Pertanika J. Trop. Agric. Sc. 43 (4): 503 - 521 (2020)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Diversity, Abundance, and Foraging Behavior of Ants (Hymenoptera: Formicidae) Scavenging on American Cockroach in Various Habitats of Nasarawa State, Nigeria

Mohammed Ahmed Ashigar[1,2] and Abdul Hafiz Ab Majid[1]*

[1]Household and Structural Urban Entomology Laboratory, Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia
[2]Department of Zoology, Federal University of Lafia, Nasarawa State, Nigeria

ABSTRACT

Ants play a vital role in removing dead arthropods from the environment. Complex foraging patterns are used by ants to locate food items and overwhelm even larger insects such as cockroach. Consequently, the biotic interaction between the ants and the American cockroach, *Periplaneta americana*, another home infesting and a vector of major food-borne diseases, may lead to microbial handover and ease the spread of mechanically transmitted human pathogenic microbes. This study was done to determine the diversity and abundance of cockroach-foraging ants in Nasarawa State, Nigeria. Ten households were randomly selected from 14 locations: 5 residential communities from three most urbanized areas (Lafia, Akwanga, and Keffi) and 5 rural communities. Four remaining locations were nonresidential from Lafia and Akwanga, respectively. A total of 1,364 ants belonging to three subfamilies (Myrmicinae, Formicinae, and Ponerinae) were collected from 140 households. *Pheidole rugaticeps* Emery recorded the highest relative abundance (52%) followed by *Pheidole decarinata* Santschi (16%), *Pheidole* sp. (17%), *Camponotus maculatus* (7%), *Paratrechina longicornis* (7%), while both *Crematogaster* sp. and *Brachyponera sennaarensis* recorded the lowest relative abundance (1%). There is a significant difference in the species diversity between the urban and the rural communities. *Pheidole rugaticeps*, *P. decarinata*, *Pheidole* sp., and *P. longicornis* were more organized in foraging and operating in group by recruiting nest-mate

ARTICLE INFO

Article history:
Received: 22 April 2020
Accepted: 26 August 2020
Published: 27 November 2020

DOI: https://doi.org/10.47836/pjtas.43.4.07

E-mail addresses:
aashigar@gmail.com (Mohammed Ahmed Ashigar)
abdhafiz@usm.my (Abdul Hafiz Ab Majid)
* Corresponding author

ISSN: 1511-3701
e-ISSN: 2231-8542

© Universiti Putra Malaysia Press

for collecting fragments of dead cockroach. Studies on the epidemiology, conservation implications, and biocontrol potentials of these *Pheidole* species are recommended.

Keywords: Abundance, diversity, *Periplaneta americana*, *Pheidole*, scavenging ants, rural, urban

INTRODUCTION

Ants are vital arthropod pests associating with human habitation and have a diverse ecological significance in several ecosystems (Hölldobler & Wilson, 1990). About fifty ant species are reported to have adapted to the urban setting due to its heterogeneity that offers them food, nesting sites and biotic interactions (Benson & Harada, 1988; Hölldobler & Wilson, 1990; Reyes-Lopez et al., 2003). Some ants can live outdoors and forage indoors while others nest indoors and previous studies have noted that foraging activities of ants may be detrimental or beneficial (Gathalkar & Sen, 2018). Many ants invade human dwellings and cause serious direct and indirect harm, including human health issues, building damage, and interruption of other wildlife. As scavengers, they play a massive role in emptying the environment of arthropods. Their high rate of scavenging habit suggests how considerably successful they are at locating invertebrates carcasses than other scavengers like flies, cockroaches, and vertebrates (Tan & Corlett, 2012). They remove the whole or fragments of the dead invertebrates by using complex foraging patterns (Moffett, 1988), such as recruiting other nest-mates (Tan & Corlett, 2012) and/or mass foraging density (Beckers et al., 1989). This group operation as well as aggression assist them to overpower even relatively larger insects (Tan & Corlett, 2012), and foraging abilities of many ant species may have a devastating effect on the biodiversity of local taxa.

Moreover, the gathering and the storage of corpses and feces by ants have been shown to have tremendous effects on other lives and chemical components around them (Dauber et al., 2001; Dauber & Wolters, 2000; Lavelle et al., 1997; Petal, 1998). Previous studies have revealed that bacteria can remain viable and persist within the nest of ant becoming a reservoir for infection of other members of the colony (Beatson, 1972). Their presence in the ecosystem directly enables the spread of human pathogens (Boursaux-Eude & Gross, 2000; Fonseca et al., 2010). Contamination of hospital apparatuses by ants leads to the mechanical transmitting of diseases (Eichler, 1990; Lima et al., 2013), allergies, stings, and bites (Goddard, 1993; Syukriah Sabtu & Ab Majid, 2020; Williams et al., 2001), and food contamination (Lee, 2001). In the tropics, many ant species have already been incriminated as vectors of pathogens (Sarwar, 2015). Food-borne disease pathogens such as *Serratia*, *Citrobacter*, *Klebsiella*, *Enterobacter*, *Proteus*, *Staphylococcus*, and *Yersinia pestis* were isolated from ants (De Zarzuela et al., 2005; Simothy et al., 2018). *Vibrio cholerae* has previously been recovered from both ants and cockroaches (Sarwar, 2015). Yet, data on the ant's role in mechanical transmission of human pathogens is scanty compared to flies or cockroaches (Sarwar, 2015).

American cockroaches (*Periplaneta americana*) are one of the house-infesting invertebrates (Graczyk et al, 2005; Mpuchane et al., 2005) that are frequently seen in bathrooms, toilets and other parts of the houses (Dehghani et al., 2014). They are ideal carriers of various pathogens due to the filthy nature of their breeding and feeding habits (Chaichanawongsaroj et al., 2004; Graczyk et al., 2005). They play a vital role in spreading major food-borne diseases like diarrhea, dysentery, cholera, tuberculosis, and typhoid fever (Fotedar et al., 1992; Graczyk et al., 2005; Saitou et al., 2009). More species of pathogens are harbored by *P. americana* than any other cockroach species studied (Pai et al., 2003; Prado et al., 2002). Recently, the infestation trend of cockroaches has increased in household environments (Nasirian, 2017). Dead *P. americana* can frequently be observed around houses due to high infestation which attracts foraging ants into the house. The foraging activities may lead to microbial interchange and can be of epidemiological concerns as ants presence can ease the propagation and spread of human pathogens (Boursaux-Eude & Gross, 2000; Fonseca et al., 2010). Therefore, this study was to determine the diversity, abundance, and foraging behavior of ants scavenging on American cockroach in various habitats of Nasarawa State, Nigeria. The data from the study can be useful in managing household pests, especially mechanical vectors that spread diseases.

