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A Comparison of Litterfall Dynamics in Three Coniferous Plantations of Identical Age under Similar Site Conditions

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ABSTRACT: This study was carried out to evaluate litterfall dynamics in three adjacent coniferous tree plantations (larch: *Larix leptolepis;* red pine: *Pinus densiflora*; rigitaeda pine: *P. rigitaeda*) planted in the same year (1963), and growing under similar environmental conditions in the Sambong Exhibition Forests, Hamyang-gun, Gyeongsangnam-do. Litter was collected monthly between July 2006 and June 2008. Needle, broad leaf and total litter inputs followed a similar monthly pattern in the three coniferous plantations. The amounts of needles, flowers, and miscellaneous litter were significantly lower in the larch than in the two pine plantations, while branch litter was significantly higher in the larch than in the two pine plantations. Average total litterfall for two years was significantly higher for the pine (5,475 kg ha^{-1} yr^{-1} for red pine and 5,290 kg ha^{-1} yr^{-1} for rigitaeda pine) plantations than for the larch (3,953 kg ha^{-1} yr^{-1}) plantation. Needle litter comprised about 73.1% of total litterfall for the rigitaeda pine, 70.8% for the red pine and 62.9% for the larch plantations. Our results demonstrate that litterfall inputs can be affected by tree species.

Key words: *Larix leptolepis*, Litterfall, *Pinus densiflora*, *Pinus rigitaeda*, Stand types

INTRODUCTION

Litterfall inputs represent important components of the carbon and nutrient cycles in forest ecosystems because the turnover of litter is a major pathway by which carbon and nutrients enter forest soils (Bray and Gorham 1964, Gower and Son 1992, Kavvadias et al. 2001, Kim et al. 2005, Berg and Laskowski 2006). However, the amount of litterfall depends on several ecological factors and forest management activities, such as tree species, climate, site quality, stand increment, stand age, stand density, fertilization, and thinning (Binkley 1986, Perdersen and Bille-Hansen 1999, Kim et al. 2005, Kim et al. 2008, Park et al. 2008). Tree species can have a significant influence on litterfall because of differences among species in the amounts of leaf litter or non-leaf litter produced (Bray and Gorham 1964). However, it is not easy to compare litterfall inputs and amounts among tree species due to the potentially confounding effects of site and management factors.

Red pine (*Pinus densiflora*) is the most important coniferous tree species in Korea, with red pine forests occupying more than 23.5% (1.5 million ha) of Korean forest lands (Korea Forest Service 2006). Larch (*Larix leptolepis*) forests were also planted on about 600,000 hectares between 1957 and 1990 (Forestry Administration 1994). Rigitaeda pine (*P. rigitaeda*), a hybrid of pitch (*P. rigida*) and loblolly (*P. taeda*) pines, also shows good growth characteristics with enhanced cold resistance compared with pitch or loblolly pine. These three coniferous species have been the most important species planted in reforestation programs throughout Korea during the last forty years.

Although several studies have reported litterfall inputs in pine and larch plantations in central Korea (Kim and Chang 1989, Mun and Joo 1994, Kim et al. 1996, Kim et al. 2005), no comparative study to date has yet examined seasonal and yearly litterfall inputs in coniferous stands in southern Korea. In addition differences among tree species in seasonal or yearly patterns of total litter production or litterfall inputs may have important consequences for stand carbon and nutrient cycling (Sharma and Pande 1989, Gower and Son 1992, Berg and Laskowski 2006). The objectives of this study were to determine seasonal and annual litterfall input patterns in plantations of three coniferous tree species of the same age under identical site conditions.

