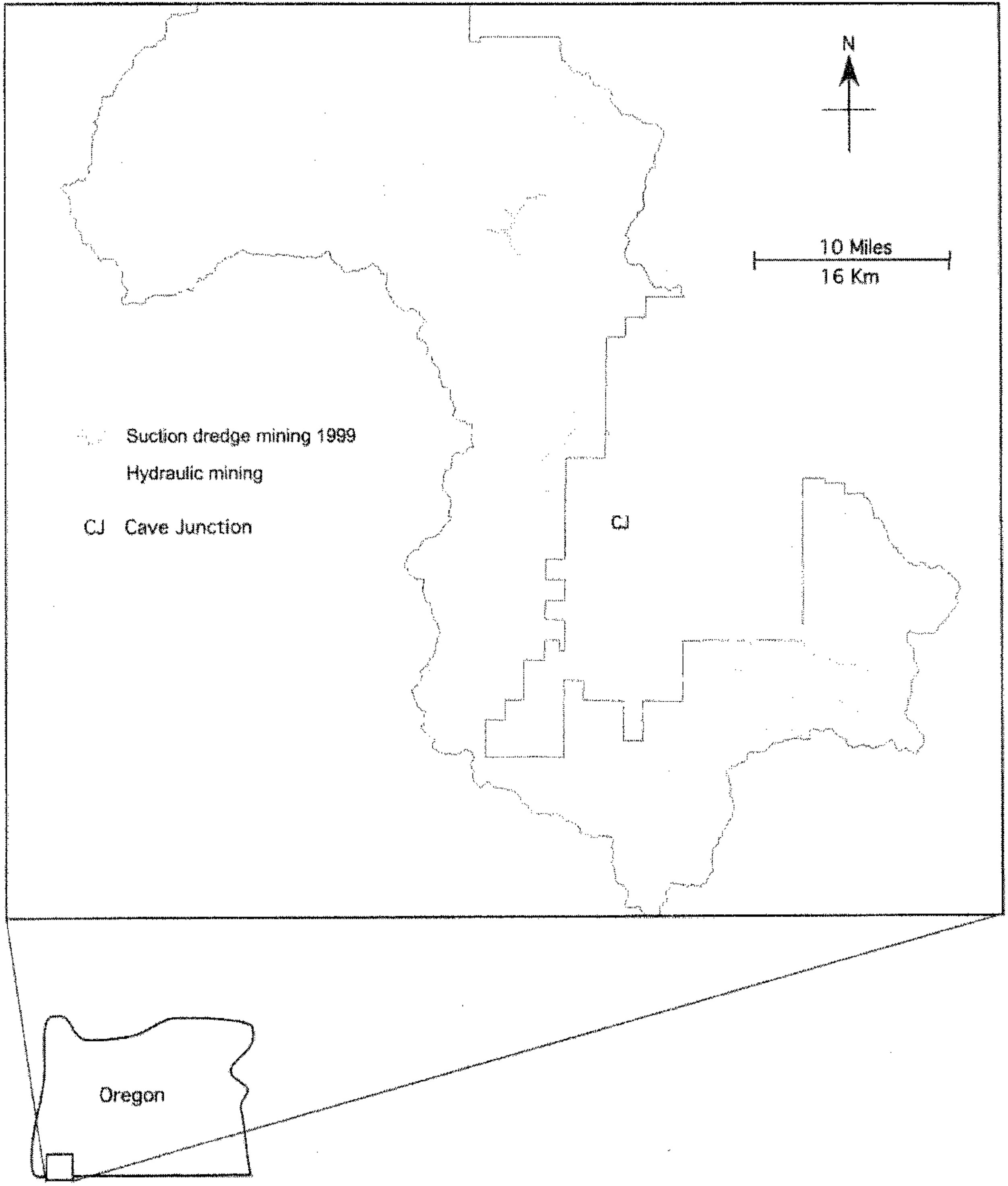


Fig. 2. Illinois river subbasin and location, showing reaches where suction dredge mining activities and early hydraulic mining occurred. Black line shows boundary of the Siskiyou National Forest.

