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A Field Comparison of the Substrate Composition of California Golden Trout Redds Sampled with Two Devices

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Abstract.—Stream substrates are frequently sampled with several different devices, and it is often assumed that the resulting samples have comparable compositions. We compared substrate samples taken with an excavated corer (15-cm-diameter plastic pipe) with those taken with a freeze corer from redds of California golden trout *Oncorhynchus mykiss aguabonita* in a stream dominated by small substrates (geometric mean diameter of redd substrates, approximately 6 mm). The proportions of individual particle size-fractions and the percent of fine sediment in the upper portion of excavated cores were similar to those in freeze cores. Geometric mean particle diameters of excavated-core and freeze-core samples were influenced by differences in the proportional weight of particles larger than 12.5 mm: as a result, geometric mean diameters were most similar when these larger size-fractions were omitted. Samplers did not differ in their probability of encountering egg pockets. A power analysis of the substrate size-fraction comparisons showed that the power of our analyses to detect differences between samplers was usually high (≥ 0.8). Therefore, the general lack of significant differences in the substrate composition from samples taken by the excavated corer and freeze corer is probably the result of few true differences and not of shortcomings in our sampling design. For small streams dominated by fine substrates, we conclude that the inexpensive excavated-core sampler we used is a viable alternative to the expensive and cumbersome freeze-core sampler, even when sampling in redds, and that it has several advantages over other excavated-core samplers or a shovel when sampling outside of redds.

Researchers interested in habitat use by spawning salmonids and the effects of land management activities on salmonid populations often sample stream substrates to assess the quality of spawning gravel (e.g., Platts et al. 1979; Platts et al. 1989; Scrivener and Brownlee 1989; Grost et al. 1991a). Common substrate sampling devices include freeze-core (FC) samplers (Walkotten 1976; Everest et al. 1980), excavated-core (EC) samplers

(McNeil and Ahnell 1964), and shovels (Hausle and Coble 1976). Although some authors have assumed that results from these different sampling devices are comparable (Shirazi and Siem 1979; Everest et al. 1980), recent research suggests that this may not be true.

Grost et al. (1991b) and Young et al. (1991a) compared the composition of substrate samples collected by FC samplers, EC samplers, and shovels, and found that the FC sampler produced samples that were significantly different from those produced by either the EC sampler or a shovel. Young et al. (1991a) attributed these differences primarily to the tendency of FC samplers to oversample larger particles. However, FC samplers appeared to accurately estimate the relative abundance of small particles (Young et al. 1991a). Samples obtained with an EC sampler or shovel were similar to each other, and both types of samplers have been recommended over FC samplers because of their increased accuracy (Young et al. 1991a) and ease of use (Grost et al. 1991b). However, some fine sediment is suspended in the water contained within the EC sampler and is not collected (Young et al. 1991a). The potential sampling bias resulting from the failure to capture this suspended sediment may be particularly severe in streams with abundant fine particles. Such substrates were not included in the study by Grost et al. (1991b), and the authors warn that their results may only be applicable to streams similar to the ones they sampled (i.e., with substrates dominated by larger particles).

The purpose of our study was to determine whether an inexpensive and lightweight EC sampler could be used as an alternative to the expensive and cumbersome FC sampler when sampling redds of California golden trout *Oncorhynchus mykiss aguabonita* (Behnke 1992) in substrates dominated by fine sediment. Because our ongoing re-

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search on California golden trout spawning biology is conducted at remote study sites, the use of an EC sampler would greatly simplify the logistics of sampling stream substrates. Our study area was located in the Sierra Nevada at the downstream end of Horseshoe Meadow, Cottonwood Creek, Inyo National Forest, California. Geometric mean diameter (D_g) of substrates in California golden trout redds in Cottonwood Creek and nearby streams ($D_g \approx 6$ mm; Stefferud 1993; Knapp and Vredenburg 1996; this study) is among the smallest ever recorded for salmonid redds (for a recent review, see Kondolf and Wolman 1993).