MATERIALS AND METHODS

The study was conducted in the Sambong Exhibition Forests located in Hamyang-gun, Gyeongsangnam-do, and administered by Seobu National Forest Office, Korea Forest Service. Annual mean precipitation in this area is 1,322 mm/yr and the annual mean temperature is 12.8℃. Experimental plots were located in adjacent red pine, larch and rigitaeda pine plantations on moderately productive sites (Table 1). Soil characteristics at the study site were described by Kim and Cho (2004). Plantations of all three species were es-

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Table 1. General characteristics of three coniferous plantations in the study sites (2006). Values in brackets represent ranges. $N = 3$ plots per species

Plantation	Location	Elevation (m)	Stand density (trees/ha)	DBH (cm)	Basal area (m^2/ha)
L. leptolepis	35° 27' 440" N 127° 38' 492" E	674	350 [300~400]	31.1 [27.2~36.5]	27.6 [18.1~35.6]
P. densiflora	35° 27' 474" N 128° 38' 446" E	684	216 [200~250]	34.8 [31.3~36.3]	20.7 [19.7~21.3]
P. rigitaeda	35° 27' 445" N 128° 38' 512" E	678	550 [450~650]	29.4 [28.5~30.3]	35.8 [29.9~41.3]

tablished in 1963 on northeast facing slopes (5~15°) with small pits and mounds. The study sites have identical macroclimates as well as being of identical quality and stand age.

Understory species in the larch plantation were *Viburnum dilatatum, Lindera erythrocarpa, Rubus parvifolius, Quercus serrata, Q. acutissima, Q. variabilis, Castanea crenata, Schizandra chinensis, Staphylea bumalda, Zanthoxylum schinifolium,* and *Elaeagnus umbellata.* Understory species in the red pine plantation were *Rhododendron mucronulatum, Q. serrata, Q. aliena, Lindera glauca, L. obtusioloba, Smilax china* and *Juglans mandshurica.* Understory species in the rigitaeda pine plantation were *Styrax japonica, Stephanandra incisa, Z. schinifolium, Cornus controversa, Q. aliena, Q. serrata, Symplocos chinensis* for. *pilosa, J. mandshurica* and *Rhus sylvetris.*

Data were collected from three 20 × 10 m plots within each plantation. Mean stand densities in the experimental plots were 216 trees/ha for the red pine plantation, 350 trees/ha for the larch plantation and 550 trees/ha for the rigitaeda pine plantation (Table 1). Mean DBH was greatest in the red pine plantation (34.8 cm), followed by the larch (31.1 cm) and rigitaeda pine plantations (29.4 cm). Stand basal area was 35.8 m^2/ha in the rigitaeda pine, 27.6 m^2/ha in the larch, and 20.7 m^2/ha in the red pine plantations. To measure litterfall, we installed three circular litter traps with a surface area of 0.25 m^2 at randomly chosen locations 60 cm above the forest floor in each plot for each plantation (total 27 litter traps). Litter was collected at monthly intervals between July 2006 and June 2008. The litter from each trap was transported to a laboratory and then oven-dried at 65℃ for 48 hours. The dried samples were then separated into the needle, bark, cone, branch, flower, and other components, and each portion was weighed. Litterfall component data from each of the three plantations were compared using analysis of variance and the Tukey test (SAS Institute Inc. 1989).

RESULTS AND DISCUSSION

The monthly litterfall input of needles, broad leaves, branches, bark, flowers, cones, and other miscellaneous components for each plantation is shown in Fig. 1. Litterfall inputs in the three coniferous plantations followed similar monthly patterns because litterfall inputs are affected by insect infestations (Pedersen and Bille-Hansen 1999), site, stand age (Bray and Gorham 1964), climate, and weather patterns (Gresham 1982), all of which are similar for the three study stands. Needle litterfall in all three coniferous plantations showed a seasonal pattern of variation, reaching its maximum values in autumn. Many studies have reported a similar pattern for coniferous tree species because needles in temperate forests experience natural senescence in autumn (Bray and Gorham 1964, Kim et al. 1997, Kim et al. 2005). Broad leaf litter showed a similar peak in autumn, the season of heaviest litterfall in deciduous tree species in temperate forests (Kim et al. 1997, Park et al. 2008), except in the red pine plantation. However, the contribution of broad leaf litter to the total litterfall was minimal because most shrubs in the study plots were cut before litter trap installation.

