Leveraging citizen science for bird monitoring: A case study assessing the impacts of urbanization on bird assemblages of the Nilgiris

By

David Phinehas N

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Under the supervision of

Shri. Varun S Kher

Dr. V.V. Robin

Dr. Ashish Jha

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भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Leveraging citizen science for bird monitoring: A case study assessing the impacts of urbanization on bird assemblages of the Nilgiris",** is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Shri. Varun S Kher, Scientist-C**, **Wildlife Institute of India,** and co-supervision of **Dr. V.V. Robin, Associate Professor, Indian Institute of Science, Education and Research, Tirupati**. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

David Phinehas N

Enrolment No: 50BB22A73009

Place: Dehradun

Date: 31-07-2024

31/7/24

Shri. Varun S Kher **Supervisor**	**Dr. V. V. Robin** **Co-supervisor**	**Dr. Ashish Jha** **Co-supervisor**

भारतीय वन्यजीव संस्थान
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CERTIFICATE

This is to certify that the thesis by **David Phinehas N** entitled "**Leveraging citizen science for bird monitoring: A case study assessing the impacts of urbanization on bird assemblages of the Nilgiris"** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

David Phinehas N has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

Shri. Varun S Kher
Supervisor

Dr. Ruchi Badola
Dean
Faculty of Wildlife Science

पत्रपेटी सं 18 चन्द्रबनी देहरादून-248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun-248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स .+91-135-2640111 से 2640115, फैक्स :0135-2640117
EPABX +91-135-2640111 to 2640115, Fax · 0135-2640117
ई–मेल/E-mail wii@wii.gov.in, वेब/website . www.wii.gov.in

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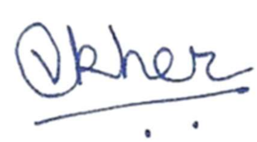

Dr. Manohar Pathak
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Supervisor

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1. Executive Summary

1. Anthropogenic alteration of habitats is the leading cause for biodiversity loss across the world. To accommodate the ever increasing human population, intensification of urbanised areas have led to the most extreme forms for habitat alteration (Batáry et al., 2018) and imposes a unique set of ecological filters.
2. Over that last 2 centuries during the colonial past, the Nilgiris has witnessed large-scale change in the landscape structure from native shola-grassland matrix to extensive tea and eucalyptus plantations. Currently it has emerged into a tourist haven, attracting millions every year, leading to expansion of the urban cover to accommodate the growing demand.
3. This study illuminates the profound effects of urbanization on bird communities in the Nilgiris, showcasing how habitat transformation alters community parameters such as, species richness, abundance, and composition. My results indicate a stark pattern: as urbanization intensifies, species richness declines, while a select few generalist species thrive in high abundance.
4. My findings reveal that settlements and proximity to remnant shola patches are the primary factors influencing avian community structure. Areas with higher settlement percentages and greater distances from shola patches exhibit reduced species richness and diversity. In contrast, less urbanized areas, closer to natural habitats, maintain higher biodiversity. This aligns with the hypothesis that urban environments simplify habitat structures, creating a 'filter' that only a limited number of species can pass through, thereby fostering biotic homogenization.
5. Urban generalists, such as the House Sparrow, Rock Pigeon, and House Crow, flourish in highly urbanized zones due to their ability to exploit the abundant food resources and nesting sites provided by human activities. These species benefit from the homogenized

urban landscape, which offers ample opportunities for foraging and nesting, often at the expense of more specialized species. Conversely, endemic shola forest specialists, such as the Nilgiri Laughingthrush and the Black-and-orange Flycatcher, suffer due to their stringent habitat requirements and limited dispersal abilities. These findings highlight the ecological trade-offs imposed by urbanization, where habitat degradation and loss disproportionately impact species with narrow niche widths.

6. This study also highlights the usefulness of citizen science as a tool for collection of large-scale data in a short time span. I also tested for the accuracy of the citizen science data against a research-grade benchmark, ie, data collected by me. The results suggest that no significant variations were detected between the two datasets.
7. Conservation Implications: Monitoring species with vulnerable traits to keep track of further degradation of the habitat and involvement of the local citizens is needed. The study highlights a critical need to preserve remaining shola fragments and implementation of biodiversity friendly urban planning.

2. Introduction:

Studying processes at a landscape level requires biological data to be collected across large spatial and temporal scales (Robinson et al., 2020). This is often cost and time-intensive, thus limiting the scale, extent and periodicity of sampling. Due to such sampling constraints, inferences are usually made from limited amount of data or are limited toa smaller study area. Such small scale inferences are often not generalizable, particularly in heterogenous environments, and constrain our understanding of ecological process while also hindering effective monitoring and planning of conservation actions (Bonney et al., 2009; Kobori et al., 2016; Lewenstein, n.d.; Robinson et al., 2020).

Citizen science is a practical way to bridge this resource gap, with projects typically mobilizing volunteers to gather data following a protocol developed by experts (Wei et al., 2016). The use of semi-structured citizen science-generated data to answer ecological questions has been a common practice in Europe and North America (Silvertown, 2009), but is not so widespread in the global south. In countries where bird watching is popular, scientists have been successful in engaging and integrating citizen volunteers into bird-monitoring exercises (McCaffrey, 2005; Squires et al., 2021). Such studies have been particularly successful in areas close to urban centres, as birding interest and voluntary support is often higher here. Thus, monitoring of urban biodiversity through citizen science is an exciting prospect and needs to be explored rigorously.