Methods

We sampled 24 recently completed California golden trout redds in Cottonwood Creek on 14–15 June 1994 (for a map of the study area, see Stefferud 1993). The selected redds represented all redds located in a 150-m stream reach. Redds were identified by their characteristic pit and tailspill (Chapman 1988; Crisp and Carling 1989). For detailed descriptions of California golden trout redds and golden trout spawning biology see Knapp and Vredenburg (1996). One FC sample and one EC sample were taken from the tailspill of each redd. We restricted our sampling to the front and central portion of the tailspill because this is the most likely area to contain egg pockets (Grost et al. 1991a). The position of the FC sampler relative to the EC sampler (upstream versus downstream) was determined by the flip of a coin. The downstream sample was always taken before the upstream sample. Because we wanted to compare only substrates that had been disturbed by spawning females (and not the undisturbed gravel under the redd), we collected only the upper 5 cm of streambed in our EC and FC samples. We chose 5 cm as the separation depth between disturbed and undisturbed gravel because this was the average depth of the bottom of California golden trout egg pockets in a nearby stream (range, 4–6 cm; Knapp and Vredenburg 1996).

The FC sampler was modified from the design of Walkotten (1976) and consisted of a single steel probe, 2.5 cm in diameter and 150 cm long. The probe was driven into the stream substrate to a depth of 20 cm. A plastic cylinder (15 cm in diameter) surrounding the probe was pushed 5 cm into the substrate to reduce water velocity at the substrate surface. Carbon dioxide was delivered from a pressurized cylinder to the probe through a hose and manifold assembly similar to that described by Walkotten (1976). After 10 min of car-

bon dioxide injection, the probe and attached frozen substrate was lifted from the stream and thawed with a propane torch. After the outside of the core was inspected for the presence or absence of eggs, the upper 5 cm was separated from the lower portion of the sample, and the upper portion was placed into a resealable plastic bag for transport to the laboratory.

Most EC samplers are based on the design of McNeil and Ahnell (1964). The McNeil sampler consists of a coring tube and an integrated chamber for holding excavated substrate. This sampler is cumbersome, heavy (15 kg), and expensive to construct (US\$900; Grost et al. 1991b). Our excavated core sampler was a 40-cm-long section of polyvinyl chloride (PVC) pipe, 15 cm in inside diameter. Similar samplers have been used by other researchers (e.g., Stefferud 1993). We inserted the cylinder into the substrate to a depth of 5 cm, and excavated substrate to this depth by hand. The substrate was placed directly into resealable plastic bags, and each handful of gravel was checked for eggs. No attempt was made to collect fine sediment suspended in the water contained within the coring tube. If eggs were not found in either the EC or FC samples, the entire redd was excavated by hand to determine whether eggs were present in places other than those sampled.

Substrate samples were dried for a minimum of 12 h at 70°C until they showed no further loss of weight. Samples were agitated on a mechanical shaker for 10 min through 10 standard testing sieves (mesh openings of 50, 25, 12.5, 9.5, 6.3, 3.35, 1.7, 0.85, 0.42, 0.21 mm). The fraction of each sample that passed through all sieves was classified as smaller than 0.21 mm. Each size-fraction was weighed to the nearest 0.1 g on an electronic balance. The proportional weight of each size-fraction was calculated by dividing the weight of the size-fraction by the total sample weight. Geometric mean diameters were calculated by the product-of-moments formula given by Lotspeich and Everest (1981). The percent fine sediment was calculated as the percent of sediment that was less than 6.3 mm, 3.4 mm, 1.7 mm, or 0.85 mm (Young et al. 1991b).

Because all of the parameters used to characterize sediment size-composition are based on the proportional weight of a series of size-fractions, the bias of FC samplers toward larger particle sizes (Young et al. 1991a) can result in biases in the proportional weight of other size-fractions. To evaluate the extent of these biases, we calculated geometric mean diameter, percent fine sediment,

and proportional weight of individual size-fractions based on samples from which we omitted all particles (1) larger than 50 mm, (2) larger than 25 mm, and (3) larger than 12.5 mm. Because only one sample contained particles larger than 50 mm, we did not make any size composition calculations based on complete samples.

