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Photographic Techniques for Characterizing Streambed Particle Sizes

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Abstract.—We developed photographic techniques to characterize coarse (>2-mm) and fine (≤2-mm) streambed particle sizes in 12 streams in Anchorage, Alaska. Results were compared with current sampling techniques to assess which provided greater sampling efficiency and accuracy. The streams sampled were wadeable and contained gravel—cobble streambeds. Gradients ranged from about 5% at the upstream sites to about 0.25% at the downstream sites. Mean particle sizes and size-frequency distributions resulting from digitized photographs differed significantly from those resulting from Wolman pebble counts for five sites in the analysis. Wolman counts were biased toward selecting larger particles. Photographic analysis also yielded a greater number of measured particles (mean = 989) than did the Wolman counts (mean = 328). Stream embeddedness ratings assigned from field and photographic observations were significantly different at 5 of the 12 sites, although both types of ratings showed a positive relationship with digitized surface fines. Visual estimates of embeddedness and digitized surface fines may both be useful indicators of benthic conditions, but digitizing surface fines produces quantitative rather than qualitative data. Benefits of the photographic techniques include reduced field time, minimal streambed disturbance, convenience of postfield processing, easy sample archiving, and improved accuracy and replication potential.

The composition of streambed particles can have important effects on fish populations and can be particularly important in streams supporting salmonids. The size composition of these particles affects the quality of spawning and incubation habitat (Bjornn and Reiser 1991), and interstices between gravel and cobble provide refuge for fry (Chapman and Bjornn 1969; Hillman et al. 1987). Embedding of large particles (>2 mm) by fines can diminish the suitability of spawning areas (Buck and Barnhardt 1986) and reduce fry habitat (Cordone and Kelly 1961; Bjornn et al. 1977). Abundant fines can also reduce embryo survival by limiting permeability of redds (McNeil and Ahnell 1964; Tappel and Bjornn 1983; Chapman 1988; Lisle and Lewis 1992) and preventing emergence of alevins (Phillips et al. 1975; Everest et al. 1987). An increase in sand and silt or a shift to a homogenous mix of particles can degrade invertebrate food sources (Williams and Mundie 1978; Minshall 1984; Alexander and Hansen 1986). Most habitat surveys include a description of the streambed particle size composition, although techniques used to collect these data can vary greatly in accuracy and effort.

One primary method of quantifying coarse particle size composition is the Wolman pebble count (Wolman 1954; Potyondy and Hardy 1994; Bain and Stevenson 1999). For this, an observer walks along a transect and picks up particles at toepoint, which are then measured along the intermediate axis. A large sample can be acquired rapidly and used to generate a particle size-frequency distribution, which is used to determine if one site has smaller or larger particles than a reference site. This procedure is especially useful for examining effects of land use on stream habitat, particularly at the watershed level (Bain and Stevenson 1999), because activities anywhere in a basin can change the composition of a streambed. However, observer bias and the repeatability of pebble counts are of concern (Kondolf 1997; Bain and Stevenson 1999).

Stream embeddedness describes the extent to which fines the size of sand or smaller (≤2 mm) fill the interstices between larger streambed particles. Embeddedness often is measured using visual estimation (Platts et al. 1983; Fitzpatrick et al. 1998; Bain and Stevenson 1999). A sample location typically is assigned a qualitative rating based on an estimated percentage of fines covering larger particles. Although this qualitative rating may provide data useful for a baseline evaluation,

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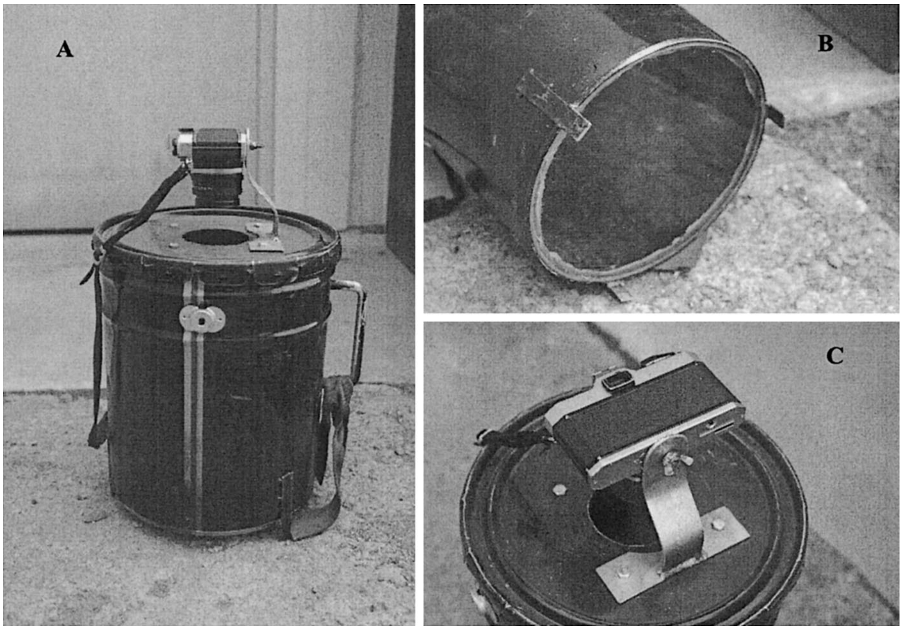

