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Original article

Temporal and spatial assemblages of invasive birds occupying the urban landscape and its gradient in a southern city of India

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ABSTRACT

Common birds play an important role in regulating the functioning of urban ecosystems. Typically, a few common species have become invasive species threatening biodiversity worldwide. Our understanding of the dynamics of invasive birds in an Indian context is still in its infancy. Hence, we studied the gradual adaptation of invasive birds to novel habitats and their dispersal dynamics in a southern city of India. We tested the prediction that urban matrix are increasingly composed of invasive generalist species. The results illustrate the dominance of invasive species such as *Corvus splendens*, *Acridotheres tristis*, *Acridotheres livia*, and *Milvus migrans* in the urban environment. The significant abundance of *C. splendens* exhibited urbanization-induced homogenization. The land-use pattern showed more inclination toward the urban structures than the vegetative attributes. Specialist groups from the frugivore guild were found to decline from the urban environment, which may shed light on the ecological factors that constrain their distribution.

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Introduction

Urban ecosystems may play a vital role in supporting biodiversity; however, these ecosystems are often the prime locations for the spread of invasive species. Invasive species are now recognized as one of the major drivers of global biodiversity loss and they pose a serious threat to biodiversity (Butchart et al 2010). Urbanization-induced environmental changes favor the spread of invasive species, thereby reducing accessible areas for native species (Bigirimana et al 2012; Clavel et al 2011; Duncan et al 2011; Zhang et al 2011). There is growing evidence that large numbers of birds are invading areas beyond their natural geographical distribution due to human activities (Cohen and Carlton 1998; Mack et al 2000). As urbanization increases, habitat fragmentation and invasion of species hasten around urban centers, causing substantial environmental (competition, hybridization, and predation) and economic impacts (agriculture, livestock, forestry, human health) to the regions of their introduction (Pimentel et al 2000). Conversion of urban matrixes often favors birds (Chace and Walsh 2006; Marzluff et al 2001a; Moller 2009) as their environments are characterized by more anthropogenic food resources and favorable climatic conditions (Rebele 1994). Previous studies have shown that bird species that are widespread and abundant in their native regions are more likely to be introduced than narrowly distributed species (Blackburn and Duncan 2001; Cassey et al 2004; Jeschke and Strayer 2006). Studies have also shown that invasive birds belong to a limited range of families, such as Anatidae, Phasianidae, Psittacidae, and Passeridae (Duncan et al 2006; Kark and Sol 2005).

However, which particular species of bird may become invasive is difficult to predict as different habitats and varied climatic conditions may provide invasion for different species of birds. Some of these species establish beyond their native range and spread (Kolar and Lodge 2002), and hence are called “invasive.” Invasive birds are classified based on criteria such as higher population density of breeding birds than nearby rural populations (Moller 2009; Moller et al 2012), species that are able to breed in urban centers (Croci et al 2008), or the difference in population density between urban and rural habitats (Evans et al 2011). Most of the research on invasion biology focuses on quantifying the impact of existing invasions and their distribution rather than analyzing the potential for future invasions and their impact (Kolar and Lodge 2002). Two factors that are frequently used to explain patterns of invasion are the climate or habitat suitability of a species in an urban environment (Hulme 2009; Murray et al 2012). Fewer studies have also highlighted the importance of anthropogenic factors (Roura-

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Pascual et al 2011) such as housing density (Amelie et al 2014) and novel feeding innovations (Moller 2009) as important predecessors for invasion. Most of the literature available in invasion biology considers only a single invasive bird species in a particular geographic region and ignores the presence of co-occurring invaders. Moreover, there is only fragmentary evidence on invasive birds in developing countries (Vila et al 2011), including India. Hence, we studied the gradual adaptation of invasive birds and the co-occurring invaders to novel habitats, their abundance, and their dispersal dynamics in a southern city of India, Tiruchirappalli. This study attempts to bridge the gap between urban avifauna with emphasis on invasive species and the anthropogenic factors that influence the spread of invasive birds. We propose and test the following hypotheses: (1) urbanization-induced homogenization is more prevalent in invasive birds and co-occurring invaders and (2) urbanization-related factors are responsible for homogenization of birds. In addition, the study also predicts that *Corvus splendens* may be the most dominant species occupying the urban matrix.

Materials and methods

Study site

The study was conducted in Tiruchirappalli, a southern most city of India, which is more exposed to urbanization developments being in the center of the Tamil Nadu state with rapid growth of urban population and an attractive tourist destination. It lies between 10°10′ and 11°20′ of the Northern latitude and 78°10′ and 79°0′ of the Eastern longitude. Tiruchirappalli lies on the banks of the river "Cauvery," and has numerous tributaries flowing through the district. Being one of the oldest inhabited cities in Tamil Nadu, its earliest settlements date back to the second millennium BC and the ancient monuments here attract a large number of invasive birds providing favorable nesting sites. The district has an surface area of 4404 km^2 and is the fourth largest district in Tamil Nadu, with a population of 27 million, according to the Union Government of India census, 2011. The city is also the fourth largest urban agglomeration in the state. The district exhibits hot and dry climate with high temperature and low degree of humidity throughout the year, with a short period of rainy season and winter from September to December.

Sampling design

Birds were surveyed at 80 locations within the urban matrix for a period of 24 months. These 80 sampling points were visited on a monthly basis with a total record of 1920 observations. For sufficient coverage of survey sites in terms of bird abundance in the urban matrix, the gradient of urbanization was representative of three zones, namely, *urban*, *suburban*, and *urban fringes* (Figure 1). The urban zone is demarcated with 26 points, suburban with 26 points, and urban fringes with 28 points. The study points were spaced at 500 m and were georeferenced with a Garmin handheld global positioning system (GPS). At each point, bird surveys were conducted using the point count method (Bibby et al 2000) within 25 m radius, for 10 minutes from 06:00 AM to 09:00 AM on a monthly basis to maximize count efficiency. Point counts were recorded on a monthly basis to accommodate the breeding period. In consideration of the interspecific and intraspecific interactions among species in a community, both invasive and native species were surveyed (Blair 2004). At each point count, spatial and temporal variations in the most abundant birds were recorded. Species identification was carried out using binocular and field guides including *Birds of Southern India* (Grimmett and Inskipp 2005), *The Book of Indian Birds* (Ali 2003) and *Birds of the Indian Subcontinent* (Inskipp et al 2000), and all birds detected visually and acoustically were recorded. When counting birds, special care was taken that individuals were counted only once. Bird community composition at the different sampling points was expressed by diversity, richness, and the abundance of each species, and a "species by site"

