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Methods to Measure Sedimentation of Spawning Gravels

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Sediment transport occurring after spawning can cause scour of incubating embryos and infiltration of fine sediment into spawning gravel, decreasing intergravel flow and preventing hatched fry from emerging from the gravel. Documentation of these effects requires measuring gravel conditions before and after high flow periods and combining methods to record scour and fill and sediment infiltration by different grain sizes at different depths in the streambed. Scour and fill is best measured with scour chains, which can record the depth of maximum scour that occurs during high flow. Repetitive sampling of bed material with bulk-core or freeze-core samplers can be hindered by the large size of sample required to adequately characterize gravel mixtures compared to the size of fish redds. Freeze tubes, porous- and solid-walled containers, and infiltration bags can be used to recover experimental gravel of known grain size after it has been infiltrated with fine sediment. An array of devices is suggested to measure both scour and fill and sediment infiltration.

Retrieval Terms: spawning gravel, fine sediment, channel scour, methods

Sediment transport in stream channels can pose two major threats to incubating embryos of salmon and trout. High rates of sediment transport can induce deep scour and fill of the bed,[1-3] thereby removing embryos or burying them deeply. Fine sediment infiltrating redds can "plug" the gravel, thereby reducing intergravel flow of oxygenated water, impairing respiration by embryos,[4,5] and preventing the emergence of hatched fry from the gravel.[6] Survival to emergence depends on the amount and grain size of fine sediment deposited at different depths in spawning gravel, as well as on biologic and water-quality factors.[7] Despite complexities in determining its effects on embryo survival, sediment transported during the incubation period poses a clear and quantifiable threat.

Because fish constructing redds can cause much of the fine sediment in spawning gravel to be winnowed,[5] merely measuring the concentration of fine sediment before or immediately after redd construction cannot adequately quantify sedimentary conditions of spawning habitat. Instead, one must have some measure of the changes in redd material resulting from sediment transport in the period between redd construction and emergence of fry. Such measurements, combined with records of sediment transport and flow, have the potential of linking sediment transport regime to an important component of fish habitat.

This note describes some methods to measure scour and fill of a streambed and the amount and depth of infiltration of fine sediment into a gravel bed.

MEASURING SCOUR AND FILL

Cross Sections

Cross sections are elevation transects surveyed from bank to bank perpendicular to the center line of the channel. Each end of a cross section is monumented with a steel post or other permanent feature. Once established, cross sections can usually be resurveyed in less than 30 minutes each. They provide high precision and accuracy in monitoring bed elevations over time, but do not document the depth of maximum scour *(fig. 1).* During a flood, the bed may scour below the pre-flood level and then return to a higher level. These short-term changes in bed elevation would not be detected by resurveying cross sections after the flood.

Scour Chains

Scour chains measure maximum scour depth occurring over a period of time.[8] A chain or strong cord is buried or inserted vertically into a streambed so that one end extends below the depth of anticipated maximum scour and the other end drapes over the bed surface. The free end of the chain stays on the surface as the bed scours and is buried as the bed fills. The final level of the horizontal section of chain indicates maximum scour depth.

Scour chains can be inserted into a streambed with a probe constructed of pipes and pipe fittings[9] or stainless steel *(fig. 2).*[10] One end of the chain is attached to an eyelet screwed into a section of dowel, and the other end is threaded into the bottom of the probe and out through a slot or one of the

