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Effects of various urban land-uses on the epigeic beetle communities in Bangalore city, India

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Abstract: Urban landscapes harbor diverse man-made land-uses ranging from highly modified residential and industrial areas to semi-natural habitats with their associated biotic communities. Understanding the ecological patterns and processes of urban landscapes is required for the maintenance of urban biodiversity and planning in the face of expanding cities and increasing populations. Therefore, we studied the epigeic beetle communities in Bangalore city (India) to examine their responses to different types of urban land-uses. They were systematically sampled using pitfall traps from four land-use types (remnant forest patches, campuses, public parks and vacant residential plots). Different taxonomic groups within the epigeic beetle communities dominated different land-use types. In general, the alpha diversity was higher in residential plots and remnant forest patches than parks and campuses, indicating their differential responses to habitat disturbance. The overall beta diversity was high, with moderate levels of similarity between the sampled locations indicating spatial heterogeneity of urban environments. Among trophic guilds, predators and detrivores dominated residential plots and remnant forest patches, respectively. Finally, we conclude that future urban planning in Bangalore should include even small patches of natural vegetation for conservation of native flora and fauna, as these small patches can provide refuge to native biotic communities, including insects.

Key words: Habitat disturbance, habitat loss, intermediate disturbance hypothesis, spatial heterogeneity, PERMANOVA.

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Introduction

The urban environment is created from, and is continuously shaped by, various anthropogenic factors representing the most intense form of human influence, resulting in landscapes formed of heterogeneous mosaics of residential dwellings, commercial properties, industrial areas, green spaces, roads and pavements etc. (McIntyre 2000; McIntyre *et al.* 2000). The biodiversity in urban landscapes is different from those in “natural” areas due to such extensive human influence (McIntyre 2000). The process of urbanization can have both positive and negative effects on the local biodiversity. It facilitates increase in biodiversity through the addition of non-native species with high dispersal ability that replace native species at a faster rate (Mack & Lonsdale 2001; McKinney 2000, 2006). It also leads to higher spatial heterogeneity resulting in increased levels of beta diversity (Niemelä 1999), and greater primary productivity due to the availability of water and nutrients in the form of organic waste (Adams 1994; Falk 1976). Urbani-zation causes the loss of

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species diversity and extinction of native species due to fragmentation and isolation of vegetated areas (Blair & Launer 1997), and structural simplification of vegetation (Czech *et al.* 2000; Marzluff & Ewing 2001). Still, biodiversity in such heterogeneous environments plays several important roles that include ecosystem services (Bolund & Hunhammar 1999), aesthetic enjoyment and recreation (Miller 2006), and nature education (Miller & Hobbs 2002). In addition, urban biodiversity provides livelihood services such as grazing, fishing, fuel wood collection etc. to many in the tropics.

The effects of urbanization on many biotic communities have been well documented (McKinney 2008). Most studies on plants, birds, mammals, reptiles, amphibians and invertebrates indicate that diversity rapidly decreases with increasing urbanization, especially in the central core areas of cities. However, species diversity of most taxa increases in places with moderate urbanization. In a review, McKinney (2008) showed that taxonomic group, intensity of urbanization, spatial heterogeneity, intermediate disturbance and presence of non-native species influence patterns of diversity distributions in urban ecosystems.

In urban biodiversity studies, insects are preferred indicators of biodiversity change due to their species and functional diversity,which provide a snapshot of the overall diversity of an area; their quick response to environmental changes due to their short generation time; and their sociological, agronomical and economic importance (McIntyre 2000). Epigeic insect communities such as rove beetles (Deichsel 2006), carrion beetles (Ulrich *et al.* 2007), ants (Kamura *et al.* 2007; Savitha *et al.* 2008), ground beetles (Fujita *et al.* 2008) and ground arthropods (Sattler *et al.* 2010) are commonly chosen indicator taxa to evaluate the effects of urbanization.

This study was conducted to determine the effects of urbanization on the epigeic beetle communities (Order: Coleoptera) within Bangalore city, India. Epigeic beetles are ideal focal taxa for urban biodiversity studies; because they are both taxonomically and functionally diverse, are present in a wide range of terrestrial habitats and can be easily sampled (New 2007). In addition several epigeic beetle communities such as rove beetles (Family: Staphylinidae), ground beetles (Carabidae) and dung beetles (Scarabaeidae) are extensively used as indicators of habitat disturbance (Eyre *et al.* 2003; Hodkinson & Jackson 2005; Niemelä *et al.* 2002).

Bangalore is known as the 'Garden city of India' despite having a dubious distinction of being the fastest growing metropolitan area in the country. The city is characterized by large green spaces such as public parks and institutional campuses, while it is also dotted with numerous smaller well-planned parks, vacant residential plots, playgrounds, roads, pavements, and commercial and residential properties. Several villages and small towns are being absorbed into the city limits due to the rapid growth of the city, which has led to the conversion of surrounding agricultural land to urban areas. Despite such drastic changes in habitat structures, these various land-uses do provide refuge to numerous biotic communities, including epigeic beetles. As little is known about the effects of the city's various land-uses on local biodiversity, we studied the responses of epigeic beetles to different land-uses. In this paper, we make an attempt to understand the effects of urban land-uses on epigeic beetle communities by comparing their diversity and composition across four predominant types of land-uses in the city.

