The Use of Plastic Strips to Measure Leaf Retention by Riparian Vegetation in a Coastal Oregon Stream

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ABSTRACT: The feasibility of using strips of plastic instead of leaves for estimating the rate of retention of coarse particulate organic matter (CPOM; >1 mm in diam) in streams was tested by simultaneously measuring retention of leaves and strips of plastic cut to approximately the same size as the leaves in six third- and fourth-order streams. There was no significant difference in the retention rates between the two methods when all six study reaches were considered together, nor was there a difference in the location of retention of leaves and strips of plastic within a reach. However, the retention rate of plastic strips was significantly higher than that of leaves in the two reaches with the highest flows.

Plastic strips were used to assess the importance of shrubby riparian vegetation in retaining CPOM in a third-order stream. The density of streamside shrubs was reduced to approximately 60% and 0% of naturally occurring levels, and retention was measured by releasing known quantities of plastic strips into the stream. Retention was highest in the reaches where shrub densities were not reduced, intermediate in reaches that were thinned, and lowest in reaches where shrubs had been completely removed. Riparian vegetation was directly or indirectly responsible for 68% of the retention in the cleared reaches, 79% of the retention in the thinned sections and 84% of the retention in the control reaches.

INTRODUCTION

The increase in intensive management of Northwest forests over the last 100 years has dramatically affected streams draining these forests. Management-related changes in canopy density influence the amount of primary production, invertebrate production and fish production in streams (Murphy and Hall, 1981). Changes in the amount and type of riparian vegetation affect the quantity, form and timing of organic inputs to the stream (Hynes, 1975). Increases in the sediment load of the stream, frequently caused by land use activities, affect stream channel morphology, channel stability and the types of habitat available to aquatic organisms (Madej, 1978; Bilby and Likens, 1980). Removal of vegetation causes changes in the flow regime of the stream that influence virtually all instream processes (Harr *et al.*, 1979). An understanding of the effects of various land use practices on stream processes is necessary to assess potential effects before long-term damage is done to the system. To evaluate the effects of a disturbance on a stream, we must be able to quantify the parameters that are affected by the disturbance.

Small streams flowing through forested watersheds are detrital-based systems. More than 95% of the energy available for use by stream organisms is provided by the adjacent terrestrial system (Petersen and Cummins, 1974). In these streams, the amount, form, timing and retention of terrestrial inputs play a major role in stream function. Retention of terrestrial organic matter by the streams is critical because the processing of this material by microbes and macroinvertebrates may require several months to a year or more. Even relatively labile organic matter, such as alder leaves, requires a week or more of in-stream conditioning before it can be readily used by stream organisms (Anderson and Sedell, 1979). Complete processing of alder leaves requires approximately 3 months. Processing of more refractory material (*e.g.*, conifer needles or wood) can take more than a year (Sedell *et al.*, 1975; Anderson and Sedell, 1979). Therefore, measurement of the amount and duration of retention of organic inputs in a stream is essential in evaluating stream function. The degree of retention in first- to fourth-order streams is particularly important because these streams constitute a vast majority of the drainage network and receive most of the terrestrial inputs. Retention processes occurring in the upper reaches of the watershed are major determinants of the amount, form and timing of organic inputs to downstream reaches (Minshall *et al.*, 1983).

Retention of coarse particulate organic matter (CPOM >1 mm in diam) in streams has been quantified by introducing a known number of nonnative leaves to the stream, measuring the distance travelled by each leaf before it is retained, fitting the results to a negative exponential model and using the slope of the curve as a measure of retention rate (Speaker *et al.*, 1985). Although this method provides a good estimate of retention, it requires collection, storage and counting of large numbers of nonnative leaves.

Measurement of retention is simplified considerably by using strips of plastic cut to the approximate length of the natural leaves (Bilby and Likens, 1980). The cutting and counting process is easily mechanized, and the variety of colors of plastic available enables several aspects of retention to be investigated simultaneously.

