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Monitoring Spawning Gravel in Managed Forested Watersheds

A Proposed Procedure

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MONITORING SPAWNING GRAVEL IN MANAGED FORESTED WATERSHEDS

A Proposed Procedure

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report proposes procedures which can be used to monitor the effects of watershed manipulations on spawning gravels of salmonid fishes.

CONTENTS

1. OBJECTIVE

Silvicultural activities in the Pacific Northwest introduce various levels of sediments and debris into streams, often degrading spawning habitats of salmonid fishes. In these mountain streams spawning takes place in riffles where the water velocity is usually 1.5 to 2.5 ft/sec and water is 6 to 36 inches deep. The substrate in these riffles are ideal habitats for aquatic insects which in turn respond adversely to excessive sedimentation. For these reasons, the study of spawning habitats could provide a relatively simple and sensitive indicator of watershed management impacts.

Simple but reliable procedures are needed to monitor spawning substrate to assess the level of these impacts. This paper presents a preliminary rationale for conducting a monitoring program to assess the impact of watershed management activities on stream spawning habitats; both on individual spawning sites as well as for the entire stream.

There are many problems in developing a program that is simple yet reliable under varied conditions. A major difficulty is the absence of comprehensive and reliable historical data that document these types of impacts. It is hoped that the procedure outlined here will provide the groundwork for a serious effort in compiling a comprehensive data base to simplify future studies and increase their reliability.

2. Site Selection

The primary requirement for stream site selection is that the gravel must have been used by fish for spawning. This information is usually available from the State's Regional Fisheries Biologist. Since most monitoring work must be done during low flow periods, the knowledge that the area has been used for spawning eliminates the need to forecast appropriate flow level and water velocity requirements during and after spawning at a given site.

Once a site is selected, the areal extent and the quality of the spawning gravel must be determined. Numerous approaches have been made. For example, Platts (1974) established monitoring transects across the stream at equally spaced distances along a spawning area. He then selected two or more samples along these fixed transects, identifying those samples that were within redds or in non-redd areas. Corley (1978) selected a parcel of gravel, about 25 by 25 feet in a spawning area. Then he randomly picked several gravel samples from within this area for analysis. Koski (1966) conducted gravel analyses from samples taken within actual redds.

After analyzing results from these investigations it appears that reasonable balance can be achieved between an acceptable reliability and minimum number of samples by (a) estimating the area of the gravel in the site that is potentially usable by fish and (b) within this area, selecting representative samples to provide a quantitative measure of the range of conditions and thus the quality of the gravel. This proposed procedure will be discussed in the remainder of this paper.

The exact boundary of the spawning gravel is difficult to identify with precision. The gravel may be patchy, interspersed with boulders, gravel spots and sandy spots. As an extreme example, if the flow conditions are suitable, a steelhead trout might be able to dig a redd in an area as small as 1 by 3 feet. Under more ideal conditions the spawning gravel would be as wide as half the width of the riffle or even extending along the entire stream width. The gravel patch can be as long, even many times longer than it is wide. It is normally uniform in composition which simplifies identification.

Once the approximate boundaries of the gravel areas are identified within a riffle, the total usable area should be estimated with no particular attention to patch geometry or distribution within the riffle.

For the purpose of monitoring possible impacts of logging, road construction, etc., several gravel areas both upstream and downstream from anticipated impact areas should be surveyed. Changes in the magnitude and gravel quality of these areas can be used systematically to record impact.

After a heavy storm, gravel bars and patches shift, shrink or expand and change composition. When assessing cultural impacts, results must be interpreted with caution and reliability in separating the natural from cultural events must not be anticipated. This interpretation is critical since it determines the level of accuracy and more important, the amount of effort that must be devoted to the task. It is at best an order of magnitude analysis, distinguishing only the major impacts. More subtle impacts may be detected only with an extensive data base.

