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Diversity of Spider Communities in a Pesticide-treated Pine (*Pinus densiflora*) Forest

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ABSTRACT: The diversity of spider communities was investigated in the pine forest of *Pinus densiflora* in Songri-san, where chemical pesticides had been applied to control pine gall midge (*Thecodiplosis japonensis*). Spider communities were surveyed in four areas: a pesticide-untreated natural forest (area A), a forest with vinyl-covered ground surface (area B), an aldicarb-treated forest (area C) and a forest treated with a systemic pesticide (phosphamidon) (area D). A total of 74 spider species from 17 families were collected from the four survey areas. There were 54 species from 15 families in area A, 27 species from 12 families in area B, 29 species from 9 families in area C and 34 species from 9 families in area D, respectively. The species diversity of spider communities was highest in pesticide-untreated area A, and much lower in the other three areas. The monthly species diversity of spider communities was highest in May and lowest in January. The similarity of the spider communities was highest in areas B and D. The monthly similarity of the spider communities was highest in November and February. The dominant species was *Clubiona jucunda* (12.71%, *N*=304 individuals). According to our results, the application of aldicarb and phosphamidon dramatically decreased spider diversity and the number of individuals in the forests. Thus, the application of these two pesticides to natural forests should be restricted, or alternative pesticides need to be developed. Our results also indicated that application of the pesticides should be avoided in May and June when high spider diversity is expected.

Key words: Arthropod community, Pesticide, *Pinus densiflora*, Spider, *Thecodiplosis japonensis*

INTRODUCTION

One of the main challenges in developing pest control strategies is to understand the effects of pesticide treatments on the diversity of local arthropod communities (Wiktelius et al. 1999, Despres et al. 2007). The application of pesticides to pest-infested forests may have serious impacts on beneficial spiders, which play a role as potential natural predators of insect pests (Baatrup and Bayley 1993, Bogya and Marko 1999, Fountain et al. 2007). Therefore, understanding the effect of the pesticides on the spider communities is an essential step in the recovery of pest-damaged forests.

Spiders inhabit nearly all terrestrial habitats world-wide. Spiders are important components of forest ecosystems because they contribute greatly to biodiversity and play a beneficial role in natural pest control (Marc et al. 1999, Öberg et al. 2007). There are the 108 families of spiders worldwide, including 39,725 species in 3,667 genera (Platnick 2007). The Korean spider fauna comprises at least 679 species from 256 genera and 45 families (Kim et al. 2005). Since spiders kill many insect pests (Fountain et al. 2007), they may make an important contribution to biological control of pests in pests_damaged forests.

Spiders are positioned in the top tropic level of invertebrate food chains of forests and are important predators (Marc et al. 1999). Populations of litter-dwelling spiders are subject to many anthropogenic disturbances including insecticides, pollution, agriculture and other land management practices, which expose them to physical and chemical stresses (Wardle et al. 2000, Fountain et al. 2007). Because spiders are generalist feeders on many pest insects, they are of great value for ecological control of pest-damaged forests (Marc et al. 1999). Therefore, it is important to investigate the impacts of pesticides on the structure of spider communities in the forests which are pesticide-treated to control insect pests.

The pine tree gall midge (*Thecodiplosis japonensis*) infests the red pine (*Pinus denszpora*) and the black pine (*Pinus thunbergii*) in Korea (Park et al. 1985, Hwang and Yim 1990, Lee et al. 1997). In Korea, *T. japonensis* was first reported in 1929 (Takagi 1929) following the first record of the species in Japan in 1901 (Sasaki 1901). Since *P. denszpora* and *P. thunbergii* are the major components of Korean forests, *T. japonensis* has been regarded as one of the most important pests affecting Korean forests (Park and Hyun 1983, Kim et al. 1987). Treatment using chemical pesticides

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is an easy and effective method for controlling insect pests that damage forests (Loch 2005). However, such chemical treatments may negatively affect many beneficial arthropods, which also control insect pests (Bogya and Marko 1999, Loch 2005).

