

Use of the Wesche Method to Evaluate Fine-Sediment Dynamics in Small Boreal Forest Headwater Streams

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Abstract.—Fine-sediment infiltration was monitored by the Wesche sediment method in the Copper Lake watershed, Newfoundland, Canada, from June 1993 to October 1994 as part of a multidisciplinary forest harvesting buffer zone research project. Initial study in Copper Lake has focused on evaluating the ability of this method to measure sediment dynamics in small boreal forest streams and in developing methods for data analyses and interpretation. The Wesche method discerned expected differences in sediment yield among sites due to logging-road construction and seasonal trends. Stream reaches impacted by bridge construction and culvert installation had significantly higher sediment accumulation than streams not affected by road construction. The Wesche method was a relatively simple and inexpensive way to compare fine sediment yield in streams with similar hydrologic regimes and was easily used in remote locations. Due to the nonparametric nature of the data collected with this method, randomization techniques were used to develop 95% confidence intervals around the mean. Use of these statistics allowed a significance level to be used in comparisons between stream reaches, an approach easily understood by the multidisciplinary audience interested in fishery-forestry research and management.

Sediment increases in streams due to practices such as forest harvesting, road construction and use, and farming have been well documented over the last 20 years (Welch et al. 1977; Beschta 1978; Reid and Dunne 1984; Brownlee et al. 1988; Harr and Fredriksen 1988; Fahey and Coker 1992; Davies and Nelson 1993; Johnson 1993). Researchers have successfully linked these sediment increases to a variety of responses in the biotic community of stream ecosystems including reduced survival of age-0 salmonids during emergence (Platts et al. 1989; Scrivener and Brownlee 1989) and changes in the abundance and structure of the benthic macroinvertebrate community (Lenat et al. 1981). Most North American studies of this nature have been conducted either in the Pacific Northwest (e.g., Reid and Dunne 1984; Brownlee et al. 1988; Harr and Fredriksen 1988) or in the northeastern United States (e.g., Lenat et al. 1981; Alexander and Hansen 1986; Platts et al. 1989). These areas have physical and biological conditions different from those of the boreal forest of eastern Canada

(Scruton et al. 1995), which generally has shallow, erodible soils and a lower species diversity than the rest of North America.

The Copper Lake watershed is remote and difficult to access; consequently, it was necessary to use a method to measure fine sediment yield that was simple, inexpensive, and able to conclusively elucidate the effects of timber harvesting operations. Many conventional methods for measuring fine sediment in streams (i.e., various coring techniques; integrated samplers) are equipment intensive and difficult to deploy in remote areas. Suspended sediment measurements from water samples, in contrast, require little equipment but produce "point-in-time" samples. A large number of samples are required to give an indication of sediment yield over time, which makes this a labor intensive method. Sampling regimes that are labor or equipment intensive can greatly increase the cost of research.

Wesche et al. (1989) described the use of modified Whitlock-Viebert boxes for measuring fine sediment accumulation in streams. This method can be readily used in remote areas and is not labor intensive; thus, it was well suited to the Copper Lake situation. However, a review of the literature revealed that this method had never been independently validated for small streams and had only been cited once (Davies and Nelson 1993) in the past 6 years. Because several ongoing projects in eastern Canada are using this method (Cunjak et al. 1993; Scruton et al. 1995), an independent evaluation of the technique for use in small streams, with statistical considerations, was warranted.

The objective of our study was to evaluate the ability of the method of Wesche et al. (1989) to discern changes in sediment accumulation, caused either by natural or external perturbations, in small boreal forest streams of Newfoundland. This objective was accomplished by monitoring stream reaches in the Copper Lake watershed for changes in sediment yield produced by logging road construction and natural seasonal variation.

