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Significance of Aspect and Understory Type to Leaf Litter Redistribution in a Temperate Hardwood Forest

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Annual production and redistribution of leaf litter were compared among three distinct understory patches in a temperate hardwood forest dominated by *Quercus mongolica, Kalopanax pictus, Acer pseudo-sieboldianum,* and *Carpinus cordata.* Two patches were located on a southwest-facing slope: one with an understory dominated by herbaceous plants (Patch S), and the other covered with evergreen dwarf bamboo, *Sasa borealis* (Patch SS). The third patch was on the opposite slope with an understory dominated by herbaceous plants (Patch N). Annual leaf litterfall was averaged 330 g m^{-2} yr^{-1} in the three patches from 1994 to 1998. From mid-September 1996 to mid-September 1997, net transport of leaf litter over patch boundaries was 1,824 g m^{-1} from Patch S to SS, 1,465 g m^{-1} from Patch S to N, and 886 g m^{-1} from Patch SS to N. The amounts moving downslope out of Patch S, SS, and N were 2,548, 471, and 588 g m^{-1}, respectively. When a mass balance approach was employed for the data of leaf litter transport, the results were relatively consistent with 216, 631, and 724 g m^{-2} of leaf litter stores in Patch S, SS, and N, respectively, in April 1997. This study suggests that leaf litter redistribution is largely regulated by aspect and understory type and exerts a significant effect on carbon processes in the forest ecosystem.

Since early 1980s, energy and nutrient flows between landscape patches have received much attention (Forman, 1995). Nevertheless, the redistribution of leaf litter among forest patches were described in only a few studies (Welbourn et al., 1981; Boerner and Kooser, 1989).

Nutrient dynamics of a forest exposed to strong wind may be strongly influenced by leaf litter redistribution, especially when the forest includes steep slopes. For instance, little response of plant growth to fertilization was observed in a pole-size maple stand as approximately 95% of tree leaves were blown beyond the rooting area approximated by the crown periphery (Stone, 1977). A sink area of litter may become nutrient-rich while its source area becomes nutrient-poor unless the gain and loss of litter are compensated by other biogeochemical processes.

There are several factors which govern litter redistribution among patches in a forest floor. Gravity and wind are major driving forces of litter transport. These forces are influenced by aspect, slope steepness, and patch location in the slope (Orndorff and Lang, 1981; Boerner and Kooser, 1989). Orndorff and Lang (1981) also reported that leaf redistribution was affected by fallen logs and microtopographic depressions. To our knowledge, there has been no report which related litter redistribution to understory type, although it may exert major control over litter redistribution by blocking mass flow.

This study aimed at quantifing the redistribution of leaf litter among distinct patches within a hardwood forest and discussing its contribution to soil biogeochemistry. We examined litter transport among forest patches which is governed by aspect and understory type.

Materials and Methods

Site description

The vegetation of the study area is a temperate hardwood forest, located 1,010-1,030 m above sea level in Mt. Jumbong (38° 02′ N, 128° 26′ E), Kangwon Province in Korea (Fig. 1). The site is well protected as it has been included in the UNESCO Biosphere Reserve and designated as a Natural Forest Reserve by the Office of Forestry, Korea. The overstory is dominated by *Quercus mongolica, Acer pseudosieboldianum,* and *Carpinus cordata.* The area is divided into three distinct patches by aspect and understory, type especially in early spring (Fig. 2). Two patches are located on a southwest-facing slope with a 24 slope degree. One is predominantly occupied by diverse herbaceous plants, such as *Erythronium japonicum, Symplocarpus*