Pinus densiflora is the most abundant species in the pine forests in Songri-san, Chungcheongbuk-do, where the forests have been heavily damaged by pine gall midges. To control the pine gall midge, two pesticides and a vinyl ground-cover were applied to the pest-damaged forests. Though such chemical and physical treatments are effective for the control of insect pests, pesticide applications might have serious unintended impacts on spider communities as well. In this paper, we investigated the effects of pesticides on spider communities. The structure of spider communities was investigated in a pesticide-untreated natural forest, two pesticides-treated forests and a vinyl-treated forest.

MATERIALS AND METHODS

Sample Collection

Pine trees in the study area (Songri-san, Chungcheongbuk-do in South Korea) were heavily damaged by pine gall midges. With the help of the Forest Division (Agricultural Policy Bureau, Chungcheongbuk-do), pesticides and physical treatments were conducted to control the pine gall midge in infested forest once a year from 1981 to 1984.

A ground surface of 63 ha was covered with vinyl, a forest of 145 ha was treated with aldicarb (2-methyl-2-<methylthio>propionaldehyde-0-<methylcarbamoyl>oxime) and a forest of 1,740 ha was treated with the systemic pesticide phosphamidon.

The spider fauna was monitored in the pesticide/vinyl-treated forests every month from February 1982 to January 1984. Surveys of spider communities were conducted in four areas (Fig. 1): a pesticide-untreated natural forest (area A), a forest with its ground surface covered with vinyl (area B), a forest treated with aldicarb (area C) and a forest treated with the systemic pesticide with phosphamidon (area D).

To collect spiders from foliage, four pine trees were randomly selected in each survey area (areas A, B, C and D), resulted in collection from a total of 16 trees in the four surveyed areas. White vinyl (1.5 × 1.5 m) was spread over the ground surface around the trunks of the trees. Dichlorvos (D.D.V.P.; Dimethyl Dichlord Vinyl Phosphate) was spread on the foliage of each tree, and then the trunks of the trees were shaken to collect dead spiders. Collection of spiders was conducted monthly from February 1982 to January 1984.

Newly emerging spiders were collected with emergence traps. Four emergence traps (55 cm in diameter and 65 cm in height)

Fig. 1. Localities of study area. A: a pesticide-untreated forest (southern area of Naesongni-myeon), B: a forest with ground surface covered with vinyl (southern area of Malchikokae), C: a forest treated with aldicarb (northern area of Malchikokae) and D: a forest treated with the systemic pesticide with phosphamidon (northern area of Kalmok-ri).

were set up over ground surface of each survey area except area B. A total of 12 emergence traps were placed in the three areas (A, C and D). Collection of spiders was conducted every week during April in 1982. Samples were preserved in picric acid.

Spiders walking on the ground surface were collected using pitfall traps (8 cm in diameter and 19 cm in height) (Martin 1965a, b). Nine pitfall traps were set up at 5～10 m intervals in each area. The pitfall traps were placed in the ground surface of three areas (A, C and D). Collection was conducted from mid-April to the end of October in 1982.

Data Analysis

We estimated the structure of spider community based on various indices measuring dominance, similarity, evenness and species diversity. Dominance (= D) was calculated by Ns/N_{total}, here Ns is the number of a species in a survey area and N_{total} is the number of total individuals in the survey area.

Species diversity in the four areas was calculated using the Shannon-Wiever index (Shannon and Weaver 1963). The Shannon-Wiever Index assumes that individuals are randomly sampled from an indefinitely large population:

$$\text{Species diversity } (= H') = \sum Pi \log Pi$$

where *Pi* is estimated from *Ni/N*. *Ni* is the number of individuals belonging to the *i*th species and *N* is the number of total individuals belonging to all species collected in a survey area. Maximum species diversity (maximum H'), the potential maximum value of species diversity in an area, was calculated as $H'_{max} = \log S$, where *S* is the number of spider species in the survey. Evenness (J') was obtained by H'/H'_{max}. The similarity index (S.I.) was calculated from the formula, $2c/(a+b)$ multiplied by 100 (%) (Whittaker 1956). Here, *a* and *b* are the number of species in areas *a* and *b*, respectively, and *c* is the number of species common to both areas *a* and *b*.

