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Biodiversity of ants (Hymenoptera: Formicidae) in different urban environments: A case study in Shiraz, Iran

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Abstract

Ants are a major part of the ecosystem as they assist in the decomposition process and improve soil quality. In this study the species richness and biodiversity of these arthropods was assessed in the habitats with varying degrees of human impact in Shiraz, Fars Province, southern Iran. To this end, six habitats including three city parks with the least amount of human destruction (Be'sat, Janat, Babakoohi), two habitats with high amount of manipulation in order to agriculture and urbanization (a field and a destroyed garden) and a natural park without any human manipulation as control, were chosen and sampled bimonthly during 2015 and 2106. A total of 6270 ant workers belonging to 30 species, 12 genera, and three subfamilies were recorded. The most abundant subfamily was Formicinae (16 species) followed by Myrmicinae (12 species), and Dolichoderinae (two species). The biodiversity indices showed a greater diversity in both natural park and urban landscape: Be'sat and Janat parks, with the lowest amount of human effects, respectively as well as Babakoohi and the lowest in the field and destroyed garden. Although a significant difference was observed with the habitats (F= 4.255, P=0.004) and the months (F= 4.327, P=0.002) of sampling, there was not a significant difference between Babakoohi, natural park, Janat and Be'sat parks (P>0.05) nor between field and destroyed garden (P>0.05).

Keywords: Ants, Biodiversity, Iran, Species richness

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Introduction

Ants from the order Hymenoptera and Formicidae family are eusocial insects that occupy the most ecological niches and are a main component of the ecosystem by improving the soil and assisting in the decomposition process (Watanasit & Bickel, 2000). They represent a great part of the animal biomass and are estimated to contribute 15–20 % (on average) and nearly 25% (in the tropics) of terrestrial animal biomass, exceeding that of the vertebrates. Ants appeared on earth since 140 to 160 million years ago, much before the arrival of human beings, during the latest early Cretaceous. They are involved in underground processes and act as ecosystem engineers to adjust the physical and chemical features of the soil to plants, microorganisms, and other soil organisms (Folgarait, 1998). The known living ants comprising 16 subfamilies, 38 tribes, 346 genera, and 14,118 valid species have been classified (Bolton, 2022).

Ants are among the taxa which can persist in highly managed urban environments. They are found in nearly all urban habitats and have strong ecological and economic impacts (Folgarait, 1998; Sanford et al., 2008). They can act as predators, prey, detritivores, seed dispersers, and herbivores in natural habitats and play an important role in collecting and cleaning cities of garbage and human waste in urban habitats (Frankie & Ehler, 1978; Way and Khoo, 1992; Folgarait, 1998). Ants are also considered good biological indicators due to their mutualistic behavior with both flora and fauna, their presence in both intact and disturbed habitat and their rapidly respond to environmental variables (Majer, 1983; Andersen, 1990). Among the human activities, urbanization has the most effect on habitat loss and frequently eliminates a large number of native species. The diversity of ants is high but they are highly sensitive to human impact, which obviously reduces its richness (Folgarait, 1998). The sampling of ants is relatively easy and does not require expertise (Greenslade & Greenslade, 1984; Agosti & Alonso, 2000), these qualities suggest that ants provide high levels of information about an ecologically and numerically dominant group.

Several studies have been conducted on ants in Iran (Moradloo & Pashaei Rad, 2005; Paknia & Kami, 2007; Paknia et al., 2008; 2010; Firouzi et al., 2011; Ghahari et al., 2009, 2011, 2015; Hossein Nezhad et al., 2012; Mohammadi et al., 2012; Shiran et al., 2013; Moradloo et al., 2015; Hosseini et al., 2015; Torabi et al., 2017; Mohseni et al., 2017; Latibari et al., 2017; Samin et al., 2020; Esfandiari et al., 2020; Khalili-Moghadam et al., 2021; Ghahari, 2021). In most researches, the ant species belonged to only 3 subfamilies (Formicinae, Myrmicinae and Dolichoderinae). The newest report of ant species in Iran identified 248 species from seven subfamilies and 37 genera (Pashaei Rad et al., 2018); however, three new *Cataglyphis* species described from Koohrang County in central-western Iran (Chaharmahal va Bakhtiari Province) should be added to this list, bringing the known Iranian ant species to at least 251 (Khalili-Moghadam et al., 2021).

