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Original article

Enhancing Arthropod Pitfall Trapping Efficacy with Quinone Sulfate: A Faunistic Study in Gwangneung Forest

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Abstract Pitfall traps that use ethylene glycol as a preservative solution are commonly used in arthropod research. However, a recent surge in cases involving damage to these traps by roe deer or wild boars owing to the sweet taste of ethylene glycol has prompted the addition of quinone sulfate, a substance with a pungent taste, to deter such wildlife interference. This study aimed to assess the effects of quinone sulfate on arthropods collected from pitfall traps containing ethylene glycol. We strategically positioned 50 traps using ethylene glycol alone and 50 traps containing a small amount of quinone sulfate mixed with ethylene glycol in a grid pattern for systematic sampling at the Gwangneung Forest long-term ecological research (LTER) site. Traps were collected 10 days later. The results revealed a notable effect on ants when quinone sulfate was introduced. Specifically, it decreased the number of ants. In a species-specific analysis of ants, only *Nylanderia flavipes* showed a significant decline in response to quinone sulfate, whereas other ant species remained unaffected. Additionally, among the arthropod samples obtained in this survey, we identified species or morpho-species of spiders, beetles, and ants and assessed species diversity. Consequently, the utilization of quinone sulfate should be undertaken judiciously, taking into account the specific species composition and environmental characteristics of the monitoring site. Our study also highlighted the significant response of various arthropod groups to variations in leaf litter depth, underscoring the crucial role of the leaf litter layer in providing sustenance and shelter for ground-foraging arthropods. Furthermore, we have compiled comprehensive species lists of both spiders and ants in Gwangneung forest by amalgamating data from this investigation with findings from previous studies.

Key words: Arthropoda, pitfall traps, preservatives, ethylene glycol, quinone sulfate, sampling

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INTRODUCTION

Pitfall trapping is a widely adopted technique for studying arthropod diversity and abundance and assessing arthropods as a food source for wildlife (Hohbein and Conway, 2018).

Typically, pitfall traps are recognized as an effective means of capturing ground-dwelling arthropods such as beetles, spiders, and ants (Skvarla *et al.*, 2014). When the installation period of these traps is extended, they can also collect flying insects and those inhabiting vegetation (Kwon and Park, 2005).

Incorporating attractants into pitfall traps and collecting specimens the following day is a common approach (Pacheco and Vasconcelos, 2012; Sheikh *et al.*, 2018). Unfortunately, this method is often misconstrued as a standard pitfall-trapping technique. Nonetheless, it is important to note that using attractants has the drawback of selectively capturing taxa responsive to the attractant. Therefore, researchers frequently opt for preservation solutions, such as water, salt solution, ethyl alcohol, ethylene glycol, or formalin, which have minimal to no attractive effects, in ecological research investigating arthropod communities. This facilitates random sampling and ensures a more comprehensive representation of the arthropod community (Sheikh *et al.*, 2018; Kwon *et al.*, 2022). The National Institute of Forest Science of Korea uses this trapping method to continuously monitor arthropod populations across six long-term ecological research sites (LTER) and 300 climate change monitoring sites (Lim *et al.*, 2017). The standardized trapping procedure used by the institute to investigate forest-dwelling arthropods is as follows: ethylene glycol serves as the preservative within white plastic cups, specifically outdoor lunch soup cups with a diameter of 9.5 cm and a depth of 6.5 cm, filled to about one-third capacity. The trapping period ranges from 10 to 15 d.

However, a growing issue has arisen because of the increasing population of wild animals such as roe deer and wild boars. These animals consume preserved liquid or damaged traps. Currently, damage by wild boars is particularly prevalent on Mt. Gariwang and Gwangneung, whereas damage by roe deer has been found in Jeju. In 2020, at the Jeju LTER site, out of the 100 traps set up, a staggering 55 preserved liquids were lost because of roe deer consumption. In 2018, when traps were set out in a Korean pine forest in Chuncheon, a significant number of traps were damaged by grazing goats.

A field experiment was conducted to assess the impact of a preservation solution combined with saltwater or formalin incorporating malodorous bleach, which is expected to be unappealing to wildlife, to select a preservation solution that deters wild animals (Kwon *et al.*, 2022). This study concluded that a solution comprising bleach and salt water would be a suitable choice for trap preservation, aiming to reduce damage caused by wild animals. However, concerns remain regarding whether roe deer and wild boars might still be attracted to the salt solution, necessitating further investigation to ascertain whether the unpleasant odor of bleach effectively deters them. It has been proposed that adding bitter substances, such as quinine, to ethylene glycol can deter wild animals from consuming the fluid (Hall, 1991; Skvarla *et al.*, 2014).

In forest ecosystems, the fallen leaf layer is both a habitat and food source for ground-foraging arthropods. Consequently, the depth of the fallen leaf layer plays a pivotal role in the arthropod population captured in pitfall traps. Kwon *et al.* (2013) indicated that the population of detritivorous arthropods, such as flies, increased as the depth of the leaf layer increased, whereas the number of herbivorous arthropods decreased.

Therefore, this study aimed to assess the effects of adding quinone sulfate (QS) to ethylene glycol (EG) on arthropod collection. Notably, no prior studies have addressed the influence of QS addition on arthropod collection. The central hypothesis of this study asserts that there will be no significant alteration in the arthropod population concerning group (phylum, class, order, and family) and ant population by species, even with the addition of QS to ethylene glycol. In addition, we investigated the influence of fallen leaf layer depth on the population of arthropods collected in pitfall traps and compared the distribution and diversity of spiders, beetles, and ants collected in this study with previous survey results in the same study area.

