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Urbanization effect on the ant diversity and composition in an Arid City

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Simple Summary: Urbanization represents a clear threat to biodiversity at the global level, particularly in arid and semi-arid regions. To understand the effect of urbanization on the biological community in the arid region, we studied the ant community along urbanization gradients in Wadi Hanifa in Riyadh, central Saudi Arabia. We found consistency in diversity parameters (abundance, richness, evenness, and Shannon and Simpson diversities) across the urbanization gradient. However, we observed discrete differences in ant community structure across the urbanization gradients. Environmental factors such as vegetation type, soil properties and ground cover proved to be important determinants of ant species composition. Our data supports the use of ants as indicators of urbanization effects and must be considered in order to monitor impacts of urbanization on the biodiversity in arid regions.

Abstract: The dramatic increased rates of uncontrolled urbanization in various parts of the World have resulted in loss of native species and overall threats to biodiversity. Over the last few decades Saudi Arabia has witnessed a remarkably rapid population growth and unparalleled levels of urbanization, leading to threats to biodiversity. Ants were pitfall-trapped across an urban-rural gradient to evaluate ant assemblage responses to urbanization in Wadi Hanifa, Riyadh, Central Saudi Arabia. Fifteen sampling sites were selected along three different urbanization gradients, each traversing urban, suburban and rural zones. Within each site 10 traps were distributed and operated for 7 consecutive days, at 3-monthly intervals throughout one year. Vegetation, ground cover, and chemical and physical soil variables at sampling sites were analyzed concurrently. Ant abundance, species richness, evenness, and diversity indices of Shannon and Simpson were calculated for each site using PC-ORD to demonstrate diversity patterns along the urbanization gradients. Ant assemblages were assessed by detrended corresponding analysis (DCA), canonical correspondence analysis (CCA), and analysis of similarity (ANOSIM) using PC-ORD. Indicator species analysis was conducted to define representative species along the urbanization gradient. A total of 42 ant species were identified. The diversity parameters were consistent across the urbanization gradient. However, significant differences were observed in the ant assemblages between rural and urban, suburban and urban, but only marginal between rural and suburban. Eleven ant species were identified as indicator species (IV values between 50.7-80.7%). The ant assemblages were influenced by flora, ground cover, and soil variables.

Keywords: abundance; diversity; indicator species; Riyadh, species richness, urbanization; Wadi Hanifa

1. Introduction

Urbanization is spreading worldwide, especially within arid and semiarid regions. Many of these arid regions are extremely urbanized, illustrated by countries such as Qatar, United Arab Emirates, Bahrain, Saudi Arabia, and certain parts of United States and Australia. In such regions, urbanization replaces natural systems with hard surfaces and new green spaces such as urban gardens and parks, resulting in the reduction and fragmentation of habitat [1,2]. These spaces may include ponds, parks, and occasionally even biodiversity-friendly rivers and streams. Many of these spaces serve as a refuge for insect species, particularly those that can live and thrive in small areas under containment and human disturbance [3]. The impact of urbanization on arthropods comes from both fragmentation and diminishing of the rural landscape, leading to a mosaic of green remnant patches of various sizes, quality and composition, in a matrix of urban structures. Overall, the transformation of natural landscapes to urbanized landscapes threatens many arthropod species that are characteristic of natural and rural environments and tends to homogenize assemblages [4,5]. Urbanization also unfavorably affects, or at least modifies, ecological processes and interactions, such as decomposition, nutrient cycling, pollination, soil formation, food for vertebrates, and interactions between insects representing various functional groups [6]. The changing of community structure and interactions is a part of biotic homogenization where, in effect, locally distinct communities and processes are substituted by cosmopolitan communities and processes typical of the urban environment [7,8]. Recent studies that have compared ground arthropod communities of agricultural, residential, industrial and natural remnants have revealed great differences in community structure and ecosystem function [9-11].

Invertebrates, particularly arthropods, are ideal organisms for investigating urban biodiversity. Their small size, environmental needs and diversity of life histories make them major components of urban faunas. Many studies have revealed that complex arthropod communities can be found within the urban environment [12,13]. Ants display many advantages over the other arthropod taxa as possible subjects for biodiversity assessment and, as such, are one of the most important groups for studying biological diversity across an urban gradient. Worldwide, they represent approximately 14,701 species and have colonized most of the world's terrestrial biomes [14,15]. They impose a strong ecological footprint through their diverse roles as scavengers, predators, granivores, and herbivores [14]. Ants perform major ecological functions such as predation, scavenging, soil turnover, nutrient cycling and pollination, and are also responsible for dispersal of many plant species [16,17]. In addition, ants are active at almost all trophic levels of the food web [18], making them indispensable for the proper functioning of most terrestrial ecosystems [19]. Habitat disturbances and transformations affect ant communities in many ways, either by changing habitat structure, microclimate and availability of resources or by changing the balance of competitive interactions [20]. Ant assemblages are likely to recover after a few years of development, but their abundance is often characterized by the presence of invasive and cosmopolitan species, and composition is generally different to the pre-disturbance ant community [21]. Many studies of urban ant assemblages have noted the presence of exotic ant species, and most recorded a decrease in resident ant biodiversity due to their presence [22,23].

During the last few decades, the population of Saudi Arabia has substantially increased as a result of the oil boom (3.4% per annum) [24]. This has led to dramatic development of large areas of previously relatively wild lands. This is clearly seen in the Sarawat and Hijaz, and the Northern and Central regions [23]. As a consequence, many indigenous species have been locally lost and many that remain are now highly vulnerable. In spite of this, little ecological work has been done in urban settings. In a study of abundance and diversity of darkling beetles (Tenebrionidae) in Huraymala Wadi of the Central Region of Saudi Arabia, it was found that beetles were significantly more diverse in uncultivated sites compared to cultivated ones and species composition was different between these sites [25]. In a sand-fly (Psychodidae) population study covering parts of Wadi Hanifa, Riyadh Province, it was shown that species numbers and density was higher in

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undisturbed (southern part of the Wadi in regard to Riyadh city) than disturbed sites (Northern one) [26]. In order to increase our understanding of the impacts of urbanization in this extremely arid region, this study aims to assess the environmental impact of urbanization in Wadi Hanifa (WH) (Central Saudi Arabia) along an urbanization gradient (urban, suburban and rural sites) using ants as bioindicators.

2. Materials and Methods

2.1. Study area

This study was carried out at Wadi Hanifa, a valley in the middle of the Najd Plateau, Riyadh Province, Kingdom of Saudi Arabia (KSA) (Figure 1a). It is a conspicuous natural landmark that runs for 120 km from the northwest to the southeast, cutting through the city of Riyadh. The Valley depth ranges from 10-100 m, and its width ranges of 100-1,000 m; its catchment area is about 4500 km^2 [27]. A number of towns and villages lie along the valley, including Al Wassyl, Diriyah, Hair, Irqah, Jubaila, and Uyaynah. The valley passes through palm groves and farms.