3. Number of Samples Within Each Site

Analysis of large quantities of data from Platts (1967, 1972), Koski (1966) and Corely (1978) presents a convincing argument that sampling of gravel cannot and should not become a purely statistical exercise. Koski (1966) studied numerous Coho salmon redds and analyzed three gravel samples within each redd. He found a two-fold variation in the geometric mean diameter (this measure is discussed in Section 8). Corley (1978) analyzed hundreds of samples, five from within each 25 by 25 foot gravel patch. He also showed a two-fold variation in the geometric mean diameter. Platts (1974) analyzed hundreds of gravel samples for a decade along the entire South Fork of Idaho's Salmon River spawning areas. Again, the geometric mean diameter exhibited approximately a two-fold variation. The methods used by these authors were all different, but their data reveal that salmon tolerate and select a range of gravel composition within each spawning site. When measured in terms of geometric mean diameter, it is a rather wide range when viewed from the standpoint of attaining sampling accuracy. Thus, for monitoring purposes, it does not appear necessary to strive for extreme accuracies in characterizing the gravel composition. Clearly, there is no need to complicate an already difficult sampling problem, knowing there is no additional gain. Only the range of possible composition within each site is needed. This can be obtained by visual inspection. For example, within each spawning area, select three spots which appear coarse, fine and intermediate. Data analysis will indicate if the selections are reasonable. Initially, it may be desirable to duplicate the samples and document visual observation with photographs to check against the gravel analysis.

On-site analysis of the gravel (see Section 11) will reinforce this learning process. The major difficulty lies in judging the gravel composition visually as "coarse", "fine", etc., because of the underlying layers. As samples are taken at each site, this problem is reduced but serious attempts must be made to reinforce initial judgement with experience. It is only than that a purely mechanical approach becomes a simple reliable field technique.

An example showing the feasibility of the visual technique is shown in Figure 1. These sites of increasing coarseness were selected visually (site A, coarse, site B, medium, site C, fine) from a known spawning area on Canal Creek, a small stream in the Oregon Coast Range. Samples were taken at each of these sites and particle size distributions were determined. As Figure 1 shows, these particle size distributions substantiate the judgements which were made visually in the field.

The concept behind visual observation is to develop an estimation process with a small margin of error. This means integrating all information possible concerning the extremes of coarse and fine compositions of the spawnable gravel while in the field. This includes information gained as one actually collects the samples.

4. Time and Frequency of Sampling

The requirements for good gravel conditions are critical at the final stages of salmonid egg maturation where oxygen consumption is greatest. Another critical period is during emergence. It would be ideal to sample as soon as possible after egg emergence to avoid disruption of the redd and undue trampling of the spawning area. Also, in many coastal streams, the water level during this time is likely to be most suitable for sampling. Prolonged low flow conditions which often precede emergence will result in maximum deposit of fine sediment and thus coincide with the critical period mentioned above. Streams fed by snow melt exhibit somewhat different patterns. The low flow in such streams is during early fall, about the time spring chinook begin to spawn. In these circumstances the late summer flow period would be a more suitable sampling time.

Even if it were desirable, winter storms and high water levels complicate sampling of spawning areas. Therefore, it is best to avoid these conditions. It is possible, however, that certain areas must be monitored because of anticipated or actual management-related impacts. In these situations, suitable sampling times and frequencies must be worked out, on a case-by-case basis.

5. Methods of Obtaining Gravel Samples

Even though simple photographic methods have been developed for analysis of surface gravel layers in a stream bottom (Ritter and Helley, 1969), the two most common methods are frozen core samples originally developed by Walkotton (1976) and grab (or manual) samples advocated by McNeil and Abnell (1960).