Advantages of Citizen-Science Surveys

In its infancy, citizen science programs were only viewed as a tool for education and outreach (Bonney et al., 2009; Brossard et al., 2005; Jordan et al., 2011; Lewenstein, 2005); but the scope has now increased tremendously. Long-term monitoring projects that require a substantial number of observers are increasingly undertaking a citizen-science approach

(Aronson et al., 2014; Hensley et al., 2019; Isaksson, 2018; McCaffrey, n.d.). Projects that are restricted by a small timeframe or lack the necessary funds and manpower are able to gather vast amounts of data using citizen science (McCaffrey, 2005). By mobilizing large groups of citizens in cities, considerable volume of data across large spatial scales can be accumulated very quickly.

Apart from providing ease in carrying out biological sampling, numerous other benefits are received. Citizen science projects benefit the volunteers and the broader society as it inculcates a sense of belonging and responsibility in the volunteers towards the taxa or the site they sample (Bonney et al., 2009; Brossard et al., 2005; Conrad & Hilchey, 2011; Jordan et al., 2011; Lewenstein, n.d.). In addition, the participant's knowledge about their local environment gets enhanced after the findings of the projects are disseminated (Brewer, 2002).

Current Status of Citizen Science Research in Indian and Global Context:

Citizen science platforms such as ebird, Phenology Network, National Moth Recording Scheme, etc exist, are successful models and vast amounts of data are logged every year. The data is then used to monitor changes in species distributions, and abundance and also compared with habitat data to find the drivers that cause such changes (Johnston et al., 2020; Robinson et al., 2020; Squires et al., 2021). Predominantly, citizen science data is used in cases where the collection of structured data is not feasible. Due to the lack of randomness in the sampling effort, the citizen science data is fed through rigorous multi-level filtering to remove clustering biases (Hochachka et al., 2012; Johnston et al., 2020; Ramesh et al., 2022; Sullivan et al., 2014). Further, Henckel et al. 2020 compared the species distribution models, run with structured data and opportunistic data from citizen observations and found that the performance of opportunistic data was almost the same as structured data after removing any clustering bias

(Henckel et al., 2020). Another popular method to use citizen science data is to integrate it with large sets of structured data (Bradter et al., 2018; Lepczyk, 2005). Manyika et al. 2011 termed it as the ‘Big Data’ approach, where data-intensive science like computational processing and access management are incorporated to achieve large accurate data sets. Kelling et al. 2015 employed this method to structure ebird data to obtain robust species distribution models (Kelling et al., 2015).

In India, citizen science generated data has not been prevalently used in research, primarily due to the lack of widespread data. With bird watching is becoming more mainstream, India has become an active participant in citizen science initiatives. Events organized by Bird Count India and Ebird, such as Great Backyard Bird Count, Endemic Bird Day, Campus Bird Count, and other regional state-level events have seen record-breaking participation each year. Another large-scale citizen monitoring project is the Hornbill Watch, initiated to utilize citizens from all walks of life to understand the distribution and biology of Asian Hornbills (Datta et al., 2018). The recent Kerala Bird Atlas (Jayadevan et al., 2022; Jha et al., 2022) has been the latest in line of numerous bird atlases that have successfully utilized a citizen science framework to establish baseline ecological data. The major drawback of these efforts is the spatial resolution at which they have operated. The bird atlases have looked at bird assemblages and distributions at a coarse large scale. Inferences at this coarse sale will not be able to reflect the fine-scale relations effectively, for which, data across a finer spatial scale needs to be collected.

Effects of Urbanization on Bird Assemblages:

Although studies on the effects of urbanization have increased over the recent years, traditional ecological studies on the effects of land use change have either omitted or side-lined urban areas (Marzluff et al., 2001). Popularly, urbanization is expected to result in habitat homogenization where species with similar sets of biological traits are selected over others (Keddy, 1992; Mckinney, 2006). The urbanized habitats are similar in structural composition (roads, buildings, parks, ..., etc). Thus, the biotic communities between various urbanized habitats are expected to be composed of species with similar sets of biological traits leading to biotic homogenization (Hensley et al., 2019; Keddy, 1992). Native, endemic, forested, and range-restricted species are more often than not the most affected and are replaced by 'urban specialist' species having favorable traits to survive in urbanized habitats (Hensley et al., 2019). Species with different functional traits respond differently to changes in land use (Rurangwa et al., 2021). Non-migratory, large-bodied, forest specialist species with long generation times and diets of fruit, nectar, and invertebrates have been shown to be the most sensitive to land-use change (Newbold et al., 2013). With the rapid increase in urbanization, information on the effects of urban environments on wildlife and for conservation and environmentally friendly city planning is urgently needed (Garaffa et al., 2009; Pena et al., 2023).

To understand the impacts of landscape-level habitat modifications, bird assemblages are ideal subjects and have been of great interest to ecologists(Aronson et al., 2014; Bajaru et al., 2020; Jetz et al., 2007). Studies on bird assemblages have shown a decrease in species richness with increasing urbanization (Pena et al., 2023) and changes in species composition from natural areas to more urbanized landscapes (Mckinney, 2006). A meta-analysis by Newbold et al. (2012) showed that the species richness, occurrence probability, and abundance of birds are highest for primary undisturbed habitats and decrease as the intensity of land use increases.