This study consists of two main parts. In the first section, the use of plastic strips to measure stream retention was compared with the natural leaf method used by Speaker *et al.* (1985). In the second section, the density of shrubs within the riparian zone was experimentally altered and the effect of shrub density on the retention of CPOM was measured using plastic strips. This provided an estimate of the effect of riparian vegetation on retention.

METHODS

The retention rate of plastic strips of flagging and ginkgo (*Ginkgo biloba* L.) leaves was compared by simultaneously releasing 1500 strips of plastic (3 cm x 10 cm) and 1500 presoaked (12 h) ginkgo leaves into six 30-m study reaches and counting the number of leaves and strips that were retained in each reach after 3 h. Ginkgo leaves were used because they are approximately the same size as leaves of many common riparian trees, are bright yellow in autumn and easily spotted under water, and they do not occur naturally along streams in North America. Ginkgo leaves have also been shown to be retained at the same rate as several other types of leaves ranging in size and shape from willow (*Salix* spp.) to big leaf maple (*Acer macrophyllum* Pursh) in mountain streams (Speaker, 1985). The number of ginkgo leaves in transport decreases exponentially with time and after 3 h, less than 1% of the introduced leaves are still in transport (Speaker 1985).

The number of leaves and plastic strips retained was determined by subtracting the number caught in a net at the lower end of the reach from the number introduced into the stream. The leaf retention rate was calculated from the equation:

$$L_d = L_o\, e^{-kd} \tag{1}$$

where L_d is the number of introduced leaves in transport (not retained) at some distance (d) below the release point, L_o is the number of leaves introduced, d is the distance downstream from the point of release, and k is the instantaneous rate of removal of leaves from transport per meter (Young *et al.*, 1978). Leaf retention rates were then compared using a Wilcoxon Signed Rank test across all study reaches and chi-square tests within each reach.

The study sites were in third- and fourth-order reaches of Mack Creek and Lookout Creek located in the H. J. Andrews Experimental Forest on the western slope of the Cascade Range in Oregon. The discharge of each reach was measured by introducing a known amount of fluorescent dye at the upstream end of the reach and monitoring the concentration of dye through time at the lower end of the reach (Replogle *et al.*, 1976). Discharge was calculated as:

$$Q = \frac{M}{\int_0^4 c\, dt}$$

where Q is discharge, M is the total amount of dye added, c is dye concentration passing the sampling point at t, and t is time from introduction.

Two of the study reaches were searched for retained leaves and plastic strips after 3 h. The distance from point of entry and the stream feature (hydraulic and substrate) that had retained each leaf or plastic strip were noted. Hydraulic features considered were riffles, pools and backwaters. Organic substrates were classified as wood (>10 cm in diam), sticks (<10 cm in diam), stems (attached to live vegetation) and roots. Inorganic substrates were classified by size with sand measuring <2 mm along its longest axis, gravels between 2 and 64 mm, cobbles between 64 and 256 mm, small boulders between 256 and 640 mm and large boulders >640 mm (Wentworth, 1922). These data were used to compare the retention efficiency of different stream features within a reach.

Retention of plastic strips by riparian vegetation was measured at Deer Creek, a third-order stream in Cascade Head Experimental Forest on the W slope of the Oregon Coast Range. Deer Creek has a 3% gradient through the study reach and an average side slope gradient of ca. 50%. Approximately 90% of its area is riffles. The streambed is primarily gravel and cobble with a few small boulders. The average active channel width is 3.0 m at winter base flow.

Deer Creek flows through a 140-year-old western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], Sitka spruce [*Picea sitchensis* (Bong.) Carr.] forest. Red alder (*Alnus rubra* Bong.), big leaf maple (*Acer macrophyllum* Pursh) and vine maple (*Acer circinatum* Pursh) are common trees in the riparian zone. The lower streambanks, gravel bars and floodplains are densely vegetated with large shrubs, predominantly salmonberry (*Rubus spectabilis* Pursh) and stink currant (*Ribes bracteosum* Dougl.). Dense assemblages of salmonberry, devil's club (*Oplopanax horridum* (Smith) Miq.) and vine maple branches and stems are present at ground level all the way down to the active channel, above the active channel and on most gravel bars. Branches and stems extend into the stream in many places.