Study Area

The Copper Lake watershed is a small headwater system (13.5 km²) approximately 17 km



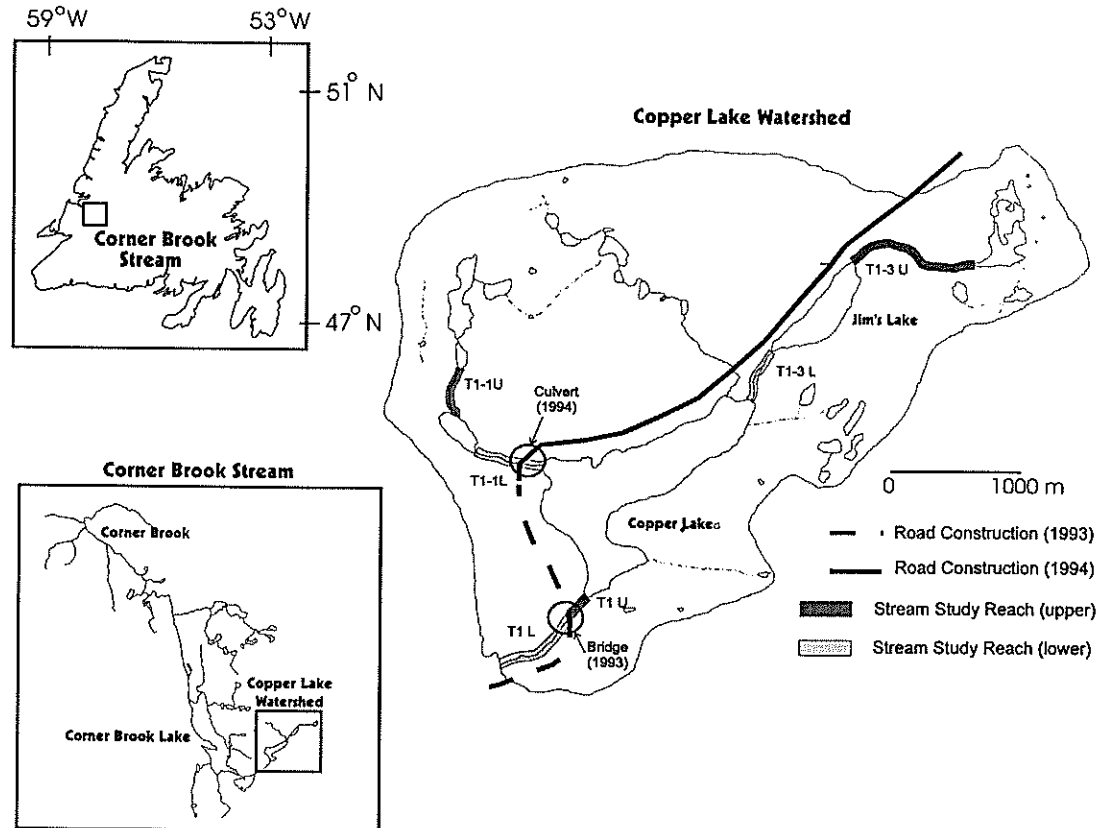


FIGURE 1.—Location of the Copper Lake watershed and identification of the experimental stream reaches and road construction sites.

southeast of Corner Brook, Newfoundland, Canada (Figure 1). The watershed is located 350–650 m above sea level and has an average annual rainfall of 1,186 mm. Fluvial habitats in the watershed included in this study consist of two headwater streams (T1-1 and T1-3) and the Copper Lake outlet (T1, a second order stream; Figure 1). Within each of these tributary streams, an upper (U) and lower (L) reach were delineated to examine the effects of road construction and forest harvesting. The physical characteristics of the study reaches are provided in Table 1. Generally, the study streams are small (ranging from 2.5 to 5.0 m in width), are dominated by small boulder–cobble substrates (>50%) and riffle habitats (>70%), and have moderate to high gradients (ranging from 2.5% to 23.8%).

The geology of the area has been described in detail by Kennedy (1981). Soils are derived from intensely deformed and highly metamorphosed rocks and are predominantly moderate to coarse glacial tills that have a relatively high moisture

content. These characteristics, coupled with the steep hillside slopes, indicate a potential for increased soil erodibility within the watershed (van Kesteren 1992). Details on the study area as well as a description of the Copper Lake Buffer Zone Study are provided in Scruton et al. (1995).