In the 1980s, the Riyadh Development Authority (RDA) commenced technical studies alongside the development of a strategy for the valley. These studies were aimed at conserving the valley's natural environment, maintaining the valley as a natural drainage course for Riyadh, using of the valley as a recreational area, and also enhancing and upgrading agricultural use [27,28]. In 2001, RDA developed the Wadi Hanifa Comprehensive Development Plan (WHCDP). The WHCDP formed part of a 10-year program of works that split the valley into five zones, with work ongoing over a distance of some 71 km. From the outcomes and achievements, they have planted 30,000 indigenous shade trees, 6,000 date palms, 50,000 shrubs and ground covers, and transplanted 2,000 large native *Acacia* trees [27]. The rich diversity of flora and fauna [29] that can be found along the vast areas of the valley has proved very attractive and now the people of Riyadh have started using the valley parks and open spaces in large numbers, as evidenced by the almost full capacity crowds on weekends [27].

The monthly climatic conditions are shown in Figure 1. Hot summers and mild winters characterize the climate of WH, with an average annual temperature of 26 °C and average relative humidity of 24.4% (Figure 2). The lowest value of 7.5°C is during January and the highest value 42.1°C during July. The rains usually start in December and extend through March, with an annual average of 85 mm [27]. During March and April, WH receives more than half amount of these rains, while no precipitation falls from June to September.

The flora of WH includes native *Acacia* trees (three species: *A. gerradii negevensis* var. *najdensis* Zoh, *A. gerradii negevensis* var. *negevensis* Zoh, *A. ehrenbergiana* Hayne, and *A. tortilis* Hayne); other shrubs and herbaceous plants are also present. In addition, there are algae and several aquatic plants that grow due to the continuous flow of water through the water channel.

2.2. Site selection

The GLOBENET (Global Network for Monitoring Landscape Change) project protocol was followed to assess the impact of urbanization on the biodiversity in WH. Accordingly, 15 sampling sites (Table 1) were selected along an urban-suburban-rural gradient within WH (Figure 1). Urban (WHU) sites were situated in the city of Riyadh, Suburban (WHS) sites were 38 km northwest of WHU, at Al Wassyl town, and Rural (WHN) sites were located in the furthest northwestern part of WH which is located 28 km northwest of WHS, near the town of Uyayna. To prevent pseudoreplication, the distance between sites was set at 300-400 m. The coordinate information for each selected site was recorded by using a GPS unit (Garmin, Montana 650 handheld Global Positioning System).

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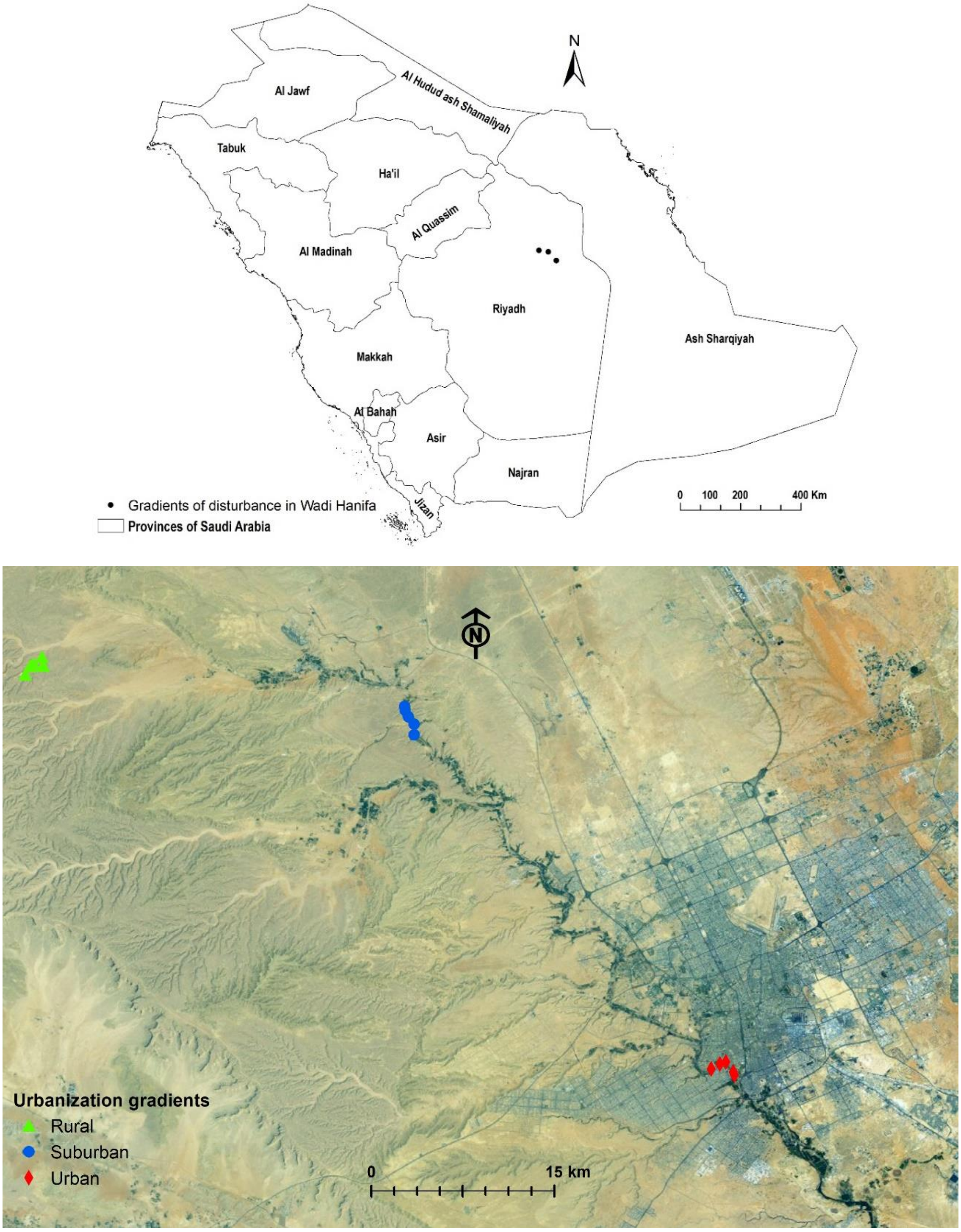

Figure 1. Location of study sites (black dots) within Wadi Hanifa in Riyadh Province, Saudi Arabia**.** The photograph shows the position of the three urbanization gradients.