Monthly patterns of production of woody litter, such as branches, bark and cones, were irregular throughout the year, although a peak in branch litterfall was observed in late spring in the larch plantation (Fig. 1). The inputs of bark litter were also highly variable, and the bark litter amounts were much higher in the red pine plantation than in the larch or rigitaeda pine plantations. Branch litterfall in the two pine species varied slightly during the study period, whereas branch litterfall fluctuated dramatically over time in the larch plantation during the study period. These large fluctuations in branch litter production in the larch plantation could be due to high inputs of small and short branch litter compared with the two pine plantations, although environmental factors such as storms or strong winds may also have pronounced effects on branch litterfall (Christensen 1975, Park et al. 2008). Strong seasonal patterns of flower litter production occurred in plantations of the two pine species, but not in the larch plantation. There was almost no flower litter in the larch plantation. Miscellaneous litter, such as needles, reproductive organs, bark and branch fragments that could not be classified, generally accumulated at higher rates in autumn than in other seasons. Seasonal patterns of variation in total litterfall among the three coniferous plantations were similar, with high litterfall in fall, and low litterfall during summer and winter. The overall seasonal patterns for total litterfall closely reflected the seasonal patterns of needle litterfall.

The amounts of needle, branch, bark, flower, miscellaneous and total litterfall were significantly different ($p < 0.05$) in the three coniferous plantations (Fig. 2), while the amounts of broad leaf and cone litterfall were not significantly different ($p > 0.05$) because of the high spatial variability of these components. Average needle litterfall was significantly higher in the two pine plantations (red