MATERIALS AND METHODS

Study Area and Sampling

This study was done to determine the diversity, abundance, and foraging behavior of ants scavenging on American cockroach in various habitats of Nasarawa State located in a middle belt of Nigeria with an estimated land area of 2,733km^2 and a population size of 330,720 according to the 2006 census by the National Population Commission. Ten households were randomly selected based on the consent of the households and relevant authorities from 14 locations, 5 residential communities from three most urbanized areas, which includes Lafia (Lafia East, Shinge, and Shabu), Keffi (GRA), Akwanga (low-cost housing estate) as well as 5 rural communities (Akunza, Gandu, Akunzan Sama, Gwandare, and Kurikyo). Four remaining locations were nonresidential areas including Federal University Lafia, Nasarawa State Polytechnic, Dalhatu Araf Specialist Hospital, and a primary healthcare center (PHC) from Lafia and Akwanga, respectively (Figure 1). Ethical clearance was obtained from the Ethics Committee of the State Ministry of Health, Nasarawa State, as the survey involves the use of insecticides (knock down, Guangzhou Konnor Daily Necessities Co., Ltd, Guangdong, China). In each community eight to ten households or sampling points were selected, where cockroaches and ants scavenging on American cockroach were collected in and around toilets, rooms, and kitchens after spraying insecticides. However, toilets and bathrooms were the most infested parts of residents by *P. americana* (Dehghani et al., 2014). The sampling took place from November 2018 to February 2019.

Observation of Foraging Behavior, Collection, and Identification of the Insects

The sample collection was done during night hours (20:00h to 22:00h) as American cockroaches are nocturnal insects. Flushing agents (knock down, Guangzhou Konnor Daily Necessities Co., Ltd.) were sprayed around cockroach observing spots such as toilets with the consent of the household (Alias et al., 2018). Thirty minutes after spraying the insecticide, we returned to the location and made the observations. The cockroaches were observed and recorded. Ants foraging on the live and dead cockroaches were monitored in and around the sprayed toilets. Dead American cockroaches were also placed along the ant trail routes in the selected houses. Where ants were observed collecting or foraging on live or dead cockroaches, both the ants and the host cockroaches were collected and preserved in 70% ethanol solutions for further analysis in the laboratory. Ants scavenging both dead and life cockroaches were gently scooped into a 20 ml vial container and the cockroaches that have not hosted ants were collected into a jar containing 70% alcohol solution for preservation for later analysis. Several ant species foraging around each cockroach were recorded to ascertain their diversity and abundance in the area. The sprayed spots were checked the following morning. The identification of the collected cockroach was done with the aid of morphological identification keys (Bell, 1981). Identification of the collected ants

Figure 1. Map of the collection sites in Nasarawa State, Nigeria. Refer to Table 1 for abbreviation of the numbers 1-14

was done using taxonomic keys (Fischer et al., 2012) and the colored images at the websites (antweb.org and antsofafrica.org, respectively). The behavior of the ants found foraging on the cockroaches was also monitored during collection. How they collect the cockroach, whether they collect live or dead cockroach, and how they transport the cockroach (whole or fragments) were all recorded. In addition, other insects that were collected by these ants and the nature of their caste and trail were listed down as well.

Data Analysis

The data collected were tabulated and statistically analyzed using SPSS Statistics 20.0. Kruskal-Wallis test was conducted to determine if there was a relationship between the distribution of *P. americana* and ants scavenging on this cockroach species in the study area. A post hoc test was conducted to compare the means of the various locations. The diversity index of cockroach-foraging ants in the urban and the rural communities was determined using the biodiversity calculator excel sheet (Zar, 1996). Diversity *t*-test was used to analyze the statistical difference between the communities and overall relative abundance of ants was determined using the formula (Alias et al., 2018) below:

$$\text{Relative abundance of a species} = \frac{\text{Number of individuals of the same species}}{\text{Number of individuals of all the species}} \times 100$$

RESULTS

Distribution of American Cockroach and The Ants Scavenging on American Cockroach

A total of 36-pit latrine (rural communities) and 89 water system toilets (rural communities) from 136 residential and nonresidential premises in the rural and the urban communities were sampled by spraying insecticide, respectively. Dead cockroaches after spraying insecticides in the water system toilets and the pit latrine toilets are presented in Figure 2.1 and Figure 2.2, respectively. A total of 3,298 American cockroaches (78.71% and 21.29% from the rural and the urban, respectively) were recorded. The result of the post hoc test is presented in Table 1 and showed that Akunza, one of the rural communities, recorded the highest mean of *P. americana* (92.50±23.64), while primary healthcare center (PHC) Akwanga, one of the urban communities, recorded the lowest mean (2.00±0.98). Moreover, the overall result from the Kruskal-Wallis test showed a significant difference in the overall distribution of the American cockroach across the fourteen sampled locations, ($X^2(13) = 40.048$, $p<0.001$). The independent samples *t*-test ($t(136) = 6.13$, $p<0.001$) also showed a significant difference in the distribution of the American cockroach between the rural and the urban areas.

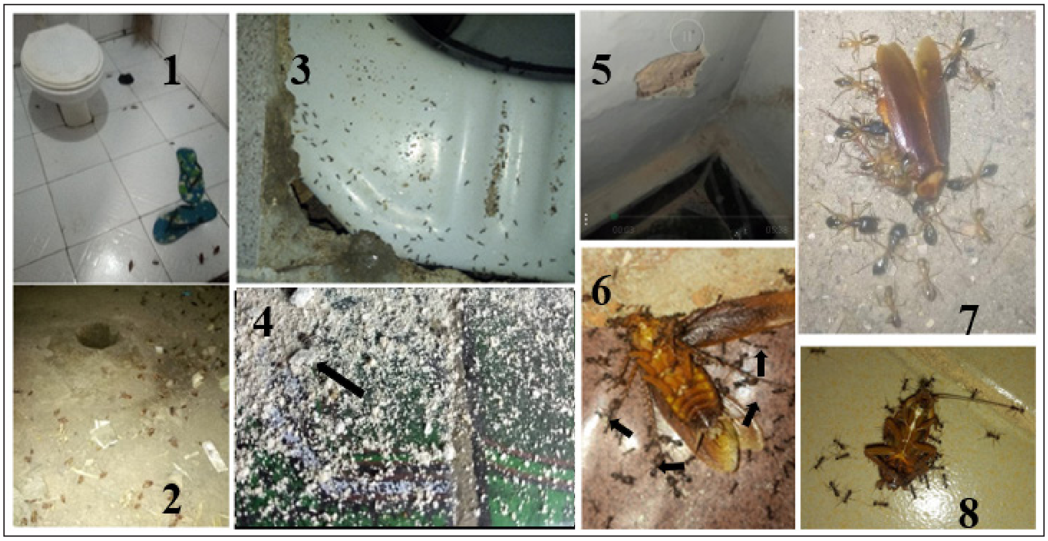

Figure 2. Dead cockroaches in water system (1) and pit latrine (2) after spraying insecticides; nest of *Paratrechina longicornis* in a toilet (3); sands and carcasses of *Brachyponera sennaarensis* just below the nest of a *Pheidole decarinata* (4); nest of *P. decarinata* on the wall (5); *Pheidole rugaticeps* spread-eagling a live cockroach (6); *Camponotus maculatus* foraging on a dead cockroach (7); and a swarm *P. longicornis* carrying a dead cockroach to their nest (8)

