GYPSY MOTH PARASITOID COMPLEX AT MT. HALLA NATIONAL PARK, CHEJU ISLAND, KOREA[1]

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ABSTRACT: A study of the parasitoid complex attacking gypsy moth, *Lymantria dispar* (L.), at Mt. Halla on Cheju Island, Korea, revealed the presence of nine natural enemies: one egg parasitoid, four larval parasitoids, one pupal parasitoid, one parasitic nematode and two diseases. NPV and *Beauveria* prob. *bassiana*, were the main mortality factors. Only 23% of the parasitoid species known to occur in mainland Korea were recovered on this volcanic island, suggesting that a number of species have not yet become established there.

Mt. Halla (elevation 1950 m) is the central volcanic mountain on Cheju Island, which is located in the Yellow Sea about 90 km south of the Korean peninsula. At lower elevations, the island is characterized as subtropical with mean average temperatures about 3 - 4° C warmer than recorded in Seoul. An area of 133 km^2 surrounds the mountain and is designated as Mt. Halla National Park. The park is home to 2,000 species of native plants (Yim et al. 1990), while insect biodiversity is only beginning to be cataloged (Paik et al. 1995). Below 600m elevation, the vegetation is primarily deciduous, but above that, evergreen coniferous forests predominate, with a shrubby habitat occurring near the summit.

The gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), was first observed damaging secondary forests at low elevations in 1995 and reached outbreak status in 1996. By 1997, the population had expanded into the primary forests at higher elevations, and the infested area covered 1,500-2,000 ha. Infestations of such a large scale are unprecedented in Korea. Many subpopulations of *L. dispar* were found in different population phases over the Mt. Halla vicinity. The moth defoliated *Carpinus*, *Quercus*, and *Rhododendron* species at several sites. Fortunately, the outbreak phase of the population cycle was short, and was followed by very low population levels. Further infestations by gypsy moth in this area seem probable, because preferred host plants are a major component of the more extensive forested areas.

The objectives of this study were to determine the species composition of the parasite complex, the relative importance of each species, and to compare the results obtained in Mt. Halla National Park with those obtained in mainland Korea. This will permit an understanding of the importance of each parasitoid

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as a biological control factor. If species that habitually attack *L. dispar* on the mainland were completely absent, they might serve as potential candidates for future introduction. Any new parasitoid-*L. dispar* associations found would be of interest to investigators looking for promising species for introduction against gypsy moth in North America.

MATERIAL AND METHODS

Study site: Cheju Island is bounded by 126° 09' 42" and 126° 56'57" E longitude and by 33° 11'27" and 33° 33'50" N latitude. Annual average temperatures in the non-mountainous area of the island are 3-4 °C warmer than at Seoul, whereas those in the Halla mountain area are 2-3 °C colder, based on the 1997 data measured at the park office at Uri-mok (970 m).

Sampling. Gypsy moth larvae and pupae were collected at ca. weekly intervals at three sites on Mt. Halla from May 13 through July 7, 1998, and nine collections were made at each of the following sites: (1) Chunwang-Sa (elevation 640m) on the NW side of the mountain, where collections were made primarily from *Carpinus laxiflora* Bl., *Carpinus tschonoskii* Max, *Quercus serrata* Thunb., *Prunus* spp., *Acer pseudo-sieboldianum* Paxton Kom, and *Cornus kousa* Buerg.; (2) the 1100 site (elevation 1100m) on the south side, where collections were made from *C. laxiflora, C. tschonoskii, Q. serrata, Prunus* spp. and *A. pseudo-sieboldianum, C. kousa, Viburnum dilattum* Thunb.; and (3) Young-Sil (elevation 1100-1200), on the south side, where collections were made mainly from *Q. serrata, C. laxiflora, C. tschonoskii, C. kousa*, and *Pinus densiflora* S. et Z.

