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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

V. Usefulness of *Formica yessensis* Forel*

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Formica yessensis is a highly polyphagous predator with a broad spectrum of prey range, i.e., live and dead lepidopterous larvae, coleopterous adults and larvae, hemipterous adults as well as honeydew secreted by aphids. The results of experiments for examining the effect of predation by the ant with the physical check method revealed that the ant is extremely effective in controlling the younger larvae of the pine caterpillar moth, *Dendrolimus spectabilis*. The ant hunts in one of two ways. The first is a direct attack by worker ants on a twig. The second is hunting by numerous workers on the ground, where caterpillars have dropped to escape from the attack by ants on the twigs. In Korea this ant maintains a very high population density with supercolonies including a number of colonial nests in red pine forests. The predaceous activities of the ant are not density-dependent. When the pine caterpillar is scarce, the ant can maintain its population by feeding on the honeydew of aphids which are not a serious pest of red pine trees. The period of activity of the ant is as long as 200 days per year. These are outstanding characters possessed by the ant, which makes it as an effective biological control agent against the pine caterpillar moth. In addition *to its role as an* effective predator, the ant may also play an important role in soil improvement and plant enrichment. Therefore, the preservation of this ant species in natural habitats, and the transplantation of its colonies to non-inhabited forests should be recommended.

INTRODUCTION

Formica (Formica) yessensis Forel occurs throughout all the regions of Korea except Jeju-Do and has a large supercolony consisting of many colonial nests in the red pine forests in Korea. The number of workers attained approximately 100,000 per nest, and number of the nests almost 1,000 in a census stand of approximately 2 ha wide (Kim and Murakami, 1980 a, b, 1981 a). These ants must consume an enormous amount of diets in order to maintain their full nest population. It should be supposed that the ant have become

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possible by developing an omnivorous habit rather than polyphagous, feeding on nector, sap, aphid honeydew, live and dead insects and earthworms, etc.

For many years an active controversy has existed among European entomologists on the pros and cons of red wood ants (*Formica rufa* group) as the biological control agents (Adlung, 1966; Finnegan, 1974). Some of the main criticisms have been (1) that ants do not hunt many live prey, but simply scavenge already died or dying insects; (2) that they destroy not only harmful insects, but beneficial insects as well; (3) that by feeding on honeydew, and thereby protecting aphids, they are indirectly responsible for aphid damage to plants (Finnegan, 1974). A list of the normal diet of *Formica rufa* Linnaeus was given by Wellenstein (1952), i.e., 62 % aphid honeydew, 33% insects (31.3% unimportant and beneficial insects, and 1.7 % harmful insects), 4.5 % tree sap, 0.3 % mushrooms and carrion, and 0.2% seeds. Because of the relatively low percentage of harmful insects in the ant diet, several authors have questioned the value of *Formica* species as the biological control agents (Adlung, 1966). Among European *F. rufa* group some species are valuable as predators but others are less useful. Adlung (1966) has stated that *Formica polyctena* (Foerster), a polygynous ant, is the most valuable, and *Formica lugubris* Zett. and *Formica aquilonia* Yarrow are useful in subalpine forests. While, the oligogynous form of *F. rufa* is less active as a predator and the monogynous form of the ant is rather unimportant as a biological control agent.

As the final report on the ecological studies on *F. **yessensis*** in Korea, the present paper deals with the diet of the ant and experiments for evaluating its effectiveness by the physical check method conducted by the senior author, and also concerns the discussion of the usefulness of the ant as a biological control agent to the pine caterpillar moth, *Dendrolimus spectabilis* Butler in Korea.

METHODS

The kind of diets preyed by *F. yessensis* was examined by nest excavations and field observations in a red pine stand at Jinseung, Jinyang-gun, Gyeongsang-Nam-Do, Korea from 1972 to 1977.