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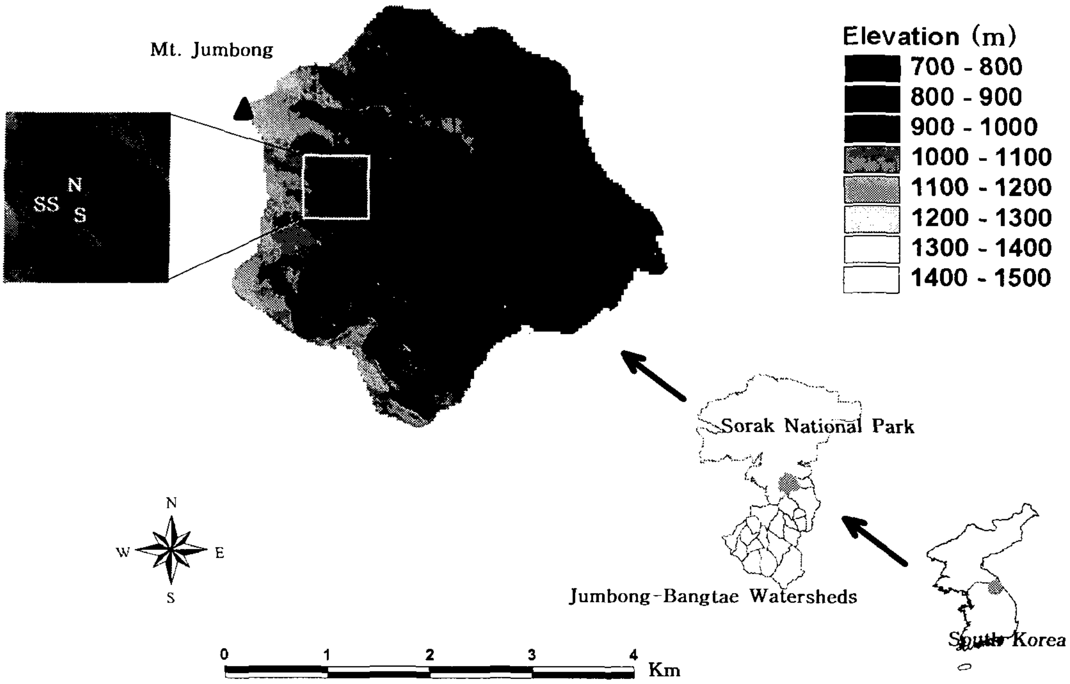

Fig. 1. A map showing the location of the study site.

nipponicus, Meehania urticifolia, and *Pimpinella brachycarpa* (Patch S) and the other by an evergreen dwarf bamboo, *Sasa borealis* (Patch SS). The third patch is on a northeast-facing slope with a 28 slope degree, and dominated by diverse herbaceous plants including *Symplocarpus nipponicus, Erythronium japonicum, Meehania urticifolia, Anemone koraiensis,* and *Cordalis turtschaninovii* (Patch N).

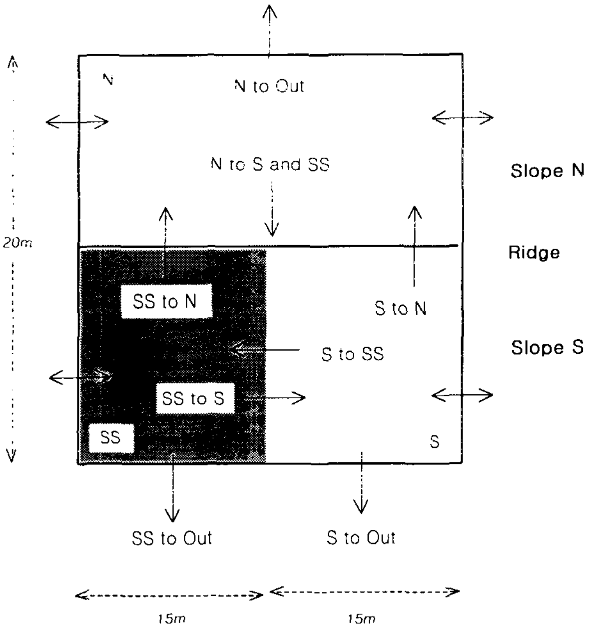

Fig. 2. Patch arrangement. The directions of arrows indicate those of leaf litter transport. The right side of Patch S and the left side of Patch SS are covered with dwarf bamboo. Either side of Patch N is dominated by ground cover similar to the one in Patch N.