Most collections were made along the scenic road at forest margins and extended up to one hundred meters into the forests, depending on the size of the gypsy moth populations. The areas of collection were usually 50,000-60,000 m^2. The larvae and pupae were collected by hand from leaves, branches and trunks, then taken to the laboratory where they were reared in screen-topped plastic boxes (20.5 by 28 by 16.5 cm) in groups of up to 100 and fed *Quercus* spp. leaves. The containers were checked once or twice a week for parasitoid emergence. Parasitoid identifications were made by the authors, by comparison with authoritatively determined voucher material from the former USDA-ARS Asian Parasite Laboratory collection. Some of those specimens are currently housed at Dongguk University. The collection and rearing procedures were similar to those followed by Pemberton et al. (1993). Egg parasitoids were obtained from eggs collected from the several different infestation sites from September, 1996, to November, 1998. Egg masses were placed in petri dishes, and parasitoid emergence was recorded. About 200 egg masses were collected, but only the presence of parasitoid species was recorded. Rates of egg parasitism were not calculated.

Gypsy moth population estimates were made for each site by calculating the hourly density (number of larvae and pupae collected per person per hour).

Parasitism also was analyzed in terms of host population phase affinities. In order to determine the population phase, egg mass density, the ratio of new to old egg masses, and hourly density of immature stages were used. The egg mass density and the ratio of new to old egg masses were measured using 5-min walks (n=12) (Schneeberger 1987). Although 5 min walks are very practical and convenient for relative abundance of egg mass density, they are not recommended for estimation of absolute density (Liebhold et al. 1991).

Different indices of parasitism, previously described by Pemberton et al. (1993), were used in this study to evaluate the relative importance of each parasitoid: (1) Mean parasitism was calculated by dividing the numbers of parasitized hosts by the number of gypsy moth immature stages obtained in the season-long collections. Thus, mean total parasitism is the average parasitism in the three season long collections from all the sites. (2) The percentages of parasitism by each species were calculated by dividing the number of emerged individuals of each parasitoid species by the number of larvae and/or pupae. These parasitism percentages for individual parasitoid species were added to yield combined parasitism rates for collection dates, sites, and ultimately, the entire study. (3) Maximum or peak parasitism was the highest rate observed for a given species at any site and sampling date. (4) Season-long parasitism is the number of individuals parasitized by each species in the samples of a season-long collection at a particular site divided by the total individuals collected. Gregarious parasites emerging from a single larva were counted as one parasite. Parasite-host associations were generally determined by the cocoon aggregations on or near the host cadavers [e.g. *Glyptapanteles liparidis* (Bouché)]. For mermithid parasitism, a mean of 2.5 parasites emerged per host in a preliminary test, in which lethargic host larvae were isolated in snap-top vials, and numbers of mermithids emerging from parasitized hosts (n = 20) were recorded. Thus, the numbers of larvae parasitized by the mermithid were estimated by dividing the total number of the nematodes observed in a rearing container by 2.5.

RESULTS

The hourly collections of larvae/pupae per person averaged 54.1, 90.4, and 74.4 at Chunwang-Sa, the 1100 site, and Young-Sil, respectively. The gypsy moth population at Chunwang-Sa was in the decline phase, where a relatively low number of egg masses ($\overline{x}$ = 18 per 5 min. walk) and low ratio of new egg masses to old egg masses (0.34) were observed. The gypsy moth population at the 1100 site was in the release phase, having the highest number of egg masses (71.3 egg masses per 5-min walk) and the highest ratio of new to old egg masses (2.9). Young-Sil had a stable, moderate population with egg mass counts of 40.7 per 5-min walk and a ratio of 0.7 new to old egg masses.

Total parasitism was 6.8%, because parasitoids killed 221 of the 3,285 larvae and pupae reared. The season-long parasitism in these collections ranged from 4.2 to 8.2 depending upon the site (Table 1). Nine natural enemies of the gypsy moth were found: one egg parasitoid, four larval parasitoids, one pupal parasitoid, one parasitic nematode and two diseases. Weekly data on numbers of hosts collected and percentage parasitism for the dominant larval parasitoids appear in Fig. 1.

