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Ecological Studies on *Formica yessensis* Forel, with Special Reference to Its Effectiveness as a Biological Control Agent of the Pine Caterpillar Moth in Korea

III. Nest Distribution and Environmental Conditions of Nest Sites

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Seasonal change of the nest distribution of ***Formicayessensis*** in the hill and biotic and abiotic environmental conditions of nest sites were investigated in red pine stands in Gyeongsang-Nam-Do, Korea in 1973-77. The nests scarcely occurred in the upper zone of slopes and concentrated in the lower and middle zones. The distribution of nests changes seasonally but the density per unit area is relatively constant (0.014-o. 022 per m^2). The active nests increase in number from spring to summer by budding, then decrease in autumn by abandonment of nests. The life span of nests was l-4 months in most cases. The abandonment occurs ***more*** frequently in newly founded and revived nests. Abandoned nests are re-utilized. the number of times the same nest was utilized being ranged between 1 and 11. The humidity above ground and soil moisture are important factors for establishing nests. The content of organic matters was higher in soils at the lower and middle zones inhabited by the ant than in the upper zone. While the content of the exchangeable Ca was lower in the former than the latter. In the upper zone the density of pine trees is relatively low and that of Zoisia is higher than the middle and lower zones. Such conditions are unfavourable for establishing nests. The lower and middle zones, on the contrary, are favourable because of the relatively high density of pine trees, but sufficient light intensity and presence of suitable plants for nest cores such as long graminaceous grasses. *Arundinella hirta*, *Pinus densiflora* (red pine trees) and ***Miscanthus sinensis*** f. *purpurascens* as well as stones serve as the core for building nests.

INTRODUCTION

Formica (Formica) yessensis Fore1 prefers grasslands close to the forest margin (Ito, 1971) or sparse secondary forests of the white birch and other deciduous trees (Morisita, 1945) as nesting sites in Japan. In Korea, however, red pine trees are relatively sparse in forests, and sufficient light intensity

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provides favourable conditions for nesting of the ant (Kim and Murakami, 1980 a). The ant, however, inhabits only limited stands among red pine forests in Korea. Some physical and biotic conditions may be responsible to establish nests.

The present paper deals with seasonal changes of distribution, density and abundance of *F. yessensis* nests in the hill growing red pine trees in Gyeongsang-Nam-Do, Korea, and various environmental conditions of nest sites such as humidity above ground, chemical properties of the soil, densities of red pine trees and floor-layer plants and suitable nest cores.

METHODS

In order to clarify the nest distribution in the hill, the slope was conveniently divided into three zones, the lower, the middle and the upper ones, approximately equal in distance, then the number of nests were counted in each zone. The investigation was made at two red pine stands in each locality in Gyeongsang-Nam-Do, Korea from October 20 to November 20, 1973. The localities are Jinyang, Goseung, Hadong, Sacheun, Sancheung and Namhae.

The seasonal census of distribution, density and abundance of nests was made by the quadrat method in a red pine stand in Jinseung (Station A), Jinyang-gun, Gyeongsang-Nam-Do. The home range in the slope of the stand was divided into 195 quadrats of 10×10 m area. A precise map of the area was made on April 30, 1973, the day of the first census, and afterwards newly appeared, abandoned and revived nests were checked monthly from April to October in 1973-77.

One of the physical factors which may affect the distribution of nests, the relative humidity above ground was determined in the same study area with intervals of a week from May to November, 1975. Twelve screens were placed in the slope and the relative humidity at 10 cm above ground was recorded twice a day (at 10 : 00 and 15 : 00).

