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The Pattern of Seed Rain in the Broadleaved-Korean Pine Mixed Forest of Xiaoxing`an Mountains, China

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Abstract : This study was conducted to understand the pattern and characteristics of seed rain in the broadleaved-Korean pine mixed forest. We established 287 0.5 m^2 circular seed traps and collected and identified fallen seeds in the traps every two weeks in 150 m×150 m sample plot of the permanent nine hectare of experimental plot in 2005. The overall average density of seed rain was 864.2/m^2. The seeds of *Betula costata* had the highest number of fallen seeds as 676.0/m^2 (78.2%), followed by *Abies nephrolepis* as 57.5/m^2, *B. platyphylla* as 37.9/m^2, *Tilia amurensis* as 32.2/m^2, *Acer ukurunduense* as 17.0/m^2, *A. tegmentosum* 14.8/m^2, and so on. *Pinus koraiensis* was recorded only 2.5/m^2 of fallen seeds mainly owing to consumption of people and animals. Even though most of seeds showed high proportion of purity, those of Korean pine had low rate of purity due to the animal and microbiological predation. Most of seed dispersal have started from the middle to late August and come to an end on the middle of November. The peak time of seed dispersal varied depending on the species. The rate of pure seed by dispersal time varied according to the species, thereupon the aspect of predation and the rate of blasted seed which had influence on the rate of purity also varied according to the species. The density of Korean pine seed rain in the forest gap was significantly different at $P \leq 0.05$ from in the closed canopy. But the other species had no difference among canopy coverage.

***Key words* :** *broadleaved-Korean pine mixed forest, seed rain, forest gap, seed dispersal*

Introduction

The successful reproduction of the forest tree is closely associated with the production and dispersal of seeds, germination, and seedling establishment. Of these seed dispersal means the departure of seeds from their seed-tree by the methods, such as wind, water, animals, gravity, or forceful ejection. Seed dispersal is the only method of moving for most of plants, avoiding high rate of mortality by maintaining high density of seeds near the seed-tree (Howe and Smallwood, 1982), colonizing appropriate place to survive (Harper, 1977), and expanding habitat for good germination and growth by specific dispersal mechanism (Wenny, 2001). Therefore seed dispersal is so important to preserve the plant species and local population (Connell and Green 2000; Masaki and Nakashizuka, 2002; Gomez, 2003), and to involve species composition, dynamics, and coexistence in the plant community (Nakashizuka *et al*, 1995; Connell and Green, 2000; Willson and Traveset, 2000).

Seed dispersal is composed two way of pre-dispersal and post-dispersal. Pre-dispersal indicates the seed rain, the process of arrival onto the ground mainly by wind or gravity. Post-dispersal involves the secondary movement of seeds by animals on the ground or the burial of seeds into the ground. The intensity and the pattern of time and space of pre-dispersal, that is seed rain, have direct influence on the predation and post dispersal (Chambers and MacMahon, 1994), on the pattern of space for seed bank composition, germination aspect, and seedling establishment (Harper, 1977; Willson 1993), on the composition of seed bank and the available space for germination and seedling establishment (Harper, 1977; Willson 1993), and on the structure and dynamics of population and community (Nathan and Muller-Landau, 2000).

The broadleaved-Korean pine forest was one of the major forest types in northeast region of China, once being extensively distributed as a climax forest type. The distribution of this forest type is presently restricted in

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the area of Changbai mountains of Jilin Province; Wanda mountain, Laoye mountain, and Zhangguangcai mountains of Heilongjiang Province; and the area of Xiaoxing`an Mountains, mainly by the misuse of forest land and over-harvesting of timber (Wang, 1995). The studies on the seed dispersal in the broadleaved-Korean pine forest have been partly conducted only on the seed of Korean pine (Liu, 1988; Lu, 2003), but hardly done on the community level for all composed species.