Materials and methods

Study area

Bangalore city in Karnataka state with its estimated human population of 8.5 million, is the third most populous city in India (Census of India 2011). Bangalore (12°59' N and 77°57' E) is situated at an altitude of 920 m asl, and covers an area of 1276 km^2 (Ramachandra & Kumar 2010). It receives a mean annual rainfall of 880 mm from both southwest monsoon (June to September) and northeast monsoon (November to December). The summer temperature ranges from 18 °C to 38 °C, while temperature during winter ranges from 12 °C to 25 °C. The natural vegetation of Bangalore was reported as thorny scrubs and dry deciduous forest (Champion and Seth 1968). However, due to the ever increasing population and industrial development along with large-scale commercial activities, most of this natural vegetation has been replaced by man-made structures (roads, buildings, pavements etc.) or maintained as urban green spaces. These green spaces (mostly public parks and campuses) are extensively modified by incorporating many non-native and exotic plant species.

Although several types of land-use are identified in the city, four predominant land-use types were selected for this study. They are remnant forest patches, institutional campuses,

Table 1. Details of the eight study sites for sampling epigeic beetles in Bangalore City.

Site	Site code	Land-use type	Latitude (N)	Longitude (E)	Altitude (m)
B. M. Kaval State Forest	VS	Remnant forest	12°51′ 34.33″	77°29′ 57.12″	808
Gandhi Krishi Vignana Kendra	GK	Remnant forest	13°05′ 11.46″	77°33′ 00.99″	932
Bangalore University	BU	Campus	12°56′ 28.94″	77°30′ 32.69″	822
Indian Institute of Science	IIS	Campus	13°00′ 59.75″	77°34′ 19.50″	932
Lal bagh	LAL	Park	12°56′ 52.14″	77°35′ 16.13″	896
Cubbon Park	CU	Park	12°58′ 41.70″	77°35′ 48.75″	915
Pampa extension	PR	Residential plot	13°03′ 05.17″	77°35′ 55.14″	912
Sahakara Nagar	SA	Residential plot	13°03′ 56.45″	77°35′ 17.55″	910

public parks and vacant residential plots. These land-use types were specifically selected because they represent a trajectory of increasing urbanization which represents varying levels of habitat modification and disturbance.

Two sites representing each of these four land-use types were selected (Table 1). Two remnant natural forests, BM Kaval state forest (VS) covering an area of 222 ha and a remnant patch of dry deciduous forest within the campus of the Gandhi Krishi Vignana Kendra (GK) on the outskirts of Bangalore city were selected. These are habitats least affected by human activities in the recent past. The second land-use type represented institutional campuses, which experienced relatively higher human activities than compared to remnant forests. The campuses of the Indian Institute of Science (IIS) and Bangalore University (BU) were selected for this study. The IIS campus, created in 1909, spreads across 180 ha, and harbors nearly 110 species of woody plants comprising both exotic and indigenous species. The BU campus was created in 1973 and it harbors native vegetation as well as plantations of Eucalyptus. The third land-use type was public parks, which are heavily modified with respect to their floristic compositions, generally encompassing more exotic tree species planted for aesthetic purpose. Two important public parks, Lal Bagh (LAL) and Cubbon Park (CU) were selected for this study. LAL is a 97 ha botanical garden built in 1760, and contains over 1000 species of flowering plants including trees that are over 100 years old. The CU created in 1870, covers an area of 120 ha within the heart of the city, and has about 6000 trees representing 68 genera and 96 species. Two vacant sites (area < 2 ha) in Pampa Extension (PR) and Sahakara Nagar (SA) were selected representing the residential plots. These are highly degraded habitats where invasive weedy species like *Parthenium hysterophorus* L. and *Lantana camara* L. have replaced most of the native flora. In addition, the vacant residential plots are used as dump sites for both organic and solid wastes by the local residents and are devoid of any site management. Both residential plots were created by clearing native vegetation during 1990 within the Byatarayanapura ward of North Bangalore. All study sites are spatially independent of each other as the minimum distance between the nearest two sites was 2 km, and the maximum distance between the farthest two sites was approximately 27 km.

Beetle sampling

Beetles were collected using 10 un-baited pitfall traps at each site. Traps were spaced 30 m apart along a line transect. Plastic jars of 500 ml capacity, 12.5 cm in height and 6 cm in diameter were used as pitfall traps. The traps were sunk into the soil so that the mouth was level with the soil surface. Ethanol, 50% mixed with a drop of glycerol was used as fixative in the pitfall traps. Traps were set for 5 days once in each season for three seasons (summer: 20–24 April 2004; monsoon: 15–19 September 2004; winter: 4–8 January 2005). The collected beetles were preserved in 70% ethanol and identified in the lab. As it is difficult to identify every beetle to species level, a more practical morphospecies or recognizable taxonomic unit (RTU) approach was adopted. A morphospecies is a morphologically distinct and recognizable organism that represents an assumed species, and is a relatively robust indicator of true species identity (Longcore 2003; Oliver & Beattie 1996). The collected beetles were identified to family using Naumann *et al.* (1970) and then sorted to RTUs. Further, the beetles were classified as either predators, detrivores or omnivores based on their mouth parts and through the literature. The voucher specimens are housed in ATREE's insect museum for further taxonomic studies and future reference.

