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Winter Activity of Ants in an Urban Area of Western Japan

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Abstract

During winter, foraging activity of ants is considered low in temperate regions. Winter activity of ground-dwelling ants was investigated using bait traps and quadrat sampling in an urban area of Fukuoka City, western Japan. Six study sites were grouped into two categories: 4 open land types and 2 forest types. A total of 18 ant species were recorded between the end of January and beginning of March. The foraging activity of ants was generally low, except during relatively warm periods when the surface ground temperature was above 6 – 7°C or soil temperature was above 4 – 5°C. *Tetramorium tsushimae*, *Messor aciculatus*, and *Pheidole noda* were the most abundant in the open land type, whereas *Nylanderia flavipes*, *P. noda*, and *Crematogaster osakensis* were the most abundant in the forest type. Bait preference varied among the different species, e.g., *P. noda* preferred tuna over honey, whereas *N. flavipes* similarly responded to tuna and honey. This is the first detailed study on the relationship between temperature and ant activity in Japanese mainland fauna.

Introduction

In temperate regions, the foraging activity of ants generally declines during winter. Ants are thermophilic and less resistant to cold temperature. Most ant species exhibit peak activity at approximately 10℃–45℃, with dramatic decreases in the activity below 10℃ (Hőlldobler & Wilson, 1990). Although rarely observed, *Prenolepis imparis* (North America: Talbot, 1943; Fellers, 1989) and *P. nitens* (Europe: Lőrinczi, 2016) have been reported to be active during winter at approximately 2℃–3℃. In addition, *Formica polyctena* exhibited higher foraging activity between mid-November and mid-March in Slovakia (Holecová et al., 2016). Because the main islands of Japan fall within a temperate region, ant activity in these areas is expected to be low during the cold winter season. To date, 296 ant species have been known from Japan (Terayama, 2014), however, no distinct “winter ants” have been reported from the Japanese ant fauna.

Several studies on the seasonal activities of ants have been conducted in the areas of western and southern Japan. In surveys from Hiroshima focused on Argentine ants, Touyama et al. (2004) revealed that *Linepithema humile* foraged in winter during the periods when temperatures were relatively warm. According to their study, *L. humile* did not forage when the ground surface temperature was below 10℃. Working in Yambaru (Okinawa), Suwabe et al. (2009) found that indigenous ant species have an activity peak between spring and early summer, whereas alien species have a peak between late summer and winter. Yamane et al. (2004) examined seasonal changes of ants in Amami-Oshima using sugar syrup traps. They found that ant activity was low from December to March. Okinawa and Amami are located in the southern

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region of Japan, where the climate is relatively hot and wet even during winter. Few comparable studies of indigenous ants have been conducted in mainland Japan, although this region contains the majority of Japan's land area.

Within the Japanese ant fauna, several invasive alien species have been reported in recent years (*Linepithema humile* by Sugiyama, 2000; Okaue et al., 2007; *Solenopsis geminata* by Yamamoto & Hosoishi, 2010; Terayama et al., 2014). In 2017, the red imported fire ants (RIFA) *Solenopsis invicta* was found within the container yards of ports at several cities across Japan (Ministry of the Environment, Japan, 2018). Despite these sightings, it seems unlikely that *S. invicta* has successfully colonized Japan. However, the Japanese ant fauna is continuously exposed to the hazards of a potential colonization due to frequent international transportations. Because the ports are typically located near urban areas, introduced ant species may invade neighboring parks or residential areas. It is unclear whether the indigenous Japanese ant species are competitively dominant over these invasive alien species, although North American winter ant *Prenolepis imparis* could persist in spite of the presence of *Linepithema humile* (Holway et al., 2002). Shipping containers are transported through the ports year-round, suggesting that alien ant species are also delivered to Japan during the winter months, a season known to be unfavorable for indigenous ants. Open green areas covered by grassland or shrubs can easily provide a breeding ground for those alien species. Therefore, regular monitoring is required in green areas, such as parks and shrine, and residential areas to detect and prevent invasion of alien ant species. The aim of the present study was to assess the foraging activity of ground-dwelling ants in western Japan during the cold winter season. This information can contribute to the risk management of invasive alien ant species.

