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Foraging activity of competing ants along altitudinal gradient on a high mountain, South Korea

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ABSTRACT

The population of *Myrmica* ants, which is most abundant in high altitudinal areas in South Korea, is expected to decrease significantly due to climatic warming, whereas *Aphaenogaster japonica* population is expected to increase in these areas. The two ant groups are similar in shape, size, and ecology, indicating intensive competition in overlapping areas. To determine the foraging activities of the two groups and their competitions, I investigated the ants at a high mountain (Mt. Gyebangsan) during two ant foraging seasons (2010 and 2011) using pitfall traps and bait traps along altitudinal gradients. Two *Myrmica* species (*kotokui* and *kurokii*) were present between 800 m to 1577 m, whereas *A. japonica* appeared up to 1200 m. Fights between ants were observed 22 times and fights between these two ant groups were most frequently found. Food discovery speed is higher in *Myrmica* species than in *A. japonica*. The food discovery capability and the nestmate recruitment were not different between *A. japonica* and *Myrmica* species.

Introduction

Insects are increasingly shifting their ranges northwards and upwards in the Northern Hemisphere due to global warming (Perry et al., 2005; Hickling et al., 2006; Hitch and Leberg, 2007; Kwon et al., 2014b). Ants in South Korea are also expected to shift their distributions northwards and upwards (Kwon et al., 2014c; Kwon and Lee, 2015). These studies predicted that ant fauna will change significantly in highlands due to range shifts. *Myrmica* ants, which are most abundant in high altitudinal areas in South Korea, will nearly disappear in those areas by 2060s, and will be replaced by *Aphaenogaster japonica*, which is currently more abundant in lowlands (Kwon et al., 2014c). It was recently found that *A. japonica* shifted upwards in Mt. Hanla in Jeju Island, South Korea (Chun et al., 2014). Interestingly, *A. japonica* is similar to the *Myrmica* species in shape and size, which indicates a niche overlap and intensive competition. *Myrmica* ants are hosts of parasitic *Maculinea* butterflies, so their populations are key to the survival of *Maculinea* species (Elmes et al., 1998). Therefore, three *Maculinea* species found in South Korean highlands (Kim et al., 2012) will be severely endangered by the decline of these *Myrmica* ants (Choi and Kim, 2012).

In North America, *Aphaenogaster* species are major herb seed dispersers in temperate forests (Giladi, 2006; Ness et al., 2009). *Aphaenogaster japonica* and *Myrmica ruginodis* transport seeds of a herb species (*Trillium tschnoskii*) in Japan (Higashi et al., 1989). The expected ant transition from *Myrmica* species to *A. japonica* will lead to a diverse effect on living organisms in Korean highlands. Trade-off between behavior dominance (interference) and food discovery rate (exploitation) was reported in various ant assemblages (Fellers, 1987; Lach, 2005). Behaviorally dominant ants are usually slow in finding foods whereas subordinate ants are quick. Tradeoff between behavior dominance and thermal tolerance was also reported in ants; subordinate ants are more tolerable to extreme temperatures (hot or cold) compared to dominant ants (Cerdá et al., 1998; Bestelmeyer, 2000; Lessard et al., 2009; Stuble et al., 2013). Master ants of all skills will always win in food competitions and eliminate other ants, resulting in disruption of interspecific balance. Therefore, these tradeoffs allow subordinate ants to coexist with superior ants in the same space (Adler et al., 2007).

Due to the dominance–thermal tolerance trade-off, *A. japonica* is expected to be competitively dominant over *Myrmica* species because the latter are more tolerable to colder condition than the former (Kwon et al., 2012). However, *A. japonica* is expected to be slower and less efficient in finding foods compared to *Myrmica* species due to the dominance–exploitation trade-off. The foraging activity of *A. japonica* may be more seasonally limited at high elevation compared to that of *Myrmica* species because the former is more warm-adapted than the latter. To test these predictions, I investigated the ants at a high mountain (Mt. Gyebangsan) during two ant foraging seasons (2010 and 2011) using pitfall traps and bait traps. Since these ants are influential insects in Korean highlands as noted above, ecological information (i.e., ranges, phenology, competition, etc.) on them provides baseline data for the prediction of the future forest ecosystem.

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Materials and methods

Study sites

Mt. Gyebangsan, with peak elevation of 1579 m, is one of the highest mountains in the north eastern mountain ranges of South Korea, located at N 37° 42~46" and E 128° 26~30" (Hwang et al., 2013). Part of the high elevation area is protected as a forest gene resource conservation area by the Korea Forest Service (Hwang et al., 2013), and part is designated as a conservation area in Odaesan National Park. The vegetation is northern temperate forest, dominated by *Quercus mongolica* (Shin et al., 2008). For a 9 year period since 1998, the annual average temperature in the area was 8.1 °C and the annual precipitation was 1483 mm according to the automatic Korea Forest Research Institute weather station in the Sucheong valley (Shin et al., 2008). Ten sampling sites for pitfall trapping were selected along the tracking road from the parking place (N 37.690288°, E 128.469242°, a.s.l. 749 m) to the top of the mountain (N 37.728242°, E128.465533°, a.s.l. 1579 m) for the purpose of identifying the altitudinal range of each species. Within the 200 m altitudinal range from 1000 m to 1200 m elevation where *A. japonica* and *Myrmica* species co-occur (Table 1), five study sites were selected at intervals of 50 m elevation for the foraging activity and ant interaction study, with elevation and vegetation taken into account. The five sites were in an oak forest (dominant tree species, *Quercus mongolica*) with moderate understory vegetation and completely covered litter layers. The slopes of the sites were 10–30° and westward.

