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Factors influencing litter delivery to streams

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ABSTRACT

Leaves and needles are an important energy source for streams. However, relatively little is known about factors that determine width of the area contributing litter to streams. We assessed the relative effect of wind speed, wind direction, litter type, tree height and riparian topography on litter delivery to streams. Wind speed effect on litter travel distance was determined by releasing needles (Douglas-fir) and leaves (red alder) from mature and young tree canopies over a range of wind velocities. Short-term litter collections were conducted to determine the effect of wind speed on litter fall. Litter travel distance increased with increasing wind speed and increasing tree height. At low wind speeds leaves traveled further than needles. Litter fall increased with wind speed. These relationships were combined with literature values for seasonal rates of litter production and an annual wind speed and direction record from a riparian area in western Washington to evaluate the relative effect of various factors on litter delivery area width. We found that width of the contributing area for needles was about 35% greater in riparian stands supporting mature conifer trees than at sites with young trees. Increasing riparian area slope from 0° to 45° increased width of contributing area by 71–95%, depending on litter type and stand age. Doubling measured wind speed increased contribution zone width 67–82%. Estimated buffer width required to capture 95% of annual litter input ranged from about 14 m to over 25 m under the conditions which we evaluated. The variety of factors influencing litter delivery area width and the spatial and temporal variation in these factors indicates that the common practice of employing fixed-width buffers to protect stream–riparian interactions cannot be consistently effective.

1. Introduction

Leaves, needles, wood and other forms of terrestrial organic matter play a key role in the support of stream food webs (Hynes, 1963; Ross, 1963; Fisher and Likens, 1973; Cummins, 1974). Terrestrial organic matter frequently constitutes over 90% of the organic matter in small streams in forested areas (Richardson et al., 2005). This organic matter, and the fungi and bacteria that colonize it after entry into a stream, is a primary food source for many macroinvertebrates and detritivorous fishes (Cummins, 1974) and terrestrial litter is often responsible for supporting a majority of the secondary production in forested stream ecosystems (Triska et al., 1975).

Vegetated buffers are often retained along streams during land clearing activities to maintain functional interactions between the stream and riparian area. Some of the functional relationships often cited as objectives for riparian buffers include temperature control, large wood delivery, maintenance of bank integrity and litter input (FEMAT, 1993; Sweeney and Newbold, 2014). The width of buffer required to maintain these functions has been estimated for some processes. For example, wood delivery to streams has been thoroughly studied (Murphy and Koski, 1989; McDade et al., 1990; Sobota et al., 2006) and this information has been used as the basis for models that predict wood delivery to streams over time under various riparian management scenarios (Van Sickle and Gregory, 1990; Welty et al., 2002; Gregory et al., 2003). The relationship between riparian buffer characteristics and shade also has been thoroughly evaluated (Brazier and Brown, 1973; Steinblums et al., 1984; DeWalle, 2010). Despite the ecological significance of terrestrial litter to streams, relatively little effort has been directed toward identifying the factors that determine the portion of the landscape most responsible for litter delivery.

Factors influencing the dispersal of leaves within forests have been evaluated in multiple studies. Not surprisingly, many of these studies have identified wind as the primary driver of litter dispersal (Stone, 1977; Welbourn et al., 1981; Staelens et al., 2003). Wind speed determines the distance litter travels after detaching from a

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tree and wind increases litter production; more leaves and needles fall during windy conditions than during calm conditions.

Vegetation characteristics also play a role in determining litter dispersal (Ferrari and Sugita, 1996) and production rates (Benfield, 1997). Litter shape, size and density vary among tree species and these characteristics can influence litter dispersal (Ferrari and Sugita, 1996). Tree height influences litter dispersal with litter travel distance increasing with the height at which the litter is produced. Topography also influences litter dispersal (Welbourn et al., 1981). On steeply-sloped ground, litter dispersal is truncated in the upslope direction and extended down slope. Secondary transport of litter after deposition on the forest floor also increases with steepness (Fisher, 1977; France, 1995; Hart et al., 2013).

In addition to wind velocity, wind direction influences the width of the zone contributing litter to a stream. Winds parallel to a stream channel will restrict litter input to only trees very close to the channel edge. Wind perpendicular to the stream channel maximizes the distance from which litter is delivered. Therefore, prevailing wind direction and speed at the time of year when litter production peaks can have a large influence on the width of the zone contributing litter to a stream.

Although it is appreciated that the factors discussed above all can influence litter delivery to a stream, there is little understanding of the relative effect each has on the litter delivery area width. We evaluated the relative role of wind speed and direction, topography, litter species and stand conditions on the distance from which litter is delivered to a stream channel using simple models based on a combination of field experiments and literature information.