The effect of stem density on leaf retention was measured by releasing plastic strips (3 cm x 10 cm) into sections of the stream where stem densities had been artificially altered. A 657-m section of the stream was divided into five control sections (total length = 447 m) where stem densities were unchanged, two thinned sections (total length = 100 m) where ground level stems were removed until it appeared that about 50% of the original stems remained and two cleared sections (total length = 100 m) where all stems were removed from a 4-m wide strip on both sides of the channel.

Plastic strips were placed on the lower streambank at the head of each section, rather than directly in the stream, to simulate the accumulation of leaves on the floodplain during autumn. In November 1983, prior to the onset of winter rains, 3000 plastic strips were placed in a 2-m by 0.5-m band at the upper end of two of the control sections and of both of the thinned and cleared sections. Plastic strips were placed within a few centimeters of the stream so that even a small increase in flow would result in some of the strips being flushed into the stream. The relative positions of the nine study sections and the points of introduction of the plastic strips are shown in Figure 3. Plastic strips of various colors were used to differentiate between the points of introduction. Stream discharge was measured using fluorescent dye as previously described. Stream stage height was monitored by measuring water depth in a culvert at the upstream end of the reach throughout the study.

In February 1984, 131 days after the plastic strips had been placed on the stream bank, the entire study reach was thoroughly searched. The distance travelled and the study section where each plastic strip was retained were recorded. Strips that were not recovered at the point of origin or within any of the 50-m study sections were assumed to have been transported completely through the entire study reach (657 m). The efficiency of recovery of introduced leaves is negatively correlated with stream size (Speaker, 1985). This model predicts that about 75% of the introduced plastic strips retained in the study reaches were found. The retention rate for each color of plastic strip in each section downstream from its point of origin was calculated from the number of strips entering the upper end of a section and the number of strips leaving the section (equation 1).

RESULTS

Plastic strips as an index of leaf retention.—Ginkgo leaves and plastic strips were retained at rates ranging from 0.009 to 0.104/m in the six study reaches (Table 1). When all six reaches were considered together, there was no difference in the rate of retention of ginkgo leaves and plastic strips in a reach ($P > 0.25$; Wilcoxon Signed Rank test).

Retention rates were much lower in the two reaches with the highest discharges (Lookout 1 and 2) because they were deeper and contained less large woody debris than the other four reaches. In these reaches, significantly more plastic strips were retained than ginkgo leaves ($P < 0.01$; chi-square). Lookout 1 and 2 were deeper and slower than the other study reaches and most of the leaves and plastic strips that were retained sank slowly to the bottom of deep pools during transport, eventually becoming caught on rocks. The higher retention rate for plastic strips in these reaches indicates that the strips used in the study may have had a slightly greater specific gravity than the presoaked ginkgo leaves, causing them to sink more rapidly. In the shallower, faster flowing reaches, both leaves and plastic strips were more readily transported at all points in the water column.

In Lookout 3 and 4, where the location of each retained ginkgo leaf and plastic strip

TABLE 1.—The rate of retention of plastic strips and ginkgo leaves in sections of Mack Creek and Lookout Creek, H. J. Andrews Experimental Forest