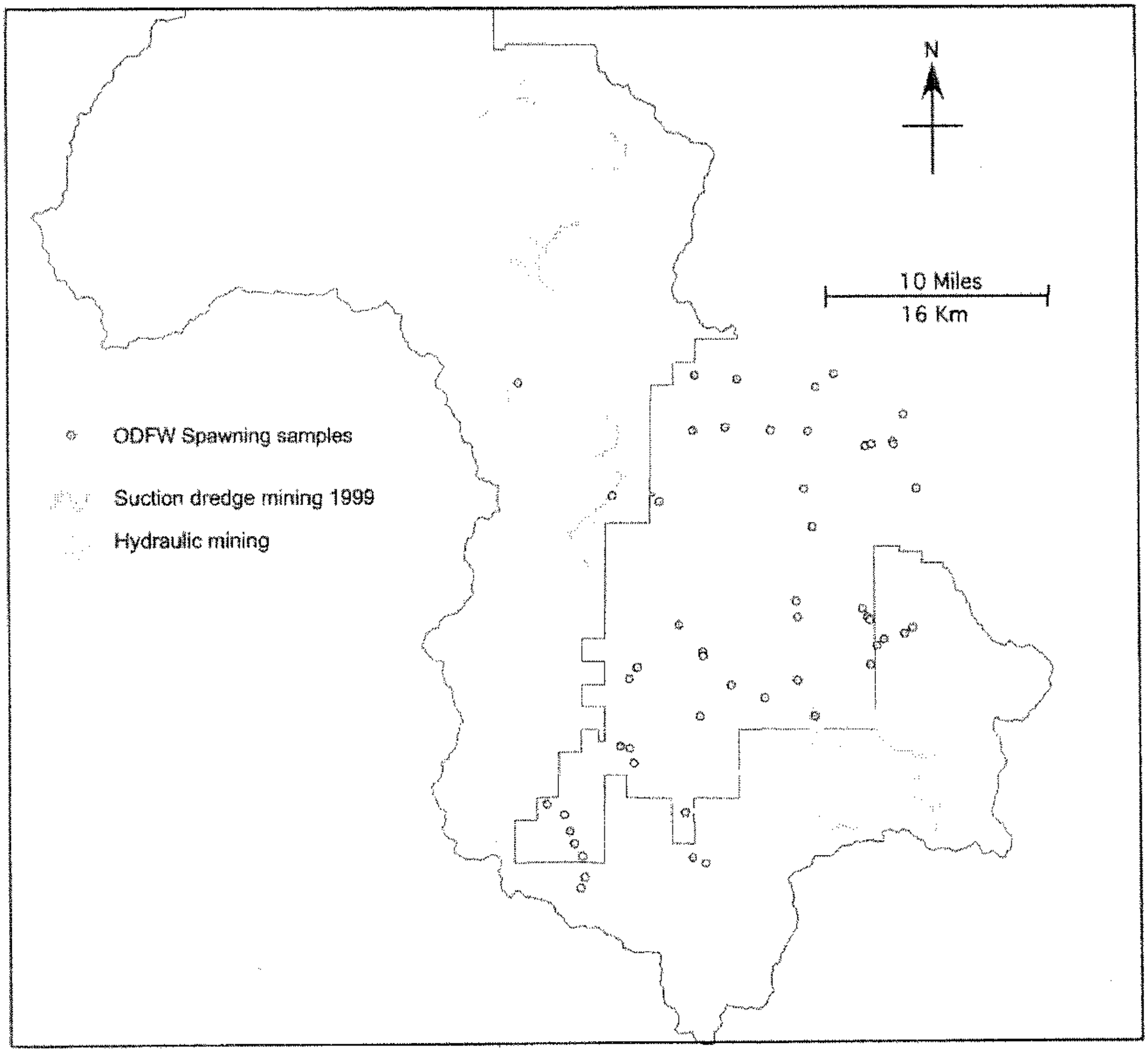


Fig. 3. Locations of ODFW Salmonid spawning stations from 1995-2000 (downstream starting points of reaches sampled) in Illinois subbasin, and reaches where suction dredge mining activities and early hydraulic mining occurred. Black line shows boundary of the Siskiyou National Forest.

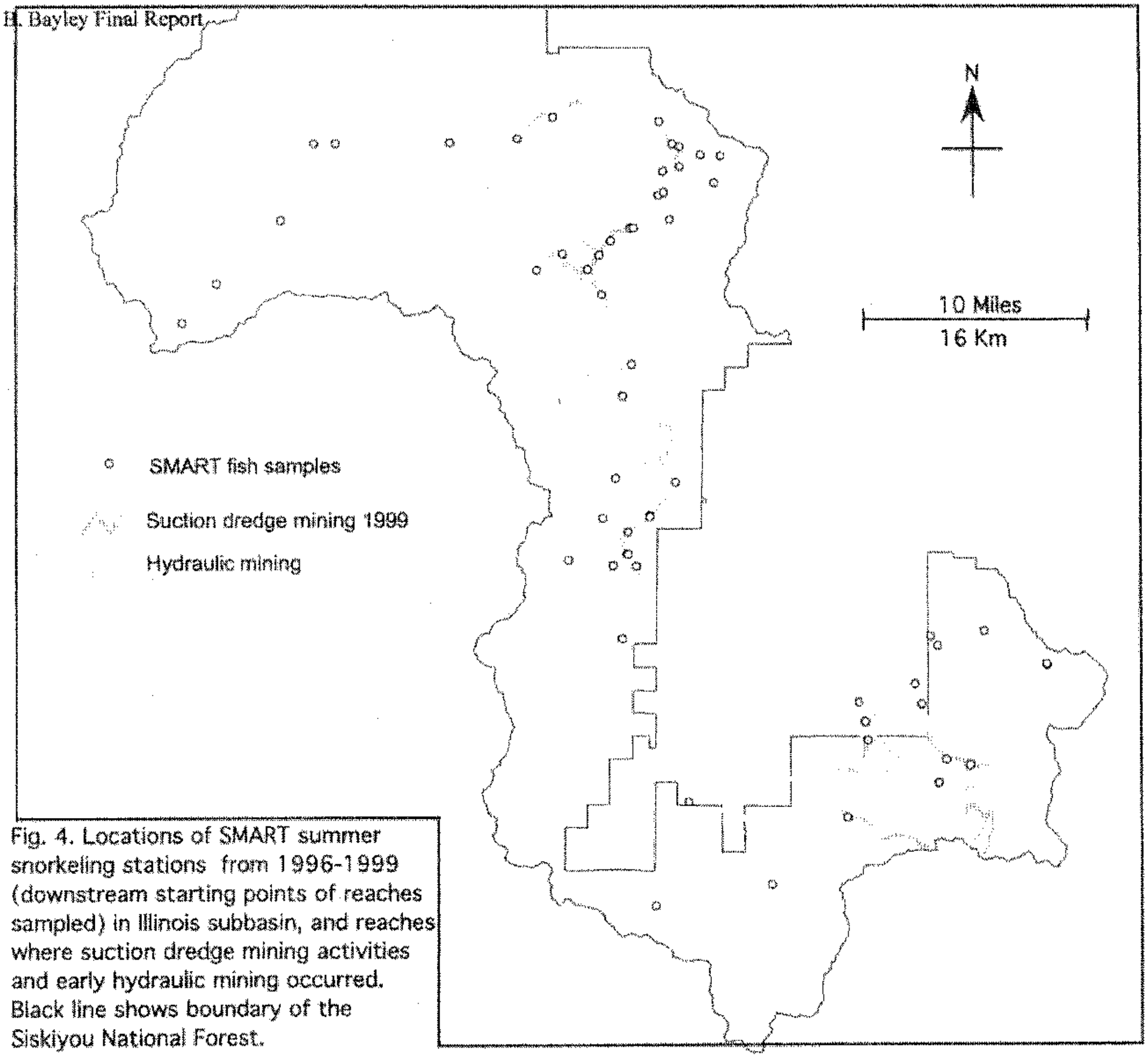


Fig. 4. Locations of SMART summer snorkeling stations from 1996-1999 (downstream starting points of reaches sampled) in Illinois subbasin, and reaches where suction dredge mining activities and early hydraulic mining occurred. Black line shows boundary of the Siskiyou National Forest.