Leaf litterfall

Eighteen traps (0.5 m × 0.5 m) were randomly placed inside and outside of the three patches in the study area in September 1994, and litter was collected every month during September-November through 1996 and every three months during the remainder of the years. The cumulative amount of leaf litterfall from September 1994 to September 1997 was plotted by year. The amount of leaf litterfall from January-September 1994 was extrapolated from the measurements of other years. This approach allowed us to estimate the mean annual leaf litterfall. Although collected twigs and reproductive parts were also weighed, those are not concerned with the current subject and thus not included in this paper.

Leaf litter transport

To measure the transport of leaf litter following deposition, three traps (0.5 m × 0.5 m) with one side open were placed on each boundary of the patches in September 1996 before autumnal leaf litterfall started. Patch arrangement is referred to in Fig. 2, where arrows indicate that leaf litter transported in their directions was collected by the traps. Litter transport was quantified by measuring the leaf litter collected from the traps in November 1996, and May and September 1997.

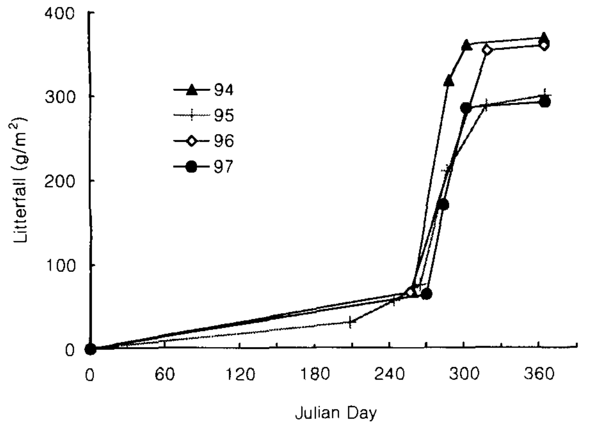

Fig. 3. Annual leaf litterfall in the area from 1994 through 1997. The dotted line is extended to the value derived from the measures of other years. Since the measures which were done during September-November accounted for more than 95% annual leaf litterfall, the estimation is reliable.

Leaf litter stores

To measure leaf litter stores per unit area of the forest floor, leaf litter was collected from 0.5×0.5 m plots, which were randomly placed in Patch S, SS, and N in February 1995, May 1995, and April 1997. Measurements were in triplicate.

The fresh litter collected from the fields was oven-dried at 80℃ for 48 h and weighed.

Results and Discussion

Leaf litterfall

Annual leaf litterfall was not significantly different among patches. Leaf litterfall occurred predominantly during the September-November period (Fig. 3). Estimated annual leaf litterfall was 369, 300, 360, and 292 g m^{-2}yr^{-1} in 1994, 1995, 1996 and 1997, respectively.

Litter transport

It was observed that there were two major fluxes of leaf litter although the fluxes were not explicitly determined during the period of study. The first flux occurred during the litterfall season. From December 1996 to early April 1997, little litter was moved since the area was covered with snow. As soon as snow had melted and the dry season started in mid-April 1997, litter was moved around. The fall and spring fluxes of litter transport suggest that stream biology may also evolve to adapt to the seasonal inputs of organic matters.

Overall, most redistribution of leaf litter was observed concurrently with predominant leaf litterfall and strong wind (Table 1). During mid-September 1996 to mid-September 1997, net transport of leaf litter was 1,465 g m^{-1} from Patch S to N, and 886 g m^{-1} from Patch SS to N and 1,824 g m^{-1} from Patch S to SS. A total of 2,548 g m^{-1}, 471 g m^{-1}, and 588 g m^{-1} slid downslope out of Patch S, SS, and N, respectively.