Statistical analyses.—All data were normally distributed (Shapiro–Wilk test). Therefore, we tested the null hypothesis of no difference in substrate composition between EC and FC samples from the same redd with paired *t*-tests for equal or unequal variances. We compared D_g , percent fine sediment, and the proportional weight of each particle size-fraction from EC versus FC samples by using paired samples from all 24 redds. Comparisons of percent fine sediment required separate tests for each of four substrate size-categories. Comparisons of proportional weights required separate tests for each of 10, 9, or 8 size-fractions (when particles larger than 50 mm, 25 mm, and 12.5 mm were omitted, respectively). To compensate for the increased chance of a type I error (α) associated with multiple comparisons, we used the Bonferroni procedure to maintain an experiment-wise α of 0.1 (Neter et al. 1985). Using this procedure, we calculated α for individual tests by dividing the experimentwise α by the number of tests in each comparison. We used an α of 0.1 instead of 0.05 to reduce the chances of type II error (i.e., β : the probability of not rejecting the null hypothesis of no difference in substrate composition when the null hypothesis is in fact false).

We also tested the null hypothesis that the probability of encountering an egg pocket would be unaffected by the type of sampler. Although the McNemar change test is particularly applicable to our sample design, expected values less than 5 made this test inappropriate (Siegal and Castellan 1988). Instead, we used the binomial test alternative recommended by Siegal and Castellan (1988). For this test, we used only the 20 redds that contained eggs.

Although our comparisons of substrate size-fractions between EC and FC samples showed very few significant differences (see Results), this lack of significant differences could be the result of either (1) a lack of true differences or (2) true differences being masked by high parameter variability or low sample sizes (resulting in type II error). Therefore, it is inappropriate to conclude that there is in fact no difference without first eliminating the possibility that the sampling design had a low probability of detecting a difference (i.e.,

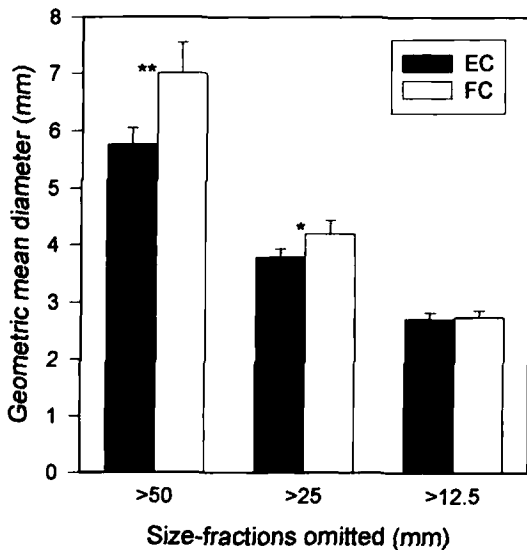


FIGURE 1.—Paired comparisons of the geometric mean diameter calculated for excavated-core (EC) and freeze-core (FC) samples after omitting particles larger than 50 mm, larger than 25 mm, or larger than 12.5 mm. Bars are means with +SE indicated. Asterisks between paired bars indicate a significant difference in geometric mean diameter between EC and FC samples ($P < 0.01$ **; $P < 0.05$ *).

low power, where power = $1 - \beta$) (Peterman 1990). High power (≥ 0.8) indicates that the observed lack of statistically significant differences is probably the result of a lack of true differences and not the consequence of an inadequate sampling design (Peterman 1990). To determine the probability of detecting a true difference with our sampling design, we used SigmaStat, Version 1.01. The power of paired *t*-tests was calculated based on a minimum detectable difference between means of 20, 30, or 40%, the standard deviation of the difference between samples (calculated as part of the paired *t*-test), a sample size of 24, and $\alpha = 0.1$.