Anastatus japonicus Ashmead (=*disparis* Ruschka) [Hymenoptera: Eupelmidae], was reared from all collections of egg masses (Suak-kyo, Sungpan-ak, 516 road, Chunwang-Sa, the 1100 site, and Young-Sil). No other egg parasitoids were recovered.

Glyptapanteles liparidis (Bouché) [Hymenoptera: Braconidae] is a gregarious, oligophagous, bivoltine parasitoid. This wasp was recovered from host larvae collected from mid May to 7 July. Larvae from the three collection sites were parasitized by this wasp at season-long rates of 1.9-5.7% (mean = 3.5%) (Table 1). It was the dominant parasite of late instars at Young-sil, where peak parasitism of 30.6% was recorded from 72 larvae collected on June 23 (Fig. 1).

Meteorus pulchricornis (Wesmael) [Hymenoptera: Braconidae] is a solitary, multivoltine parasitoid that attacked second to fourth instars of gypsy moth. It emerged from larvae collected from mid-May to 5 June. The season-long parasitization rates at the three sites ranged from 0.4 to 1.6 %, averaging 0.7% (Table 1), with the highest parasitism rate of 10.8% at Young-Sil on 5 June (Fig. 1).

Parasetigena silvestris (Robineau-Desvoidy) [Diptera: Tachinidae], an oligophagous, univoltine species that lays macrotype eggs on the integument of large larvae, was recovered at all three sites, but scarce at Young-Sil, where its season-long parasitism rate was only 1.5% (Table 1). It was the dominant parasite of late instars at Chunwang-Sa (peak parasitism 39% on 16 June) and the 1100 site (peak parasitism 20% on 29 June) (Fig.1).

Blepharipa schineri Mesnil [Diptera: Tachinidae] is an oligophagous, univoltine larval-pupal parasitoid which lays microtype eggs on foliage. Larvae of all ages can ingest these eggs as they feed and become parasitized, but older larvae were more heavily parasitized than younger larvae. *B. schineri* occurred in two season-long collections (Table 1), but was generally scarce with peak parasitism rates of 1.4% (n = 71) at the 1100 site and 3.8% (n = 80) at Young-sil.

Only one pupal parasite, *Lymantrichneumon disparis* (Poda) [Hymenoptera: Ichneumonidae], was recorded in the study. One pupa (out of 4 pupae collected) at the 1100 site was parasitized by this wasp (Table 1).

A mermithid nematode (probably *Hexamermis* sp.) emerged from larvae collected at all three sites. The highest season-long parasitism rate of 4.0 % was recorded at the 1100 site (Table 1), with the peak parasitism rates ranging from 1.5% at Chunwang-Sa (1/68) to 14% (13/95) at the 1100 site.