RESULTS

We collected 2,392 individual spiders, belonging to 74 species from 17 families in the four study areas. Of this total, 1,559 individuals (54 species, 15 families) were collected in pesticide-untreated area A, 303 individuals (27 species, 12 families) in area B, 201 individuals (29 species, 9 families) in area C and 329 individuals (34 species, 9 families) in area D (Table 1). Spiders were most abundant in area A among the four areas (Kruskal Wallis Test; χ^2= 9.47, df=3, p=0.24), and the spider abundance was not different among the other three areas (Kruskal Wallis Test; χ^2= 0.572, df=2, p=0.751).

In area A, two previously unrecorded species, *Crustulina sticta* (Theridiidae) and *Euophrys kataokai* (Salticidae) were collected, and a total of 18 species were collected only in area A: *Dipoena* sp. (Theridiidae), *Crustulina sticta* (Theridiidae), *Miagrammopes orientalis* (Uloboridae), *Uloborus prominens* (Uloboridae), *Neriene limbatinella* (Linyphiidae), *Oedothorax* sp. (Erigonidae), *Mimetus taceus* (Mimetidae), *Araneus viperifer* (Araneidae), *Coelotes songminjae* (Agelenidae), *Dolomedes sulfurous* (Pisauridae), *Pisaura lama* (Pisauridae), *Oxyopes licenti* (Oxyopidae), *Synaema globosum* (Thomisidae), *Euophrys kataokai* (Salticidae), *Evarche albaria* (Salticidae), *Icius difficilis* (Salticidae), *Itatsina praticola* (Clubionidae) and *Anahita fauna* (Ctenidae).

Table 1. Values of the species diversity index for spider communities in the four study areas

Area	Index value					
	N.S.	N.I.	H'	H'_{max}	J'	D
A	54	1,559	1.46	1.73	0.84	0.157
B	27	303	1.19	1.43	0.83	0.167
C	29	201	1.23	1.46	0.84	0.159
D	34	329	1.27	1.53	0.83	0.170

-N.I. and N.S. indicate the number of individuals and species.
-H', H'_{max}, J' and D indicate the indices of species diversity (H'), maximum species diversity (H'_{max}), evenness and dominance, respectively.

A total of 32 species from 14 families, including *Theridion subadultum* (Theridiidae) and *Leucauge subgemmea* (Tetragnathidae), were collected in area A, but not in area B. 32 species from 14 families, including *Evarche albaria* (Salticidae) and *Anypohaena pugil* (Anyphaenidae), were collected in area A, but not in area C. A total of 25 species in 14 families collected in area A, including *Anelosimus crassipes* (Theridiidae), were not collected in area D.

The composition ratio of web building spiders and ground spiders were obtained from the spider individuals collected from the total area (2,392 individuals), and each of area A (1,559 individuals), area B (303 individuals), area C (201 individuals) and area D (329 individuals), respectively (Fig. 2). The composition ratio of web building spiders did not differ from that of ground living spiders in the total area (Mann-Whitney U; Z =−0.520, p=0.603) and each of area A (Z=−0.607, p=0.544), area B (Z=−1.652, p=0.099), area C (Z=−0.854, p=0.393) and area D (Z=−609, p=0.551), respectively.

Species Diversity

A total of 54 species were collected in area A, whereas the collections of 27, 29 and 34 species were in areas B, C and D, respectively (Table 1). Species diversity (H') was highest (1.4600) in area A, probably because of higher in the number of species (54 species) and individuals (1,559 individuals) than the other areas. Both maximum H' (= H'_{max}; 1.7324) and evenness (= J'; 0.8428) were also highest in area A, whereas dominance was highest in area D (0.1697) and lowest in area A (0.1572) (Table 1).