MATERIALS AND METHODS

1. Field experiment

This study was conducted at the Gwangneung LTER site (37°44′39″N, 127°9′22″E), comprising a mature deciduous forest with a rich history of over 100 years. Remarkably, this forest has been preserved by the government for approximately 500 years (Korea Forest Research Institute, 1994). Consequently, it boasts exceptional biodiversity, housing numerous rare species, such as *Callipogon relictus*, *Leptaulax koreanus*, *Dryocopus javensis richardsi*, and *Cypripedium japonicum*. The Gwangneung Forest is the epicenter of insect research, with extensive investigations on hemipterans, butterflies, moths, arachnids, ants, and beetles (Kwon *et al.*, 2021a; KNA, 2023). The dominant tree species in the forest are *Quer-*

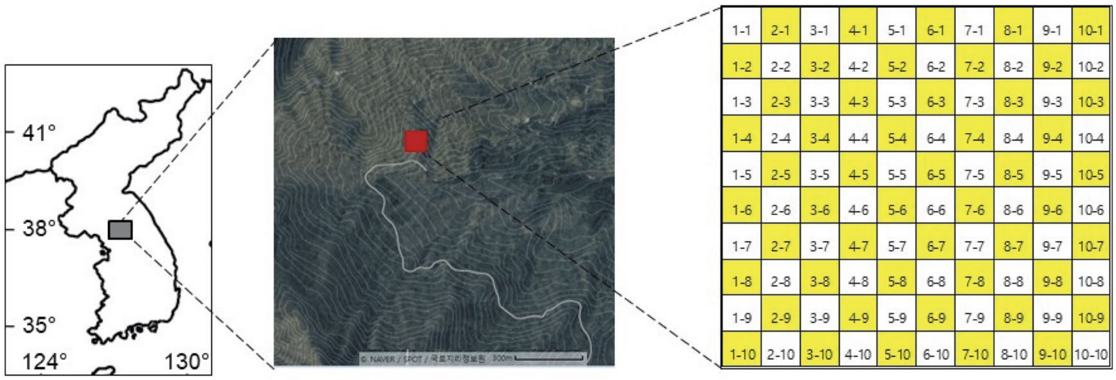

Fig. 1. Study site of Gwangneung LTER (37°44′39″N, 127°9′22″E) in South Korea with an area of 1 ha (100 m × 100 m). The numbers indicate the 100 plots (10 m × 10 m). One pitfall trap was set on the center of each plot. The yellow plots were installed with the pitfall traps with ethylene glycol (EG) added by small amount of quinone sulfate (QS), whereas the white plots were installed with those with only EG.

cus serrata and *Carpinus laxiflora*. The subtree and shrub layers are well-developed within the lower layers of the forest, although the herbaceous layer was relatively sparse. Natural dead trees are scattered throughout the study area , providing food and shelter for various arthropods. Additionally, a stream meanders through the survey area, enriching the local ecosystem. Except for the stream surroundings, the forest floor featured a well-developed layer of fallen leaves.

The survey site spanned an area of 1 ha (100 m × 100 m), subdivided into 100 plots, each measuring 10 m × 10 m, with each plot assigned a unique identifier (Fig. 1). A total of 100 traps were installed, with one trap in each plot for ten days from May 30, 2023, to June 9, 2023. Half of these traps (50) utilized ethylene glycol (EG), specifically car antifreeze (Unichem Co., Gzimcheon, 100% EG), as a preservative. The other 50 used a mixed solution containing a small amount of QS (approximately 100 mL) in EG as a preservative. The two preservation solutions were systematically arranged in a grid pattern to mitigate the potential impacts of microenvironmental factors within the survey area (Fig. 1). During the installation period, two instances of rain occurred, totaling 67 mm of precipitation. The highest recorded temperature reached 28.7°C, while the lowest was 10.3°C, with an average temperature of 20.4°C (source: https://www.weather.go.kr/).

The preservative solution within each trap was extracted using an iron mesh net, and any remaining residue was carefully stored in 100% ethyl alcohol to preserve the specimens for later identification. Springtails and mites, owing to their sheer numbers and small size, were excluded from the identification process, as counting them accurately proved challenging. Centipedes and millipedes were merged at the class level because of identification errors detected at the order level. Ants, spiders, and beetles were identified to the species or morphotype level to assess their diversity, specifically the number of species, within the LTER site. Ants were identified in each plot sample, and spiders and beetles were identified in the pooled sample. The identification process was drawn from various studies on arthropods (Choi, 1996), ants (Kwon, 2018a), beetles (Kwon *et al.*, 2018, 2019), and spiders (Namgung, 2003; Kwon, 2020). In the case of spiders and ants, a species list for Gwangneung Forest was compiled using both the existing literature (Korea Forest Research Institute, 1993; Kwon *et al.*, 2020) and the results obtained in this study.

2. Data analysis

Statistical analyses were conducted on taxa collected from more than 20 out of the 100 traps. A two-sample *t*-test was used to compare the number of individuals based on the type of preservation solution used. The influence of two key factors, the preservation solution (P) and the depth of the fallen leaf layer (L), was assessed using a generalized linear model (GLM). Four models were examined in the generalized linear model analysis.

Full model: $Y \sim P + L + P \times L$

Two-factor model: $Y \sim P + L$

One-factor model for P: $Y \sim P$

One-factor model for L: $Y \sim L$

A comparison was made among these options, considering their respective Akaike information criterion (AIC) values, with the model displaying the lowest AIC value being selected as the most appropriate model. Statistical analyses were performed using a stat package in R (R Core Team, 2020).

RESULTS AND DISCUSSION

1. Influence of QS and leaf litter depth

Damage from wild boars has occurred in this survey area in the past, but during this study, all 100 traps used were successfully collected. The total arthropod count was 13,020 individuals, representing 5 classes and 22 orders. Beetles were the most abundant, with 6,995 individuals, which constituted 54% of the total count. Ants accounted for 2,096 individuals (16%); flies for 1, 337 individuals (10%); and spiders for 832 individuals (6%). These five dominant taxa collectively account for 86% of the total arthropod population.

When comparing the number of individuals within each arthropod group between the two preservation solutions, ants were the only group that showed a significant difference. The count of ants in traps utilizing EG alone was 23.34 ± 13.30, while the count of ants in traps with the EG + QS preservative solution was significantly lower (*t*-test, $p < 0.05$) at 18.58 ± 11.42 (Table 1).

In the GLM analysis, considering both preservation solution and leaf litter depth as factors, only ants demonstrated a significant response to the type of preservation solution ($p < 0.05$) (Table 1). In contrast, the leaf litter depth significantly affected various taxa, including Araneae, Opiliones, Coleoptera, Hemiptera, Hymenoptera (excluding ants), and Diplopoda, as well as the total arthropod population.

Kwon *et al.* (2013) revealed a positive correlation between leaf litter depth and detritivorous arthropods such as Thysanoptera and Diptera, whereas plant-feeding arthropods such as Lepidoptera, Homoptera, and Orthoptera displayed a negative correlation. However, this phenomenon was not replicated in the present study. The abundance of Thysanoptera and Diptera was not significantly influenced by litter depth. In contrast, the populations of Araneae and Opiliones, both belonging to Arachnida, decreased with increasing litter depth, whereas other taxa (Coleoptera, Hemiptera, and Hymenoptera except ants, and Diplopoda) and the overall arthropod count increased. This outcome was somewhat unexpected, as an increase in leaf layer depth typically translates to more food and habitat, which should theoretically result in higher arthropod populations. Therefore, the decline in the Araneae and Opilione populations was counterintuitive to some extent.