Materials and Methods

The studied urban areas are located in Fukuoka City, in the western part of Japan (Fig 1). The elevation at the sites ranges from 5 to 61 m a.s.l. The mean annual temperature

Fig 1. Map of the study sites in Fukuoka City, western Japan. ISL, Island-City Central Park; KAS, Kashi-Gu Shrine; HPM, Hakozaki Port Memorial Park; KYU, Kyushu University Hakozaki Campus; MMC, Momochi Central Park; MIN, Minami Park.

in Fukuoka City is approximately 16.7℃ and mean annual precipitation is 1,694 mm (Fukuoka Prefecture, 2001).

These study sites consisted of open land and forest types (Table 1). Island City Central Park (ISL), Hakozaki Port Memorial Park (HPM), Kyushu University Hakozaki Campus (KYU), and Momochi Central Park (MMC) are located in the central residential area of Fukuoka City. These four sites are artificial open spaces, where the peripheral area is predominantly grassland with planted trees and shrubs. Kashi-Gu Shrine (KAS) is a shrine founded in 724, with a woody conservation area behind the shrine. Further, Minami Park (MIN) was established on a low hill side and features a woody conservation area densely covered with high broad-leaved trees. The six study sites were grouped into one of the following two categories: open land types (ISL, HFK, KYU and MMC) and forest types (KAS and MIN). In their field surveys of ants, Ogata (1998), Park et al. (2014a, 2015b) recorded 15 species in HPM, 17 spp. in MMC, 10 spp. in KYU, 32 spp. in KAS, and 25 spp. in MIN.

Our sampling followed the design proposed by Lőrinczi (2016), but we did not use bait traps on trees owing to the lower number of planted trees at some study sites. Bait traps and quadrat sampling were used to measure the foraging activity of ants. The sampling was conducted on 17 days between January 25 and March 13, 2018 in the six study sites (Table 1). In western Japan, these are the coldest months and ant activity is essentially low (Touyama et al., 2004). For bait traps, we established three sets of baits, positioned ca. 10 m apart in all study sites. Each set consisted of five baits along a line transect at ca. 3 m intervals. We set bait, a quarter-teaspoon of tuna and honey, placed on paper filters (6 cm in diameter). Tuna and honey were placed ca. 5 cm apart from each other. The bait placed on a paper attracts not only more dominant ants, but also smaller or less aggressive species due to the oil around and under the paper (Bestelmeyer et al., 2000). In this study, we employed the baits on a paper to find those smaller or less aggressive ant species. For quadrat sampling, we established three observation plots of 50 cm × 50 cm in size, separated by ca. 15 m in all study sites.

The number of workers of each ant species was recorded for each bait and quadrat over a 3-min period every hour for 5 consecutive hours from 10 a.m. to 3 p.m. Surface ground temperature at 1 cm height above ground and soil temperature at 10 cm depth were measured with a digital thermometer (AD-5624, A&D Co. Ltd.).

Voucher ant specimens are preserved at the Institute of Tropical Agriculture, Kyushu University, Fukuoka, Japan.

Results and Discussion

Among 2550 bait traps, only 77 traps (3.0%) attracted ants during the study period (tuna, 3.7% with 48/1275 traps; honey, 2.2% with 29/1275 traps). Among 255 quadrat samplings, we observed foraging ants in 70 quadrats (27.4%).

Table 1. Location and characteristics of six study sites of urban area at Fukuoka city, Japan: a, Ogata (1998); b, Park et al. (2014a); c, Park et al. (2014b).

Code	Study site	Land use type	Vegetation type	Category	GPS	Area (m²)	Established age	Survey period in 2018	Ant species
ISL	Island-City Central Park	Urban open park	Ornamental plant	Open land	33°39'52"N 135°25'15"E	100,000	2005	26th Jan., 9th, 27th Feb.	
HPM	Hakozaki Port Memorial Park	Urban open park	Ornamental plant	Open land	33°38'02"N 130°25'06"E	10,051	1973	25th, 31st Jan., 14th Feb., 6th Mar.	15[c]
MMC	Momochi Central Park	Urban open park	Ornamental plant	Open land	33°35'17"N 130°21'02"E	40,013	1988	8th, 26th Feb.	17[a,b,c]
KYU	Kyushu University, Hakozaki Campus	Urban open area	Ornamental plant	Open land	33°37'46"N 130°25'33"E	426,000	1911	13rd, 21st Feb., 7th Mar.	10[c]
MIN	Minami Park	Urban forest park	Evergreen forest	Forest	33°34'25"N 130°23'14"E	280,369	1941	23rd Feb., 13th Mar.	25[a,b]
KAS	Kashi-Gu Shrine	Shrine	Evergreen forest	Forest	33°39'12"N 130°27'10"E	NA	724	1st, 20th Feb., 2nd Mar.	32[c]