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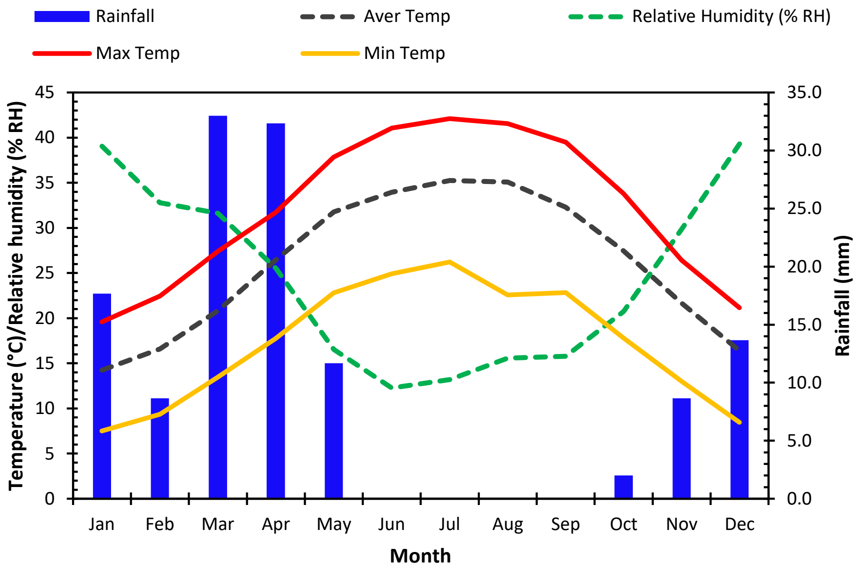

Figure 2. Climatic averages for Wadi Hanifa, Riyadh Province, Saudi Arabia.

Table 1. Sites and the coordinates within different impact levels in Wadi Hanifa, Riyadh Region, Saudi Arabia.

No.	Name	Impact level	Longitude	Latitude	Elevation (m)
1	WHN1	Rural	46.188775	24.905499	814.141
2	WHN2	Rural	46.187792	24.911898	806.755
3	WHN3	Rural	46.181702	24.90702	809.224
4	WHN4	Rural	46.179133	24.905029	810.794
5	WHN5	Rural	46.175639	24.898874	818.169
6	WHS1	Semiurban	46.456775	24.870113	707.051
7	WHS2	Semiurban	46.457495	24.86891	698.912
8	WHS3	Semiurban	46.458357	24.867577	695.296
9	WHS4	Semiurban	46.459509	24.866815	694.942
10	WHS5	Semiurban	46.461243	24.864737	693.76
11	WHU1	Urban	46.682119	24.607641	583.066
12	WHU2	Urban	46.688383	24.611302	584.465
13	WHU3	Urban	46.692789	24.61277	578.566
14	WHU4	Urban	46.698402	24.605335	580.232
15	WHU5	Urban	46.699167	24.603145	572.751

2.3. Sampling methodology

Ants were collected at each selected site using pitfall traps. Traps were 10 cm diameter plastic cups containing 250 mm of 40% propylene glycol as a killing and preserving fluid. Ten traps were set along two lines with 20-50 m between the two lines and 5 m spacing between traps in each line (Figure 3). This resulted in a total of 150 pitfall traps distributed along the urban-rural gradient. The traps were left open for 7 consecutive days and nights. Sampling was repeated four times during one year (January, April, August, November, 2019). The collected samples were transported to the Museum of Arthropods (KSMA), Department of Plant Protection, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia, for sorting and identification to species level. The number of species, as well as the abundance of each species, was recorded for each trap.

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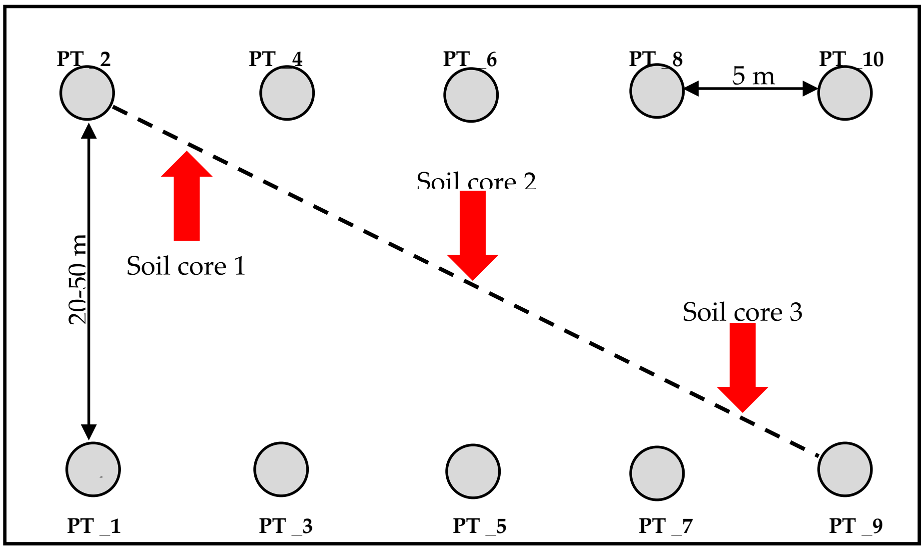

Figure 3. Spatial design of the pitfall traps (grey dots) in the field experiment and the red arrow show the location of soil core samples.

2.4. Soil sampling

Within each study site, three cores of soil were collected from the top to 15 cm by soil auger. The collected soil cores were collected along a diagonal line (Figure 3), then mixed together in one plastic bag. This resulted in each plastic bag containing about 1.5-2.0 kg of soil, which was sent for analyses of chemical and physical features at the Soil Laboratory of the Department of Soil Science, College of Food and Agriculture Sciences, King Saud University.

2.5. Vegetation measurements

To measure the vegetation cover, 10 1 m^2 quadrats were laid out within each site. The percentages of bare ground, and ground covered by leaf litter, woody debris and plant cover were recorded within each quadrat. Plant species were surveyed once during April, 2019 at each site. The plant specimens were sent for identification to the Herbarium, Department of Botany and Microbiology, College of Science, King Saud University.

2.6. Diversity parameters

Ant abundance, richness, evenness and diversity indices (Shannon and Simpson) were calculated using PC-ORD for Windows, version 4.14 [30]. Species richness was taken as the total number of species recorded. The mean of the total count of all individuals for each species collected from each site was used as a measure of abundance.