Common name	Scientific name	Total No. individuals observed	No. Pools species was observed	No. reaches species was observed
Rainbow trout*	Oncorhynchus mykiss	5368	531	55
Coastal cutthroat trout	Oncorhynchus clarki	335	127	34
Coho salmon	Oncorhynchus kisutch	21	9	4
Brook trout*	Salvelinus fontinalis	5	5	1
sculpins**	Cottus spp.	257	33	16
Redside shiner	Richardsonius balteatus	93	4	2
Northern pikeminnow	Ptychocheilus oregonensis	84	8	3
Aggregate values		6163	610	59
Total number of units sampled			611	59

* introduced species **enumerated in about half of pools sampled

Fig. 5. Numbers of fish observed by species, and numbers of pools and reaches in which separate species and all taxa were observed from 59 SMART summer snorkeling reaches visited from 1996-1999. Fish observed in non-pool habitats were excluded here and from the analysis.

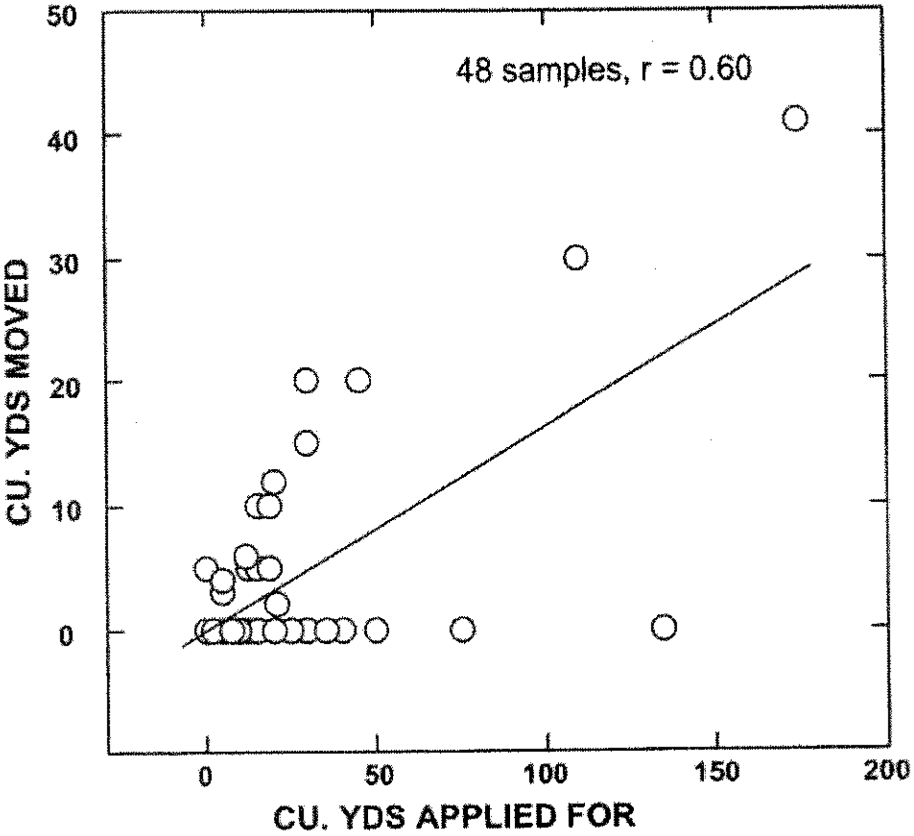


Fig. 6. Sediment moved by independent suction dredge mining operations in 1999. [x-axis = amount estimated prior to season; y-axis = amount moved downstream during season. Least squares regression line shown]
(source: Kevin Johnson, USFS, Grants Pass, OR)

Fig. 7. Examples of late 19th Century hydraulic mining (photograph at left by Norne 1900)

P. B. Bayley

Fig. 8. Sucker Creek floodplain in 2001 that was subject to 19th Century hydraulic mining.