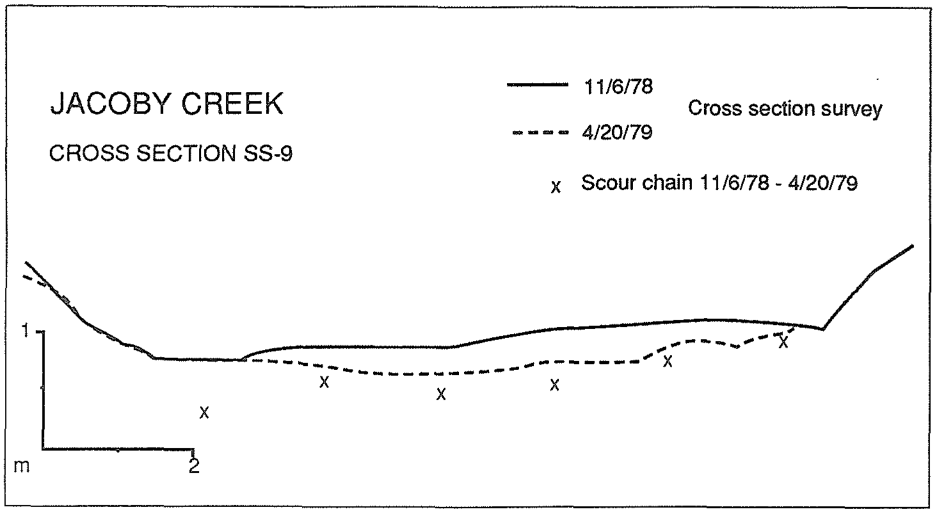

Figure 1—Cross section on Jacoby Creek near Arcata, California, showing scour and fill measured by repeated surveying over a high flow season and by scour chains inserted and recovered over the same period.

handles. To install a chain, the probe with chain is gently tapped down to the bottom of a hole left by a stout rod driven into the streambed. A thin metal rod is then inserted into the top of the probe and planted onto the base of the dowel. The rod is tapped against the dowel to hold it in place as the probe is withdrawn, leaving the chain partially buried in the bed. Finally, the surface section of the chain is laid over the bed, its length measured, and its elevation surveyed. A painted washer may be attached to the end of the chain to aid in finding it later.

After a scour-and-fill event, the chain is carefully excavated by hand to detect the exact depth of burial. To measure the depth of scour and fill, elevations of the burial depth of the chain and the final bed surface are surveyed and compared to the original bed elevation. Alternatively, scour depth can be determined by measuring the difference between the length of chain lying over the original bed surface and that lying over the final bed surface. To measure a subsequent event, the hole is filled and the chain laid out over the bed surface.

Jeff Cederholm[11] offers a modification of scour chains that circumvents the need to excavate the bed for each measurement. He threads a column of ping-pong balls onto a cord and inserts it with a larger diameter probe into the streambed. As a ball is exposed by scour it slides up to the end of the cord. Depth of scour is measured by counting the number of exposed balls and multiplying by their diameter. Neutrally buoyant objects smaller than ping-pong balls require a narrower probe and thus reduce disruption of the bed during insertion.

Precision and accuracy of measured changes in bed elevation from repeated surveys and scour chains are relatively high. In a pebble-gravel bed, precision is approximately equal to the dominant size of bed surface material, or ±2 to 5 cm. In comparison, annual maximum values of scour and fill in spawning gravels in small streams have been measured at 20 to 50 cm,[3] which is approximately equal to the range of depth of egg burial.[12] In three streams in northern California, the coefficient of variation in the annual difference between the highest surveyed bed elevation and the level of maximum scour averaged 0.23 and ranged between 0.05 and 0.42.[3] Scour and fill is especially deep in unstable channels with high transport rates and those frequently transporting large woody debris.

The depth to which eggs are buried is an obvious threshold of concern with which to compare scour depth. The depth of deposition of unsorted bed material over redds can present another threshold based on the overall percentage of fine sediment in the incubating environment. This threshold will be discussed in the section on sediment infiltration.

In each sample spawning area, scour chains are best located at regular intervals across a small number of cross sections rather than randomly over a grid for three reasons. First, scour and fill results from changes in the balance of sediment transport and tractive forces involving most or all of the full channel width; thus, observations at one point in a spawning area are not independent of those at another. Second, locating scour chains precisely once they are buried is most conveniently done along a few cross sections; locating them on a grid involves a larger number of monumented transect boundaries. Third, scour-fill data can best be related to changes in channel morphology when scour chains are located at frequent and regular intervals along surveyed cross sections. Scour depth at each cross section can be expected to range from nil to near-maximum. A reasonable density of scour chains would be every one-half to two meters (depending on channel width) across two to five cross sections, totalling 10 to 40 chains.

At each spawning area, cumulative frequency distributions of scour depth can be calculated assuming that regularly spaced chains represent equal areas of channel. Statistics of parameters of these distributions can then be determined for the sample of spawning areas.

