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Ground Beetle Fauna in *Pinus densiflora* Forests in Yangyang-gun, Kangwon Province, With a Special Reference to the Outbreaks of the Pine Needle Gall-Midge(*Thecodiplosis japonensis*)[1*]

Kôhei Kubota[2], Jong Kuk Kim[3*], Chan Young Lee[3] and Kimito Furuta[2]

江原道 襄陽郡 소나무림 내의 딱정벌레 相[1*]

- 솔잎혹파리의 被害와 關連하여 -

久保田耕平[2] · 金鍾國[3※] · 李燦鏞[3] · 古田公人[2]

ABSTRACT

Fauna, especially Carabidae (Coleoptera), on the floor of *Pinus densiflora* forests was investigated at five plantations and was compared with that in a mixed natural forest of pine and deciduous trees. There was little difference in the ground beetle fauna among the five *P. densiflora* plantations, and the bio-diversity of soil layer fauna was poor in all the pine plantations. Individual numbers of the beetles belonging to the genus *Synuchus* with increasing the infestation rate of the pine needle gall-midge (*Thecodiplosis japonensis*). These beetles seem to be important predators of the gall-midge. Comparing to the mixed forest, the number of higher taxa and the numbers of genera and species of Carabidae were all small in the pine forests. And especially, most flightless species were found only in the mixed forest. Thus, it is concluded that many species of Carabidae which had been lost from the lower mountainous areas of Korea have not recovered yet in the pine forests.

Key words : *Carabidae,* Pinus densiflora *plantation, pine needle gall-midge, bio-diversity*

要 約

강원도 양양군에서 소나무 단순림 5個所와 針葉樹와 闊葉樹가 混淆되어 있는 天然林 內의 지표동물, 특히 딱정벌레(Carabidae)를 대상으로 조사, 비교하였다. 소나무림 내에 서식하는 딱정벌레相은 장소별 차이가 적게 나타났으며 土壤動物群集의 生物多樣度도 낮았다. 딱정벌레 가운데 Synuchus 屬의 種個體數는 솔잎혹파리(*Thecodiplosis japonensis*)의 被害率이 높은 장소 일 수록 增加하는 傾向이 나타났으며, 이 屬에 속하는 種類는 솔잎혹파리를 섭식하는 주요한 捕食者로 파악되었다. 또한 침 · 활엽수가 혼효된 天然林에 비하여 소나무림에는 上位 分類群에 속하는 산림동물의 種數 및 딱정벌레科의 屬數, 種數가 모두 적었고, 특히 飛翔能力이 없는 대형 딱정벌레류의 대부분은 天然林에서만 채집되었다. 따라서 海拔高가 낮은 지역에 조성된 소나무림에서는 以前에 山林破壞로 손실된 많은 種이 아직도 回復되지 않은 것으로 파악되었다.

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[2] Department of Forest Science, Graduate School of Agriculture and Agricultural Life Sciences, The University of Tokyo.
[3] Department of Forest Resources Protection, College of Forest Sciences, Kangwon National University, Chunchon 200-701, Korea 강원대학교 산림과학대학 산림자원학부.
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* Corresponding author : jongkuk@kangwon.ac.kr

INTRODUCTION

The forests of Korea were totally destroyed by over-cutting in the previous years. The average stock volume per ha was only about 10 m^3 in 1960. After the enactment of Forest Low in 1961, the government has promoted reforestation systematically, the average stock volume came up to 48 m^3/ha in 1995 (Korea Forestry Service, 1997). Especially *Pinus densiflora*, which occupies 1,800,000 ha in total area, is widely distributed in hilly and lower mountainous area as man-made forests or secondary forests partly. The pine forests have many functions such as producing timbers, preventing floods and landslides, providing space for outdoor recreation and producing pine mushrooms.

Pinus densiflora forests in Kangwon Province have been seriously attacked by the pine needle gall-midge (*Thecodiplosis japonensis*) in 1990's. Although many environmental factors may affect the abundance of pine needle gall-midge, especially forest soil layer condition seems to be important because the larvae hibernate there. (Oda and Iwasaki, 1953, Takizawa et al., 1986).