Accordingly, this study was intended to investigate and analyze the intensity, composition, and temporal variation of seed rain in the broadleaved-Korean pine forest of Laingshui National Reserve, Xiaoxing`an Mountains, so as to examine the ecological characteristics of early stage of life history for the broadleaved-Korean pine forest type.

Material and Methods

1. The study area

The Laingshui National Reserve (47° 10' 50"N, 128° 5' 20" E) is located in the southern part of Xiaoxing`an Mountains, Heilongjiang Province. The Laingshui National Reserve is characterized by rolling mountainous terrain with 707. 4m of highest peak above sea level and 300m of lowest peak a.s.l., and average slope gradient is 10-15°. Mean annual temperature is -0.3°C with mean annual highest temperature of 7.5°C and lowest temperature of -6.6°C. Mean annual soil surface temperature is 1.2°C and the number of free-frost days are about 100-120. Mean annual precipitation is 676 mm with 78% of relative humidity and 805 mm of evaporation rate.

The Laingshui National Reserve extended 12,133ha of total land area with about 1.7 million m^3 of growing stock and 98% of canopy coverage. The Reserve has one of the most concentrated and well-conserved patch shape broadleaved-Korean pine replaced by secondary forests after major disturbances from over-harvesting around the region.

The Laingshui National Reserve is rich in forest vegetation and community type, mainly composed of *Pinus koraiensis*, *Picea koraiensis*, *Abies nephrolepis*, *Tilia amurensis*, *T. mandshurica*, *Acer mono*, *Fraxinus mandshurica*, *Ulmus laciniata*, *Betula costata*, *B. platyphylla*, *Quercus mongolica*, *Larix gmelini*, *Juglans mandshurica*, *A. ukurunduense*, and *A. tegmentosum*. It is well-known that the regional climax community is broadleaved-Korean pine forest, dominated by Korean pines. Besides, depending upon variation of site quality and species composition from the ridges to valleys, mongolian oak-Korean pine, basswood-Korean pine, birch-Korean pine, and spruce-fir-Korean pine forest types are observed in the patch shape around the region.

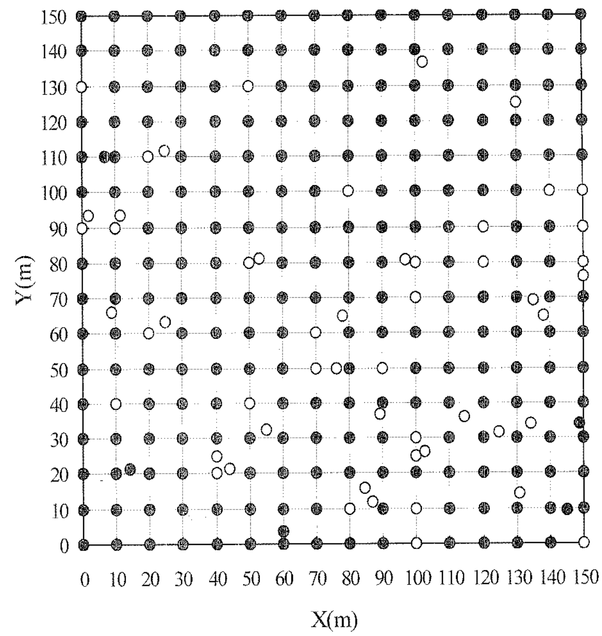

Figure 1. The location of seed traps in the main plot.

2. Data collection

A permanent experimental plot of 300m×300m was established in the typical broadleaved-Korean pine forest in the year of 2005, divided into 900 10m×10m sub-plots and planted stakes on the corner of each sub-plots to mark the position. For every woody plant greater than 2 cm of diameter, we attached the aluminum number tag, placed coordinates on the grid map, and measured DBH, height, crown width, and bole height.