The distribution and diversity of ants greatly depend on the environmental conditions and land use patterns in different regions. Recent studies in the countries of Australia, Brazil, Croatia, Ecuador, France, India, Indonesia, Italy, Mexico, and Bangladesh (Lawes et al., 2017; Franco et al., 2021; Pérez-Toledo et al., 2021; Melo et al., 2021; Jahan et al., 2022; Aguiar et al., 2022) have focused on evaluating ant diversity in areas with different land use patterns, examining the effect of environmental conditions on ant composition, and identifying key threats to ant biodiversity. Although some research has been done on the impact of human activity on the biodiversity of some groups of arthropods in Iran (Ramezani and Mossadegh, 2014, 2017, 2018; Pezhman et al., 2018; Rahgozar at al., 2019; Yahyapour et al., 2022), such studies, especially those on ant biodiversity, are limited. Paknia and Pfeiffer (2014) aimed to quantify the variation in ant assemblages and identify the environmental and spatial factors that influence ant distribution in dryland ecosystems of Iran. Mohseni and Pashaei Rad (2021) investigated the effect of edaphic factors on the distribution and abundance of ants in different habitats in central Iran. By conducting similar studies, researchers can gather valuable data on ant diversity and composition, which can be used to inform conservation efforts and improve our understanding of the ecological importance of ants. The objective of the current study was to assess the impact of urban development on the biodiversity and species richness of ants in urban ecosystems. Specifically, we investigated the distribution and diversity of ant species in various urban habitats, including a natural park that closely resembles a natural habitat, city parks, a destroyed garden that has undergone urbanization, and an agricultural field located in the vicinity of Shiraz, Fars Province, in the south of Iran. It is hoped that examining these habitats will yield valuable insight into how urbanization affects the richness and distribution of ant species.

Materials and Methods

This study was conducted in Shiraz, Fars province, south Iran which is located at the central zone of south Zagros, and is characterized by moderate climate. In order to investigate the effects of human activities on biodiversity of ants, we chose three different habitats including three human managed parks with different species of trees and shrubs (Be'sat: 29°62′ N, 52°50′ E; Janat: 29°61′ N, 52°47′ E and Babakoohi: 29°64′ N, 52°55′ E), two habitats with the most human impact (a field: 29°61′ N, 52°62′ E and a destroyed park: 29°62′ N, 52°46′ E) and a natural park (29°.60′ N, 52°.60′ E) without human intervention as a control in Shiraz. All sites were placed at altitude from 1486 m. a.s.l. The specimens were collected during April 2015 to May 2016 at two-month intervals. The sampling technique was employed by the application of 10 quadrates (2×2m quadrats) for ant collection (Mbenoun et al., 2021). All ants on the ground or the plants within the quadrat were directly hand-captured with the help of a fine brush or by an aspirator and stored in 70% ethanol. All sampling occurred between 8:00 a.m.-11:00 a.m. to standardize the collection and reduce variation due to time or temperature differences, according to Begum et al. (2021). The preserved specimens were pinned and labelled for further identification. Ant samples were examined under a stereo microscope and identified by the use of appropriate identification keys (Agosti & Collingwood, 1987; Bolton, 1994; Collingwood & Agosti, 1996). The identified specimens were confirmed by Dr. Lech Borowiec, University of Wroclaw, Poland. Specimens have been deposited in the entomology collection of the Department of Plant Protection at the Agricultural Sciences and Natural Resources University of Khuzestan, Iran.

Data analysis: We used the Simpson index of diversity (C), the Shannon–Wiener index (H), the Margalef (D) and the evenness (E) in order to assess the biodiversity and evenness index in different sampling sites using SDR software ver.4 (Seaby & Henderson, 2006).

The indices of biodiversity and the index of evenness is calculated as:

$$E = \frac{H'}{lnS}$$

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

$$C = \sum_{i=1}^{s} Pi^2$$

$$Pi = \frac{Ni(Ni-1)}{Nt(Nt-1)}$$

$$D = \frac{S-1}{\ln N}$$

Where H′ is the Shannon index and *S* is the number of the species, *C* is the Simpson's index and *D* is the Margalef index, *Pi* and *Ni* are the proportion and the number of individuals in the i^{th} species, respectively, Nt the total individuals and N is the total number of individuals in the sample (Magurran, 2004).