Many kinds of predators exist on the forest soil layer, and some of them feed on the larvae of the midge (e.g. spiders and carabid beetles : Ko et al., 1969; Kim *et al.*, 1968). As one of the predators, carabid beetles are common and abundant on the ground in forests. Though adult beetles of many carabid species behave as general predators, those of some other species and especially the larvae of many species are monophagous or oligophagous. Therefore, community structure of carabid beetles in a forest seems to be a good indicator of soil layer insect fauna in the forest. Many studies have tried to evaluate environmental situations of forests by using the carabid community (Baars, 1979; Furuta, 1983; Hosoda, 1996; Ishitani et al., 1997).

In order to study on the environmental conditions of pine needle gall-midge in *P. densiflora* forests in Kangwon Province, we investigated to insect fauna on the floor of forests. This study is aimed (1) to clarify soil layer insect fauna of the pine forest that was commonly distributed in the region, especially by the contrast with a natural mixed forest, and (2) to find any relationship between the community of ground beetles and the infestation of the midge.

Whereas Kubota et al. (2000) temporarily reported the result of the investigation in 1998, we collected additional data in 1999 and carried out analyses. Present study discusses on the carabid fauna in pine stands based on the researches for the two years.

STUDY AREA AND METHODS

1. Study Area

The study was carried out in Yangyang-gun, Kangwon Province. Six study sites were chosen (Figure 1). Sites 1-5 were man-made *Pinus densiflora* stands that were about 24-45 years old. They have altitudes of about 100 m. All these pine stands were situated near to cultivated lands or villages and seemed to have been destroyed severely by human activities in the past. Sites 1-2 and 3-5 had been attacked by pine needle gall-midges intensely and slightly, respectively. Site 6 was a natural mixed forest composed of *P. densiflora*, oak (*Quercus* spp.) and other species.

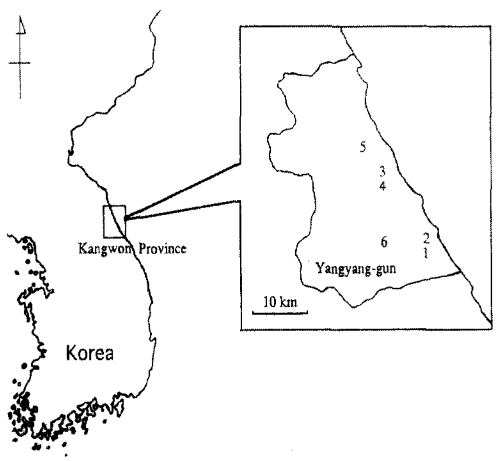

Figure 1. Survey area in Yangyang-gun, Kangwon Province, Korea.

Table 1. Outline of the study sites.

Site	Infestation rate* (%) 1998	1999	Density** (No./ha)	Cover(%) 1999	Under layer vegetation Species
Site1	58	17	4000	68	*Rhododendron schlippenbachil*, *Quercus* spp., *R. mucronulatum*, *Rhus verniciflus* etc.
Site2	50	12	1400	62	Herbs, *Quercus* spp., *Robinia pseudoacacia*, *Rhus verniciflua* etc.
Site3	18	22	4300	85	*R. schlippenbachil*, *Lespedeza bicolor*, *Quercus* spp. etc.
Site4	19	12	2700	61	*R. schlippenbachil*, *Quercus* spp., *Festuca ovina* etc.
Site5	16	15	1200	69	Herbs, *Quercus* spp., *R. schlippenbachil* etc.
	Tree species		Rate (%)		Notes
Site6	*Pinus densiflora*		44		5-21 m in height, 6-60 cm in DBH, 10-150 years old
	Quercus variabilis		29		
	Q. mongolica		12		
	Betula schmidtii		5		
	Tilia amurensis		5		
	Others		5		

* Infestation rate by *Thecodiplosis japonensis*
** Density of *Pinus densiflora*

This site was situated at about 400 m in altitude and seemed to have a history over 100 years.

Outline of the study sites is shown in Table 1. The infestation rate of pine needle gall-midges was estimated by counting the number of shoots on which the galls were made. From each of 10 trees selected randomly, 100 shoots were sampled in each tree, respectively. Thus, 1,000 shoots in total were investigated per site. Pine trees in Site 6 were not attacked by the pine needle gall-midges at all.