The photographic method is restricted to analysis of surface (or armor) material visible on a clear water stream bottom. Photographic prints of a

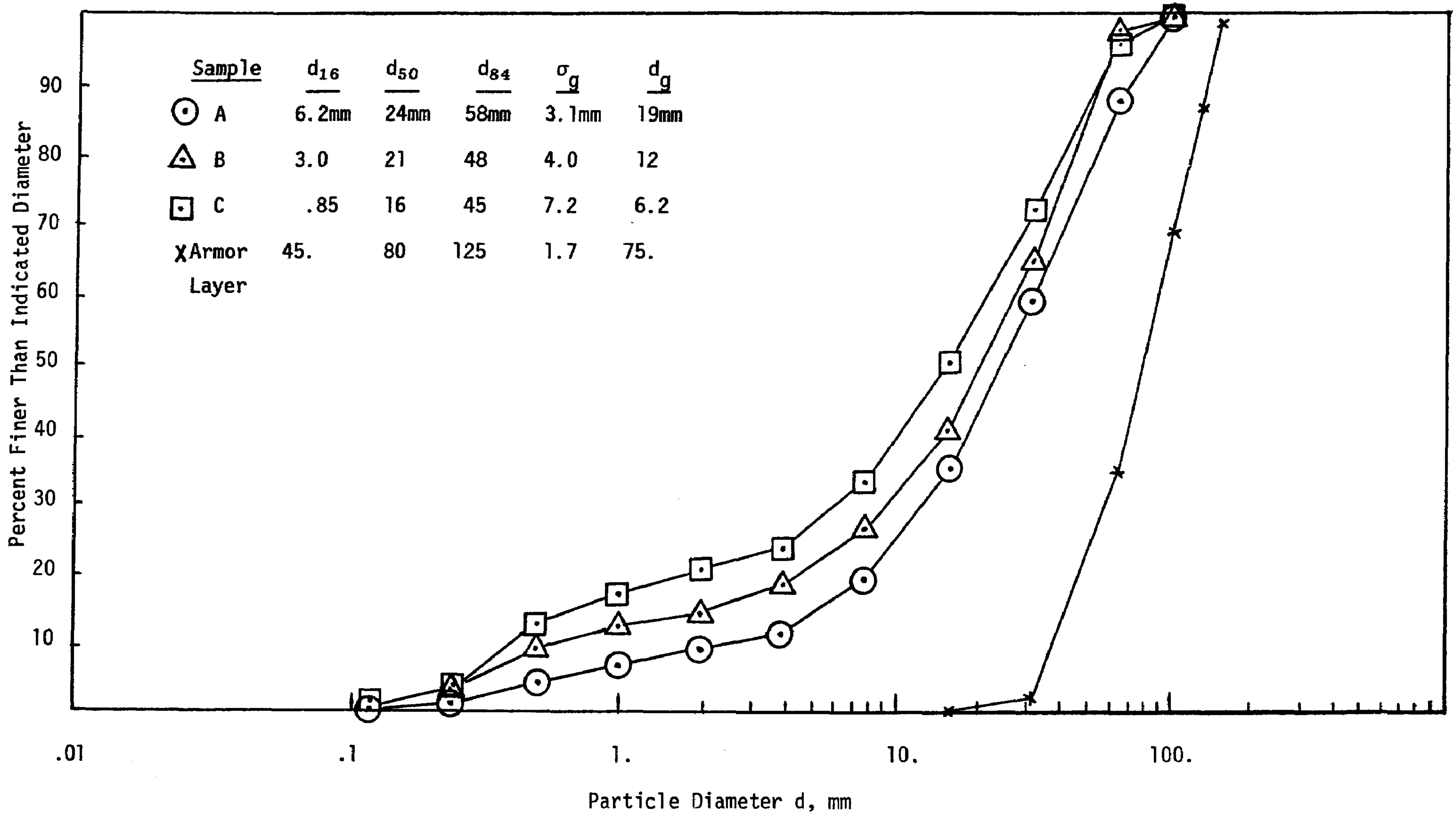

Figure 1. Particle size distribution for spawning gravels in Canal Creek, Siuslaw National Forest, Oregon

stream bottom segment are analyzed with specialized scanning equipment. These devices incorporate computation facilities that enable counting, sizing, and even particle size distribution. Once the system is set up and calibrated, photographic records of hundreds of particles can be analyzed in a matter of minutes.