In the analysis of ants at the species level, only *Nylanderia flavipes* displayed a noteworthy response to the preservation solution. Specifically, the abundance of *N. flavipes* in traps using only EG was recorded at 7.28 ± 5.10 per trap, whereas it was significantly lower at 4.16 ± 4.97 in traps utilizing the EG + QS preservation solution ($p < 0.05$). In contrast, the abundances of all other ant species remained unaffected by the type of preservation solution used. Thus, the discernible effect of the preservative solution on the ants was primarily attributed to *N. flavipes*. This finding aligns with a previous field experiment focusing on food attraction in ants, where *N. flavipes* was observed to be the swiftest species for attracting food (Kwon, 2018b). These results suggest that *N. flavipes* has a highly developed olfactory sense compared with other ant species.

GLM analysis, which considered the combined effects of the preservation solution and leaf litter depth, revealed significant effects of leaf litter depth on *Aphaenogaster japonica*, *Formica* spp. (*japonica* + others), *Pachycondyla javana*, and *Temnothorax nassonovi*. Among these species, only *T. nassonovi* exhibited a decrease in abundance as the leaf litter depth increased, whereas the abundance of the remaining species increased. This was somewhat unexpected because ants are both detritivores and predators, and a thicker fallen leaf layer typically provides more food and habitat, implying an overall increase in ant populations. However, species that prefer open habitats, such as *Formica* spp., *Camponotus japonicus*, and *Lasius* spp. (*japonicus* and *alienus*), were expected to have weak or negative correlations with leaf litter depth. Notably, this expected phenomenon was not observed in this study. Furthermore, the total ant abundance remained unaffected by variations in the depth of the fallen leaf layer.

2. Fauna of ants, beetles, and spiders

The primary focus of this study was not a comprehensive examination of fauna. Consequently, for groups with a high number of species and challenging identification, such as spiders and beetles, we chose to identify only those easily distinguishable at the species level. The remaining species were morphologically classified to determine the total number. In this study, we identified 84 spider, 138 beetle, and 20 ant species (Tables 2, 3, Appendix 1). Remarkably, there were records of 195 spider species living in Gwangneung For-

Table 1. Influences of quinone sulfate (QS) and leaf litter depth on pitfall trapping of arthropods. The *t*-test was used to test the influence of OS, and the generalized linear model was used to test the influences of two factors (QS and leaf litter depth). Response variables were the number from individuals of each taxon. Two statistical tests were conducted on the common taxa with 20 or more occurrences (100 × collected traps/total traps). *: $p < 0.05$, ***: $p < 0.001$

Class	Oder	Family	EG		EG + QS		*t*-test	GLM			
			Mean	SD	Mean	SD	*p*	Pr	Lt	R^2	*p*
Crustacea	Isopoda	Trachelipodidae	2.92	4.99	3.10	4.96			−0.05 ± 0.05	−0.00001	
Arachnida	Araneae		8.82	4.58	7.82	4.03			−0.09 ± 0.03	0.11	***
	Pseudoscorpiones		0.02	0.14	0.00	0.00					
	Opiliones		4.90	5.66	4.76	5.71			−0.18 ± 0.14	0.14	***
Insecta	Plecoptera		0.02	0.14	0.00	0.00					
	(Other)		0.30	0.79	0.24	0.56					
	Lepidoptera		0.52	0.84	0.70	1.13		−0.08 ± 0.1		−0.002	
	Hemiptera		0.40	0.76	0.36	0.63			0.03 ± 0.02	0.02	
	Psocoptera		0.14	0.40	0.18	0.66					
	Archaeognatha		0.78	1.13	0.88	1.85			0.01 ± 0.03	−0.009	
	Coleoptera		70.24	44.95	69.66	50.13			0.15 ± 0.04	0.14	***
	Orthoptera		0.86	1.28	0.86	1.20			0.01 ± 0.03	−0.008	
	Hymenoptera	Formicidae	23.34	13.30	18.58	11.42	*	−0.23 ± 0.12		0.03	*
		(Other)	6.04	4.44	5.62	3.40			0.1 ± 0.03	0.1	***
	Thysanoptera		0.02	0.14	0.00	0.00					
	Diptera		13.12	8.01	13.58	14.05			0.05 ± 0.03	0.007	
	Isoptera		0.02	0.14	0.00	0.00					
Diplopoda			0.80	1.88	0.74	1.66			0.06 ± 0.03	0.04	*
Chilopoda			0.20	0.49	0.26	0.56					
Arthopoda (Total)			133.46	58.11	127.34	64.50			0.08 ± 0.02	0.13	***

Table 2. Influences of quinone sulfate (QS) and leaf litter depth on pitfall trapping of ants. The *t*-test was used to test the influence of OS, and the generalized linear model was used to test the influences of two factors (QS and leaf litter depth). Response variables are number of individuals of each taxon. Two statistical tests were conducted on the common species with 20 or more occurrences (100 × collected traps/total traps). *: $p < 0.05$, ***: $p < 0.001$.

Species	EG		EG + QS		*t*-test	GLM			
	Mean	SD	Mean	SD	p	Pr	Lt	R^2	*p*
Aphaenogaster japonica	1.22	1.39	1.40	1.85			0.02 ± 0.01	0.02	
Camponotus atrox	0.02	0.14	0.12	0.44					
Camponotus japonicus	0.82	3.70	0.38	0.67			− 0.01 ± 0.01	0.001	
Camponotus kiusuensis	0.04	0.20	0.12	0.33					
Camponotus nipponensis	0.18	0.44	0.16	0.37					
Camponotus sp.	0.00	0.00	0.06	0.24					
Crematogaster matsumurai	0.04	0.20	0.10	0.36					
Crematogaster spp. (*teranishi* + *vagula*)	0.14	0.40	0.10	0.36					
Cryptone sauteri	0.00	0.00	0.02	0.14					
Dolichoderus sibiricus	0.02	0.14	0.04	0.20					
Formica spp. (*japonica* + other)	6.68	7.17	5.82	8.53			0.03 ± 0.02	0.02	
Lasius spp. (*japonicus* + alienus)	2.20	5.27	2.38	4.48			− 0.02 ± 0.02	− 0.002	
Myrmecina nipponica	0.12	0.39	0.02	0.14					
Nylanderia flavipes	7.28	5.10	4.16	4.97	***	− 0.25 ± 0.06		0.14	***
Pachycondyla javana	0.30	0.84	0.44	1.28			0.02 ± 0.01	0.03	*
Pheidole fervida	0.48	0.97	0.24	0.59		− 0.05 ± 0.03		0.01	
Ponera scabra	0.02	0.14	0.02	0.14					
Pristomyrmex pungens	0.26	1.07	0.14	0.57					
Temnothorax nassonovi	1.10	1.27	1.74	1.99		0.08 ± 0.05	− 0.02 ± 0.01	0.03	
Vollenhovia emeryi	0.10	0.46	0.16	0.71					
Total	21.02	11.53	17.62	11.20		− 0.09 ± 0.05		0.02	