The difference in ant species richness and diversity between different habitats and in different sampling dates was also determined using one-way ANOVA in SPSS22.

Results

A total of 6270 individuals were collected during the study period, including 30 species of ants from 12 genera of 3 subfamilies (Table 1). Subfamily Formicinae with 16 species from 5 genera (*Camponotus*, *Cataglyphis*, *Nylanderia*, *Lepisiota* and *Plagiolepis*) was the most abundant in all habitats followed by Myrmicinae with 12 species from 6 genera (*Crematogaster*, *Monomorium*, *Tetramorium*, *Pheidole*, *Cardiocondyla* and *Messor*), while subfamily Dolichoderinae is poorly recorded with only two species from one genera (*Tapinoma*). Among them the species *Cataglyphis cf. asiriensis* Collingwood, 1985, *Cardiocondyla cf. israelica* seifert, 2003 and *Messor cf. clivorum* Ruzsky, 1905 may represent new report for Iran. Also, *Cataglyphis cf. stigmata* had many characters similar to *Cataglyphis stigmata* Radchenko & Paknia, 2010 described from coast of Persian Gulf of Iran (Radchenko & Paknia, 2010) but not all characters in original description agree with our specimen and it maybe belongs to an undescribed species. However, more material is needed to complete the identification.

Table1. Ant species abundance in different urban habitats of Shiraz city, south Iran.

subfamily	Genus	Species	Bk.	Bs.	Jn	Nt.	Dr.	Fi.
Formicinae	*Camponotus*	*staryi* Pisarski, 1971	0	48	3	12	0	0
		oasium Forel, 1890	51	8	8	42	0	0
		gestroi Emery, 1878	0	1	0	1	0	0
	Cataglyphis	*Nodus* (Brullé, 1833)	124	48	88	25	62	95
		livida (André, 1881)	45	10	15	11	3	0
		cf.asiriensis Collingwood, 1985	0	0	0	1	0	0
		cf.stigmata Radchenko & Paknia, 2010	0	0	0	8	0	0
	Nylanderia	*Jaegerskioeldi* (Mayr, 1904)	1	0	13	5	0	4
	Lepisiota	*Dolabellae* (Forel, 1911)	112	85	139	8	55	0
		bipartita (Smith, 1861)	76	110	253	20	96	0
		semenovi (Ruzsky, 1905)	0	43	0	20	0	0
		frauenfeldi (Mayr, 1855)	0	0	0	2	0	0
		karawaiewi (Kuznetsov-Ugamsky, 1929)	61	0	23	12	10	27
	Plagiolepis	*pallescens* Forel, 1889	5	11	27	0	0	0
		cf. maura taurica Santschi, 1920	0	4	8	0	0	0
Myrmicinae	*Crematogaster*	*Subdentata* Mayr, 1877	75	271	304	59	4	47
		sorokini Ruzsky, 1905	0	13	0	67	0	0
	Monomorium	*abeillei* André, 1881	258	118	211	66	84	129
	Tetramorium	*caespitum* (Linnaeus, 1758)	0	61	94	31	2	23
		indocile Santschi, 1927	0	40	40	0	0	0
	Cardiocondyla	*cf. israelica* Seifert, 2003	0	1	14	0	0	0
		mauritanica Forel, 1890	9	13	74	7	0	7
	Messor	*wasmanni* Krausse, 1910	36	104	155	129	183	302
		caducus (Victor, 1839)	3	0	16	22	0	7
		cf. clivorum Ruzsky, 1905	0	0	0	0	0	1
	Pheidole	*indica* Mayr, 1879	71	121	52	9	15	2
		koshewnikovi Ruzsky, 1905	80	100	82	21	19	7
Dolichoderinae	*Tapinoma*	*erraticum* (Latreille, 1798)	55	52	92	86	2	30
		simrothi Krausse, 1911	340	367	577	235	131	304

Nt. Natural Park, Bk. Babakoohi park, Bs. Be'sat park, Jn. Janat Park, Dr. Destroyed Garden, Fi. Field.