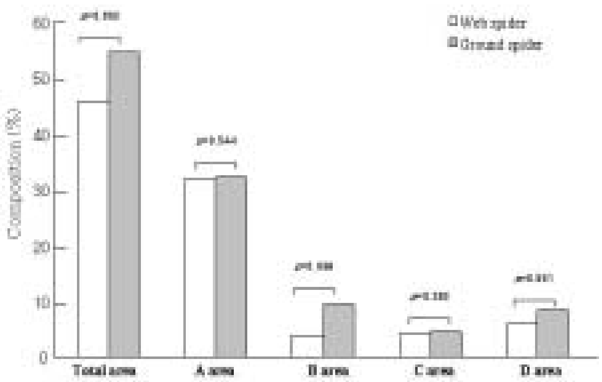

Fig. 2. The percent composition of web building spiders and ground spiders in the spider individuals collected from the total area (2,392 individuals), area A(1,559 individuals), area B (303 individuals), area C (201 individuals) and area D (329 individuals).

Monthly species diversity was calculated in the combined samples from all four areas (Table 2). The highest numbers of samples were collected in May and June, respectively. We collected 515 individuals (50 species) in May and 518 individuals (44 species) in June in the four areas. The lowest numbers of individuals were collected in December (23 individuals, 6 species) and in January (11 individuals, 4 species), respectively.

Monthly species diversity ranged from 1.0761 to 1.4031 from April to October and from 0.4849 to 0.8941 from November to January. The highest species diversity (1.4031) was recorded in May and the lowest species diversity (0.4849) was recorded in January. Maximum species diversity was also highest (1.6990) in May and lowest (0.6021) in January.

The highest evenness was 0.8746 in October and the lowest evenness was 0.6220 in February. Monthly species diversity in the four areas is shown in Table 3. Species diversity was highest (1.2525) in area A and lowest (0.9312) in area B (Table 3). In area A, species diversity was highest (1.2525) in June and lowest (0.2442) in January. The numbers of species (44 species) and individuals (518 individuals) were higher in area A than in other areas, resulting in the highest species diversity in the area. The species most abundant in samples from area A were *Neoscona-scylloides* (Araneidae) (84 individuals), *Theridion latifolium* (Theridiidae) (72 individuals), and *Episinus affinis* (Theridiidae) (62 individuals).

Monthly changes in the numbers of species and individuals in the survey areas were investigated (Table 4 and Fig. 3). The highest numbers of individuals were collected in May and June, when 515 and 518 individuals were collected, respectively. The lowest numbers of individuals were collected in October (11 individuals) and February (74 individuals).

Table 2. Monthly species diversity for spider communities in the four study areas

Month	Index value				
	N.S.	N.I.	H'	H'_{max}	J'
Jan.	4	11	0.48	0.60	0.81
Feb.	10	74	0.62	1.00	0.62
Mar.	13	101	0.89	1.11	0.80
Apr.	32	250	1.28	1.51	0.85
May	50	515	1.40	1.69	0.83
Jun.	44	518	1.30	1.64	0.79
Jul.	33	328	1.23	1.52	0.81
Aug.	26	254	1.09	1.42	0.77
Sep.	26	211	1.14	1.42	0.80
Oct.	17	71	1.08	1.23	0.88
Nov.	11	36	0.88	1.04	0.84
Dec.	6	23	0.59	0.78	0.76

Similarity

The similarity among spider communities in the survey areas is shown in Table 5. The highest similarity was between spider communities in areas B and D (56.11%) and the lowest similarity was between spider communities in areas C and D (48.01%).

We also calculated the monthly similarity among spider communities (Table 6) in the combined sample. The highest similarity was in December and January (76.69%), whereas the similarity between spider communities in January and March was 0%. Most spider species hibernate during winter, but a few individuals and species, including *Miagrammopes orientalis* (Uloboridae), *Misumenops japonicus* (Thomisidae), *Philodromus fusomarginatus* (Thomisidae) and *Tmarus rimosus* (Thomisidae), were collected in December and January.