The high elevations of the Nilgiris (Ooty, Coonoor, and Kotagiri) have witnessed large-scale habitat modification over the last two centuries. The majority of the previous studies in the Nilgiris have primarily focused on bird responses to historical land use change -tea, eucalyptus, acacia, and agriculture (Lele et al., 2020; Rajamani & Robin, 2012; Robin et al., 2014). The occupancy of tropical montane birds of the Western Ghats, a biodiversity hotspot, is strongly driven by climatic factors, especially temperature seasonality (Ramesh et al., 2022). On the other hand, studies have shown that biotic factors such as vegetation structure and resource availability can influence species diversity and composition as well (Newbold et al., 2013). Owing to the spatial heterogeneity, landscape-level covariates will be better suited to explain the trends in occupancy, abundance, richness, and composition across the urbanization gradient (Ramnarayan & Shanthi, 2018). However, studies on the effects of urbanization at a landscape level are very few (Ramnarayan & Shanthi, 2018).

As mentioned earlier, urban centres have great potential for citizen science projects. However, carrying out a study in urban areas is a great challenge, due to the heterogeneity and the vast nature of the landscape (Wei et al., 2016). Even though, citizen science provides a good method to collect a large amount of ecological data, it is criticized for lacking scientific rigor (McCaffrey, 2005). This study thus tries to understand the effects of urbanisation on montane birds of the western ghats using a citizen science framework, while simultaneously testing the efficacy of this framework for answering such a question.

2.1 Aim

Through this study, we plan to leverage citizen science to understand the effects of urbanization on bird assemblages in the Nilgiris and assess whether such surveys can be used for research-grade monitoring efforts. Simultaneously, we plan to assess whether guided citizen science based surveys can replace research grade studies in monitoring of urban and peri-urban biodiversity.

2.1.1. Objectives

- To use citizen science surveys to understand the effects of urbanization on occupancy, abundance, and habitat use of bird assemblages in the Nilgiri hills.
- To assess the utility of citizen science surveys for bird monitoring in the Nilgiris, and test the accuracy of citizen science dataset.

2.1.2. Research Questions & Hypothesis

a) How do taxonomic diversity and composition of bird assemblages differ across the urbanization gradient (Natural habitats interspersed with hamlets -> semi-urbanized areas with monoculture -> urban sprawls) and to determine the factors influencing them?

Hypothesis: Biotic homogenization leads to Native/endemic/forest species being filtered out and replaced by ‘urban specialist’ species that have favourable traits to survive in urbanized habitats (Hensley et al., 2019)

Prediction: Taxonomic diversity is expected to decrease; with an increase in urbanization. Composition is expected to be similar between grids of similar urbanization levels

b) How does the occupancy of select species of conservation importance (Native/endemic/forest species) vary across this gradient?

Hypothesis: Birds that are non-migratory, forest specialist species having diets of fruit, nectar, and invertebrates will be more sensitive to land-use change (Newbold et al., 2013)

Prediction: Occupancy of forest-dependent diet specialists will decrease more steeply with an increase in urbanization.

c) To test the accuracy of citizen science-generated data (Volunteer dataset vs Research grade dataset).

Hypothesis: Encounter rates of species will be significantly different between the datasets as volunteer datasets will not encounter shy and dull birds in the same way as research grade observers.

Prediction: Encounter rate for shy and dull birds will be lower in volunteer dataset

3. Methodology

3.1. Study Area

The study area is located in the district of Nilgiris, situated in the western corner of the Indian state of Tamil Nadu. It covers an area of 2545 sq. km (11° 12' to 11° 37' North and 76° 30' to 76° 55' East) and is part of the Nilgiri Biosphere Reserve and the Western Ghats and Sri Lanka global biodiversity hotspot. The upper Nilgiris plateau rises sharply from the surrounding country and forms a high-elevation plateau. The vegetation of the upper Nilgiris can be broadly classified into southern montane wet forests, grasslands, and plantations (Rodgers & Panwar, 1988) Southern montane wet forest type, classified as subgroup 11A/type C1 is popularly known as shola. Grasslands located at high elevation areas fall under subgroup 11A type C1 (Rodgers & Panwar, 1988).

The study area is composed of three major hill stations Ooty, Coonoor, and Kotagiri combined together to cover 100 sq. km (approx.). These cities are situated at a altitude of 1800m to 2000m. The extent of each city was mapped using night light satellite data (DMSP OLS: Nighttime Lights Time Series Version 4, Defense Meteorological Program Operational Linescan System). The 3 cities are composed of various habitat types such as remnant shola patches, tea plantations, eucalyptus plantations, agricultural fields, urban areas, and urban green spaces (home gardens, parks, botanical gardens). The three cities vary between each other on the level of urbanization, Ooty being the most urbanized and Kotagiri the least

These cities were established by the British colonialist for the monoculture of tea and eucalyptus in the 1820s. They soon developed into a ideal location to escape the harsh summer temperature of the adjoining plains. Later Ooty, erstwhile Ottacamund became the summer capital of the then Presidency of Madras. By this time majority of the Shola-grassland matrix was cleared to make way for tea and eucalyptus plantations. Housing units for estate workers and bustling market depots grew in number. After the completion of the Nilgiri Mountain Railway Track in 1889, Ottacamund became a summer tourist destination. Over the last century, the Nilgiris has come be known as the "Queen of hill stations" with a boon in tourism. During the peak summer, Nilgiris is plagued by extreme levels of over tourism. An estimated 20000 vehicles enter Nilgiris every day during this season.