At the center portion of 150m×150m in the permanent experimental plot, total number of 256 0.5m^2 circular seed traps were equipped at the corners of sub-plot to collect seeds from the above canopy. Of these 229 traps were under the closed canopy, 27 traps were on the forest gap, 26 traps were set on the gap outside of the sub-plot corner, and 5 traps were randomly located under the closed canopy (Figure 1). In the season of seed dispersal, we collected fallen seeds from the traps every two weeks and brought to the laboratory to identify the species and evaluated the status of purity for the seeds such as viability, predation, immature, blastedness, contamination, and so on.

3. Data analysis

The composition of seed rain by tree species, the number of seeds per unit area, temporal variation of seed rain were statistically analyzed from the seed collection data of sample traps. The analysis variance and *t*-test were performed for the difference of seed rain between forest gap and closed canopy (Rosner, 2005), reviewed the influence of forest gap on the seed rain pattern.

Results and Discussion

1. The stand composition of the broadleaved-Korean pine forest

The status of stand composition and structure were presented in Table 1 from the vegetation data in nine hectare permanent experimental plot. Forty-eight woody plant species were surveyed for greater than 2 cm of diametered trees. The numbers and basal area per hectare were 1716.7 stems and 40.94m^2 of basal area (Table 1). *Pinus koraiensis* had highest importance value of 25.42%, holding the most dominant in the study forest, followed by *Corylus mandshurica* (10.85%), *Acer mono* (9.16%), *Abies nephrolepis* (6.71), *Tilia amurensis* (6.39), *Acer ukurunduense* (6.12%), *Ulmus laciniata* (5.08%), *Betula costata* (4.61%), and *Acer tegmentosum* (3.80%).

Corylus mandshurica showed highest relative density (22.85%) with 392.3 stems per hectare, but only 0.46% of relative coverage, indicated the occurrence of large number of small diametered trees. On the other hand, *Pinus koraiensis* was calculated as 7.7% of relative density and 58.32% of relative coverage, indicated the occurrence of comparatively small number of large diametered trees. Those species which had higher value of relative frequency, such as *Acer mono* (11.55%), *Pinus koraiensis* (10.21%), *Corylus mandshurica* (9.22%), and *Abies nephrolepis* (7.9%) were considered to have wider range of distribution in the study forest. Consequently, it might be noted that the forest was dominated by Korean pine and associated with other mesophytic deciduous tree species and several conifers, presenting the typical broadleaved-Korean pine forest.

2. The intensity and composition of seed rain for the species

The intensity of seed rain represents the potentiality of seed production and furthermore regeneration of the corresponding stand. The density of seed rain in the broadleaved-Korean pine forest was totalized 864.2/m^2. *Betula costata* had the largest number of 676.0 seeds/m^2 (78.2%), followed by *Abies nephrolepis* (57.5 seeds/m^2), *B. platyphylla* (37.9 seeds/m^2), *Tilia amurensis* (32.2 seeds/m^2), *Acer ukurunduense* (17.0 seeds/m^2), and *A. tegmentosum* (14.8 seeds/m^2) (Table 2).

In spite of higher density of canopy trees, the Korean pine had lower density of seed rain, which is related to the people's collection of pine cones for harvesting pine nuts. The harvesting of pine nuts have had negative influence not only on the seed supply for regeneration but also on the population size of rodents inhabiting the broadleaved-Korean pine forest (Liu *et al.*, 2004; Liu *et al.*, 2005; Ji *et al.*, 2002). It requires an appropriate solu-

Table 1. Species composition of the studied broadleaved-Korean pine mixed forest.