Dominance

In the combined analysis of samples collected from all four areas, the dominant species were *Clubiona jucunda* (Clubionidae) (12.71%), *Philodromus subaurelous* (Thomisidae) (9.03%), *Neoscona scylloides* (Araneidae) (8.57%), *Theridion pinastri* (Theridiidae)

Table 3. Monthly species diversity for spiders in each study area

	H'											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	0.244	0.481	0.802	1.193	1.235	1.253	1.179	0.968	0.965	0.697	0.536	0.278
B	0.301	0.000	0.477	0.878	0.904	0.755	0.881	0.931	0.869	0.716	0.555	0.000
C	0.000	0.301	0.301	0.859	0.825	1.113	0.965	0.899	0.872	0.602	0.579	0.276
D	0.301	0.714	0.714	0.967	0.984	0.992	0.944	0.943	0.941	0.759	0.555	0.301

Table 4. Monthly changes in the number of spider species and individuals in each study area

Area	No. individual/ species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
A	N.I.	4	61	88	158	254	394	255	169	123	25	17	11	1,559
	N.S.	2	6	8	25	32	35	29	22	21	7	5	3	54
B	N.I.	4	1	3	50	85	55	18	30	31	14	7	5	303
	N.S.	2	1	3	11	14	10	9	10	9	6	4	1	27
C	N.I.	1	2	2	12	36	36	33	28	27	16	5	3	201
	N.S.	1	2	2	8	11	17	11	9	8	6	4	2	29
D	N.I.	2	10	8	30	140	33	22	27	30	16	7	4	329
	N.S.	2	6	5	11	16	13	10	10	10	8	4	2	34
Total	N.I.	11	74	101	250	515	518	328	254	211	71	36	23	2,392
	N.S.	4	10	13	32	50	44	33	26	26	17	11	6	74

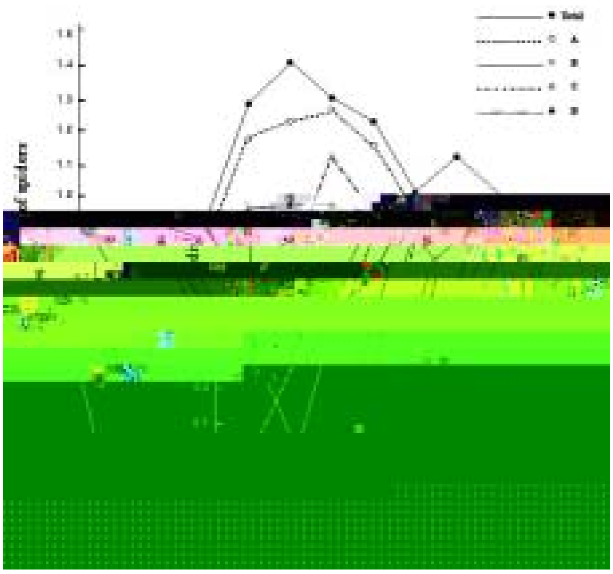

Fig. 3. Monthly changes in the species diversities of spiders in the four areas.

Table 5. Similarity among spider communities in the four areas

Area	A	B	C	D
A				
B	50.59			
C	56.04	48.37		
D	51.73	56.11	48.01	

(6.77%), *Misumenops japonicus* (Thomisidae) (5.56%) and *Leucauge subblanda* (Tetragnathidae) (4.60%) (Table 7).

According to the dominance analysis for each area (Table 7), *Clubiona jucunda* (12.32%) was the dominant species in area A, *Philodromus subaureolus* (26.08%) in area B, *Theridion pinastri* (16.42%) in area C and *Clubiona jucunda* (17.93%) in area D.

Monthly changes in the numbers of species and individuals were investigated in the four areas (Fig. 4). The number of species collected was highest in May, whereas the number of individuals was highest in June. The monthly dominance of important spiders is shown in Fig. 5. In May, dominant species included *Clubiona jucunda* (Clubionidae), *Philodromus subaureolus* (Thomisidae), *Philodromus fuscomarginatus* (Thomisidae), *Misumenops japonicus* (Thomisidae), *Neolinyphia nigripectoris* and *Theridion latifolium*, *Neoscona scylloides* (Araneidae). *Neoscona scylloides* was the most dominant species in both June and July, whereas *Clubiona jucunda* was the most dominant in August. With the exception of *Clubiona jucunda*, the number of samples from each species collected decreased after October. Generally, the patterns of dominance curves for each species were similar to those for the number of individuals (Fig. 5).