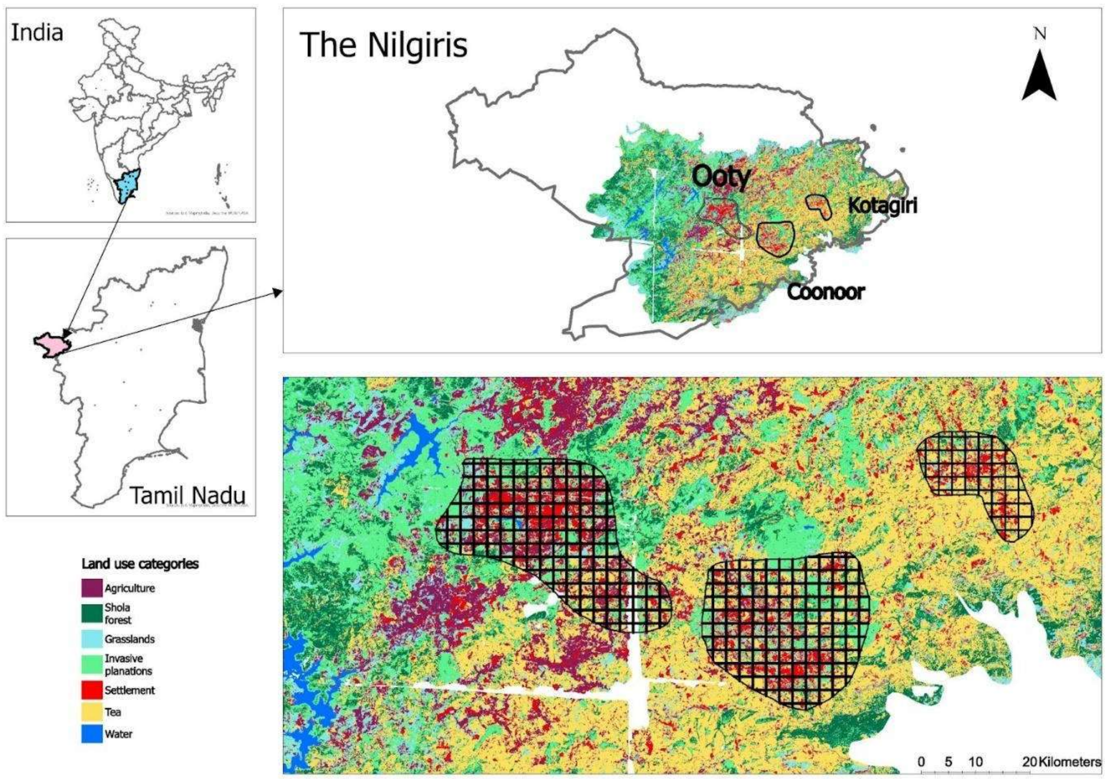

Figure 1: Map showing the study area classified into various land-use categories and divided into 500x500m grids.

3.2. Study Design and Field Methods

A bird atlas framework was adopted (Jayadevan et al. 2022; Jha, Jayadevan, and PO 2022) to sample birds across the landscape. The 100 Sq.km (approx.) of the study area (Ooty, Coonoor & Kotagiri) was divided into 1 km x 1 km cells (see Fig 1). Further these 1 km x 1 km grids were divided into four 500m x 500m grid cells. One 500m x 500m grid cell per 1 km x1 km grid was randomly selected. The grid cells were classified into the following four classes based on the percentage of urban cover: i) class 1 (>30%); ii) class 2 (30 - 15%); iii) class 33 (15-5%); and iv) class 4 (<5%). The urban cover will be determined using a LULC map (Sentinel-2, Ramesh unpublished data, 2019, 94.8% accuracy). Any inaccessible grid cell was substituted by the closest accessible cell of the same category. A total of 97 grid cells were sampled and each grid cell was replicated 3 times temporally. Each grid cell has one 300 to 340 m trail that cuts across the diverse land use types present in the grid.

3.2.1 Trails

Trails were preferred over point counts to mimic the conditions in which bird watching is generally done. The trails are distance-bound (300m-340m) and covered the maximum possible land-use types present in the grid. The trails were shared with all the volunteers through the Locus app. They were instructed to collect data pertaining to the species observed, number of individuals, habitat type, name of the observer, and other covariates for every observation in the form of ebird checklists and kobo collect forms. The ebird checklists were shared to a common ebird ID.

3.2.2 Bird Sampling

Volunteer Surveys

Survey team: 2-3 members constitute a survey team, and each team will be comprised of

- an expert birder (Team Leader)
- amateur/novice birder
- a forest guard/watcher (wherever required)

They recorded all birds seen/heard during the length of the trail. The surveys were conducted either in the morning (6.30 am - 10.30 am) or evening (3.30 pm - 6.00 pm). A total of 3 temporal replicate, i.e, 3 checklists were collected from each grid.

Research grade Surveys

25 out of the 97 grids were randomly selected and I carried out distance sampling method of data collection. Data was collected along the same trails used by the volunteers. Distance data and sighting angles for each observation were collected. Each grid was replicated temporally three times.