Study reach	Length (m)	Discharge (m^3/s)	Plastic strips: Number retained	Plastic strips: Retention rate (per m)	Leaves: Number retained	Leaves: Retention rate (per m)
Mack 1	30	0.034	1351	0.077	1334	0.073
Mack 2	30	0.034	1424	0.099	1433	0.104
Lookout 4	30	0.035	1363	0.080	1370	0.082
Lookout 3	30	0.096	1326	0.072	1358	0.079
Lookout 2	30	0.140	626	0.018	394	0.010
Lookout 1	30	0.140	487	0.013	367	0.009

was noted, the longitudinal patterns of retention of both were nearly identical (Fig. 1). The largest difference in the retention of leaves and plastic strips at any point in either reach was 5.5%, and the difference was generally less than 3%. There were no differences in the number of leaves and plastic strips retained on particular substrates in riffles and pools in each reach (Fig. 2). In riffles in Lookout 3, both leaves and plastic strips were primarily retained on sticks, cobbles and small boulders. In riffles in Lookout 4, retention of leaves and plastic strips was predominantly on sticks, cobbles and small and large boulders. Riffles made up about 85% of the area and 80-89% of all leaves and plastic strips were retained in riffles in both reaches.

The similarities in retention rates and retention properties of ginkgo leaves and plastic strips over these six study reaches suggest that comparable results will be obtained using either to evaluate retention of CPOM in small streams in most cases. In larger streams, more rapid sinking by the denser plastic strips produces artificially high estimates of retention rate.

Terrestrial vegetation as a retention feature. — Stem densities were significantly different in the control, thinned and cleared sections after manipulation ($P < 0.01$; t-test) (Table 2). In the thinned sections, stem density was 61% of that in the control section. No stems remained in the cleared sections.

A mean of 87% (range 69-95%) of the plastic strips that were placed on the bank at the upstream ends of the experimental reaches entered the stream during the experiment. Streamflow was 0.062 m^3/sec when the plastic strips were placed on the stream bank. Streamflow was fairly constant until 22 January 1984, during which time few plastic strips entered the stream. From 23-25 January, 32.1 cm of rain fell and streamflow increased to 0.346 m^3/sec. Most of the plastic strips entered the stream during this flood and were in the stream for 30 days before they were retrieved. Of the plastic strips that entered the stream, 37.7% were retained within the study reach and recovered, and the remaining 62.3% were assumed to have been transported out of the study reach.

Rate of retention of plastic strips was strongly related to the density of stems in and

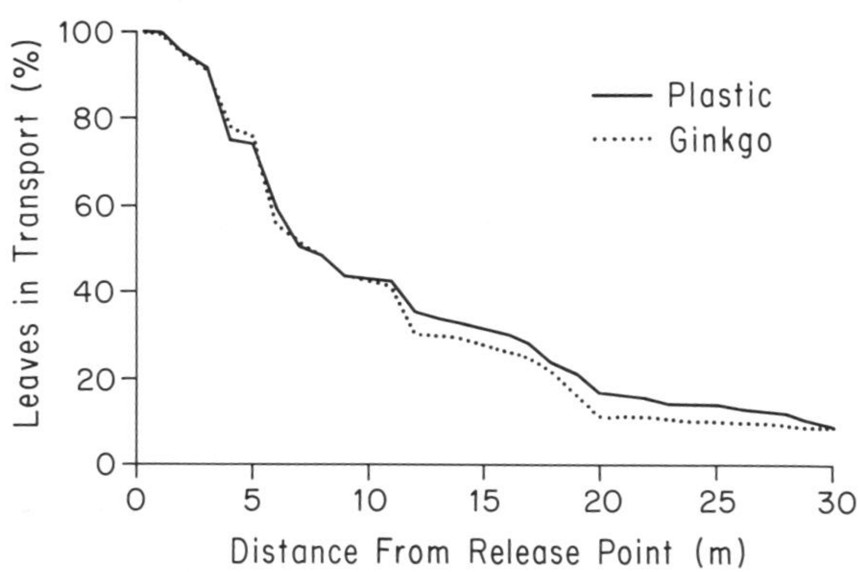

Fig. 1. — Longitudinal retention patterns for ginkgo leaves (solid line) and plastic strips (dashed line) in Lookout Creek 3, H. J. Andrews Experimental Forest

adjacent to the stream (Table 2). Retention rates in the control sections were higher than in the thinned sections ($P<0.08$; t-test) and the cleared sections ($P<0.005$), and retention rates in the thinned sections were higher than in the cleared sections ($P<0.002$) (Fig. 3). The average retention rates in the cleared and thinned sections were 80% and 45% lower, respectively, than in the control sections.

