Sociobiology 73(1): e11872 (March, 2026) DOI: 10.13102/sociobiology.v73i1.11872

Sociobiology
An international journal on social insects

RESEARCH ARTICLE - ANTS

Pheidole obscurithorax Naves, 1985 (Hymenoptera: Formicidae) as a Key Species in Detecting and Removing Food Waste in Urban Areas

Matheus S. R. Fernandes[1,3], Eder C. B. De França[2], Cecília B. De Albuquerque[3], Jarbas M. Queiroz[4]

1 - Programa de Pós-Graduação em Biologia Animal, ICBS, UFRRJ, Seropédica-RJ, Brazil
2 - Programa de Pós-Graduação em Entomologia, UFPR, Curitiba-PR, Brazil
3 - Laboratório de Ecologia, Conservação e Mirmecologia, DCA, UFRRJ, Seropédica-RJ, Brazil
4 - Departamento de Ciências Ambientais, IF, UFRRJ, Seropédica-RJ, Brazil

Article History

Edited by
Evandro Nascimento Silva, UEFS, Brazil

Received	30 June 2025
Initial acceptance	03 December 2025
Final acceptance	06 January 2026
Publication date	12 March 2026

Keywords
Ecosystem service, Urban environments, Ant ecology.

Corresponding author
Matheus S. R. Fernandes
Programa de Pós-Graduação em Biologia Animal, ICBS, UFRRJ, Seropédica-RJ, Brasil.
E-Mail: matheusraccafernandes@gmail.com

Abstract

Ants are essential components in the maintenance of ecosystem services in natural systems, contributing significantly to ecosystem stability. In urban environments, they play a key role in the removal and recycling of organic matter accumulated in densely populated areas, providing a service that is crucial for both public health and environmental quality. In this study, we investigated differences in ant communities and the ecosystem services they provide across two contrasting urbanized environments in southeastern Brazil. To evaluate ant functional efficiency, we used two metrics: discovery time (DT) and total removal time (TRT) of food waste. Urban environments with higher levels of human intervention exhibited greater ant activity compared to those with lower levels of disturbance. No statistically significant differences in species diversity were found between the two urban habitat types. The results showed that the mean DT was approximately 40% lower in highly disturbed areas. A positive association was observed between the presence of Pheidole obscurithorax and the proportion of food stations removed within and after 30 minutes, highlighting the key role of this species in food waste detection and removal in urban settings.

Introduction

Ants (Hymenoptera: Formicidae) play a pivotal role in maintaining various ecological processes, such as nutrient cycling, organic matter decomposition, and soil formation (Folgarait, 1998; Del Toro et al., 2012; Perfecto & Philpott, 2023). In tropical forests, for instance, ants are responsible for removing and recycling more than 50% of the available food resources, surpassing other arthropod groups and even vertebrates in this process (Griffiths et al., 2018). These animals are opportunistic and generalist, with a remarkable ability to locate resources, making them functionally irreplaceable in natural ecosystems. The proper functioning and stability of ecosystems depend heavily on the ecological services provided by ants (Hölldobler & Wilson, 1990; Lavelle et al., 2006).

The high adaptability of ants, combined with dispersal and introduction facilitated by human activities, has enabled them to successfully establish populations in urban environments. Their presence is notably diverse and abundant across a wide range of habitats, from public green spaces to build structures and domestic interiors (McGlynn, 1999; Kamura et al., 2007; Santos, Delabie & Queiroz, 2019). The interplay of biotic and abiotic factors, alongside the historical, structural, and social characteristics of cities, plays a crucial role in the survival of species, creating unique microhabitats that shape populations, influence physicochemical processes, and alter ecological relationships (McKinney, 2008; Aronson et al., 2016; Liu et al., 2019).

In urban ecosystems, ants can play positive roles, such as recycling improperly discarded food and providing

Open access journal: http://periodicos.uefs.br/index.php/sociobiology
ISSN: 0361-6525

essential services to both the environment and public health (Gómez-Baggethun et al., 2013; Perfecto & Philpott, 2023). According to Hosaka et al. (2019), the rate of food removal in suburban and urban habitats, managed by ants, may be comparable to that observed in natural environments. In some cases, the presence of particular species can have a more significant impact than species diversity in urban areas, increasing the food removal capacity and promoting waste recycling at rates up to two or three times higher than usual (Youngsteadt et al., 2015).

In addition to contributing to urban waste recycling, ants in urban areas are equally effective at removing organic matter not directly associated with human activities. The accumulation of invertebrate carcasses in urban fragments is primarily removed by necrophagous ants, which often dominate this process in comparison to other necrophagous arthropod groups, such as flies and cockroaches, which have medical and sanitary importance (Tan & Corlett, 2012; Ashigar & Ab Majid, 2020). Aggressive behavior and large-scale foraging, common in some urban ant species, increase their capacity to remove resources (Wilson, 2003; Penick et al., 2015; Youngsteadt et al., 2015). These findings emphasize the importance of dominant generalist species in urban ecosystems – such as certain species of the genera *Pheidole* and *Solenopsis*, which are commonly dominant in urban areas and known for their behavioral plasticity and ecological importance, particularly in tropical ecosystems (Chen & Neoh, 2023; Ashigar & Ab Majid, 2020).

While the number of studies examining the ecological services provided by ants in urban ecosystems has increased in recent years, a significant gap still exists in understanding how these processes function in urban environments, particularly in tropical regions. Most studies have focused on how urbanization affects ant biodiversity and abundance (Santos, 2016; Laakel et al., 2024; Lanhoso et al., 2024; Orivel et al., 2025). However, this approach, which emphasizes diversity and abundance, misses key insights into the functional significance of ants in anthropogenic habitats.

In this study, we investigated differences in ant communities and the ecosystem services they provide across two contrasting urban sites: one with low levels of human intervention and the other with high levels. To assess their functional efficiency, we employed two metrics: discovery time and total food resource removal time. The following hypotheses were tested in this study: 1) the richness and species composition of the ant community are affected by the level of human intervention in the environment; 2) ants display variations in foraging behavior, providing ecosystem services that can be detected even in micro-temporal analyses; 3) the higher functional diversity of ant species in spaces with low human intervention results in greater efficiency in the discovery and removal of food resources compared to the high human intervention spaces. Therefore, we aimed to understand how ant species behave at a microtemporal scale across different environments and, consequently, to contribute to understanding the ecosystem services they can provide in urban spaces.

Materials and methods

Study site

This study was conducted on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ), located in the municipality of Seropédica, in the state of Rio de Janeiro (RJ), Brazil (22°45’56”S; 43°41’33”W). The campus features colonial-style buildings with internal gardens, which are surrounded by extensive open green areas and forested zones. The local climate is classified as tropical, with an average annual temperature of 24 °C and average annual precipitation of 1,260 mm (Alvares et al., 2013).

