CHANGES IN COMPOSITION OF THE STREAMBED BETWEEN 1973 AND 1985 AND THE IMPACTS ON SALMONIDS IN CARNATION CREEK

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The immediate objectives of the gravel-quality programs at Carnation Creek are to assess the effects of current forest harvesting practices on the composition and quality of spawning gravel and their influence on the survival or condition of emerging fry. Changes and sources of sediment production are also being investigated. This 13 year data series (1973-85) can provide information on the rates of sedimentation and erosion of different particle sizes in the streambed. Data are available from upstream of the counting fence and from the area of intense chum spawning in the estuary.

RESULTS AND DISCUSSION

Changes in Gravel Composition

Since 1976, pea gravel (9.55-2.38 mm) and sand (2.38-0.074 mm) have increased 4.6% and 5.8%, respectively, in total composition of the streambed within or below the area of intense streamside logging (Scrivener and Brownlee, in press). Fines have also increased in the deeper layers of the streambed (Fig. 1). The patterns and rates of change in its composition were different for top (1-15 cm) and bottom (15-30 cm) layers. Rates of change and turnover were much greater in the top layer (Fig. 1). Both accumulation and cleaning of fines was detected first in the top layer. These results indicate that sudden pulses of fines entering a stream would tend to be deposited, and then cleaned away within a few years provided the system was not overloaded with sediment and provided that erosion sources healed. After a few years, when source areas of sediment became chronic and fines intruded deeper in the bed, prospects diminished for a rapid return to prelogging conditions. Net changes were similar for both layers because fines tended to accumulate at a low rate and not clean from the bottom layer, while they deposited more rapidly and cleaned partially in the top layer.

The rate of change of particles in the streambed is a function of particle size and depth. Net change and mean rates of change, as a proportion of a particle size's percentage composition, were greater for the smaller particle sizes (Fig. 1). For example, in the top layer 11.0% of the pea gravel turned over annually (mean rate 1.89% yr -1 /16.4% pea gravel in 1973-76; Fig. 1) compared with 47% of fine sand (mean rate 0.25% yr -1 /0.53% fine sand in 1973-76). Silt and clay size particles were an exception (Fig. 1). Here rate of change was so rapid that only small annual net changes were observed. Seasonal sampling of estuary spawning gravel has shown that silt and clay particles accumulated during the summer and were eroded away during the winter (Scrivener and Brownlee 1982). The smaller the particle size the greater the potential for its annual change in percentage composition.

Similar changes have occurred in the area of intense chum spawning, but here the gravel cores were split into top (0-10 cm), middle (10-20 cm) and bottom (20-30 cm) layers. Fines increased with depth, but the magnitude of change tended to decrease with depth in the streambed (Fig. 2 and 3). Fines were cleaned from the top layer, but this rarely occurred in the