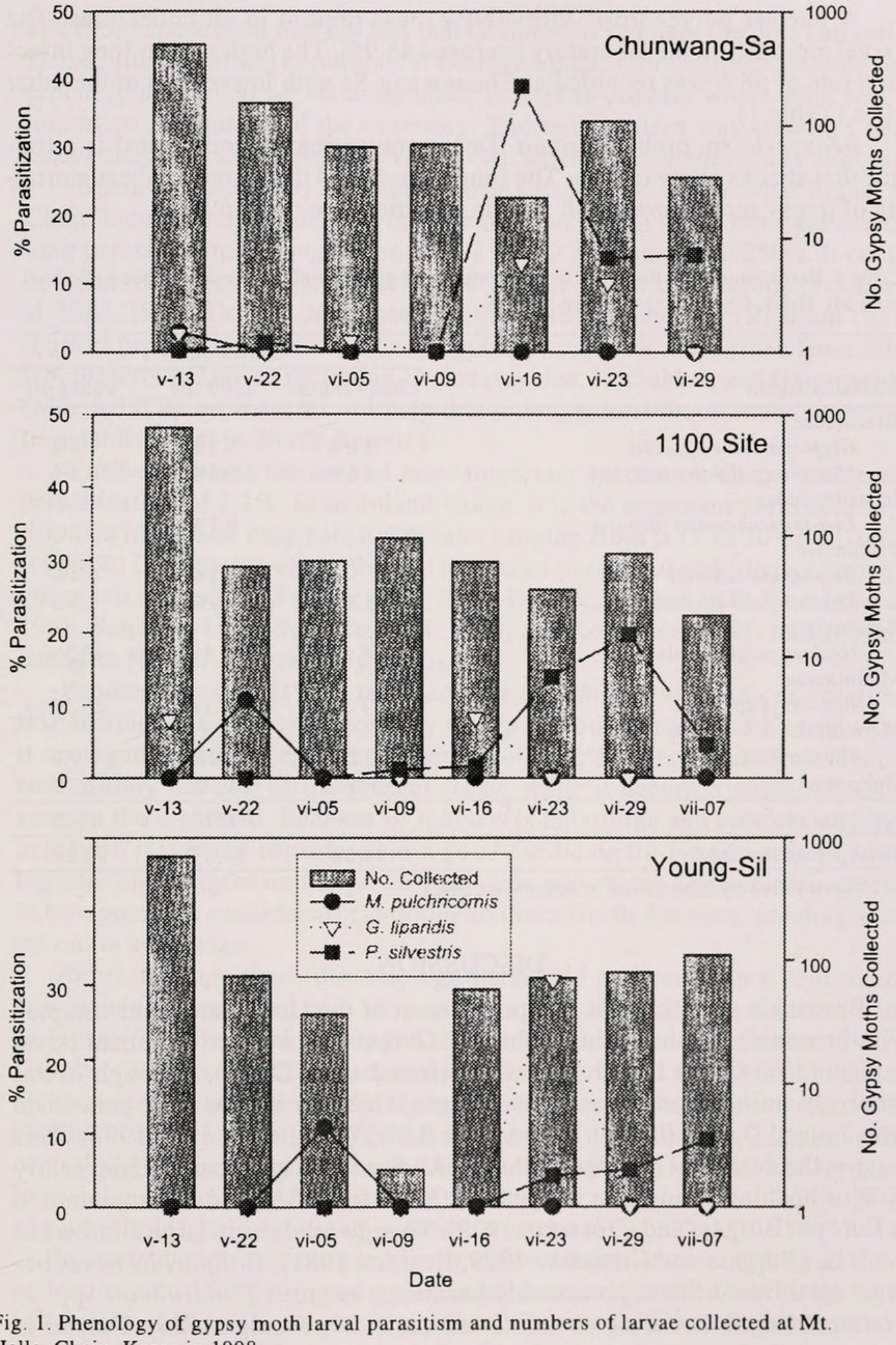

Fig. 1. Phenology of gypsy moth larval parasitism and numbers of larvae collected at Mt. Halla, Cheju, Korea in 1998.

A nuclear polyhedrosis virus (NPV) was present in all collections. The larval mortality in the laboratory averaged 48.9%. The high season-long infection rate of 68% was recorded at Chungwang-Sa with lower rates at the other sites (Table 1).

Beauveria sp. prob. *bassiana* [Deuteromycotina: Zygomycetes] is a fungus that attacks many insects. The fungus produced the second highest mortality of gypsy moth larvae with a mean infection rate of 22.6%.

Table 1. Percentage parasitism and other mortality of gypsy moth larvae and pupae collected from Mt. Halla, Cheju Island, Korea in 1998 .

	Collection sites		
Mortality Agent	Chonwang-Sa	1100 site	Young-sil
Braconidae			
Glyptapanteles liparidis	3.0%	5.7%	1.9%
Meteorus pulchricornis	1.6%	0.5%	0.4%
Ichneumonidae			
Lymantrichneumon disparis	-	0.1%	-
Tachinidae			
Blepharipa schineri	-	0.1%	0.4%
Parasetigena silvestris	3.3%	1.9%	1.5%
Baculoviridae			
Nuclear polyhedrosis virus	68.0%	32.4%	46.3%
Moniliaceae			
Beauveria sp.	17.3%	24.2%	26.3%
Mermithidae			
Unidentified sp.	0.2%	4.0%	0.9%
Unknown*	1.0%	4.2%	14.5%
No. hosts examined	965	1178	1142
Total percentage dead	94.4%	73.0%	92.2%

*Host killed by desiccation or unknown causes.