Six sampling areas were selected for this study (Fig 1A): three internal gardens (Institute of Biology (IB), Institute of Chemistry (IC), and Central Pavilion (CP)); and three open areas densely covered by trees, shrubs, and herbs (Botanical Garden (BG), Student’s Residence Halls (DAF), and Central Library (CL)). These sites were grouped into two environmental categories: (I) High Human Intervention Environments (HHI) and (II) Low Human Intervention Environments (LHI). The IB, IC, and CP sites were classified as HHI, characterized by the presence of ornamental vegetation (trees, shrubs, herbaceous plants, most exotic) and urban infrastructure such as sidewalks, concrete surfaces, and constructed borders (Fig 1 B, C, D). In contrast, BG, DAF, and CL were classified as LHI, with more abundant and spontaneous vegetation, most native, lacking paved surfaces or formal infrastructure (Fig 1 E, F, G).

Abiotic factors

Temperature and humidity were measured at each sampling site with a digital Thermo-Hygro-Anemometer-Luxmeter (LM8000). Each factor was measured three times to obtain an average value – once at the beginning, once during, and once at the end of the experimental period.

To indicate exposure conditions, each food station was classified as either in sunlight or in shade, depending on its position. On fully overcast days, food stations were in the shade because there was no direct sunlight on the acetate plate.

Ant community structure and functional diversity

To assess ant diversity and activity in each environment, five pitfall traps were installed per site between 18 and 19 November 2024, yielding 30 samples (15 for HHI and 15 for LHI environments). The placement of the traps was based on the geographic dimensions of each area and on the previously established transects for ecosystem service sampling. All traps were removed 24 hours after installation. Ants collected from the traps were counted, preserved in 70% ethanol, and identified to the lowest possible taxonomic level following the complete sorting of material from each trap.

Fig 1. A) Map of the six sampling sites at the campus of Federal Rural University of Rio de Janeiro (UFRRJ); **B)** Internal garden of Institute of Biology (IB); **C)** Internal garden of Central Pavilion (CP); **D)** Internal garden of Institute of Chemistry (IC); **E)** Forested area near Central Library (CL); **F)** Botanical Garden (BG); **G)** Forested area near student's residence halls (DAF).

We categorize the functional group of ant species in each environment based on the methodology adopted by Estrada et al. (2023), for the functional groups proposed by Delabie et al. (2000), Silvestre et al. (2003), Macedo et al. (2011), Groc et al. (2014), and de Carvalho Pereira et al. (2016). We classified them according to information on foraging, nesting, and feeding habits, resulting in six functional groups: Arboreal Omnivores; Epigeic Generalist Omnivores; Epigeic-Arboreal Omnivores; Epigeic Generalist Predators; Fungus-growers and Leafcutters.

Experimental design

In each designated area, 36 food items (18 pieces of sausage and 18 pieces of cookies) were offered to simulate discarded food in urban environments, comprising 216 samples in this study. The use of two food types (protein vs. carbohydrate) aimed to address preferences among different functional groups and to evaluate potential variations in ant response time, based on food category, as reported in previous studies (Tan & Corlett, 2012; Youngsteadt et al., 2015). Sampling stations were established at 10-meter intervals, adjusted to the dimensions of each site. The food items were placed on acetate plates (7×7 cm) and secured to the ground using wooden sticks fixed at the lateral ends. The acetate surfaces ensured good visibility for identification and collection while providing stability against mechanical disturbances and other potential disruptions.

Sampling was conducted on dry days between May 31 and July 5, 2024. Each food item was standardized in quantity (50 mg) and size (0.5-1 cm). This amount was determined through pilot trials to enable a finer-scale assessment of detection and removal times by ants. Moreover, according to Youngsteadt et al. (2015), when food fragments are small (<2 g), similar to accidentally discarded residues, arthropods alone can remove 100% of the material within 24 hours in urban environments.

Ant species observed removing the food items were collected at the sampling stations using brushes and forceps and transferred to vials containing 70% ethanol for subsequent preparation and identification. Species were identified through comparison with the laboratory reference collection and in accordance with the literature. To minimize interference with ant foraging behavior, collection was avoided when only a few individuals were present at the food item. In large aggregations, individuals were collected normally, with preference given to those around the acetate plate. In all cases, ants were not collected during the actual removal process.

Discovery Time and Total Removal Time

To investigate the food removal capacity of ants in greater detail, observations were conducted over a 30-minute period, starting from the moment the food items were placed on the ground. Based on this timeframe, seven time categories were established for data recording and analysis (Table 1). Two criteria were used to assess removal efficiency and to allocate observations into the predefined time categories: Discovery Time (DT) and Total Removal Time (TRT) of the food fragments at each site.

Table 1. Time categories for measuring Discovery Time (DT) and Total Removal Time (TRT) of food stations.

DT and TRT categories	1	2	3	4	5	6	7
Time (min)	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25	26 - 30	31 +

Discovery Time (DT) was defined as the moment two or more ants were observed at the food item, or when a single ant was present and actively removing the material on its own, following placement. Total Removal Time (TRT) was defined as the complete removal of the food piece from the acetate plate. In cases where the item became stuck to the wooden sticks or other accidental obstacles, the removal was still considered complete, and TRT was recorded accordingly. In instances where no ants were observed at the food item, both DT and TRT were still recorded, following the same observational protocol.

To examine potential differences in foraging activity across different times of day, sampling was conducted at six distinct time intervals – three in the morning (09:00–10:00, 10:00–11:00, and 11:00–12:00) and three in the afternoon (14:00–15:00, 15:00–16:00, and 16:00–17:00). On each sampling day, one site from category I and one from category II were alternately visited, with each location sampled only once a day. This alternating sampling design helped to minimize the influence of site-specific or circumstantial factors that could otherwise bias the results.

Statistical analysis

Ant activity between the two types of urban environments (HHI and LHI) was compared using a t-test applied to the total number of workers recorded in the pitfall traps. Differences in species richness were evaluated through rarefaction curves based on incidence data, enabling standardized comparisons of species richness across environments.

To verify differences in species composition at each location, a Jaccard dissimilarity index (1) was calculated using the vegan package (v. 2.7.2) in R, based on data obtained from pitfall traps in the six sampled areas, which were subsequently grouped into two categories of environments (HHI and LHI). In Equation 1, *a* represents the number of species shared between sites, while *b* and *c* represent the number of species exclusive to each site. If the species composition is the same between sites, the value is 0, and if the composition is completely different, the value is 1.

$$(1)\quad 1 - J = \frac{b + c}{a + b + c}$$

Beta diversity was analyzed using multivariate dispersion analysis (PERMDISP), based on Jaccard dissimilarity, calculated from presence/absence data collected using pitfall traps. Differences in compositional heterogeneity between the two types of urban environments (HHI and LHI) were tested using the betadisper() function from the vegan package (v. 2.7.2) in R.