Data analysis

The efficiency of sampling epigeic beetles by pitfall trapping was assessed through individual based Coleman's rarefaction curves to provide a measure of expected species richness (mean ± SD) across the sites. This particular non-parametric species richness estimator was preferred over other methods as it is generally less biased by sampling efforts than other diversity indices (Gotelli & Colwell 2001).

The beetle species richness and abundance were compared across the three seasons using Kruskal-Wallis ANOVA, which were followed by Mann-Whitney U test for pair-wise comparison whenever the Kruskal-Wallis ANOVA yielded significant results.

The beetle diversity and dominance were assessed by comparing the Shannon's diversity and Simpson's dominance indices across the sites. Shannon index was calculated as $H' = \sum p_i \ln p_i$, where p_i is the proportion of individuals found in the i^{th} species and ln is the natural logarithm (Krebs 1999). The Shannon diversity index usually falls between 1 and 3.5, where high values are produced when there is more number of species in the sample (Margalef 1972). Simpson's dominance index (Simpson 1949) was calculated as:

$D = \sum[\frac{ni(ni-1)}{N(N-1)}]$, where ni is the number of individuals in the i^{th} species and N is the total number of individuals. The value of this index ranges from 0 to 1, where values closer to zero indicates higher dominance by one or a few species and values closer to 1 indicates higher evenness. In addition, the beetle community structure at each site was examined by plotting rank abundance curves, where the abundance of each species was plotted on a logarithmic scale against the species rank in the order of most abundant to least abundant species.

The differences in species richness and abundance of beetles were compared across different land-use and different sites using general linear models based on Poisson regression. Initial exploratory data analyses revealed that both the response variables were non-normally distributed, and square root transformation was not satisfactory to correct this. Therefore, Poisson regression was preferred over ordinary least squares regression. Furthermore, Tukey HSD *post-hoc* tests for multiple comparisons among means were performed to assess significant differences as revealed by the general linear models for the data. However, due to lack of sufficient replication, trap specific data was used.

The beta diversity or the community similarities across sites were analyzed with an aim to finding natural groupings of sites according to land-use (Clark & Warwick 1994). Similarities in the community composition across the eight sites were examined using hierarchical cluster analysis based on a non-weighted pair-group average algorithm with the Bray-Curtis dissimilarity index. In the Bray-Curtis dissimilarity index, distance = 1 means that there is nothing in common with two sample sites, while distance = 0 means that the species composition is the same among two sites. As a complement to cluster analysis, a two factor permutational multivariate ANOVA with land-use and sites as explanatory variables was performed. As the datasets represented multiple response variables (species) and multiple objects (sites), the non-parametric multivariate analysis such as permutational MANOVA was highly relevant for statistically testing the effects of the factor on the species composition (Anderson 2001), which can handle large multiple species datasets containing more species than replicates with a matrix having numerous zeros or species absences (McArdle & Anderson 2001). The species abundance matrix was standardized by row totals and Bray-Curtis distance measure was used as the basis for the permutational MANOVA with 9999 permutations. In addition, pair-wise comparisons based on Monte-Carlo randomization (4999 permutations) were performed to test for the differences among land-uses and sites if the permutational MANOVA analysis was found significant. All the analyses were performed using vegan: Community Ecology Package v 1.15.3 (Oksanen *et al.* 2009) and BiodiversityR Package v 2.2.4 (Kindt & Coe 2005) on R v 2.8.1 (R Development Core Team 2008), and permutational MANOVA was performed using the software PERMANOVA (Anderson 2005).

Finally, the differences in the abundances of different feeding guilds across the land-use types were tested using non parametric ANOVA. Non parametric ANOVA was preferred against parametric ANOVA as data transformation was insufficient to approach normality.

Table 2. Comparison of beetle species richness and abundance across three seasons.

Response variable	Summer (Mean ± SD)	Monsoon (Mean ± SD)	Winter (Mean ± SD)	Kruskal-Wallis ANOVA test statistic	Kruskal-Wallis ANOVA *P*–value
Species richness	6.5 ± 2.56	13.75 ± 4.46	10.12 ± 3.97	$\chi^2_{(2,7)}$= 5.915	0.051
Abundance	29.88 ± 28.97	127.2 ± 109.26	44.0 ± 31.34	$\chi^2_{(2,7)}$= 0.429	0.80