Species	Living stems		Basal area		Frequency		Importance value (%)
	Num.*/ha	(%)	(m^2/ha)	(%)	Abso. Fre.#	(%)	
Pinus koraiensis	132.2	7.70	23.87	58.32	0.65	10.21	25.41
Corylus mandshurica	392.3	22.85	0.19	0.46	0.59	9.22	10.85
Acer mono	178.8	10.41	2.26	5.51	0.74	11.55	9.16
Abies nephrolepis	87.6	5.10	2.92	7.14	0.51	7.90	6.71
Tilia amurensis	96.6	5.62	2.96	7.23	0.40	6.30	6.39
Acer ukurunduense	171.7	10.00	0.38	0.92	0.48	7.45	6.12
Ulmus laciniata	86.0	5.01	1.39	3.40	0.44	6.83	5.08
Betulla costata	74.0	4.31	1.96	4.79	0.30	4.74	4.61
Acer tegmentosum	87.7	5.11	0.42	1.03	0.34	5.26	3.80
Syringa reticulata var. *mandshurica*	73.7	4.29	0.22	0.54	0.27	4.25	3.03
Fraxinus mandshurica	37.6	2.19	1.14	2.78	0.23	3.58	2.85
Picea koraiensis	16.7	0.97	0.89	2.17	0.15	2.34	1.83
Euonymus pauciflorus	30.9	1.80	0.02	0.04	0.20	3.20	1.68
Prunus padus	48.8	2.84	0.12	0.30	0.12	1.81	1.65
Populus ussuriensis	13.6	0.79	0.98	2.39	0.05	0.73	1.30
Acanthopanax senticosus	28.6	1.66	0.01	0.03	0.12	1.81	1.17
Ulmus japonica	24.4	1.42	0.23	0.56	0.10	1.51	1.16
Philadelphus schrenkii	19.7	1.15	0.01	0.03	0.13	2.00	1.06
Tilia mandshurica	26.9	1.57	0.24	0.58	0.06	1.01	1.05
Aralia elata	20.8	1.21	0.03	0.08	0.11	1.72	1.00
Others (29 species)	68.4	3.99	0.70	1.70	0.42	6.58	4.09
Total	1716.7	100.0	40.94	100.0	6.40	100.0	100.0

*Num.; Number of stems # Abso. Fre.; Absolute Frequency

Table 2. The component of seed rain in the broadleaved-Korean pine mixed forest.

Species	Seeds/m²/year	Proportion (%)					
		Sound seeds	Vacant seeds	Immature seeds	Damaged seeds*	Decayed seeds	Others
Betula costata	676.0 ± 1078.63	95.87	1.76	0.00	2.36	0.01	0.01
Abies nephrolepis	57.5 ± 69.91	89.98	4.52	0.00	5.43	0.01	0.06
Betula platyphylla	37.9 ± 33.54	96.36	1.51	0.07	1.91	0.02	0.13
Tilia amurensis	32.2 ± 64.81	87.86	7.83	0.17	3.74	0.02	0.37
Acer ukurunduense	17.0 ± 34.42	93.21	5.03	0.00	1.76	0.00	0.00
Acer tegmentosum	14.8 ± 24.18	79.92	18.85	0.00	1.09	0.09	0.05
Acer mono	9.7 ± 10.62	71.46	23.65	0.00	4.67	0.00	0.22
Picea koraiensis	6.7 ± 10.40	67.01	25.49	0.00	7.28	0.10	0.10
Fraxinus mandshurica	4.5 ± 13.20	96.45	0.77	0.31	2.01	0.00	0.46
Tilia mandshurica	3.5 ± 14.62	82.63	7.98	0.00	8.98	0.20	0.20
Pinus koraiensis	2.5 ± 9.32	34.37	17.46	0.00	46.76	0.00	1.41
Others	1.9 ± 10.40	61.40	15.07	0.00	12.50	1.10	9.93
Total	864.2 ± 1082.41	94.08	3.04	0.01	2.80	0.01	0.06