In the frozen core method a metallic tube about one inch in diameter is driven into the gravel. Liquid carbon dioxide (CO_2) is throttled into the tube through a bank of small nozzles. The expansion of the gas rapidly freezes interstitial water outside the tube, thereby attaching a solid core of gravel and sediment to the tube, which is then extracted for analysis. The dimensions of the core and the total size of the sample can be varied by a combination of (a) depth of tube penetration into the gravel, (b) length of time CO_2 is applied and (c) use of more than one tube in a given spot.

The manual sampling method consists of inserting a stove pipe or a large diameter tube (4 to 12 inches) into the gravel bed to a depth of 4 to 12 inches and extracting by hand or scoop the gravel and sand inside the pipe. An estimate of the suspended material that escapes the gravel sample is obtained by retaining, for subsequent analysis, a subsample of the water column in the pipe, once the contained water is thoroughly mixed.

There are shortcomings and advantages for all methods discussed. The photographic method is excellent for extremely large quantities of work but is restricted to the analysis of the surface layer of the gravel. A suitable alternative for estimating the particle size distribution of the surface is to simply pick up one particle every 6 or 12 inches for subsequent sieving. About one hundred particles should be collected from each site. This method can be easily combined with benthic sampling if the particles are removed carefully from the stream and placed in a bucket for subsequent scraping of attached insects before the gravel is analyzed.

Main advantages of the frozen core method are (a) ability to analyze samples with depth, (b) ability to sample in deep water and under ice or frozen streams, and (c) routine application of uniform procedures, i.e., duration of CO_2 application and depth of core. Disadvantages are (a) need for elaborate equipment such as CO_2 tanks, nozzles, tubes, strong driving rods, hammer, tripod and pully to extract the sample, and adequate backup equipment in case of failure in the field, (b) cost of CO_2 recharge, (c) some prior experience with the method, and (d) difficulty of sampling in coarse gravel.

Gravel sampling with the frozen core method cannot be combined with benthic sampling. Many insects attached to rocks are driven away by the initial pounding of the rod into the gravel and possibly by the application of the CO_2. Also, the coarse surface layers that contain most insects are least likely to freeze because of flowing water. Moreover, frozen cores cannot be obtained from gravel patches that are not submerged.

Advantages of manual sampling are (a) simplicity of equipment and procedure, (b) flexibility in modifying sample size, and (c) suitability for combining with benthic sampling. Disadvantages are (a) loss of suspended fines, (b) difficulty of sampling in deep water, (c) bias associated with different operators who might extract the gravel selectively, and (d) difficulty of inserting stovepipe into coarse gravel bed.

Usually the disadvantages of frozen core and manual sampling can be reduced to acceptable levels. For example, Lotspiech (1978) has used steel tubes instead of copper to reduce problems of bending during extraction. He also used aluminum CO_2 tanks to minimize carrying weight while increasing refrigerant capacity.

Suspended particles in manual samples can be collected in 63 micron mesh nylon nets using a Hess-type sampler, which also collects the benthic insects. The sampler is placed in the stream with its two solid sides facing the stream banks. The upstream side has a sliding screen to allow flow of water in the chamber yet prevent the drift of suspended matter or insects into the chamber. The downstream side has a 63 micron net to capture suspended sediment and insects released from the substrate. Gravel is scraped and washed into the net before extraction. With this design, gravel samples not only are combined with benthic samples, but suspended sediments are not lost. To minimize operator bias "all" substrate components must be removed to a pre-determined depth, a scoop should be used when possible.

We recommend manual sampling as discussed above for monitoring purposes, even if not combined with benthic sampling. The overriding advantage is the flexibility to change the sample size. The larger the sample, the smaller the sampling bias. And, to obtain the same degree of accuracy with coarser gravels, the sample size must be increased. With coarse gravel, it is more difficult to obtain a large frozen core; thus, these are practical reasons for manual sampling. The sample size problem is further discussed in the following section.