DISCUSSION

The impacts of pesticide-/physical-treatments on spider communities were investigated in the pesticide-treated forests of Songri-san (Mt. Songri), where pine tree forests of *Pinus densiflora* was highly damaged by pine gall midges (*Thecodiplosis japonensis*). According to our results, such the treatments had serious effects on the predatory spider communities.

We collected 74 species from spider 17 families in the four study areas. Among them, 54 species from 15 families were collected

Table 6. Monthly similarity among spider communities in the four survey areas

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Jan.												
Feb.	20.26											
Mar.	0.00	25.21										
Apr.	7.20	11.00	28.36									
May	10.09	9.85	24.27	64.18								
Jun.	8.49	8.11	14.30	39.38	43.92							
Jul.	10.61	5.87	16.67	35.80	39.62	75.33						
Aug.	11.02	6.64	16.91	37.79	41.28	48.63	56.01					
Sep.	9.00	6.34	15.46	39.00	42.09	73.62	47.85	76.44				
Oct.	23.17	6.81	13.97	46.77	50.20	29.56	36.42	34.75	51.86			
Nov.	13.89	10.96	9.71	31.38	42.01	35.19	34.04	43.91	48.19	52.99		
Dec.	76.69	20.26	0.99	13.40	18.49	17.78	18.45	28.46	21.02	24.57	24.17	

Table 7. The number of individuals and dominance of the important spider species in four areas

Species	Survey area								Total	
	A		B		C		D			
	N.I	D (%)	N.I	D (%)	N.I	D (%)	N.I	D (%)	N.I	D (%)
Theridion latifolium	66	4.23	7	2.31	–	–	11	3.34	84	3.51
T. pinastri	115	7.38	–	–	33	16.42	12	3.65	160	6.69
Anelosimus crassipes	38	2.44	11	3.63	8	3.98	–	–	57	2.38
Neriene nigripectoris	54	3.46	7	2.31	3	1.49	–	–	64	2.68
Neoscona scylla	30	1.92	13	4.29	6	2.99	–	–	49	2.47
N. scylloides	165	10.58	5	1.65	21	10.45	14	4.26	205	8.57
Leucauge subblanda	48	3.08	22	7.26	5	2.49	35	10.64	110	4.60
Misumenops japonicus	69	4.43	22	7.26	18	8.96	24	7.29	133	5.56
M. tricuspidatus	45	2.89	7	2.31	7	3.48	9	2.74	68	2.84
Philodromus davidi	41	2.63	11	3.63	19	9.45	19	5.78	90	3.76
P. subaureolus	104	6.67	76	25.08	8	3.98	28	8.51	216	9.03
Tmarus rimosus	32	2.05	17	5.61	19	9.45	11	3.34	79	3.30
Clubiona jucunda	192	12.32	35	11.55	18	8.96	59	17.93	304	12.71
No. total individuals in dominant sp.	999	64.08	233	76.90	165	82.09	222	67.48	1629	68.10
No. total individuals collected in each area+	1,559		303		201		329		2,392	

+ indicates total individuals collected in each survey area (for total individuals in each area, refer to Tables 1 and 4).

-A dominance score of over 1% was regarded as indicating important species.

-D is the dominance.