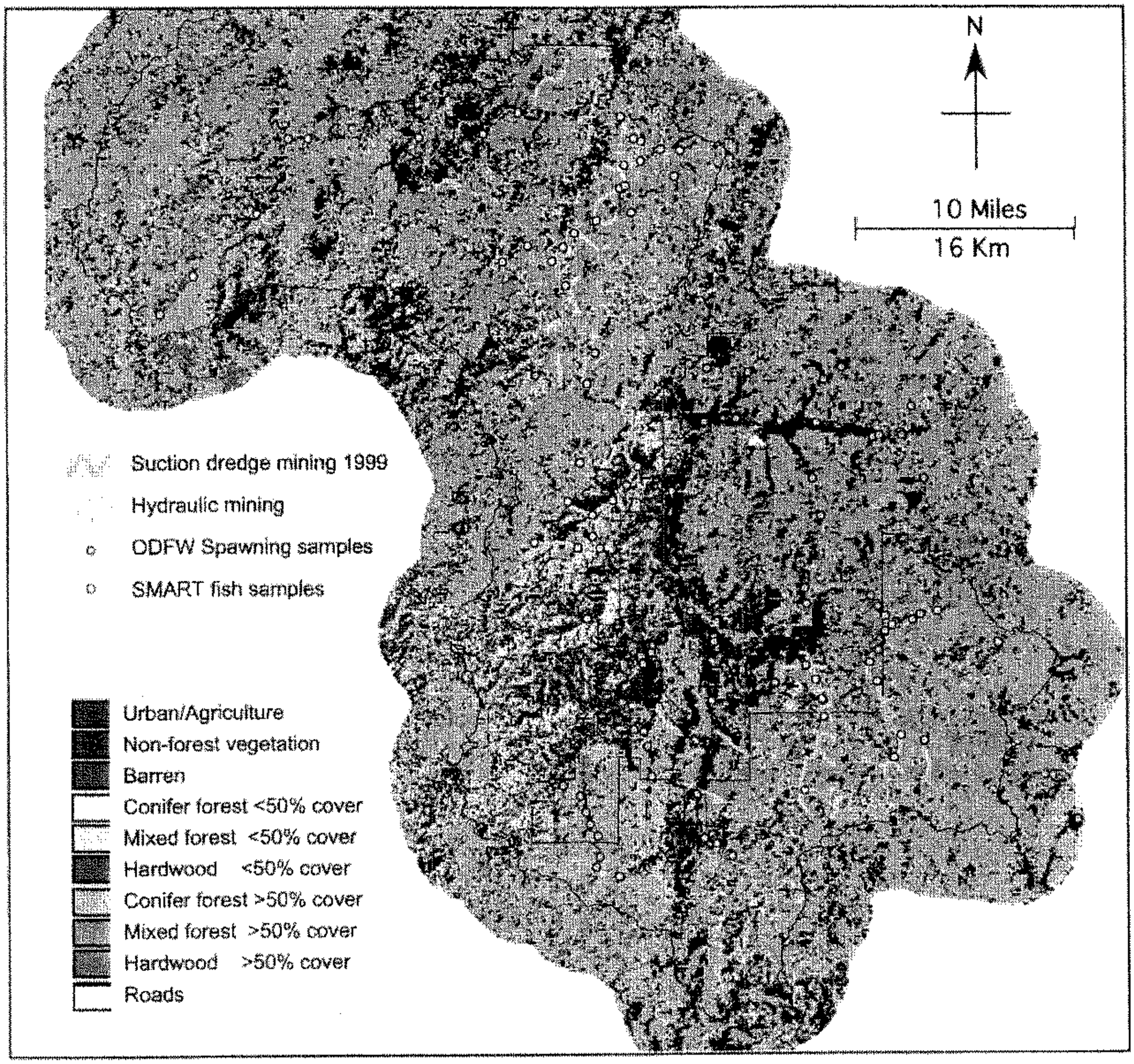


Fig. 9. WODIP classification of land-cover types in the Illinois subbasin, fish sample locations, and reaches where suction dredge mining activities and early hydraulic mining occurred. (Roads are are too fine to be observable at this scale.) Black line shows boundary of the Siskiyou National Forest.