In order to get an idea of the discrepancy that can result purely from uncontrolled sample size, data are presented in Figure 2 for manual and freeze core.* These samples were obtained from two coastal streams near Corvallis, Oregon. The manual samples in Oak Creek were obtained with a wooden frame 30 x 30 x 30 cm inserted in the bed and the freeze core samples were obtained at a site very close to that for the manual samples. The manual samples from Berry Creek were obtained from within a metallic pipe 30 cm in diameter inserted into the gravel. Before the gravel was extracted the freeze core sample was obtained from the material inside the pipe. The combined freeze core and remaining gravel within the pipe gives the manual data. The discrepancy is at times great, varying both above and below the manual sample. The average sample size with manual method was 24.5 kg, with a range of 8 to 40 kg. The average sample size for the freeze core was 3-5 kg, with a range of 1.1 to 8 kg. All freeze core samples were obtained with a single tube.

6. The Size of Gravel Samples

The previous discussion relates primarily to the mechanical advantages and disadvantages of various sampling methods. Some sampling bias can be reduced by taking a very large sample. Obviously all attempts to minimize bias should be made before increasing sample size. Increasing sample size

*The data were obtained from an analysis of unpublished results during the course of the non-point source study program in Corvallis, Oregon. Data were collected by Shirazi, Lee, Lotspeich and Reid during the summers of 1977 and 1978.