2. COLLECTING METHODS

Animals were collected by pitfall traps. As a trap, plastic cup with 6.5 cm of top diameter and 7.5 cm of height was filled with a little amount of pupal powder of silkworm and ethanol as bait. We also sprayed a little bit of mustard oil to avoid the disturbance by mammals. At each site, 100 traps were buried on lines in 2 m intervals of which 50 were in forest and 50 at the edge of it.

Traps were established in July and October of 1998 and 1999. For each collecting, traps were kept for 2 days. All animals trapped were classified and counted.

3. ANALYSES

We analyzed the family Carabidae (order Coleoptera) chiefly, since the species belonging to Carabidae have often been treated as an indicator of soil layer insect fauna as mentioned previously. Moreover, The other reasons are that they feed on midge larvae and are captured easily by pitfall traps. So, we treated other animals as supplementary data.

For analyses, individual numbers were transformed in log10. We used species richness and Shannon-Wiener diversity index for evaluation of species diversity. Species richness was corrected by the first-order jackknife estimator;

$$S^* = S + \{(n - 1)/n\} f1, \quad (1)$$

where S is the total species number, n is the total individual number and $f1$ is the number of species of which only one individual was recorded in a site for every research time (Burnham and Overton, 1979). We analyzed the community structure by DCA (detrended correspondence analysis) and NMDS (non-metric multidimensional scaling) using indexes of Whittaker's percentage similarity among sites, which were the average values based on the values calculated separately for every research time. The index of Whittaker's percentage similarity was calculated as follows :

$$PS = \sum \min(pai, pbi), \quad (2)$$

where pai and pbi are the proportion of individual numbers of species i to the total individual numbers at Site a and Site b, respectively. The relationships between individual numbers of some carabid groups and the infestation rate of the midges were found in pine stands.

DCA and NMDS were calculated using PC-ORD Varsion 4 (McCune and Mefford, 1999) and SYSTAT Version 5 (SYSTAT, Inc. 1992), respectively.

RESULTS

1. Animals captured by pitfall traps

Table 2 shows the number of all animals captured (15,092 individuals in total for 2 years). They were 2 frogs, 3 snails and 8 earthworms and mostly arthropods. At order level, Coleoptera (8,304 individuals) occupied more than half of the total numbers, followed by Hymenoptera (3,880), Araneae (1,268) and Isopoda (631). In Coleoptera, 7,870 individuals belonged to Carabidae. Thus, Carabidae was 52 % of all the captured animals.

The number of Carabidae captured is shown in Table 3. We used the individual numbers of each species for analyses. On some species, which were difficult to identify and were treated as "spp." in Table 3, the number of individuals of species in the group was used. The larvae of Carabidae were neglected because of their small number (9 individuals in total) and difficulty for identification.

Dominant group of Carabidae was the species belonging to the genus *Synuchus*. The subfamily Carabinae (*Carabus sternbergi - Damaster smaragdinus* in Table 3) were mostly captured only at Site 6 (in a natural mixed forest) except *D. smaragdinus*. Although more individuals were captured in July than in October, *Synuchus* which was a autumn breeder showed the opposite trend.

Since the weight per individual varied greatly depending on the difference of species, we didn't use biomass for analysis.

2. Species richness and diversity of Carabidae

The number of species captured (species richness) and Shannon-Wiener diversity index for species diversity of Carabidae at each site are shown in Figure 2 and Figure 3, respectively.

For both indexes, Site 6, which was situated in a natural mixed forest, showed higher values than other sites on the every occasion. Among Sites 1-5, which were in pine forests, any significant difference was not found (one-way ANOVA, $P>0.05$).

The number of species in pine forests was very small. Average numbers of the species were 8.2, 5.8, 7.4 and 5.8 in July 1998, October 1998, July 1999 and October 1999, respectively. These values were only half of those of the natural mixed forest (18, 12, 14 and 11 in time order).

3. DCA and NMDS for Carabidae community structure

By DCA and NMDS, using the Whittaker's percentage similarity for Carabidae community structure, Site 6 was separated from other sites (Figure 4). On the other hand, Sites 1-5 were aggregated. Especially Site 1, 2 and 4 were very close each other.