Ant survey

To find the altitudinal ranges of ant species, ants were collected with pitfall traps at 10 sampling sites located at intervals of 100 m or 50 m elevation (Table 1). Ten pitfall traps (diameter 9.5 cm, 7 cm deep) were buried linearly with an interval of 5 m for a period of 10 days. Pitfall traps had been filled up one third with propylene glycol as a conservative agent for ant samples. The pitfall trapping was conducted in July 2010 (most sites) or in July 2011 (1050 and 1150 m sites). Ants were collected by pitfall traps for 2 weeks. Ant species were identified using the key by Kwon et al. (2012).

Bait traps are widely used for fauna surveys and ants competition studies (Fellers, 1987; Cerdá et al., 1998; Kwon, 2010). In a preliminary experiment at the study site (1000 m), pupae of *Bombyx mori*, which is a popular secondary food for Korean people, was more attractive to ants than tuna and fly larvae (*Musca domestica*), so it was used as bait in this field experiment. Ten acryl boards (15 cm × 15 cm) with three moth pupae (each about 0.85 g) were placed linearly on the ground with an interval of 5 m. After the bait setting, ants on the board were monitored twice at 5 min and at 20 min because ants are abundantly attracted toward baits within 20 min (Kwon, 2010). The baiting survey was performed for a short, warm period (10:00 to 16:00) in high elevation at five sites along the elevation gradient because active ant foraging is limited by low temperature at high elevations.

I recorded the total number of ants as well as the number of ants fighting for 20 s on each board. In interspecific fights, winning species and defeated species were recorded. Ant species that were repulse, disabled, killed or carried away by opponents after the fight were classified as defeated, whereas the opponent species were classified as winners. Ongoing fights with no results during the observation period were classified as neutral. Two *Myrmica* species (*kotokui*, and *kurokii*) could not be identified at the species level in the field, so they were treated as a species group (*Myrmica* spp.). The baiting survey was conducted biweekly from early May to mid-October in 2011, except in July (rainy season) when one survey was conducted. During the baiting season, pitfall surveys were also conducted at the baiting sites. Ant specimens from the pitfall and bait surveys were deposited at the forest ecology laboratory in the Korea Forest Research Institute.

Data analysis

Occurrences in pitfall traps represent the relative abundance of ants, whereas those in bait traps indicate the response of ants toward food. Hence, comparison of occurrences between pitfall traps and bait traps indicate the food discovery capability (FDC) of ants (Cerdá et al., 1998). The FDC of each species was estimated with the following equation: 2 × (occurrence on bait traps) / (occurrence on bait traps + occurrence in pitfall traps), where occurrence is the number of occurred traps. Food discovery speed was estimated as food discovery time (FDT) per ant which was calculated with the following equation: $(5 * N_5 + 20 * N_{20}) / N_t$, where N_5 = no. of ants in 5 min, N_{20} = no. of ants in 20 min, and $N_t = N_5 + N_{20}$. This metric is a mean time of ants for arriving at foods. Data obtained during the warm season (i.e., from middle May to early September) was used to measure FDT. Recruitment of nestmates was estimated with the following equation: $(N_{20} - N_5) / N_5$. For this measure, only the data from bait cards where N_{20} surpassed N_5 and where N_5 was not zero was used. Although nestmate recruitment may be affected by nest distance, it was very unlikely that the nest distance was significantly different between two species because pitfall traps were constructed in regular interval without considering ant nests. Colony size may influence the recruitment, but its influence might not be great because the colony sizes of two species are small and similar (Kwon, personal observation). One-way ANOVA was used to test influence of altitude and time on abundance (pitfall traps and bait traps), whereas two-way ANOVA was used to test influences of species, altitude and their interaction on FDC, FDT, and nest recruitment (Table 2). The Tukey post-hoc test was

Table 1
Ants collected at 10 sampling sites along the altitudinal gradient on Mt. Gyebangsan, South Korea. In each site, ants were collected in 10 pitfall traps which had been kept on the ground for 10 days in July 2010 (most sites) or in July 2011 (1050 m and 1150 m sites). The pitfall traps were placed linearly with an interval of 5 m.

Species	Elevation (m)										Total	%
	800	900	1000	1050	1100	1150	1200	1300	1400	1577		
Ponera japonica	3										3	0.4
Pheidole fervida	34	17	14		2						67	8.9
Nylanderia flavipes	53	1	3		1						58	7.7
Stenamma owstoni	7	5	4	2	2						2	0.3
Aphaenogaster japonica	13	19	39	6	13		4				94	12.5
Camponotus atrox		1							1		2	0.3
Temnothorax nassonovi			15	2	12	1	1				31	4.1
Lasius spp. (*jap.* + *al.*)				3	5		1				9	1.2
Lasius spathepus					3						3	0.4
Myrmica kotokui	33	2	30	46	36	12	34	17	35	20	265	35.2
Myrmica kurokii			3	4	18	7	14	11	1	90	148	19.7
Formica japonica										70	70	9.3
Number of species	6	6	7	6	9	3	5	2	3	3	12	
Number of individuals	143	45	108	63	92	20	54	28	37	180	752	