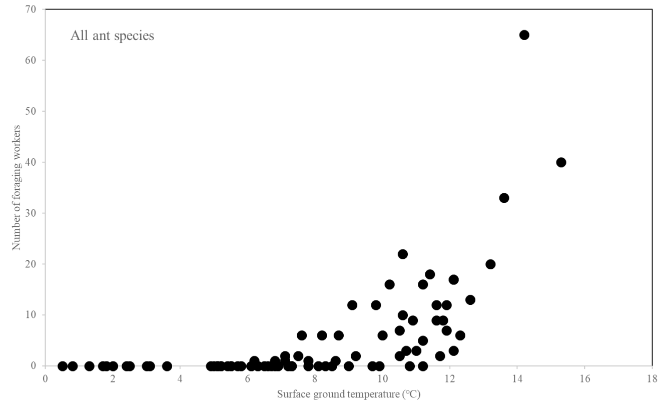

Fig 2. Abundance of foraging worker ants relative to surface ground temperature between January 25 and March 13, 2018. Abundances of 18 ant species are plotted together.

Further, a total of 435 worker ants (bait, 218 individuals; quadrat, 217 individuals) were observed during this study, belonging to 14 genera and 18 species (Table 2). The most abundant species at the open land types were *Tetramorium tsushimae*, *Messor aciculatus*, and *Pheidole noda*. On the other hand, *Nylanderia flavipes, P. noda*, and *Crematogaster osakensis* were most abundant at the forest types.

Table 2. Occurrence of ants in winter season between January 25 and March 13, 2018.

Species	ISL	HPM	KAS	KYU	MIN	MMC
DOLICHODERINAE						
Ochetellus glaber	x					
Tapinoma saohime	x					
FORMICINAE						
Formica hayashi					x	
Formica japonica		x				
Lasius japonicus						x
Nylanderia amia	x					x
Nylanderia flavipes			x		x	
MYRMICINAE						
Aphaenogaster famelica					x	
Crematogaster osakensis			x		x	
Messor aciculatus				x		x
Pheidole noda	x		x	x		x
Pristomyrmex punctatus				x		
Strumigenys lewisi					x	
Temnothorax congruus	x					
Temnothorax spinosior				x		
Tetramorium bicarinatum						x
Tetramorium tsushimae	x	x		x		
PONERINAE						
Brachyponera chinensis		x				x
Total number of species richness	6	3	3	5	5	6

Overall, the bait and survey data revealed low levels of winter foraging activity of the indigenous ants of western Japan (Fig 2). Although no winter ants such as *P. nitens* and *P. imparis* have been found in Fukuoka, western Japan, some Japanese ant species indicated the temperature-related foraging patterns in the area during winter. Figure 3 shows the activity patterns observed for the five most abundant species during the study period. We could not detect distinct activity patterns for the remaining less abundant species due to a lack of sufficient data. Foraging activities of worker ants were positively correlated with surface ground temperature (Spearman's rank correlation ($n = 85$), $rs = 0.44$, $p < 0.01$ for *T. tsushimae*; $rs = 0.30$, $p < 0.01$ for *P. noda*; $rs = 0.31$, $p < 0.01$ for *M. aciculatus*; $rs = 0.37$, $p < 0.01$ for *N. flavipes*; and $rs = 0.36$, $p < 0.01$ for *C. osakensis*). As our analyses did not show a significant relationship between foraging activity and soil temperature for *N. flavipes* and *C. osakensis*, we used the relationship between foraging activity and surface ground temperature. The respective lowest surface ground temperature at which worker ants were active was as follows: *T. tsushimae*, 11℃–12℃ at the baits and 8℃–9℃ in the quadrats; *P. noda*, 7℃–8℃ at the baits and 7℃–8℃ in the quadrats; *M. aciculatus*, 11℃–12℃ at the baits and 6℃–7℃ in the quadrats; *N. flavipes*, 8℃–9℃ at the baits and no data available in the quadrats; *C. osakensis*, 13℃–14℃ at the baits and at 11℃–12 ℃ in the quadrats (Fig 3).