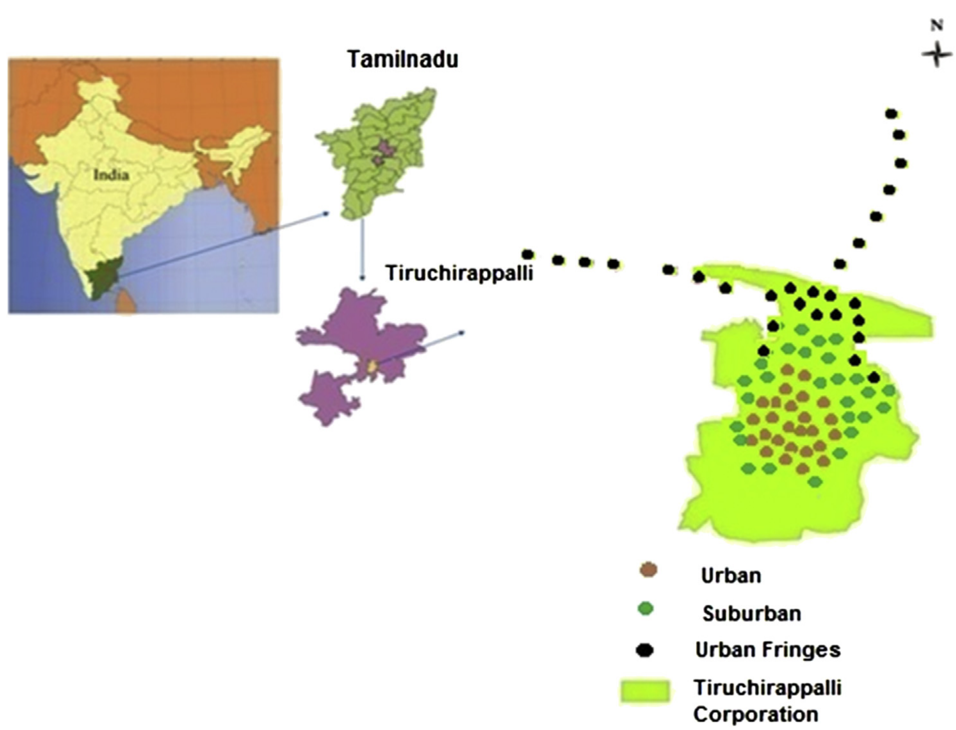

Figure 1. Study area with the sampling locations.

matrix was obtained. *Species richness* for each sampling point was defined as the total number of species detected during each visit. *Abundance* for each sampling point was defined as the maximum number of individuals present in the point counts. At each point count, spatial and temporal variations in species abundance of birds were recorded. To ameliorate the difficulties with observer variability, the entire sampling was carried out by a single observer. Bird surveys were not conducted during heavy rains, fog, and strong winds, because these conditions reduce bird activity and detectability (Sutherland 2004).

Landscape factors

Vegetation structure was evaluated in terms of tree cover, shrub cover, herb cover, number of trees, number of shrubs, and number of herbs. The percent cover of shrub and herb was categorized using the Braun–Blanquet categorical scale (Kent and Coker 1992), within a 50 m radius around each point count station with four 5×5 m^2 subplots. The cover scale was 0 (<1%), 1 (1–5%), 2 (6–25%), 3 (26–50%), 4 (51–75%), and 5 (76–100%). In addition, the variables tree cover and built cover were also simultaneously measured using Google Earth Images and processed in ArcGIS 10. All the sample locations were recorded as GPS points in ArcGIS and 100-m (diameter) buffer polygons were created. Once the Google Earth Images were imported, georeferencing and mosaicking of Google Earth Images were performed. Before assigning land use and land cover (LU/LC) categories to all land parcels, digitization of LU/LC features was performed using ArcGIS. Then, error rectification and cross-validation were carried out. Finally, the shape file was converted into a feature class and the areas of all LU/LC features were recorded. Environmental variables were correlated with invasive bird abundance using the data provided by the local metrological department.

Anthropogenic pressure

Urban structures were evaluated in terms of built cover, number of built structures, road cover, and road width. Human activity was described by pedestrian movement/min, vehicular traffic/min, and noise levels were measured in decibels, dB(A)/15 min at the 80 point counts. Noise level (dB) was quantified using a sound level meter (model Lutron SL 4001, Lutron Electronic Enterprise Co., Ltd, Taiwan), which was precalibrated to 94 dB before measurement. At each location, 60 observations were made for 15 minutes and sound levels were recorded for the nonpeak hours as this coincided with the bird survey.

Data analyses

Species abundance values were plotted with box plots to represent the dominance of invasive birds in the urban matrix and with error bars to illustrate temporal variations at all study points. Principal component analysis (PCA) was carried out using Paleontological Statistics Package PAST (version 2.15) and SPSS (version 16) to identify the factors determining avian community structure within the urban landscape. PCA transforms the set of variables into a smaller set of linear combinations that retain the original information as much as possible. PCA provides the patterns of correlation between variables identified within a simplified ordination space. Principal components with an initial eigenvalue score greater than 0.5 were considered to show a strong relationship to the principal component. Eigenvector scores that depart from 0 indicate an increasing importance of that variable to the principal component. Once the principal components were identified, the measure with the highest eigenvector score for each component was selected to represent the variability along that component. To correlate these variables with its significance level in the urban landscape, Pearson correlation was calculated between bird abundance, vegetative attributes, and anthropogenic factors. To better understand the bird community structure in different study zones, neighboring cluster analysis was performed based on a Bray–Curtis similarity index. Detrended correspondence ordination plots were used to determine the similarity of the sample clusters within and between study zones. Detrended correspondence analysis (DCA) provides simultaneous ordinations of both species and sample sites in the same multidimensional space, yielding a score for each species and each sample site.

Results

Urban matrix demarcated in the study area covers 71.47 km^2 with a total of 1920 observations. The urban study area is inclusive of twin cities, Tiruchirappalli and Srirangam, and consists of varied landscape (built environment, road/railway networks, river, wetlands, canals, waste land, and greenery) and land-use patterns (commercial, residential, and agricultural). A total of 78 bird species were recorded in the urban ecosystem from 17 orders and 44 families. The highest recorded species were from the Passeriformes order (37 species recorded). The mean diversity indexes of 0.42 ± 0.20 (Simpson_1-D Index), 0.84 ± 0.35 (Shannon Index), 0.99 ± 0.77 (Margalef Index), and 1.71 ± 1.71 (Fisher alpha) were recorded for each point count in the urban ecosystem (Menon et al 2015). The mean taxa of birds in the urban ecosystem were recorded at 4.31 ± 1.46 and evenness was recorded at 0.65 ± 0.18. The mean abundance of birds in the urban ecosystem was recorded at 38.51 ± 33.52. The relative abundance of birds within urban landscapes at each point ranged from four to 223 individuals, with minimum and maximum mean abundance values ranging between 3.62 and 223.29.