2. Methods

We utilized a combination of experiments and literature information to estimate the litter delivery area width. We conducted experiments to determine the effect of wind speed on travel distance of litter from two, common tree species in the Pacific Northwest. We also conducted experiments to evaluate the effect of wind speed on litter production. We then utilized annual records of wind speed and direction collected from a riparian area in the Cascade Mountains of western Washington and the results from our litter travel and litter production experiments to evaluate the relative influence of wind speed and direction, tree species, stand age and riparian topography on the distance from which litter is delivered to a stream channel.

2.1. Effects of wind on litter travel distance

We examined the effect of wind speed on litter travel distance by releasing needles and leaves from a riparian tree canopy at various wind speeds and measuring the distance that the released material was transported. Two types of litter were included in these experiments; Douglas-fir (*Pseudotsuga menzesii*) needles and red alder (*Alnus rubra*) leaves. These species are very common in coastal regions of the Pacific Northwest from northern California to southern British Columbia.

Green Douglas-fir needles were stripped from branches and allowed to air dry for at least two weeks prior to being used in release experiments. The needles were dried to approximate the moisture content of naturally shed needles. Recently-shed, red alder leaves were collected from the ground in autumn. Alder leaves were placed in plastic bags and refrigerated. This storage method retained the moisture level of the shed leaves and retarded decomposition.

Douglas-fir needles or red alder leaves were released from a nylon bag raised into the canopy of a riparian forest. The nylon bag had a Velcro closure along the bottom with nylon lines attached to each side of the closure to open the bag. The bag was raised to the bottom edge of the live tree crown using a rope looped over a branch and attached to the top of the bag. Releases were made from the bottom edge of the live crown because it was not possible to maneuver the release bag further into the canopy and still operate the lines that opened the bag.

Three liters of red alder leaves or Douglas-fir needles were placed in the release bag for each experiment. When red alder leaves were added to the bag care was taken to avoid crushing or otherwise deforming the leaves as an alteration in shape could have affected the distance they traveled after release. As a result, the weight of alder litter placed in the bag was less than the comparable volume of fir needles. Average weight of red alder leaves placed in the bag was 83.9 g (std. error = 2.6 g) and average weight of Douglas-fir needles was 408.6 g (std. error = 5.6 g). There was no surface moisture on the leaves, enabling them to rapidly disperse with the opening of the bag. The Douglas-fir needles also showed no evidence of clumping following release.

Released litter was captured in rectangular, plastic containers (60 cm × 43 cm) arrayed downwind from the release point. These traps were placed in rows at 3-m intervals starting below the release point and extending downwind from the release point. The traps were all located within 12 m of the release point during periods of low winds but extended beyond 25 m from the release point during windy conditions. Approximately 30 litter traps were used during each release experiment. Liter traps were opened immediately prior to release of litter to minimize confounding effects from any natural litter that might fall into the trap. Litter captured in each trap was placed in a labeled paper bag, dried at 60 °C and weighed. A weighted-average travel distance for each release experiment was calculated from the weight of litter captured in traps at various distances from the release point.

Litter releases were made in two riparian stand types, mature conifer and second-growth conifer (hereafter referred to as "mature" and "young"). Litter releases were made at multiple mature and young locations to evaluate whether there was among site variation in the relationship between wind speed and litter travel distance. Experiments were conducted at four mature sites and three young sites. Three of the mature forest sites were located in the Cascade Mountains and one was located in the coastal mountains of western Washington. Two of the young forest sites were located in the Cascade Mountains and one in the coastal mountains. Sites with very little topographic relief were selected for litter release experiments to facilitate placement of the litter traps.

Stand characteristics at the release sites were measured in a 50 m × 50 m plot centered on the litter release point. Very little (<1%) of the litter from the release experiments traveled beyond the surveyed plot. Diameter breast height (DBH) and tree height was measured for each tree in the plot. Height of the lower edge of the live crown was also measured at all sites except one of the mature release sites. Tree diameter at breast height at the mature sites averaged 68.5 cm and height averaged 47.0 m (Table 1). Corresponding values for the young sites were 50.5 cm and 32.4 m. The height of the bottom of the live canopy differed considerably between the mature and young stand types (Table 1). The live canopy at mature forest sites began about 30 m above the forest floor. The bottom of the live crown at the young forest sites was about 15 m above the ground. We also measured the height to the bottom of the live canopy of stream-adjacent, mature red alder trees at three sites near the young forest release sites and found it was about 15 m above the forest floor, comparable to the young conifer stands. Because of the similarity in lower live crown height