2.7. Data analysis

The following analyses were performed on the ant assemblage composition, using the two ordination techniques, detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA). DCA is an improved eigenvector ordination technique that is based on reciprocal averaging. DCA corrects the two main faults of ordination techniques - arch distortion and violation of the orthogonality criterion [31]. CCA is a multivariate technique that maximizes the correlation between species and sample scores along an assumed gradient [32]. DCA was carried out using the PC-ORD package. Data for all seasons combined were analyzed. Only species that were found at two or more sites were included in the DCA analysis.

Association of both species and sites with the environmental variables was investigated by CCA using the CANOCO statistical software. CCA is a direct gradient ordination technique, where results are simultaneously based on species abundance and environmental variables [33]. The technique selects the linear combination of environmental variables that maximizes the dispersion of the species scores. This provides the first axis. Similarly, the second and subsequent axes also select the linear combinations of environmental variables that maximize the dispersion of the species scores, but these are subject to the constraint of being uncorrelated with the previous axes. CCA differs from DCA in that the axes are constrained to optimize their relationship with a set of environmental variables. Arrows depict the direction (maximum change) of environmental variables in the ordination, while the length of the arrows shows their degree of influence. The option of species scores as weighted mean sample scores was used in choosing the scaling of CCA ordination scores. The CCA was done in the forward-selection mode of the CANOCO program [33], and the significance of each variable was tested in a sequential fashion using a Monte-Carlo simulation algorithm before it was added to the final model. All variables that were significant at $p<0.05$ were included in the final model. Only the five most significant flora variables were selected for producing the CCA ordination diagram.

Differences in the ant community composition between sites along the three-urbanization gradients were tested by analysis of similarity (ANOSIM, [34]) with a 2-way nested design. Analysis was conducted on the Bray-Curtis similarity matrices [35], with 999 permutations, based on square-root transformed ant abundance data. The ANOSIM analysis was conducted using PRIMER ver. 7.0.17.

Characteristic species (indicator species) were identified for the urbanization gradients using the Indicator Value Method [36]. This method calculated the proportional abundance of a particular species in a particular group, relative to the abundance of that species in all groups. Then, the method calculated the relative abundance of a certain species in a certain group and calculated the proportional frequency of the species in each group. These percentages were regarded as representations of the faithfulness or constancy of presence within a particular group. The two proportions were then multiplied to yield a percentage, which was used as an indicator value for each species in each group. Conversely if either term is low, then the species is considered a poor indicator. Because the component terms are multiplied, both indicator criteria must be high for the overall indicator value to be high. The highest indicator value for a given species across group is saved as a summary of the overall indicator value (IV) of that species and evaluated by the Monte Carlo method, with randomly reassigned SUs (sample units) to groups taking place 1000 times. The probability of a type I error occurring was the proportion of times that the IV from the randomized data set equals or exceeds the IV from the actual data set. The null hypothesis is that IV is no larger than would be expected by chance [37]. The analysis of indicator species was performed using the PC-ORD statistical package. Where possible, natural groupings of sites were visually identified from the clustering of points on the DCA and CCA ordination diagrams.

3. Results

3.1. General trends

A total of 42 ant species were encountered from 24,510 specimens (Table 2). Ten of these were known or probable non-native, invasive or cosmopolitan species. A voucher collection is deposited in the Museum. *Monomorium niloticum*, alone made up 38.34% of the total catch and was the most abundant species in all three sampling gradients (Table 2). This was followed by *Cataglyphis holgerseni* (11.10%) and *Lepisiota simplex* (7.14%) and by the less (or rare species) abundant species; *Cataglyphis aurata*, *Monomorium afrum* André, 1884 and *Tetramorium syriacum* each with values of 0.004%. Nine species were unique to rural sites, one to suburban ones, and eight to urban sites; 16 species (38.09%) were shared among the three gradients (Table 2).

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Table 2. Number of specimens of each ant species trapped over the course of one year along the urbanization gradient in Wadi Hanifa, Riyadh, Saudi Arabia. Species with asterisks are probably non-native invasive species.

	Rural						Suburban						Urban					
Species	WHN1	WHN2	WHN3	WHN4	WHN5	Total	WHS1	WHS2	WHS3	WHS4	WHS5	Total	WHU1	WHU2	WHU3	WHU4	WHU5	Total
Dolichoderinae																		
Tapinoma simrothi Krausse, 1911	4	7	10	3	3	27	3	2	4			9	206	122	40	418	704	1490
Dorylinae																		
Lioponera longitarsus (Mayr, 1879)*													1	2		2	1	6
Formicinae																		
Camponotus sericeus (Fabricius, 1798)		42	76	32	5	155	250	61	28	34	33	406			7	8	23	38
Camponotus thoracicus (Fabricius, 1804)	64	92	54	60	144	414	190	50	44	39	25		2		13	9	7	31
Cataglyphis aurata Menozzi, 1932	1					1												
Cataglyphis holgerseni Collingwood & Agosti, 1996	157	134	181	86	558	1116	302	348	303	229	242	1424			48	60	72	180
Cataglyphis livida (André, 1881)	97	132	246	102	312	889	57	148	77	93	43	418			44	44	13	101
Cataglyphis minima Collingwood, 1985		1	2			3												
Cataglyphis sp.					9	9												
Lepisiota simplex (Forel, 1892)	125	96	80	156	573	1030	11	18	90	62	19	200	3	185	156	117	60	521
Nylanderia jaegerskioeldi (Mayr, 1904)							1	1	1		2	5	2					
Paratrechina longicornis (Latreille, 1802)*								3	978	2		983			76	19		95
Plagiolepis boltoni Sharaf, Aldawood & Taylor, 2011		4				4							16			4		20
Myrmicinae																		
Cardiocondyla bicoronata Seifert, 2003	2	4	4			10									3		2	5
Cardiocondyla fajumensis Forel, 1913			4			4			1			1	3	1	1	2		7
Cardiocondyla mauritanica Forel, 1890*													3	2		6		11
Cardiocondyla minutior Forel, 1899*													1		1	3		5
Cardiocondyla sp.																	1	1
Messor ceresis Santschi, 1934	1	72	3			76	1	19	1			21						
Messor ebeninus Santschi, 1927	34	21	9	37	205	306	2	39	13	2	10	66			11	1	3	15
Monomorium abeillei André, 1881	79	167	177	23	24	470	103	235	22	25	43	428	4	8	13	135	20	180
Monomorium afrum André, 1884														1				1
Monomorium bicolor Emery, 1877													2	8		20		30