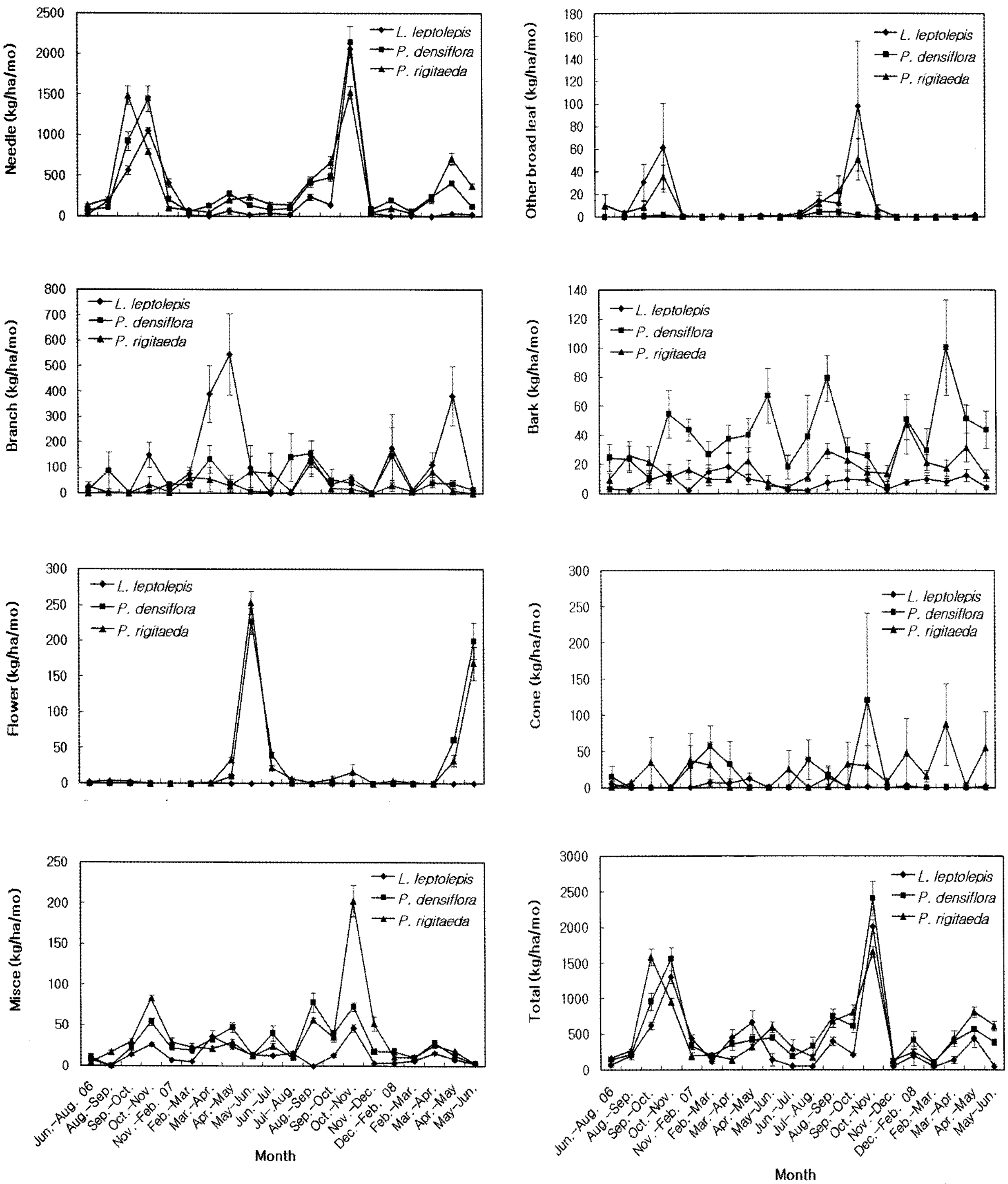

Fig. 1. Monthly litterfall inputs for three coniferous plantations under similar site conditions. Vertical bars indicate one standard error.