The most important retention features were sticks (64.5% of retained plastic strips), inorganic sediments (15.3%), roots from terrestrial vegetation (10.4%) and stems from terrestrial vegetation (4.1%) (Table 3). Even in sections that had been nearly cleared of riparian vegetation, the roots, sticks and vegetation that remained accounted for 67.7% of the retention. In the thinned and control sections, features related to terrestrial vegetation accounted for ca. 85% of the retention.

Retention rates were much lower in sections where riparian stems were thinned or removed even though stems only accounted for 2-8% of the overall retention of plastic strips. Much of the difference in retention may have resulted from a difference in the number of sticks, the primary retention feature, between sections. Stems from riparian vegetation are the major source of sticks for the stream and also play an important role in retaining sticks that enter a reach.

DISCUSSION

Natural leaves have been used successfully to measure rates of leaf retention in

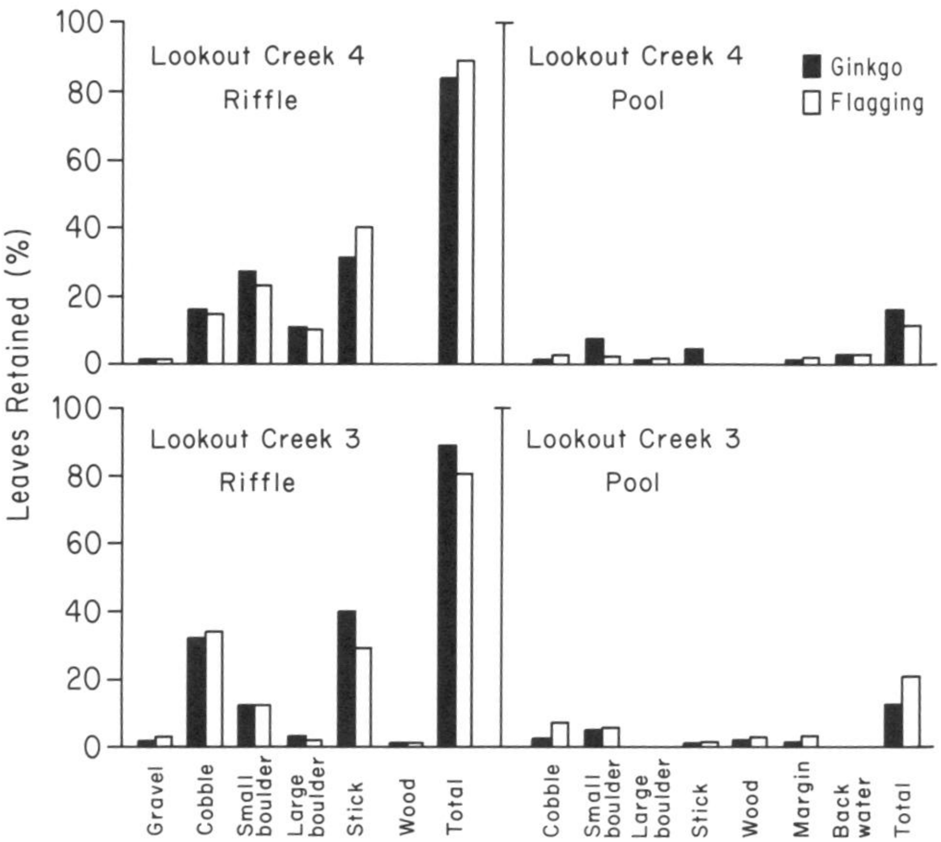

Fig. 2.—Retention of leaves and plastic strips on different substrates in riffles and pools in two sections of Lookout Creek, H. J. Andrews Experimental Forest

streams (Young *et al.*, 1978; Speaker *et al.*, 1985). This approach accurately quantifies the immediate retention of leaves after entering the stream or being dislodged within the stream and transported into the water column. These studies are restricted to short periods of time, generally less than a week, because the marker leaves are altered by physical fragmentation, microbial decomposition, and consumption by invertebrates. Measurement of retention and redistribution of leaves over longer periods of time is not possible because the introduced leaves cannot be recognized.