A total of 1,364 ants (31% rural and 69% urban) were collected from the 136 sampling points. Unlike the distribution of the cockroach, the overall distribution ants scavenging on American cockroach obtained from Kruskal-Wallis test showed no statistically significant difference across all the locations ($X^2(13) = 9.455$, $p = 0.738$) and between the rural and the urban areas (*t*-test, $t(25) = 0.15$, $p<0.876$). The highest mean occurrence of ants scavenging on American cockroach was recorded in Akunza (20.80±15.72) and the lowest was recorded in Gandu Sarki (0.00±0.00) as shown in Table 1. The percentage of each ant species collected around *P. americana* in each location is shown in Table 2. *Pheidole rugaticeps* had been recorded in all except 4 locations (Table 2). Other species such as *Crematogaster* sp., *B. sennaarensis*, and *P. megacephala* were only recorded in one location. Table 2 shows the total number and the percentages of each ant species collected foraging on *P. americana* in each location. Lafia East had the highest number of ant species (Table 2).

Species Diversity and Abundance of the Ants Scavenging on American Cockroach

The 1,364 ants collected from 136 sampling spots belong to three subfamilies: Myrmicinae (85.27%), Formicinae (13.41%), and Ponerinae (1.32%). *Pheidole* species were the most dominant ants in all communities and forms the most abundance subfamily, Myrmicinae (together with *Crematogaster* sp.). The overall result of the

Table 1
Locations, coordinates, range, and mean abundance of Periplaneta americana *and ants scavenging on American cockroach in the sampling locations*

Serial no.		Locations	Habitat*	Coordinates	N	Range		Mean	
						American cockroach	Ants	American cockroach	Ants
1	Urban	Lafia East (LE)	UB/RA	08°29'33.57" N 08°32'27.10" E	10	1-40	18-38	11.40(±3.67)	11.50(±5.37)
2		GRA, Keffi	UB/RA	08°50'53.25" N 07°53'08.48" E	10	0-34	22-69	6.56(±3.60)	16.89(±9.43)
3		Fulafia (FUL)	NRA	08°28'25.70" N 08°33'22.42" E	9	0-21	0-34	4.89(±2.39)	3.78(±3.78)
4		Shinge (SHG)	UB/RA	08°30'37.92" N 08°29'34.34" E	9	0-58	31-67	12.44(±6.20)	10.89(±7.80)
5		Shabu (SHB)	UB/RA	08°34'45.06" N 08°33'32.73" E	9	0.60	0-21	13.80(6.77)	2.10(±2.10)
6		Nasarawa State Polytechnic (POLY)	NRA	08°32.47.55" N 08°32'09.81" E	10	0-14	0-72	2.78(±1.48)	8.00(±8.00)
7		Dalhatu Specialist Hospital (DASH)	NRA	08°30'08.95" N 08°31'21.95" E	9	0-44	20-103	8.60(±4.60)	18.70(±11.36)
8		Low-cost Housing, Akwanga (LHE)	UB/RA	08°55'38.29" N 08°24'46.91" E	10	0-7	44-115	2.80(±0.88)	15.90(±11.85)
9		Primary Healthcare Center (PHC), Akwanga	NRA	08°54'50.41" N 08°24'51.86" E	10	0-10	0-87	2.00(±0.98)	8.70(±8.70)
10	Rural	Akunza (AKZ)	RR/RA	08°28'11.69" N 08°35'24.03" E	10	15-206	5-156	92.50(±23.64)	20.80(±15.72)
11		Gandun Sarki (GND)	RR/RA	08°46'59.37" N 08°00'57.68" E	10	1-121	-	47.70(±11.95)	0.00(±0.00)
12		Akunzan Sama (AKZS)	RR/RA	08°28'07.87" N 08°36'04.02" E	10	10-134	20-42	48.90(±17.44)	6.20(±4.45)
13		Gwandara (GDR)	RR/RA	08°34.11.95" N 08°29'50.59" E	10	50-105	0-50	35.20(±11.37)	5.00(±5.00)
14		Kurikyo (KRK)	RR/RA	08°31'32.09" N 08°35'51.59" E	10	5-113	25-76	35.30(±10.68)	10.10(±7.73)
		Total			136			23.18(±3.329)	9.90(±7.24)

Note. UB = Urban areas; RR = Rural areas; RA = Residential areas; NRA = Non-residential areas. Kruskal Wallis test shows a significant difference in the overall distribution of the American cockroach, $X^2(13) = 40.048$, $p<0.001$ across all locations and between the rural and the urban ($t(136) = 6.13$, $p<0.001$) according to the independent samples *t*-test. As for ants the test shows no significant difference in the overall distribution $X^2(13) = 9.455$, $p = 0.738$ and between the rural and the urban areas ($t(25) = 0.15$, $p<0.876$)

Table 2
Total number of ant species collected foraging on Periplaneta americana *and their percentages (%) occurrence in each location*

	Myrmicinae				Formicinae		Ponerinae			
Communities	*Pheidole rugaticeps*	*Pheidole decarinata*	*Pheidole* sp.	*Crematogaster* sp.	*Camponotus maculatus*	*Paratrechina longicornis*	*Brachyponera sennaarensis*	Total	No. of ant spp.	%
LE	-	36	-	20	14	45	18	133	5	9.75
GRA	61	69	-	-	22	-	-	152	3	11.14
FUL	-	-	34	-	-	-	-	34	1	2.49
SHG	67	-	-	-	31	-	-	98	2	7.18
SHB	-	-	-	-	-	21	-	21	1	1.54
POLY	72	-	-	-	-	-	-	72	1	5.28
DASH	103	64	-	-	20	-	-	187	3	13.71
LHE	115	44	-	-	-	-	-	159	2	11.66
PHC	87	-	-	-	-	-	-	87	2	6.38
AKZ	47	-	156	-	5	-	-	208	3	15.25
GND	-	-	-	-	-	-	-	0	0	0.00
AKZS	20	-	42	-	-	-	-	62	2	4.55
GDR	50	-	-	-	-	-	-	50	1	3.67
KRK	76	-	-	-	-	25	-	101	2	7.40
Total	698	213	232	20	92	91	18	1,364		100
%	51.17	15.62	17.01	1.47	6.74	6.67	1.32			