DISCUSSION

Braconids and tachinids comprised most of the larval parasitoid complex with braconids outnumbering tachinids. *G. liparidis* was the dominant larval parasitoid on Cheju Island (hereafter referred to as Cheju), although it was relatively unimportant in mainland Korea where its season-long parasitism rates ranged from 0.05 to 0.7% (mean = 0.3%) (Pemberton et al. 1993). This wasp is the dominant larval parasitoid of *L. dispar* in Japan, parasitizing nearly 50% of host larvae in some collections (Schaefer 1981), and is also common in Europe (Burgess and Crossman 1929). Though released in large numbers in the U.S. (Burgess and Crossman 1929, Reardon 1981), *G. liparidis* never became established there, presumably because it requires *Dendrolimus* spp. as overwintering hosts (Burgess and Crossman 1929, Kamiya 1938). Fuester et al. (1983) speculated that the fact that *G. liparidis* requires the pine caterpillar *Dendrolimus pini* L. (Lepidoptera: Lasiocampidae) for an overwintering host probably accounted for its dominance at sites in Austria where pine was an important component of the overstory. The same pattern was seen on Cheju; peak parasitism was highest at Young-Sil, where *P. densiflora* was common.

Mean parasitism by *M. pulchricornis* (0.9%) was somewhat higher on Cheju than on the mainland, where Pemberton et al. (1993) reported season-long parasitism rates ranging from 0.02% to 0.7% (mean = 0.25%). It occurs in Japan (Schaefer 1981), China (Schaefer et al. 1984), and Europe (Fuester et al. 1983, 1988). Despite its release in large numbers in the U.S. (Reardon 1981), it never became established. This polyphagous species is recorded from other lepidopterous families including Lasiocampidae, Noctuidae, and Geometridae (Marsh 1979), so it seems unlikely that alternate host requirements preclude its establishment in North America.

P. silvestris was the second most important species on Cheju with mean parasitization of 2.2%. In mainland Korea, it is the dominant parasitoid of *L. dispar* with season long parasitism rates ranging from 0.11 to 30.01 % (mean = 9.88%) (Pemberton et al. 1993). It is a major parasitoid of *L. dispar* throughout much of Eurasia (Fuester et al. 1983, Drea & Fuester 1979, Fuester et al. 1988, Schaefer 1981, Schaefer et al. 1984, and Kolomiets 1987) and is established in North America (Hoy 1976).

Pemberton et al. (1993) reported that *B. schineri* was the control agent responsible for most pupal mortality of gypsy moth in mainland Korea, where it averaged 37.5%, with peak parasitism of 76.2%. This tachinid was recovered at only one site in the present study, while it occurred at all collection sites on the mainland. Because *B. schineri* is univoltine and requires no alternate host, it is being considered as a good candidate for introduction as a biological control agent on Cheju. For the same reason, we consider this species to be a potential candidate for introduction into North America, pending studies on its host range.

Anastatus japonicus, the only egg parasitoid recovered on Cheju, is the dominant egg parasitoid of *L. dispar* in northern South Korea, northern parts of Japan (Schaefer et al. 1988) and the Far East of Russia (Kolomiets 1987). Despite extensive field collections (>200 egg masses from six localities), *Ooencyrtus kuvanae* (Howard) [Hymenoptera: Encyrtidae] was not recovered on Cheju. Schaefer et al. (1988) found it to be the dominant egg parasite in the central and southern parts of south Korea and in Japan on Honshu and Kyushu. In mainland Korea, it parasitized up to 10.9% of the gypsy moth eggs. Both egg parasitoids are established in North America (Hoy 1976).