Soil chemical analysis was conducted with samples collected from the same slope on April 25, 1973. From each zone of the slope, three sites were selected for sampling soil. Five hundred g of soil sample was collected from each depth of O-20, 20-40 and 40-60cm at each site. In order to determine the content of exchangeable Ca, 500ml of CH_3COONH_4 was added to 5g of each dried soil sample. After shaking for 30 min, it was filtered through a Toyo No. 2 filter paper. Then 20ml distilled water was added to 5 ml of the filtrate. Five ml of 8 M-NaOH and 1 ml of 10 % $NH_2OH \cdot HCl$ were added to it. It was then titrated with 0.005 M-EDTA using about 0.1 g of N-N indicator (2-hydroxy-1-(2-hydroxy-4-sulfo-1-naphthylazo)-3-naphthoic acid). For the determination of the content of exchangeable Mg, 5 ml of 1.26 M-NH_4Cl•3. 70 M-NH_4OH buffer (pH 10.5) was added to 5 ml of the above mentioned filtrate. Then lml of 10% $NH_2OH \cdot HCl$ was added to it. The solution was titrated with 0.005 M-EDTA using about 0.1 g EBT (1-(1-hydroxy-2-naphthylazo)-6-nitro-2-naphthol-4-sulfonic acid) as indicator. The content of organic materials was determined by the Walkley-Black method.

As for the biotic conditions of nesting sites, densities of red pine trees and floor-layer plants were estimated in the same study slope. For the red pine density, five quadrats of 10×10 m area were sampled at random from the lower, the middle and the upper zones of the slope respectively. The density was represented by the number of trees taller than lm and older than 10 years per 100 m^2. For the density of floor-layer plants, 10 quadrats were sampled at random with a frame of 1 xl m area from each zone of the slope, then the species and the individual number of plants growing there were examined. These investigations were made on July 10, 1974.

The material utilized as the nest core was investigated in several natural habitats of the ant in Jinyang, Jinseung, Goseung, Sacheun and Namhae in July, 1974.

RESULTS

Nest distribution and abundance

I) *Vertical distribution of nests*

Vertical distribution of nests at twelve red pine stands in six localities was shown in Fig. 1. The nests scarcely occurred in the upper zone of slopes but were concentrated in the lower and the middle zones. Of 966 nests examined in these forest stands, 631 nests or 65.3 % were in the lower and 325 nests or 33.6 % were in the middle, but only 10 nests or 1.0 % were in the upper zone of slopes.

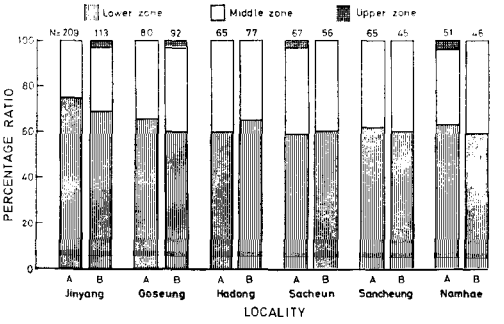

Fig. 1. Percentage ratios of nests distributed in the lower, middle and upper zones of hills inhabited by ***F. yessensis***.

2) *Seasonal change in* ***vertical distribution of nests***

Fig. 2 shows vertical distributions of nests in a slope of a hill at Jinseung (Station A) in April, July and October, 1973. In April, nests were mostly distributed in the lower zone. The nests, however, spread over the middle zone by July, then became similar distribution to that of April again in October.

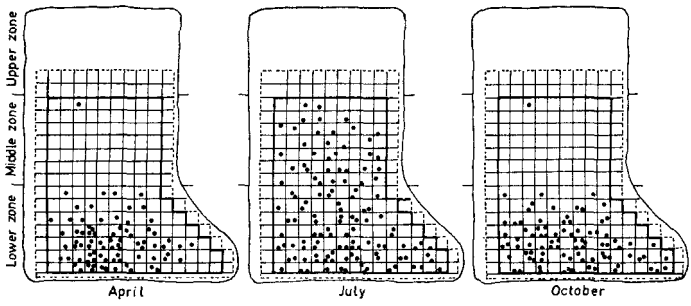

Fig. 2. Diagram of seasonal change of nest distribution in 1973 in a natural habitat (Jinseung, Station A) of ***F. yessensis***. A slope of the hill was conveniently divided into three zones, and the home range of the ant was divided into 195 quadrats of 10×10 m area.