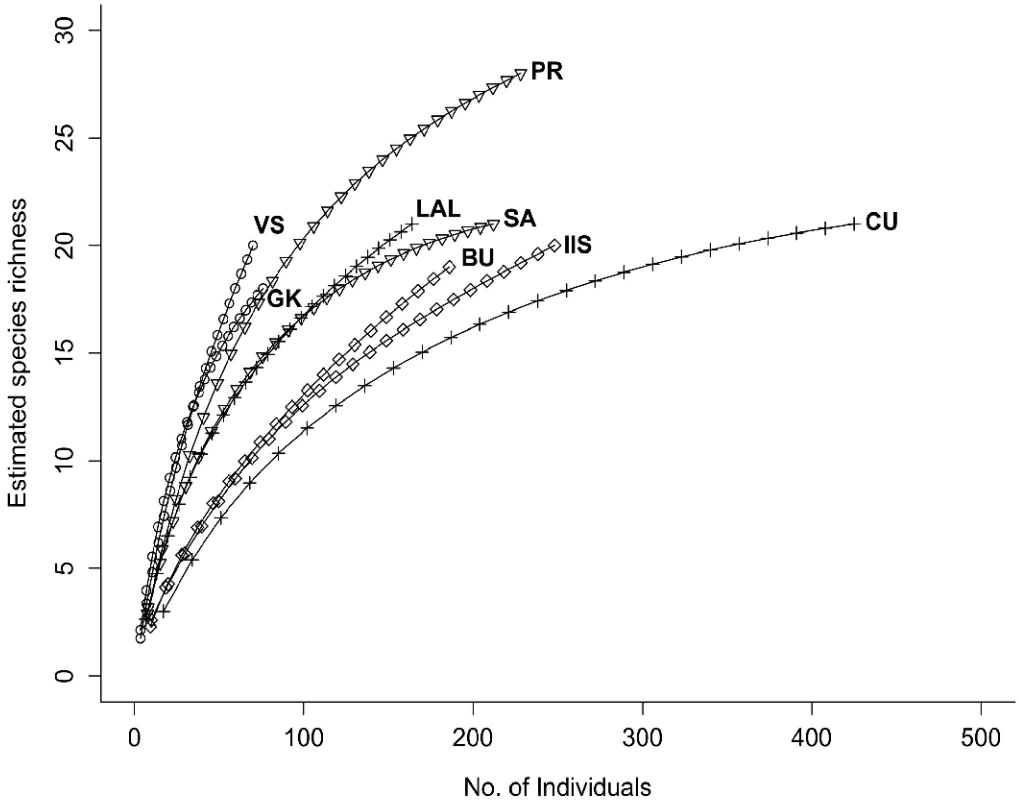

Fig. 1. Rarefaction based on Coleman curve for estimation of beetle species richness for each site. Sites belonging to the same land-use type are depicted with similar signs.

Results

A total of 1,609 adult beetles representing 55 species (25 families) were captured from 240 pitfall traps in eight sites (Table S1). Beetle families such as Scarabaeidae (14.54%), Staphylinidae (12.72%) and Carabiidae (12.72%) accounted for higher species richness. The bulk of the total individual beetles captured were represented by Staphylinidae (41.4%), Scarabaeidae (24%), Tene-brionidae (9.6%), Silphidae (6.5%) and Histeridae (6.3%). Although the mean number of species and individuals trapped were higher during monsoon than in winter and summer, the differences were not significant (Table 2).

Rarefaction estimates from Coleman curves revealed that sampling was not sufficient as none of the curves reached an asymptote (Fig. 1). In general, the rate of species accumulation was much higher in the forested sites as compared to other human land-uses. However, when the curves were compared at a standardized number of 70 individuals, both the remnant forests along with the two residential plots showed higher estimated species richness (ranging from 15 to 20 species), while the two campuses and parks had lower estimates for species richness (ranging from 12 to 14 species).

The beetle species diversity and dominance varied across the sampled sites (Table 3). The Shannon's diversity and Simpson's dominance measures were higher in remnant forest sites and residential plots along with one of the parks (i.e., LAL). This indicated that these sites harboured a