Table 1. Transport of leaf litter among patches (g m^{-1}±SD) from mid-September 1996 to mid-September 1997

Direction	Sept. 1996-Nov. 1996	Nov. 1996-May 1997	May 1997-Sept. 1997	Total
S to N	1568	93 (± 50)*	70 (±14)*	1731
SS to N	446	302	404	1152
N to S, SS	157 (± 23)*	78 (± 21)	31 (± 9)	266
SS to S	45 (± 25)*	25 (± 12)	5 (± 1)	75
S to SS	1212 (±152)*	563 (±210)	124 (±52)	1899
N to Out	165 (± 33)**	105 (±170)	318 (±94)	588
S to Out	1482 (± 32)*	765 (±151)	301 (±0.2)*	2548
SS to Out	331 (±231)*	99 (±119)*	41 (±34)*	471

N, S, and SS denote Patch N, S and SS, respectively.
The number of observation was 1, 2 or 4 for values with no standard deviation, upper suffix * and **, respectively. The others were triplicate.

A large amount of leaf litter was transported from the southwest-facing slope to the northeast facing slope. This suggests that leaf litter can move over the watershed boundary in a region which experiences strong wind, and that litter dynamics should be considered in nutrient budget estimation, especially in small forested watersheds.

Interestingly, a large amount of leaf litter was moved upward from Patch S to SS. It is noted that the left (west) side in Fig. 1 is located in a relatively high area of the same faces. A similar tendency was also observed in the area by another study (Lee et al., unpublished data). When colored papers were placed on the patches in November and December, many of them were moved from patch S to SS. Presumably, the transport of leaf litter was dominantly governed by valley winds in Patch S, because valley winds scratch the forest floor more effectively than ridge winds. The transport of leaf litter may be similar to the way in which fire spreads in forested slopes. It is known that upward winds are effective in expanding fire while convective winds inhibit the fire's downslope spread (Waring and Running, 1998). Nevertheless, leaf litter is prone to slide down by gravitational transport. Unless it is trapped by any ground features, it is eventually translocated downslope by consistent forces of flowing water and downward wind.

Apparently, more leaf litter slid down from Patch S than from Patch SS and N, indicating that both aspect and understory type are important to leaf litter redistribution in the forest. While aspect governs the pathway of winds, stiff understory hinders the movement of litter by roughening the forest surface.

The amount of leaf litter which slides downslope may indicate the magnitude of fluvial losses. Considering that there is direct litterfall to forested streams, it is presumed that the input of leaf litter to streams is higher than 471-2,548 g m^{-1} yr^{-1} from southwest-facing slopes in the forested watershed, and approximately 588 g m^{-1} yr^{-1} from the northeast-facing slopes (Table 1). The values may be transformed ones per unit area when stream bed per unit length is determined. Naiman et al. (1992) reported that a riparian forest directly lost 300-600 g Cm^{-2} annually to small streams.

Table 2. Dry mass of leaf litter store (g m^{-2}±SD) in the patches

		Date		
Patch	N	Feb. 18, 1995	May 28, 1995	April 12, 1997
S	3	216 (±145)	39 (±11)	216 (±100)
SS	3	441 (± 37)	416 (±72)	631 (±394)
N	3	-	1077 (±70)	724 (±270)

In April 1997, undecomposed leaf litter of 216, 631, and 724 g m^{-2} was stored in Patch S, SS, and N, respectively (Table 2). This result is consistent with those of the above litter transport experiment in which Patch S acts as a source and Patch N as a sink of leaf litter.

Estimation of contribution of leaf litter to soil respiration

The amount of leaf litter stored in the patch was estimated from Table 1, based on a mass balance approach. The mass balance in a patch is expressed as follows: amount of leaf litter = leaf litterfall + transport input - transport output - decomposition.

It was assumed that lateral transport which occurred between the unmeasured boundaries was balanced. Litter decay was not considered in this estimation, as it is negligible due to its low decomposition rate in the winter. This is not the case from May through September, but may not cause a large error as a relatively small amount of leaf litter falls and moves in the forest floor during the growing season (Lee et al., unpublished data).