Invasive species trends

Based on the abundance and spatial distribution pattern, the most dominant species (Table 1) recorded were *C. splendens* (house crow), *Acridotheres tristis* (common myna), *Columba livia* (blue rock pigeon), and *Milvus migrans* (black kite). These species had a broader spatial distribution and were well adapted to human-dominated landscapes. *C. splendens* and *A. tristis* exceptionally recorded higher abundance and were the most common species in Tiruchirappalli. The four species (*C. splendens, A. tristis, C. livia,* and *M. migrans*) constituted 78.15% of the total bird abundance that was recorded in the study area (Figure 2) with

Table 1. The most dominant birds in the urban landscape/point count station.

Species	Mean ± standard deviation/point count
Eudynamys scolopacea (Asian koel)	0.23 ± 0.22
Corvus splendens (house crow)	26.01 ± 15.22
Acridotheres tristis (common myna)	2.32 ± 1.08
Psittacula krameri (rose-ringed parakeet)	0.64 ± 0.30
Turdoides affinis (yellow-billed babbler)	0.61 ± 0.28
Columba livia (blue rock pigeon)	2.07 ± 0.71
Cypsiurus balasiensis (Asian palm swift)	0.34 ± 0.28
Milvus migrans (black kite)	1.43 ± 0.81
Apus affinis (house swift)	0.40 ± 0.44
Nectarinia zeylonica (purple-rumped sunbird)	0.21 ± 0.18
Pycnonotus cafer (red vented bulbul)	0.17 ± 0.13
Dicrurus macrocercus (black drongo)	0.18 ± 0.07
Corvus macrorhynchos (jungle crow)	0.92 ± 0.25

other species constituting the remaining 21.29%. The invasive bird abundance was found to be significantly higher in the urban landscape compared with suburban and urban fringes except for *A. tristis* (Figure 3). These species thrived well in the urban environment, preferred heavily built structures, and their habitat requirements relied on building cavities rather than on the vegetation cover (Blair 1996; Lim and Sodhi 2004; Melles et al 2003). In addition, the temporal patterns of the four species recorded an increase in population except for *C. livia* and *M. migrans* (Figure 4).

Corvus splendens, an alien invasive species, recorded the highest invasive abundance values (26.01 ± 6.83) in the urban environment. Taxa analysis of the sites confirmed that the high abundance of *C. splendens* outnumbered the other invasive bird species exhibiting a process of biotic homogenization. Based on the scale of urbanization of the study points, it was found that *C. splendens* had a broader spatial distribution and broader environmental tolerance, exploiting wider resources in the urban environment (Points 1–80). They were found abundant in areas of high commercial developments (Point 59: 110.70 ± 70.41 and Point 39: 66.04 ± 71.69), residential areas (Point 1: 48.08 ± 25.27 and Point 2: 34.91 ± 24.22), and also in regions of higher inflow of tourists (Point 10: 46.70 ± 24.65). Their population did not show any significant seasonal variations among the different habitats in the urban ecosystem due to their resident pattern.

Acridotheres tristis, the second most abundant invasive species, recorded a mean abundance of 2.32 ± 1.08 individuals/point count station. Based on the scale of urbanization of the point counts, *A. tristis* was found to be highly abundant in closely packed residential areas (Point 43: 11.29 ± 9.27 and Point 64: 8.95 ± 21.19), followed by commercial areas (Point 78: 6.25 ± 9.33).

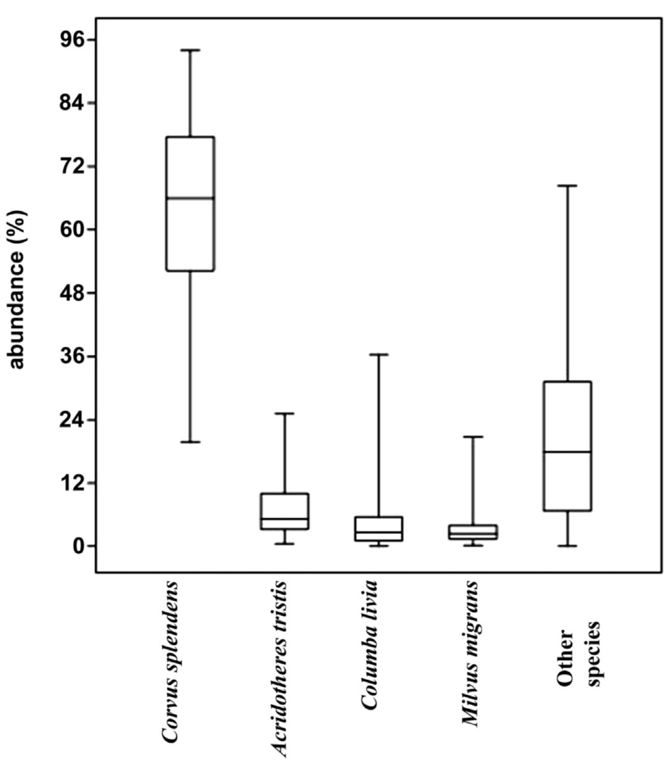

Figure 2. Box plot showing percent abundance of dominant birds and other species in the urban matrix.

Columba livia recorded a mean abundance of 2.07 ± 0.71 individuals/point count station. They agglomerated in regions of closely packed residential areas (Point 77: 9.62 ± 12.37 and Point 75: 9.29 ± 20.68) and commercial areas (Point 1: 7.16 ± 12.47 and Point 2: 6.33 ± 8.76) with tall buildings.

Milvus migrans, a raptor, was the fourth most dominant species occupying the urban landscape of Tiruchirappalli with a mean abundance of 1.43 ± 0.81 individuals/point count station. The spatial distribution of the species recorded higher abundance in regions of residential areas (Point 20: 6.83 ± 24.20), dumping yards (Point 56:4.45 ± 5.67), and commercial activity (Point 59: 25.16 ± 9.83; Figure 5).

A significant increase in abundance was recorded in the population of *C. splendens* (d.f. = 1, $f = 17.53$, $p < 0.001$) and *A. tristis* between 2010–2011 and 2011–2012 (d.f. = 1, $f = 23.72$, $p < 0.001$). However, no significant increase in the populations of *C. livia* (d.f. = 1, $f = 0.65$, $p = 0.42$) and *M. migrans* was recorded between 2010–2011 and 2011–2012 (d.f. = 1, $f = 2.56$, $p = 0.12$) in the study area.