3) *Seasonal and annual changes of nest density*

Based upon the result obtained from the quadrat census in the home range in a slope of a hill at Jinseung (Station A), seasonal changes of nest densities in 1973-77 were estimated. The density means the number of nests per m^2 in quadrats where one or more nests occurred. The number of nests in the whole census area (19, 500 m^2) and the density are shown in Table 1. Although the number of whole nests in the census area increased in July, the density per m^2 was rather constant, slightly decreasing in July.

Table 1. Seasonal and annual changes of nest density in a slope of a hill at Jinseung (Station A) in 1973-77.

Year	No. of nests in the whole census area			No. of nests/m^2 in quadrats nests occurred		
	April	July	October	April	July	October
1973	66	124	90	0.017	0.015	0.018
1974	66	110	89	0.017	0.015	0.022
1975	77	122		0.017	0.016	0.022
1976	50	147	112	0.018	0.017	0.018
1977		64	50	0.015	0.014	0.017

4) *Seasonal change of the nest abundance*

Formica yessensis, a polydomous ant, exhibits nest proliferation by budding (Ito, 1973; Higashi, 1976; Kim and Murakami, 1980 b). Fig. 3 shows the results of the monthly census of nests from April to October in 1973-77 at the study area (Jinseung, Station A). The initiated nests mean the nests newly appeared during a month after the previous census, the continued nests mean those continued from the previous census, the deserted nests mean those abandoned during a month after the previous census, and the revived nests mean those re-utilized which had been abandoned previously. The number of existing active nests at each census is a total of the initiated, continued and revived

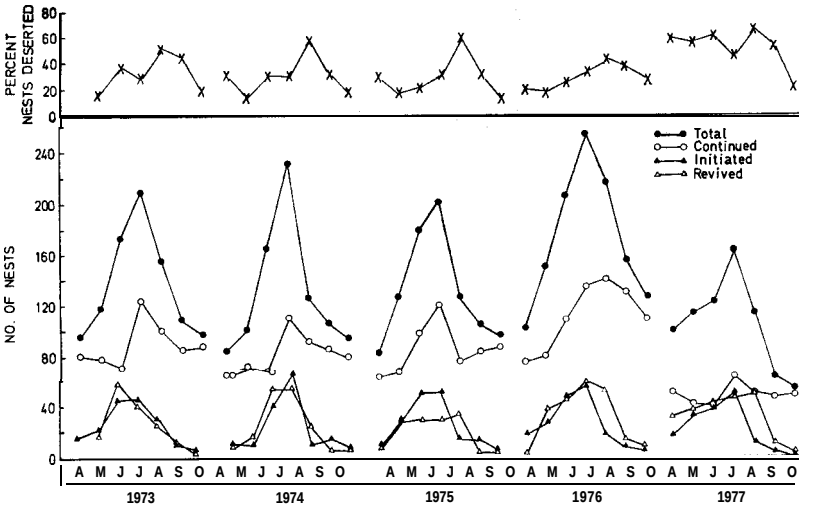

Fig. 3. Seasonal trends of the nest number for successive years and percentage of nests deserted in a slope of a hill at Jinseung (Station A) in 1973-77.

ones.

The active nests increased after the first census in April till July, and decreased in August to October. In July the number of the active nests attained 1.6-2.8 times as many as in April. In August the active nests decreased because the deserted nests increased in spite of increasing of newly initiated nests. The seasonal trends of the revived nests were similar to those of the initiated nests.