In order to examine the effect of predation by the ant, two experiments were conducted by the physical check method in the same stand as above at Jinseung in 1972. In both experiments twelve small trees (1.5-Z. Om high) were sampled and classified into three treatments and a control (three trees for each). Treatment A means uncaged trees with an ant nest at their base. Here the ants and other natural enemies were free to attack the larvae of the pine caterpillar moth at will. Treatment B means trees with an ant nest at their base but in cages of organdie. Here the ants were free to attack the caterpillar but other natural enemies were excluded. Treatment C means organdie-caged trees without ant nests at their base and treated with sticky flypaper on the trunk to exclude the ant and other natural enemies.

Control trees were uncaged trees but without ant nests at their base.

The first experiment was conducted from May 8 to 29 and the second one from August 25 to September 8. In the experiment conducted in May, 50 post-hibernating mature larvae of the pine caterpillar moth were placed on each experiment tree. In the second experiment conducted in August-September, 50 first to third instar larvae were placed on each experiment tree. The number of living larvae on these experiment trees was counted with three-day interval in the first experiment, whereas with two-day interval in the second one.

RESULTS

Diets of *F. yessensis*

Eleven species of insects were found from nests of the ant, i.e., lepidopterous larvae, coleopterous adults and larvae, and hemipterous adults (Table 1). Among them, larvae of ***D. spectabilis*** was only species observed being attacked by the ant in the field. The ant hunts in one of two ways. The first is a direct attack by the numerous worker ants on a twig. The second is hunting by numerous workers on the ground, where the caterpillar has dropped to escape from the attack by ants on the twigs. Other than the pine caterpillar moth, scarabaeids and chrysomelids were observed to be important prey of the ant.

Table 1. A list of prey hunted by ***F. yessensis*** which were observed in a red pine stand at Jinseung, Gyeongsang-Nam-Do, Korea in 1972-1977.

Prey species	Prey stage
Lepidoptera	
Dendrolimus ***spectabilis*** Butler	Larva
Archippus oporana ***similis*** Butler	Larva
Coleoptera	
Episomus turritus Gyllenhal	Adult
Apoderus jekelii Roelofs	Adult
Agelastica coerulea Baly	Adult, larva
Chrysomela populi Linnaeus	Adult, larva
Epicauta chinensis Motschulsky	Adult
Lachnosterna morosa Waterhouse	Adult
L. kiotonensis Brenske	Adult
Heptophylla picea ***Motschulsky***	Adult
Hemiptera	
Velinus ***nodipes*** Uhler	Adult

Another important diet of the ant was honeydew secreted by a lachnid aphid, *Cinara piniformosana* Takahashi.

Experiments for evaluating the effectiveness of the ant

The result of the experiments for the effect of predation by the physical check method was given in Figs. 1 and 2.

In the experiment of the effect on post-hibernating mature larvae, the

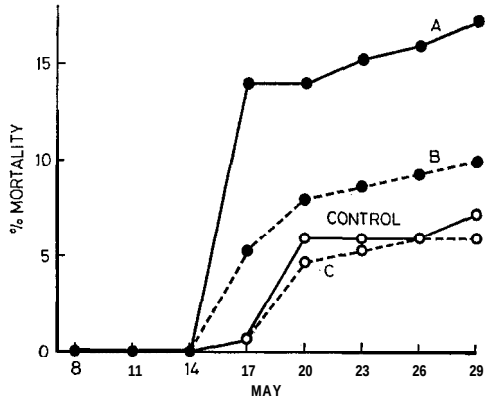

Fig. 1. The mortality of post-hibernating mature larvae of *D. spectabilis* in an experiment of predation of *F. yessensis*. Treatment A: uncaged trees with an ant nest at their base; treatment B: caged trees with an ant nest at their base; treatment C: caged trees without ant nests at their base and treated with sticky flypaper on the trunk; control: uncaged trees whithout ant nests at their base.

mortality attained only 17.3 %, even 21 days after treatment A. There is less difference in mortality between treatments B (affected by the ant only) and C (excluded the act of the ant), and control (Fig. 1). Therefore, the ant is not effective in controlling the mature larvae of the pine caterpillar moth.