From the urban to urban fringes, that is, along an urbanization gradient, there was a decline in invasive bird abundance: *C. splendens* (26.01 ± 15.22 > 13.15 ± 6.23 > 6.60 ± 2.56), *C. livia* (2.07 ± 0.71 > 1.12 ± 1.29 > 0.57 ± 0.46), *M. migrans* (1.43 ± 0.81 > 0.30 ± 0.23 > 0.29 ± 0.15) except for *A. tristis* (2.32 ± 1.08 > 2.95 ± 1.44 > 3.02 ± 0.87), which exhibited higher abundance toward suburban matrix and further increased toward urban fringes. Further, the correspondence analyses (CAs) of invasive taxa were carried out and relay plots were ordered according to CA column scores. The length of bar represents relative abundance of the species studied, and distance between bars represents relative relationship (lesser distance means more similarity). The result shows that taxa were ordered according to their positions in the urban landscape and exhibited a unimodel peak. The CA column scores recorded a unimodel peak for *A. tristis,* which partly overlapped with the peak of the next taxonomic species *C. livia* in the urban landscape (Hennebert and Lees 1991). A similar unimodel peak was observed for *M. migrans* and *C. splendens* (Figure 6). This result confirms that species irrespective of their taxon are affected by the scale of urbanization and that invasive species agglomerate at regions of higher urbanization. Bird abundance was ordinated to detect similarities or differences between the bird communities in different zones of the urban landscape. The DCA ordination of bird species abundances for all 80 plots produced eigenvalues of 0.88 for Axis 1 and 0.09 for Axis 2. DCA scores indicated significant overlap between the invasive bird communities found in different zones of the urban landscape, depicting high similarity in land-use patterns of the species.

Influence of landscape characteristics on invasive bird abundance

Urban habitat features affect bird abundance both positively and negatively. To understand the likely factors that determine the abundance of invasive birds, PCA was conducted with survey-site characteristics derived at each study point (vegetation cover, built cover, and number of trees). Principal components with an initial eigenvalue score greater than 0.5 were considered to show a strong relationship to the principal component. Once the principal components were identified, the measure with the highest eigenvector score for each component was selected to represent the variability along that component. PCA between *C. splendens* and habitat attributes including scores of urbanization explained two main factors of the classification analysis with 50.12% of the variance (Factor 1 = 38.32%, Factor 2 = 11.80%). Variables such as tree cover, tree height, DBH (Diameter at Breast Height), number of trees, shrub cover, pedestrian movement, cable poles, road

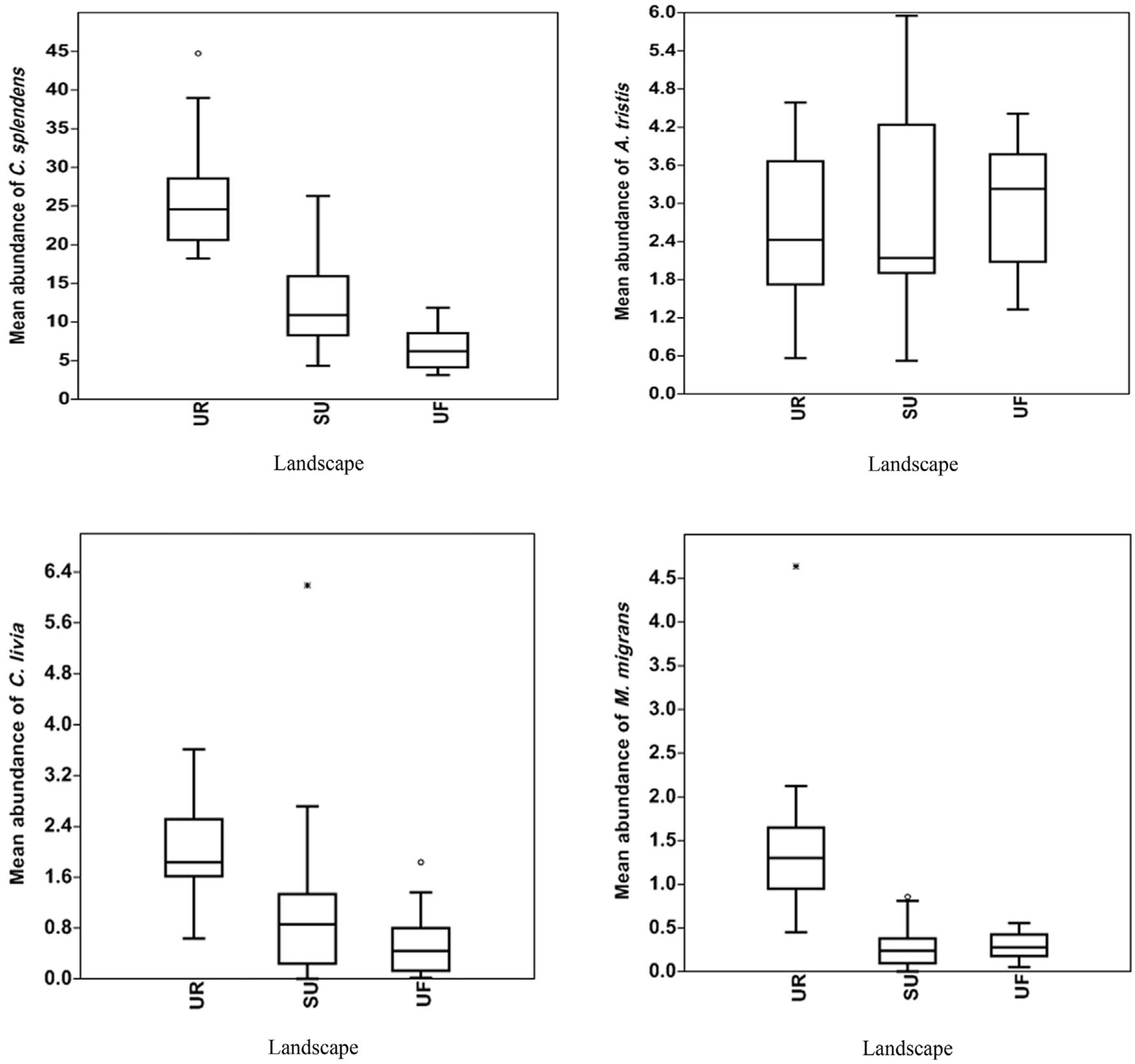

Figure 3. Box plots showing mean monthly abundance of invasive birds across an urbanization gradient. (UR-Urban, SU-Suburban, Urban Fringes-UF).