3.2.3 Collection of habitat covariates

The following habitat variables were collected or remotely sensed:

Land-use landcover map of the study are was borrowed from Ramesh et al., 2022. The LULC map consist of 7 classes, namely, agriculture, shola forest, shola grassland, settlements, invasive plantations, tea plantation and water bodies.

Table 1: Local and landscape Factors collected in field/ remotely sensed.

Habitat Variables	Sampling
Landscape covariates	
Habitat composition (within each grid)	Percentage of each land use-landcover type was calculated from the LULC map (Sentinel-2, Ramesh et al., 2022, 94.8% accuracy) in ArcGIS Pro.

Distance to Shola	Distance to the nearest shola patch from the centroid of each grid was calculated using the Euclidean distance function in ArcGIS Pro.
Distance to urban centre	The centroid od each city polygon was considered as the urban centre. Distance from centroid of each grid to the closest of the 3 urban centres was calculated using the Euclidean distance function in ArcGIS Pro.
Local covariates	
Vegetation Structure (Canopy and understory)	Collected by ocular estimation by the volunteers from each grid. The volunteers termed the canopy and understory cover as either High, Medium or Low.

3.3. *Analytical methods*

3.3.1 Bird Species Richness and Abundance

All aquatic bird species were omitted and only terrestrial species were used for the analysis. To compare local bird species richness and abundance, the grids were classified into the following four urban classes (Dale, 2018) based on the percentage of urban cover: i) class 1 (>30%); ii) class 2 (30 - 15%); iii) class 33 (15-5%); and iv) class 4 (<5%). Analysis of Variance (ANOVA) was conducted to check for significant differences.

3.3.2 Community Composition

To visualise the differences in community composition, the grids were classified into four urban classes based on the percentage of settlements within each grid. Species-site matrix of each class was used to calculate the dissimilarity matrix. Bray-Curtis index of similarity was used to estimate the ecological distance between the communities of the urban classes. Further, ordination of the data was performed using non-metric multidimensional scaling (NMDS), using vegan package in R. two dimensions were selected and the stress scores were made sure to be below 0.2. Permutational Multivariate Analysis of Variance (perMANOVA) was used to test for significant difference between the community cluster.

3.3.3 Drivers of species richness, abundance and diversity

To identify the drivers of species richness and abundance, generalised linear models (GLM) were used. In case of diversity, log transformation of the diversity values were made and liner models were used. The local and landscape factors of each grid were used as predictor variables. Univariate models were run between the response and all variables to look for statistically significant effect ($p < 0.05$). Only the variable with statistically significant effect were included in the global model.

Model selection was based on the information theoretic approach (Aho et al., 2014) and was performed in the following way: a) A global model with all covariates was created and all simpler combinations of this model were produced using the dredge function in ‘MuMIN’ package of R. b) the best model was selected based on AIC values. c) The variables that had a significant directional effect on species richness were identified based on the effect size and p-value. d) Relative effects of different variables were visualised using response curves.

3.3.4 Bird species occupancy

To understand the species level response towards urbanization, occupancy estimates of bird species were calculated using Single-species single-season models in ‘unmarked’ package in R, for each urban class. Species were grouped into 3 categories, forest specialist, urban generalists and generalists (Tobias et al 2022). Forest specialist species were defined as narrow endemics which are restricted to forest patches. Species that thrive in urban sprawls were considered as urban generalists and finally generalists were species that were present in equal abundance across the urban classes.

3.3.5 Testing Citizen science data vs Research grade data

To test the robustness of the citizen science data, encounter rates of the most detected set of species from both Citizen Science and Research grade datasets were calculated. Species which have been detected at in at least 5 sites out of the 25 sites were shortlisted. A paired T-test was conducted to look for significant difference in encounter rates. Further to know whether similar communities were captured by the two datasets, we generated Bray-Curtis and Jaccard’s dissimilarity scores for corresponding sites of the two datasets. Since the data was collected during the same time period by both methods, we assume the community to be closed.

4. Results

A total of 11,889 individuals belonging to 86 species were recorded by the citizen volunteer surveys during the sampling period (January 2024 to March 2024), while 3099 individuals belonging to 68 species were recorded in the research grade survey. Overall, 14988 individuals belonging to 96 species were recorded during the field surveys.

4.1. Species richness and abundance

The mean species richness between the urban classes was significantly different (ANOVA, df = 3, F = 10.55, p = < 0.05). Class 1 was the least species rich and Class 4 had the highest species richness (Table 2), thus, indicating that species richness was lower at high levels of urbanization. The mean abundance was also significantly different between the urban classes (ANOVA, df = 3, F = 5.45, p = < 0.05). Class 1 had the highest mean abundance, while Class 4 had the least.

Table 2: Mean species Richness (SE) and Mean Abundance (SE) of all urban classes.