On the other hand, the result of the experiment with first to third instar larvae of the moth revealed that the ant was extremely effective in controlling the younger larvae. In the cases of treatments A and B in which the ants were acting, the mortality attained 100% within only four days after

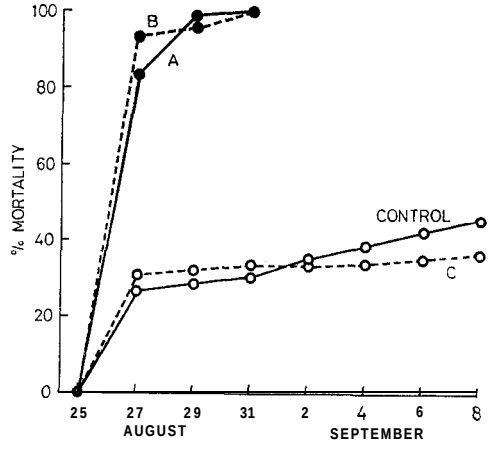

Fig. 2. The mortality of first to third instar larvae of *D. spectabilis* in an experiment of predation of *F. yessensis*. Treatments and control are the same as in Fig. 1.

treatments, whereas the mortality attained only 36.7 % in treatment C, and 46.0 % in control even 14 days after treatments (Fig. 2).

DISCUSSION

Few records have been published on the food of *F. yessensis*. Teranishi (1916) cited a letter from Mr. S. Yamamura who had observed dead scarabaeids in nests of the ant in Korea. Morisita (1940) stated the ant attacked grasshoppers and other insects in Mt. Norikura, Nagano Prefecture, Japan. Higashi (1974) recorded that many workers of the ant collected the honeydew of aphids on the leaves of oak trees in summer and autumn in Ishikari Shore, Hokkaido, Japan. He also observed the ants were hunting live or dead insects and earthworms (Higashi, 1974).

The prey insects given in Table 1 are only a small part of diets of the ant in Korea, but the list suggests *F. yessensis* is a polyphagous predator having a tremendous wide food range. Thus, such a polyphagous behaviour of the ant means that the ant hunts not only harmful insects but also beneficial ones. Therefore, it is a problem that *F. yessensis* may play a beneficial role as a natural enemy of harmful pests such as the pine caterpillar moth, but play an injurious role as well.

In addition to this the ant may protect aphids particularly C. *piniformosana*. Müller (1958) stated that aphid population was often ten times higher near ant nests than in areas out of range of nests. The amount of honeydew carried into a nest by *F. polyctena* (=*F. rufa rufopratensis minor* Gösswald) was estimated to be 290-320 kg, and by *F. rufa* (=*F. rufa rufopratensis major* Gosswald) 450-500 kg per year (Zoebelein, 1956). It would seem evident that loss of such quantities of assimilates must have an influence on tree growth (Adlung, 1966). The controversy about the potential usefulness against forest pests of red wood ants among European entomologists is based upon these problems (Adlung, 1966; Finnegan, 1974). The authors will discuss the problem later.

Various ants have been recorded to attack the pine caterpillar at the first larval stage, particularly newly hatched young larvae or larvae moving on twigs. Hirose (1963) observed two species of ants, *Crematogaster laboriosa* Smith and *Iridomyrmex glaber* (Mayr) (=I. *itoi* Forel) attacked larvae of the pine caterpillar moth just hatched from eggs in pine stands in a shore in Fukuoka Prefecture and a mountain in Kumamoto Prefecture, Kyushu. Furuta (1968) also observed in a red pine stand in Kyoto Prefecture that I. *glaber* and *Tetramorium caespitum* (Linnaeus) aggregated to surroundings of large egg masses of the moth and preyed larvae just hatched from them. He pointed out this predation was one of the most important mortality factors in the first larval stage of the moth. Kokubo (1971) studied mortality factors of the pine caterpillar moth in the suburbs of Chiba City and reported that larvae just hatched from eggs dropped easily onto the ground by such physical factors as rain and wind, and that most of these larvae died of starvation or predation by ants. Kobayashi and Kuroda (1972) observed in pine stands in Saitama Prefecture that *Monomorium nipponense* Wheeler, *Pristomyrmex pungens* Mayr, *Crematogaster*

matsumurai Forel, *Lasius niger* (Linnaeus) and *Formica japonica* Motschulsky attacked larvae hatching from eggs of the pine caterpillar moth as well as the first instar larvae moving on twigs. Matsui and Kokubo (1974) observed egg masses of the pine caterpillar moth attacked by ants in a pine stand in Tanashi, Tokyo Prefecture and reported that *L. niger* and *F. japonica* aggregated to the egg masses of the moth and preyed hatching larvae and those moving to needles.