INFILTRATION OF FINE SEDIMENT

Definition of Fine Sediment

Fishery biologists and sedimentologists assign different ranges of grain size to their definitions of fine sediment for different problems. Effects of fine sediment on biota depend on the tendency of particular grain sizes to deposit at certain levels in the bed where they may influence aquatic organisms. Just as in rearing habitat in which different factors can limit fish production under different situations, different grain sizes deposited at different depths can limit survival of incubating embryos in spawning gravels in different ways. For example, the depth to which fine sediment infiltrates into a relatively clean gravel bed and its effect on incubating ova of fish depend on the size of infiltrating sediment relative to that of the gravel.[3] Silt and fine sand can penetrate deeply to the level of egg burial (commonly 0.2 m to 0.4 m) and reduce intergravel flow, and associated fine organic matter can consume dissolved oxygen and thus inhibit respiration of the eggs. Sand and fine gravel trapped in near-surface interstices of the framework gravel can prevent emergence of alevins.[13,14]

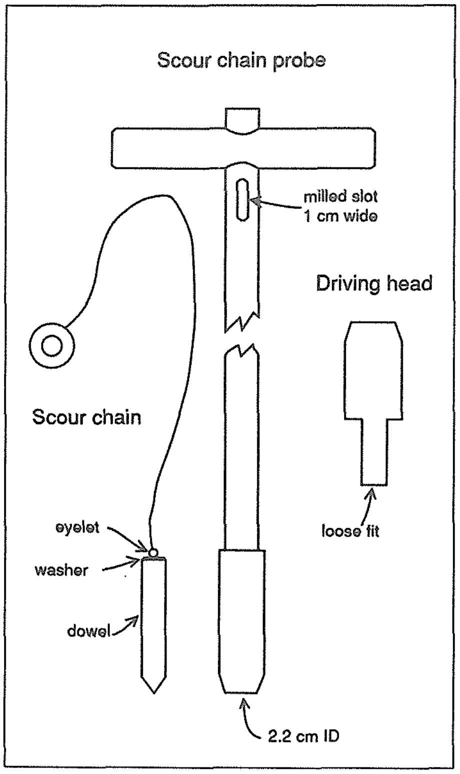

Figure 2—Scour chain probe and scour chain. The driving head fits into the top of the probe and prevents damage to the probe as it is pounded into the bed.

The level of intergravel deposition of various grain sizes in the fine-sediment range can vary widely, depending on the size distribution and packing of the gravel bed before fine sediment is introduced, grain size distributions of fine sediment in transport, hydraulic conditions during transport, and rates of sediment transport.[3] For example, abundant sand from weathered crystalline bedrock is likely to fill surface interstices of bed surfaces, whereas higher proportions of silt and fine sand produced from volcanic rock are likely to penetrate deeper into a gravel bed.

From a sedimentological standpoint, fine sediment in a heterogeneous bed can be defined as the mixture of smaller particles that fill the matrix of the bed framework created by large bed particles in grain-to-grain contact.[15] If the size distribution of bed material is bimodal, that is, with distinct fine and coarse modes on a size-frequency diagram, then fine (matrix) material can be easily distinguished from framework material. If the distribution is unimodal, however, the distinction is problematical. In this case, a reasonable upper limit for the diameter of fine material is 2 mm, which separates sand from gravel on the Wentworth scale.[16,17]

Before selecting a method to measure infiltration of fine sediment into a gravel bed, therefore, it is important to define the grain size of the fine sediment to be measured.

Grain Size Analysis

It is not surprising to find confusion in the choice of sieves and grain size parameters used to analyze bed material for spawning quality. From the discussion above, it should be clear that no single grain size parameter can be expected to universally predict embryo survival to emergence for a given species.[18] Instead it is more prudent to identify the grain size range, depth of infiltration, and the threatened developmental stage of fish in the stream being investigated, and then refer to the experimental literature to assess lethal thresholds.[12] Thresholds of concern for fine sediment content vary between experiment, species, and grain size of fine sediment, but most commonly fall around 20 percent.

A comprehensive set of sieves—one whose sizes fall on all intervals of the Wentworth scale[19,20] and span the entire size range of the sample—allows the greatest flexibility in interpretation of results. Any grain size statistic such as geometric mean, sorting coefficient, or percent finer than a certain size can be easily extracted from a comprehensive grain size distribution.