FIGURE 1.—**(A)** Device used for photographing streambeds, as modified from a 5-gal (1 gal = 3.79 L) metal can; a handle fixed to the upper exterior of the can was used for transport and for steadying it in the current. **(B)** A Plexiglas bottom in this device provided a clear view of the streambed. **(C)** The fittings of a camera tripod served to mount the camera.

the subjective nature of this procedure makes replication and accuracy questionable for more quantitative uses.

The objective of this article is to describe photographic techniques for characterizing streambed particle sizes and to compare the results of these techniques with those of techniques currently used by many fisheries scientists. Sedimentologists and geomorphologists have been using photographic particle size techniques for years (Kellerhals and Bray 1971; Adams 1979; Ibbeken and Schleyer 1986; Diepenbroek and De Jong 1994), many of which are described by Bunte and Abt (2001). However, this technology is not well integrated into fisheries applications at this time. We have developed a device and technique for photographic particle size analysis that we believe works especially well for evaluating fish habitat. Describing this technique in detail and evaluating it against more familiar techniques should help fishery scientists develop practical applications. For coarse particles, we compare a photographic technique with Wolman pebble counts in five study reaches. We also compare embeddedness ratings determined from photographs with field ratings for 12 study reaches. Finally, as a quantitative alternative to visual estimations of embeddedness, we evaluate measures of surface fines achieved by digitizing photographs.

Methods

Three 150-m-long study reaches were established in each of four streams in Anchorage, Alaska. Gradients ranged from about 5% at upstream sites to 0.25% percent at downstream sites. All streams were wadeable, and streambeds consisted primarily of gravel—cobble mixtures. In each study reach, three sample points were established on each of 11 equidistant transects, including one point at the thalweg (Fitzpatrick et al. 1998).

Wolman pebble counts were conducted along transects in five study reaches, and embeddedness was visually assessed (Fitzpatrick et al. 1998) at sample points in all 12 study reaches. The extent that coarse particles were embedded by fines was estimated to the nearest 10% at all sample points. Photographs were taken at all sites at the sample points where the water was wadeable. Use of a submergible device to improve visual resolution for photography was necessary.

Photographs were taken using a device constructed from a 5-gal (1 gal = 3.79 L) metal can with a watertight Plexiglas bottom and a camera mounted over a hole in the lid (Figure 1). Legs

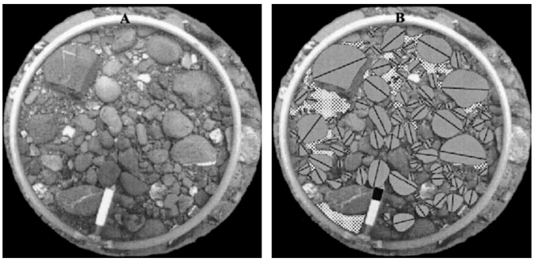

FIGURE 2.—**(A)** Example of a streambed image from one sample point and **(B)** the digitized image, including pebbles, medial axes, fines, and the scale polygon.

approximately 5 cm long were affixed to the bottom to prevent the Plexiglas from being scratched and to assure that enough light would get to the streambed surface. The opacity of the can and lid was extremely important because reflections and glare rendered images useless in similarly configured transparent and translucent devices. The device was adjusted to an approximately level position by the observer.

A manual, single-lens reflex (SLR) camera fitted with a 28–105-mm F/4–5.6 lens and ultraviolet and circular polarizer filters was used to photograph the streambed. To compensate for low light levels, we used 400-speed slide film. The targeting quadrat, a tethered circular metal ring about 0.08 m^2 in size with a calibrated scale, was placed on the streambed. Minimum effective depth for photography was about 8 cm; maximum effective depth was a function of clarity, light penetration, and the observer's leg length and height.

Developed slides were scanned using a high-resolution scanner and saved as tagged image format (TIF) files. Any image requiring photomanipulation for brightness or contrast was duplicated and adjusted in Adobe Photoshop.

An ArcView project (ESRI 2000) was created for all 12 study reaches, and each TIF image was imported into a separate view (Figure 2a). A magnification constant (K) was computed for each view from the relationship of the true scale bar size to its size in screen dimensions:

$$K = A_T/A_S,$$

where A_T equals the true area in square millimeters and A_S equals the area in screen dimensions. The screen area of the scale bar was determined by digitizing it as a polygon. The true area (mm^2) of polygons was calculated from the magnification constant. Screen size of polygons was determined using the ArcView area calculator, and the dimension was arbitrary.