A Complementarity Index analysis was performed for the six functional groups between the two types of urban environments (HHI and LHI) using equation 2. The closer the value of each functional group is to 1, the more distinct the species will be for each type of environment (Colwell & Coddington, 1994).

$$(2)\quad Cindex = 1 - \frac{species\ shared}{total\ species}$$

To investigate the factors influencing food discovery time (DT) and total food removal time (TRT) by ants, generalized linear mixed models (GLMMs) were fitted using the glmer() function from the lme4 package in R. The fixed effects included the level of human intervention in urban spaces (high or low), food type (protein or carbohydrate), exposure condition (shade or sun), period of the day (morning or afternoon), and ambient temperature. Sampling day was included as a random effect to account for temporal variation. Both models assumed a Poisson distribution, suitable for count data. Model overdispersion was assessed using the dispersion_glmer() function from the blmeco package. Fixed effects were interpreted based on the estimated coefficients and p-values obtained from the model summaries.

Given the lack of statistically significant effects for TRT in the GLMM analysis, we conducted an additional chi-square test of independence to further investigate potential differences in food removal patterns between habitats. This exploratory analysis categorized food removal events as occurring within or after 30 minutes and compared their distribution between environments with high and low levels of human intervention.

At the species level, we performed a Discovery Ability Index (DAI) analysis between the two environments to assess each species potential for resource detection, following Dáttilo & MacGregor-Fors (2021) with some modifications. We considered only the ant species recorded at the food stations and ranked them by the number of times each species occurred at the stations in each environment (HHI and LHI) for 15 minutes of the experiment. Then, we divided the value of each species by the highest observed value to normalize the DAI index and analyzed the highest values as indicators of the most efficient species in discovering available resources.

We also evaluated the role of *Pheidole obscurithorax* Naves 1985, the most frequently recorded species, in comparison to the remaining species in the community. This analysis considered only food items with ants present, following the same categorization used in the habitat-level comparison. A chi-square test was used to determine whether *P. obscurithorax* was associated with a higher proportion of rapid food removal events.

Results

Number of individuals collected

We collected a total of 751 individuals from pitfall traps, belonging to 36 ant species and 4 subfamilies. Myrmicinae was the most collected subfamily (n = 22 sp, 61%), followed by Formicinae (n = 10 sp, 28%), Ectatomminae (n = 2 sp, 5%) and Ponerinae (n = 2 sp, 5%). Among the ants collected, *Pheidole obscurithorax* was the most active species (n = 396), followed by *Atta sexdens* (Linnaeus, 1758) (n = 97) and *Solenopsis geminata* (Fabricius, 1804) (n = 59). In high human intervention environments, the most active species were *P. obscurithorax*, *S. geminata*, and *Pheidole radoszkowskii* Mayr, 1884. In contrast, in low human intervention environments, *A. sexdens*, *P. obscurithorax*, and *Pachycondyla striata* Smith, 1858 were the most active (Table S1, Supplementary Material).

A total of 22 ant species were recorded across 177 food stations. The most frequent species in both high human intervention and low human intervention environments was *P. obscurithorax* (n = 82, 38%), primarily found removing sausage and cookie fragments, followed by *S. geminata* (n = 33, 15%) and *Pheidole oxyops* Forel, 1908 (n = 13, 6%). The food stations in LHI environments exhibited higher species richness (n = 21) than those in HHI environments (n = 10). *Pheidole* species occurred in 53,73% of the food stations (Table S2, Supplementary Material).

Diversity, functional groups, and activity

Of the 36 species collected in pitfall traps, 15 are shared between the two categorized environments (HHI and LHI), with 11 exclusives to environments with low human intervention and 10 to environments with high human intervention. Only 5 (14%) of the shared species also occurred at food stations in both environments.

Analysis of species richness between the two urban environments did not reveal statistically significant differences, as evidenced by the overlapping rarefaction curves (Fig 2). In contrast, species composition differed significantly between environments (PERMANOVA, F = 6.5318, p = 0.001, n = 999 permutations), as did species Beta diversity (PERMDISP, F = 31.54, p = < 0.001) (Fig 3). Based on the Jaccard index, the CP and IB sites showed a high similarity in species composition, with IQ showing an intermediate similarity to these two sites. CL was the most different environment among the others in terms of composition. The sites categorized as LHI environments showed greater heterogeneity in species composition than HHI sites (Fig 4).

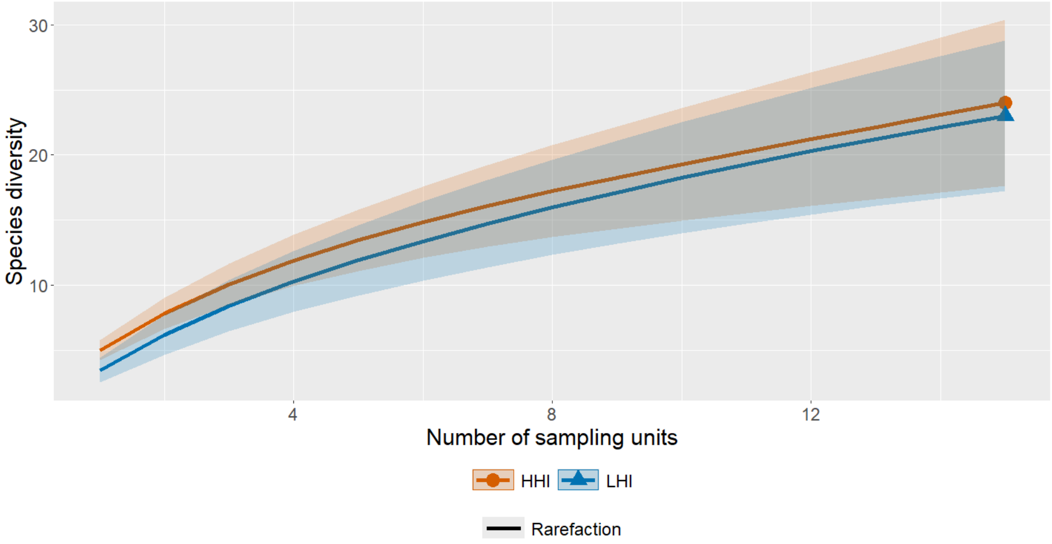

Fig 2. Ant species diversity in two types of urban environments (HHI = high human intervention environments; LHI = low human intervention environments) with samples collected by 24-hour pitfall-traps (15 traps for each group) at the campus of Federal Rural University of Rio de Janeiro (UFRRJ).