*: Damaged by insects or other animals

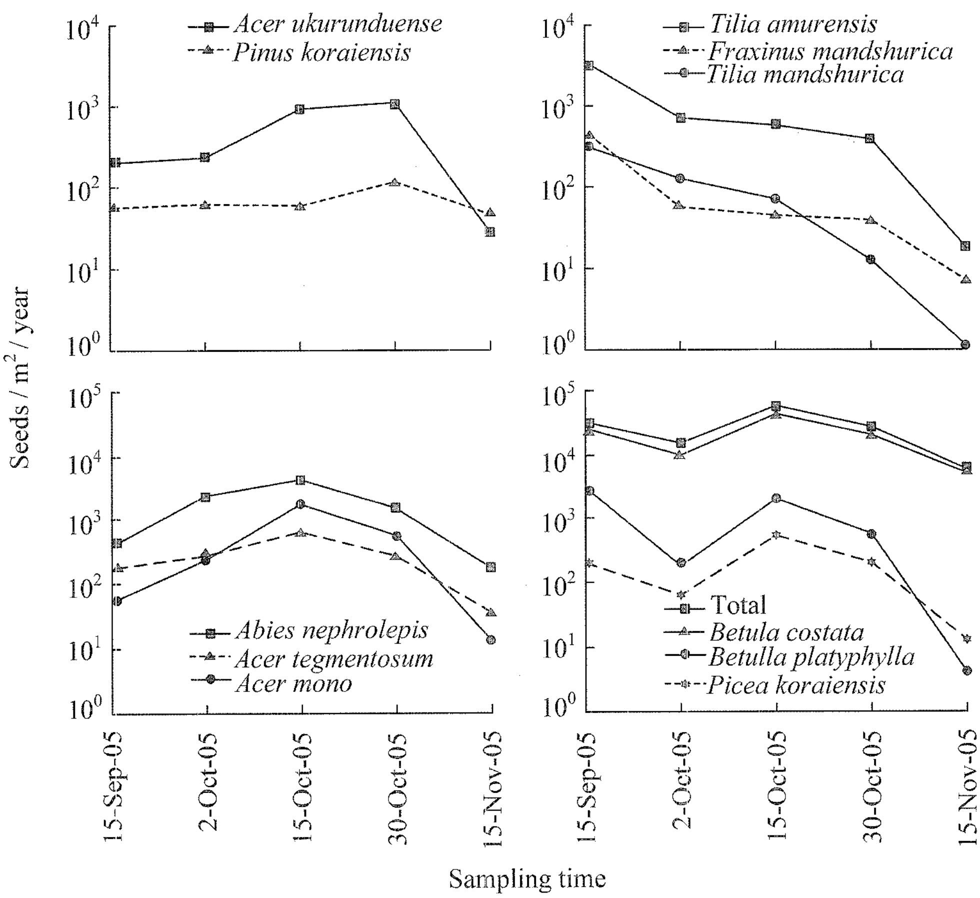

Figure 2. Numerical dynamics of seed rain of major tree species in the broadleaved-Korean pine mixed forest (0.5m², *N*=287).

tion to the problem by forest managers.

The status of seed purity showed a great variation depending upon species. Major species showing high rate of seed purity were *Fraxinus mandshurica* (96.45%), *Betula platyphylla* (96.36%), *B. costata* (95.87%), *Acer ukurunduense* (93.21%), *Abies nephrolepis* (89.98%), *Tilia amurensis* (87.86%), and so on. The species with high rate of blasted seeds were *Picea koraiensis* (25.49%), *Acer mono* (23.65%), *A. tegmentosum* (18.85%), *Pinus koraiensis* (17.46%), and so on. The *Pinus koraiensis* showed the highest rate (46.76%) of predation by animals, followed by *Tilia mandshurica* (8.98%), *Picea koraiensis* (7.28%), *Abies nephrolepis* (5.43%), *Acer mono* (4.67%) (Table 2).

As shown in Table 2, the number of seeds and the rate of seed purity had indicted great variation by species. However, since larger number of seeds of a certain species would not always mean higher rate of seedling occurrence in the reality, more observation should be needed for more scientific results.