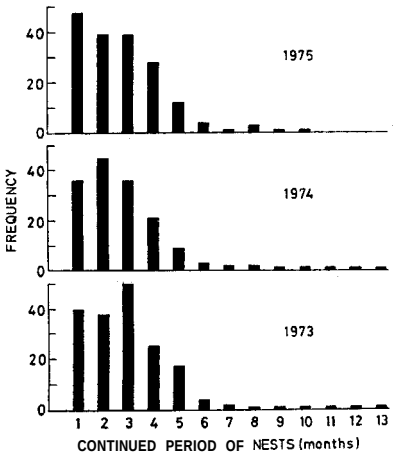

Fig. 4. Frequency distributions of nest longevity in a slope of a hill at Jinseung (Station A) in 1973-75.

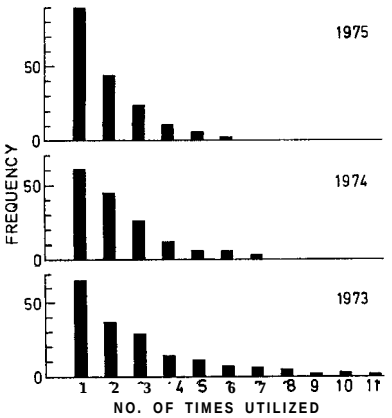

Fig. 5. Frequency distributions of number of times the same nest was utilized during a year in a slope of a hill at Jinseung (Station A) in 1973-75.

5) Longevity of nests

The frequency distributions of the period during which each newly founded nest was being utilized were shown in Fig. 4 for the results obtained in 1973-75. From these results it was concluded that the life span of nests was 1 to 4 months in most cases and 13 months in maximum. Thus, many new nests are abandoned within the year. The abandonment occurs more frequently in the inactive nests such as newly founded and revived nests, but relatively rare in the active nests. The number of times the same nest was utilized during a year is as shown in Fig. 5.

Environmental conditions in natural habitat of the ant

1) Humidity above ground

From the relative humidity determined at 10 cm above ground at twelve sites in the natural habitat of the ant in a slope of the red pine stand in Jinseung (Station A), a map of vertical distributions of the averaged relative humidity from May to September and from October to November is shown in Fig. 6. With the relationships between nest distribution and the humidity from May to September when nests of the ant spread over lower to middle zones in the slope, it is supposed that the upper limit of the nest distribution (near the boundary between middle and upper zones) almost coincides with the line of 75 % RH. In the upper zone where the humidity is lower, the nest of the ant never occurred. In pre-hibernation period from October to November, nests are retreated to the lower zone of the slope where the humidity is higher than 74% RH. At that time the humidity becomes lower than in the previous season in the middle zone.

2) *Chemical properties of the soil*

The result of the soil chemical analysis in the natural habitat of the ant in the slope at Jinseung is shown in Table 2. In the lower and middle zones

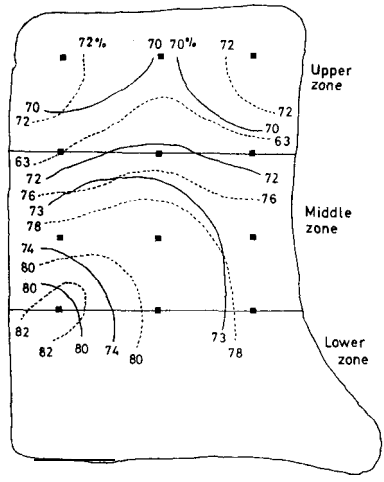

Fig. 6. Contour lines of relative humidities at 10 cm above ground in a slope of a hill at Jinseung (Station A) in 1975. Broken lines show average humidity from May to September, solid lines from October to November. Solid square : points of determination.

inhabited by the ant, the content of exchangeable Ca in soil was extremely low, and organic matters and water contents were considerably higher than in the upper zone, though pH and the content of exchangeable Mg were not significantly different.

Table 2. Results of the soil chemical analysis in a slope of a hill at Jinseung (Station A), a natural habitat of *F. yessensis*.