The Genus *Lepisiota* with five species followed by *Cataglyphis* and *Camponotus* each with four species had the highest number of species among the twelve collected genera. Two species of Dolichoderinae (*Tapinoma erraticum* (Latreille, 1798) and *Tapinoma simrothi* Krausse, 1911) and some species such as *Messor caducus* (Victor, 1839), *Monomorium abeillei* André, 1881, *Crematogaster subdentata* Mayr, 1877, *Tetramorium caespitum* (Linnaeus, 1758), *Pheidole koshewnikovi* Ruzsky, 1905, *Pheidole indica* Mayr, 1879 and *Cardiocondyla mauritanica* Forel, 1890 from Myrmicinae and *Lepisiota bipartite* (Smith, F., 1861), *Lepisiota dolabellae* (Forel, 1911), *Cataglyphis nodus* (Brullé, 1833), *Cataglyphis livida* (André, 1881), and *Nylanderia jaegerskioeldi* (Mayr, 1904) form Formicinae have been widely distributed in all habitat sampling sites. Interestingly, *Messor cf. clivorum* was unique to the field; and *Lepisiota frauenfeldi* (Mayr, 1855) in natural park. The most abundant species was *T. simrothi* with 1954 individual followed by *M. abeillei* and *C. subdentata* with 866 and 760 individuals, respectively.

The study of biodiversity at different times showed that in different months of the year, the diversity of ants fluctuated and had a significant difference (F=4.897, P=0.001) (Table 4) so that the lowest rate of Shannon diversity index (0.79) and then the value of 1.02 was registered in January in the field and Janat Park respectively and the highest was recorded on May (2.37) and August (2.36) in Janat Park and then in March (2.343) in natural park. In general, the highest Shannon diversity index of all samples was in the natural park (2.577 ± 0.163) followed by Be’sat and Janat parks (2.568±0.135 and 2.479 ± 0.344), respectively, and the lowest (1.803 ± 0.1416) and (1.984 ± 0.0891) were recorded in field and destroyed garden, respectively (Table 2). However, the highest Simpson index (9.51± 1.329 and 8.81±1.449) was observed in Be’sat and the natural park, and the highest Margalef index (3.513± 0.406 and 2.964±0.332) was seen in the natural park and Be’sat park, respectively (Table 2). The lowest Simpson index (4.558±0.642) and Margalef (1.85±0.189) were seen in the field and destroyed garden, respectively (Table 2).

Although a significant difference was observed with different habitats (F= 4.255, P=0.004) and different months (F=6.935, P=0.012) of sampling (Table 4), no significant difference was found between Babakoohi, Natural Park, Janat and Be’sat parks (P>0.05) nor between the field and destroyed garden (P>0.05) (Table3).

The highest equitability of the ant species was seen in late winter (0.69, 0.68, 0.67 in natural park, Babakoohi and Be’sat park, respectively) and middle spring (0.70 in Janat Park) and the lowest was seen in mid to late autumn (0.54, 0.42, 0.32 and 0.30 in Janat Park, Natural Park, destroyed garden and Be’sat park, respectively). However, the highest totally index was seen in natural park and Be’sat park (0.76±0.05) and the lowest was seen in the field (0.53±0.041).

Table 2. Ant diversity indices from different urban habitats of Shiraz city, south Iran.

Habitat types	Number of Species	Shannon Index	Margalef index	Simpson Index	Evenness
Nt.	25	2.577±0.163	3.513	8.813±1.449	0.76
Bk.	17	2.356	2.209	8.039±1.152	0.69
Bs.	23	2.568±0.135	2.964	9.508±1.329	0.76
Jn.	22	2.479±0.034	2.715	8.457±0.383	0.73
Dr.	13	1.984±0.089	1.847	6.016±0.994	0.58
Fi.	14	1.803±0.142	1.886	4.558±0.642	0.53

Discussion

In the present survey, 30 species of ants from 12 genera representing three subfamilies (Formicinae, Myrmicinae and Dolichoderinae) were reported. Although some studies (Bhoje et al., 2014; Mohseni et al., 2017; Esfandiari et al., 2020; Begum et al., 2021) have reported the largest number of species being in the subfamily Myrmicinae, the current study, like those of Shiran et al. (2013) and Ghahari et al. (2009) found the subfamily Formicinae to be the most abundant in all habitats, and the subfamily Dolichoderinae was poorly recorded with only two species from one genus (*Tapinoma*).