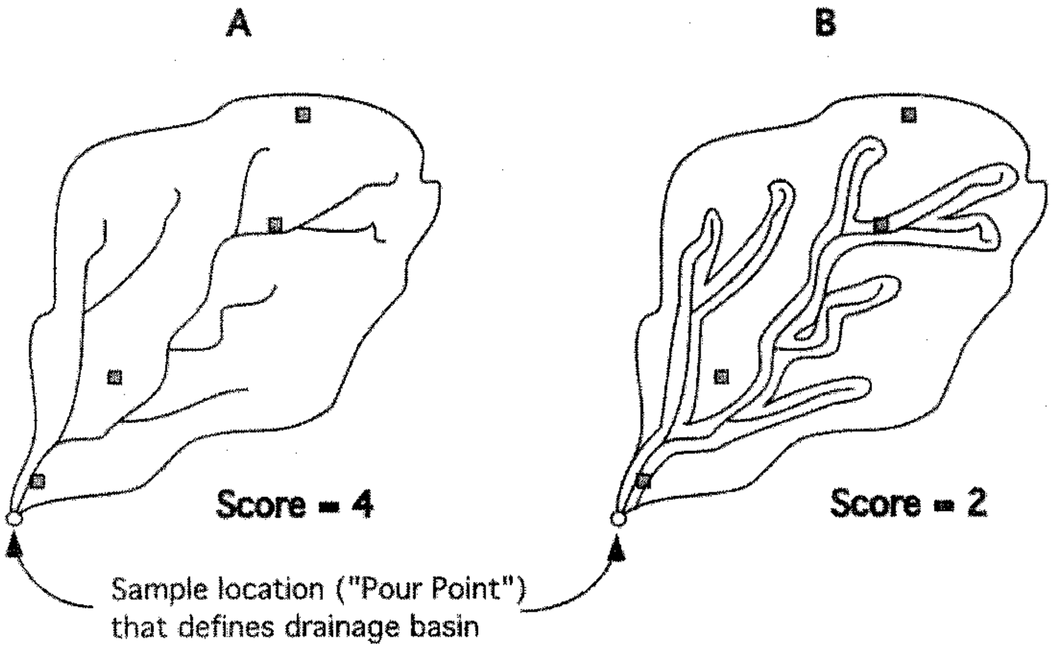
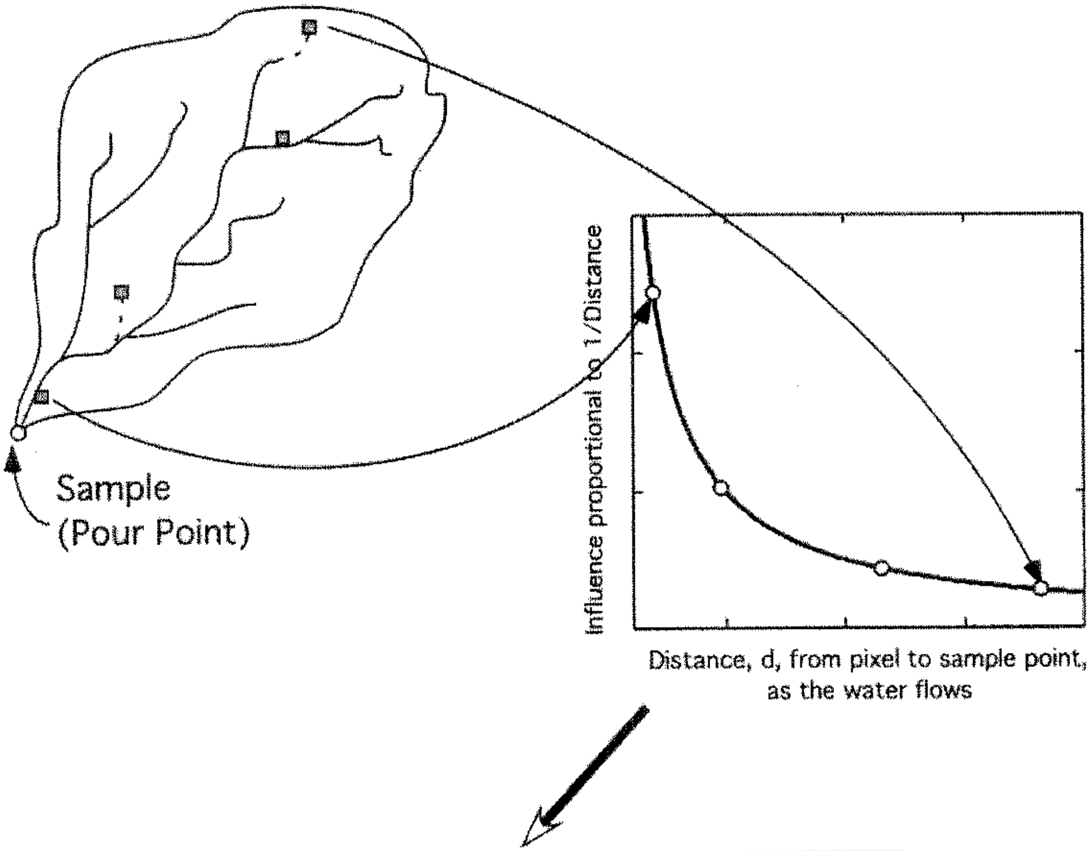
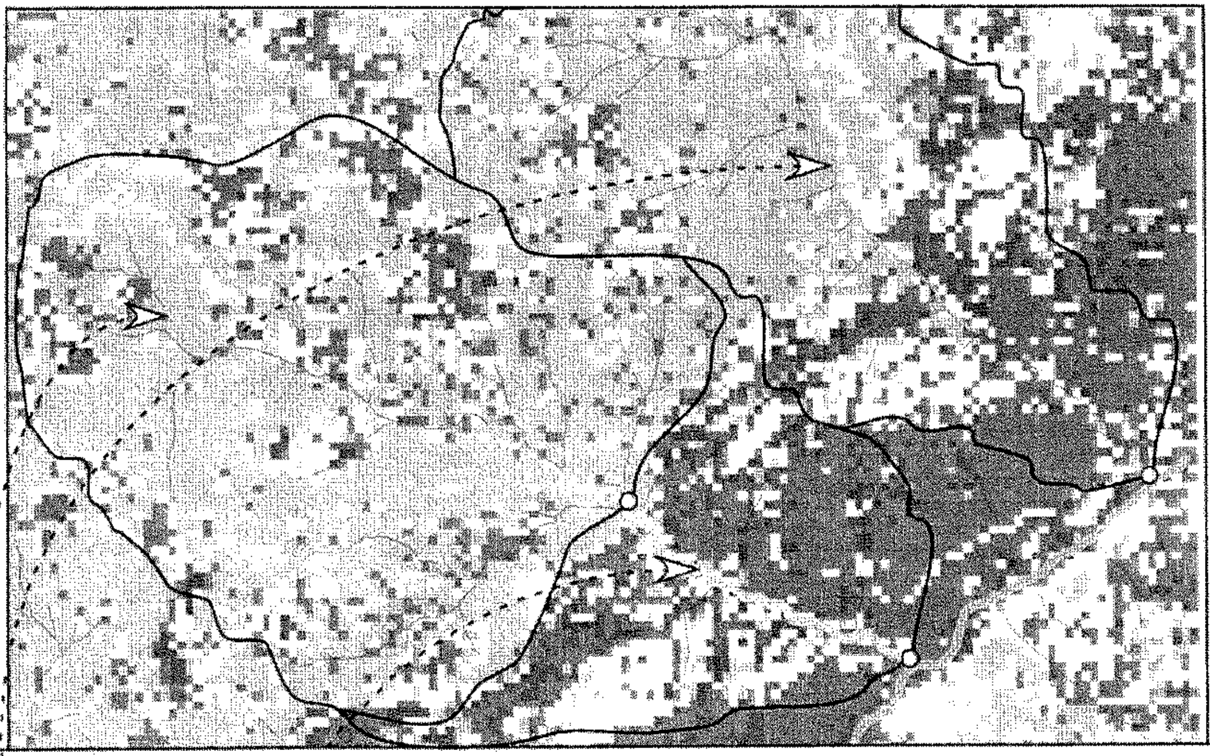


Fig. 10. Examples of scoring land-use classifications for potential influence on a stream sample (A) All pixels for a given classification in the drainage basin summed, (B) Only pixels falling within a defined buffer zone arounf permanent stream are summed.



$$\text{Total potential influence score} = \frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4}$$

Fig. 11. Example of scoring land-use classifications for potential influence on a stream sample in which all pixels for a given classification are weighted by their inverse distance to the sample location and summed (dotted lines show flow paths overland from off-channel pixels determined by a flow map derived from a 10-m DEM (Digital Elevation Map)).