Zone	Depth (cm)	pH	Exchangeable Ca (me /100 g)	Exchangeable Mg (me /100 g)	Organic mat. (%)	Moisture (%)
Lower	O-20	5.2	0.71	1. 10	2.88	21.23
	20-40	5. 1	0.75	1. 84	2. 75	22.10
	40-60	5. 1	0.62	1.9%	2. 41	22.47
Middle	o-20	5. 1	0.74	0. 96	2.86	50.11
	20-40	5. 2	0.73	1.00	2. 60	21.36
	40-60	5. 2	1.79	1.10	2.10	21.45
upper	0-20	5. 1	2.31	1. 10	1.21	11.56
	20-40	5. 1	2.14	1.04	1.54	14.14
	40-60	5. 1	2.22	1. 26	I. 19	13.31

3) *Density of red pine trees*

The density of red pine trees in the natural habitat of the slope at Jinseung (Station A) is shown in Table 3. In the lower and middle zones inhabited by the ant, the density of red pine trees older than 10 years age was higher than in the upper zone.

4) *Density of floor-layer plants*

Fifty-seven species of floor-layer plants were found in the study area of

Table 3. Density of red pine trees taller than 1 m and older than 10 years per 100 m² in a slope of a hill at Jinseung (Station A), a natural habitat of ***F. yessensis*** in July, 1974.

Age (years)	Lower zone	Middle zone	Upper zone
10-14	1.2	5.6	5.8
15-19	16.8	13.6	7.2
20-24	5.2	1.2	0.a
25-29	0	0.4	0
30-34	0	0.4	0
35-39	0	1.6	0
40-44	0	0.8	0
45 ≤	0	0: 4	0
Total	23.2	24.0	13. a

the red pine stand inhabited by the ant. Among them dominant species were the following 10 species; ***Andropogon brevifolius*** Swartz, *Arundinella* hirta Tanaka, *Cymbopogon tortilis* var. ***Goeringii*** Handmazz, ***Spodiopogon cotulifer*** Hackel, *Festuca* ***ovina*** L., ***Miscanthus sinensis*** forma ***purpurascens*** Makino, *Eulalia* ***speciosa*** Kuntze, *Themeda triandra* subsp. ***japonica*** Tanaka, ***Zoisia japonica*** Steud and ***Rhododendron yedoense*** var. ***poukhanense*** Nakai. The densities and frequencies of these plants are shown in Table 4. In the lower and middle zones inhabited by the ant, it was grown with ***A. brevifolius, A. hirta, C. tortilis*** var. ***Goeringii, S. cotulifer*** and ***F. ovina*** but not with ***E. speciosa*** nor ***Z. japonica.***

5) Suitable ***nest cores utilized by the ant***

Thirty-one kinds of materials were utilized as the nest core in five natural habitats of the ant as shown in Table 5. Among them, two species of long graminaceous grasses, ***Arundinella hirta (33.7 %)*** and *Miscanthus* ***sinensis*** f. *purpurascens* (17.7 %), red pine trees, *Pinus densiflora* Sieb. et Zucc. (23.9 %), oak trees, *Quercus* sp. (5.1 %), wild azalea trees, ***Rhododendron yedoense*** var. *poukhanense* ***(3.8 %)*** were main core plants. Stones (8.0 %) also serve sometimes as the **core.**

Table 4. Densities and frequencies of the ten dominant species of floor-layer plants of a red pine stand in a slope of a hill at Jinseung (Station A), ***a natural*** habitat of ***F. yessensis*** in July, 1974.

Species	Density (per m²)			Frequency (%)		
	Lower zone	Middle zone	Upper zone	Lower zone	Middle zone	Upper zone
					90	50
Andropogon brevifolius	***49.6***	***120.5***	***28. 6***	***100***	90	90
Cymbopogon tortilis var. ***Goeringii***	**38. 7**	**30. 2**	**4.7**	100	80	60
Spodiopogon cotulifer	11.4	18.6	19.5	***90***	90	70
			6. 1	70	50	30
Miscanthus sinensis f. ***purpurascens***	***14.6***	***a. 4***	5. 6	20	90	30
Rhododendron yedoense var. ***poukhanense***	***4.7***	I.1	0'	50	30	0
Eulalia speciosa	0	0	14.7	***0***	0	80
Themeda triandra japonica	0	***4.*** a	1. 0	0	30	10
Zoisia japonica	0	0	3. 5	0	0	20

Table 5. Number of nests built by utilizing various plants and stones as nest cores in Gyeongsang-Nam-Do, Korea.