Bulk Cores

Bulk samples of spawning gravel can be taken subaqueously by inserting a cylinder into the streambed and extracting bed material from inside the cylinder.[21] Various versions of these samplers and the advantages and disadvantages of bulk core sampling are discussed thoroughly elsewhere.[18,20] The primary advantage of bulk core samplers in my experience is that a *large* sample can be obtained relatively easily. Our sampler is 30 cm in diameter, and we usually insert it at least 30 cm into the streambed. Some disadvantages of bulk core samplers are that variations of gravel conditions with depth are nearly impossible to measure, and fine sediment tends to settle into the bottom of the excavation as the coarser material is removed. We compensate for the latter problem by taking large samples and by obtaining a sample of agitated water, measuring the concentration (and grain size, if desired) of fine sediment, and multiplying by the volume of water inside the cylinder.

Freeze Cores

Freeze cores[15,22-24] are vertical sections of bed material bound by frozen interstitial water to one or more probes that are driven into the bed and injected with liquid nitrogen or carbon dioxide. The freeze core method was designed to extract a vertical section of relatively undisturbed streambed material and thereby avoid the homogenization of streambed material that occurs using bulk core samplers. Such undisturbed cores would allow measurement of variation of grain size and porosity with depth. Freeze cores have been used to investigate the internal structure of redds and egg pockets.[24,25] To monitor changes in gravel composition, freeze cores can be taken before and after an event that causes sedimentation.

There are two serious drawbacks to using freeze cores to measure changes in bed material. First, the pounding of 2-cm-diameter probes no more than 10 cm apart into the bed may disrupt stratification by shaking fine sediment deeper into the bed.[26,27] Second, freeze cores are commonly too small to prevent large variations in the sample even if entire cores are lumped, unless a large array of probes is used and freezing efficiency is improved.[24] Comparisons between freeze cores and bulk samples have shown inconsistent differences, but freeze core samples are usually coarser.[18] The smaller the sample, the greater is the bias created by the irregular sample boundary, which around freeze cores is dominated by large particles.

In a small sample, the presence or absence of one large particle can greatly affect the overall size distribution or percentage of fine sediment. Using a rule of thumb that the largest particle should not comprise more than 5 percent of the sample, a sample whose largest particle is 100 mm in intermediate diameter should weigh at least 30 kg; for a 1 percent error, 50 kg are required.[28] Our freeze cores, which are nearly 0.5 m deep and taken with three probes, have commonly weighed 10 to 15 kg, and thus each core is inadequate to provide a reliable size distribution.

The requirement for large samples and the comparatively small volume of gravel within an individual redd present a dilemma for one attempting to document changes by repetitive sampling. Replicate small samples that remove insignificant amounts of material from the population (redd) can yield an estimate of variance, but the variance for such small samples may be so high that differences can be difficult to detect and evaluate. Conversely, large samples or a large number of small samples provide a more precise measure of fine sediment content but may seriously deplete the remaining material needed for a subsequent set of samples. This dilemma can be overcome by implanting a volume of gravel of known size distribution and then sampling it later, using several methods described below.

Freeze Tubes

To avoid disturbing the bed, a freeze core can be extracted using a copper tube that is buried in a column of bed material of known size distribution *before* the monitoring period begins. First, a column of bed material is removed by excavating from an open cylinder to a depth equaling the length of the freeze tube. The tube is held upright as the hole is filled with experimental material of some known size distribution or native bed material from which fines have been sieved. The tube is then capped. A cork is tied onto an eyelet on the cap to aid finding the tube if it is buried. A welding rod is inserted through the eyelet at an angle into the bed directly upstream in order to shed organic material that might otherwise build up and cause additional scour around the tube if erosion of the bed exposes the tube. To obtain the core, a slightly smaller diameter tube is inserted into the freeze tube and injected with liquid CO_2. Because freeze tubes are not hammered into the bed, they can be made of more heat-conductive, thin-walled copper which can freeze the surrounding bed material more efficiently than standard freeze core probes, and thus produce larger cores. Nevertheless, interpretation of freeze tube samples is limited by their small size. The greatest value of freeze tubes is to provide an undisturbed stratigraphic record of infiltration of fine sediment.