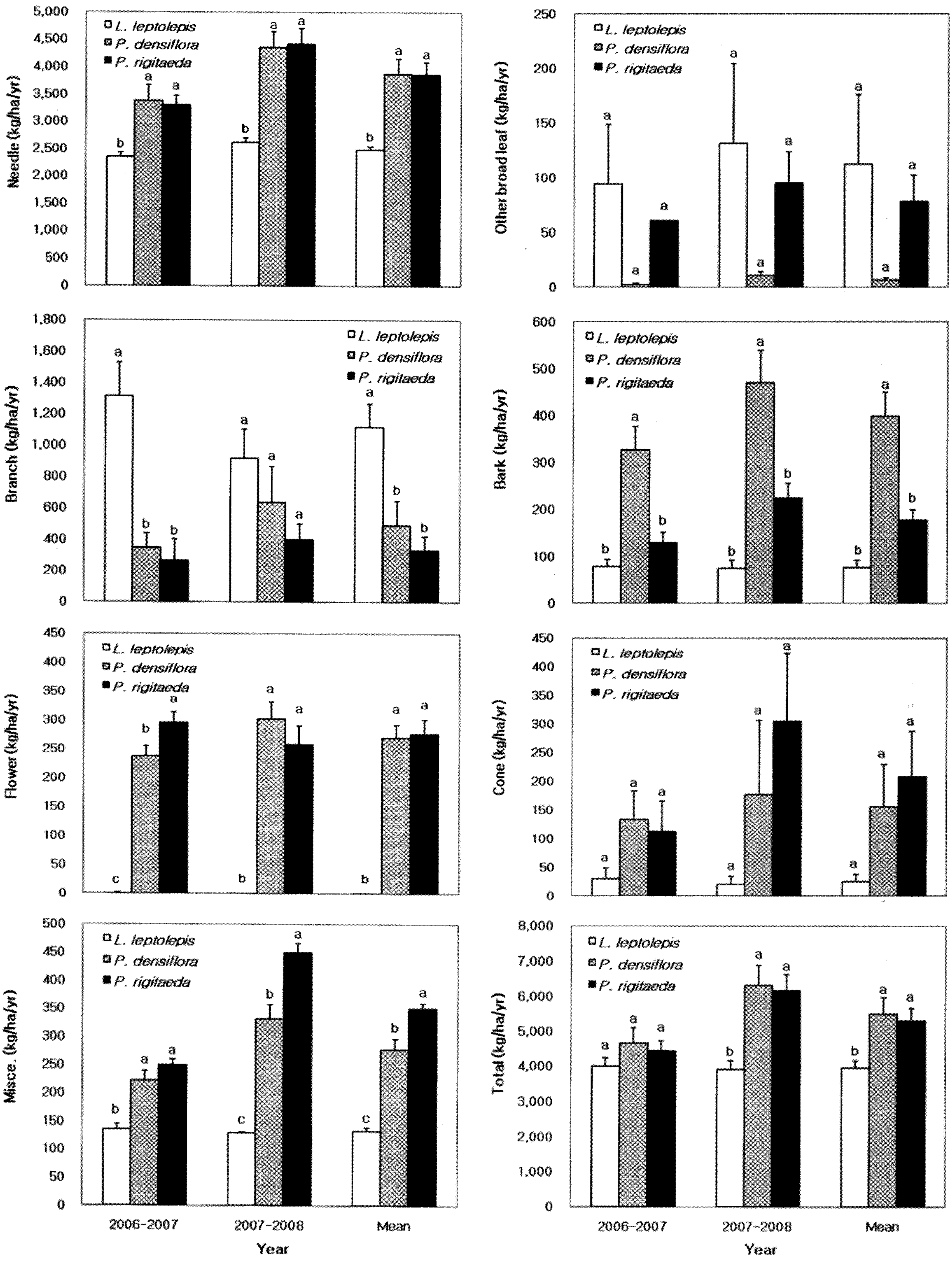

Fig. 2. Amounts of litterfall components in three coniferous plantations under similar site conditions. Vertical bars indicate one standard error. Different letters on each litterfall component indicate a significant difference at $p = 0.05$.

pine: 3,875 kg ha^{-1} yr^{-1}; rigitaeda pine: 3,866 kg ha^{-1} yr^{-1}) than in the larch plantation (2,488 kg ha^{-1} yr^{-1}) during the two-year study period. These results could be due to differences in the morphological characteristics of larch needles and pine needles. Other studies have also reported that larch shows low needle litter production than pine species (Kim et al. 2005). There does not seem to be a clear relationship between needle litterfall and basal area or stand density in the three coniferous plantations, although basal area is affected by both the number of trees per hectare and the size of these trees. In addition, there was no significant difference between the red pine and rigitaeda plantations in the rate of needle litter production, despite a considerable difference in basal area and stand density between the pine plantations. The absence of variation in the amount of needle litter produced in the pine plantations could be attributed to canopy closure in these mature plantations, as annual needle litterfall remains relatively constant after canopy closure (Bray Gorham 1964, Gessel and Turner 1976). The production of flower and miscellaneous litter was significantly higher in the two pine plantations than in the larch plantation (Fig. 2). However, branch litter production was significantly lower in the pine plantations than in the larch plantation, while bark litter production was higher in the red pine plantation than in the larch or rigitaeda pine plantations. Higher bark litter production in red pine stands could be due to the morphological characteristics of red pine bark.