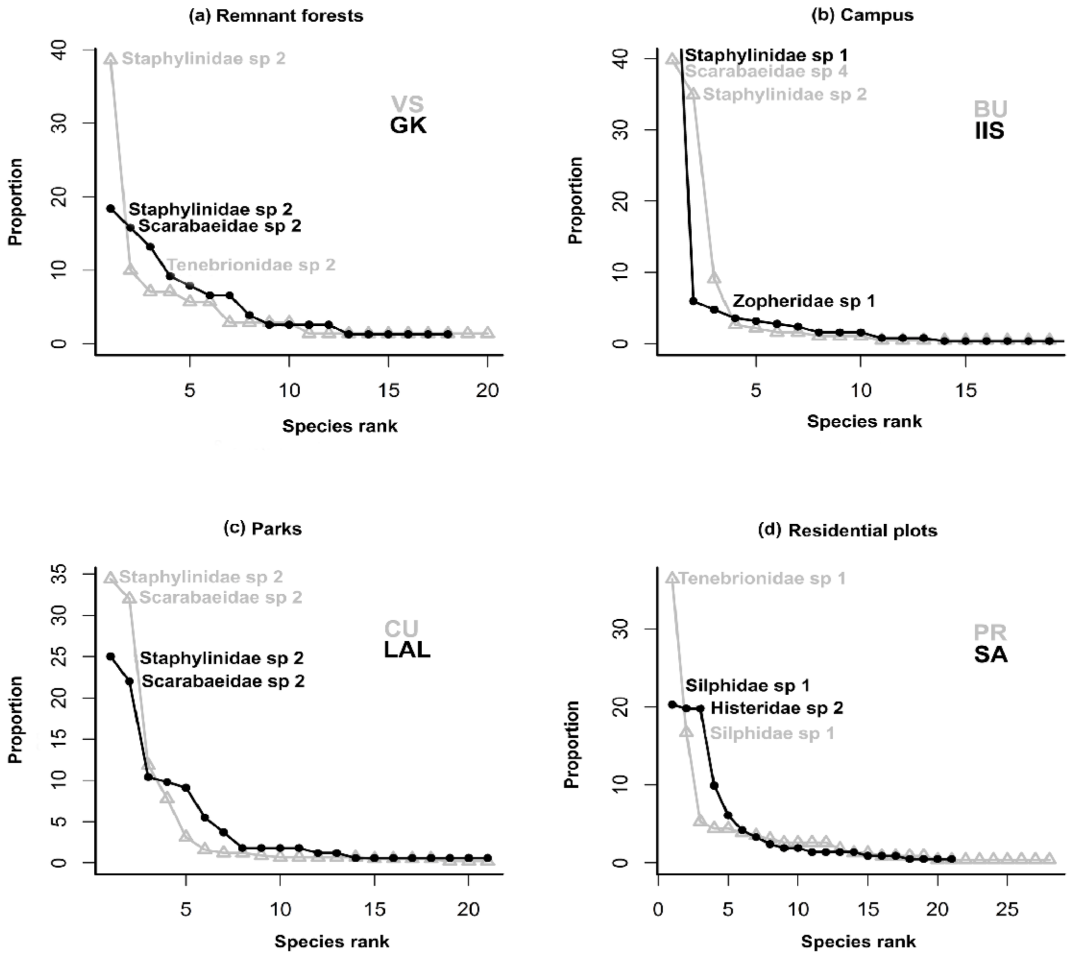

Fig. 2. Rank abundance curves fitted to beetle assemblages in each site under (a) remnant forests, (b) campus, (c) parks, and (d) residential plots.

Table 3. Comparison of beetle diversity and dominance based on diversity indices calculated for each site.

Land-use type	Sites	Shannon diversity (H')	Simpson dominance (D)
Forest	VS	2.31	0.81
Forest	GK	2.50	0.85
Campus	BU	1.66	0.70
Campus	IIS	1.47	0.54
Park	CU	1.82	0.75
Park	LAL	2.28	0.85
Residential	PR	2.39	0.82
Residential	SA	2.32	0.86

higher number of species and also that the individuals were more evenly distributed among them. On comparing the species rank curves, rove beetles (Staphylinidae) and dung beetles (Scarabaeidae) dominated all the land-use types except the residential plots (PR and SA), which were dominated by the tenebrionid and silphid beetles which are detrivores (Fig. 2).

The general linear models revealed that there were significant changes in trap specific species richness and abundance of beetles across the different land-use types (Table 4). The species richness and abundance were higher in forests, parks and residential plots as compared to campuses (Fig. 3). The variation in species richness was significantly explained by land-use alone, while the variation in the abundance was explained by both land-use and site.

The cluster analysis based on Bray-Curtis dissimilarity measures showed two distinct clusters (Fig. 4). In the first cluster, the remnant forests and the residential plots grouped together. The percent similarity in beetle composition between

Table 4. General linear models for beetle species richness and abundance across land-use and sites as the two factors.

Response variable	Explanatory variable	*d.f.*	Deviance	Probability
Species richness	Land-use	3	30.66	< 0.001
	Site	4	3.14	0.53
	Errors	72	73.07	
	Total	79	106.89	
Abundance	Land-use	3	298.18	< 0.001
	Site	4	129.49	< 0.001
	Errors	72	832.06	
	Total	79	1259.73	

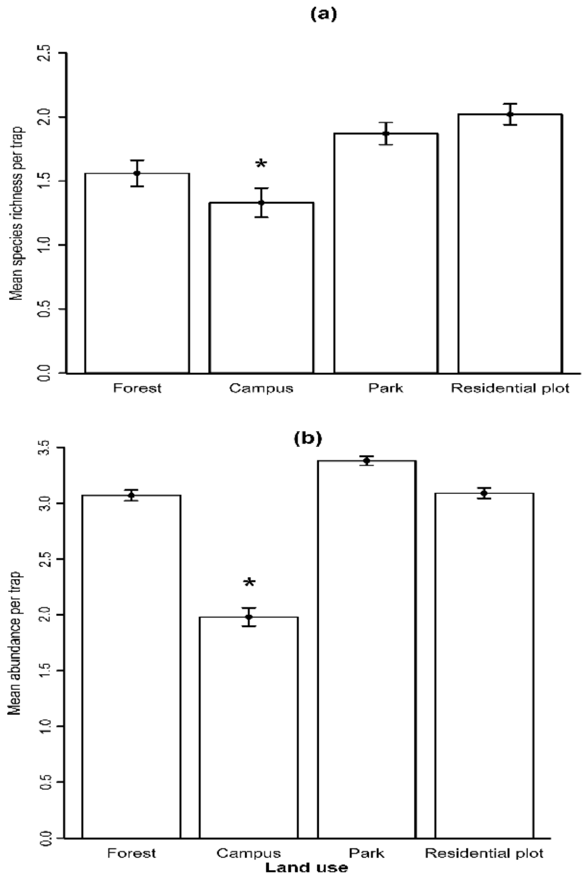

Fig. 3. Comparison of trap specific (a) species richness and (b) abundance across the four land-use categories (* sign indicates significant difference at alpha = 0.05).

the two residential plots was 78%, while it was 58% for the two remnant forests. However, the similarity in beetle composition across all the sites within the cluster ranged from 54 to 66%, which indicated that at least half of the species found in