Cataglyphis species are known for their remarkable ability to thrive in hot and arid environments where temperatures can reach extreme levels. To survive in such conditions, these ants possess several adaptations at both individual and colony levels that enhance their thermotolerance and allow them to overcome the challenges of communication in these environments (Boulary et al., 2017). While previous studies have suggested that the species of *Cataglyphis* are specific to hot, dry, and desert areas (Boulary et al., 2017; Mohseni et al., 2017), four species of this genus were collected by the current study in areas with rich vegetation and temperate climates. Moreover, *T. simrothi* and *L. dolabellae* have been reported from regions with different climatic conditions (Mohseni et al., 2017) and were collected from all sampling sites with large populations in the current study.

Table 3. One-way ANOVA of diversity index by region.

Regions		**Simpson LSD**		**Shannon LSD**	
(I) region	**(J) region**	**Mean Difference (I-J)**	**Sig.**	**Mean Difference (I-J)**	**Sig.**
Bk.	Nt.	-0.67943	0.485	-0.20886	0.297
	Dr.	1.67300	0.091	0.35343	0.082
	Ag.	2.11600*	0.034	0.45493*	0.027
	Jn.	-1.46714	0.136	-0.33029	0.103
	Bs.	-0.44929	0.643	-0.08643	0.664
Nt.	Dr.	2.35243*	0.020	0.56229*	0.007
	Ag.	2.79543*	0.006	0.66379*	0.002
	Jn.	-0.78771	0.418	-0.12143	0.542
	Bs.	0.23014	0.812	0.12243	0.539
Dr.	Ag.	0.44300	0.648	0.10150	0.610
	Jn.	-3.14014*	0.002	-0.68371*	0.001
	Bs.	-2.12229*	0.034	-0.43986*	0.032
Fi.	Jn.	-3.58314*	0.001	-0.78521*	0.000
	Bs.	-2.56529*	0.011	-0.54136*	0.009
Jn.	Bs.	1.01786	0.297	-0.24386	0.225

*. The mean difference is significant at the 0.05 level.

Table 4. ANOVA in different regions and different months with index of diversity.

Predictors	**Model**		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Month	1	Regression	1.229	1	1.229	6.935	0.012
		Residual	7.090	40	0.177		
		Total	8.319	41			
Region	1	Regression	3.405	5	0.661	4.990	0.001
		Residual	4.271	36	0.136		
		Total	8.319	41			

The Shannon index of diversity showed significant differences (F = 4.035, P = 0.002) in the sampling sites, with the highest diversity index seen in Natural Park (2.577) and Be'sat Park (2.568) and the lowest in the field (1.8) and destroyed garden (1.98). However, the diversity index in the destroyed garden and the field did not differ significantly (P=0.648 and P=0.610 for Simpson and Shannon indices, respectively). These findings are consistent with previous studies by Sanford et al. (2008), Begum et al. (2021), and Uno et al. (2010), which also reported significant differences in total species richness among different habitat types. These results suggest that habitat type plays an important role in determining the diversity of ant species in the studied area. Jahan et al. (2022) assessed the effects of vegetation types and habitat disturbance on species richness and found that vegetation and soil conditions can significantly affect the overall diversity and composition of ants in Lawachara National Park in Bangladesh. Melo et al. (2021) noted that the maintenance of urban forest habitats is crucial for the conservation of biodiversity in the area and for preserving the ecological functions performed by the species within the forest areas. The authors found that the diversity and abundance of ant and spider species were significantly influenced by the landscape structure, with forest remnants being important habitats for these arthropods in urban environments (Melo et al., 2021). Mohseni and Pashaei Rad (2021) studied the effects of edaphic factors on the distribution and abundance of ants in different habitats in central Iran and observed that an increase in the abundance and richness of plant species had a positive impact on the abundance and richness of ants. Several other studies have investigated the impact of urbanization and human activity on the biodiversity of soil micro arthropods in different regions. These studies have consistently shown that the index of biodiversity is higher in areas with permanent and well-established vegetation, such as gardens, which are subject to less manipulation and degradation. In contrast, areas subjected to human manipulation, such as agricultural land, have been found to have lower biodiversity indices (Ramezani and Mossadegh, 2014, 2017, 2018; Kahrarian et al., 2017; Pezhman et al., 2018; Rahgozar at al., 2019; Melo et al., 2021; Jahan et al., 2022; Yahyapour et al., 2022). The findings of these studies highlight the importance of preserving natural and well-established habitats, such as gardens, to maintain soil microorganism diversity and ecosystem functioning. Furthermore, reducing human disturbance and manipulation of natural habitats, particularly agricultural land, can help preserve soil biodiversity and promote sustainable agriculture. Similarly, areas with high diversity and permanent vegetation were found to have a higher index of biodiversity compared to areas with high levels of disturbance and low vegetation. In the current study, natural and well-preserved urban parks were found to have a higher diversity of ant species compared to disturbed habitats such as fields and destroyed gardens. Maintaining urban green habitats is crucial for the conservation of biodiversity in the area and for preserving the ecological functions performed by the species within these areas. The lower diversity index in the field and destroyed garden may be due to the reduced availability of suitable nesting sites, food sources, and other resources necessary for the survival of ant populations.