Upon entering forested mountain streams with typical alternating riffle-pool sequences, most leaves are rapidly retained in riffles by being pressed against rocks, sticks or large woody debris. A much smaller proportion of leaves are initially retained in pools, backwaters, along the streambank or among riparian vegetation (Speaker *et al.*, 1985). As streamflow increases, many leaves are again transported downstream and redistributed to areas out of the main flow. In the Cascade Range streams, where short-term retention was measured, less than 1% of the leaves and plastic strips were initially retained on features associated with the streambank or riparian vegetation. In Deer Creek, where the plastic strips were redistributed by high flows, however, ca. 18% of the strips were retained by riparian vegetation or along the bank. The importance of areas along stream margins in retaining leaves after high flows in other streams may be even greater than this study found because Deer Creek has very few side pools and backwaters.

Use of strips of plastic that simulate the approximate size and specific density of natural leaves provides a method for examining patterns of retention in streams over several months. Comparison of instantaneous rates of retention of both natural leaves and plastic strips revealed no significant differences in their retention characteristics, at least over the first 3 h. In shallow, riffle-dominated streams, slight differences in specific density between natural leaves and plastic strips will have little effect on retention patterns; but in streams that contain large areas of pool habitat, the specific density of artificial material should be matched as closely as possible to the naturally occurring leaves of local riparian vegetation.

Many leaves enter streams when streambanks are inundated at high flow, and use of artificial material to simulate leaves makes it possible to study these events. Color-coded plastic strips can be placed on streambanks at low flow and will not decompose prior to inundation. They will enter the stream in a manner that closely simulates the entry of natural leaves into streams during floods, and the researcher is not required to be on site at the start of the flood. This technique extends our ability to examine the process of retention in streams over broader time frames and hydrologic regimes.

The ability of stream channels to retain leaves decreases as stream discharge increases (Speaker, 1985), but this change in retention potentially is mediated when increasing streamflows enter stands of riparian vegetation adjacent to streams. The complexity created by both the roots and stems of living vegetation and the dead boles, branches and litter derived from riparian vegetation results in much greater channel roughness (Barnes, 1967), which increases the potential for retention of particulate ma-

TABLE 2. — Density of riparian vegetation and the rate of retention of plastic strips in Deer Creek, Cascade Head Experimental Forest

	Stems at ground level (number/m²)			Retention rate (per m)		
	$\bar{x}$	SD	n	$\bar{x}$	SD	n
Control	13.9	4.56	20	0.00138	0.00083	17
Thinned	8.5	4.68	20	0.00076	0.00031	8
Cleared	0	—	—	0.00027	0.00017	7

terial. This is evidenced by the large accumulations of material trapped on the stems and branches of streamside vegetation after flood waters recede.

Experimental manipulation of the density of streamside shrubs in this study demonstrated the importance of riparian vegetation in the retention of leaves during high flows. Removal of 39% of the vegetation resulted in a 45% decrease in retention efficiency, and complete removal of the streamside vegetation reduced the retention efficiency of the reach by 80%. Although the absolute retention efficiency changed greatly, the retention features that were responsible for trapping the majority of the markers did not change as a result of clearing the vegetation. Sticks, roots and inorganic sediments accounted for more than 85% of the retention in both the manipulated and unmanipu-