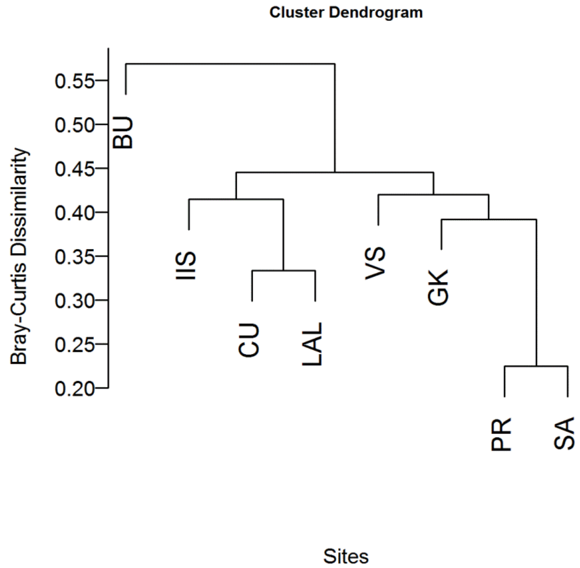

Fig. 4. Cluster analysis for the beetle species composition based on Bray-Curtis dissimilarity measure.

the remnant forests inhabit the residential plots. The second cluster included two parks along with the IIS, where the beetle composition between the two parks was 67%, while the IIS shared 59% of species with the two parks. Lastly, the species composition of the BU was the most dissimilar as it shared less than half of the total beetle species captured in the other sites.

The non-parametric MANOVA indicated that the beetle species composition differed across land-use types and sites (Table 5), and pair-wise comparisons revealed significant differences across all the different land-use types (Table 6). A pair-wise comparison of sites indicated that sites that belonged to the same land-use did not differ (forests (VS and GK: $t = 0.8941$, $P = 0.6392$), parks (CU and LAL: $t = 1.1056$, $P = 0.1492$) and residential plots (PR and SA: $t = 1.1948$, $P = 0.1642$)), while both the campuses differed significantly (BU and IIS: $t = 2.1295$, $P = 0.0002$). This confirms the grouping of sites in the cluster analysis.

The abundance of various insect feeding guilds differed significantly across the land-use types (detrivores: $\chi^2 = 9.14$, df = 3, $P < 0.05$; omnivores: $\chi^2 = 13.40$, df = 3, $P < 0.01$; predators: $\chi^2 = 13.94$, df = 3, $P < 0.01$). The abundances of detrivores and omnivores were generally higher in parks and campuses as compared to remnant forests. On the contrary, the residential plots and the forests harboured more predatory beetles (Table 7).

Table 5. Results from the two factor non-parametric MANOVA with land-use types and sites representing the two factors tested against beetle species composition. (MC) = Monte-Carlo randomization.

Source	d.f.	SS	MS	F	P(MC)
Land-use	3	41469.462	13823.154	3.6181	0.0001
Sites	4	32679.378	8169.8446	2.1384	0.0001
Residuals	72	275081.22	3820.5725		
Total	79	349230.06			

Table 6. Pair wise comparison of beetle species richness among the four land-use types. (MC) = Monte-Carlo randomization.

Land-use	pairs	t-value	P (MC)
Campus	Forest	1.5253	0.0002
Campus	Parks	1.7871	0.0002
Campus	Residential	2.1649	0.0002
Forest	Parks	1.5294	0.0034
Forest	Residential	1.8515	0.0002
Parks	Residential	2.1831	0.0002

Table 7. Comparison of median and median absolute deviation (MAD) values for the three feeding guilds across the sites.

Site	Detrivores	Ominvores	Predators
	Median ± MAD	Median ± MAD	Median ± MAD
GK	2.0 ± 1.4	8.0 ± 4.4	3.5 ± 2.2
VS	2.5 ± 0.7	10.0 ± 4.4	4.1 ± 1.3
BU	8.0 ± 2.8	14.0 ± 3.3	1.0 ± 0.4
IIS	7.5 ± 1.7	24.0 ± 5.7	1.0 ± 0.4
CU	8.5 ± 2.6	18.0 ± 6.3	1.0 ± 0.4
LAL	6.5 ± 2.2	15.5 ± 7.4	1.0 ± 0.4
PR	5.5 ± 2.1	13.5 ± 6.6	6.3 ± 2.0
SA	6.5 ± 2.1	13.0 ± 7.4	7.3 ± 3.5

Discussion

Urban environments present a variety of land-use forms from complex habitat in remnant forest patches to simplified habitat in residential areas. The beetle responses to urban land-use may be derived from evaluating their specific responses to habitat structure or modifications characteristic to each land-use type. Most studies on beetle community responses to urbanization have shown a negative association between species richness and urbanization along the land-use trajectory gradient (McIntyre *et al.* 2001; Kratzer *et al.* 2006). However, contrary to our expectations, the forest patches along with residential areas exhibited higher diversity and species turnover of beetles than other land-use categories. This pattern could be explained by the intermediate disturbance hypothesis (Connell 1978) which predicts the highest level of diversity at moderate levels of disturbances. Here, unlike the forest patches and residential sites, the parks and campuses frequently undergo site specific management, which results in high levels of disturbance at regular interval of time leading to decline in local insect diversity. In addition, it is assumed that frequent dumping of organic wastes provides an abundant food resource to detrivorous and omnivorous beetles resulting in high beetle diversity in residential plots. Often, considerable quantities of organic waste found within resource-depleted environments such as vacant residential plots can substantially increase detrivorous beetle diversity (Eggert and Wallace 2003). Furthermore, the higher abundance of predatory beetles in residential plots may be due to an increase in resource base (prey items).