Thus, the pine caterpillar moth is attacked by various ants only in the first instar larval stage. In the experiments of predation by *F. yessensis* presented here, it was concluded that the ant was extremely effective in controlling the first to third instar larvae, though it was not effective against the post-hibernating mature larvae. Younger larvae of the pine caterpillar moth on twigs or needles drop easily to the ground by a slight stimulus such as of contact with ants or of rain, wind and other physical factors. Almost of the dropped larvae are hunted by *F. yessensis.*

As mentioned before, an active controversy has existed for many years among European entomologists on the value of the red wood ants for the purpose of forest pest control. Here the authors will discuss the value of *F. yessensis* as a biological control agent of the pine caterpillar moth in Korean forests as a conclusion of the serial studies.

DeBach and Bartlett (1964) discussed various methods for evaluating the effectiveness of natural enemies and concluded that the experimental method was the most adequate for the precise determination of the importance of natural enemies in regulation of an insect's average population density. The physical check method or the mechanical exclusion technique is one of the experimental method of evaluation. The senior author employed the technique to examine the effect of predation by *F. yessensis* and has concluded the ant was extremely effective in controlling the younger larvae of the pine caterpillar moth in Korea.

As pointed out by DeBach and Bartlett (1964), the cage-exclusion method, however, may have limitations either the applicability to larger and highly motile hosts or an influence on factors other than natural enemies, because the cage may limit the dispersal of the hosts and modify the microclimate. Therefore, the method employed in the present study may not give an accurate measure of the efficacy of *F. yessensis.* It is ideal to evaluate the effect of natural enemies by investigating population dynamics of the pests and the role of natural enemies under natural conditions.

Kokubo (1965) studied the population fluctuations and natural mortality factors of the pine caterpillar moth from 1950 to 1963 in Kashima district of Ibaraki Prefecture where outbreaks occurred in the summer generation of 1950, 1955 and 1961 (In this district the moth has two generations per year). The main reason for the outbreak seemed to be high survival rate of the young larvae in summer. He concluded the climate in July had strong influence upon the survival of the young larvae. He also stated that the effect of natural enemies was usually the greatest on the egg population in both generations and that much greater number of immature stages in the over-

wintering generation was destroyed by parasitoids and diseases than in the summer generation. Then he concluded that a rapid increase of the moth populations in autumn was considered to be caused by a combined effect of climatic conditions and of natural enemies.

In Korea, Kim (C. W.) and Hyun (1965), Kim (C. W.) *et al. (1966)* and Hyun (1968) studied the population dynamics of the pine caterpillar moth and the important mortality factors affecting the fluctuations of the moth population in Mt. Kwangkyo, Jijidae and Mt. Chilbo, Keyngki-Do from 1964 to 1966. They concluded that (1) the mortality in the egg stage ranged between 19 and 41 %, and the parasitization by egg parasitoids, particularly by *Trichogramma dendrolimi* Matsumura was the most important; (2) the mortality in the early hatched larval stage was 53~78 %, the greatest one throughout the life span; (3) the most important factor of this mortality was the dropping on the ground in August by rain and other physical factors; (4) the mortality of young larvae by rain was caused by a combined effect of rain intensity, temporal coincidence between rain and hatch of the moth eggs, and size of crown of pine trees; (5) the younger larvae within one week after hatch suffered high mortality by rain; (6) the overwintering larvae suffered 0.3–9.1 % mortality, mostly caused by temperature conditions in March to April and the parasitization by *Phanomeris spectabilis* Matsumura; (7) the larvae after hibernation suffered 0.9-3.2 % mortality, mostly caused by the parasitization of *Pimpla disparis* Viereck; (8) the pupae suffered 0.01-2.6 % mortality, mostly caused by the parasitization of *Brachymeria obscurata* Walker ; *(9)* the generation mortality was 98.66–99.85 %; and (10) the mortality required to maintain the population at a steady state was calculated as 99.66 %, the mortality in the newly hatched larval stage was the highest throughout generation, and it was the key factor for the population fluctuations.