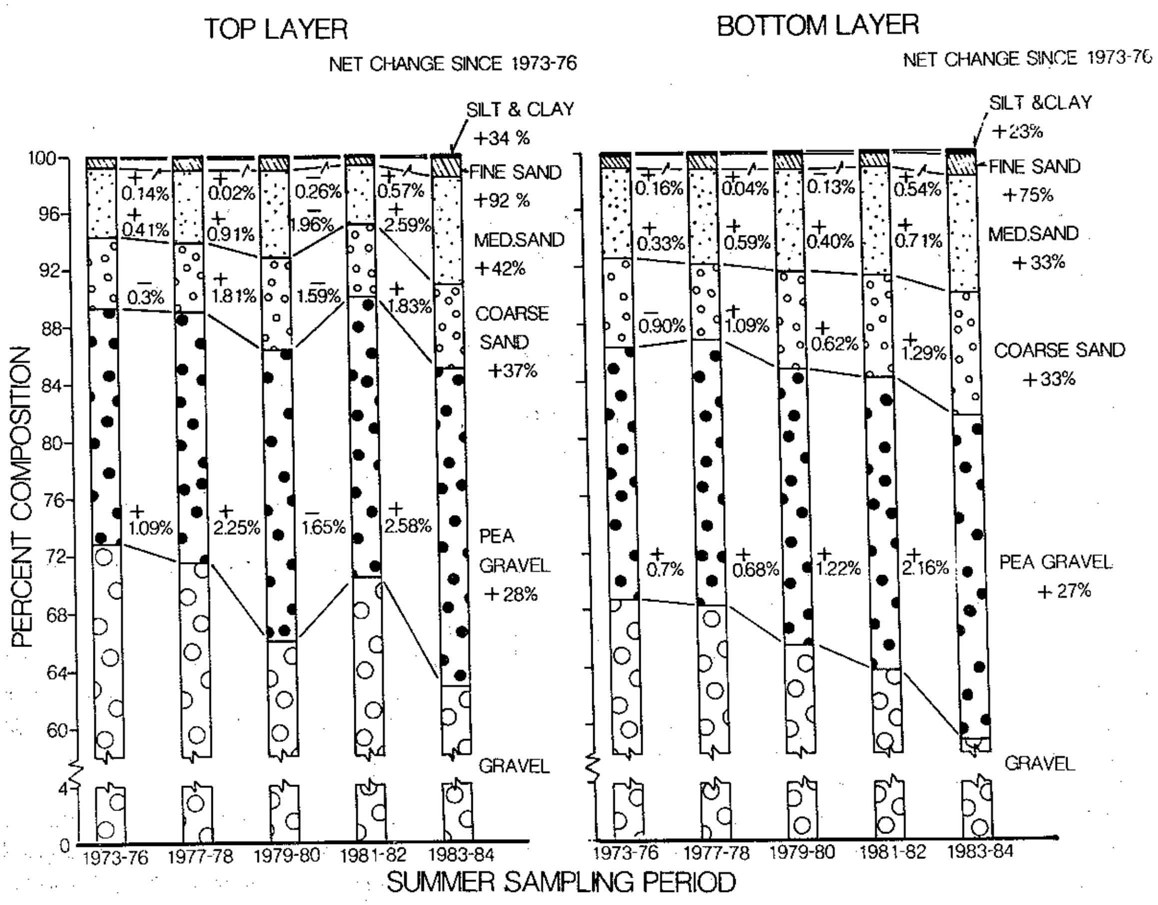

Figure 1. Percentage composition, rate of change, and net change since 1973-76 of pea gravel, coarse sand, medium sand, fine sand and silt/clay in the top and bottom layers of gravel cores from Carnation Creek.

middle or bottom layers. In this area, fines began declining in the top layer 1 year later than observed in upstream samples. This is typical of the spatial variability observed in streams (Adams and Beschta 1980). It also indicated that sediments tend to move downstream in waves (Everest et al. 1987). Eight years after the intense streamside logging, changes in gravel composition were still accelerating.

Impacts on Incubating Eggs and Fry

Two conditions contributed to decreased egg to fry survival in the post-logging period. Egg to fry mortality increased as accumulating pea gravel and sand reduced the mean particle size (Dg) of materials in the streambed (Fig. 4). Pre-emergence mortality of coho was also correlated with the magnitude of severe freshets (Holtby and Healey 1986; Scrivener and Brownlee, in press). The size of emerging chum and coho salmon were positively correlated with gravel quality (Scrivener 1987; Scrivener and Brownlee, in press), suggesting also that reduced pore size in the gravel contributed to a greater mortality among large alevins. Fry size on emergence of coho and on emigration of chum salmon has an important influence on survival (Chapman 1966; Healey 1982). Coho salmon compensated for these negative impacts when their growing season was lengthened, because emergence was earlier; and when their growth rates increased, because of lower densities during the summer (Hartman et al. 1984).

Sources of Sediment and Mode of Transport

In watersheds with forest harvesting, three major sources of sediment are from landslides or debris