Methods

Fine particulate sediment accumulation was monitored with the method described by Wesche et al. (1989). Sediment samplers consisted of modified Whitlock–Vibert boxes (14 × 6.4 × 8.9 cm, with 3.5 × 13-mm openings; Wesche et al. 1989). These boxes (typically used for egg incubation) were filled with cleaned gravel (approximately 25 mm in diameter), and a strip of duct tape was added to the bottom of the boxes to prevent loss of accumulated fines. The boxes were placed on the stream bottom but were not buried as in Wesche et al. (1989). To help reduce box loss, each box was tied to two pieces of rebar that were driven into the stream bottom. Sediment traps were re-

TABLE 1.—Physical characteristics of the study reaches in the Copper Lake watershed. Only the main substrate types are listed; NA means not available.

Study reach	Stream order	Length (m)	Mean width (m)	Mean depth (cm)	Gradient (%)	Habitat types (%)	Substrate (%)
T1L	2	560	5.26	20.4	5	Riffle (82) Rapids (13) Flat (4) Other (1)	Bedrock (1) Large boulder (17) Small boulder (35) Rubble (17) Cobble (14) Gravel (5) Sand (2)
T1U	2	840	10.84	11.6	5	Riffle (55) Rapids (44) Steady (1)	Bedrock (2) Large boulder (21) Small boulder (37) Rubble (24) Cobble (10) Gravel (2)
T1-1L	1	528	3.35	6.5	6	Riffle (91) Steady (6) Other (3)	Bedrock (5) Large boulder (4) Small boulder (17) Rubble (26) Cobble (32) Gravel (2)
T1-1U	1	270	NA	NA	23.8	NA	NA
T1-3L	1	403	9.99	10.9	2.5	Riffle (75) Steady (25)	Large boulder (11) Small boulder (26) Rubble (29) Cobble (26) Gravel (4)
T1-3U	1	1,257	3.07	8.3	6.7	Riffle (70) Rapids (3) Steady (8) Run (17) Other (2)	Bedrock (3) Large boulder (6) Small boulder (20) Rubble (23) Cobble (12) Gravel (15) Sand (3)

trieved by carefully lifting them to the surface to prevent loss of the accumulated fine sediment and were transferred to plastic collection bags for later analysis. Samples were wet-sieved through a set of standard nested sieves (2.50, 1.40, 0.85, 0.50, and 0.09 mm), dried at 70°C for 24 h, and weighed in each of the four size fractions (<1.40, <0.85, <0.50, <0.09 mm in diameter).

In the first year of the study (1993), 15 sediment boxes were deployed in June at each of three stream reaches: (1) upstream of the proposed road crossing on T1 (T1U), (2) downstream of the road crossing (T1L), and (3) in a stream reach (T1-1L) not affected by the road in 1993 (Figure 1). Sediment boxes were arranged in five stations longitudinally distributed in each stream reach; three boxes per station were distributed across the wetted-width of the channel. Sediment boxes were collected and replaced in October 1993 after road construction for that year was complete. Sediment traps were redeployed in October 1993 in T1L and T1-1L; monitoring of T1U was discontinued. At the same time sediment traps were deployed in

T1-1U, T1-3L, and T1-3U (Figure 1) to expand sedimentation monitoring as part of a larger buffer zone study (Scruton et al. 1995).

Continuation of road construction in 1994 allowed for replication of the perturbation experiment carried out in 1993 as the road bisected a second tributary (T1-1) in the spring of 1994. Sediment samplers were collected and redeployed in both June and October 1994, which encompassed two seasonal periods: (1) the ice-free, low-flow period from June to October and (2) the over-winter period including peak spring and fall flows. This sampling regime allowed for seasonal comparison of sediment yield in these streams, while the monitoring of road construction effects on T1L and T1-1L continued.

Visual inspection of the data distributions collected from the Whitlock-Vibert boxes revealed that the data were not normally distributed in all cases. To avoid assumptions of statistical distribution that may not have been met, randomization with replication was used to estimate the 95% confidence interval around the mean for each stream

reach (Sokal and Rohlf 1981; Edgington 1987). The raw sediment yield (g) for each box collected in a particular stream reach was replicated 200 times, producing a population of 1,600–3,000 numbers depending on the number of traps retrieved (N), which ranged 8–15 per sampling period per stream reach. From these populations, N numbers were randomly sampled and their mean calculated 1,000 times. The 95% confidence interval around the mean was then estimated from these 1,000 means. Statistical significance between stream reaches was determined graphically; a failure of the mean of one distribution to fall within the 95% confidence interval of another distribution was considered a significant difference at $P \leq 0.05$.