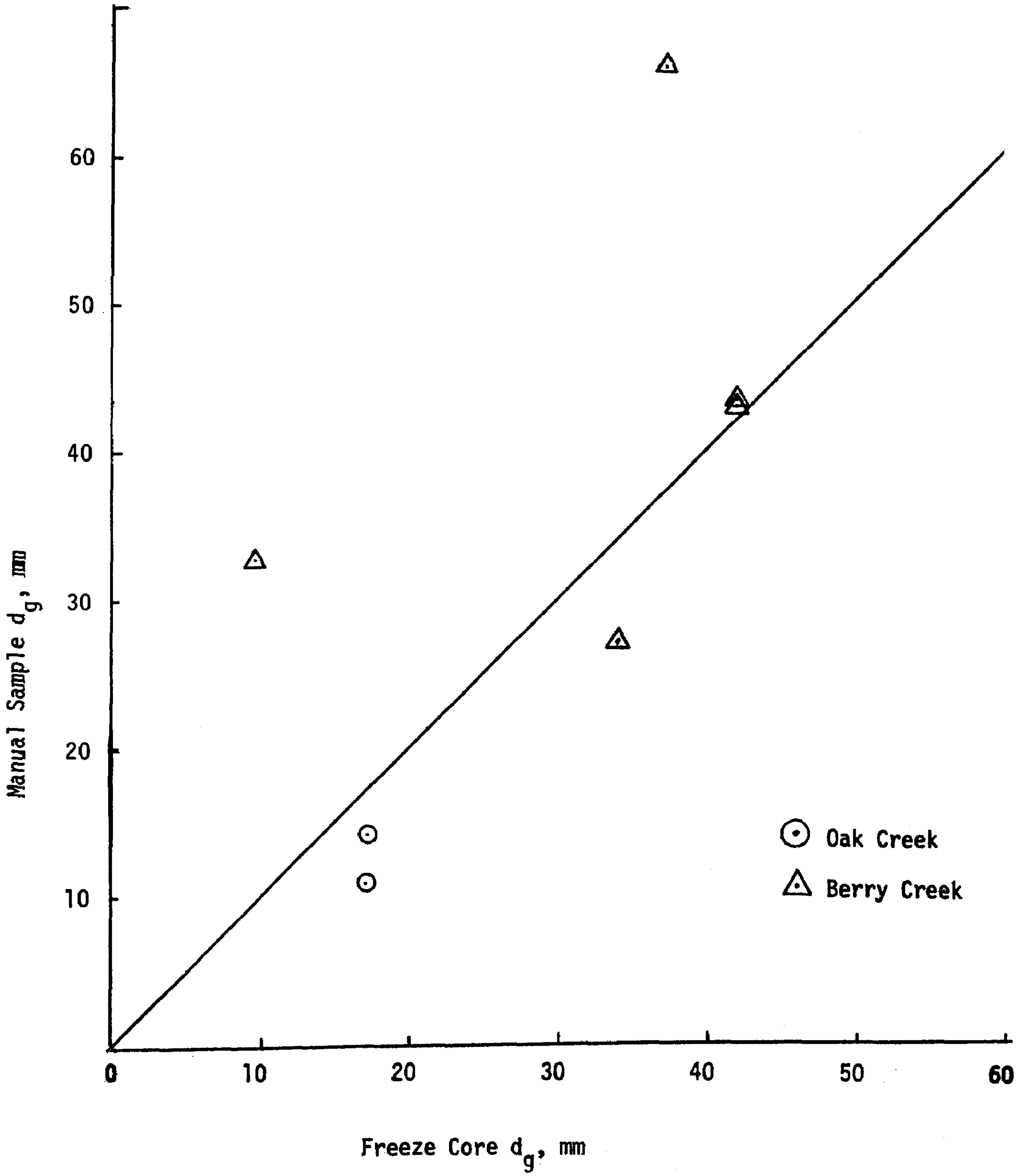

Figure 2. Comparison of gravel samples taken with freeze core and manual sample at Oak Creek and Berry Creek, Oregon

should not be used to disguise problems inherent in the sampler itself. For example, with the Hess-type sampler, the main bias results from selective hand sampling. This bias can be reduced by using a scoop. Another example is the bias in frozen core sampling when the frozen water is not at least as thick as the largest particle sizes attached. If only tips of the large particles are frozen, when the core is pulled out these large attached particles will separate from the unfrozen surrounding fine particles and bias the sample toward large particle sizes. If many exposed large particles are lost while extracting the core, it will be biased toward smaller size particles. In general, bias can be anticipated on both ends of the particle size range.

The problem of adequate sample size has not been resolved satisfactorily. Experiments with various gravel compositions are in progress to establish some guidelines. Preliminary results seem to indicate that:

(a) the dimensions of the sampler should be several times (two to four times) greater than the size of largest rocks found in the sample, and

(b) the percent weight of largest particles in relation to total sample weight should be small (less than 10%).

For example, core samplers 6 inches in diameter should be adequate if the gravel is predominately less than 2 inches with 10% by weight larger than 3 inches. When sampling in chinook spawning areas in Idaho, Corley (1978) used a 12 inch core. He took 50 to 90 lb. samples, and percent by weight of rocks greater than 3 inches ranged from zero to 40%. While this does not give a definite rationale for sample size selections, it does give an example of the upper size limits investigators use. Corley's general rule was to pick 5 gallons of gravel per sample, with no special attention given to changing the sample size for various compositions.

7. <u>Analysis of Gravel--Wet Sieving</u>

Access to spawning areas is not always possible with motorized vehicles. Therefore, transporting large gravel samples from the stream bank to the laboratory often presents a problem. Consider a sample size of 50 lbs. Carrying as few as 5 samples through rough terrain even one-fourth of a mile is backbreaking. Serious consideration should be given to on-site analysis of the gravel. Additional equipment required includes a set of sieves, a bucket with an overflow nozzle and a graduated cylinder. Only 5 coarse sieves and 2 fine sieves are needed. These are 2-1/2" (64 mm), 1-1/4" (32 mm), 5/8" (16 mm), 5/16" (8 mm) and 5/32" (4 mm) as well as a 63 micron sieve. The content of the coarse sieves can be analyzed volumetrically using the bucket and graduated cylinder. The contents of the fine sieves, i.e., size ranges less than 5/32" (4 mm) and greater than 63 microns should be taken to the laboratory for dry weight analysis. Particles below 63 microns are ignored. If this is unacceptable, a smaller size sieve must be used to replace the 63 micron sieve. Contents of the 2-1/2" (64 mm) sieve can be further discriminated by passing each rock through individually constructed rigid square wire frames as a substitute for carrying larger sieves to the field.