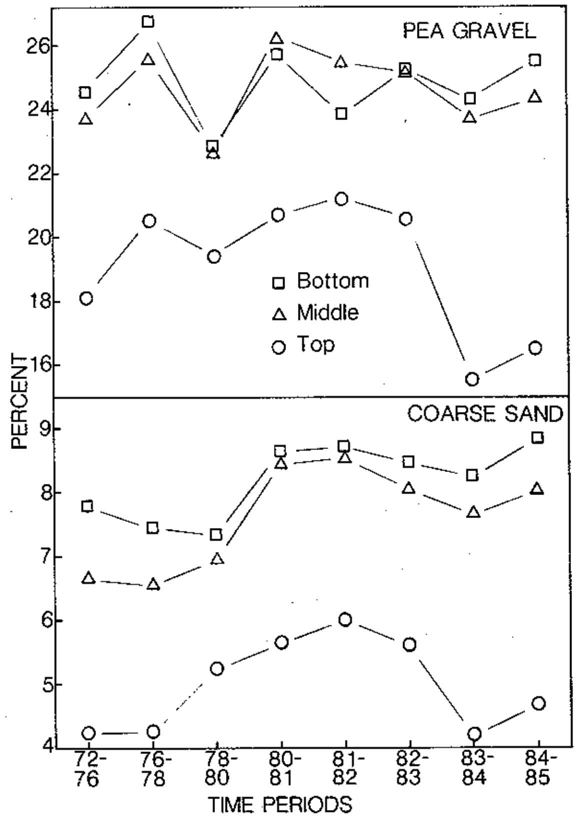

Figure 2. Composition of pea gravel and coarse sand in the streambed of Carnation Creek estuary. After logging was begun, time periods indicated egg incubation years (September to March).

torrents (Everest et al. 1987; Poulin 1986), from surface erosion on logging roads (Beschta 1978; Cederholm et al. 1981), and from upstream storage or from erosion of the stream banks (Anderson 1971; Hartman et al. 1987).

Since logging was begun in 1976/77, five landslides and three debris torrents in steep valley wall tributaries have occurred in Carnation Creek watershed (Scrivener and Brownlee, in press). The areas involved were small and some sediment from only one of the debris torrents was deposited in the main channel. Most of the material was deposited on roads, on lower valley slopes, or on the valley floor (Hartman et al. 1987). Therefore, these sources probably contributed little to the changes in the quality of spawning gravel.

Road surfaces can be a major source of sediment. In the Clearwater River basin, fine sediments that washed off roads equalled that produced by landslides (Cederholm et al. 1981). Particles smaller than 0.85 mm in diameter in the streambed were correlated with area of roads in the watershed. At Carnation Creek, roads were constructed from blast rock and surfaced with hard and coarse gravel, so few fine particles were eroded and heavy truck traffic would fragment little of this surfacing material (Ottens and Rudd 1977). Since most roads were located well away from the stream, since most of the sediment affecting quality of spawning gravel were medium sands or larger, and since sediments washed from road surfaces are usually finer (Beschta 1978; Cederholm et al. 1981); roads were probably not a major source of sediment that accumulated in the stream.

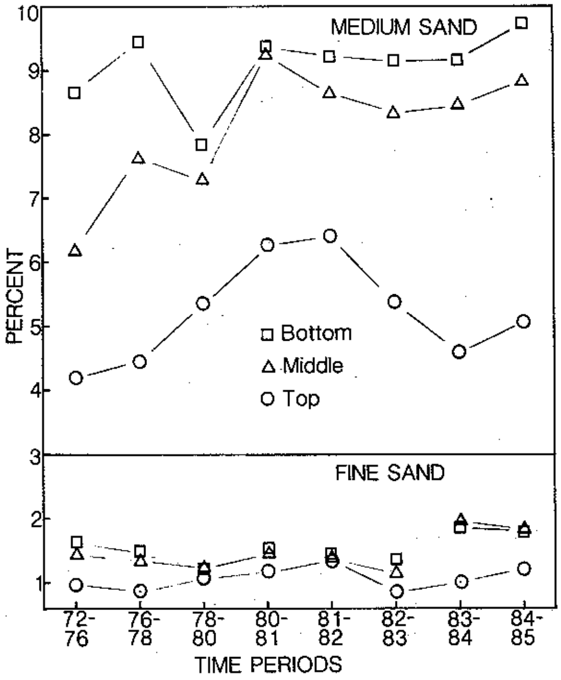

Figure 3. Composition of medium and fine sands in the streambed of Carnation Creek estuary. After logging was begun, time was the period of egg incubation (September to March).