Stream	1/Distance weights (Percent coverage in basin)				
	Ag-Urban -Roads	<50% Forest	>50% Forest	Hydraulic Mining	Dredge Mining
Days Gulch	4.7 (5.2)	68 (49)	27 (46)	14 (1)	7.5 (12)
Fiddler Gulch	2.4 (3.2)	63 (46)	35 (51)	36 (11)	0 (0)
Fiddler Gulch (upper)	3.8 (4.3)	28 (29)	69 (67)	27 (3.4)	0 (0)

▨ Urban/Agriculture
▨ Non-forest vegetation
▨ Barren
☐ Conifer forest <50% cover
☐ Mixed forest <50% cover
▨ Hardwood <50% cover
▨ Conifer forest >50% cover
▨ Mixed forest >50% cover
▨ Hardwood >50% cover
☐ Roads

Suction dredge mining (SDM) 1999
Hydraulic mining
○ SMART fish samples
Drainage basin boundaries (sketched)

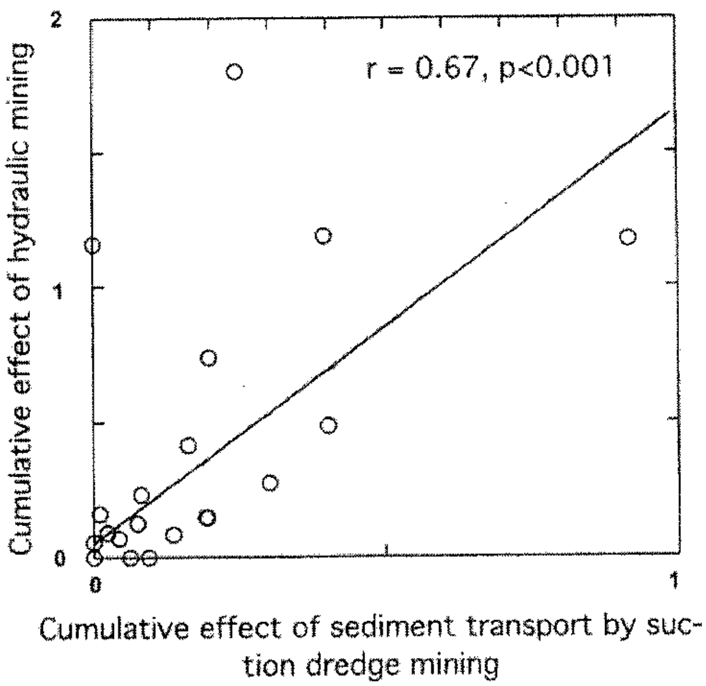
Fig. 12. Example of distribution of original land-use and mining classifications (25-by-25-m pixels), showing three SMART fish sampling locations in Josephine Creek basin, and explanatory variable results. Table shows inverse distance weighting measures for aggregated land-use and mining classifications, which were the explanatory variable values used, in the three drainages. (Percent coverage values based on sums of pixels are shown in parentheses for comparison)

	Urban -Ag	Non-For _Veg	Barren	Forest <50% canopy Conifer	Forest <50% canopy Mixed	Forest <50% canopy Hwood	Forest >50% canopy Conifer	Forest >50% canopy Mixed	Forest >50% canopy Hwood	Roads	Hydraul Mining	Suction Dredge Mining
Urban-Ag	1.000											
Non-For_Veg	0.12	1.000										
Barren	0.152	0.770***	1.000									
Con_For<50%	0.019	0.710***	0.667***	1.000								
Mix_For<50%	0.282	0.405	0.399	0.422	1.000							
Hwd_For<50%	-0.510**	-0.519**	-0.443	-0.504**	-0.757***	1.000						
Con_For>50%	-0.469*	-0.893***	-0.758***	-0.759***	-0.527**	0.659***	1.000					
Mix_For>50%	-0.464*	-0.790***	-0.770***	-0.572**	-0.353	0.569**	0.824***	1.000				
Hwd_For>50%	-0.333	-0.577***	-0.501**	-0.585***	-0.444	0.743***	0.595***	0.632***	1.000			
Roads	-0.300	0.015	-0.157	0.076	-0.399	0.179	0.051	-0.019	-0.100	1.000		
HM	-0.210	0.055	0.257	0.298	0.019	-0.189	-0.043	-0.099	-0.280	0.334	1.000	
SDM	-0.203	0.133	0.406	0.366	-0.121	-0.045	-0.142	-0.179	-0.225	0.442	0.670***	1.00

Fig. 13. PEARSON CORRELATION MATRIX of cumulative effects of drainages defined by 53 ODFW salmon spawning samples. Bonferroni-corrected probabilities: * $P<0.05$, ** $P<0.01$, **$P<0.001$.

(Urban-Ag = Urban and agriculture areas combined; Non-For_Veg = Non-forest vegetation; HM = Hydraulic mining; SDM = Suction Dredge Mining)

Fig. 14. CORRELATION between cumulative effects of Hydraulic mining and Suction Dredge Mining from drainages defined by 53 ODFW salmon spawning samples.



				Forest <50% canopy			Forest >50% canopy					Suction
	Urban -Ag	Non-For _Veg	Barren	Conifer	Mixed	Hwood	Conifer	Mixed	Hwood	Roads	Hydraul Mining	Dredge Mining
Urban-Ag	1.000											
Non-For_Veg	-0.022	1.000										
Barren	-0.070	0.825**	1.000									
Con_For<50%	0.025	0.835**	0.890**	1.000								
Mix_For<50%	-0.178	0.530**	0.442*	0.509**	1.000							
Hwd_For<50%	-0.081	0.157	0.072	0.155	0.078	1.000						
Con_For>50%	0.009	-0.947**	-0.875**	-0.927**	-0.634**	-0.217	1.000					
Mix_For>50%	0.060	-0.647**	-0.759**	-0.640**	-0.098	0.239	0.575**	1.000				
Hwd_For>50%	0.017	-0.427*	-0.482**	-0.497**	-0.115	0.377	0.364	0.473*	1.000			
Roads	-0.063	-0.303	-0.352	-0.433*	-0.340	-0.448*	0.333	0.015	0.080	1.000		
HM	-0.117	-0.111	0.022	-0.017	-0.066	-0.309	0.118	-0.079	-0.343	0.039	1.000	
SDM	-0.045	-0.049	0.034	-0.011	-0.112	-0.145	0.078	-0.106	-0.113	-0.057	0.255	1.00