Most species that were captured only at Site 6 belong to the subtribe Carabinae (*Carabus sternbergi*, *Morphocarabus venustus*, *Tomocarabus fraterculus* and *Damaster jankowskii*) or the genus *Pterostichus* (*P. scurra*, *P. scurroides* and *P. bifidiphallus*)(Table 3). They are comparatively large and flightless

Table 2a. Number of animals captured by pitfall traps in 6 sites infested area by *Thecodiplosis japonensis* of Yangyang, Kangwon in 1998.

	Date	Ⅶ. 1998						Ⅹ. 1998					
		Site						Site					
Class	Order	1	2	3	4	5	6	1	2	3	4	5	6
Arachnida	Opiliones	6		2	5	9	2						1
	Acari	9	30	1	4	22	7					1	1
	Araneae	130	124	228	163	157	68	6	3	39	29	3	2
Crustacea	Isopoda	32	16	21	4	74	17	1		1	1		3
	Amphipoda			15	5	1	22	1					1
Diplopoda	Chordeumatida										1		
	Julida												3
Chilopoda	Scolopendromorpha						2						6
	Scutigeromorpha	1	2	3	3		2					1	
Insecta	Microcoryphia	6		3									
	Orthoptera	12	1	4	2	10	6			1			
	Dermaptera			1	1	25	5						1
	Blattodea		3										
	Hemiptera	19	1	3	11		2	20	7	6	5	5	
	Neuroptera								1				
	Coleoptera	165	153	201	133	186	213	2558	658	451	116	779	212
	Hymenoptera	53	198	82	235	110	74	2					4
	Diptera		5	5	4	5	3	1		2	1		1
	Lepidoptera	5	1	1	2	9	1		29	2	2	105	
Amphibia	Anura		1										
	Total	438	535	570	572	608	424	2589	698	502	155	894	235

Table 2b. Number of animals captured by pitfall traps in 6 sites infested area by *Thecodiplosis japonensis* of Yangyang, Kangwon in 1999.

	Date	Ⅶ. 1999						Ⅹ. 1999					
		Site						Site					
Class	Order	1	2	3	4	5	6	1	2	3	4	5	6
Gastropoda	Stylommatophora											2	1
Oligochaeta	Haplotaxida			4		2	1						1
Arachnida	Opiliones	4			5	1	1						
	Acari	30	17		8	46	213	2					
	Araneae	63	45	82	68	107	32	6	4	10	16	3	25
Crustacea	Isopoda	15	3	6	2	6	12		2			1	5
	Amphipoda	5	17	8	12	11	12						
Diplopoda	Polydesmida	1		6	1	10							
	Julida						1						25
Chilopoda	Lithobiomorpha	3		4	2	1	21						4
	Scolopendromorpha												2
	Geophilomorpha				1		1						
Insecta	Microcoryphia												1
	Orthoptera	27	1	2	6		14	1	1			1	3
	Dermaptera			3		33	3						1
	Blattodea		3	1					1			1	
	Hemiptera	7	2	2	3	3		3	2	1			
	Neuroptera							1				1	
	Coleoptera	175	348	180	79	426	156	122	151	215	68	514	123
	Hymenoptera	299	861	204	650	356	130	98	139	86	85	193	21
	Diptera	4	2	4	4	3	22	3					2
	Trichoptera					1							
	Lepidoptera	5		4	2	5		1		2	1		
Amphibia	Anura			1									
	Total	638	1299	511	843	1011	619	237	300	314	170	716	214

Table 3a. Number of Carabidae captured by pitfall traps in 6 sites infested area by *Thecodiplosis japonensis* of Yangyang, Kangwon in 1998 (adults only).