In contrast to low insect parasitism, disease infection was high at all three collection sites. NPV-infected gypsy moth larvae were abundant in the field collections. Likewise, similar high mortality was recorded from laboratory rearings. However, with respect to infections by fungal pathogens, there was a disparity between laboratory rearings and field observations. High levels of fungus-induced mortality were observed in the laboratory rearings, but no fungus-infected cadavers were observed in the field during 1998, although some were seen in 1997. Thus, we conclude that fungus-induced mortality was overestimated in the laboratory rearings. The opposite situation may hold for insect parasitism, because parasitoids failed to develop successfully in diseased gypsy moth larvae. Notably absent was the fungus *Entomophaga maimaiga* (Humber, Shimazu, Soper and Hajek) [Zygomycotina: Zygomycetes] which frequently decimates high density populations in Japan (Soper et al. 1988).

Relatively high mortality was caused by nematodes at the 1100 site (mean parasitism = 2.2%), though nematode-induced mortality was rare on the mainland (Pemberton et al 1993). Biological characteristics of the nematodes recovered in this study were similar to those of the *Hexamermis* sp. reported from Japan by Schaefer and Ikebe (1982), being recovered only from host larvae collected in moist, deciduous forests. The infection period for this species was nearly the entire period of gypsy moth larval development.

The major parasitoid families attacking the gypsy moth were similar to those reported from the mainland, but the species diversity and total parasitism differed in the two separate areas. Only four species of larval parasitoids were recovered from the season-long collections at three sites on Mt. Halla, whereas the mainland study showed much higher parasitoid diversity, ranging from 7 to 12 species in season-long collections at various localities. It is noteworthy that some of the dominant larval parasitoids listed by Pemberton et al. (1993) as important control agents of *L. dispar* on the mainland [the braconids *Cotesia melanoscelus* (Ratzeburg) and *Cotesia schaeferi* (Marsh), and the ichneumonids *Phobocampe unicincta* (Gravenhorst) and *Phobocampe lymantriae* Gupta] appeared to be absent on Cheju. Likewise, only one pupal parasite, *L. disparis*, was recovered, but other species frequently reported from gypsy moth in the Far East [e.g. the chalcidid *Brachymeria lasus* (Walker) and ichneumonid *Pimpla disparis* Viereck] were not recovered. We compared our results with the previous report from mainland Korea (Pemberton et al. 1993) and found that mean total parasitism rates also differed greatly in the two studies, being only 6.8% at Mt. Halla vs. 23.7% on the mainland. In Austria, Fuester et al. (1983) found a positive correlation between the number of species of larval parasitoids recovered at a site and mean total parasitism at that site.

The composition of the gypsy moth's larval parasitoid complex changes over time, and parasitism by many species is related to the phase of the host cycle (Ticehurst et al.1978). In Austria, *G. liparidis* was the dominant parasite recovered at sites having no previous history of gypsy moth outbreaks (Fuester et al. 1983). Similar findings were obtained in our study. At Chunwang-Sa, where no high population of *L. dispar* was observed previously, we observed extraordinary high abundance of this parasitoid in 1997 and substantial parasitism in 1998 (Fig. 1). However, *P. silvestris* and NPV caused more mortality in the declining population at Chunwang-Sa in 1998. Parasitism by *P. silvestris* usually reaches maximum levels after gypsy moth populations have declined from high levels in both Europe (Glanz and Mills 1982) and North America (Ticehurst 1981, Elkinton et al. 1989).

We don't know if gypsy moth was recently introduced or native to Cheju. There were no reports of serious gypsy moth infestations until 1995, when significant damage was first observed on Cheju. Previous observations (1990) indicated the presence of very low gypsy moth populations on the island (JHL and Robert W. Pemberton, unpublished data). The lack of many parasitoid species (egg, larval, and pupal) commonly associated with *L. dispar* in the Far East suggests that Cheju Island should be considered a secondary distribution area for gypsy moth and that many of this defoliator's habitual natural enemies have lagged behind. In any case, the natural enemy complex on the island appears to be somewhat depauperate, and abiotic mortality factors probably have not compensated for the rather low mortality exerted by the complex. Thus, limited natural enemy presence owing to the island's geography has probably contributed to the recent outbreaks of *L. dispar*.

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