relative abundance showed that *P. rugaticeps* (51.2%) recorded the highest abundance, together with *P. decarinata* (15.6%) and other *Pheidole* species (17.1%) made up 83.8% of all the ants collected. This explains the fact that *Pheidole* was the most abundant and diverse formicids in the area. However, *B. sennaarensis* (subfamily: Ponerinae) and *Crematogaster* sp. (subfamily: Myrmicinae) were the least collected with (1.3% and 1.5%, respectively) as shown in Table 2. The community-based distribution of these ants showed a difference in the diversity of ants scavenging on American cockroach between the urban communities ($H' = 1.35$, $E = 0.7$) and the rural communities ($H' = 0.93$, $E = 0.67$). Based on the result of the diversity *t*-test ($t(800) = 28.26$, $p>0.05$), it indicated that they were more diverse in the urban communities. The genus, *Pheidole* was the dominant ant species in all the communities and *P. rugaticeps* was the most abundant species in almost all the communities. Surprisingly, the result of the diversity reveals that the richness of species in the urban communities was increased (Figure 3). The highest percentage of the ants was recorded in Akunza (15.25%) while Gandun Sarki (0.00%) had the lowest percentage and both are the rural communities. However, the highest number of ant species (5 ant species) was recorded in Lafia East, which is an urban community (Table 2). The relative abundance of the ants scavenging on *P. americana* based on the communities studied is presented in Figure 4.

Foraging Behavior of the Ants Scavenging on American Cockroach

Table 3 shows the total number of each species of ants and the percentage of American cockroach infestation by these ants. *Pheidole rugaticeps* had the highest number and percentage of infestation with up to 54% as shown in Table 3. Among the ant species collected, *P. rugaticeps*, *P. decarinata*, *Pheidole* sp., and *P. longicornis* were more organized in their foraging activity by operating in the group and recruiting nest-mate. All the ants were

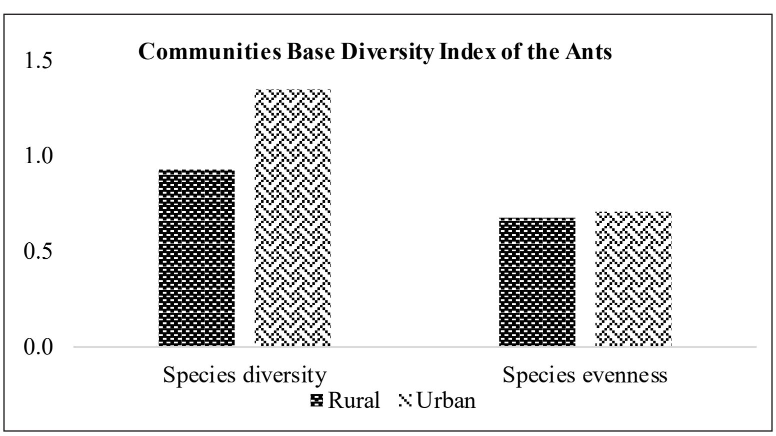

Figure 3. Species diversity and species evenness of the ants in the rural and the urban communities

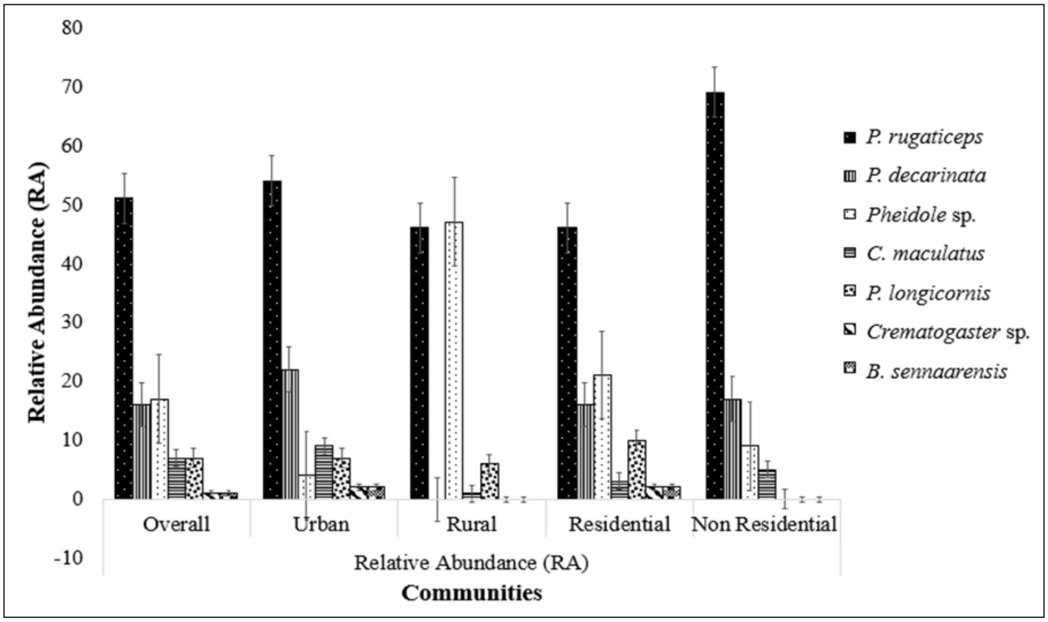

Figure 4. Relative abundance of the scavenging on *Periplaneta americana* according to communities (overall, urban, rural, residential, and non-residential communities)

observed collecting fragments of the dead cockroach after fragmenting it. Furthermore, *P. longicornis* and *Pheidole* species, except for *P. decarinata*, were also observed dragging the whole cockroach into their nest and sometimes, they overwhelm live struggling American cockroaches by spread-eagling (unfolding the legs and the wings of the cockroach) as shown in Figure 2.6. *Pheidole decarinata*, the tiniest of all the collected ants were also observed recruiting nest-mates. However, major workers of *P. decarinata* broke the dead cockroach into fragments and the minor workers carried them back to their nest it to their nest. *Pheidole rugaticeps*, *P. decarinata*, *Pheidole* sp., *P. longicornis*, and *Crematogaster* sp. were all collected indoors mainly near and inside the toilets. Figure 2.3 shows a nest of *P. longicornis* in a void at the edge of Turkish toilet while Figure 2.5 shows an indoors nest of *P. decarinata* in a cavity on the wall. Moreover, Figure 2.8 shows *P. longicornis* dragging a cockroach to their nest. Surprisingly, the study observed that most of the *Pheidole* ants came out of the nest only when the size of the prey was relatively large and proximate to their nest. The majors (soldiers) of this group of ants aid the workers in transporting the prey especially when the prey was relatively bigger. However, when the distance of the prey was far from the nest, only the minors were observed collecting the prey to their nest. *Camponotus maculatus* was also collecting only fragments of the dead cockroach and moved the fragments to their nest. Figure 2.7 shows *C. maculatus* foraging on dead cockroaches.