Conclusion

The current results showed that ant community composition changes in response to urban development and that urbanization has dual effects on ant biodiversity. On one hand, ant biodiversity was decreased in the destroyed garden and the field, but on the other hand, an increase was seen in the more sustainable city parks. Moreover, the highest ant species richness was found in the parks, and the lowest levels were seen in the field and destroyed garden, both of which had more disturbances associated with urbanization. The results of this study highlight the importance of preserving natural habitats and minimizing human disturbances to maintain the diversity of ant species in urban and suburban areas.

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تنوع زیستی مورچه ها (Hym. Formicidae) در محیط های مختلف شهری، مطالعه موردی در شیراز، ایران

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چکیده

مورچه‌ها بخش مهمی از اکوسیستم را تشکیل می‌دهند. آنها به فرآیند تجزیه مواد کمک کرده و کیفیت خاک را بهبود می‌بخشند. در این پژوهش غنای گونه‌ای و تنوع زیستی این بندپایان در زیستگاه‌های با درجات مختلف تأثیر انسانی در شهر شیراز، استان فارس، جنوب ایران مورد ارزیابی قرار گرفت. به همین منظور شش زیستگاه شامل سه باغ شهری با کمترین میزان تخریب انسانی (بعثت، جنت، باباکوهی)، دو زیستگاه با میزان بالای دستکاری به منظور کشاورزی و شهرسازی (یک زمین کشاورزی و یک باغ تخریب شده و متروکه به منظور شهرسازی) و یک باغ طبیعی بدون هیچ گونه دستکاری انسانی به عنوان شاهد، انتخاب و هر دو ماه یکبار طی سال های ١٣٩٤تا ١٣٩٥ از مورچه‌های موجود در آنها نمونه‌برداری صورت گرفت. در مجموع ٦٢٧٠ نمونه مورچه متعلق به ٣٠ گونه، ١٢ جنس و ٣ زیرخانواده جمع‌آوری شد. بیشترین گونه‌ها (١٦ گونه) متعلق به زیرخانواده Formicinae بود و پس از آن زیر خانواده Myrmicinae با ١٢ گونه و زیر خانواده Dolichoderinae با ٢ گونه قرار گرفتند. شاخص‌های تنوع زیستی هم در باغ طبیعی با کمترین میزان تأثیرات انسانی و هم در پارک‌های شهری بعثت، جنت و همچنین باباکوهی تنوع بیشتری را نشان دادند و کمترین میزان در زمین کشاورزی و باغ تخریب شده دیده شد. اگر چه تفاوت معنی‌داری در شاخص تنوع در زیستگاه‌های مختلف (F= 4.255, P=0.004) و نیز در ماه‌های مختلف نمونه‌برداری (F= 4.327, P=0.002) مشاهده شد، اما این اختلاف در بین پارک‌های شهری (باباکوهی، جنت و بعثت) و باغ طبیعی با هم و همچنین بین مزرعه و باغ متروکه (P>0.05) معنا دار نبود.

کلیدواژه‌ها: ایران، تنوع زیستی، مورچه، غنای گونه‌ای

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