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Monomorium exiguum Forel, 1894	1584	60	58	735	608	3045	1040	397	760	523	704	3424	115	488	1654	366	304	2927
Monomorium niloticum Emery, 1881													1				2	3
Monomorium venustum (Smith, F., 1858)		13	8			21										100		100
Monomorium sp. 1	10	21	2	20	32	85	295	31	6			332	106	5	13	135	341	600
Monomorium sp.2		1		1		2												
Monomorium sp.3															1			1
Pheidole indica Mayr, 1879*							72					72					8	8
Pheidole sp.1			1	1		2												
Pheidole sp.2							2					2						
Solenopsis abdita Thompson, 1989*					2	2			1			1						
Tetramorium caespitum (Linnaeus, 1758)*	4	17	42	18	31	112	17	20	9	8	1	55	1	2	3	14	4	24
Tetramorium juba Collingwood, 1985			2			2												
Tetramorium saudicum Sharaf, 2013		4				4												
Tetramorium sericeiventre Emery, 1877	2	29	76	149	61	317	412	18	1	2	12	445	1			1	2	4
Tetramorium simillimum (Smith, F., 1851)*			2			2				2		2	5		1	1		7
Tetramorium syriacum Emery, 1924		1				1												
Trichomyrmex mayri (Forel, 1902)*			23	82	58	163	103	4	20	43		170		3		3		6
Trichomyrmex sp.	1	1	4			6												
Ponerinae																		
Brachyponera sennaarensis (Mayr, 1862)*	44	22	4			70		1	1			2	463	32	40	25	369	929

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3.2. Trends in ant diversity

The ant diversity parameters were relatively constant across the urbanization gradient ($P > 0.05$; Table 3). Site WHN3 showed the highest value for species richness (23 species) and the mean species richness across all sites was 17.3 ant species. For ant species abundance the highest value (68 individuals) was recorded by the suburban site (WHS1). The mean species abundance across all sites was 38.9 ant species. The ant species diversity (Shannon and Simpson) and evenness exhibited their highest values in the rural site WHN2 and their lowest values in the urban site WHU3 (Table 3). However, one-way analysis of variance indicated no significant difference between site types for any of the variables

Table 3. Summary of diversity parameters for ants sampled across the urbanization gradient in Wadi Hanifa, Saudi Arabia. Species number (S), evenness (E), Shannon diversity (H'), and Simpson diversity (D').

Site	Mean abundance	S	E	H'	D'
WHN1	52.6	16	0.419	1.161	0.473
WHN2	22.4	22	0.797	2.463	0.894
WHN3	25.4	23	0.734	2.301	0.868
WHN4	35.8	15	0.671	1.816	0.727
WHN5	62.5	15	0.730	1.977	0.829
Rural Average	**39.8**	**18.2**	**0.670**	**1.943**	**0.758**
WHS1	68.1	17	0.705	1.996	0.810
WHS2	33.2	17	0.693	1.964	0.813
WHS3	56.2	19	0.522	1.536	0.705
WHS4	25.3	13	0.620	1.591	0.697
WHS5	27.0	11	0.516	1.237	0.565
Suburban Average	**41.97**	**15.4**	**0.611**	**1.665**	**0.718**
WHU1	22.3	19	0.489	1.440	0.679
WHU2	20.5	13	0.486	1.247	0.610
WHU3	50.6	18	0.344	0.994	0.386
WHU4	35.5	23	0.679	2.129	0.832
WHU5	46.1	18	0.602	1.739	0.773
Urban Average	**35.0**	**18.2**	**0.520**	**1.510**	**0.656**
Total Average	**38.9**	**17.3**	**0.600**	**1.706**	**0.711**

3.3. Trends in ant assemblages

3.3.1. DCA analysis

Figure 4 shows the result of the DCA ordination analysis for ant species. The output for this procedure also explains the ant species that contributed to the grouping of sites on the ordination diagram. The four urban sites (WHU1, WHU2, WHU4 and WHU5) are located near the right-hand end of the first axis while site WHU3 was placed near the center of the graph. These sites were characterised by species *Tapinoma simrothi*, *Brachyponera sennaarensis*, *Cardiocondyla minutior*, *Lioponera longitarsus*, *Monomorium exiguum* and *Cardiocondyla mauritanica*. The suburban sites and the rural sites lie at the other end of the first axis with no clear separation between them, although they can be loosely divided into two groups (WHS3, WHS4, WHS5 and WHN1) and (WHN2, WHN3, WHN4, WHN5, WHS1 and WHS2) along axis 2; they were characterised by *Tetramorium caespitum*, *Camponotus thoracicus*, *Camponotus sericeus*, *Tetramorium sericeiventre* and *Cataglyphis livida*, all of which were common at these sites. The eigenvalues for the first and second axis were 0.31 and 0.147 respectively explained 50 % of the total variation in the species data.

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The ANOSIM analysis confirmed differences between the three urbanization gradient sample groups (*R* = 0.97, *P* = 0.001). Pair-wise tests revealed significant differences between rural and urban (*R* = 0.73, *P* = 0.008), suburban and urban (*R* = 0.79, *P* = 0.008), but only marginal significant differences between rural and suburban (*R* = 0.25, *P* = 0.06).

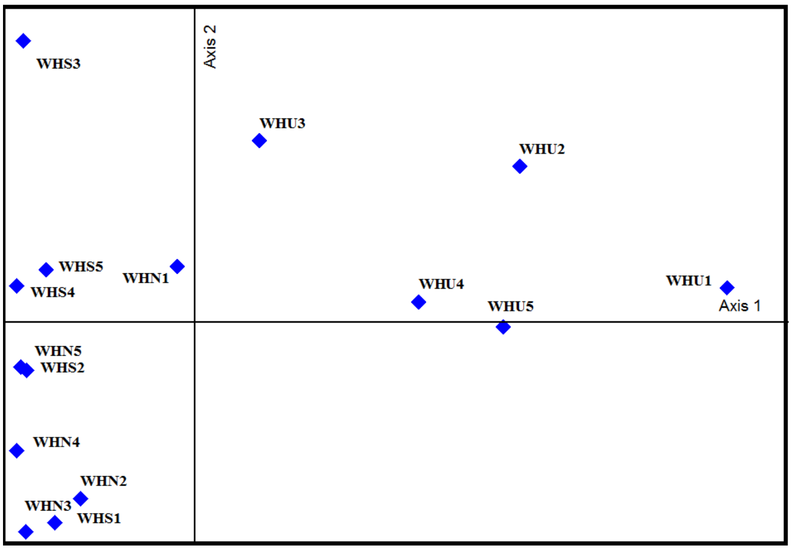

Figure 4. The detrended correspondence analysis (DCA) of ant community composition based on presence/absence data at 15 sampling sites along the urbanization gradient in Wadi Hanifa, Riyadh, Saudi Arabia.