Results

We encountered egg pockets in 20 of 24 redds. In 14 redds, egg pockets were found in substrate samples; in the 6 other redds, egg pockets were found during redd excavation. Ten of 24 FC samples and 11 of 24 EC samples included egg pockets; the probability of encountering an egg pocket was not significantly different between samplers ($N = 7$, mean = 3, $P > 0.5$). Based on observations of eggs in freeze cores, the bottom of egg pockets in redds averaged 5.4 cm deep ($N = 10$; range,

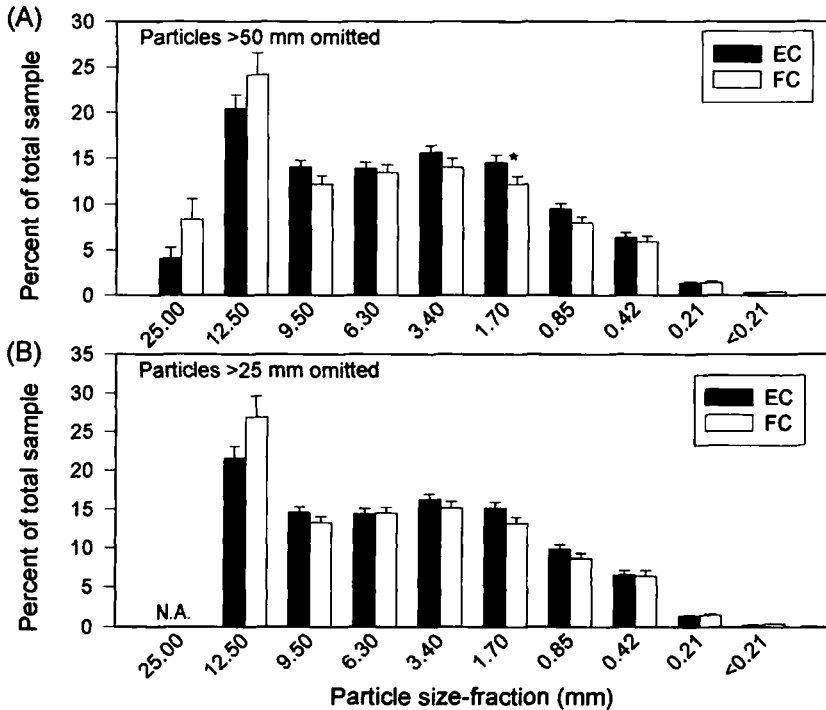


FIGURE 2.—Paired comparisons of the proportional (%) weight of individual substrate size-fractions from excavated-core (EC) and freeze-core (FC) samples. The percent weight of each size-fraction was calculated with (A) particles larger than 50 mm omitted, and (B) particles larger than 25 mm omitted. Bars are means with +SE indicated. For samples with particles larger than 50 mm omitted, $\alpha = 0.010$; for samples with particles larger than 25 mm omitted, $\alpha = 0.011$. An asterisk between paired bars indicates a significant difference in percent weight of an individual size-fraction between EC and FC samples ($P < 0.01$); N.A. = not applicable.

5.0–6.5 cm; SE, 1.8 cm). Therefore, separating upper and lower portions of freeze cores at a depth of 5 cm and collecting only the uppermost 5 cm of substrate with the excavated corer should have produced samples that only included substrate disturbed by spawning females. The upper portions of FC samples were significantly smaller than the EC samples (524 g versus 1,554 g; two-sample *t*-test, $N = 24$, $t = 24.1$, $P < 0.001$).