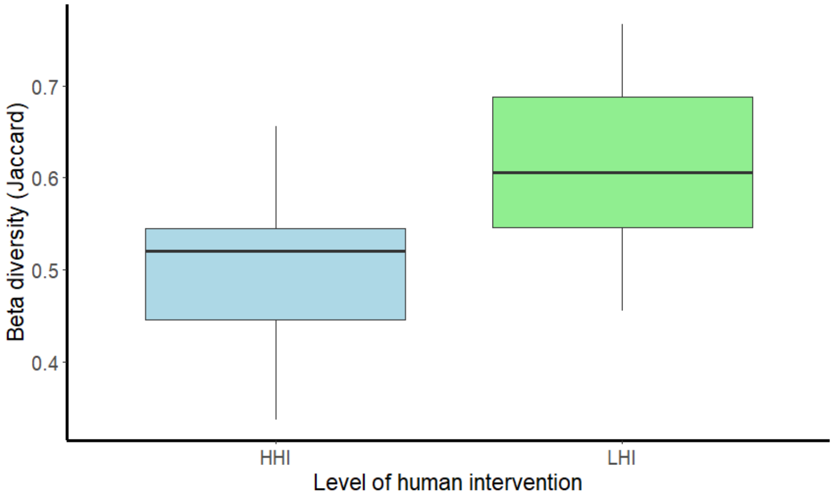

Fig 3. Beta diversity based on pitfall samples between two types of urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) at the campus of Federal Rural University of Rio de Janeiro (UFRRJ). The Beta diversity, measured by the Jaccard index, was different between types of urban environments (PERMDISP, F = 31.54, p = <0.001).

Fig 4. Species composition among the six sampled areas on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ).

Among the six functional groups established, the Epigeic Generalist Omnivores group showed the highest richness, with 15 species recorded, seven of which were shared between the two environments (HHI and LHI) and 4 of which were exclusive to each environment. The Fungus Growers group had the second highest richness, with seven species, followed by Epigeic Arboreal Omnivores, with six species. The Leafcutters functional group was the least diverse, with only one species recorded (Table 4).

The urban environments evaluated exhibited significant differences in ant activity (t-test, t = 2.6539, df = 28, p = 0.01297), with areas under high levels of human intervention showing greater ant activity than those under low levels of intervention (Fig 5).

Table 4. Complementarity index of functional groups of ants between the two types of urban environments (HHI = high human intervention; LHI = low human intervention).

Functional Group	**Environments**		**Species shared (%)**	**Total species**	**Cindex**
	HHI	**LHI**			
Arboreal Omnivores	2	1	0 (0%)	3	1.00
Epigeic Generalist Omnivores	4	4	7 (46%)	15	0.53
Epigeic Generalist Predators	2	0	2 (50%)	4	0.50
Epigeic Arboreal Omnivores	2	2	2 (33%)	6	0.66
Fungus Growers	1	5	1 (15%)	7	0.85
Leafcutters	0	0	1 (100%)	1	0

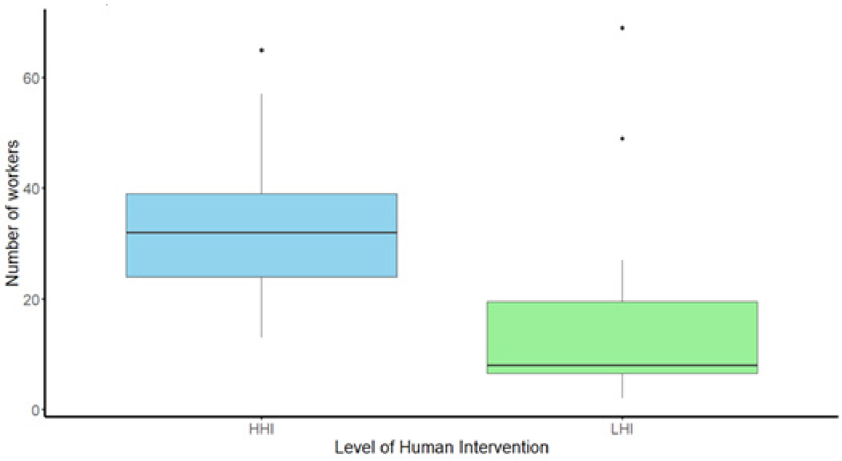

Fig 5. Ant activity across the two urban environments with different levels of human intervention (HHI = high human intervention; LHI =low human intervention) at the campus of Federal Rural University of Rio de Janeiro (UFRRJ). Ant activity, measured as the number of foraging workers collected by 24-hour pitfall-traps (15 traps for each group), was higher in habitats with greater human intervention (T teste; t = 2.65, df = 28, p = 0.013).

Ecosystem Service and the role of species

The results indicate that both habitat type and food type significantly influenced the discovery time (DT) of the food item fragments by ants. Generalized Linear Mixed Models (GLMMs) revealed that mean DT was significantly shorter in HHI environments (β = -0.392, p = 0.001) (Fig 6). Specifically, mean DT in HHI was approximately 40% lower than in LHI samplings. Likewise, sausage fragments were discovered more rapidly than cookie fragments (β = -0.263, p = 0.002), suggesting a preference for protein-rich resources. The mean DT for sausage was approximately 2.3 (6–10 min), while for cookie, it was 3.0 (11–15 min) (Fig 7).

A trend toward increased DT under sun exposure conditions was observed (β = 0.153, p = 0.089), potentially due to thermal stressors, increased solar radiation, or desiccation effects; however, this result was not statistically significant. Neither the period of day (morning vs. afternoon) nor ambient temperature significantly influenced DT, indicating these factors do not strongly modulate initial foraging behavior in this context.

Regarding total removal time (TRT), only the type of food offered had a statistically significant effect on ant behavior. Sausage fragments were removed more quickly than cookie fragments (β = -0.437, p = 0.001). The mean TRT for sausage was 3.8 (range: 11–15 min), whereas for cookie it was 5.8 (21–25 min), reflecting a substantial difference in transport efficiency (Fig 8).

Other predictors – habitat type, exposure condition, period of day, and temperature – did not exhibit significant effects on TRT. Nevertheless, there was a tendency for faster removal in HHI environments (β = -0.095, p = 0.133) and under sun exposure (β = -0.112, p = 0.107), although these did not reach statistical significance.