Table 3
The frequency, density, infestation level (%), and other foraging activities of the of the ant species collected around Periplaneta americana *between November 2018-Febroury 2019*

Ant species	N	No. of *Periplaneta americana* infested	Average no. per cockroach	Infestation (%)	Mode of infestation	Collects	Indoors/ Outdoors
Pheidole rugaticeps	698	26	26.8	54	Dead and alive	Whole/ Fragment	Indoors and Outdoors
Pheidole decarinata	213	7	30.4	15	Dead	Fragment	Indoors and Outdoors
Pheidole sp.	232	4	58	8	Dead and alive	Whole/ Fragment	Outdoors
Camponotus maculatus	92	5	9.2	10	Dead	Fragment	Outdoors
Paratrechina longicornis	91	4	11.4	8	Dead and alive	Whole/ Fragment	Indoors and Outdoors
Crematogaster sp.	20	1	20	2	Dead	Fragment	Outdoors
Brachyponera sennaarensis	18	1	20	2	Dead	Fragment	Outdoors
Total	1,364	48	28.4	100			

DISCUSSION

Insects are by large underrepresented in studies related to biodiversity and conservation despite the importance they play globally in the overall ecosystems functioning, stability, and monitoring (Fox, 2013; McKinney, 1999; Thomas et al., 2004; Wilson, 1976). Apparently, few studies exist on ant populations and trends in most ecosystems, except for few invasive species (Cooling & Hoffmann, 2015; Vogel et al., 2010). This, however, reveals uncertainty in the future of many ants (Sánchez-Bayo & Wyckhuys, 2019). Fast-growing human activities because of the trade and development are major promoters of the establishment of exotic species that can have a tremendous impact on biodiversity around human settlements. Widespread litter and trash accumulations, particularly in cities, are suitable habitats for the establishment of ant species (Sharaf et al., 2017). Dead cockroaches are one of such liters around homes that attract foraging ants into the house. Most importantly, this finding reveals that *Pheidole* species are the dominant ant species collecting dead *P. americana*. Consequently, these ants have previously been reported to have successfully spread their range globally and regularly found in kitchens, restaurants, greenhouses, and gardens. Other ants, such as *P. longicornis* and *Brachyponera* species, collected in this study were also shown to be attracted to human settlement by the accumulation of litter and trash (Sharaf et al., 2017).

Recent research has revealed that the mean infestation trend of *P. americana* in household environments has an increasing range of 50.0–75.0% (Nasirian, 2017). It has also been established that there was a high abundance of American cockroaches in most Nigerian households (Bala & Sule, 2012; Iwuala & Onyeka, 1997). Recently, a study has shown that bathrooms and toilets are the most infested by this cockroach species in houses (Dehghani et al., 2014). The present study compared the infestation of an American cockroach in toilets between the rural and the urban communities as well as residential and non-residential areas and found that the infestation was higher in the rural communities than in the urban communities. This may not be unconnected to the level of hygiene of these two sets of communities as cockroach infestation has been revealed to have a significant correlation with poor sanitation (Nasirian, 2017) and are the commonest indoor pest in low-income housing (Brenner, 1995; Wang et al., 2008). Little or no application of insecticides and poor toilet facilities (particularly use of pit latrine) are other problems associated with these rural communities and low-income housing in the urban communities. Similarly, studies have also revealed that an increasing percentage of Nigerians live in poverty and it is higher in the rural areas.

Nevertheless, the Kruskal-Wallis test showed that the distribution of the ants scavenging on cockroach at all locations did not differ statistically. This finding further supports the idea that most ants are generalist feeders with the ability to thrive them almost everywhere (Cerdá & Dejean, 2011). Nevertheless, it is interesting to note from the richness of the species that more species have been recorded in the urban communities than in the rural communities. This must be due to the adaptation of several species of ants to the urban environment because of its heterogeneity that offers them food, nesting sites and biotic interactions (Benson & Harada, 1988; Hölldobler & Wilson, 1990; Reyes-Lopez et al., 2003). Although these results slightly differ from some published studies (Mckinney, 2002; Ab Majid et al., 2016) that there are fewer species diversities of ants and many taxa in the urban core than in the rural areas, they are consistent with the fact that suburban has a high ant species richness. This is because the urban communities sampled in this study are, to a certain extent, suburban. Study has also shown that widespread litter and trash deposits are suitable habitats for the formation of abundant species, especially in the city centers (Sharaf et al., 2017). Dead arthropods are one of those deposits around human settlements with a high concentration that attracts other insects to the house, especially ants. Dead *P. americana* is one of these deposits, where the level of sanitation is poor, which makes human settlement suitable for many ant species.

The present study determined the diversity and abundance of the ants that forage on American cockroach and 1,364 ants were collected belonging to three subfamilies of the Formicidae: Myrmicinae, Formicinae, and Ponerinae. *Pheidole* species

(Myrmicinae) were the most dominant ants in terms of diversity and abundance. The overall result of the relative abundance showed that *P. rugaticeps* recorded the highest abundance followed by *P. decarinata* and other *Pheidole* species. Generally, *Pheidole* species are revealed to have discriminating capability of both collecting corpses and effectively invading colonies of other competing ants (Dejean et al., 2007). This study also observed that *P. rugaticeps* not only foraged on dead cockroaches, but was also able to spread-eagle struggling *P. americana* shortly after insecticide application and drag the cockroach into their nest. Highly organized foraging activity of teamwork and nest-mate recruitment observed from the *Pheidole* species provide them with the prospect of excluding other competitors in the habitat. This study also observed *P. rugaticeps* catching other live competitors, such as *C. maculatus* and collecting other dead insects. This clearly agrees with the fact that *Pheidole* is the most abundant and diverse formicids within tropical areas (Ward, 2000; Wilson, 2003) with the highest species richness globally (Longino, 2009) and worldwide distribution (Wilson, 1976). Other ant species that were previously observed scavenging on dead cockroaches and corpses of other arthropods, such as *P. longicornis* and *Brachyponera* sp. (Sharaf et al., 2017), were recorded in this study (2% and 8%, respectively). *Paratrechina longicornis* has also been reported as the most widely distributed ant species (Wetterer, 2008) feeding on a host of live and dead arthropods, and transmit pathogenic microorganisms (Roxo et al., 2010). Likewise, a pr*evious study have also* observed *Brachyponera spp*. scavenging on dead cockroaches and other organisms (Rice & Waldvogel, 2017). Our studies have not recorded *B. sennaarensis* and *Crematogaster* spp. in the rural communities, although they are among the most abundant insect species in human settlements, and *B. sennaarensis has* previously been *reported* in Nigeria (Al-khalifa et al., 2015). Whereas, *C. maculatus* recorded 10% of the ants observed around dead *P. americana* in this study. Previous study have also pointed out that media workers of *C. maculatus* and other ants can recruit nestmates and capture preys dead or alive of 4-18 mm in size (Dejean, 1988).