Geometric mean diameters were significantly larger in FC relative to EC samples when particles larger than 50 mm and 25 mm were omitted ($P < 0.1$), but they were not significantly different when particles larger than 12.5 mm were omitted ($P > 0.8$; Figure 1). Comparisons of the proportional weight of substrate size-fractions between EC and FC samples from which particles larger than 50 mm were omitted showed that the most noticeable differences were between the 25- and 12.5-mm size-fractions, but only the 1.7-mm size-fraction was significantly different (Figure 2A). When size-fractions larger than 25 mm were omitted, there

were no statistically significant differences between size-fractions (Figure 2B). There were also no significant differences when size-fractions larger than 12.5 mm were omitted. These results suggest that particles larger than 12.5 mm were oversampled by the FC sampler relative to the EC sampler and that differences in the proportions of these size-fractions influenced calculations of substrate size composition.

The general lack of significant differences in the proportional weight of size-fractions from the EC and FC samples could be the result of a true lack of differences or of an inadequate sampling design. Our power analysis showed that the sampling design was generally sufficient to detect differences of 20–30%. When particles larger than 50 mm were omitted, our sampling design was sufficient to detect differences of 20% between EC and FC intermediate size-fractions (9.5–0.85 mm), while maintaining power above 0.8 (Figure 3A). In addition, the sampling design was sufficient (power, >0.8) to detect 30% differences in substrate com-

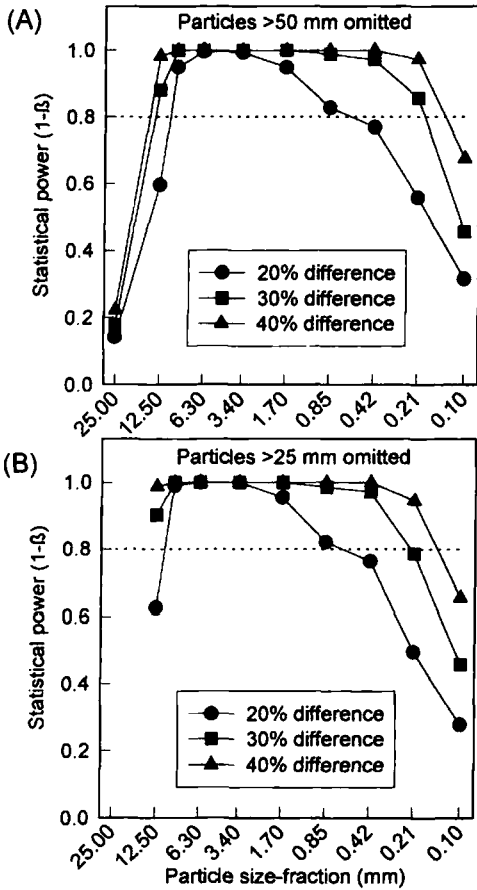


FIGURE 3.—Power ($1 - \beta$) of paired comparisons of the percent weight of individual substrate size-fractions from excavated-core (EC) and freeze-core (FC) samples. Power is shown for differences between sample means of 20%, 30%, and 40% for samples from which (A) particles larger than 50 mm were omitted and (B) particles larger than 25 mm were omitted. The dotted line indicates the minimum recommended level of power (≥ 0.8 ; Peterman 1990) for rigorous interpretation of nonsignificant differences.

position for all but the largest and smallest size-fractions (Figure 3A). Results of the power analysis based on samples from which particles larger than 25 mm were omitted provided similar results (Figure 3B). Therefore, the general lack of significant differences in the substrate composition between EC and FC samples is probably the result of a true lack of differences. It should be noted, however, that because of relatively large variability in the proportional weight of the 25-mm and smaller than 0.21-mm size-fractions between samples, the power of comparisons using these size-fractions would be unacceptably low even at dif-