est from the 1910s up to 1993 (Appendix 1). The fact that this study, representing only a single survey within a small 1-hectare area, uncovered 84 spider species is particularly noteworthy. This number accounted for 43% of the cumulative species count. These results underscore the effectiveness of pitfall traps as a robust collection method for assessing spider diversity. To provide some context, Kwon (2017) conducted a year-long survey between 1992 and 1993, setting out pitfall traps and conducting sweeps in eight coniferous forests and eight broad-leaved forests throughout the Gwangneung region. This comprehensive effort yielded 141 beetle species via pitfall traps and 166 via sweeps, amassing 271 species.

The results obtained in this study (138 beetle species) were not only closely aligned with the findings from the pitfall traps (141 species), but also represented 51% of the total species count. Cumulative survey results from Gwangneung since 1992 have identified 41 ant species. This implies that, even including ants, nearly 50% of the species could be recorded in a single survey. These results affirmed that the survey method currently used at the LTER sites, comprising 100 pitfall traps installed in late May and collected ten days later, is a suitable and effective approach for monitoring various arthropods.

The Korea Forest Research Institute (1993) published a comprehensive list of 195 spider species investigated by researchers at the National Institute of Forest Science, spanning the Japanese colonial period from the 1910s to the early 1990s (Appendix 1). Upon comparing this extensive list with the recent Korean spider list (Yoo *et al.*, 2015), it became evident that a significant number of species were not accounted for domestically (denoted by species without a country name in the table). This discrepancy can be attributed to frequent alterations in spider species nomenclature and changes in classification systems, potentially leading to the use of names that differ from those currently used. This record

Table 3. Beetle species identified in this study. EI: ecological indicator species with their abundance predicted by Kwon *et al.* (2015), D means a decrease in abundance in the future. LTER site, L1: collected by 300 pitfall traps per year in 2002~2012, L2: around or on the logs in 2007~2008, L3: this study in 2023. Other area, O1: 16 sites (8 coniferous and 8 deciduous forest) in 1992~1993. L1 was reported by Kwon *et al.* (2019), and L2 was reported by Lee *et al.* (2012). O1 was reported by Kwon (2017).

Family	Species	Korean name	EI	LTER site			Other area
				L1	L2	L3	O1
Carabidae	*Brachinus stenoderus*	꼬마목가는먼지벌레		1		1	1
Carabidae	*Chlaenius naeviger*	쌍무늬먼지벌레		1	1	1	1
Carabidae	*Coptolabrus jankowskii*	멋쟁이딱정벌레	D		1	1	1
Carabidae	*Eucarabus* spp.	우리딱정벌레	D	1	1	1	1
Carabidae	*Nebria coreica*	고려먼지벌레		1		1	1
Carabidae	*Synuchus cycloderus*	붉은칠납작먼지벌레		1	1	1	1
Carabidae	*Synuchus nitidus*	윤납작먼지벌레		1	1	1	
Carabidae	*Synuchus* spp. 2	소형납작먼지벌레류	D			1	1
Cerambycidae	*Pidonia puziloi*	넉점각시하늘소		1		1	
Curculionidae	*Asphalmus japonicus*	윤줄바구미		1	1	1	1
Discolomidae	*Aphanocephalus hemisphericus*	아기쪽박벌레				1	
Leiodidae	*Catopodes fuscifrons*	빗수염애송장벌레		1		1	
Lucanidae	*Platycerus hongwonpyoi*	원표애보라사슴벌레		1	1	1	1
Passalidae	*Leptaulax koreanus*	사슴벌레붙이		1		1	
Scarabaeidae	*Onthophagus fodiens*	모가슴소똥풍뎅이		1	1	1	1
Silphidae	*Nicrophorus quadripunctatus*	넉점박이송장벌레		1	1	1	1
Staphylinidae	*Ocypus weisei*	노랑털검정반날개	D	1		1	1
Staphylinidae	*Osorius taurus*	투구반날개		1	1	1	1
Staphylinidae	*Platydracus brevicornis*	홍딱지반날개	D	1	1	1	1
Staphylinidae	*Scaphidium amurense*	밑빠진버섯벌레		1		1	
Staphylinidae	*Scaphidium optabile*	애밑빠진버섯벌레				1	
Staphylinidae	*Tympanophorus sauteri*	큰눈점박이반날개				1	
Tenebrionidae	*Anaedius mroczkowskii*	묘향산거저리	D	1	1	1	1
Tenebrionidae	*Misolampidius* spp.	호리병거저리류	D		1	1	
Tenebrionidae	*Uloma marseuli*	민우묵거저리			1	1	
Trogidae	*Trox formosanus*	대만송장풍뎅이			1	1	

is preserved in the National Institute of Forest Science's report (Korea Forest Resrach Institute, 1994) and may pose accessibility challenges for researchers not affiliated with the institute. It is worth noting that many of the species with Korean names were absent from the recent list. This highlights the need for a comprehensive review by domestic spider taxonomists of the species listed in Appendix 1.

Ten spider species (*Comaroma maculosa*, *Drassyllus truncatus*, *Sernokorba pallidipatellis*, *Oia imadatei*, *Solenysa geumoensis*, *Helicius yaginumai*, *Pseudeuophrys iwatensis*, *Telamonia vlijmi*, *Crustulina guttata*, and *Thymoites ulleungensis*) were newly discovered in the study area, despite the focus of this study on identifying only easily recognizable species. This finding suggests that numerous spider species, not listed in Appendix 1, inhabit Gwangneung Forest. It is possible that many of the 64 unidentified species collected in this survey, represented previously undocumented species.