TABLE 1.—Embeddedness index for streambeds modified from a rating system by Platts et al. (1983). Coarse particles include those greater than 2 mm, and fines include materials less than or equal to 2 mm.

Index	Level of embeddedness	Description
0	Negligible	Coarse particles have <5% of their surface covered by fines
1	Low	Coarse particles have 5–25% of their surface covered by fines
2	Moderate	Coarse particles have 25–50% of their surface covered by fines
3	High	Coarse particles have 50–75% of their surface covered by fines
4	Very high	Coarse particles have >75% of their surface covered by fines

Layers created for each image included pebbles, medial axes, and fines (Figure 2b). Coarse particles were digitized as pebbles, and any that were embedded or not entirely visible were ignored. An ArcView script was used to make a line representing the longest axis of each pebble polygon, and the intermediate axis, defined as a line perpendicular to the longest axis, was estimated and digitized as a line. The recorded size for a pebble was based on the intermediate axis, as described for a Wolman count (Bain and Stevenson 1999). All visible areas consisting of fines were digitized and expressed as a percentage of the quadrat area.

Each photo also was qualitatively assessed for embeddedness via a rating system of five levels defined by percentage estimates of the degree that fines appeared to be filling the interstices between gravel and cobble (Table 1; Platts et al. 1983). The embeddedness estimates from the field were converted to this rating system for comparison purposes. Only sample points from the field that also were photographed were used in the analysis.

The data for coarse and fine particles were examined separately. Sample sizes for Wolman counts ranged from 237 to 779 and for photographic digitizing ranged from 491 to 1,868. A standard, independent sample *t*-test was used to determine whether the methods produced significantly different ($\alpha = 0.05$) means, and the Kolmogorov—Smirnov test was used to determine whether the particle-size distributions were significantly different. The number of embeddedness ratings for each site ranged from 15 to 33. Wilcoxon's rank-sum test was used to test for significant differences between ratings observed by the two methods. Scatterplots were used to examine

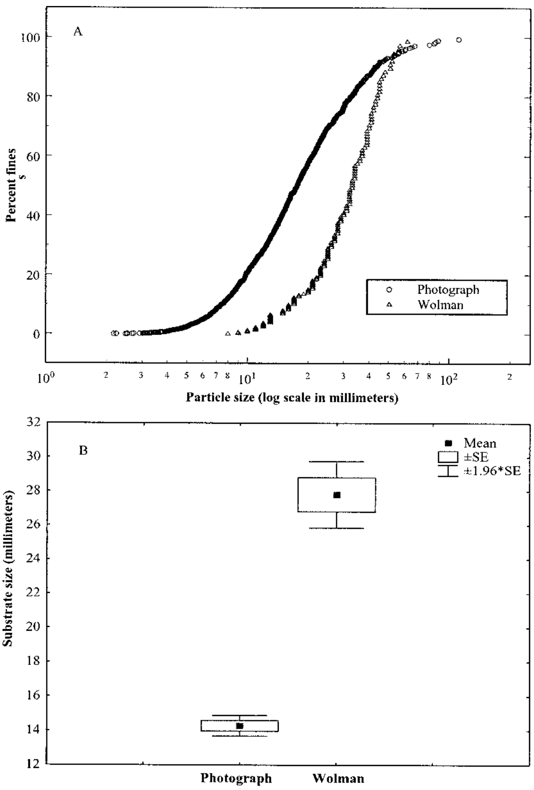

FIGURE 3.—Comparison of streambed particle size data (upper panel = percentage data; lower panel = measured size) acquired by photographic digitizing and by a Wolman pebble count at one study reach.

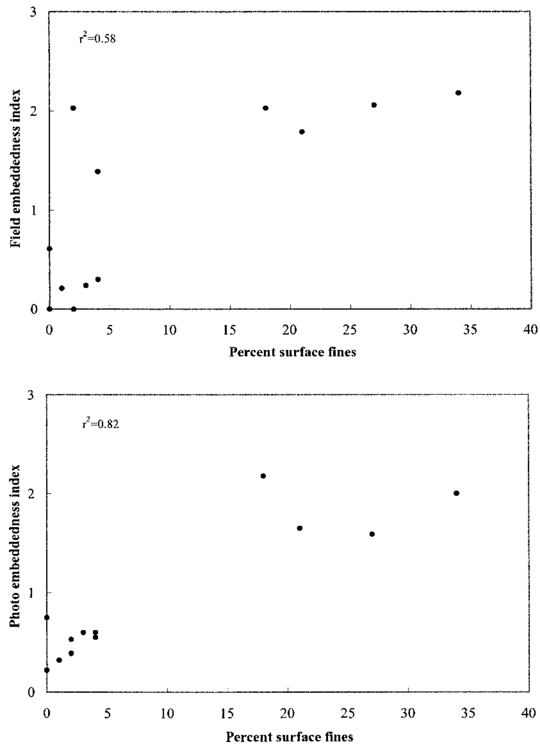

FIGURE 4.—Relationships between means of digitized percent surface fines and embeddedness ratings estimated from field and photographic observations for all study sites.

the relationship between the means of digitized percent fines and embeddedness ratings estimated from field and photographic observations for all study sites.