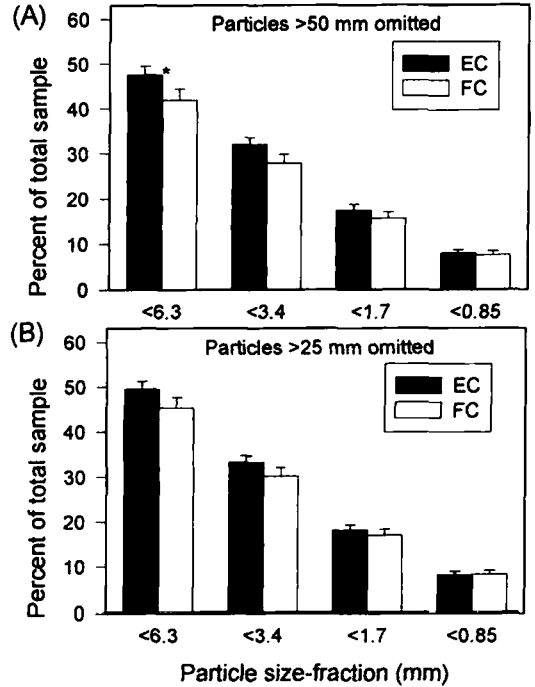


FIGURE 4.—Paired comparisons of the percent weight of fine sediment (<6.3 mm, <3.4 mm, <1.7 mm, <0.85 mm) from excavated-core (EC) and freeze-core (FC) samples. The percent weight of each sediment category was calculated with (A) particles larger than 50 mm omitted and (B) particles larger than 25 mm omitted. Bars are means with +SE indicated. For individual comparisons, $\alpha = 0.025$. An asterisk between paired bars indicates a significant difference in percent fine sediment between EC and FC samples ($P < 0.02$).

ferences greater than 40% (Figure 3A). Therefore, the lack of significant differences in these size-fractions between EC and FC samples should be interpreted with caution.

The comparisons of percent fine sediment (<6.3 mm, <3.4 mm, <1.7 mm, <0.85 mm) in EC versus FC samples were also affected by the different proportions of large particles between sampler types. The percent fine sediment smaller than 6.3 mm was significantly greater in EC than in FC samples when particles larger than 50 mm were omitted (Figure 4A). In contrast, there were no significant differences in percent fine sediment when we omitted particles larger than 25 mm (Figure 4B) or larger than 12.5 mm.

A power analysis of the percent fine sediment comparisons showed that the sampling design was generally sufficient to detect differences of 20% between EC and FC samplers while maintaining power at 0.8 or above (Figure 5). This was true

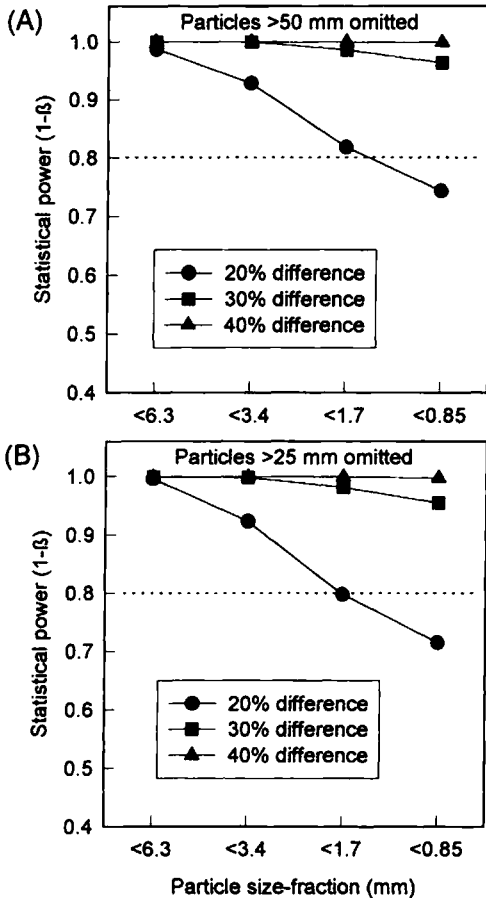


FIGURE 5.—Power ($1 - \beta$) of paired comparisons of the percent weight of fine sediment (<6.3 mm, <3.4 mm, <1.7 mm, <0.85 mm) from excavated-core (EC) and freeze-core (FC) samples. Power is shown for differences between sample means of 20%, 30%, and 40% for samples from which (A) particles larger than 50 mm were omitted and (B) particles larger than 25 mm were omitted. The dotted line indicates the minimum recommended level of power (≥ 0.8 ; Peterman 1990) for rigorous interpretation of nonsignificant differences.

for comparisons from which particles larger than 50 mm (Figure 5A) or larger than 25 mm were omitted (Figure 5B). Therefore, the general lack of significant differences in fine sediment composition of EC and FC samples is probably the result of no true differences between samples and not of shortcomings of our sampling design.