Beetles are relatively more straightforward to identify than other insects, such as Diptera. However, based on the extensive experience with beetle identification, it becomes apparent that achieving precise species identification is challenging. In a study in which beetle experts re-evaluated the species names of 1,249 beetle specimens previously identified by parataxonomists, including the use of morphological characteristics, the degree of agreement in species nomenclature was only 21% (Kwon *et al.*, 2019). Initially, the identification of beetle species collected from 300 forest survey sites throughout the country relied on reference specimens that

Table 4. Ant species list in the Gwangneung forest. LTER site, L1: collected by 300 pitfall traps per year in 2002~2012, L2: this study in 2023, L3: around or on the logs in 2007~2008, L4: collected from 4 vertical layers (vegetation, ground, litter, and soils) in 2012. Other area, O1: pine forest and forest gaps in the Jugyeop Mt. in 2011, O2: large forest gap and forest, collected from 4 vertical layers (vegetation, ground, litter, and soils) in 2013, O3: Korean pine forest and young plantation in 2011, O4: 8 forest sites (4 coniferous and 4 deciduous forests) in the Soribong area in 1992~1993, O5: same sites in 2009, and O6: oak forest around the peak of the Soribong in 2013 and 2014. O4 and O5 were reported by Kwon (2014), and O6 by Kwon (2018b). The remaining records were reported by Kwon (2018b).

Species	LTER site				Other area					
	L1	L2	L3	L4	O1	O2	O3	O4	O5	O6
Aphaenogaster japonica	1	1	1	1	1	1	1	1	1	1
Camponotus atrox	1	1	1	1	1	1	1	1	1	1
Camponotus japonicus	1	1	1	1	1	1	1	1	1	
Camponotus kiusuensis	1	1	1	1	1	1	1	1	1	1
Camponotus nipponensis	1	1	1	1	1	1	1		1	1
Camponotus sp.1	1	1		1						
Crematogaster matsumurai	1	1	1	1			1		1	
Crematogaster osakensis			1						1	
Crematogaster spp. (*teranishi* + *vagula*)	1	1	1	1	1	1		1		1
Cryptone sauteri	1	1	1	1		1			1	1
Dolichoderus sibiricus	1	1	1				1		1	
Formica truncorum								1		
Formica spp. (*japonica* + other)	1	1	1	1	1	1	1	1	1	1
Hypoponera sp.	1			1	1	1		1	1	
Lasius meridionalis						1				
Lasius spathepus			1		1	1		1	1	
Lasius spp. (*japonicus* + *alienus*.)	1	1	1	1	1	1	1	1	1	1
Lasius talpa			1		1	1				
Myrmecina flava						1				
Myrmecina nipponica	1	1	1	1		1	1	1	1	1
Myrmica kotokui								1		
Nylanderia flavipes	1	1	1	1	1	1	1	1	1	1
Nylanderia sakurae					1	1		1		
Pachycondyla chinensis	1		1	1	1			1	1	
Pachycondyla javana	1	1	1	1	1	1	1	1	1	1
Pheidole fervida	1	1	1	1	1	1	1	1	1	1
Polyrhachis lamellidens			1							
Ponera japonica	1		1	1		1			1	1
Ponera scabra	1	1	1	1	1	1		1	1	1
Pristomyrmex pungens	1	1	1		1	1	1			
Proceratium itoi						1				
Pyramica japonica			1			1				
Stenamma owstoni	1								1	
Strumigenys lewisi	1		1	1	1	1	1	1	1	1
Technomyrmex albipes										1
Technomyrmex gibbosus			1			1				
Temnothorax nassonovi	1	1	1	1	1	1	1	1	1	1
Temnothorax sp. 3	1		1			1				
Temnothorax sp. 4	1									
Tetramorium caespitum						1	1		1	
Vollenhovia emeryi	1	1	1	1	1	1	1	1	1	1

were determined using photographic resources (Kwon *et al.*, 2018, 2019). Subsequently, secondary identification was performed by cross-referencing the initial results with the reference specimens stored in the insect specimen repository. Secondary identification revealed that 38% of the initially identified species were incorrectly identified. This highlights the significant challenge of achieving accurate species identification based solely on photographic resources found in insect field guides without the opportunity for direct comparison with reference specimens. In the context of biodiversity studies encompassing numerous taxa, it is impractical to insist on or assume flawless species identification for every species.

Among the 138 beetle species collected in this study, we compiled a list of species (Table 3, Appendix 1) for which confident species identification could be achieved without comparison with reference specimens or assessment of genital morphology. These species are relatively common and can be found in various locations when pitfall traps are used for surveying. Notably, three of the species listed in the table represent species groups rather than distinct individual species. In the context of ecological investigations, especially in long-term monitoring studies where identification is carried out by parataxonomists such as ecologists, the use of these species groups becomes a practical alternative when closely related species share similar morphological characteristics that can only be differentiated by experts. Notably, seven of these species were designated as climate change indicator species by Kwon *et al.* (2015), with predictions concerning their future abundance and distribution changes. All seven of these species were originally northern species with a low species temperature index, which is an average based on the mean annual temperatures at their occurrence sites. These species are expected to decrease in number as the temperature increases. This observation underscores the likelihood of a significant shift in arthropod fauna owing to increasing temperatures. It is anticipated that many of the existing northern species residing in Gwangneung Forest will diminish and be replaced by new southern species because of this temperature-driven transition.

Table 4 lists the ant species collected from various surveys conducted in the Gwangneung Forest since the early 1990s. A total of 41 species have been documented, constituting a significant proportion of the ant species identified in Korea. One of the defining features of the ant fauna in Gwangneung Forest is the coexistence of cold-adapted species typically found in alpine regions and warm-adapted species that inhabit warmer southern areas. Notable cold-adapted species include *Myrmica kotokui*, *Camponotus atrox*, *Stenamma owstoni*, and *Temnothorax nassonovi*, while representative warm-adapted species include *Crematogaster osakensis*, *Pachycondyla chinensis*, *Pachycondyla javana*, and *Pristomyrmex pungens*. Kwon (2014) noted certain signs of the influence of climate change by comparing ant assemblages from the early 1990s and 2009. The most compelling evidence emerged from the absence of *M. kotokui*, a dominant alpine species found at elevations above 1000 m, in the early 1990s but not in 2009. However, *M. kotokui* was rediscovered around the forest road near the Yukrimho Reservoir and on the Bongseonsa Temple trail in Gwangneung Forest between 2016 and 2018 (Kwon, unpublished). Currently, the ant colony at Bongseonsa Temple has not been observed, and the colony of *F. truncorum*, which used to reside at the top of Sori Peak, has not been sighted since the 2010s. The red-brown *Formica* species group including *F. truncorum*, *F. sanguinea*, and *F. yessensis* often referred to as fire ants in Korea, was once common but has become increasingly elusive. Given the unique mix of cold- and warm-adapted species in Gwangneung Forest, this location presents an ideal setting for investigating the effects of climate change. Long-term monitoring data on ants from the Gwangneung LTER site are expected to contribute significantly to climate change research.