In Carnation Creek, much of the sediment affecting quality of spawning gravel probably came from eroding stream banks or from channel storage upstream. The loss of large "roughness elements" such as logs and root wades have greatly reduced channel stability (Toews and Moore 1982; Everest et al. 1987; Hartman et al. 1987). In the areas of intensive and careful streamside treatment, bank erosion increased 2.7 times since logging was begun

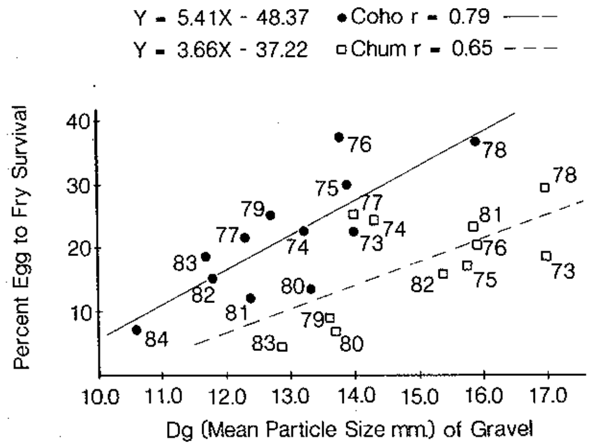

Figure 4. Relationships between annual egg-to-fry survival of coho and chum salmon and mean particle size in the bottom and top layers, respectively of gravel cores from the undisturbed and intensive treatment areas.

(Fig. 5). A slight increase occurred in the leave strip treatment. During a January 1984 freshet, loss of a debris and gravel wedge in the canyon released a torrent which deposited in the careful treatment area. New sediment was deposited to a maximum depth of 1.5 m in this area. These sediments were now available for transport in the areas used by spawning salmon and trout.

Two modes of sediment transport are often described for streams: 1. suspended transport of fine particles which are maintained in suspension by the turbulence of flowing water; and 2. bedload transport of coarser particles which roll, slide, or saltate downstream in close proximity to the bed. The transport of suspended particles can occur during most flow conditions, because the hydraulic forces required to keep these particles in suspension are relatively low once they become entrained. When suspended sediment infiltrates the streambed it fills the pores of the gravel from the bottom up, leaving the upper layers relatively clean (Einstein 1968). The size of particles in suspension increases as flows increase. This was a major mode of sediment transport and sedimentation which led to reduced quality of spawning gravels in the Alsea, Oregon (Fig. 6) and Clearwater, Washington basins (Beschta 1978; Adams and Beschta 1980; Cederholm et al. 1981). The impacts can occur quite quickly (<1 year). Conversely spawning gravels can be cleaned of these fines just as quickly (Adams and Beschta 1980). This material often originates from the surface of logging roads. In Carnation Creek, yields of suspended sediment were low and changed little during road construction or during logging (Fig. 7). Annual yields were 40% to 200% of prelogging values and 10% to 40% of postlogging values that were observed during the Alsea watershed study (Fig. 6 and 7).

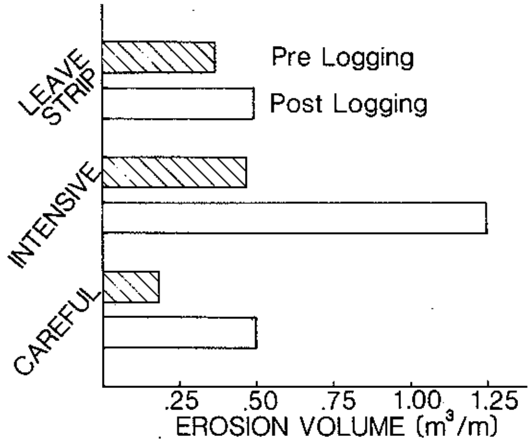

Figure 5. Streambank erosion increases in the undisturbed, intensive, and careful streamside treatments in Carnation Creek. Changes are compared for three prelogging and postlogging years.