cover, number of buildings, and building height had positive factor loadings on the F1 axis, whereas noise levels, build cover, and number of vehicles had negative factor loading on the F1 axis. PCA between *A. tristis* and habitat attributes explained two main factors with 50.64% of the variance (Factor 1 = 38.34%, Factor 2 = 12.30%) with factor loadings similar to that of the *C. splendens*. PCA between *C. livia* and habitat attributes explained two main factors with 50.64% of the variance (Factor 1 = 38.43%, Factor 2 = 11.78%). Higher abundance of *C. livia* was found in regions of higher pedestrian movement, higher number of buildings, and greater road cover. PCA between *M. migrans* and habitat attributes explained two main factors with 50.64% of the variance (Factor 1 = 38.06%, Factor 2 = 11.78%). Similar to the other three species, *M. migrans* showed positive factor loadings on the F1 axis for tree cover, shrub cover, tree height, cable poles, number of buildings, building height, and negative factor loadings for noise levels, built cover, and vehicular movement. The results showed that the urban-dwelling bird species mostly frequented areas with high pedestrian movement, cable poles, tall buildings, landscapes with tall trees, and greater road cover (Figure 7). Among the four invasive species, *A. tristis* exhibited greater positive inclination toward vegetative factors. Pearson correlation showed significant correlation of *C. splendens* with tree cover ($r = 0.26$, $p = 0.01$), *A. tristis* with tree cover ($r = 0.24$, $p = 0.02$), shrub cover ($r = 0.23$, $p = 0.03$), herb cover ($r = 0.32$, $p = 0.004$), number of trees ($r = 0.23$, $p = 0.03$), road cover ($r = 0.36$, $p = 0.001$), and pedestrian movement ($r = 0.33$, $p = 0.003$). *C. livia* showed significant correlation with shrub cover ($r = 0.24$, $p = 0.02$), herb cover ($r = 0.25$, $p = 0.02$), building height ($r = 0.22$, $p = 0.04$), and number of buildings ($r = 0.22$, $p = 0.04$). Invasive bird abundance in the urban landscape was also associated with various environmental variables including rainfall, temperature, and humidity. *C. splendens* and *A. tristis* showed significant positive correlation with maximum temperature ($r = 0.63$, $p = 0.001$ and $r = 0.45$, $p = 0.02$, respectively), minimum temperature ($r = 0.57$, $p = 0.003$ and $r = 0.41$, $p = 0.04$, respectively), and humidity ($r = 0.48$, $p = 0.01$ and $r = 0.43$, $p = 0.03$, respectively). However, the correlation with rainfall was insignificant. *C. livia* did not show any significant correlation with any of the environmental variables, whereas *M. migrans* showed positive correlation with minimum rainfall ($r = 0.44$, $p = 0.02$).

Discussion

The four invasive species were distributed evenly across the urban landscape, benefiting from local disturbances, and well

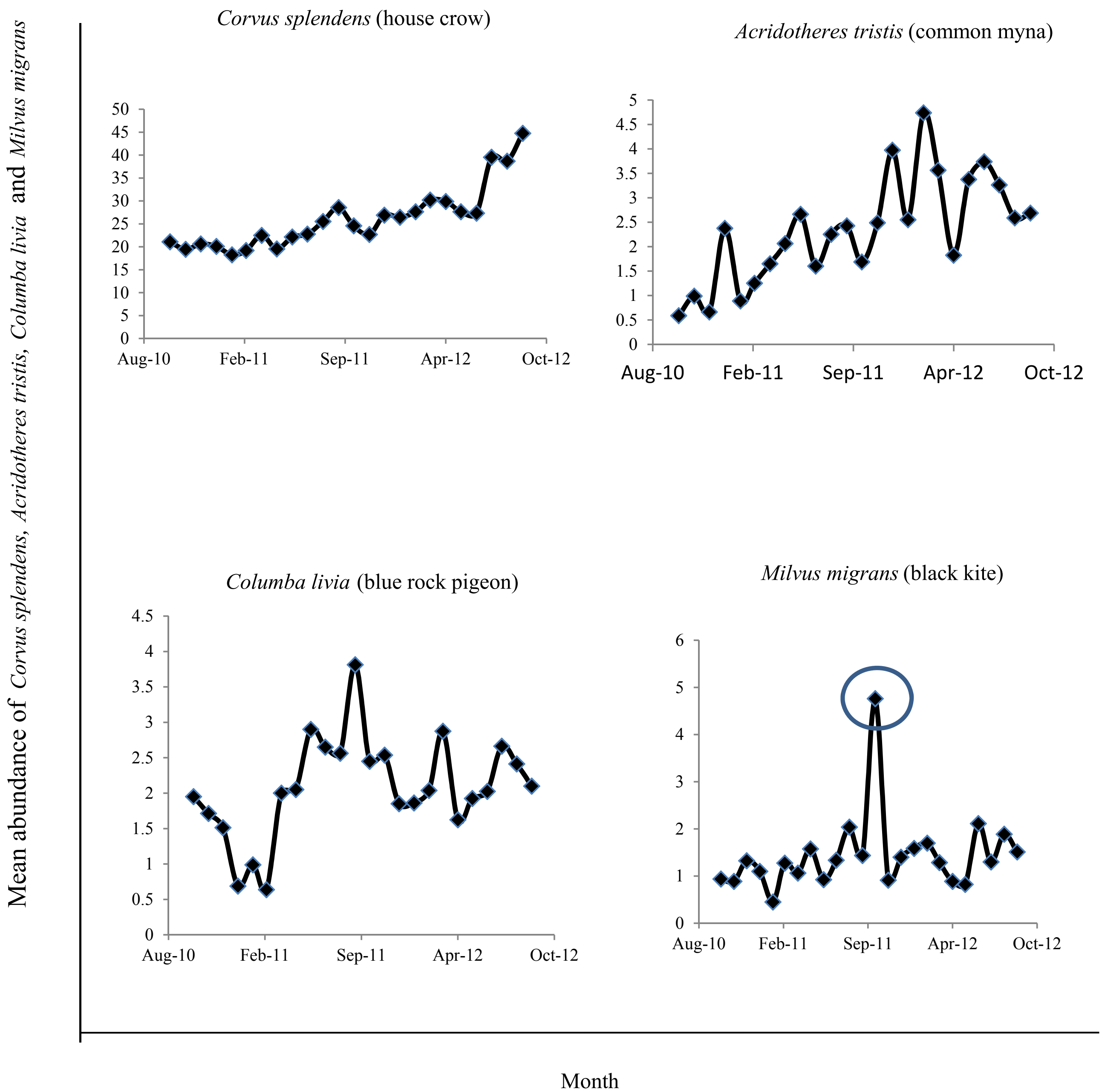

Figure 4. Temporal variation of *Corvus splendens*, *Acridotheres tristis*, *Columba livia*, and *Milvus migrans* in the urban environment.

associated with human habitations. One of the best examples of an urban-exploiter species in the study area was *C. splendens.* They had a wider spatial distribution and were found to thrive well in an urbanizing landscape exploiting wider resources and were influenced by factors related to spatial scaling. They were unaffected by habitat reduction and external disturbances (Scott 1985), and thus, are becoming one of the most dominant urban-dwelling bird species in Tiruchirappalli. Despite crowded urban structures and commercial establishments, these species efficiently foraged food resources and the urban structures provided favorable nesting and roosting sites for them. The species *C. splendens* and *A. tristis* were also regionally common and abundant species in their natural habitats. Earlier studies have also reported similar effects of urbanization providing favorable habitat and resources for fewer “invasive” species, which take advantage of the altered habitat characteristics and reach high abundance (Faeth et al 2005; Marzluff et al 2001a; Rodewald and Shustack 2008). Invasive birds were often found to agglomerate in highly packed residential areas, commercial sites, and at waste dumping grounds, recording maximum abundance. Often, habitats with increased abundance may function as a sink for a species and may have limited value in sustaining population (Morrison et al 1998). With the exception of *C. livia*, the most abundant species in this zone are all predominantly omnivorous and adaptive socially. In general, there was less abundance of frugivorous birds in the urban ecosystem except for the species *Psittacula krameri* (rose-ringed parakeet) that was recorded in higher abundance, followed by *Nectarinia zeylonica* (purple-rumped sunbird) and *Pycnonotus cafer* (red vented bulbul). The results showed that LU changes and wider resources in the urban areas have resulted in taxonomic homogenization of the