Fig. 15. Pearson correlation matrix of cumulative effects of drainages defined by 59 SMART samples. Bonferroni-corrected probabilities: * P<0.05, ** P<0.01, **P<0.001.
(Urban-Ag = Urban and agriculture areas combined; Non-For_Veg = Non-forest vegetation; HM = Hydraulic mining; SDM = Suction Dredge Mining)

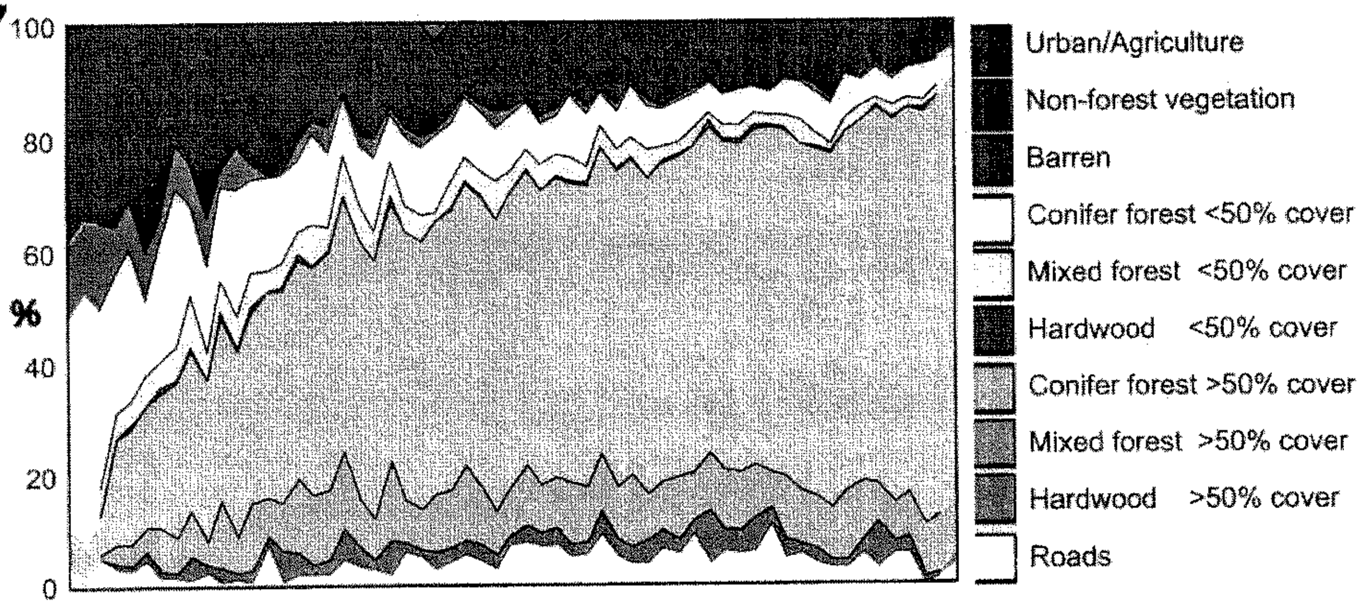


Fig. 16. Proportions of WODIP-based explanatory variables, by area of drainage occupied, from drainages defined by 59 SMART fish samples. (Samples ordered on x-axis by increasing canopy >50% of all forest to illustrate ranges of explanatory variables. The legend identifies the variables in the same order as shown on the graph).

	Urban + Agric. + Roads	Forest <50% canopy + Non-For_Veg + Barren	Forest >50% canopy	Hydraulic Mining	Suction Dredge Mining
(1) Urban-Ag-Roads	1.00				
(2) For.<50%+Non-For.+Barren	-0.401*	1.00			
(3) Forest >50% canopy	0.299	-0.994***	1.00		
(4) Hydraulic Mining	0.019	-0.061	0.059	1.00	
(5) Suction D. Mining	-0.064	-0.031	0.040	0.255	1.00

Fig. 17. PEARSON CORRELATION MATRIX of reduced set of cumulative effects of drainages defined by 59 SMART samples. Bonferroni-corrected probabilities: * P<0.05, ** P<0.01, **P<0.001. [see text for (1), (2), etc.,].
(Urban-Ag-Roads = Urban, agriculture and road areas combined;
For.<50%+Non-For.+Barren = +Forest less than 50% canopy, Non-forest vegetation, and barren areas combined)