Overall, the bait traps did not strongly attract ants during the studied winter season. Bait preference slightly varied among the observed species. *Nylanderia flavipes* did not show a distinct preference for tuna or honey baits (Wilcoxon signed rank test, $T = 16$, $p = 0.82$, $n = 8$), whereas *P. noda* preferred tuna baits over honey baits (Wilcoxon signed rank test, $T = 0$, $p < 0.01$, $n = 10$). The bait preferences were not available for the remaining species due to a lack of sufficient data.

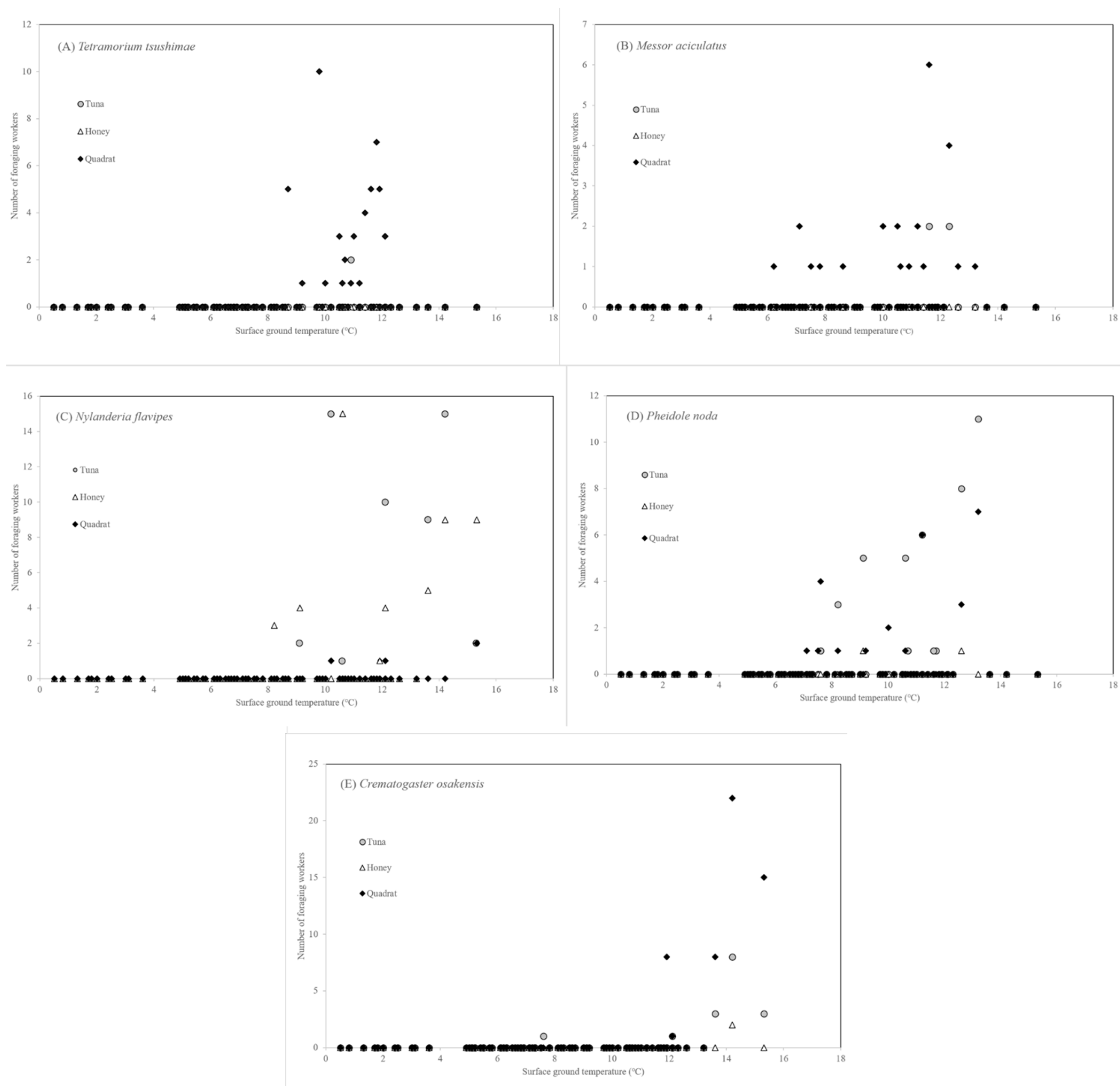

Fig 3. Winter activity patterns of the five most abundant ant species to surface ground temperature between January 25 and March 13, 2018. (A), *Tetramorium tsushimae*; (B), *Messor aciculatus*; (C), *Nylanderia flavipes*; (D), *Pheidole noda*; (E), *Crematogaster osakensis*.