Urban Class	Mean Species Richness	Mean Abundance
1	11.73 (0.95)	149.26 (14.9)
2	15.95 (0.85)	136 (11)
3	17.68 (0.91)	117.92 (8.6)
4	18.81 (0.97)	93.18 (6.1)

Table 3: ANOVA- Mean Species Richness

Species Richness ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	698.375	3	232.792	10.5561	4.86E-06	2.70251
Within Groups	2050.9	93	22.0527			

Table 4: ANOVA – Total Abundance

Abundance ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	44207.5	3	14735.8	5.45997	0.00168	2.70251
Within Groups	250996	93	2698.89			

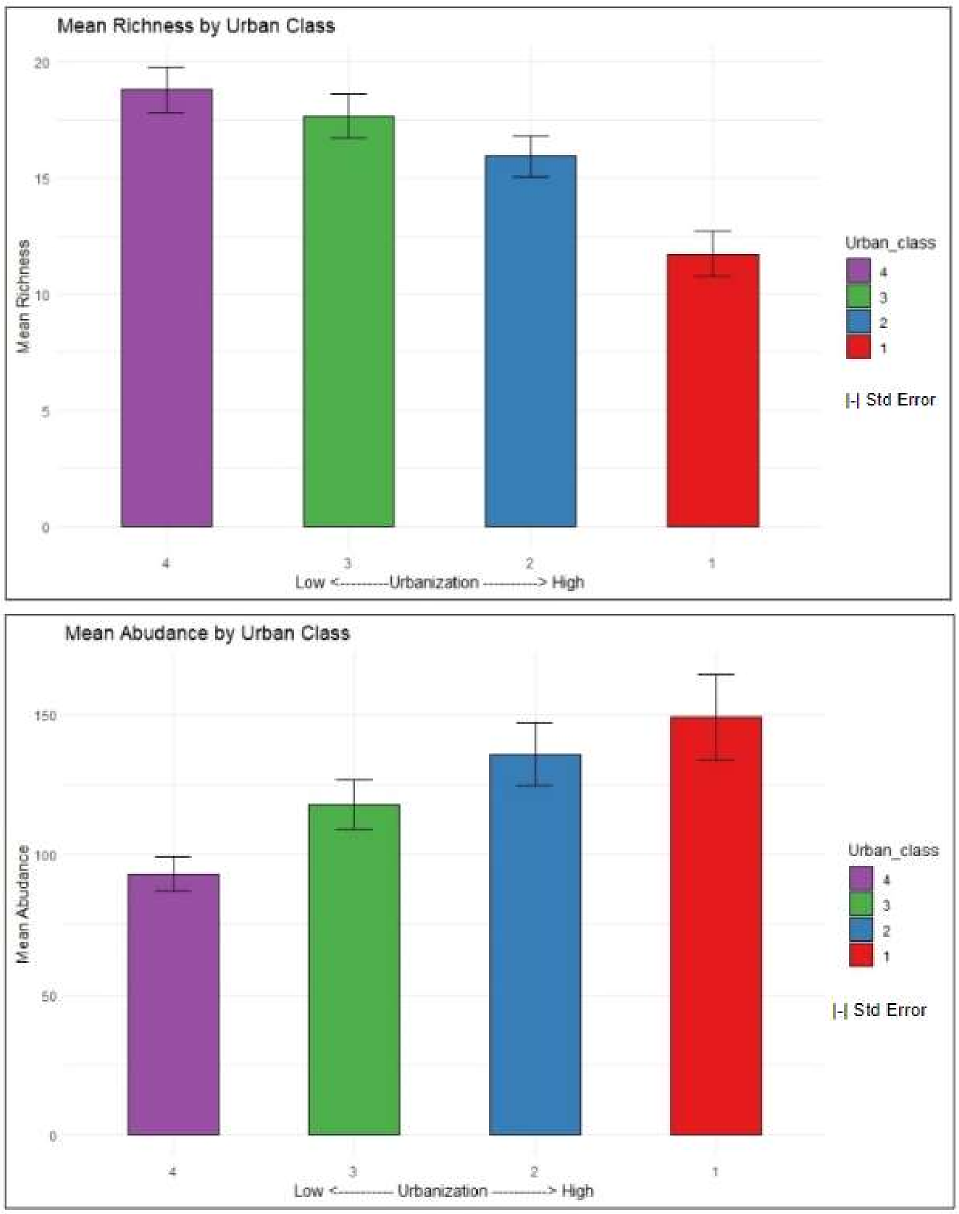

Figure 2: Bar plots showing the mean species richness (top) and mean abundance (bottom) across the urban classes.

4.2. Dominance

The rank abundance curves of the four urban classes showed that respective communities differed in their evenness. Urban class 1 had the most uneven community. Whereas, urban class 4 had the most even community.