These were results of the population studies investigated in pine stands not inhabited by *F. yessensis.* However, both studies have a common feature; i.e. the mortality in the young larval stages, particularly in the newly hatched larvae is the most important factor for the population fluctuation of the pine caterpillar moth. Kokubo (1965) stated the climate in July had an important effect on the survival of the young larvae, and Hyun (1968) concluded the rain in August was greatly concerned to the mortality of the young larvae by the dropping on the ground.

It is supposed that the predation by *F. yessensis* may be the most important mortality factor in the young larval stages in the forest inhabited by the ant from the authors' studies. Since climatic conditions are variable annually, the intensities of the mortality by the climatic factors may be also variable year by year. In the pine forests inhabited by *F. yessensis,* on the other hand, it is expected that the population density of the pine caterpillar moth may be controlled continuously with a consistent mortality by the predation of *F. yessensis.* This may be supported by the empirical observations that injury by the moth was extremely low in a pine stand inhabited by the ant even in the year the outbreak of the moth was observed in neighboring stand not inhabited by the ant. Further investigations should be conducted for several years by more

precise comparative studies between forests inhabited and not inhabited by the ant for evaluating quantitatively the effectiveness of the ant as a biolog ical control agent.

There is a belief among biological control workers that the best possibilities of achieving the greatest degree of control are by using monophagous (specific) parasitoids or predators. However, if the host population is periodically depressed by other factors, a specific natural enemy will suffer most, whereas a more general feeder will maintain itself on other hosts during adverse periods (Doutt and DeBach, 1964). It8 and Miyashita (1968) studied on the population dynamics of the fall webworm, *Hyphantria* ***cunea*** Drury in the urban area of Tokyo, and concluded that the population of ***H. cunea*** were mainly controlled by polyphagous predators and parasitoids. They suggested that a factor which prevented this species for entering the forest zone in Japan might be predation by birds and other polyphagous predators. Ehler and van den Bosch (1974) stated that polyphagous predators such as *Chrysopa carnea* Stephens, *Orius* ***tristicolor*** (White) and other bugs were largely responsible for maintaining the cabbage looper, *Trichoplusia ni* (Hübner) population density at innocuous levels on cotton in California and that the mortality caused by these generalists could be density independent and the agents could be said to a poorer regulator but a better control factor. Thus, some polyphagous predators have an ability to maintain the prey population at a low level, since the act of generalists was less affected by decrease of the prey density and at shortage of a food they can maintain their population by hunting other kinds of prey.

F. yessensis has evolved as a polyphagous predator having a tremendous broad spectrum of food range. Such polyphagous habit of the ant may be an important attribute by which the density of the pine caterpillar moth could be consistently maintained at a low level.

Finnegan (1974) emphasized several outstanding qualities possessed by predaceous red wood ants, which were not commonly found among other predators of forest pests. Most of the attributes are true in the case of ***F. yessensis*** in the pine forests in Korea. ***F. yessensis*** can attain a very high population density, requiring a large and continuous supply of food. It is not dependent on a specific prey, but vary its diet according to the prey available. When live prey becomes in short supply, it can divert its attention to honeydew secreted by the pine lachnid aphid, C. *piniformosana*, and thereby maintain its full nest population. As a result there may be little or not numerical lag behind an increasing pest population. The hunting ground of ***F. yessensis*** covers all levels of the forest ranging from the forest floor to the uppermost branches of the crowns. The period of activity is very long, approximately two hundred days from mid April to November in Jinju district. The ant is polygynous and forms colonial nests. Only difference from the more desirable attributes emphasized by Finnegan (1974) is that ***F. yessensis*** does limit its predation to the young larval stage of the moth.