Kind of nest cores	Locality					Total
	Jinseung	Namhae	Goseung	Jinyang	Sacheun	
A. hirta	23	73	88	63	30	***277***
Pinus ***densijlora*** (red pine)	48	39	68	32	9	***196***
M. ***sinensis*** f. *purpurascens*	7	25	79	29	5	***145***
S. cotulifer	0	0	0	12	0	12
T. triandra japonica	0	0	17	2	0	19
Impera cylindrica	0	0	7	5	0	12
Quercus sp.	7	11	20	0	4	42
R. yedoense var. ***poukhanense***	21	3	0	6	1	31
Juniperus ***chinensis***	0	3	0	0	0	***3***
Castanea ***crenata***	1	0	0	0	0	***1***
Indigofera kirilowii	0	0	0	10	0	***10***
F. ovina	1	0	0	5	1	***7***
Stones	2	21	15	26	2	66
Total	110	175	294	190	52	821

DISCUSSION

Nest distribution in slopes of hills naturally inhabited by ***F. yessensis*** is concentrated in the lower and middle zones but scarcely in the upper zone. The distribution changes with seasonal fluctuation of nest number. From autumn to early spring, the nests are distributed only in the lower zone of the slope, while in summer they spread over the middle zone according to the increase in nest number since the density of nests per unit area is constant seasonally.

Although red pine forests in Korea provide a favourable environment for ***F. yessensis,*** the upper zone of the hill seems not to be so favourable for establishing nests because of several reasons. In the upper zone the density of pine trees is relatively low and that of *Zoisia* grasses is higher than in the middle and lower zones. Such floral conditions are associated with lower humidity above ground and moisture in soil. The lower moisture of soil is also related to lower content of organic matter in the upper zone.' In the lower and middle zones inhabited by the ant the content of exchangeable Ca in soil was extremely lower than in the upper zone, but it is uncertain whether it would be a cause or a result. Petal (1978) stated that ants modified the physical and chemical properties of both the soil used construction of nests and the adjacent soil. The concentration of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) in nests, however, is slightly higher than in the surrounding soil in *Myrmica* sp. and *Lasius flavus* (Fabricius) according to the data cited by him.

In Ishikari Shore, Hokkaido, the distribution of nests of ***F. yessensis*** shows a remarkable correlation with the spatial change of vegetation, mostly confined within the zone occupied by eulalia ***(Miscanthus sinensis*** Anderss.) and sweet brier ***(Rosa*** *rugosa* Thunb.) and that occupied by vines (*Rubus parvifolius* L., *Vitis Coignetiae* Pulliat, etc.) with moderately dense plant matrix, while absent

both in sparse shore side vegetation and thick inland oak forest (Ito, 1971). Lower and middle zones of the hill, a study station at Jinseung, are favourable for the ant owing to relatively high density of red pine trees, but sufficient light intensity and presence of suitable plants for nest cores such as long graminaceous grasses.

Contrasting with European species of *Formica rufa* group, *F. yessensis* can establish nests without appropriate cores. The establishment, however, is facilitated by the presence of certain structures suitable as cores. In Ishikari Shore, more than half of nests were found around or under the root system of *Miscanthus sinensis* (Ito, 1971). Hayashida (1960) also suggested that the best site was around the root of living trees. Thus, the presence of suitable nest cores was regarded as one of factors responsible for the nest abundance. In Korea, various plant including *Arundinella hirta, Pinus densiflora* (red pine trees) and *Miscanthus sinensis* forma *purpurascens* as well as stones serve as the core for building nests.

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