The beta diversity indicated a higher species turnover highlighting the spatial heterogeneity, with differing species composition among sites. The beetle assemblage showed similarities between the sites within remnant forest patches, parks and residential plots. This conforms to similar pattern observed in other studies on beetle assemblage in urban ecology (Carabid beetles: Alaruikka *et al.* 2002; Staphylinid & Carabid beetles: Deichsel 2006; Silphid beetles: Wolf & Gibbs 2004). Interestingly, the cluster analysis revealed that the two residential plots (where the original vegetation was cleared ~20 years ago) were subsets of the forest patches which harbor the native vegetation. Similarly, the historical sites representing the two parks (CU and LAL) and a campus (IIS) which were created almost a century ago were grouped together. Based on this observation, it is assumed that the age of land-use could also be an important factor in determining the local species diversity. For example, Sadler *et al.* (2006) found that beetle diversity declined in older urbanized areas as compared to those woodlands that were recently converted to urban land-use types. In addition, we assume that the BU was isolated in the cluster analysis because it represented eucalyptus plantations and also is spatially isolated.

The differences in beetle trophic guilds among the urban land-use types indicate the vital role played by them in ecosystem functioning (Cook & Faeth 2006, McIntyre *et al.* 2001). In this study, the residential plots harbored significantly more individuals of detrivorous beetles than those in other land-use types. In contrast, the forest patches had higher predatory beetles than in parks or campuses, whereas the abundance of the omnivores was more or less the same in all land-use types. Thus, differences in trophic guilds suggest that nutrient cycling in these land-use types could be affected by factors such as human activities and site-specific management. For example, vacant residential plots act as dump site for organic wastes, while the leaf litter in parks is removed periodically as part of management process.

Further, due to various constraints faced during this study, the differences in physical habitat structure such as vegetation and floristic composition, along with confounding factors such as presence of organic wastes and management aspects were not quantified. Despite this, the categorization of sites based on land-use types, which is a popular practice in urban ecology (Niemelä 1999) was sufficient in elucidating the underlying diversity patterns of epigeic beetle communities. However, in future, studies with fewer constraints may benefit from quantifying habitat covariates, which would help in establishing the relationship between habitat features and beetle community responses.

Due to faster expansion of the city, there is an increasing pressure on urban green space such as campuses and parks for conversion to built-up areas. Although, these green spaces provide refuge to many generalist species, they also provide niche to some specialist species which may have hitherto remained unknown to science. For example, a new arboreal ant species *Dilobocondyla bangalorica* was discovered in the Indian Institute of Science (IIS) campus (Varghese 2006). Therefore, conservation efforts in Bangalore should prioritize such green spaces. In future, urban planning should include even the smaller patches of natural vegetation for conservation of native flora and fauna, as such small patches can provide refuge to native biotic communities including insects.

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References

Adams, L. W., 1994. *Urban Wildlife Habitats*. University of Minnesota Press, Minneapolis.

Alaruikka, D., J. D. Kotze, K. Matveinen & J. Niemela. 2002. Carabid beetle and spider assemblages along a forested urban-rural gradient in southern Finland. *Journal of Insect Conservation* **6**: 195–206.

Anderson, M. J. 2001. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* **26**: 32–46.

Anderson, M. J. 2005. *PERMANOVA: A FORTRAN Computer Program for Permutational Multivariate Analysis of Variance.* Department of Statistics, University of Auckland, Auckland, New Zealand.

Blair, R. B. & A. E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. *Biological Conservation* **80**: 113–125.

Bolund, P. & S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* **29**: 293–301.

Census of India. 2011. *Primary Census Abstract–Andhra Pradesh, Karnataka and Lakshwadweep.* Directorate of Census Operations. Government of India, New Delhi.

Champion, H. G. & S. K. Seth, 1968. *A Revised Survey of the Forest Types of India.* Government of India Press, New Delhi.

Clark, K. R. & R. M. Warwick. 1994. *Change in Marine Communities: an Approach to Statistical Analysis and Interpretation*. Browne Press, Bournemouth, UK.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science* **199**: 1302–1310.

Cook, W. M. & S. H. Faeth. 2006. Irrigation and land use drive ground arthropod community patterns in an urban desert. *Environmental Entomology* **35**: 1532–1540.

Czech, B., P. R. Krausman & P. K. Devers. 2000. Economic associations among causes of species endangerment in the United States. *BioScience* **50**: 593–601.

Deichsel, R. 2006. Species change in an urban setting – ground and rove beetles (Coleoptera: Carabidae and

Staphylinidae) in Berlin. *Urban Ecosystems* **9**: 161–178.

Eggert, S. L. & J. B. Wallace. 2003. Litter breakdown and invertebrate detritivores in a resource-depleted Appalachian stream. *Archiv fur Hydrobiologie* **156**: 315–338.

Eyre, M. D., M. L. Luff & J. C. Woodward. 2003. Beetles (Coleoptera) on brownfield sites in England: An important conservation resource? *Journal of Insect Conservation* **7**: 223–231.

Falk, J. H. 1976. Energetics of a suburban lawn ecosystem. *Ecology* **57**: 141–150.

Fujita, A., K. Maeto, Y. Kagawa & I. T. O. Noboru. 2008. Effects of forest fragmentation on species richness and composition of ground beetles (Coleoptera: Carabidae and Brachinidae) in urban landscapes. *Entomological Sciences* **11**: 39–48.

Gotelli, N. J. & R. K. Colwell. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* **4**: 379–391.