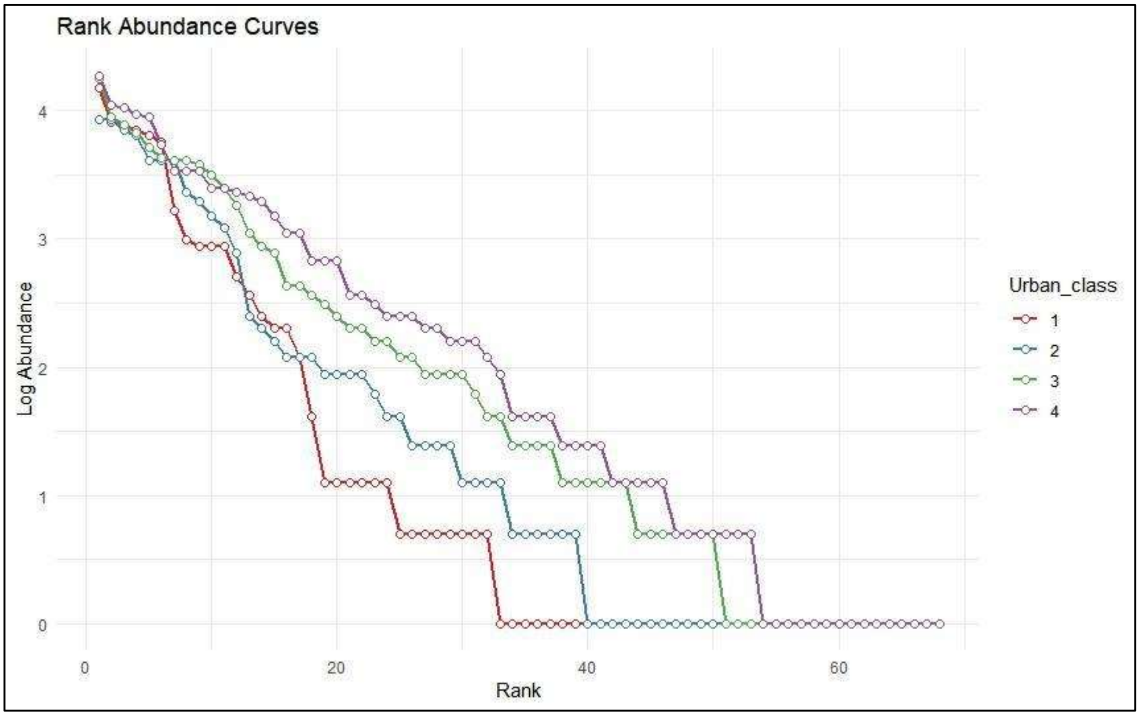

Figure 3: Rank abundance curve showing the evenness of the community

4.3. Community composition

The community composition of bird species across the urban classes was visualized using non-metric multidimensional scaling (NMDS). NMDS axis 1 and 2 explained 76.64% and 20.83% of the constrained variance. The stress score was 0.062. To test if the communities were significantly different across urban classes, a Permutational Multivariate Analysis of Variance test (perMANOVA) was carried out. The result was significant (p<0.001) indicating the communities differed from across the urban classes.

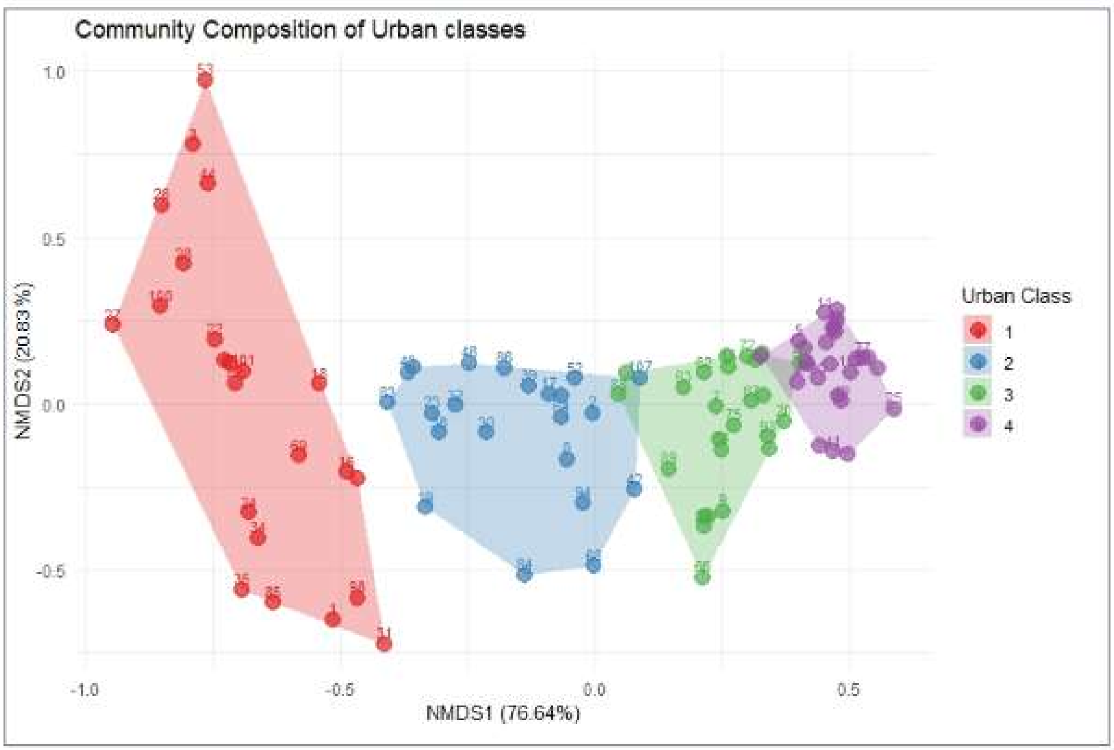

Figure 4: NMDS plot showing the difference in bird community composition of the urban classes. NMDS axis 1 and 2 explained 76.64% and 20.83% of the constrained variance. The stress score was 0.062

Table 5: perMANOVA test for significant difference between the community composition of the urban classes

	Df	SumsOfSqs	Mean Sqs	F.Model	R2	Pr(>F)
urban_class	3	6.1304	2.04347	36.705	0.54213	0.001 ***
Residuals	93	5.1776	0.05567		0.45787	
Total	96	11.308			1	

4.4. Drivers of species richness and abundance

The best model indicates that distance to shola and percentage of settlements are negatively influencing species richness, while other factors did not have a significant effect (Table 3). The best fit model had an AIC value of 571.65 and explained 33% of the variance in the data. In case of total abundance, the best model suggests that the percentage of settlements and distance to the city centre had a positive influence, while the percentage of shola had a negative influence (Table 3). The best model had an AIC score of 2445.4 and explained 18% of the variance in the data.