Results

Total sediment yield in October 1993 was significantly higher downstream from the newly constructed bridge on T1 (T1L) than that observed above the bridge (T1U) and in the control reach T1-1 (T1-1L) (Figure 2). A similar result was observed in tributary T1-1 in June 1994 after a culvert was installed in the stream (Figure 2). Reach T1L still had an elevated sediment yield in June 1994, but it was not significantly different than that of T1-1L. The undisturbed stream reaches T1-1U and T1-3U had similar sediment yields in June 1994, and the T1-3L reach had a significantly lower sediment yield (Figure 2). The October 1994 sample revealed a similar pattern to that observed in June 1994; T1L and T1-1L had significantly higher total sediment yields than the stream reaches unaffected by road construction (Figure 2).

A comparison of seasonal variation in sediment yield for 1994 revealed that sediment yield was significantly higher in all stream reaches in the June sample compared with the October sample (Figure 3). Decreases in sediment yield for the undisturbed stream reaches T1-1U, T1-3L, and T1-3U from June to October 1994 were 90.2%, 52.4%, and 86.1%, respectively, from October 1993 to June 1994 yields. The smallest decrease observed, T1-3L (52.4%), was due to consistently lower sediment yields throughout the monitoring period. The stream reaches that were affected by the road crossings, T1L and T1-1L, had seasonal patterns of sediment accumulation similar to the other stream reaches, but the magnitude of decrease from June to October was lower (69.7% and 75%, respectively; Figure 3).

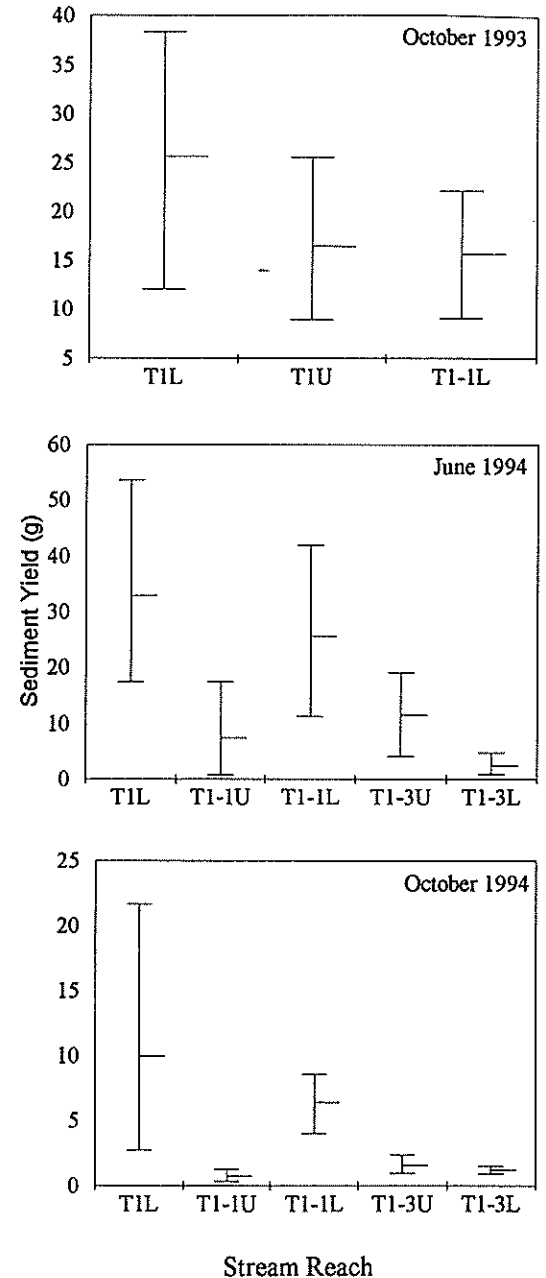


FIGURE 2.—Total fine particulate sediment (<2.5 mm) collected in the stream reaches during the three sampling dates. Vertical lines indicate the 95% confidence interval around the mean.