Average total litterfall was significantly different ($p < 0.05$) in the three coniferous plantations. Total litterfall was higher for the two pine plantations than for the larch plantation during the study period. Total annual litterfall during the 2-year sampling period averaged 3,953 kg ha^{-1} yr^{-1} in the larch plantation, 5,291 kg ha^{-1} yr^{-1} in the rigitaeda pine plantation and 5,475 kg ha^{-1} yr^{-1} in the red pine plantation. These values all fall within the range established for temperate coniferous forests in Korea (Kim et al. 2005), but are lower than the global mean value (about 5,500 kg ha^{-1} yr^{-1}) for warm-temperate forests (Bray and Gorham 1964). Kim et al. (2005) reported somewhat higher values for total litterfall for pitch pine (5,802 kg ha^{-1} yr^{-1}) and larch plantations (4,562 kg ha^{-1} yr^{-1}) in the Gwangnueng Experimental Forest in central Korea.

The order of importance for litter components was: needles > branches > miscellaneous > broad leaves > bark > cones > flowers in the larch plantation; needles> branches > bark > miscellaneous > flowers > cones > broad leaves in the red pine plantation; and needles > miscellaneous > branches > flowers > cones > bark > broad leaves in the rigitaeda pine plantation (Table 2). Needle litterfall was the major component of total litterfall in all three coniferous plantations, accounting for about 62.9% of total litterfall in the larch plantation, 70.8% in the red pine plantation, and 73.1% in the rigitaeda pine plantation. The proportion of needlefall in this study was similar to that reported for a larch plantation in a previous study (62.5% of total literfall; Kim et al. 2005), while needlefall in the two pine plantations in this study was higher than the 62.8% reported by Kim et al. (2005). The two pine tree species showed similar cone, flower and miscellaneous distributions, while branch and bark litter production was higher in the red pine plantation than in the rigitaeda pine plantation. The very low proportion of broad leaf litter in the three coniferous plantations can be attributed to the cutting of understory deciduous vegetation before installation of the litter traps. In contrast, the high proportion of miscellaneous litter in the two pine plantations as compared with the larch plantation was due to larger inputs of needles, bark, and reproductive organ fragments that were difficult to sort.

The pattern of inter-annual variation of litterfall was different in the three coniferous plantations. The larch plantation exhibited re-

Table 2. Distribution of litterfall components among three coniferous plantations. Values represent percentages of total litterfall by dry mass

Year	2006～2007			2007～2008			Mean		
Litterfall component	*L. leptolepis*	*P. densiflora*	*P. rigitaeda*	*L. leptolepis*	*P. densiflora*	*P. rigitaeda*	*L. leptolepis*	*P. densiflora*	*P. rigitaeda*
Needles	58.73	72.71	74.75	67.26	69.30	71.87	62.94	70.77	73.08
Branches	32.78	7.47	6.06	23.59	10.10	6.48	28.25	8.99	6.31
Bark	1.98	7.03	2.95	1.92	7.47	3.65	1.95	7.26	3.36
Broad leaves	2.35	0.05	1.38	3.37	0.17	1.54	2.86	0.12	1.47
Cones	0.74	2.87	2.53	0.52	2.81	4.94	0.63	2.83	3.93
Flowers	0.02	5.10	6.69	0.01	4.86	4.19	0.02	4.93	5.23
Miscellaneous	3.40	4.77	5.64	3.33	5.28	7.32	3.36	5.07	6.62
Total	100	100	100	100	100	100	100	100	100

latively consistent rates of litterfall, with only minor variation between years. However, annual litterfall in both pine plantations showed much larger annual variation: total litterfall in both pine plantations was much higher in 2007～2008 than in 2006～2007. This difference could be due to changes in evergreen needle fall, because the longevity of evergreen needles depends upon internal and external conditions.

CONCLUSION

The amounts of litterfall components, such as needles, flowers, branches, miscellaneous, and total litter were significantly different in the three coniferous plantations. The annual rates of litterfall were relatively constant for the larch plantation, while other two pine plantations showed substantial annual variation. Our results indicate that the litterfall inputs differ considerably between the two pine plantations and the larch plantation despite their similar site conditions, while both pine species show similar overall patterns of litterfall.

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