3.3.2. CCA analysis

Site variables that we measured in this study (flora, soil pH, soil organic carbon, litter cover, litter depth and log) exhibited important differences between habitat types.

The CCA for the ant species and flora is shown in Figure 5. The forward selection procedure resulted in the retention of three significant plant species from the 43-plant species present, *Phragmites australis* (Cav.) Trin. ex Steud. (Sp32) (*P* < 0.01), *Atriplex nummularia* Lindl. (Sp51) (*P* < 0.01), *Pennisetum setaceum* (Forssk.) (Sp58) (*P* < 0.01). The other two-plant species *Lactuca serriola* L. (Sp.36) and *Achillea fragrantissima* (Forssk.) (Sp.42) were not significant. This separation of sites was to an extent reflected in the site groupings from the DCA analysis, which distinguished three groups. The five rural sites (WHN1, WHN2, WHN3, WHN4 and WHN5) and the two suburban sites (WHS1 & WHS2) were separated from the rest of the sites, which were in turn divided into two groups: (WHU1, WHU2, WHU4 and WHU5) and (WHS3, WHS4, WHS5 and WHU3). The three significant species were the most important factors in both axes and increased towards four urban sites (WHU1, WHU2, WHU4 and WHU5) and decreased towards the other two groups. The importance of *L. serriola* increased towards the first group while the importance of *A. fragrantissima* increased towards the third group (WHS3, WHS4, WHS5 and WHU3). The eigenvalues for the first and second axis were 0.290 and 0.123 respectively.

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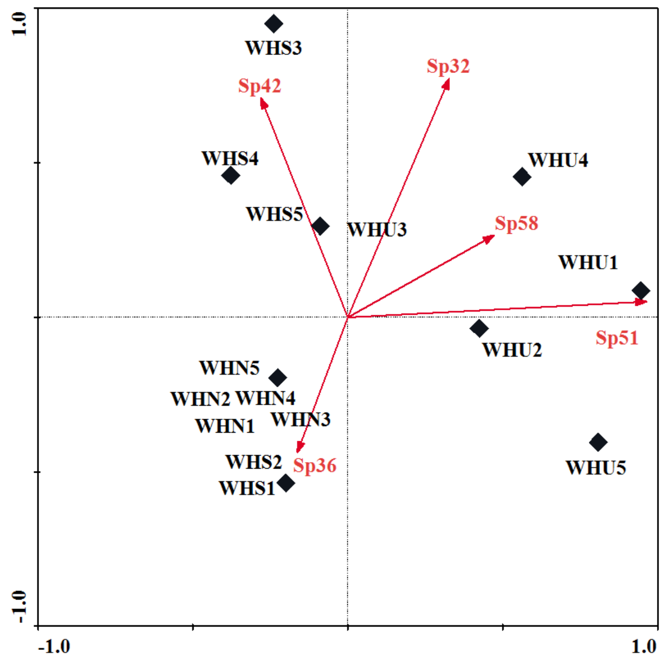

Figure 5. Canonical correspondence analyses (CCA) ordination biplot for axes 1 and 2. The most important contributing flora variables (5 of 43) are represented by arrows and the studied sites are represented by diamonds. Sp32 = *Phragmites australis;* Sp36 = *Lactuca serriola*; Sp42 = *Achillea fragrantissima*; Sp51 = *Atriplex nummularia*; Sp58 = *Pennisetum setaceum*.

Figure 6 shows the CCA biplot for the ant species and soil variables. Only two out of the seven variables, soil pH ($P < 0.01$) and soil organic carbon (SOC) ($P < 0.01$) were significant. Soil pH increased towards both the rural and suburban sites, which clustered in one group associated with the abundant species *Tetramorium caespitum*, *Camponotus thoracicus*, *Camponotus sericeus*, *Tetramorium sericeiventre* and *Cataglyphis livida*. Soil organic carbon increased towards the urban sites with their characteristic species *Brachyponera sennaarensis*, *Cardiocondyla mauritanica*, *Cardiocondyla minutior*, and *Monomorium exiguum* and decreased towards the other group. The two urban sites (WHU3 and WHU4) were concentrated at the middle of the diagram, indicating a weaker association with the soil organic carbon variable. The overlap of soil organic carbon and soil organic matter indicates that they were inter-correlated. The eigenvalues for the first and second axis were 0.279 and 0.11 respectively.

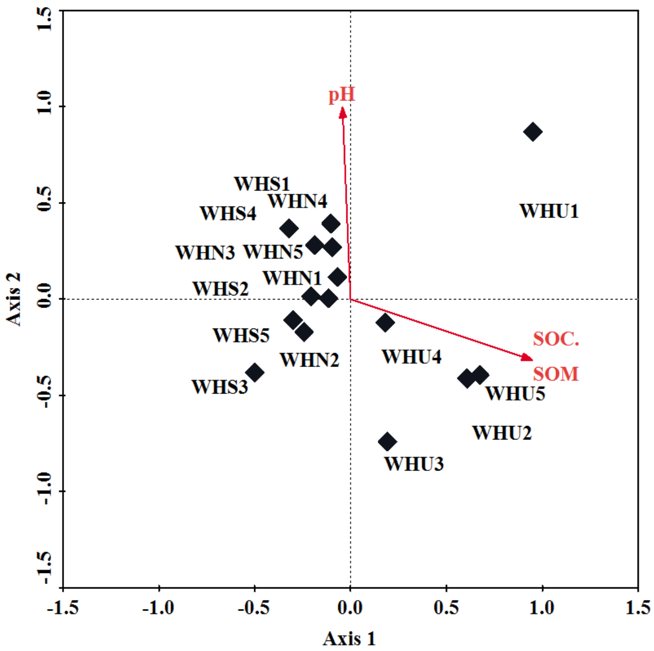

Figure 6. Canonical correspondence analyses (CCA) ordination biplot for axes 1 and 2. The most important contributing chemical and physical soil variables (2 from 7 variables) are represented by arrows and different studied sites represented by diamonds.

The relation between the ant species and the five ground cover variables; bare ground%; litter cover %; litter depth "cm"; wild plant cover% and log% (dead wood) is shown in Figure 7. The forward selection procedure resulted in the retention of three significant variables from the five variables, namely: litter cover (Litter C) ($F = 4.93$, $P < 0.01$), litter depth (Litter D) ($F = 2.38$, $P < 0.01$) and the log variable (Log) ($F = 2.85$, $P < 0.01$). The three factors showed a positive correlation with four urban sites (WHU1, WHU2, WHU4 and WHU5) along with their characteristic species (*Brachyponera sennaarensis*, *Cardiocondyla mauritanica*, *Cardiocondyla minutior*, and *Monomorium exiguum*) and a negative correlation with the other two groups WHS3, WHS4 and WHU3 (two of the suburban sites and one of the urban sites) and the sites WHN1, WHN2, WHN3, WHN4, WHN5, WHS1, WHS2, and WHS5, which represent the five rural sites and three of the suburban sites. The eigenvalues of the two CCA axes were 0.287 and 0.111.