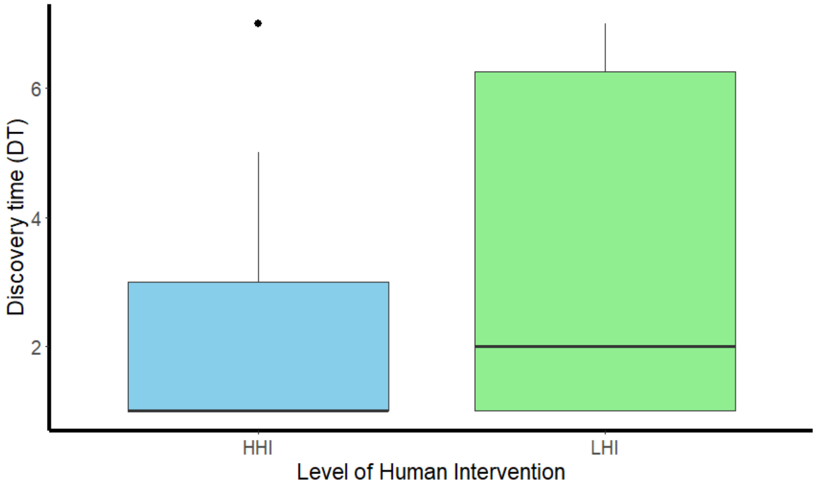

Fig 6. Mean discovery time (DT) of food items in two urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ). The mean DT in HHI environments was approximately 40% lower than in LHI samplings (GLMMs, β = –0.392, p = 0.001).

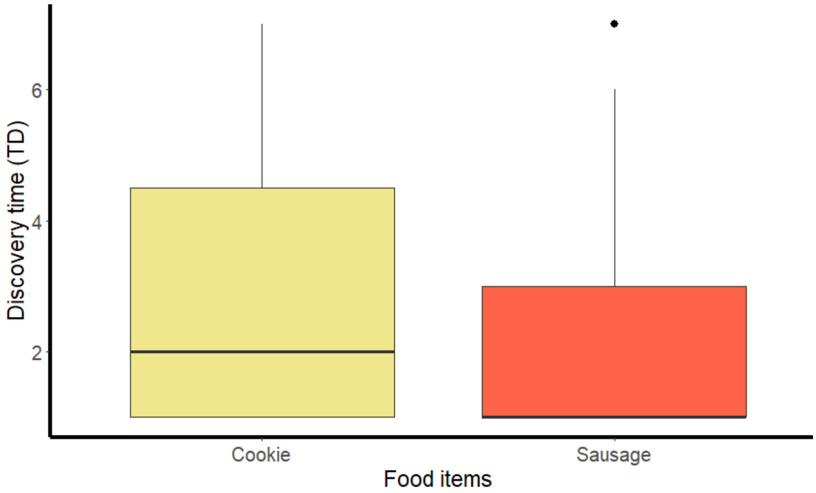

Fig 7. Mean discovery time (DT) of sausage and cookie fragments offered in two urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ). Sausage fragments were discovered more rapidly than cookie fragments (GLMMs, β = –0.263, p = 0.002).

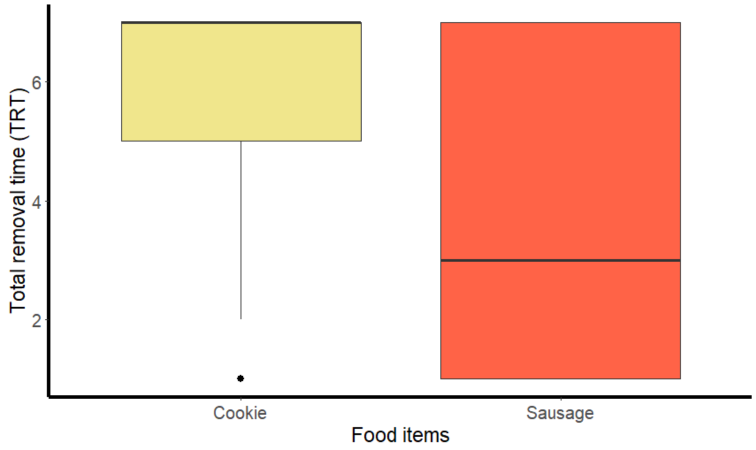

Fig 8. Mean total removal time (TRT) of sausage and cookie fragments offered in two urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ). Sausage fragments were removed more quickly than cookie fragments (GLMMs, $\beta = -0.437$, $p = 0.001$).

The chi-square test of independence revealed a significant association between habitat type and the proportion of food items removed within and after 30 minutes ($\chi^2 = 5.37$, df = 1, p = 0.0205) (Fig 9). In HHI environments, a greater proportion of food item fragments were removed within 30 minutes (61.1%) compared to LHI environments (44.4%). Conversely, in LHI environments, the proportion of food items removed after 30 minutes was higher (55.6%) than in HHI environments (38.9%).

At the species level, we identified a few species with high ability to detect resources between the two urban environments (HHI and LHI) (Fig 10). Of the 11 species that occurred at feeding stations in HHI, only 2 (9%) showed high discovery values. For LHI environments, only 4 (19%) of the 21 species that occurred at the stations showed a high ability to discover. *P. obscurithorax* and *S. geminata* were the species with the highest index between the two urban environments.

A positive association was observed between the presence of *P. obscurithorax* and the proportion of food items removed within and after 30 minutes ($\chi^2 = 8.5787$, df = 1, p = 0.0034), indicating that *P. obscurithorax* removed food items proportionally faster than other ant species (Fig 11). Among the food fragments removed by *P. obscurithorax*, 60 (76.9%) were removed within 30 minutes, and 18 (23.1%) after 30 minutes. In contrast, other ant species removed 54 items (54.5%) within 30 minutes and 45 items (45.5%) after this period.

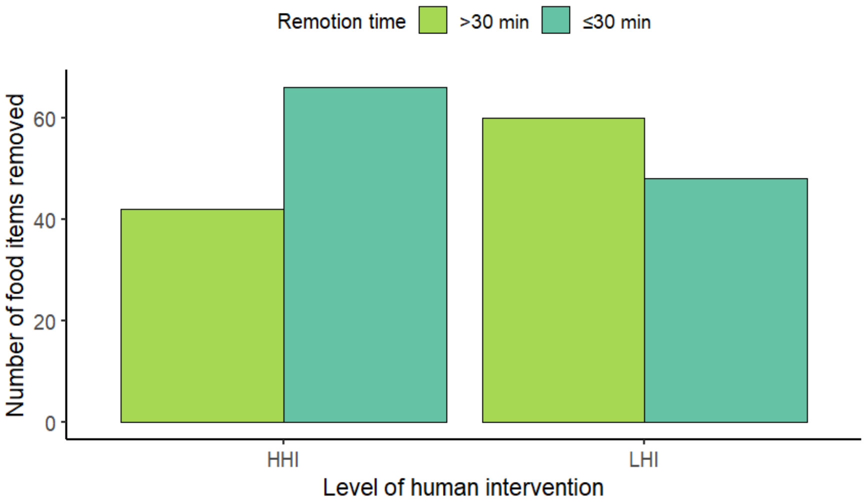

Fig 9. Proportion of food items removed within and after 30 minutes in two urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ). A significantly higher proportion of food items was removed within 30 minutes in HHI environments compared to LHI environments ($\chi^2 = 5.37$, df = 1, p = 0.0205).