Hodkinson, L. D. & J. K. Jackson. 2005. Terrestrial and aquatic invertebrates as bioindicators for environmental monitoring, with particular reference to mountain ecosystems. *Environmental Management* **35**: 649–666.

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

Kindt, R. & Coe, R. 2005. *Tree Diversity Analysis. A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies.* World Agroforestry Centre (ICRAF), Nairobi.

Kratzer, E. B., J. K. Jackson, D. B. Arscott, A. K. Aufdenkampe, C. L. Dow, L. A. Kaplan, J. D. Newbold & B. W. Sweeney. 2006. Macroinvertebrate distribution in relation to land use and water chemistry in New York City drinking-water-supply watersheds. *Journal of North American Benthological Society* **25**: 954–976.

Krebs, C. J. 1999. *Ecological Methodology*. 2nd edition. Harper and Row, New York.

Longcore, T. 2003. Terrestrial arthropods as indicators of restoration success in coastal sage scrub (California, U.S.A.). *Restoration Ecology* **11**: 397–409.

Mack, R. N. & W. M. Lonsdale. 2001. Humans as global plant dispersers: getting more than we bargained for. *BioScience* **51**: 95–102.

Margalef, R. 1972. Homage to Evelyn Hutchinson, or why is there an upper limit to diversity? *Transactions of Connecticut Academy of Arts and Science* **44**: 211–235.

Marzluff, J. M. & K. Ewing. 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. *Restoration Ecology* **9**: 280–292.

McArdle, B. H. & M. J. Anderson. 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* **82**: 290–297.

McIntyre, N. E. 2000. The ecology of urban arthropods: a review and a call to action. *Annals of the Entomological Society of America* **93**: 825–835.

McIntyre, N. E., K. Knowles-Yanez & D. Hope. 2000. Urban Ecology as an interdisciplinary field: Differences in the use of "Urban" between the social and natural sciences. *Urban Ecosystems* **4**: 5–24.

McIntyre, N. E., J. Rango, W. F. Fagan, and S. H. Faeth. 2001. Ground arthropod community structure in a heterogeneous urban environment. *Landscape and Urban Planning* **52**: 257–274.

McKinney, M. L. 2000. Urbanization, biodiversity, and conservation. *BioScience* **52**: 883–890.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. *Biological Conservation* **127**: 247–260.

McKinney, M. L. 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems* **11**: 161–176.

Miller, J. R. 2006. Restoration, reconciliation, and reconnecting with nature. *Biological Conservation* **127**: 356–361.

Miller, J. R. & R. J. Hobbs. 2002. Conservation where people live and work. *Conservation Biology* **16**: 330–337.

Naumann, I. D., P. B. Crane, J. F. Lawrence, J. P. Nielsen, R. W. Spradbery, R. W. Taylor, M. J. Whitten & M. J. Littlejohn. 1970. *The Insects of Australia: A Textbook for Students and Research Workers.* Division of Entomology, Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia.

New, T. R. 2007. Beetles and conservation. *Journal of Insect Conservation* **11**: 1–4.

Niemelä, J. 1999. Ecology and urban planning. *Biodiversity and Conservation* **8**: 119–131.

Niemelä, J., D. J. Kotze, S. Venn, L. Penev, I. Stoyanov, J. Spence, D. Hartley & E. M. de Oca. 2002. Carabid beetle assemblages (Coleoptera, Carabidae) across urban–rural gradients: an international comparison. *Landscape Ecology* **17**: 387–401.

Oksanen, J., R. Kindt, P. Legendre, B. O'Hara, G. L. Simpson, P. Solymos, M. H. Stevens & H. Wagner. 2009. *vegan: Community Ecology Package.* R package version 2.2-0. http://CRAN.R-project.org/package=vegan

Oliver, I. & A. J. Beattie. 1996. Designing a cost-effective invertebrate survey: a test of methods for rapid assessment of biodiversity. *Ecological Application* **6**: 594–607.

R Development Core Team. 2008. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Ramachandra, T. V. & U. Kumar. 2010. Greater Bangalore: emerging heat island. *GIS for Development* **14**: 86–104.

Sadler, J. P., E. C. Small, H. Fiszpan, M. G. Telfer & J. Niemela. 2006. Investigating environmental variation and landscape characteristics of an urban–rural gradient using woodland carabid assemblages. *Journal of Biogeography* **33**: 1126–1138.

Sattler, T., P. Duelli, M. K. Obrist, R. Arlettaz & M. Moretti. 2010. Response of arthropod species richness and functional groups to urban habitat structure and management. *Landscape Ecology* **25**: 941–954.

Savitha, S., M. Barwe & P. Davidar. 2008. Response of ants to disturbance gradients in and around Bangalore, India. *Tropical Ecology* **49**: 235–243.

Simpson, E. H. 1949. Measurement of divesity. *Nature* **163**: 688.

Ulrich, W., M. Zalewski & K. Komosinski. 2007. Diversity of carrion visiting beetles at rural and urban sites. *Community Ecology* **8**: 171–181.

Varghese, T. 2006. A new species of the ant genus Dilobocondyla (Hymenoptera: Formicidae) from India, with notes on its nesting behaviour. *Oriental Insects* **40**: 23–32.

Wolf, J. M. & J. B. Gibbs. 2004. Silphids in urban forests: Diversity and function. *Urban Ecosystems* **7**: 371–384.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Table S1. List of beetle families and morphospecies captured from the eight study sites in Bangalore city.