Discussion

Our comparisons of proportional weights of sediment size-fractions and fine-sediment categories between EC and FC samples show that samples produced by these different sampling devices were

generally very similar. However, the significantly larger geometric mean particle diameter of FC samples compared with EC samples when 12.5–50-mm size-fractions were included in calculations and the lack of any significant differences when these larger particles were omitted suggests that the FC samples contained a proportionally larger weight of particles larger than 12.5 mm than did the EC samples, and that this difference influenced calculations of substrate composition. However, the lack of any significant differences in the proportional weight of the 12.5-mm size-fraction between EC and FC samples despite high power and the lack of any significant differences in percent fine sediment regardless of whether particles larger than 25 or 12.5 mm were omitted suggests that the difference between samplers may have been particularly strong only for size-fractions larger than 25 mm. Young et al. (1991a) also found that FC samples contained more large particles than EC samples, and Grost et al. (1991b) reported that these large particles had a strong influence on calculations of the substrate composition of FC samples. In addition, Grost et al. (1991b) also reported that the removal of these particles from calculations of substrate composition reduced the differences between EC and FC samples.

Because we did not know the actual composition of sampled substrates, we cannot assess the accuracy of either sampler. However, our frequent observation in freeze cores of large particles jutting up to 5 cm beyond the cylinder of frozen sediment suggests that the FC sampler oversampled these larger particles. This is supported by the results presented in Young et al. (1991a) that show that FC samplers oversampled particles larger than 50 mm relative to EC samplers and shovels.

Previous studies that compared the efficiency of FC samplers, EC samplers, and shovels concluded that EC samplers and shovels were superior to FC samplers because of their increased accuracy (Young et al. 1991a) and efficiency (Grost et al. 1991b) in estimating substrate composition. Both of these studies acknowledged, however, that FC samplers would be required whenever sampling needed to be restricted to particular depth strata (e.g., when sampling redds). Our results suggest that any advantage of using a FC sampler to sample the upper depth strata of redds is eliminated if the EC sampler is used to sample only to the average or minimum egg pocket depth.

Grost et al. (1991b) concluded that shovels may be the best alternative for routine substrate sampling (i.e., sampling outside of redds) in small

streams because of low cost and ease of use under field conditions. The shovel, however, may also have drawbacks under some sampling conditions. For example, collecting a sample that contains the same volume of sediment from all sampled depths may be difficult with a shovel. The use of a shovel also may result in biased samples when water current is high enough to wash fine sediments out of the sample (Grost et al. 1991b).

Our EC sampler was inexpensive (US\$3), lightweight (0.5 kg), and easy to use. When sampling in California golden trout redds was restricted to streambed depths typically disturbed by redd-digging females, it produced samples with a composition generally similar to that of samples taken from the same depth with a FC sampler. The proportional weight of fine sediment in samples obtained from the EC and FC samplers was similar despite the abundance of fine sediment in the substrate of the study stream and the fact that we did not attempt to collect the fine sediment suspended in the coring tube of the excavated corer. Relative to estimates of substrate composition obtained from shovel samples, EC samples will equally represent all sampled streambed depths and will be unaffected by current velocity. Therefore, we suggest that for small streams and small substrates, an EC sampler constructed of a PVC coring tube is a viable alternative to the FC sampler, even when sampling in redds. Our EC sampler also has several advantages over the McNeil sampler and the shovel that may make it a better substrate sampling device when sampling outside of redds.

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