The five most abundant species in this study are also the most common ant species observed in the study area during spring to autumn (Ogata et al., 1998; Park et al., 2014a, 2014b). The number of ant species observed at each study site represented ca. 20%–50% of the total documented fauna at the open land types and ca. 9%–20% of the species diversity documented at the forest types. Although the sampling effort differed among the study sites, ant activities seemed to be higher at the open land types than at the forest types. These differences might be driven by the higher number of disturbance-associated species found in the open land types.

Foraging activity patterns of ants differed among species (Fig 3). Briese and Macauley (1980) found a close relationship between foraging activity and soil surface temperature for harvester and non-harvester ants in semi-arid Australia. They documented active ant foraging at soil surface temperature above 10℃–15℃. Some species, e.g., *Odontomachus* sp. and *Camponotus* sp. A became active above 10℃, whereas *Camponotus* sp. B foraged above 17℃–18℃ (Briese and Macauley 1980). Similarly, our results indicate slight differences among species. In particular, *T. tsushimae*, *M. aciculatus*, *P. noda* and *N. flavipes* foraged at lower temperatures, whereas *C. osakensis* foraged at higher temperature (Fig 3).

The bait preferences of foraging ants depend on their nutritional needs and the condition in the nest. Ant workers select carbohydrate-rich honey to accelerate their activity and collect proteinaceous tuna to develop broods (Cook et al., 2010). It should be noted that we did not continuously observe each colony and the following discussion is based on the limited number of observations and mixed samples. The alates of *N. flavipes* are produced in May-June (Japanese Ant Database Group, 2008), suggesting that their colonies need proteinaceous foods during winter to spring. Our study showed that *N. flavipes* equally preferred tuna and honey during the study period. Few carbohydrate-rich foods are available during winter. Honey was carried to worker ants to accelerate foraging and then tuna was provided for brood development. The ants' foraging activities seem to be supported by a larger number of worker ants. *Pheidole noda* distinctly preferred tuna over honey, suggesting that the colonies of this species were inclined to brood development using a smaller number of foraging workers during winter.

Generally, the quadrat observations revealed higher number of individuals than those observed using the bait traps. In the quadrat surveys, no foraging worker ants were observed carrying prey items in our study. However, Lőrinczi (2016) found several foraging workers of *P. nitens* carrying small invertebrates such as springtails and potworms. We found several workers of *T. tsushimae* and *Ochetellus glaber* on the ground or on stones during sunny days. Blatrix et al. (2016) suggested a radiant-energy hypothesis, proposing that the radiant energy that heats foraging substrates is among the factors most constraining ant community diversity. Both ant species, *T. tsushimae* and *O. glaber*, possibly use radiant energy for foraging outside during winter.

Invasive alien ant species exhibit temperature-related foraging patterns. *Linepithema humile* was active at ground surface temperatures above 10℃ in Hiroshima (Touyama et al., 2004), *S. invicta* at ground surface temperature above 10℃ in Texas (Wuellner & Saunders, 2003) or soil temperature above 15℃ in Florida (Porter & Tschinkel, 1987), and *S. geminata* at ground surface temperature above 15℃ in Texas (Wuellner & Saunders, 2003). The Ministry of the Environment, Japan (2018) conducted the surveys using bait traps for alien ants in several Japanese ports in February 2018, but they did not find the alien *Solenopsis* species during winter sampling periods. The results of the present study support the finding of Touyama et al. (2004) that ant activity is almost zero below 10℃ duirng winter in mainland Japan. This suggests that colony budding or foraging outside the nest are presumably difficult for *S. invicta* and *S. geminata* during winter. If the two *Solenopsis* spp. inhabiting shipping containers venture outside the nest during winter, they will encounter the five most abundant ant species reported in this study. Local ant fauna and activities should be investigated in the cold winter season when ant activity is low. The ant fauna of western mainland Japan is generally similar to that of eastern mainland Japan, but the fauna is quite different in northeastern or southern mainland Japan. The information provided by surveys such as those presented in this study will provide a foundational data set for the risk management of invasive alien ant species.

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Authors' Contribution

SH, MMR, TM conceived and designed the study; SHP, YK provided samples. SH, MMR performed experiments and analysis; SH analyzed the results. SH, MMR, KO led the writing. All authors read, discussed and approved the final manuscript.

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