Preliminary analysis of wet gravel sieving for sizes below 5/32" (4 mm) shows that considerable bias can occur because of the water-holding capacity of finer gravels. Table 1 shows how this error varies as a function of sieve size for one sediment sample. A 61% error in determination of percent fines can result for this sample from wet sieving with the 63 micron sieve.

Table 1. ERROR IN PARTICLE SIZE DETERMINATION USING WET SIEVING

Sieve Size (mm)	Percent (by weight) Water in Retained Sample
2	10
1	19
.5	29
.125	49
.063	61

Wet sieving is further complicated by the fact that the error, since it is also a function of other variables (especially particle size distribution), will be different from sample to sample. For this reason, dry sieving is recommended for particles smaller than 5/32" (4 mm). Combining the volumetric and gravimetric analysis requires knowledge of average gravel density. For this purpose, the dry contents of the 5/64" (2 mm) sieve should be used for rock density determination by simply dividing the dry weight of the material in grams to its displaced volume of water in cubic centimeters.

8. Analysis and Presentation of Results

The most complete analysis of gravel composition consists of a tabulated listing of gravel size (contents of each sieve) and the weight associated with that size. This information can be used readily to obtain other useful statistics. The most widely used presentation is a tabulated listing of particle size and percent by weight of finer (or coarser) particles. From this table one can find (by interpolation) d_{84} and d_{16}, that is, the particle diameters below which, respectively, 84% and 16% of the gravel is finer. The geometric average (dg) of these two particle sizes has long been used as a first-order representation of gravel composition. This same number (dg) has been shown to relate to spawning success. For a more detailed discussion refer to Platts, Shirazi and Lewis (1978). The geometric mean diameter can be calculated as follows:

$$dg = \sqrt{d_{84} d_{16}}$$

9. Additional data

Implicit in monitoring gravel compositions is the evaluation of a stream segment used by fish as a spawning habitat. This is only one indication of the general condition of a stream system. To broaden the use of this information in the context of the total stream system, additional data on the watershed, on the hydraulics and on the benthic insects may be included.

Important watershed data are soil type, soil composition, vegetation, drainage area, general slope of the terrain, and silvicultural activities, including the type and extent of clear-cutting and road building.

Hydraulic information includes water velocity and water depth at each sampling site, general morphology of the stream bank and bottom, bankfull water depth, water dredging, general bottom slope and water surface slope, and when possible the hydraulic conditions during spawning.

When sampling gravel, using the Hess-type sampler, an excellant opportunity exists to simultaneously collect the benthic insects attached to the rocks and included within the intersticies.

In general, these data provide the basis for further evaluation of the impact of watershed management on the stream system. In particular, the specific use of the data must be decided on a case-by-case basis determined by the objectives of the study.

10. Estimating Localized and Streamwide Impacts

The ultimate goal of monitoring is to assess the possible impact of cultural activities on spawning gravel. The parameters used as measures of this impact can be classified in the categories: (a) changes in the area of spawning gravel, i.e., the change in the available habitat, and (b) changes in the composition of the gravel, i.e., the quality of the habitat. For the latter measures the geometric mean diameter dg is assumed to be a sufficient 1st order of magnitude indicator, for it can be conveniently related to spawning success. To demonstrate how this information can be used, assume that the following qualitative judgement applies to gravel composition.

dg mm	quality
>10	good
>9 <7	marginal
<6	poor

Let us also assume that data in Table 2, a hypothetical table, were obtained from measurements of gravel quality and area on Dream Creek prior to a hypothetical land slide in 1966. It is shown that throughout the four miles of the creek the spawning gravel, totaling 510 m^2, is of good quality.

Table 3 shows the same information after a land slide. It shows that the quality of the gravel is reduced throughout, even though the total spawning area is increased from 510 m^2 to 540 m^2. The creek has been affected most drastically in the upstream reaches.