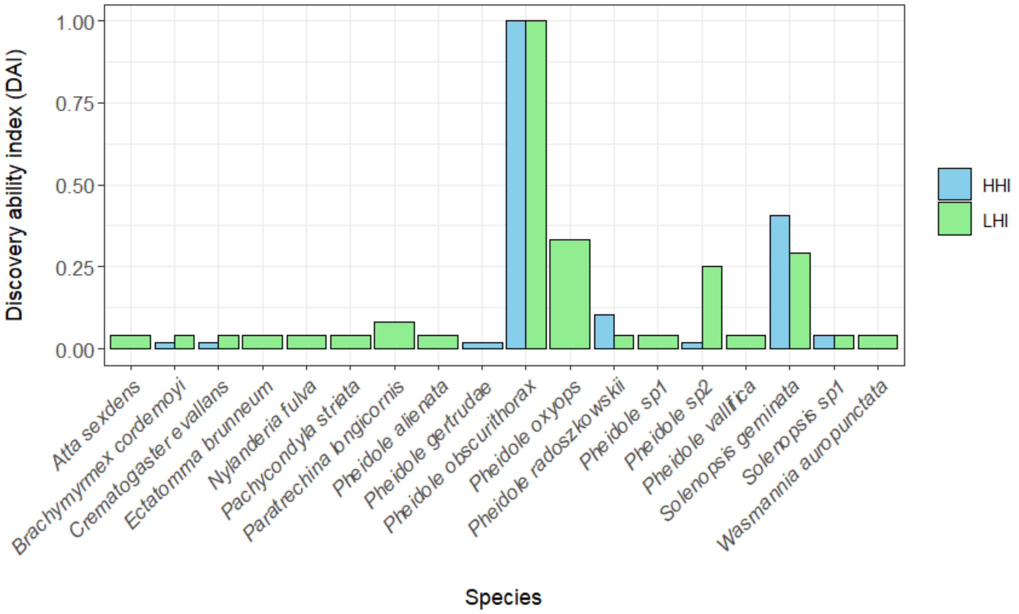

Fig 10. Discovery ability index (DAI) of ant species at food stations in two urban environments with different levels of human intervention (HHI = high human intervention; LHI = low human intervention) on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ).

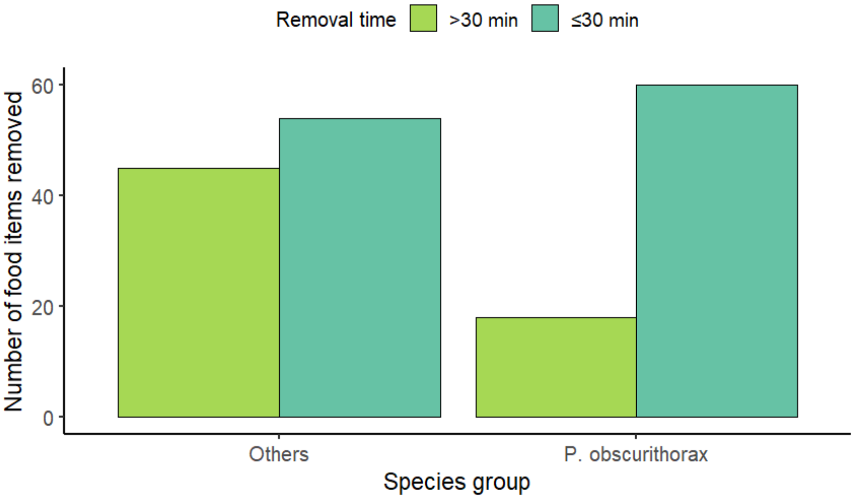

Fig 11. Proportion of food items removed within and after 30 minutes by *Pheidole obscurithorax*, the most frequent species, and by other ant species on the campus of the Federal Rural University of Rio de Janeiro (UFRRJ). A significantly higher proportion of food items was removed within 30 minutes by *P. obscurithorax* compared to other species (χ^2 = 8.5787, df = 1, p = 0.0034).

Discussion

This study employed two complementary experimental approaches to evaluate the relationship between ant community composition and the food waste removal services provided by different species. The first approach used pitfall traps over a 24-hour period to assess ant activity and species diversity, while the second focused on analyzing the discovery and removal times of food fragments placed at food stations. Pitfall traps detected differences in ant activity, diversity, and species composition between environments. In contrast, the food stations revealed a pronounced difference in the number of species attracted to cookie and sausage fragments, with high human intervention environments supporting approximately half the species richness observed in low human intervention environments. Moreover, in high human intervention environments, both the discovery and removal times of food fragments were shorter than those recorded in low human intervention environments.

Diversity, functional groups, and activity

Here, we detected a negative effect of the level of human intervention on ant species diversity and composition between the two urban environments (HHI and LHI). These effects also affected the functional groups based on differences in species richness and composition in each environment. Increased anthropogenic intervention in these locations may reduce ant species' richness and diversity due to increased impervious surfaces and the presence of exotic species, contributing to biotic homogenization in these environments. (Santos et al., 2019; Hosaka et al., 2019; Lokatis & Jeschke, 2022; Laakel et al., 2024). This may also align with greater similarity in species composition observed between environments categorized as HHI compared to LHI. The high level of heterogeneity in areas with low human intervention allows for more balanced species maintenance, unlike areas with high human intervention, which exhibit the same structural pattern.

We detected a direct effect of human intervention level on ant activity, with HHI environments exhibiting higher activity. This pattern suggests that, although many species are sensitive to environmental changes, tolerant or dominant species may intensify their foraging in these environments. The behavior of these animals throughout the day can be influenced by temperature, competition, and landscape characteristics (Camarota et al., 2018; Chen & Neoh, 2023; Harris et al., 2024). In addition, areas with fewer food resources for ants require greater search efficiency for alternative food sources (Penick et al., 2015), thereby favoring species with more efficient foraging strategies in urban environments.

Ecosystem Service and role of species

The difference in TD between HHI and LHI environments appears to be related to the dominance exercised mainly by *Pheidole obscurithorax* at food stations. This species was frequently recorded in both pitfall trap samples and at food stations, particularly in HHI environments, with high discovery ability index values and playing a key role in the rapid removal of food items – often within 30 minutes. This pattern highlights the functional importance of *P. obscurithorax* in detecting and transporting food resources in urbanized environments, as already reported by Sales et al. (2014). The species is known for its strong competitive ability and flexible foraging strategies under varying environmental conditions (Storz & Tschinkel, 2004). Notably, this study also provides the first recorded occurrence of *P. obscurithorax* in the state of Rio de Janeiro, expanding its known distribution. The critical role of a single species in providing ecosystem services has also been reported in related studies (Penick et al., 2015; Youngsteadt et al., 2015; Hosaka et al., 2019; Chen & Neoh, 2023).