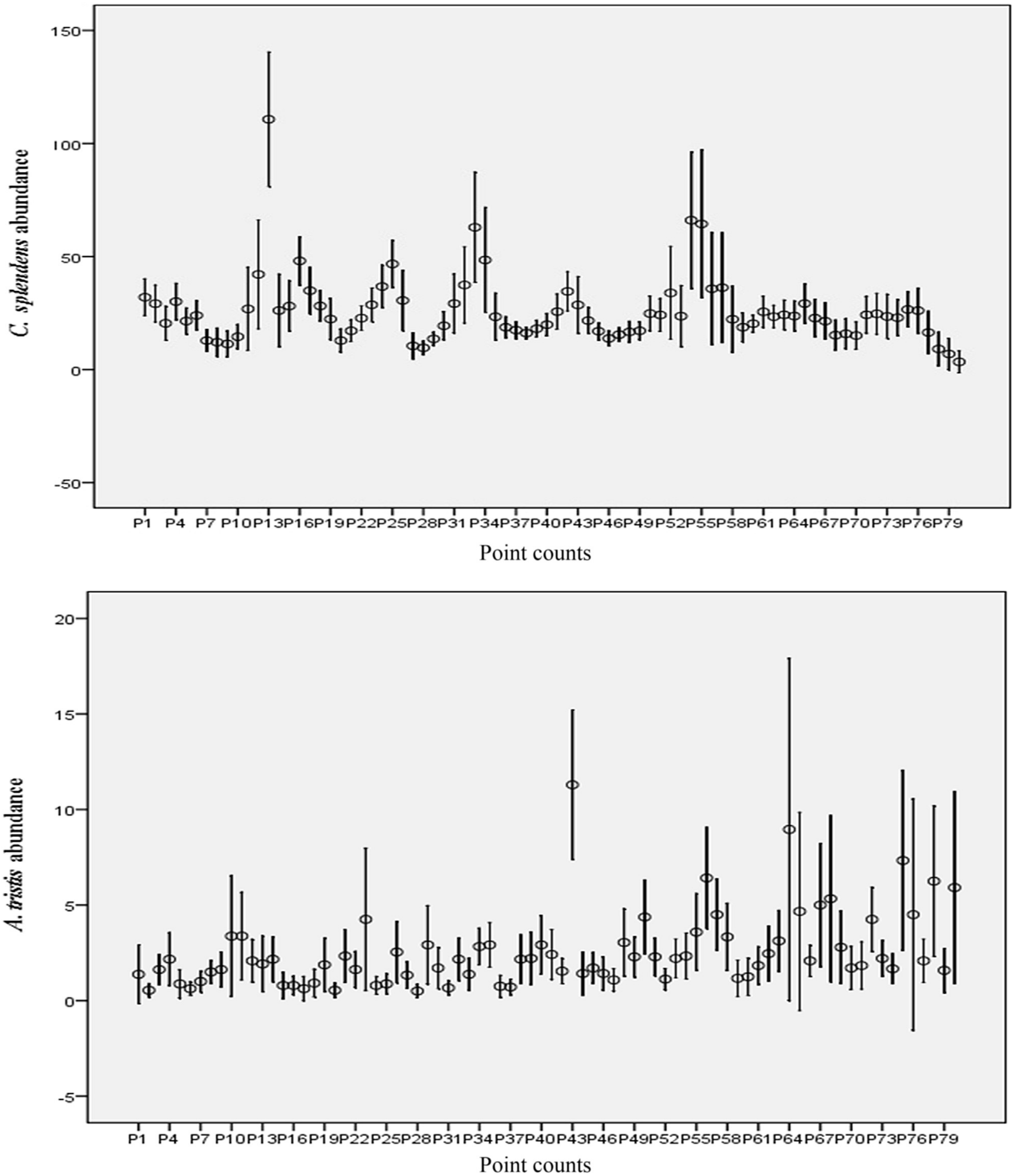

Figure 5. Spatial variation of *C. splendens*, *A. tristis*, *C. livia* and *M. migrans* across sampling stations based on the scale of urbanization. (P represents Point Counts).

species *C. splendens*. The results of our study also confirm previous findings indicating an increase in taxonomic homogenization as urbanization increases (Blair 2001; Crooks et al 2004; Lockwood and McKinney 2002). Although taxonomic homogenization may benefit invasive species, it may have negative effect on specialist species in a community (Brouat et al 2004; Clergeau et al 2001; Devictor et al 2008; McKinney 2002, 2006; McKinney and Lockwood 1999; Ortega-Alvarez and MacGregor-Fors 2009). The study shows that often the persistence of one particular invasive species in higher abundance will strive to prevent or control the spread of other invasive species in the same habitat and climatic conditions. However, based on the scale of urbanization, that is, along an urbanization gradient from urban to urban fringes, we see a decline in invasive bird abundance, except for *A. tristis*, which exhibited higher abundance toward suburban matrix and further increasing toward urban fringes. The study also recorded a