Table 2. SPAWNING GRAVEL AREA AND QUALITY BEFORE LANDSLIDE OF 1966 IN DREAM CREEK

Mile post	Area m^2	dg mm	% of Total Area Good	Marginal	Poor
1	100	13	19	0	0
2	300	10	59	0	0
3	50	12	10	0	0
4	60	15	12	0	0
Total	510		100	0	0

Table 3. SPAWNING GRAVEL AREA AND QUALITY AFTER LANDSLIDE OF 1966 IN DREAM CREEK

Mile post	Area m^2	dg mm	% of Total Area Good	Marginal	Poor
1	60	6	0	0	11
2	300	8	0	55	0
3	100	9	0	19	0
4	80	10	15	0	0
Total	540		15	74	11

11. Conclusions and Recommendations

The foregoing rationale for a monitoring program was presented to assess possible impact of silvicultural activities in a watershed on salmonid spawning habitat. Two measures, one relating to composition of spawning gravel and another to the available spawning habitat were proposed. The first measure, i.e., the geometric mean diameter of the spawning gravel directly affects survival of fertilized eggs to emergence. It is not difficult to propose ranges of geometric mean diameter for good, marginal and poor survival. The second measure, the total area of spawning gravel in a given reach, is keyed to the quality of this habitat, namely the composition of the spawning gravel. This information is useful in itself, for it permits comparison of gravel quality before and after the impact. Conceptually, it is related to effects on fish survival in larval stages. However, by itself, the information is an inadequate measure of fish production. It must be supplemented by data on the carrying capacity of the stream so that one can reach a balance between the desire to maintain a quality spawning habitat and the optimum number of fish that the stream can support in a given season. This is a difficult problem to resolve. Even though there are many on-going attempts to make a rational analysis of this problem, it will be several years before a satisfactory answer is found. Meanwhile the use and refinement of the proposed method for monitoring the spawning gravel should be helpful.

To restate the recommended procedure:

1. Select known spawning areas in stretches of a stream being impacted.
2. Identify patches of spawning gravel and measure the areas.
3. Estimate the range of gravel composition in each patch or, if possible in the spawning riffle by taking three samples, one each in coarse, fine and intermediate spots.
4. Use a grab sampler under low water conditions soon after emergence.
5. Collect at least three gallons of gravel, more if the gravel is coarse.
6. Wet-sieve the gravel on-site and analyze the coarse fraction (i.e., coarser than 5/32" (4 mm)) volumetrically.
7. Collect remaining gravel in 63 micron sieve, dry-sieve in the laboratory and analyze gravimetrically.
8. Estimate gravel density, combine analysis and determine geometric mean diameter.
9. Make a matrix of area--geometric mean diameter of all patches along the stream reach for comparison after impact.

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16. ABSTRACT

Silvicultural activities in the Pacific Northwest introduce various levels of sediments and debris into streams, often degrading spawning habitats of salmonid fishes. In these mountain streams spawning takes place in riffles where the water velocity is usually 1.5 to 2.5 ft/sec and water is 6 to 36 inches deep. The substrate in these riffles are ideal habitats for aquatic insects which in turn respond adversely to excessive sedimentation. For these reasons, the study of spawning habitats could provide a relatively simple and sensitive indicator of watershed management impacts.

Simple but reliable procedures are needed to monitor spawning substrate to assess the level of these impacts. This paper presents a preliminary rationale for conducting a monitoring program to assess the impact of watershed management activities on stream spawning habitats; both on individual spawning sites as well as for the entire stream.

After analyzing results from these investigations it appears that reasonable balance can be achieved between an acceptable reliability and minimum number of samples by (a) estimating the area of the gravel in the site that is potentially usable by fish and (b) within this area, selecting representative samples to provide a quantitative measure of the range of conditions and thus the quality of the gravel.

17. KEY WORDS AND DOCUMENT ANALYSIS

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