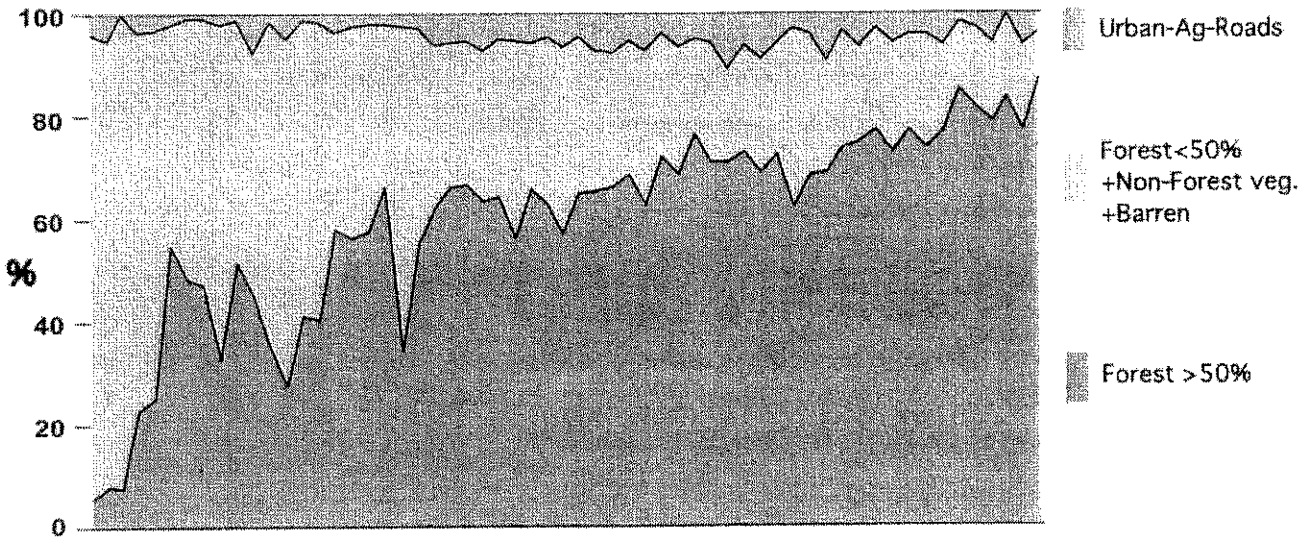


Fig. 18. Proportions of reduced WODIP-based explanatory variables, by area of drainage occupied, from drainages defined by 59 SMART fish samples.

(A) Model: Response: Density of Salmonids 1yr-old
Explan. vars.: Ag-Urban-Roads + Forest>50% + Hydraulic Mining
+ Suction Dredge Mining + Hydraulic Mining*Suct.Mining

Coefficients:

	Value	SE	t-value
(Intercept)	4.04		
Ag-Urban-Roads	-4.96	5.65	-0.88
Forest>50%	0.39	0.73	0.53
Hydraul.Mining	-0.40	0.19	-2.04#
Suct.Mining	-0.33	0.29	-1.16
Hydraul.*Suct.Mining	0.25	0.23	1.06

(B) Model: Response: Density of Salmonids 1yr-old
Explan. vars.: Ag-Urban-Roads + Forest>50% + Hydraulic Mining
+ Suction Dredge Mining

Coefficients:

	Value	SE	t-value
(Intercept)	3.86		
Ag-Urban-Roads	-5.45	5.68	-0.96
Forest >50%	0.66	0.68	0.97
Hydraul.Mining	-0.36	0.19	-1.90
Suct.Mining	-0.05	0.08	-0.56

(C) Model: Response: Density of Salmonids 1yr-old
Explan. vars.: Ag-Urban-Roads + Forest>50% + Hydraul.Mining

Coefficients:

	Value	SE	t-value
(Intercept)	3.85		
Ag-Urban-Roads	-5.46	5.67	-0.96
Forest >50%	0.68	0.67	1.00
Hydraulic Mining	-0.38	0.18	-2.13# (P=0.03)

Fig. 19. General linear model results using negative binomial fits to 59 SMART fish samples on the density of Native Salmonids ≥1yr-old (* = interaction between two variables; # signidicant coefficient at P<0.05; see text for refs. to A, B, and C).

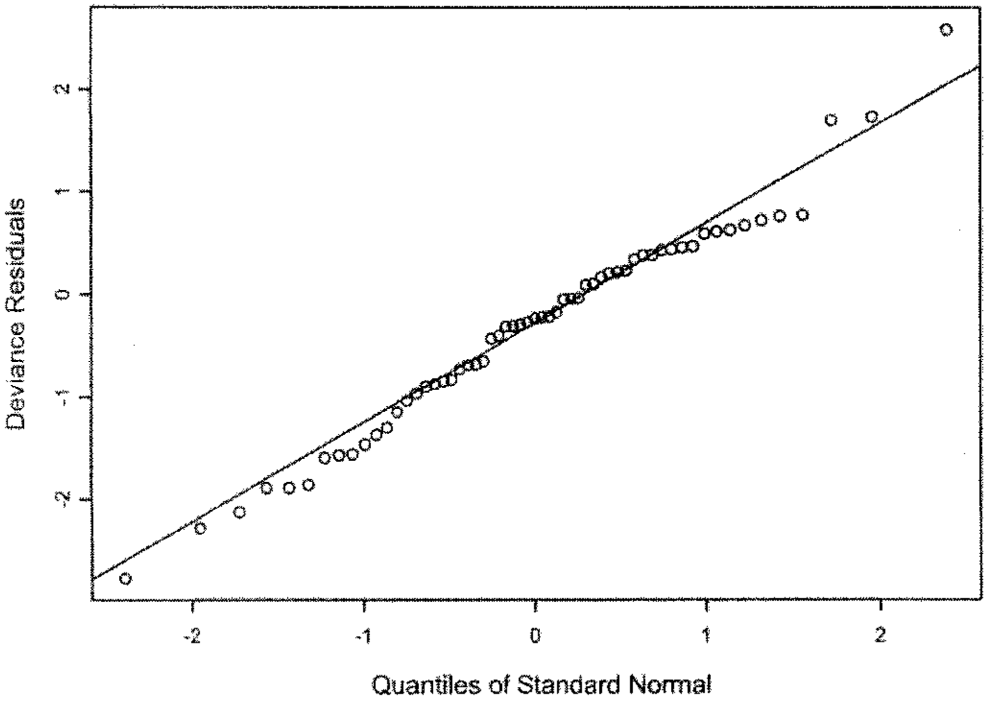


Fig. 20. Normal probability plot of deviance residuals from model in Fig. 19C.

	Predicted density if Hydraulic Mining had		
	existed as recorded,	or, not occurred	Predicted change
Althouse Creek (lower)	30	52	71%
Josephine Creek (mouth)	30	45	50%
Days Gulch (mouth)	39	43	12%

Model: Density of Salmonids 1yr-old (#/1000 m^2)
= exp(3.85-5.46*Ag-Urban-Roads + 0.68*Forest>50% - 0.38*Hydraul.Mining)

Fig. 21. Predicted change in salmonid density (older that YOY) in selected streams if hydraulic mining effect had not occurred.

Effects of Recreational Suction Dredge Operations on Fish and Fish Habitat.

Konopacky Environmental

Final Report - 1996

Project No. 064-0

"The effects of REGULATED suction dredge mining are insignificant"