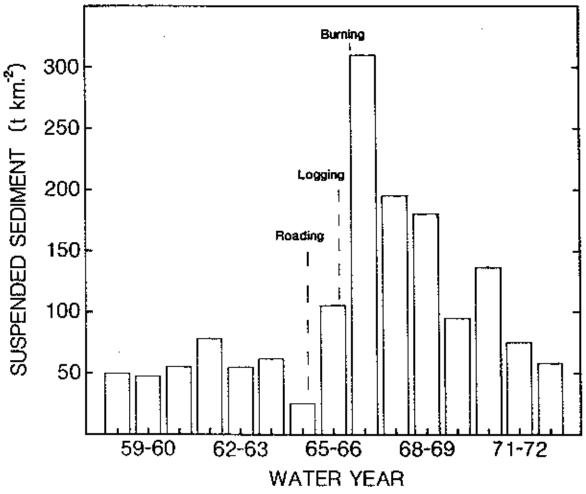

Figure 6. Increases in annual suspended sediment yield after road building and 82% clear-cut logging on Needle Branch, Alsea watershed, Oregon, redrawn with permission of R.L. Beschta (19 78).

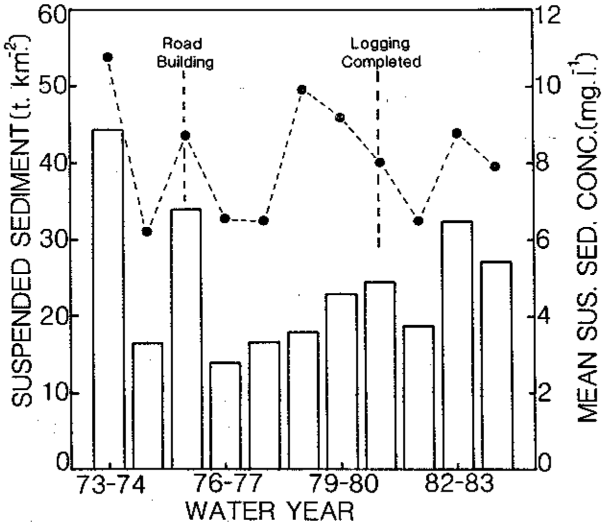

Figure 7. Suspended sediment yield and mean concentration by water year (October to September) observed at B weir in Carnation Creek watershed.

The major mode of sedimentation in Carnation Creek is by bedload transport. As particles saltate downstream during freshets, they become trapped in the voids on the surface of the substrate and this forms a barrier to further intrusion (Beschta and Jackson 1979). As flows increase the size of particles, the distance they move, and the depth of scour also increase. Now, sand particles become trapped a few cm. below the depth to which scour occurs during the freshet (Beschta and Jackson 1979). Therefore sedimentation occurs from the top down in the streambed and the composition of deeper layers is unchanged until a freshet occurs that is large enough to cause extensive scouring. As a basin is exposed to larger freshets with longer return periods, the depth to which sand seals are formed becomes greater. Cleaning of the streambed occurs in the same manner. The larger the fine particles and the deeper their penetration, the slower their rate of cleaning. Data from Carnation Creek show this pattern of sedimentation and erosion. Changes in gravel composition were dependent on frequency of peak flows, on spatial relations to streamside treatments (source of sediment) and on timing of logging activities (Scrivener and Brownlee, in press). When new sources of sediment decline, cleaning of spawning gravels will also depend on the frequency of large freshets. Pea gravel and sands are still accumulating in the deeper layers, 9 years after logging was begun.

MANAGEMENT IMPLICATIONS

Resource managers must understand these fluvial processes in a watershed in order to develop the best forest harvesting plan for it. Increased mortality among incubating salmon eggs was reported during the Clearwater (Cederholm et al. 1981; Tagart 1984) and Carnation Creek (Scrivener and Brownlee, in press) watershed studies. This was also implied for the Alsea watershed and Queen Charlotte Island studies, when the quality of spawning gravel declined (Moring 1975; Poulin 1986), but the size of offending particles in the streambed, their mode of transport and sedimentation and their source areas varied among the studies as discussed earlier. Therefore, the required management prescriptions to reduce these mortalities would have to be different.

Time frames of impacts must also be understood by managers if the best resource options are to be chosen. For example, short term impacts from sedimentation of silt and clay size particles might be more tolerable than longer term sedimentation of larger particles. The magnitude of possible impacts can also effect the time frame of the impact. When the length of sediment impacts increase the probability of natural regulators occurring also increase. Naturally occurring events such as floods in the stream or el Nino processes in the ocean can act synergistically with these man induced impacts to severely effect the resilience of a salmon stock (Cederholm et al. 1981; Holtby, 1988).

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