3. The temporal variation of seed rain

Most of seed dispersal in the broadleaved-Korean pine forest have started from the middle to late August and come to an end on the middle of November. On the basis of the data of seed collection every two week, temporal distributional patterns were divided by four types, i.e., normal distribution type I, normal distribution type

Table 3. Characteristics of temporal variation of seed rain by species.

	Species	Sampling time				
		2005-9-15	2005-10-2	2005-10-15	2005-10-30	2005-11-15
Intact seed (%)	*Betula platyphylla*	94.50	97.55	98.52	96.18	100.00
	Betula costata	88.68	97.49	98.54	97.37	98.98
	Picea koraiensis	63.59	74.63	69.85	59.80	100.00
	Pinus koraiensis	4.92	34.33	45.31	41.88	39.13
	Acer ukurunduense	56.22	93.40	95.08	97.69	100.00
	Tilia mandshurica	77.55	88.24	91.38	100.00	-
	Abies nephrolepis	66.74	93.81	91.94	86.50	79.29
	Acer tegmentosum	83.93	81.48	78.15	82.78	92.31
	Fraxinus mandshurica	96.61	93.10	98.04	98.36	83.33
	Acer mono	61.33	78.51	68.43	75.44	85.00
	Tilia amurensis	84.74	92.46	92.68	92.19	72.00
	Others	59.78	53.85	75.86	73.91	-
	Total	87.63	95.35	96.58	95.50	97.55
Blasted seed (%)	*Betula platyphylla*	2.83	0.49	0.38	0.32	0.00
	Betula costata	7.31	0.12	0.01	0.04	0.00
	Picea koraiensis	18.43	19.40	25.81	35.78	0.00
	Pinus koraiensis	26.23	20.90	17.19	16.24	4.35
	Acer ukurunduense	32.97	5.58	3.45	1.66	0.00
	Tilia mandshurica	11.22	3.68	3.45	0.00	-
	Abies nephrolepis	7.49	4.24	4.44	4.48	2.96
	Acer tegmentosum	7.14	13.43	21.54	16.30	0.00
	Fraxinus mandshurica	0.85	0.00	0.00	0.00	16.67
	Acer mono	32.04	13.64	29.01	19.01	7.50
	Tilia amurensis	10.50	4.35	3.73	4.53	0.00
	Others	10.06	38.46	20.69	8.70	-
	Total	7.60	1.87	1.71	1.39	0.21
Suffered from predation by insects or other animals (%)	*Betula platyphylla*	2.39	0.98	1.05	3.18	0.00
	Betula costata	3.98	2.33	1.45	2.59	1.02
	Picea koraiensis	17.05	5.97	4.34	4.41	0.00
	Pinus koraiensis	60.66	44.78	37.50	41.88	56.52
	Acer ukurunduense	10.81	1.02	1.46	0.65	0.00
	Tilia mandshurica	10.88	7.35	5.17	0.00	0.00
	Abies nephrolepis	25.29	1.87	3.62	9.03	16.57
	Acer tegmentosum	8.93	3.70	0.31	0.92	7.69
	Fraxinus mandshurica	1.48	6.90	1.96	1.64	0.00
	Acer mono	6.63	7.44	2.56	5.56	2.50
	Tilia amurensis	4.08	2.69	3.59	3.27	12.00
	Others	15.08	5.13	3.45	17.39	-
	Total	4.53	2.63	1.70	3.10	2.06

Table 4. *F*-test for equality of variation and *t*-test for means of seed rain between closed canopy and forest gap.