	Date	Ⅶ. 1998						Ⅹ. 1998					
		Site						Site					
Genus	Species	1	2	3	4	5	6	1	2	3	4	5	6
Carabus	*Carabus (Eucarabus) sternbergi*						14						
Morphocarabus	*Morphocarabus venustus*						20						
Hemicarabus	*Hemicarabus tuberculosus*			1									
Tomocarabus	*Tomocarabus fraterculus*												1
Leptocarabus	*Leptocarabus (Adelocarabus) semiopacus*						4						
	Leptocarabus (Weolseocarabus) koreanus		1				1						
Damaster	*Damaster (Coptolabrus) jankowskii*						6						
	Damaster (Coptolabrus) smaragdinus	44	11	13	20	6	5		1		1		
Nebria	*Nebria* sp.							7	1				
	Nebria spp.											1	2
Pterostichus	*Pterostichus scurra*						1						
	Pterostichus scurroides						8						
	Pterostichus bifidiphallus						5						1
	Pterostichus spp.			4		7					1	39	3
Pristosia	*Pristosia vigil*			8									3
Calathis	*Calathis halensis*												
	Calathis coreicus						26						
Synuchus	*Synuchus nitidus*	6	3	2	2	6	9	9	12	132	2	15	12
	Synuchus cycloderus	40	3	2	1	11	11	763	24	113	3	377	17
	Synuchus melantho			1									6
	Synuchus spp.	22	95	19	9	11	43	1772	615	202	102	323	157
Amara	*Amara* spp.						1						2
	Amara (Curtonotus) ovalipennis							4	2		3	6	
Anisodactylus	*Anisodactylus* sp.			1									
Harpalus	*Harpalus (Harpalus) bungii*					1							
	Harpalus (Harpalus) corporosus	1											
	Harpalus (Pseudoophonus) eous			1									
	Harpalus (Pseudoophonus) griseus			1		14	1					4	
	Harpalus (Pseudoophonus) sinicus		1										
	Harpalus (Pseudoophonus) tridens			3		21						10	
	Harpalus (Pseudoophonus) spp.							1					1
Trichotichnus	*Trichotichnus congruus*												1
Chlaenius	*Chlaenius naeviger*	6		91	25	36	11						
	Chlaenius virgulifer			3	2								
	Chlaenius ocreatus						2						
	Cymindis sp.												
Brachinus	*Brachinus* sp.						3						
	Total	119	114	150	59	113	171	2556	655	447	112	775	206

Table 3b. Number of Carabidae captured by pitfall traps in 6 sites infested area by Thecodiplosis japonensis of Yangyang, Kangwon in 1999 (adults only).

	Date	Ⅶ. 1999						Ⅹ. 1999					
		Site						Site					
Genus	Species	1	2	3	4	5	6	1	2	3	4	5	6
Carabus	*Carabus (Eucarabus) sternbergi*						14						
Morphocarabus	*Morphocarabus venustus*						1						
Hemicarabus	*Hemicarabus tuberculosus*	1		3									
Tomocarabus	*Tomocarabus fraterculus*												2
Leptocarabus	*Leptocarabus (Adelocarabus) semiopacus*						1						
	Leptocarabus (Weolseocarabus) koreanus						4	1					
Damaster	*Damaster (Coptolabrus) jankowskii*						39						
	Damaster (Coptolabrus) smaragdinus	14	12	8	16					1			
Nebria	*Nebria* spp.									2			2
Trigonognatha	*Trigonognatha coreana*		1			2							
Pterostichus	*Pterostichus bifidiphallus*						2						
	Pterostichus spp.				2	29						6	
Pristosia	*Pristosia vigil*												3
Calathis	*Calathis coreicus*						2						
Synuchus	*Synuchus nitidus*		7	5	4	10	3	42	10	100	12	41	7
	Synuchus cycloderus	20		18	4	15	57	12	7	54	25	120	43
	Synuchus melantho				1		7					1	2
	Synuchus spp.	49	311	54	19	286	25	50	125	48	17	342	53
Amara	*Amara* spp.							2					
	Amara (Curtonotus) ovalipennis							2				1	
Anisodactylus	*Anisodactylus* sp.			2		2							
Harpalus	*Harpalus (Harpalus) bungii*												1
	Harpalus (Pseudoophonus) eous							2					
	Harpalus (Pseudoophonus) griseus				1	2	8	5					
	Harpalus (Pseudoophonus) tridens	29	3			2				4		1	
	Harpalus (Pseudoophonus) spp.									1			
Trichotichnus	*Trichotichnus* sp.									1			1
Chlaenius	*Chlaenius naeviger*	19	2	70	25	20	6						
	Chlaenius virgulifer			1			4						
	Cymindis sp.												1
Brachinus	*Brachinus* sp.												1
	Total	132	336	161	72	368	173	116	142	211	54	512	116