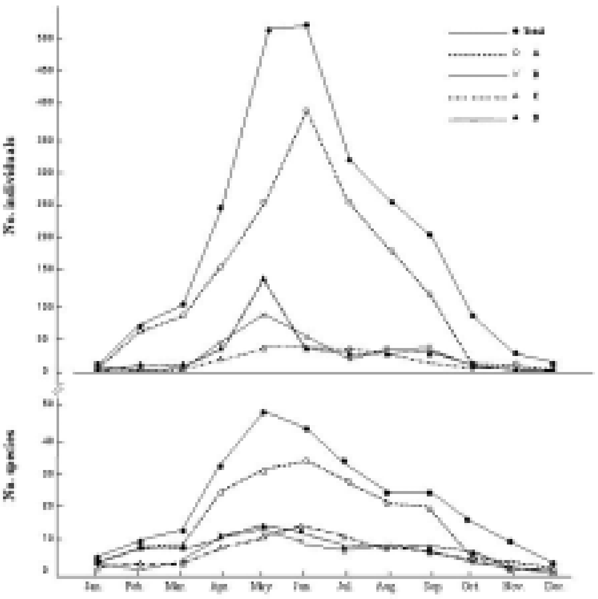

Fig. 4. Monthly changes in the numbers of species and individuals in the four areas.

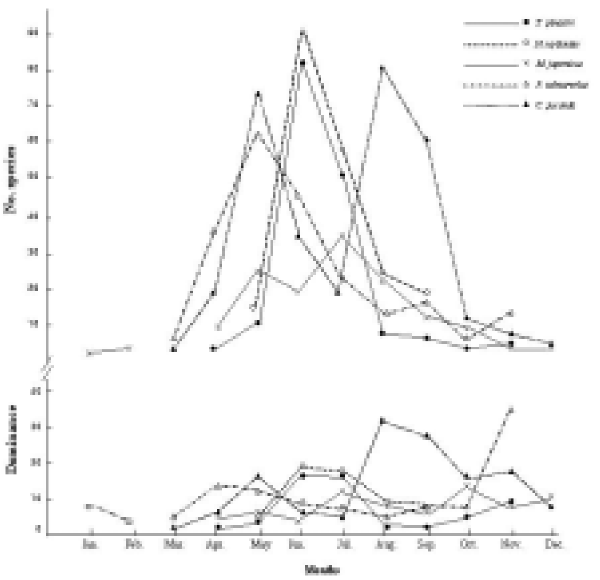

Fig. 5. Monthly changes in dominance and the numbers of the most dominant spider species (*T. pinastri, N. scylloides, M. japonicus, P. subaureolus, C. jucunda*).

in pesticide-untreated area A, whereas only 29 species from 9 families were collected in area C and 34 species from 9 families in area D. In vinyl-covered area B, 27 spider species from 12 families were collected. As expected, the species diversity of spider communities was high in area A (14,600), but much lower in the other areas. In area A, abundant pine gall midges as well as other insects are potential food sources for predatory spiders, resulting in higher diversity of spider species than is found in the other three areas. The dominant spider species was *Clubiona jucunda* (12.71%), and this species was most abundant in the collections (81 individuals) in August. The monthly species diversity of spider communities was highest in May (1.4031), right before summer, and lowest in January (0.4819).

65.18% (1,559 individuals) of the total individuals were collected in area A, whereas only 12.67% (303 individuals) of total individuals were collected in pesticide-treated area B, 8.40% (201 individuals) in pesticide-treated area C, and 13.75% (329 individuals) in vinyl-covered area D.

The percent composition of web building spiders and ground spiders did not differ in all of study areas ($0.05<p$; Fig. 2). In area B (viny-covered area) the percent composition of ground spiders was higher than that of web building spiders, though the percent value was not different significantly ($Z=-1.652$, $p=0.099$). Ground-covering vinyl may positively affect the survivorship of ground spiders, probably because of preserving the ground temperature during winter (Costello and Daane 1998).

Our results suggest that applications of the two pesticides, aldicarb and phosphamidon, dramatically decreased the species diversity and abundance of spiders in pine forests. Since the number of spider individuals was lowest in aldicarb-treated area C, the application of the aldicarb should be minimized, or it should be replaced by other chemical agents to mitigate the impacts of the pesticides on spider communities.

Spider communities in the area were most diverse in May (14,031) and June (13,033). Since emerging females of *T. japonensis* lay eggs on developing pine needles in spring (Lee et al. 1985, Hwang and Yim 1990, Lee 1994), applying pesticides before May may be an effective strategy for protecting predatory spiders in pesticide-treated areas.

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