CONCLUSIONS

Our field experiment yielded valuable insights, indicating that the inclusion of quinone sulfate in ethylene glycol within pitfall traps generally has no discernible impact on arthropod collection, with the exception of ants. Notably, the addition of quinone sulfate led to a significant decrease in the abundance of ants, with the most pronounced effect observed in the ant species *Nylanderia flavipes*. This particular ant species holds paramount ecological importance as it represents the predominant and widespread ant species in Korean forests, serving as a vital indicator of climate change. Consequently, the utilization of quinone sulfate should be undertaken judiciously, taking into account the specific species composition and environmental characteristics of the monitoring site. Our study also highlighted the significant response of various arthropod groups to variations in leaf litter depth, underscoring the crucial role of the leaf litter layer in providing sustenance and shelter for ground-foraging arthropods. Furthermore, we have compiled comprehensive species lists of both spiders and ants in Gwangneung forest by amalgamating data from this investigation with findings from previous studies.

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Author contribution TSK and YSP contributed to the study conception and design. Field sampling was performed by TSK, YKP, DSL, DYL, DWS, and YSP. The research project was managed by SJK and YSP. Data management and analyses were conducted by TSK, YKP, SJK, and DYL. TSK wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Appendix 1. Spider species list in the Gwangneung forest. Record, 1: Korea Forest Research Institute (1993), 2: Kwon *et al.* (2020), 3: this study. Some of the species names in Record 1 were revised according to Yoo *et al.* (2015).

Family	Species	Korean name	Record		
			1	2	3
Agelenidae	*Agelena koreana*	고려풀거미	1		
Agelenidae	*Agelena labyrinthica*	대륙풀거미	1		
Agelenidae	*Agelena limbata*	들풀거미	1	1	
Agelenidae	*Agelena opulenta*	애풀거미	1		
Agelenidae	*Alloclubionoides lunatus*	속리가게거미	1		
Agelenidae	*Coelotes exitialis*	어리가게거미	1		
Agelenidae	*Iwogumoa songminjae*	민자가게거미	1		
Agelenidae	*Pireneitega spinivulva*	한국깔때기거미	1		
Amaurobiidae	*Titanoeca albofascita*		1		
Anapidae	*Comaroma maculosa*	갑옷도토리거미			1
Anyphaenidae	*Anyphaena pugil*	팔공거미	1		
Araneidae	*Alenatea fuscocoloratus*	먹왕거미	1		
Araneidae	*Araneus diadematus*		1		
Araneidae	*Araneus ishisawai*	부석왕거미	1		
Araneidae	*Araneus stella*	뿔왕거미	1		
Araneidae	*Araneus triguttatus*	방울왕거미	1		
Araneidae	*Araneus tsurusakii*	당왕거미	1		
Araneidae	*Araneus uyemurai*		1		
Araneidae	*Araneus ventricosus*	산왕거미	1	1	
Araneidae	*Argiope amoena*	호랑거미	1		
Araneidae	*Argiope bruennichi*	긴호랑거미	1	1	
Araneidae	*Argiope minuta*	꼬마호랑거미		1	
Araneidae	*Chorizopes nipponicus*	머리왕거미	1		
Araneidae	*Cyclosa insulena*		1		
Araneidae	*Cyclosa japonica*	복먼지거미	1	1	
Araneidae	*Cyclosa octotuberculata*	먼지거미	1	1	
Araneidae	*Cyclosa sedeculata*	넷혹먼지거미	1	1	
Araneidae	*Cyclosa valiata*	녹두먼지거미	1		
Araneidae	*Gasteracantha kuhli*	가시거미	1	1	
Araneidae	*Gibbaranea abscissus*	층층왕거미	1		
Araneidae	*Hypsosinga sanguinea*	산짜애왕거미	1		
Araneidae	*Lariniaria argiopiformis*	어리호랑거미	1		
Araneidae	*Mangora crescopicta*	무당귀털거미		1	
Araneidae	*Mangora herbeoides*	귀털거미		1	
Araneidae	*Neoscona pseudonautica*	어리집왕거미		1	
Araneidae	*Neoscona scylla*	지이어리왕거미	1	1	
Araneidae	*Neoscona semilunaris*	삼각무늬왕거미	1		
Araneidae	*Neoseona adianta*	각시어리왕거미	1		
Araneidae	*Neoseona doenitzi*	들어리왕거미	1		
Araneidae	*Neoseona mellotteei*	점연두어리왕거미	1		
Araneidae	*Neoseona nautica*	집왕거미	1		
Araneidae	*Neoseona scylloides*	연두어리왕거미	1		
Araneidae	*Neoseona subpullata*	분왕거미	1		
Araneidae	*Nephila clavata*	무당거미	1	1	
Araneidae	*Plebs sachalinensis*	북왕거미	1	1	

Appendix 1. Continued.