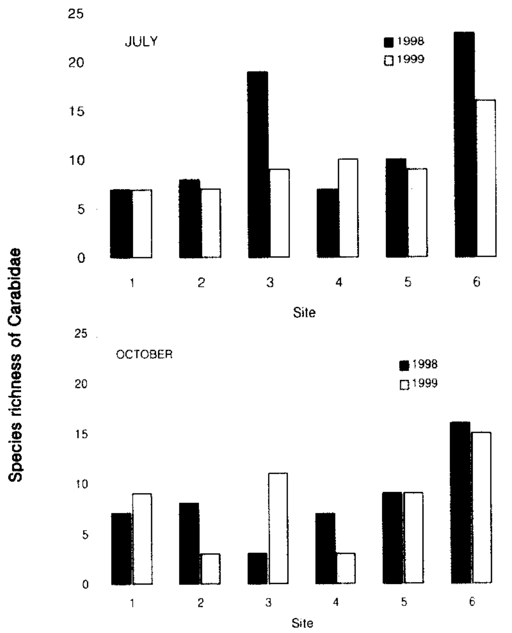

Figure 2. Species richness of Carabidae corrected by the first-order jackknife estimator.

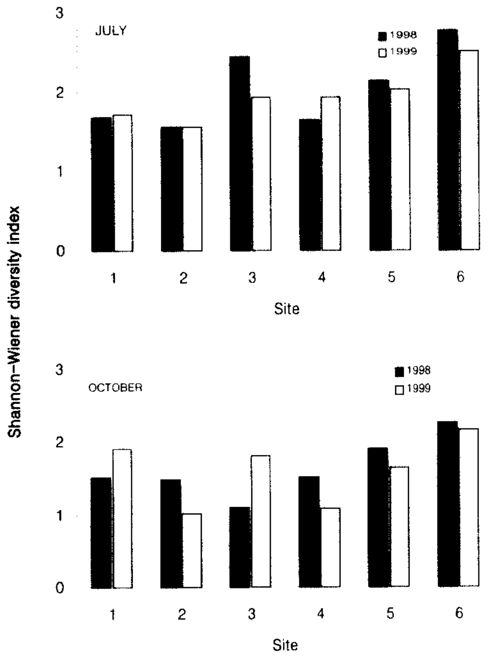

Figure 3. Shannon-Wiener diversity index of Carabidae species compostition.

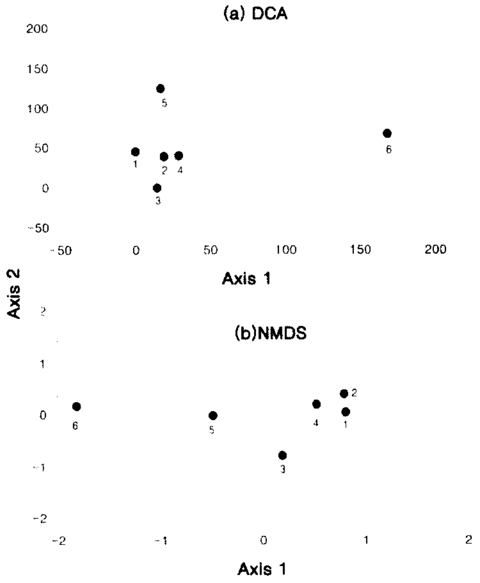

Figure 4. Ordination of Carabidae community structure. (a)DCA, (b)NMDS.

caused by atrophied hind wings. The fact that such species were found only at Site 6 must be the most important point in the distribution of carabid beetles in the study area.

Although the species compositions didn't show any remarkable variation among the pine stands (Sites 1-5), Individuals belonging to the genus *Synuchus* were found numerously in Site 1 and 2 in 1998. On the other hand, *Chlaenius naeviger* were rare there (Table 3).