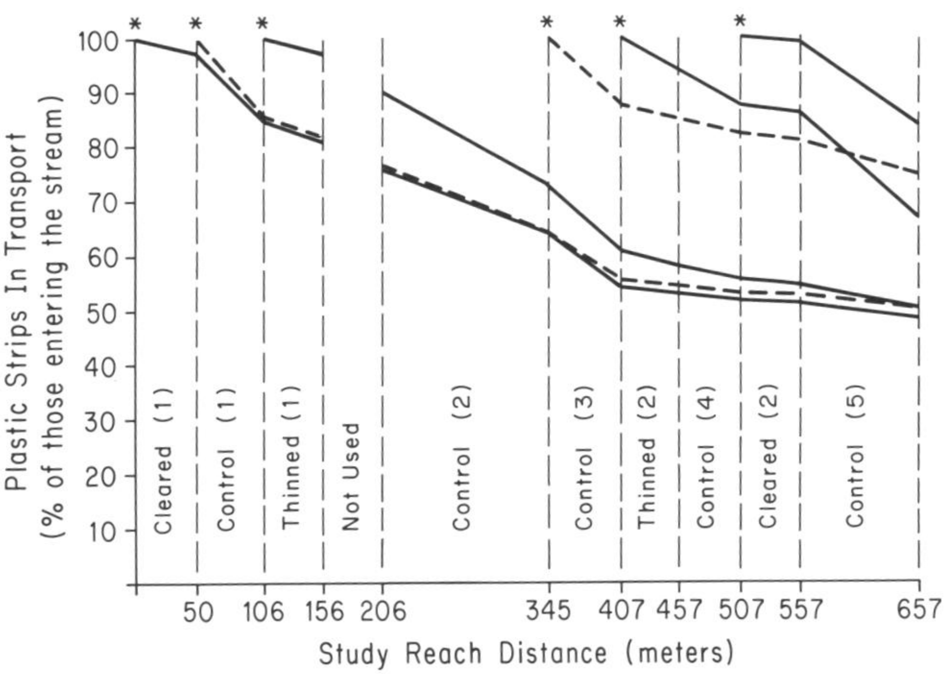

Fig. 3.—The percent of the original number of plastic strips in transport vs. the distance downstream from the point of introduction in Deer Creek, Cascade Head Experimental Forest (* denotes locations where plastic strips were placed on the stream bank)

TABLE 3.—The percent of retained plastic strips caught on various substrates in Deer Creek, Cascade Head Experimental Forest

Retention feature	Leaves retained (%) Control	Thinned	Cleared	Mean
Sticks	71.0	67.7	54.9	64.5
Roots	11.9	9.4	10.0	10.4
Stems	1.8	7.7	2.8	4.1
Wood	0.3	1.4	0.0	0.3
Inorganic sediment	13.6	10.7	21.5	5.3
Bank	1.5	3.4	6.5	3.5

lated reaches. Riparian vegetation and dead material derived from that vegetation were responsible for approximately 70-85% of the retention within the stream reaches. The importance of small woody material in retention in this coastal stream is consistent with retention patterns observed in streams of the Cascade Range in Oregon and the northeastern United States (Bilby and Likens, 1980; Speaker *et al.*, 1985).

Streams are often viewed as conduits that transport material to the oceans, a perspective that overlooks their retentive nature. Floods in particular are assumed to remove vast quantities of material from stream reaches. This study of a third-order coastal stream demonstrates that stream ecosystems actually retain much of the material that enters them, even during high flow events. More than a third of the "artificial leaves" in this stream were retained within 660 m over the course of winter high flows. The retentive nature of streams is determined to a great extent by the interface between the terrestrial and aquatic ecosystems, the riparian zone. At low flow, the physical structure within the wetted channel is responsible for the retention of organic matter; but during high flow events, the vegetation along streams and rivers effectively combs material out of transport, allowing it to be processed subsequently by the aquatic biota. Stream ecosystems are intricately linked to the terrestrial ecosystems around them, not only with respect to the inputs of food resources but also the retention of those resources.

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