Discussion

Logging road construction significantly increased the sediment yield in the small headwater streams of the Copper Lake watershed. These increases were observed at two independent stream

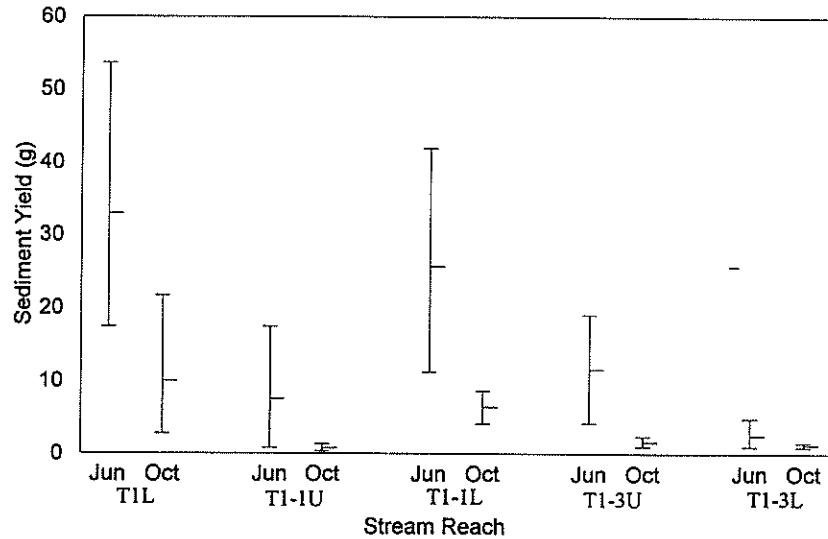


FIGURE 3.—Seasonal differences in total fine particulate sediment collected in the experimental stream reaches during 1994. Vertical lines indicate the 95% confidence interval around the mean.

crossings—a bridge and a culvert. Stream reaches affected by road construction did not exhibit the same seasonal reduction in summer sediment yield as that observed in the undisturbed streams. The difference in sediment yield over the summer was more pronounced in the affected streams than that observed after spring breakup. These initial results raise concerns about the survival and feeding ability of brook trout *Salvelinus fontinalis* that use these streams for their first 2 years of growth, as well as the ability of aquatic insects to recolonize affected streams. These biological processes depend heavily on ideal conditions during the summer, and increased sediment yield has been shown to reduce salmonid fry emergence (Platts et al. 1989) and growth (Everest et al. 1987) and to reduce the habitat suitability for aquatic insects (Lenat et al. 1981).

The Wesche et al. (1989) method for measuring fine sediment produced qualitative data that were comparable within the watershed. The approach was able to discern expected differences in sediment yield between stream reaches resulting from road construction and seasonal variation. The data produced by this method were not normally distributed and randomization techniques were used to compare sediment yields between stream reaches. Alternative nonparametric statistics, such as those used by Davies and Nelson (1993), are also valid for this type of study; however, the randomization method allowed for statistical comparisons

by means of more widely understood statistics. Use of commonly understood statistics is of importance when presenting results to a multidisciplinary audience with various backgrounds.

The Wesche sediment method was not without its problems during this study. A minor problem was the loss of sediment boxes, which ranged from 0 to 7 boxes out of 15 during any one sampling period. This loss was probably related to the "flashy" nature of the study streams, a consequence of their steep gradients. We judged, however, that these losses did not significantly alter the ability of the method to discern expected differences in sediment yield. A second, more important consideration was the effect on the data of differing hydrologic regimes within the watershed. This may have been the cause of the consistently low sediment yields in T1-3L, which may have been related to standing water in the middle of the stream reach acting as a sediment trap (see Figure 2). The low yield could also have been a result of differences in water velocity related to stream gradient or of interbasin differences in hill slope and soil characteristics. Thus, it is important to consider these hydrologic attributes when comparing sediment yield collected by the Wesche method between differing streams. Overall, however, the method supplied an easy, inexpensive method for comparing natural and perturbation-induced differences in fine sediment yield in these small boreal forest streams.

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