Family	Species	Korean name	Record		
			1	2	3
Araneidae	*Zilla astridae*		1		
Cheiracanthidae	*Chiracanthium eutittha*	농발어리염낭거미	1		
Cheiracanthidae	*Chiracanthium japonicum*	애어리염낭거미	1		
Cheiracanthidae	*Chiracanthium lascivum*	큰머리장수염낭거미	1		
Cheiracanthidae	*Chiracanthium unicum*		1		
Clubionidae	*Clubiona japonicola*	노랑염낭거미	1		
Clubionidae	*Clubiona jucunda*	살깃염낭거미	1		
Clubionidae	*Clubiona lena*		1		
Clubionidae	*Clubiona maculata*		1		
Clubionidae	*Clubiona rostrata*		1		1
Ctenidae	*Anahita fauna*	너구리거미	1	1	
Cybaeidae	*Cybaeus mosanensis*	모산굴뚝거미	1		
Dicynidae	*Dictyna felis*	잎거미	1		
Gnaphosidae	*Callilepis schuszteri*	쌍별도끼거미	1		
Gnaphosidae	*Cladothela boninensis*		1		
Gnaphosidae	*Drassodes lapidosus*		1		
Gnaphosidae	*Drassodes serratidens*		1		
Gnaphosidae	*Drassyllus biglobus*	쌍방울참매거미		1	
Gnaphosidae	*Drassyllus truncatus*	절두참매거미			1
Gnaphosidae	*Gnaphosa komprirensis*	넓적이거미	1		
Gnaphosidae	*Gnaphosa potanini*	포타닌넓적니거미		1	1
Gnaphosidae	*Poecilochroa hosiziro*		1		
Gnaphosidae	*Poecilochroa unifascigera*		1		
Gnaphosidae	*Sernokorba pallidipatellis*	석줄톱니매거미			1
Gnaphosidae	*Urozelotes rusticus*	주황염라거미	1		
Gnaphosidae	*Zelotes asiaticus*	아시아염라거미	1		
Gnaphosidae	*Zelotes pallidipatelis*	엑스표염라거미	1		
Gnaphosidae	*Zolotes x-notatus*		1		
Hahniidae	*Neoantistea quelpartensis*	제주외줄거미	1		1
Linyphiidae	*Doenitzius peniculus*	용접시거미	1		
Linyphiidae	*Doenitzius pruvus*	땅접시거미	1	1	1
Linyphiidae	*Erigone koshiensis*		1		
Linyphiidae	*Floronia exornata*	꽃접시거미	1		
Linyphiidae	*Ketambea nigripectoris*	검정접시거미	1		
Linyphiidae	*Linyphia japonica*		1		
Linyphiidae	*Linyphia montana*		1		
Linyphiidae	*Neriene albolimbata*	살촉접시거미	1	1	
Linyphiidae	*Neriene limbatinella*	쌍줄접시거미	1		
Linyphiidae	*Neriene longipedella*	농발접시거미	1	1	
Linyphiidae	*Neriene oidedicata*	고무래접시거미	1		
Linyphiidae	*Neriene radiata*	테두리접시거미	1		
Linyphiidae	*Nippononeta projecta*	뿔꼬마접시거미		1	1
Linyphiidae	*Oia imadatei*	낫애접시거미			
Linyphiidae	*Ostearius melanopygius*		1		
Linyphiidae	*Solenysa geumoensis*	금오개미시늉거미			1
Linyphiidae	*Strandella pargongensis*	팔공접시거미	1		

Appendix 1. Continued.

Family	Species	Korean name	Record		
			1	2	3
Linyphiidae	*Syedra oii*	검은눈테두리접시거미	1	1	
Linyphiidae	*Tapinopa longidens*		1		
Lycosidae	*Alopecosa hokkaidensis*		1		
Lycosidae	*Alopecosa pulverulenta*		1		
Lycosidae	*Alopecosa virgate*		1		
Lycosidae	*Arctosa diasetzuzana*		1		
Lycosidae	*Arctosa ebicha*		1		
Lycosidae	*Arctosa kwangreungensis*	광릉논늑대거미		1	1
Lycosidae	*Arctosa subamylacea*	논늑대거미		1	
Lycosidae	*Lycosa ishikarina*		1		
Lycosidae	*Lycosa suzukii*	땅늑대거미	1		
Lycosidae	*Pardosa astrigera*	별늑대거미	1	1	
Lycosidae	*Pardosa brevivulva*	뫼가시늑대거미	1	1	
Lycosidae	*Pardosa herbosa*	풀늑대거미		1	
Lycosidae	*Pardosa koponeni*	흰표늑대거미	1		
Lycosidae	*Pardosa laura*	가시늑대거미	1		
Lycosidae	*Pardosa paramushirensis*		1		
Lycosidae	*Pardosa pseudoannulata*	들늑대거미	1		
Lycosidae	*Pardosa takahashii*		1		
Lycosidae	*Pardosa t-insignita*	점짜늑대거미	1		
Lycosidae	*Pirata piraticus*	늪산적늑대거미	1		
Lycosidae	*Pirata subpiraticus*	황산적늑대거미		1	
Lycosidae	*Piratula yaginumai*	방울늑대거미	1		
Lycosidae	*Trochosa terricola*		1		
Mimetidae	*Mimetus testaceus*	큰해방거미	1		
Oonopidae	*Ischnothyreus narutomii*		1		
Oxyopidae	*Oxyopes koreanus*	분스라소니거미	1		
Oxyopidae	*Oxyopes licenti*	아기스라소니거미	1		
Oxyopidae	*Oxyopes sertatus*	낯표스라소니거미	1		
Philodromidae	*Philodromus auricomus*		1		
Philodromidae	*Philodromus spinitarsis*	나무결새우게거미		1	
Philodromidae	*Philodromus subaureolus*	갈새우게거미	1		
Philodromidae	*Philpdromus davidi*	집새우게거미	1		
Philodromidae	*Thanatus miniaceus*		1		
Philodromidae	*Thanatus nipponicus*		1		
Pholcidae	*Pholcus crypticolens*	산유령거미	1		
Pholcidae	*Pholcus manueli*	대륙유령거미	1		
Pholcidae	*Pholcus woongil*			1	
Phrurolithidae	*Phrurolithus nipponicus*		1		
Phrurolithidae	*Phrurolithus pennatus*	살깃도사거미	1	1	
Phrurolithidae	*Phrurolithus sinicus*	꼬마도사거미		1	
Pisauridae	*Dolomedes angustivirgatus*		1		
Pisauridae	*Dolomedes hercules*		1		
Pisauridae	*Dolomedes raptor*	먹닷거미	1		
Pisauridae	*Dolomedes saganus*		1		
Pisauridae	*Dolomedes sulfureus*	황닷거미	1	1	
Pisauridae	*Pisaura lama*	아기늪서성거미	1	1	

Appendix 1. Continued.