Most ants are generalist feeders, even the predators collect corpses of insects and other arthropods (Cerdá & Dejean, 2011). They are the most successful scavengers that feed on even corpses of invertebrates (Tan & Corlett, 2012). Nest-mates recruitment in large numbers who troop out in mass, helps them in transporting the cockroach to their nest by spread-eagling the live cockroach (Figure 2.6). These mass density foraging activity has been described as a factor for the success of most ground dwelling ants (Beckers et al., 1989). Mass recruitment and collective foraging along well-defined trail system perhaps employed when bait is larger than their size are features exhibited by all the *Pheidole* species and *P. longicornis* collected during this study (Moffett, 1988). Surprisingly, the study also observed that major workers of the *P. rugaticeps* came out of their nest only when the size of the prey was relatively large. However, *P. decarinata* and *C. maculatus* were found only collecting fragments of dead cockroach and this has previously been reported by Yamamoto et al. (2009). Moreover, the majors of *P. decarinata* only fragment the corpses of the cockroach while the minors transport the fragments to their nest. This ability is a possibility that these ant species may be a serious source of ecological and conservation concern for other native urban ecosystem taxa (Kouakou et al., 2018). The aggressive behavior of the *Pheidole* species can also be used to control them (Lim & Ab Majid, 2019).

Though not much has been reported of ant's medical and veterinary importance like flies or cockroaches, it has been confirmed that *Vibrio cholerae* could be obtained from ants and cockroaches (Sarwar, 2015). In the tropics, ants have already been incriminated as vectors of pathogens (Sarwar, 2015). Gathering and storing corpses and feces by ants have been disclosed to have huge effects on other lives and chemical components around them (Dauber et al., 2001; Dauber & Wolters, 2000; Lavelle et al., 1997; Petal, 1998). Studies have revealed that bacteria can remain viable and persist within the nest of ant and become a reservoir for other workers of the colony to be infected (Beatson, 1972). Interestingly, most of the ant species recorded in this study nested inside toilets (see Figure 2.3) or a few meters away from the toilets. The foraging pattern and activities, as well as nest sites of these ants, can have health implications on the host community, especially *Pheidole* species, *C. maculatus*, and *P. longicornis* that were frequently collected in the aforementioned places. Their foraging activity on *P. americana*, an ideal carrier of several pathogenic microorganisms due to the filthy nature of its breeding habits and feeding mechanism (Chaichanawongsaroj et al., 2004; Graczyk et al., 2005) can be a source of great concern. *Periplaneta americana* harbored more species of pathogens than other cockroach species (Pai et al., 2003; Prado et al., 2002) and the foraging activity of ants on them can be an unnoticed medium of dissemination of diseases causing pathogens in human societies, particularly during an outbreak of diseases such as cholera.

CONCLUSIONS

Pheidole rugaticeps, *P. decarinata*, *Pheidole* sp., *C. maculatus*, *P. longicornis*, *Crematogaster* sp., and *B. sennaarensis* were the ant species that foraged on *P. americana* around human habitat and these scavenging ants had higher species richness in the urban than the rural communities. *Pheidole* species were the most abundant group of ants. The organized foraging patterns such as nest-mate recruitment, teamwork, and raiding in mass exhibited by *Pheidole* species must be the reason for their success. The rural communities had a higher abundance of *P. americana* than the urban communities because of poor toilet facilities and household's inability to afford insecticides, which are serious problems in most tropical rural households. Studies on the epidemiological and conservation implications of the *Pheidole* species in the urban communities are recommended. The foraging patterns of the *P. rugaticeps* may also be an important area of exploration for biological control of insect pests.

ACKNOWLEDGEMENT

This research was funded under Universiti Sains Malaysia (USM), Bridging Fund (304 / PBIOLOGI / 6316510).

REFERENCES

Ab Majid, A. H., Ellias, S. S., Ahmad, H., Ahmad, A. H., & Dieng, H. (2016). Tropical household ants species composition and distribution in rapid urbanization area in Penang, Malaysia. *Journal of Entomoomology and Zoology Studies*, *4*(1), 496–500.

Al-khalifa, M. S., Mohamed, A., Mashaly, A., Siddiqui, I. M., & Al-Mekhlafi, F. A. (2015). Samsum ant, *Brachyponera sennaarensis* (Formicidae : Ponerinae): Distribution and abundance in Saudi Arabia. *Saudi Journal of Biological Sciences*, *22*(5), 575–579. doi: 10.1016/j.sjbs.2015.05.011

Alias, Hadi, U. K., & Retnani, E. B. (2018). Diversity and abundance of cockroaches (Insecta : Dictyoptera) in ships at Bau-Bau port. *Journal of Entomology and Zoology Studies*, *6*(3), 29–34.

Bala, A. Y., & Sule, H. (2012). Vectorial potential of cockroaches in transmitting parasites of medical importance in Arkilla, Sokoto, Nigeria. *Nigerian Journal of Basic and Applied Sciences*, *20*(2), 111–115. doi: 10.4314/njbas.v20i2.

Beatson, S. H. (1972). Pharaoh's ants as pathogen vectors in hospitals. *Public Health*, *299*(7747), 425–427. doi: 10.1016/S0140-6736(72)90869-0

Beckers, R., Goss, S., Deneubourg, J. L., & Pasteels, J. M. (1989). Colony size, communication and ant foraging strategy. *Psyche: A Journal of Entomology*, *96*(3-4), 239–256. doi: 10.1155/1989/94279

Bell, W. J. (1981). Cockroach diversity and identification. In *The laboratory cockroach* (pp. 1-14). Dordrecht, Netherlands: Springer.

Benson, W., & Harada, A. Y. (1988). Local diversity of tropical and temperature ant faunas (Hymenoptera, Formicidae). *Acta Amazonica*, *18*(3–4), 275–289. doi: 10.1590/1809-43921988183289

Boursaux-Eude, C., & Gross, R. (2000). New insights into symbiotic associations between ants and bacteria. *Research in Microbiology*, *151*(7), 513–519. doi: 10.1016/S0923-2508(00)00221-7

Brenner, R. J. (1995). Economics and medical importance of German cockroaches. In M. K. Rust, J. M. Owens, & D. A. Reierson (Eds.), *Understanding and controlling the German cockroach* (pp. 77–92). Oxford, United Kingdom: Oxford University Press.