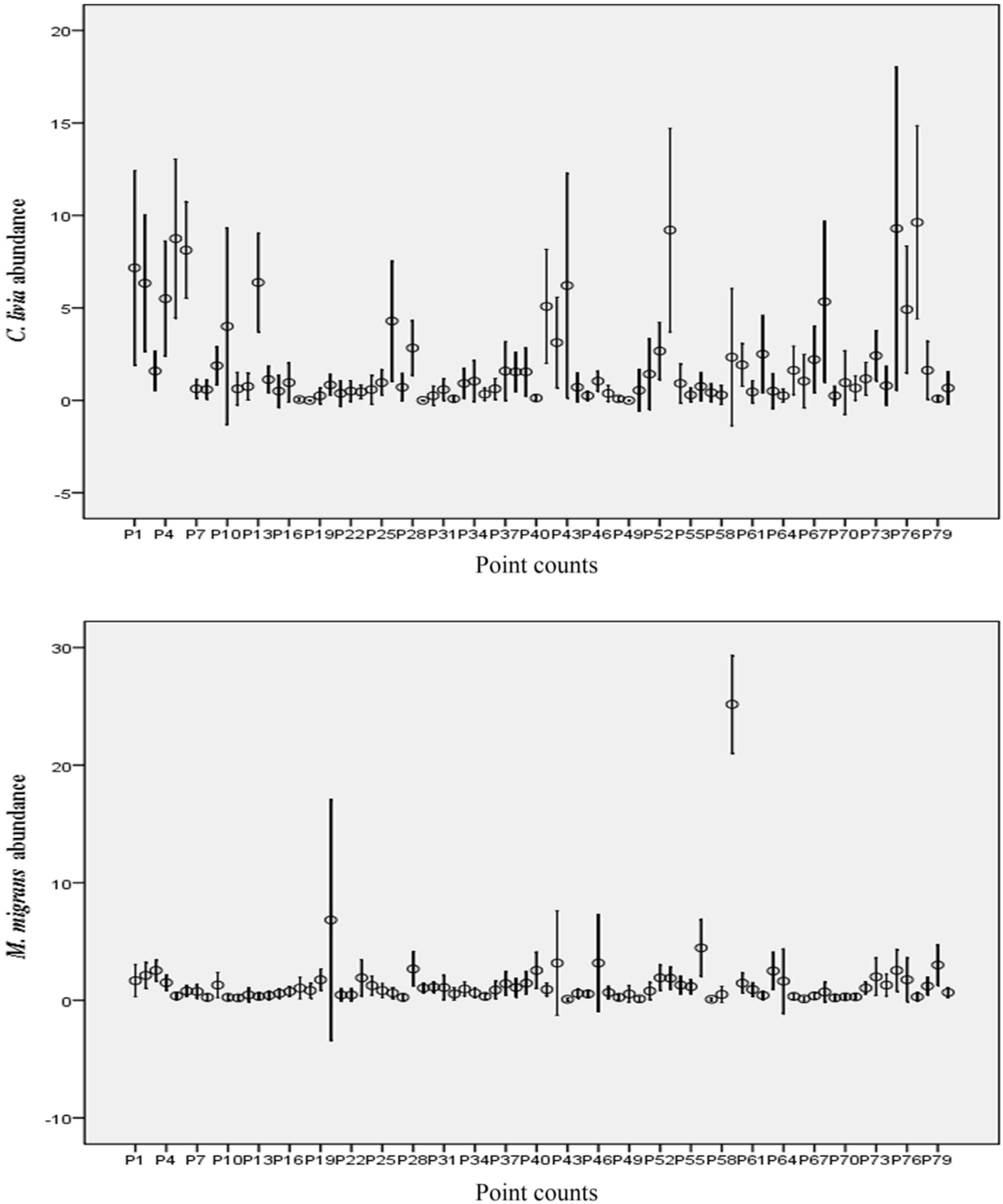

Figure 5. (*continued*).

phenomenal process of local migration of species between landscapes. Recently, fewer insectivorous species—*Dicrurus macrocercus* (black drongo) and *Cypsiurus balasiensis* (Asian palm swift)—of the agricultural landscapes were often found frequenting the urban landscape (Menon et al 2015). This may over a period augment to the list of "synanthropic birds" presently recorded in the urban ecosystem.

The result showed that urban-dwelling bird species such as *C. splendens*, *A. tristis*, *C. livia*, and *M. migrans* mostly frequented areas with high anthropogenic activities and used urban structures for nesting. Although invasive species often use urban structures for nesting, significant correlation with various vegetative factors in the environment was also recorded. The study shows that tree cover is also an important element for urban-

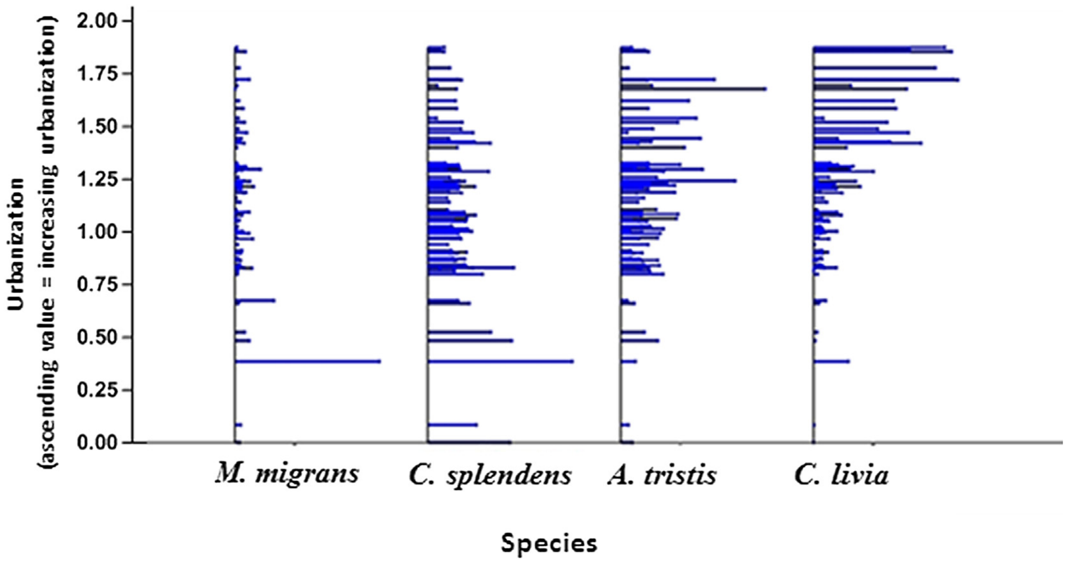

Figure 6. Relay plot illustrating the within-station variability of the faunal structure in the urban ecosystem.