	Closed canopy (n=234)		forest gap (n=53)		F	P (t-test)
	Mean	Variation	Mean	Variation		
Betulla platyphylla	19.56	320.57	16.23	106.18	3.019	0.072
Betula costata	354.36	343944.34	265.77	57670.33	5.964	0.081
Picea koraiensis	3.42	29.91	3.04	15.04	1.989	0.554
Pinus koraiensis	1.41	26.23	0.49	1.56	16.790	0.016
Abies nephrolepis	26.95	1024.90	36.74	2070.93	0.495	0.143
Acer ukurunduense	8.08	310.60	10.47	238.68	1.301*	0.363
Tilia mandshurica	1.93	63.59	0.94	9.36	6.792	0.143
Acer tegmentosum	7.47	145.84	6.96	152.77	0.955*	0.783
Fraxinus mandshurica	2.24	49.95	2.34	16.73	2.986	0.895
Acer mono	4.90	28.68	4.60	26.97	1.063*	0.713
Tilia amurensis	17.25	1227.68	11.06	262.29	4.681	0.054
Others	0.61	4.35	2.45	126.87	0.034	0.240
Total	448.18	346249.38	361.09	58843.63	5.884	0.089

*: $P \leq 0.05$ ($F_{233,52,\ 0.025}=0.671$, $F_{233,52,\ 0.975}=1.581$)

II, reverse J-shape type, and two-humped-shape type (Figure 2). *Acer ukurunduense* and *Pinus koraiensis* belonged to the normal distribution type I, showing peak seed rain on the middle of October. The seed rain of *Abies nephrolepis*, *Acer tegmentosum*, and *A. mono* was greatest on 2nd of October, presenting typical normal distribution shape. *Tilia amurensis*, *Fraxinus mandshurica*, and *Tilia mandshurica* displayed the peak seed rain time on the middle of September, after that the amount of seed dispersal was getting continuously decreased until November, showing reverse J-shape graph. *Betula costata*, *B. platyphylla*, and *Picea koraiensis* exhibited two-humped-shape of seed rain distribution, indicated that low seed rain density was associated with the frequent precipitation in the late September. Since the size of seed of *Betula costata*, *B. platyphylla*, and *Picea koraiensis* is extremely small, being supposed to be difficult in seed dispersal by the frequent precipitation in the late September. Overall seed rain distribution presented two-humped-shape, manly because *B. costata* occupied more than 78% of seed rain.

Generally speaking, the proportion of pure seed has been known to be low at the beginning and end of dispersal time. Table 3 presented the composition of seed rain purity pattern for each species by collecting time from the seed traps. The results indicated that the proportion of seed purity did not much varied on the species of *Betula platyphylla*, *Acer tegmentosum*, and *Fraxinus mandshurica*. The factors which has influence on the rate of seed purity are blasted condition and predation by insects and rodents, having shown some variation by species and seed dispersal time in this study. The rate of basted seeds was gradually decreased until the end of dispersal time, except *Picea koraiensis*.

Levey *et al.* (2002) reported that the variation of seed dispersal pattern and the rate of seed purity by species was resulted from the long term evolutionary phenomena among tree species and between trees and animals. More propound and long term research should be needed to lighten such complex phenomena.

4. The effect of forest gap on the distribution of seed rain

The formation of forest gap could make seeds to arrive easily on the forest floor by reducing dispersal resistance. Once Denslow (1987) reported the effect of forest gaps on the seed dispersal in detail. We made the experiment on the difference of seed rain density from seed traps between in the closed canopy and in the forest gap of the broadleaved-Korean pine forest. After the examination of the variance equality of seed rain density for two different places, we performed corresponding *t*-test. The result noted that *Acer ukurunduense*, *A. tegmentosum*, and *A. mono* had similar variance, but the other species were different in variance. Corresponding *t*-test showed that, although *Pinus koraiensis* had significant difference at the 95% probability level for the amount of seed dispersal between two places, the other species did not show the difference (Table 4). It could be noticed that in pre-dispersal manner since *Pinus koraiensis* dispersed its seeds vertically by gravity, the location of seed-tree had large influence on the seed rain density at a particular position. On the other hand, most of the other species with wind seed dispersal mechanism was not influenced by the formation of forest gap.

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