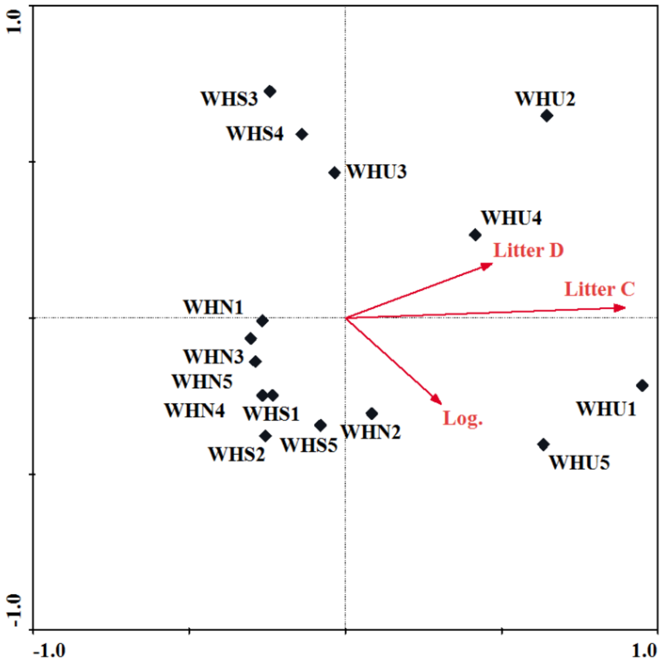

Figure 7. Canonical correspondence analyses (CCA) ordination biplot for axes 1 and 2. The most important contributing ground cover (2 of 5 variables) are represented by arrows and different studied sites represented by diamonds. (D = depth, C = cover).

3.4. Ant indicator species

Eleven ant species (26.2% of the total) with significance ($P < 0.05$) were identified as indicators for the urbanization gradient (Table 4). Six species were identified for urban sites, five for rural sites plus two suburban sites WHS1 and WHS2, and no indicator species were found in the suburban sites WHS3-5 (Table 4).

Table 4. Indicator species analysis showing ant species significantly associated to urbanization gradient at Wadi Hanifa, Riyadh, Saudi Arabia.

Species	Gradient*	Indicator value (IV in %)	*P* Value
Tetramorium caespitum	0	53.6	0.003
Camponotus thoracicus	0	53	0.011
Camponotus sericeus	0	55.4	0.047
Tetramorium sericeiventre	0	79.6	0.003
Cataglyphis livida	0	50.7	0.02
Tapinoma simrothi	2	83.7	0.001
Brachyponera sennaarensis	2	78.3	0.009
Cardiocondyla minutior	2	60	0.03
Lioponera longitarsus	2	80	0.007
Monomorium exiguum	2	60	0.025
Cardiocondyla mauritanica	2	60	0.025

*0 = WHN2-5 and WHS1-2; 2 = WHU1-5

4. Discussion

Urbanization is intimately associated with habitat modifications, and it is thought that community attributes interact in a number of ways with it [20,38-41]. The fact that ant diversity does not vary but species composition does vary across the urbanization gradient is one of the main findings of this study.

4.1. Species diversity

Overall, 42 different species of ants across the three urbanization gradients were trapped. *Monomorium niloticum* was the most abundant followed by *Cataglyphis holgerseni*, *Lepisiota simplex*, *Tapinoma simrothi*, *Cataglyphis livida*, and *Monomorium abeillei*. These species are considered native generalists [42-44].

We found that ant diversity parameters (species richness, abundance, evenness, and Shannon and Simpson's indices) did not vary significantly along the urbanization gradient. Thus, these findings at variance with both the increasing disturbance hypothesis [45] or the intermediate disturbance hypothesis [46]. However, as in our investigation, several other studies have also failed to support these hypotheses [9,47-49].

The lack of significant difference in ant diversity parameters might be attributed to the difference in reactions of different species to urbanization. Urban habitat is highly susceptible to being inhabited by both native and exotic species [50-53]. Some native ants are able to coexist with invasive ants as a result of many factors. One is the fact that certain invasive species are not yet numerically dominant [54]. This is the case with *Monomorium exiguum* (30 individuals in urban sites out of a total 24,510); this invasive is at the border of its abiotic tolerance [55]. Secondly, both native species such as *Camponotus sericeus*, *C. thoracicus*, *Cataglyphis aurata*, *C. holgerseni*, *C. minima*, *Monomorium abeillei*, *M. niloticum*, *M. bicolor*, *M. venustum*, and invasive or cosmopolitan species such as *Brachyponera sennaarensis*, *Cardiocondyla mauritanica*, *C. minutior*, *Lioponera longitarsus*, *Paratrechina longicornis*, *Pheidole indica*, *Solenopsis abdita*, *Tetramorium caespitum*, *Tetramorium simillimum*, and *Trichomyrmex mayri* occupy different niches (resource partition) and can use different food resources [56,57], or use they can forage at different time (e.g. *C. thoracicus*, and *C. holgerseni* [56,58] or they may possess potent chemical defenses (*Brachyponera sennaarensis*) [21].

4.2. Species composition

Many studies have shown a decrease in ant species richness along gradients of rural to urban forest [50], sometimes associated with reduced size and senescence of habitat fragments surviving in urban areas [59], ranging from parks at urban edges to inner-city squares [52]. By contrast, others have found no decline in ant richness with increases in urban extension or with decreasing size of natural habitat fragments in urban areas [9,47,49]. However, almost all studies have shown clear changes in ant species composition in urban habitats compared with nearby natural areas. Although our results have not shown a change in ant richness along the urbanization gradient, our results have demonstrated that the species composition does vary between habitat types. The urban habitat has an ant composition that differs between rural and suburban habitats, as evidenced by the DCA results. The lack of relationship between species richness and disturbance might be related to the occurrence of generalist species (e.g. *Cataglyphis holgerseni*, *C. livida*, *Monomorium abeillei*, *M. niloticum*) which offests the loss of some disturbance-sensitive species (e.g. *Messor meridionalis*, *Messor picturatus*, *Crematogaster chiarinii*, *Trichomyrmex chobauti*. These can also be replaced by other more generalist species such as *Brachyponera sennaarensis*, *M. exiguum*, *Tapinoma simrothi* or opportunist species [42,60-62]. In such a way, as Hoffmann [63] has emphasized, the disturbance has caused changes in species composition, but not to species richness. Urban communities can be a subset of the regional species pool, often biased towards generalists (63.3% of the total species) that are better adjusted to a stressful environment [64,65], or they may be novel to the region, comprising many non-native species [53].