Results

Mean particle sizes from digitized photographs and Wolman counts differed significantly for all five sites, as did the particle size distributions. The differences were consistent for all samples, Wolman counts at each site producing larger particles than did digitizing. Examples of the distributions acquired for one study location show that only the very largest size classes were classified similarly (Figure 3a) and that mean values differed by more than 10 mm (Figure 3b). A difference of 10 mm or more in mean values occurred at four of the five sites. Additionally, a greater number of particles were measured by the photographic analysis (mean = 989) than by the Wolman count (328).

Embeddedness indices from field and photographic observations differed significantly at 5 of 12 reaches, and discrepancies were inconsistent, field ratings being higher at 5 and lower at 7 reaches than ratings made from photographs. Scatterplots of site embeddedness means with means of digitized percent surface fines show a positive correlation for both types of observations (Figure 4). However, a greater degree of covariation existed between digitized percent surface fines and the photographic embeddedness indices ($r^2 = 0.82$) than there was between digitized percent surface fines and the field embeddedness indices ($r^2 = 0.58$). A regression line was not fitted through the scatterplot for the field data because of an apparent lack of linearity, nor was one fitted through the scatterplot for the photographic data because the gap between the two clusters of points made it difficult to assess the appropriateness of a linear (or other) model.

Discussion

The disparate results from the two techniques of describing coarse particle size composition are noteworthy because a significant error may exist for one of the techniques. We could not determine which technique is more accurate, but the digitized images should theoretically produce values more representative of the streambed surface because all traceable particles are sampled and a bias for selection of larger sizes is eliminated. It is possible that larger particles have a greater probability of being picked up during a Wolman count even by the most objective observer. However, a small error in obtaining the intermediate axis measurement from photographs is possible due to the orientation of some particles. Regardless, the much larger sample sizes obtained from digitizing should reduce variability.

We cannot confirm which technique of estimating embeddedness is more accurate, so caution is important where either is used to assess stream habitat. The fact that 5 of 12 estimates were significantly different between the field and photograph observations demonstrates the difficulty in making consistent decisions. The positive relationship between embeddedness and surface fines may be typical in streams. Although these parameters cannot be used interchangeably because they measure two different properties, they may both be valuable indicators of benthic conditions. The advantage of digitizing fines from photographs is that this technique produces a quantitative value.

The permanence of photographs and the capabilities of current software provide opportunities to improve sampling efficiency and accuracy when characterizing streambed particle sizes. Benefits of the described techniques include reduced field time, minimal streambed disturbance, convenience of postfield processing, and sampling ease. Having an actual photograph of the streambed is an invaluable visual aid for comprehending the meaning of summary statistics used to characterize streambed particle size composition. Application of these techniques at permanent photograph locations could be especially valuable in documenting spatial and temporal changes in streambed dynamics.

There are a few limitations to these techniques, primarily equipment costs and processing time. However, the increase in costs and time is relatively low, given the potential improvement in data accuracy. The camera-mounting device can be fabricated from inexpensive materials, and scanners and necessary software are commercially available. Postfield processing is the most time-demanding aspect of the technique, but little training is necessary for personnel. Sampling at base flow conditions can minimize the primary physical constraints of water depth and clarity.

The use of an SLR camera instead of a more expensive digital camera is one way to keep costs down, although both have their advantages. Dropping a digital camera into water results in a loss of all data currently being stored, whereas an SLR camera often can be repaired and film can still be processed. Scanned film also typically produces higher resolution images than digital cameras, and digital cameras can have additional problems in extreme conditions (e.g., cold temperatures). Alternatively, using a digital camera eliminates processing costs and images can be immediately downloaded and backed-up in the field.

Further experimentation with photographic streambed analysis would help determine the potential for future applications. Using the technique to analyze samples of known composition would provide more information on the level of accuracy. Having several individuals analyze the same photographs would test for a potential source of variability. Quantifying costs and field and processing times would provide practical information regarding the best applications for the technique. A standardized technique for quickly and accurately characterizing streambed particle sizes would not only be useful to fisheries biologists, but also would be useful in other areas of stream ecology.

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