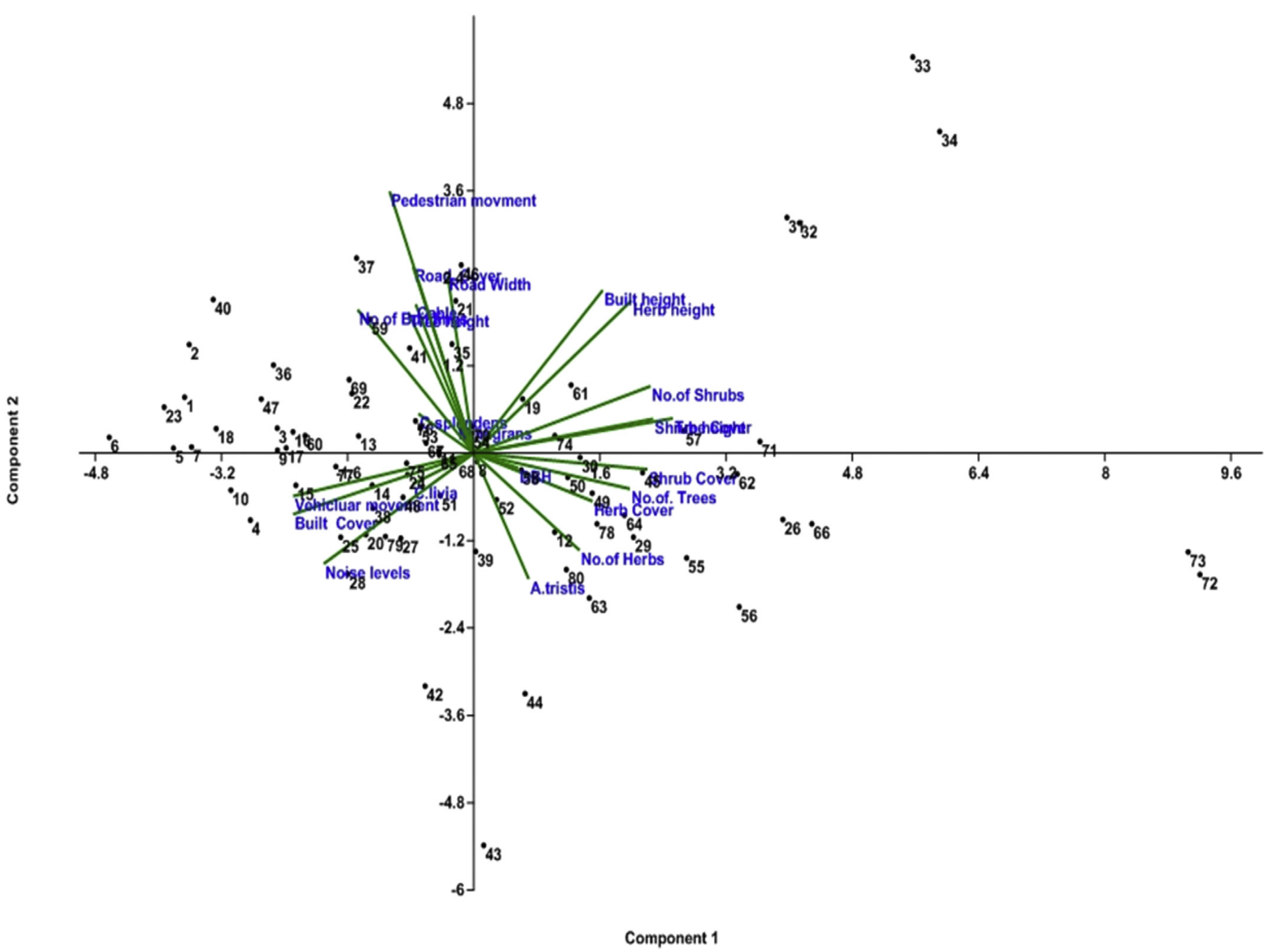

Figure 7. Relationship between invasive bird abundance and habitat attributes. The numbers (1–80) represent the sampling points.

dwelling invasive birds. Landscapes with tall trees were frequented by birds for nesting, foraging, roosting, and hiding. Urban-dwelling birds often select tall trees with greater diameter, landscapes with greater shrub cover, and areas with varied taxa of trees. Urban structures may affect urban-dwelling birds either positively or negatively (MacGregor-Fors and Schondube 2011). The important anthropogenic elements that attract birds toward urban landscapes are tall buildings, cable poles, areas with higher pedestrian activity, and greater road cover. Tall buildings and cable poles provide alternative roosting and nesting sites for invasive birds. Tall buildings also provide a better aerial view of the possible sighting of food resources and also provide a safe refuge from predators and vehicular collisions. Significant abundance of invasive birds in areas with higher pedestrian movement and greater road cover suggests that these areas may provide alternative feeding grounds for the urban-dwelling birds. The higher abundance of invasive birds in areas with urban structures depicts the successful adaption of urban birds to human-related resources. The invasive birds' omnivorous nature, wider spatial distribution, innovative feeding techniques, and adaptability to novel environments have been associated with their successful invasion. Moreover, urban structures provide better breeding opportunities to invasive birds as they are highly capable of constructing nests on manmade structures (Kark et al 2007). Suburban landscapes and urban fringes, represent significantly lower invasive abundance patterns as these landscapes do not constitute preferred habitat for birds, especially tall buildings and building cavities. Our study shows that urban exploiters were mostly invasive species, although there may also be a few native species; by contrast, urban avoiders were mostly native, local migratory, and rare species.

The city exhibits hot and dry climate with high temperature and low degree of humidity throughout the year, which could be associated with higher invasive bird abundance in the study area as these conditions provide suitable breeding corridors for invasive birds. Urban areas mostly provide better habitats for corvids and raptors as warmer climatic conditions and enormous resources around human settlements help in minimizing their energy expenditure (Marzluff et al 2001b). Often species such as *M. migrans* were recorded gliding in the sky during minimum rainfall. This may be a behavior associated with raptors as these conditions provide better visibility of prey.

The study substantiates with previous studies indicating that urban environments are more dominated by a few generalist, often invasive, bird species (Chace and Walsh 2006; Marzluff 2001; Shochat et al 2006). Overall, the results suggest that invasive communities in urban environments are governed by differential responses of individual bird species to urban structures, developmental activities, and habitat fragmentation. The study shows that there is high variability in how different invasive species adapt and respond to landscape changes and fragmentation not only in the urban landscape but also along the urban, suburban and urban fringes (Crooks et al 2004; Marzluff 2001; Melles et al 2003; Sandstrom et al 2006; Tratalos et al 2007). Although the abundance of invasive species may increase species diversity at a regional level, they may pose threat to global diversity (Bigirimana et al 2011; Collins et al 2002; Sax and Gaines 2003). In most Indian cities, invasive birds have increased in high abundance and are geographically widespread, potentially reducing the available habitat and resources for native species. In few metropolitan cities of India, species such as *C. splendens* dominate the urban landscape, whereas in few others, *C. livia* were found to successfully invade urban centers mostly depending on the scale of urbanization and the region of analysis.

Conclusion

In the Indian context, there are not many publications regarding the abundance of invasive birds. In addition, there are only limited studies that quantitatively assessed the impacts of environmental variables and habitat attributes on invasive bird abundance. Resource availability in the urban areas and successful adaption to human-related resources coupled with their omnivorous nature have made invasive birds the most successful urban dwellers leading to gradual elimination of native, migratory, and rare birds. From the findings of this study, it is important to note that few suburban regions were also important environment for invasive birds, especially for species such as *A. tristis*. Urban foresters and policy makers should take efforts to prevent new introductions and spread of invasive birds to a particular geographic region. To achieve these, steps need to be taken to monitor and scrub dumping yards and open dumping sites from the incursion of invasive birds. Moreover, we need to develop conservation guidelines to protect urban forest and provide suitable nesting sites to attract native and rare species of birds. The concept of urban forests and habitat corridors should be a part of legislative guidelines to address the decline of native birds. Finally, careful documentation, monitoring, and species-specific monitoring systems are required at both the regional and global levels to assist management and restrain the abundance of invasive birds to urban environments.

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