Cerdá, X., & Dejean, A. (2011). Predation by ants on arthropods and other animals. In C. Polidori (Ed.), *Predation in the Hymenoptera: An evolutionary perspective* (pp. 39–78). Washington, D. C., USA: National Academy of Sciences.

Chaichanawongsaroj, N., Vanichayatanarak, K., Pipatkullachat, T., Polrojpanya, M., & Somkiatcharoen, S. (2004). Isolation of Gram-negative bacteria from cockroaches trapped from urban environment. *Southeast Asian Journal of Tropical Medicine and Public Health*, *35*(3), 681–684.

Cooling, M., & Hoffmann, B. D. (2015). Here today, gone tomorrow: Declines and local extinctions of invasive ant populations in the absence of intervention. *Biological Invasions*, *17*(12), 3351–3357. doi: 10.1007/s10530-015-0963-7

Dauber, J., Schroeter, D., & Wolters, V. (2001). Species specific effects of ants on microbial activity and N-availability in the soil of an old-field. *European Journal of Soil Biology*, *37*(4), 259–261. doi: 10.1016/S1164-5563(01)01094-9

Dauber, J., & Wolters, V. (2000). Microbial activity and functional diversity in the mounds of three different ant species. *Soil Biology and Biochemistry*, *32*(1), 93–99. doi: 10.1016/S0038-0717(99)00135-2

De Zarzuela M. F. M., Campos-Farinha A. E. C., & Pecanha M. P. (2005). Evaluation of urban ants (Hymenoptera: Formicidae) as carriers of pathogens in residential and industrial environments: I. Bacteria. *Sociobiology*, *45*(1), 9–14.

Dehghani, R., Atharizadeh, M., Moosavi, S. Gh., Azadi, S., Rashidi, M., & Paksa, A. (2014). Analysis of cockroach fauna and frequency in human residential habitats of North of Isfahan , Iran. *International Archives of Health Sciences*, *1*(1), 25–29.

Dejean, A. (1988). Prey capture by *Camponotus maculatus* (Formicidae: Formicinae). *Biology of Behaviour*, *13*, 97–115.

Dejean, A., Moreau, C. S., Uzac, P., Le Breton, J., & Kenne, M. (2007). The predatory behavior of *Pheidole megacephala*. *Comptes Rendus Biologies*, *330*(9), 701–709. doi: 10.1016/j.crvi.2007.06.005

Eichler, W. (1990). Health aspects and control of *Monomorium pharaonis*. In K. R. Meer, K. Jaffe, & A. Cedeno (Eds.), *Applied myrmecology, a world perspective*. Boulder, Colorado: Westview Press.

Fischer, G., Garcia, F. H., & Peters, M. K. (2012). Taxonomy of the ant genus *Pheidole* Westwood (Hymenoptera: Formicidae) in the Afrotropical zoogeographic region: Definition of species groups and systematic revision of the *Pheidole pulchella* group. *Zootaxa*, *3232*(1), 1–43. doi: 10.11646/zootaxa.3232.1.1

Fonseca, A. R., Batista, D. R., Amaral, D. P. D., Campos, R. B. F., & Silva, C. G. D. (2010). Formigas (Hymenoptera: Formicidae) urbanas em um hospital no município de Luz, Estado de Minas Gerais [Urban ants (Hymenoptera: Formicidae) in a hospital in the municipality of Luz, State of Minas Gerais]. *Acta Scientiarum Health Science*, *32*(1), 29–34. doi:10.4025/actascihealthsci.v32i1.5805

Fotedar, R., Banerjee, U., Samantry, J. C., & Shriniwas (1992). Vector potential of hospital houseflies with special reference to *Klebsiella* species. *Epidemiology and Infection*, *109*(1), 143–147.

Fox, R. (2013). The decline of moths in Great Britain: A review of possible causes. *Insect Conservation and Diversity*, *6*(1), 5–19. doi: 10.1111/j.1752-4598.2012.00186.x

Gathalkar, G., & Sen, A. (2018). Foraging and predatory activities of ants. In V. D. C. Shields (Ed.), *The complex world of ants* (pp. 51–70). London, England: IntechOpen Limited.

Goddard, J. (1993). *Physician's guide to arthropods of medical importance*. Boca Raton, USA: CRC Press.

Graczyk, T. K., Knight, R., & Tamang, L. (2005). Mechanical transmission of human protozoan parasites by insects. *Clinical Microbiology Reviews*, *18*(1), 128–132. doi:10.1128/CMR.18.1.128-132.2005

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

Iwuala, M. O. E., & Onyeka, J. W. A. (1997). Types and distribution pattern of domestic insects in Nsukka, East Central State, Nigeria. *Environmental Entomology*, *6*(1), 43-49. doi: 10.1093/ee/6.1.43

Kouakou, L. M. M., Dekoninck, W., Koné, M., Delsinne, T., Yeo, K., Ouattara, K., & Konate, S. (2018). Diversity and distribution of introduced and potentially invasive ant species from the three main ecoregions of Côte d'Ivoire (West Africa). *Belgian Journal of Zoology*, *148*(1), 83-103. doi: 10.26496/bjz.2018.19

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., … Dhillion, S. (1997). Soil function in a changing world: The role of invertebrate ecosystem engineers. *European Journal of Soil Biology*, *33*(4), 159–193.

Lee, C. (2001). Urban pest ants - Biology, human perceptions and management strategies. In C. S. Chen (Ed.), *Proceedings of the 13th FAOPMA Pest Control Convention and Exhibition* (pp. 74–86). Taipei, Taiwan: Chinese Pest Control Association.

Lim, L., & Majid, A. H. A. (2019). Plant derived pesticides (*Citrus hystrix* DC, *Mentha* x *piperita* L., *Ocimum basilicum* L.) in controlling household ants (*Tapinoma indicum* (F.), *Pheidole megacephala* (F.), *Monomorium pharaonis* (L.)) (Hymenoptera: Formicidae). *Pertanika Journal of Tropical Agricultural Science*, *42*(4), 1321–1342.