While we recorded few non-native species (23.8%, 10 species) along the entire gradient, the urban sites in this study harbored many generalist (63.3%) and open-land species (e.g. *Camponotus sericeus, Cataglyphis holgerseni, Cataglyphis livida, Lepisiota simplex,* *Monomorium niloticum*), which is in line with other studies (e.g. [64,65]). Urban sites were inhabited by ant species that were practically absent from the rural and suburban sites. The unique aspects of the ant composition in urban sites can be partially explained by the occurrence of species pre-adapted to urban environments, such as *Cardiocondyla mauritanica* and *C. minutior* [66], invasive generalized foragers such as *Monomorium exiguum* [44],0 native generalized scavengers such as *M. afrum* and *M. bicolor*; and an invasive arboreal twig-nesting *Lioponera longitarsus* [67].

The lack of variation in overall species abundance or richness or diversity indices across the gradients should not be considered as unresponsiveness of ant communities, but rather as a weakness of such variables as indicators of environmental impact. By contrast species composition changed in all studies where it has been used (e.g. [68-70]).

4.3. Environmental variables

In rural-suburban-urban gradients, variables including habitat, landscape, and competitive interactions are the main groups of factors that affect ant community composition [20,23,59]. Habitat fragmentation [71,72], the degree of urban development [50,73,74], soil properties and vegetation structure [23,75,76], and the role of exotic ant species [22,23,77,78] are important determinants of ant community responses to urbanization. Site environmental variables, such as flora, ground cover, and soil properties measured in our study may explain much of the variation in the ant composition.

In accordance with our results, earlier studies have indicated that relatively high anthropogenic disturbance favours the occurrence of various types of plants in urban areas [79,80], often as a result of the introduction of exotic plant species, such as *Atriplex nummularia* (Chenopodiaceae), *Pennisetum setaceum* (Gramineae), and *Phragmites australis* (Poaceae) [81,82]. As shown by the CCA analysis, the difference in plant composition could possibly explain the difference in ant community on both the rural and the suburban than those of the urban areas [83].

Based on our CCA results, several soil elements (soil pH, SOC and SOM) explained the part of the variation in the ant community. These soil attributes could affect ants directly via their nesting activities or indirectly via their effect on plants [84]. In general soil organic matter (SOM) often increases in perennial vegetation [85]. Moreover, a lower soil pH in urban sites is related to a higher amount of organic matter and available nutrients [86], which enhances the suitability of nest sites [87]. All the urban ant species revealed some association with soil factors. The abundance of *Brachyponera sennaarensis*, *Cardiocondyla mauritanica*, *Cardiocondyla minutior*, and *Monomorium exiguum* abundance were positively related to high concentrations of SOC, SOM and lower pH. In the rural and suburban sites, abundance of *Tetramorium caespitum*, *Camponotus thoracicus, Camponotus sericeus, Tetramorium sericeiventre* and *Cataglyphis livida* were negatively correlated with high SOC and SOM and positively with increased pH.

The conversion from native flora to perennial vegetation and the irrigation in unmanaged urban sites leads to the increase in litter cover and depth and log percentage, which all showed a significant effect on the variation among the different studied sites in the CCA result. Logs are an important nesting resource for both leaf-litter and arboreal ant species [88,89]. Many ant species that forage in the leaf litter use logs for protection and foraging and to enlarge their colonies [90-92]. In accordance with several studies [93-95], we found a positive correlation between the ant species, *Brachyponera sennaarensis*, *Cardiocondyla mauritanica*, *Cardiocondyla minutior*, and *Monomorium exiguum* in urban sites and the presence of deep litter cover and logs (dead wood).

4.4. Indicator species

Discrete differences in ant community structure were seen across the sites. Urban sites with the highest degree of disturbance differed in their composition from the other rural and suburban sites. Eleven indicator species were identified for different habitats, suggesting that these predominant species are key to shaping ant community composition and indicating that the variation within each habitat is driven by shifts in the highly abundant species. These indicator species showed different ecological behavior within each habitat [90,91]. Six predominant urban ant species have been identified as urban bioindicators that can easily be found in high abundance and can adjust their nesting habits to different human environments. *Brachyponera sennaarensis* is a general scavenger tramp species that nests in humid urban and disturbed sites next to human settlements, especially where waste ground and rubbish dumps exist [43,60,96]. *Tapinoma simrothi* is a native species, a generalized forager and nests among roots of Gramineae plants in wild habitats of the Arabian deserts, where it attends mealybugs [97]. It is observed attending aphids and protecting them from predators [98]. *Cardiocondyla minutior* is a tramp species that nests directly in humid soil of disturbed sites and date palm plantations of the Arabian Peninsula and in the Socotra Archipelago where soil is rich in waste of domestic livestock [99]. Little is known about the biology of this species but the majority of *Cardiocondyla* species are known to inhabit anthropogenically or naturally disturbed sites [66]. The predatory ant, *Lioponera longitarsus*; is another tramp species, that build nests directly in ground with a single, small entrance hole [100]. However, *Lioponera longitarsus* is known to nest in hollow twigs [67] and this nesting habit facilitates species dispersal when organic material is moved around by humans. *Monomorium exiguum* is a native species, and is a generalized forager that inhabits the leaf litter and topsoil layer in public gardens, date palm plantations, and urban sites near to human settlements where there is plenty of organic matter [99,101].

Five indicator native species showed an affinity towards both rural and suburban environments, namely *Cataglyphis livida*, *Camponotus sericeus*, *C. thoracicus*, *Tetramorium sericeiventre*, and *T. caespitum*. These are generalized scavengers, that build nests directly in the ground under stones and other objects next to *Acacia* and *Calotropis procera* (Apocynaceae) trees of the Arabian Peninsula [102].

5. Conclusions

Our results indicate that the ant diversity parameters do not vary appreciably along the three-urbanization gradient (urban, suburban and rural). By contrast, discrete differences in ant community structure exist across the urbanization gradient. Urban sites with the highest degree of disturbance differed in their composition from the other rural and suburban sites. Environmental factors such as vegetation type (native and exotic species), soil properties (soil pH, SOC and SOM) and ground cover (litter cover litter depth and wood debris) proved to be important determining factors of ant species composition. As with similar investigations, this study demonstrates that ants are good indicators of urbanization effects and remain successful and dominant in all habitats.

Supplementary Materials: Not applicable.

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