The overwhelming presence of *P. obscurithorax* at the food stations may have contributed to the absence of detectable differences in activity between morning and afternoon periods. As *P. obscurithorax* plays a key role in resource detection, it is plausible that its dominance and efficiency suppressed the foraging activity of other species. A previous study conducted in structurally similar environments reported that ant activity peaks between 09:00 and 15:00, particularly in urbanized areas (Chen & Neoh, 2023). Since our observations were carried out primarily within this time window, it is likely that we captured the peak foraging period of *P. obscurithorax*. Future studies should consider extending the observation period to determine whether food waste removal dynamics vary throughout the day and whether other species become more active outside this core activity window.

Although Fellers (1987) proposed the existence of a trade-off between discovery and dominance, subsequent studies indicate that species that detect the resource first come to dominate it, preventing other species from accessing the available source and supporting the discovery-defense strategy (Parr & Gibb, 2012; Camarota et al., 2018; Antoniazzi et al., 2021; Dáttilo & MacGregor-Fors, 2021). The high dominance of *P. obscurithorax* and *Solenopsis geminata* at food stations in HHI environments is the result of these species' ability to monopolize resources. In disturbed areas, the establishment of these dominant species can reduce opportunities for coexistence between species with different foraging strategies and, consequently, impact competition for resources.

A smaller proportion of food stations were completely removed within 30 minutes in LHI environments. Despite the high functional richness in LHI environments at food stations, mainly of epigeic generalist predators, the low values of the species discovery ability index that occurred exclusively in LHI environments may have affected food removal. These results suggest that high diversity and the presence of multiple functional groups do not guarantee a higher rate of resource removal, as reported in other studies (Penick et al., 2015; Youngsteadt et al., 2015; Hosaka et al., 2019).

The variation in detection and removal times between sausage and cookie fragments indicates a preference for protein rich foods. These results reflect the diets of ants in urban and suburban areas. Penick et al. (2015) reported that the consumption of nitrogen rich foods by urban ants increases in line with the urbanization gradient, demonstrating that these animals have been consuming human foods more frequently.

The absence of significant differences in food detection and removal across exposure conditions or ambient temperature may be due to the short observation window used in the experiment. The 30-minute time frame may have limited our ability to detect subtler behavioral shifts associated with food quality or microclimatic factors. Other studies have found that these effects become more evident over longer temporal scales (Hosaka et al., 2019; Chen & Neoh, 2023). We had expected that ant species in disturbed habitats would demonstrate greater resilience in locating and removing food under sun exposure and elevated temperatures, given their higher tolerance to the extreme conditions typical of urban settings (Angilletta Jr. et al., 2007; Diamond et al., 2018).

Conclusion

This study demonstrates that ants in urban environments can rapidly detect and remove scattered food fragments, providing an important ecosystem service by limiting the availability of resources to undesirable species, such as pests and disease vectors. In high human intervention environments (HHI), food removal efficiency was largely driven by a small number of competitively dominant species, particularly *Pheidole obscurithorax*, whose high resource discovery and monopolization capacity accelerated removal rates. Our results highlight how changes in composition and functional diversity, driven by the level of urbanization, affect ant foraging activity and the ecological processes involved. These findings contribute to a better understanding of ant foraging dynamics in urban landscapes and underscore the ecological role of ants in maintaining key ecosystem processes in human-modified environments. Moreover, this study offers valuable insights into these dynamics in tropical urban systems, which are currently underrepresented in scientific literature.

Acknowledgements

We thank the reviewers for their suggestions and CAPES for providing financial support for the research conducted.

Authors' Contribution

MSRF: Conceptualization, methodology, formal analysis, investigation, visualization, writing-review & editing.
ECBF: Validation, investigation.
CBA: Investigation, visualization.
JMQ: Conceptualization, methodology, formal analysis, investigation, visualization, writing-review & editing, supervision.

References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. D. M. & Sparovek, G. (2013). Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22: 711-728.

Angilletta Jr, M. J., Wilson, R. S., Niehaus, A. C., Sears, M. W., Navas, C. A. & Ribeiro, P. L. (2007). Urban physiology: city ants possess high heat tolerance. PLoS One, 2: e258.

Aronson, M. F., Nilon, C. H., Lepczyk, C. A., Parker, T. S., Warren, P. S., Cilliers, S. S., Goddard, M. A., Hahs, A. K., Herzog, C., Katti, M., La Sorte, F. A., Williams, N. S. G. & Zipperer, W. (2016). Hierarchical filters determine community assembly of urban species pools. Ecology, 97: 2952-2963.

Ashigar, M. A. & Ab Majid, A. H. (2020). Diversity, Abundance, and Foraging Behavior of Ants (Hymenoptera: Formicidae) Scavenging on American Cockroach in Various Habitats of Nasarawa State, Nigeria. Pertanika Journal of Tropical Agricultural Science, 43: 503-521.

Antoniazzi, R., Camarota, F., Leponce, M. & Dáttilo, W. (2021). Discovery-defense strategy as a mechanism of social foraging of ants in tropical rainforest canopies. Behavioral Ecology, 32: 1022-1031.

Camarota, F., Vasconcelos, H. L., Koch, E. B. & Powell, S. (2018). Discovery and defense define the social foraging strategy of Neotropical arboreal ants. Behavioral Ecology and Sociobiology, 72: 110.

Colwell, R. K. & Coddington, J. A. (1994). Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 345: 101-118.

Chen, Y. H. & Neoh, K. B. (2023). Urbanization causes shifts in the functional traits and foraging activity, and alters food particle size preference and biomass removal of urban-dwelling ants. Frontiers in Ecology and Evolution, 11: 1044485.

Dáttilo, W. & MacGregor-Fors, I. (2021). Ant social foraging strategies along a Neotropical gradient of urbanization. Scientific Reports, 11: 6119.

Delabie, J. H., Agosti, D. & Nascimento, I. D. (2000). Litter ant communities of the Brazilian Atlantic rain forest region. In: Agosti, D., Majer, J., Alonso, L.; Schultz, T. (eds.) Sampling Ground-dwelling Ants: Case Studies from the World's Rain Forests. Curtin University of Technology School of Environmental Biology Bulletin, 18. p. 1-17.

de Carvalho Pereira, L. P., Almeida, F. S., Vargas, A. B., de Araújo, M. S., Mayhé-Nunes, A. J. & Queiroz, J. M. (2016). Seasonal analysis of taxonomic and functional diversity of poneromorph ant assemblages in the Amazon Forest. Sociobiology, 63: 941-949.