Lima, W. R. dos S., Marques, S. G., Rodrigues, F. S., & Rebêlo, J. M. M. (2013). Ants in a hospital environment and their potential as mechanical bacterial vectors. *Revista Da Sociedade Brasileira de Medicina Tropical*, *46*(5), 637–640. doi: 10.1590/0037-8682-1607-2013

Longino, J. T. (2009). Additions to the taxonomy of new world *Pheidole* (Hymenoptera: Formicidae). *Zootaxa*, *2181*(1), 1-90. doi:10.11646/zootaxa.2181.1.1

McKinney, M. L. (1999). High rates of extinction and threat in poorly studied taxa. *Conservation Biology*, *13*(6), 1273–1281. doi: 10.1046/j.1523-1739.1999.97393.x

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *BioScience*, *52*(10), 883-890. doi: 10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2

Moffett, M. W. (1988). Foraging dynamics in the group-hunting myrmicine ant, *Pheidologeton diversus*. *Journal of Insect Behavior*, *1*(3), 309–331. doi: 10.1007/BF01054528

Mpuchane, S., Allotey, J., Gashe, B. A., Matsheka, M. I., Coetzee, S. I., Jordaan, A., & Oteng, M. (2005). Association between German cockroaches (*Blattella germanica*) and street food vending: Implications for food safety in Botswana. In C. Y. Lee & W. H. Robinson (Eds.), *Fifth International Conference on Urban Pests* (pp. 123–130). Singapore: International Conference on Urban Pests (ICUP).

Nasirian, H. (2017). Infestation of cockroaches (Insecta: Blattaria) in the human dwelling environments: A systematic review and meta-analysis. *Acta Tropica*, *167*, 86–98. doi: 10.1016/j.actatropica.2016.12.019

Pai, H. H., Ko, Y. C., & Chen, E. R. (2003). Cockroaches (*Periplaneta americana* and *Blattella germanica*) as potential mechanical disseminators of *Entamoeba histolytica*. *Acta Tropica*, *87*(3), 355–359. doi: 10.1016/S0001-706X(03)00140-2

Petal, J. (1998). The influence of ants on carbon and nitrogen mineralization in drained fen soils. *Applied Soil Ecology*, *9*(1–3), 271–275. doi: 10.1016/S0929-1393(97)00052-8

Prado, M. A., Pimenta, F. C., Hayashid, M., Souza, P. R., Pereira, M. S., & Gir, E. (2002). Enterobacteria isolated from cockroaches (*Periplaneta americana*) captured in a Brazilian hospital. *Pan American Journal of Public Health*, *11*(2), 93–98. doi: 10.1590/s1020-49892002000200005

Reyes-Lopez, J., Ruiz, N., & Fernándes-Haeger, J. (2003). Community structure of ground-ants: The role of single trees in the Mediterranean pastureland. *Acta Oecologica*, *24*(4), 195–202. doi: 10.1016/S1146-609X(03)00086-9

Rice, E. S., & Waldvogel, M. (2017). *Entomology-insect biology and management: Asian needle ant*. Retrieved April 02, 2020, from the NC State Extension website: https://entomology.ces.ncsu.edu/asian-needle-ant/

Roxo, E., Campos, A. E. C., Alves, M. P., Couceiro, A. P. M. R., Harakava, R., Ikuno, A. A., … Melo, F. A. F. (2010). Ants' role (Hymenoptera: Formicidae) as potential vectors of mycobacteria dispersion. *Arquivos Do Instituto Biológico (São Paulo)*, *77*(2), 359–362.

Saitou, K., Furuhata, K., Kawakami, Y., & Fukuyama, M. (2009). Isolation of *Pseudomonas aeruginosa* from cockroaches captured in hospitals in Japan, and their antibiotic susceptibility. *Biocontrol Science*, *14*(4), 155–159. doi: 10.4265/bio.14.155

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, *232*, 8–27. doi: 10.1016/j.biocon.2019.01.020

Sarwar, M. (2015). Insect vectors involving in mechanical transmission of human pathogens for serious diseases. *International Journal of Bioinformatics and Biomedical Engineering*, *1*(3), 300–306.

Sharaf, M. R., Fisher, B. L., Collingwood, C. A., & Aldawood, A. S. (2017). Ant fauna (Hymenoptera: Formicidae) of the Socotra Archipelago (Yemen): Zoogeography, distribution and description of a new species. *Journal of Natural History*, *51*(5–6), 317–378. doi: 10.1080/00222933.2016.1271157

Simothy, L., Mahomoodally, F., & Neetoo, H. (2018). A study on the potential of ants to act as vectors of foodborne pathogens. *AIMS Microbiology*, *4*(2), 319–333. doi: 10.3934/microbiol.2018.2.319

Syukriah Sabtu, F., & Ab Majid, A. H. (2020). Genetic distance and phylogenetic relationships of *Tetraponera rufonigra* Jerdon (Hymenoptera: Formicidae) populations in Penang, Malaysia. *Serangga*, *25*(1), 39–52.

Tan, C. K. W., & Corlett, R. T. (2012). Scavenging of dead invertebrates along an urbanisation gradient in Singapore. *Insect Conservation and Diversity*, *5*(2), 138–145. doi: 10.1111/j.1752-4598.2011.00143.x

Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., … Lawton, J. H. (2004). Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science*, *303*(5665), 1879–1881. doi: 10.1126/science.1095046

Vogel, V., Pedersen, J. S., Giraud, T., Krieger, M. J. B., & Keller, L. (2010). The worldwide expansion of the Argentine ant. *Diversity and Distributions*, *16*(1), 170–186. doi: 10.1111/j.1472-4642.2009.00630.x

Wang, C., El-Nour, M. M. A., & Bennett, G. W. (2008). Survey of pest infestation, asthma, and allergy in low-income housing. *Journal of Community Health*, *33*(1), 31–39. doi: 10.1007/s10900-007-9064-6

Ward, P. S. (2000). Broad-scale patterns of diversity in leaf-litter ant communities. In D. Agosti, J. D. Majer, L. E. Alonso, & T. R. Schultz (Eds.), *Ants: Standard methods for measuring and monitoring biodiversity* (pp. 99–121). Washington D. C., USA: Smithsonian Institution Press.

Wetterer, J. K. (2008). Worldwide spread of the longhorn crazy ant, *Paratrechina longicornis* (Hymenoptera: Formicidae). *Myrmecological News*, *11*, 137–149.

Williams, D. F., Collins, H. L., & Oi, D. H. (2001). The red imported fire ant (Hymenoptera: Formicidae): An historical perspective of treatment programs and the development of chemical baits for control. *American Entomologist*, *47*(3), 146–159. doi: 10.1093/ae/47.3.146

Wilson, E. O. (1976). Which are the most prevalent ant genera? *Studia Entomoligca*, *19*(1-4), 187–200.

Wilson, E. O. (2003). Pheidole *in the new world: A dominant, hyperdiverse ant genus*. Cambridge, USA: Harvard University Press.

Yamamoto, A., Ishihara, S., & Ito, F. (2009). Fragmentation or transportation: Mode of large-prey retrieval in arboreal and ground nesting ants. *Journal of Insect Behavior*, *22*(1), 1–11. doi: 10.1007/s10905-008-9126-3

Zar, J. H. (1996). *Biostatistical analysis*. Upper Saddle River, USA: Prentice Hall.