Family	Species	Korean name	Record		
			1	2	3
Salticidae	*Asianellus festivus*	산길깡충거미		1	
Salticidae	*Carrhotus xanthogramma*	털보깡충거미	1		
Salticidae	*Euophrys frontalis*		1		
Salticidae	*Euophrys undulatovittata*	번개깡충거미	1		
Salticidae	*Evarcha albaria*	흰눈썹깡충거미	1	1	
Salticidae	*Evarcha coreana*	한국흰눈썹깡충거미		1	
Salticidae	*Evarcha crassipes*		1		
Salticidae	*Evarcha flammata*		1		
Salticidae	*Hakka himeshimensis*	해안깡충거미		1	
Salticidae	*Harmochirus brachiatus*	산표깡충거미	1		
Salticidae	*Hasarius crucifer*	십자맹송깡충거미	1		
Salticidae	*Helicius yaginumai*	골풀무깡충거미			1
Salticidae	*Heliophanus ussuricus*	우수리해님깡충거미		1	
Salticidae	*Marpissa milleri*	왕깡충거미	1	1	
Salticidae	*Mendoza canestrinii*	수검은깡충거미	1		
Salticidae	*Mendoza elongata*	살깃깡충거미	1		
Salticidae	*Myrmarachne inermichelis*	각시개미거미	1		
Salticidae	*Myrmarachne japonica*	불개미깡충거미	1		
Salticidae	*Neon reticulatus*	네온깡충거미	1	1	
Salticidae	*Orienticius vulpes*			1	
Salticidae	*Phintella abnormis*	갈색눈깡충거미		1	
Salticidae	*Phintella cavaleriei*	멋쟁이눈깡충거미		1	
Salticidae	*Phitella bifurciliena*		1		
Salticidae	*Phitella difficilis*		1		
Salticidae	*Plexippoides annulipes*	큰줄무늬깡충거미	1		
Salticidae	*Plexippoides doenitzi*		1		
Salticidae	*Pseudeuophrys iwatensis*	검은머리번개깡충거미		1	
Salticidae	*Rhene atrata*	까치깡충거미	1	1	
Salticidae	*Sibianor pullus*	반고리깡충거미		1	
Salticidae	*Synagelides agoriformis*	어리개미거미	1	1	1
Salticidae	*Telamonia vlijmi*	검은날개무늬깡충거미		1	
Sparassidae	*Micrommata virescens*		1		
Sparassidae	*Sinopoda stellatops*	별농발거미	1		
Tetragnathidae	*Leucauge blanda*	중백금거미	1		
Tetragnatidae	*Leucauge celebesiana*	꼬마백금거미	1	1	
Tetragnatidae	*Menosira ornata*	가시다리거미	1		
Tetragnatidae	*Meta reticuloides*	얼룩시내거미	1		
Tetragnatidae	*Pachygnatha clercki*	턱거미	1		
Tetragnatidae	*Tetragnatha caudicula*	꼬리갈거미	1		
Tetragnatidae	*Tetragnatha extensa*	큰배갈거미	1		
Tetragnatidae	*Tetragnatha mixillosa*		1		
Tetragnatidae	*Tetragnatha praedonia*	장수갈거미	1		
Tetragnatidae	*Tetragnatha shinanoensis*	미녀갈거미		1	
Theridiidae	*Achaearanea asiatica*	주황왕눈이꼬마거미	1		
Theridiidae	*Achaearanea japonica*		1		
Theridiidae	*Achaearanea kompirensis*		1		

Appendix 1. Continued.

Family	Species	Korean name	Record		
			1	2	3
Theridiidae	*Anelosimus crassipes*	가시잎무늬꼬마거미	1		
Theridiidae	*Argyrodes cylindrogaster*	꼬리거미	1		
Theridiidae	*Coleosoma blundum*		1		
Theridiidae	*Coleosoma octomaculatum*		1		
Theridiidae	*Crustulina guttata*	점박이사마귀꼬마거미		1	
Theridiidae	*Dipoena mustelina*	게꼬마거미	1		
Theridiidae	*Enoplognatha abrupta*	가랑잎꼬마거미	1		
Theridiidae	*Episinus affinis*	뿔마름모거미	1		
Theridiidae	*Nihonhimea japonica*	점박이꼬마거미	1	1	
Theridiidae	*Paidiscura subpallens*	회색꼬마거미		1	
Theridiidae	*Parasteatoda tabulata*	큰종꼬마거미		1	
Theridiidae	*Parasteatoda tepidariorum*	말꼬마거미		1	
Theridiidae	*Phycosoma mustelinum*	게미진거미		1	
Theridiidae	*Platnickina sterninotata*	살별꼬마거미	1		
Theridiidae	*Rhomphaea sagana*	창거미		1	
Theridiidae	*Stemmops nipponicus*	검정토시꼬마거미		1	1
Theridiidae	*Takayus chikunii*	갈비꼬마거미	1		
Theridiidae	*Takayus latifolius*	넓은잎꼬마거미	1	1	
Theridiidae	*Theridion lepidariorum*		1		
Theridiidae	*Theridion pinastri*	등줄꼬마거미	1		
Theridiidae	*Theridion rapulum*	삼각점꼬마거미	1		
Theridiidae	*Theridion subadultum*	이끼꼬마거미	1		
Theridiidae	*Theridion takayense*	넉점꼬마거미	1		
Theridiidae	*Thymoites ulleungensis*	울릉코보꼬마거미			1
Theridiidae	*Yaginumena castrata*	검정미진거미	1		
Theridiidae	*Yunohamella subadulta*	이끼꼬마거미		1	
Thomisidae	*Bassaniana decorata*	나무껍질게거미	1		
Thomisidae	*Coriarachne fulvipes*	꼬마게거미	1		
Thomisidae	*Diaea subdola*	각시꽃게거미	1	1	
Thomisidae	*Lysiteles coronatus*		1		
Thomisidae	*Misumenops tricuspidatus*	꽃게거미	1		
Thomisidae	*Oxyptila decorata*	왜곤봉게거미	1		
Thomisidae	*Oxyptila striatipes*	줄연구게거미	1		
Thomisidae	*Oxytate parallela*	중국연두게거미		1	
Thomisidae	*Oxytate striatipes*	줄연두게거미		1	
Thomisidae	*Pistius undulatus*		1		
Thomisidae	*Synaema chikunii*		1		
Thomisidae	*Synaema globosum*	불짜게거미	1		
Thomisidae	*Thomisus labefactus*	살받이게거미	1		
Thomisidae	*Xysticus insulicola*	콩밭게거미	1		
Thomisidae	*Xysticus saganus*		1		
Thomosidae	*Tmarus piger*	참범게거미	1		
Thomosidae	*Tmarus rimosus*	언청이범게거미	1		
Thomosidae	*Xysticus croceus*	풀게거미	1		
Thomosidae	*Xysticus ephippiatus*	대륙게거미	1	1	1
Trachelidae	*Orthobula crucifera*	십자삼지거미	1		1

Appendix 1. Continued.

Family	Species	Korean name	Record		
			1	2	3
Trachelidae	*Trachelas japonicus*	일본괭이거미	1		
Uloboridae	*Hyptiotes affinis*	부채거미	1		
Uloboridae	*Miagrammopes orientalis*	손짓거미	1		
Uloboridae	*Octonoba sybotides*	꼽추응달거미	1		
Uloboridae	*Octonoba varians*	울도응달거미		1	
Uloboridae	*Uloborus prominens*	왕관응달거미	1		
Uloboridae	*Uloborus sinensis*		1		
Uloboridae	*Uloborus varians*	울도응달거미	1		
Uroteidae	*Uroctea limbata*	납거미	1		