Adlung (1966) reviewed detrimental effects of the red wood ants in Europe on beneficial insects and protection of aphids by them. Gösswald (1951) point-

ed out, however, that the effect of aphids particularly on conifers should be of no great concern to foresters, for the damage was minimal and did not affect plant growth to any marked extent. Bruns (1954) stated that by specializing to hunt the abundant insect, usually pest, there were much fewer beneficial insects captured by red wood ants during infestations. Furthermore, Finnegan (1974) did not deny some of the detrimental effects of red wood ants, but claimed that by and large the accusations had been shown to be insignificant. He pointed out that much of the early criticism probably had resulted from insufficient information on the various species involved in the ***F. rufa*** group. Following their proper taxonomic separation, it was found that some species were indeed poor predators, while others were very effective (Finnegan, 1974).

Based upon the fact observed in Korean pine forests, the aphid, C. *piniformosana* is considered not to be injurious to the adult trees in spite of that the aphids were visited intensively and protected against natural enemies by the ants. Instead, honeydew secreted by the aphid serves as a useful supplementary food when prey insects are in short supply.

Red wood ants are known to be useful not only because a predator of forest pests but also because they affect the forest in several other ways. For example, their excavations aerate the soil in the environs of their nests. The soil is enriched by organic substances that are carried underground. As a result trees are extremely viable and make rapid growth in the environs of ant colonies (Adlung, 1966). Ants also play an important role in transporting sub-soil to the surface, which increase the cation exchange and water-holding capacities of the soil to a considerable extent (Finnegan, 1974). Ants transport seeds of many trees, shrubs and weeds as food and nest building material. The transportation of seeds aids greatly in the distribution and establishment of many kinds of plants. The increase in plants leads an increase in the variety and number of animals, particularly birds (Finnegan, 1974). The seed transport and plant establishment are of special importance in areas where the soil is subject to active erosion (Gosswald, 1951; Adlung, 1966). In Korea ***F. yessensis*** plays similar roles in silvicultural effects in pine forests. Therefore, it is desirable that the ant colonies should be preserved. It is also advisable to transplant artificially the ant nests to forests not inhabited by the ant. As mentioned in the previous paper (Kim and Murakami, 1981 b), the transplantation of red wood ants has been tested in Europe (Gösswald, 1951). *F. lugubris* has been successfully transplanted from northern Italy to the Apennines and the Island of Sardinia (Adlung, 1966), and also introduced into Quebec, Canada in 1971 and 1973 (Finnegan, 1975). In Quebec the ant was well established, and it has been demonstrated that the ant has the capacity to hunt large number of the spruce budworm, *Choristoneura fumiferana* Clem. larvae (McNeil et ***al.,*** 1978).

Although ***F. yessensis*** distributes throughout Korea except Jeju-Do uninvestigated (Kim and Murakami, 1980 a), red pine forests inhabited by the ant are confined in relatively small proportion. From results of the transplantation experiments of ***F. yessensis*** colonies, it has been concluded that it may be pos-

sible to establish the ant colonies by artificial colonization into forests where the environmental conditions are similar with those in forests naturally inhabited by the ant (Kim and Murakami, 1981 b). The colonization should be made from May to July when the active nests increase in number by budding (Kim and Murakami, 1981 a). Thousands of worker ants and several mated queens should be collected from mounds of nests with nest material in forests inhabited by the ant, then transplanted to red pine forests not inhabited. It is recommended also that the environmental conditions of the forests are modified to a certain degree so as to facilitate the establishment if the forests may not be suitable for colonizing nests. For example, when the red pine stand is not suitable because the density of pine trees is so high that sunlight is insufficient to the forest floor, it may be recommended to admit sunlight by thinning out the forest. It may be promising to utilize *F. yessensis* actively for the protection of the red pine forests against *D. spectabilis* by preservation and transplantation of nests including manipulation of environment to favour the ant.

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