4. Infestation rate of the midges and abundance of the genus Synuchus

The relationships between the infestation rate in each year and the individual numbers of each species or group of species did not show any remarkable tendencies except for the genus *Synuchus* (Figure 5). Since carabid beetles are exceedingly active and tend to be trapped effectively in their reproductive season (Kubota, 1998), comparison of the trapped individual numbers between different seasons has no meaning. Therefore, we analyzed *Synuchus* (autumn breeder : Kubota, 1998) on their individual numbers in October.

The abundance of *Synuchus* has a positive correlation with the infestation rate significantly (Pearson's coefficient of correlation, P<0.05). Although, *Chlaenius naeviger* (spring breeder : Kubota, 1998) has a negative but no significant correlation with infestation rate on its individual numbers in July.

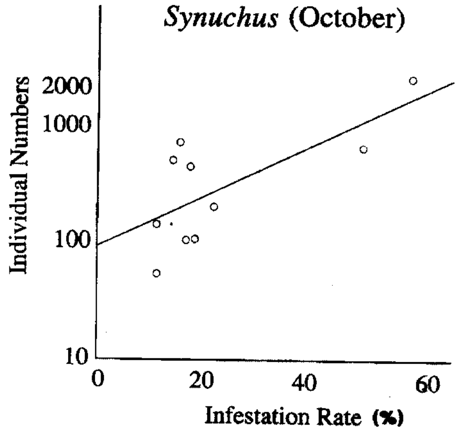

Figure 5. Relationship of the damage rate by the pine needle gall-midge and the individual number of Synuchus (Site 1-5. October in 1988 and 1999).

DISCUSSION

We find a large number of species of plants and animals in forests. For example, it was counted in a census in 1988 so that there were 389 plant species and 1,563 animal species except soil fauna in Mt. Shiragatake, Kumamoto Prefecture, Japan (Nature Conservation Bureau, 1988). 95 % of the captured animals in study area was insects. It is clear that insects are the most dominant members of forest ecosystems.

There is no use to say that destruction of forests brings destruction of insect fauna and reforestation leads recovery of insect fauna in the forest. In Korea, reforestation has been done intensively in past forty years and man-made forests of *Pinus densiflora* now extend over the country. In our study in Yangyang-gun, it was shown that even after 25-45 years of reforestation, fauna of carabids is not recovered well.

In Japan, *Synuchus* is one of the dominant genera in pine stands (Kubota et al., 2000). *Harpalus* and *Chlaenius*, which are common in pine stands, have a tendency to increase in numbers after destruction of a forest (Kubota et al., 2000). More than half genera of carabids in pine stands in our study were also common in those of Japanese forests which had been highly disturbed by human activities.

All the man-made pine stands in this study had simple Carabidae communities (Figures 2, 3). Smaller number of higher taxa, and also smaller numbers of genera and species of Carabidae were found in the pine stands than the natural mixed forest (Tables 2, 3, Figure 2). Although the difference in altitude between the pine stands and the natural forest studied may affect the difference in Carabidae species compositions, most of the species found in the natural forest were the ones which were distributed over hilly or lower mountainous areas. The possible causes of the species difference between pine stands and the natural forest are that (1) some species prefer matured mixed forests to young pine stands and (2) others can not disperse easily from a refuge to man-made forests. Since there is no other tall trees except pines in the pine stands and many species of Carabidae are flightless, it will take much longer than 25-45 years for them to disperse throughout the pine stands.

Several parasitic wasps, several birds, dozens of spiders and more than ten species of Carabidae are recognized as natural enemies for the pine needle gall-midge (Kim et al., 1968; Ko et al., 1969; Ko and Lee, 1971; Lee et al., 1985). Of the Carabidae species trapped in this study, *Chlaenius naeviger* was reported as a predator for the midge (Kim et al., 1969) and some species belonging to *Synuchus* actively ate the larvae of midge given artificially (Kim, J.K., unpublished data).

The number of *Synuchus* had a positive correlation with infestation rate of the midges (Figure 5). It is likely that there are some interactions between Carabidae and the midges in the outbreak area of the midges, but we could not ascertain them. Clarifying the relationship between environmental factors and abundance of Carabidae, and quantitative relation between them through predation by further studies may offer an information for the function of Carabidae as a predator for the pine needle gall-midge.

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