According to the mass balance calculations, litter mass in Patch S was negative. This result indicates that there was another source of leaf litter which was not considered in the calculations. The candidate source is lateral transport from outside of the patches. When zero is assigned to the negative values, the estimates of litter were 0, 365, and 437 g m^{-2} in November 1996, 0, 367, and 444 g m^{-2} in May 1997, and 0, 365, and 419 in September 1997 on Patch S, SS, and N, respectively. The order of estimates is comparable to the amount of leaf litter collected in the patches (Table 2). Leaf litter transport into Patch N seems to be underestimated. The underestimation might be caused by undetermined lateral transport and/or leaf litter transport over the traps 0.5 m in height.

Bowden et al. (1993) reported that organic matter derived from above-ground sources at the Harvard Forest in north-central Massachusetts was responsible for 138 g Cm^{-2} yr^{-1} (37%) of annual soil respiration. If we assume that (1) the system is in a steady-state, (2) the carbon fraction of leaf litter is 48% (Bowden et al., 1993; Gower et al., 1996; Aertes, 1997), and (3) there is no transport of litter downslope, the contribution of leaf litter to soil respiration will be approximately 173 g Cm^{-2} yr^{-1}, estimated from the leaf litterfall of 1996. On the other hand, the mean value estimated after litter transport which is accounted for is 122 g Cm^{-2} yr^{-1}. The difference is ascribed to the loss of leaf litter slid down.

Table 3. Carbon sources and estimated contribution of each source to soil respiration in the forest patches

Compartment	Patch			References
	S	SS	N	
Carbon source (g m^{-2})				
aboveground litter	0	365	419	This study
	(216)[a]	(631)	(724)	〃
Understory biomass[b]	53	281	83	〃
Reproductive litter			72	Hendrick and Pregitzer, 1993
Woody litter			35	〃
Belowground litter			484	〃
Fine root biomass			510	McClaugherty et al., 1982
Estimated contribution to soil respiration (g Cm^{-2} yr^{-1})				
aboveground litter[c]	0	175	201	
	(104)	(303)	(348)	
Understory[cd]	25	27	40	
Reproductive litter[c]			35	Hendrick and Pregitzer, 1993
Woody litter[c]			17	〃
Belowground litter[e]			110	Bowden et al., 1993
Root respiration[e]			123	Bowden et al., 1993

[a] Estimated from the amounts of leaf litter in the patches on April 12, 1997.
[b] Determined on May 24, 1997 (Kang et al., unpublished data).
[c] Assumed that carbon fraction of leaf litter is 48%.
[d] Assumed that 20% aboveground biomass of dwarf bamboo and 100% of herb are converted to litter in the steady state.
[e] Adapted from Bowden et al. (1993).

The estimated carbon budget of each patch is given in Table 3, where data of other studies were also compiled to determine the relative contribution of leaf redistribution to soil respiration. Although many assumptions should be included for the budget estimation at this moment, a mass balance approach helps estimate how significant leaf litter transport is to carbon processes in the forest ecosystem and provides the research frame for a future study of carbon cycling in the study area. In order to understand a site-specific process, for example, we need to assess the amount of litter derived from reproductive and woody part, root biomass and respiration, and leaching loss.

In conclusions, leaf litter redistribution has a potential to play an important role in the carbon processes of forest ecosystems. By quantifying the transport of leaf litter among distinct patches, we observed many of the factors influencing litter redistribution. Most redistribution of leaf litter occurred during September-November when the forest experienced the greatest period of leaf litterfall and strong winds. A large amount of leaf litter was transported from the southwest-facing slope to the northeast-facing slope during this time. This indicates that leaf litter moves over watershed boundaries in a region subject to strong winds. Thus litter redistribution should be included in carbon and nutrient budgets, especially when a small forested watershed is studied.

Understory plants such as evergreen dwarf bamboo were also significant to litter redistribution in forest floors because they trapped a large amount of leaf litter. It is suggested that surface roughness, largely associated with the characteristics of understory, is a factor governing leaf litter dynamics in forest floors.

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