Solid-Walled Containers

Solid-walled containers (usually buckets or cans) filled with gravel of known size distribution and buried flush with the bed surface can be used to collect infiltrated fine sediment.[3,29] Surface bed particles are removed before the containers are buried and replaced afterwards so that initially sediment infiltrates through a bed surface that replicates a natural one. The containers are retrieved after a sediment transport event and their contents sieved to measure the volume of infiltrated sediment. Containers can be easily slipped in and out of the bed through loosely fitting collars that are buried initially with the containers. Wide rubber gaskets that are cut from innertubes and stretched around the top rim of the collars can prevent sediment from jamming the space between collars and containers (*fig. 3*).

The main advantage of solid-walled containers is the ease of installation and replacement. Institution-sized food cans provide a reasonable size and are readily available. Easy installation and replacement enables measurement of sediment infiltration at a large number of points on the bed during individual runoff events.

The main disadvantages of solid-walled containers are that scour can expose a container above the moving layer of bed load, and fill can cover the opening with a protective seal of deposited bed load. Although Lisle[3] failed to detect a significant effect of scour or fill on volumes of material collected in cans in a natural channel, it is hard to imagine that sustained scour or fill does not affect the volume collected. Another disadvantage of solid-walled containers is that they exclude sediment transported by intergravel flow. Thus they most effectively measure infiltration of sand (sieve size between 0.062 and 2 mm), which in most cases cannot be transported laterally by weak intergravel flow velocities, but instead enters the bed surface and then falls under the force of gravity.

Porous-Walled Containers

Open-work baskets or containers with openings allow sediment carried by intergravel flow to enter and deposit in the experimental framework material.[30,31] They too are commonly buried near the bed surface, and so are subject to the same problems from scour and fill as solid-walled containers. If containers with holes are used, the size and density of holes should be standardized and not inhibit sediment from entering the containers. The main disadvantage of porous-walled containers is that, as they are taken out of the bed, water bearing infiltrated sediment flows out of the containers.

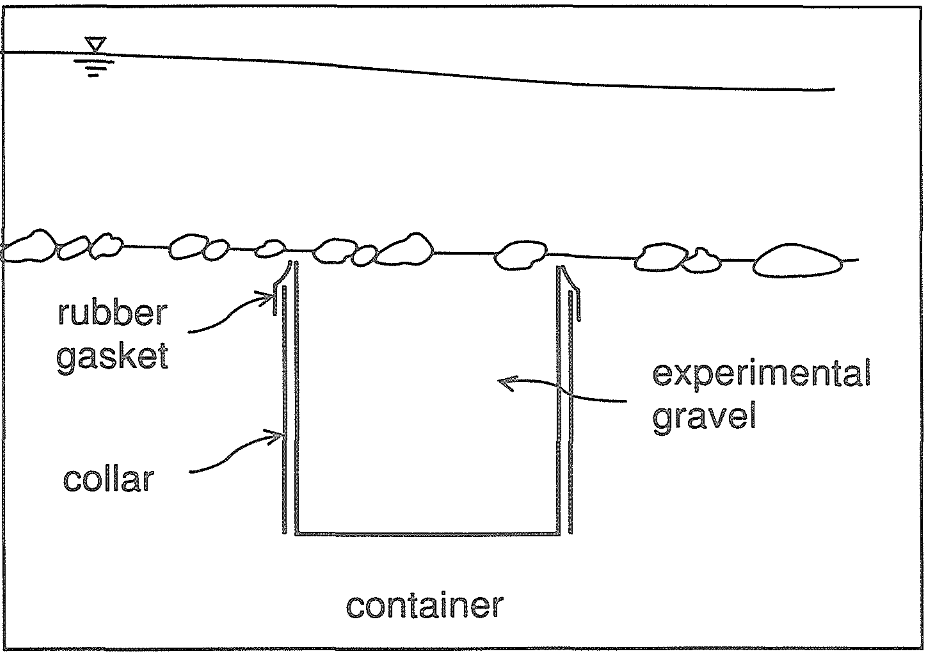

Figure 3—Solid-walled container used to measure infiltration of fine sediment.