Del Toro, I., Ribbons, R. R. & Pelini, S. L. (2012). The little things that run the world revisited: a review of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). Myrmecological News, 17: 133-146.

Diamond, S. E., Chick, L. D., Perez, A., Strickler, S. A. & Zhao, C. (2018). Evolution of plasticity in the city: urban acorn ants can better tolerate more rapid increases in environmental temperature. Conservation Physiology, 6: coy030.

Estrada, M. A., Pereira, J. R., de Almeida, Â. A., Vargas, A. B. & Almeida, F. S. (2023). Ant functional groups and their effects on other insects in organic and conventional cropping areas. EntomoBrasilis, 16: 3.

Fellers, J. H. (1987). Interference and exploitation in a guild of woodland ants. Ecology, 68: 1466-1478.

Folgarait, P. J. (1998). Ant biodiversity and its relationship to ecosystem functioning: a review. Biodiversity and Conservation, 7: 1221-1244.

Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'farrell, P., Anderson, E., Hamstead, Z. & Kremer, P. (2013). Urban ecosystem services. In: Elmqvist, T. et al. (Eds). Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment, Springer, p. 175-251.

Griffiths, H. M., Ashton, L. A., Walker, A. E., Hasan, F., Evans, T. A., Eggleton, P. & Parr, C. L. (2018). Ants are the major agents of resource removal from tropical rainforests. Journal of Animal Ecology, 87: 293-300.

Groc, S., Delabie, J. H., Fernandez, F., Leponce, M., Orivel, J., Silvestre, R., Vasconcelos, H. L. & Dejean, A. (2014). Leaf-litter ant communities (Hymenoptera: Formicidae) in a pristine Guianese rainforest: stable functional structure versus high species turnover. Myrmecological News, 19: 43-51.

Harris, B. A., Stevens, D. R. & Mathis, K. A. (2024). The effect of urbanization and temperature on thermal tolerance, foraging performance, and competition in cavity-dwelling ants. Ecology and Evolution, 14: e10923.

Hölldobler, B. & Wilson, E. O. (1990). The ants. Harvard University Press.

Hosaka, T., Di, L., Eguchi, K. & Numata, S. (2019). Ant assemblages on littered food waste and food removal rates in urban-suburban parks of Tokyo. Basic and Applied Ecology, 37: 1-9.

Kamura, C. M., Morini, M. S. C., Figueiredo, C. J., Bueno, O. C. & Campos-Farinha, A. D. C. (2007). Ant communities (Hymenoptera: Formicidae) in an urban ecosystem near the Atlantic Rainforest. Brazilian Journal of Biology, 67: 635-641.

Laakel, N., Aissat, L., Bounab, L. & Yahiaoui, C. (2024). Diversity and species composition of ants in urban and suburban environments in Bejaia City (Algeria). Sociobiology, 71: e9698.

Lanhoso, H., Lima Vieira, M. E., Pacheco, P. J., Teseo, S., Châline, N. & Ferreira, R. S. (2024). Composition and inter-species relationships within ant communities across differentially anthropized urban environments: a case study. International Journal of Tropical Insect Science, 44: 129-138.

Lavelle, P., Decaens, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P. & Rossi, J.P. (2006): Soil invertebrates and ecosystem services. European Journal of Soil Biology, 42: S3-S15.

Liu, K. L., Peng, M. H., Hung, Y. C. & Neoh, K. B. (2019). Effects of park size, peri-urban forest spillover, and environmental filtering on diversity, structure, and morphology of ant assemblages in urban park. Urban Ecosystems, 22: 643-656.

Lokatis, S. & Jeschke, J. M. (2022). Urban biotic homogenization: Approaches and knowledge gaps. Ecological Applications, 32: e2703.

Macedo, L. P. M., Berti Filho, E. & Delabie, J. H. C. (2011). Epigean ant communities in Atlantic Forest remnants of São Paulo: a comparative study using the guild concept. Revista Brasileira de Entomologia, 55: 75-78.

McGlynn, T. P. (1999). The worldwide transfer of ants: geographical distribution and ecological invasions. Journal of Biogeography, 26: 535-548.

McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. Urban ecosystems, 11: 161-176.

Penick, C. A., Savage, A. M. & Dunn, R. R. (2015). Stable isotopes reveal links between human food inputs and urban ant diets. Proceedings of the Royal Society B: Biological Sciences, 282(1806): 20142608.

Orivel, J., Hircq, M., Etienne, S., Gervais, B., Merle, A., Monnier, A. & Petitclerc, F. (2025). Ant communities and urbanization: insights from tropical territories in French overseas regions. Urban Ecosystems, 28: 185.

Parr, C. L. & Gibb, H. (2012). The discovery-dominance trade-off is the exception, rather than the rule. Journal of Animal Ecology, 81: 233-241.

Perfecto, I. & Philpott, S. M. (2023). Ants (Hymenoptera: Formicidae) and ecosystem functions and services in urban areas: a reflection on a diverse literature. Myrmecological News, 33: 103-122.

Sales, T. A., Hastenreiter, I. N., Ribeiro, L. F. & Lopes, J. F. S. (2014). Competitive Interactions in Ant Assemblage in a Rocky Field Environment: Is Being Fast and Attacking the Best Strategy? Sociobiology, 61: 258-264.

Santos, M. N., Delabie, J. H. & Queiroz, J. M. (2019). Biodiversity conservation in urban parks: a study of ground-dwelling ants (Hymenoptera: Formicidae) in Rio de Janeiro City. Urban Ecosystems, 22: 927-942.

Santos, M. N. (2016). Research on urban ants: approaches and gaps. Insectes Sociaux, 63: 359-371.

Silvestre, R., Brandão, C. R. F. & Da Silva, R. R. (2003). Grupos funcionales de hormigas: el caso de los gremios del Cerrado. In: Fernández, F. (Ed.). Introducción a las hormigas de la región tropical. Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt, Bogotá. Colombia. 113-148p.

Storz, S. R. & Tschinkel, W. R. (2004). Distribution, spread, and ecological associations of the introduced ant *Pheidole obscurithorax* in the southeastern United States. Journal of Insect Science, 4: 12.

Tan, C. K. & Corlett, R. T. (2012). Scavenging of dead invertebrates along an urbanisation gradient in Singapore. Insect Conservation and Diversity, 5: 138-145.

Wilson, E. O. (2003). *Pheidole* in the New World: a dominant, hyperdiverse ant genus (Vol. 1). Harvard University Press.

Youngsteadt, E., Henderson, R. C., Savage, A. M., Ernst, A. F., Dunn, R. R. & Frank, S. D. (2015). Habitat and species identity, not diversity, predict the extent of refuse consumption by urban arthropods. Global Change Biology, 21: 1103-1115.