Table 6: summary results of the best-fit GLM models for species richness and abundance. The significant predictors are highlighted.

Avg.Richness ~ Distance to shola forest + % Settlements + Distance to City centre + % Shola_forest				
	Estimate	**p value**	**AIC**	**R^2**
(Intercept)	20.6	< 0.001	571.65	0.33
Distance to shola forest	**-0.0002**	**0.003**		
% Settlements	**-0.1**	**< 0.001**		
Distance to City centre	0.001	0.66		
% Shola_forest	<-0.001	0.75		
Total.Abundance ~ Distance to shola forest + % Settlements + Distance to City centre + % Shola_forest				
(Intercept)	4.63	< 0.001	2445.4	0.18
Distance to shola forest	< -0.001	0.22		
% Settlements	**0.008**	**< 0.001**		
Distance to City centre	**0.005**	**< 0.001**		
%Shola_forest	**< -0.001**	**< 0.001**		

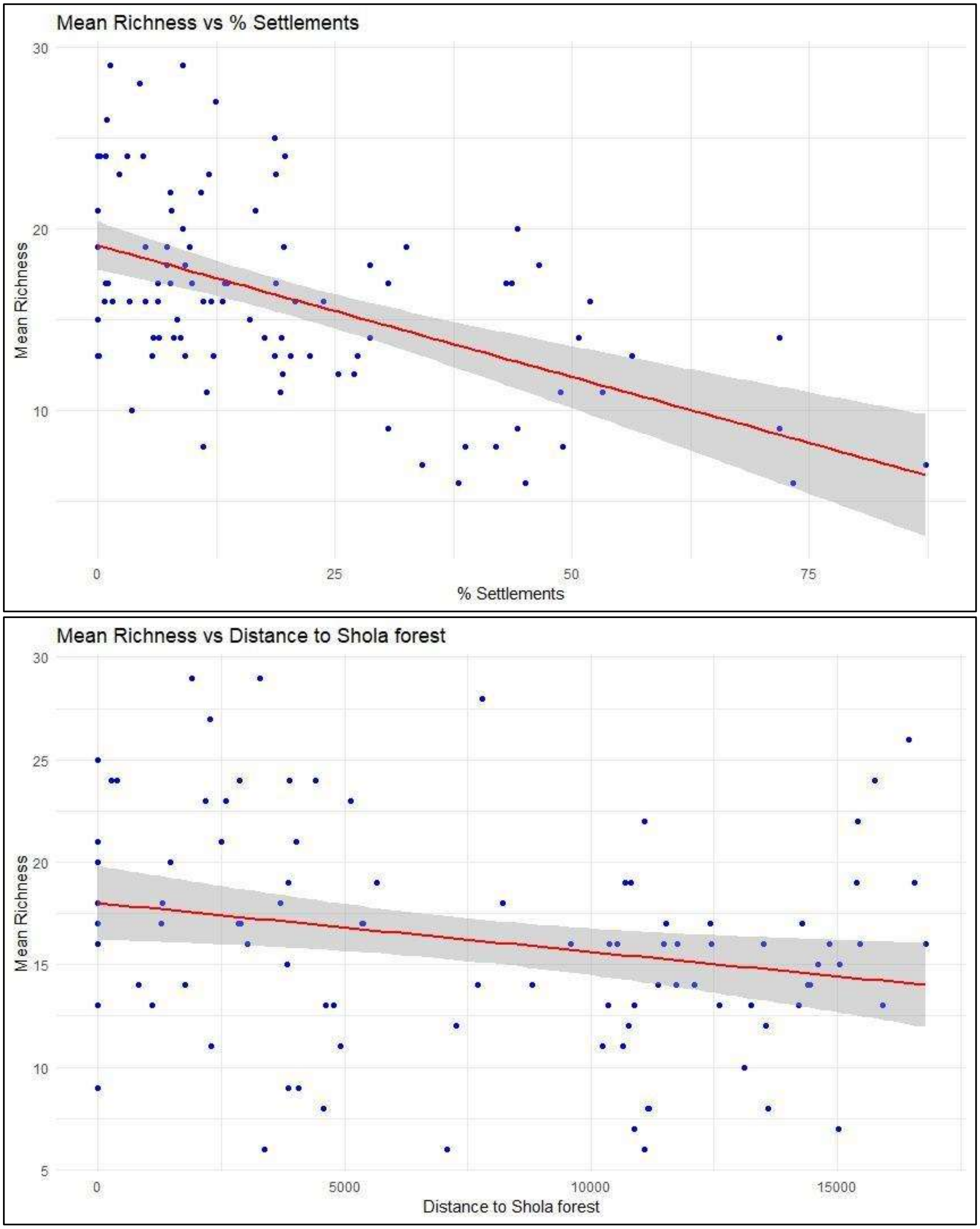

Figure 5: Plots showing the effects of the significant drivers of Species richness. Top- % of shola forest, bottom- distance of shola forest

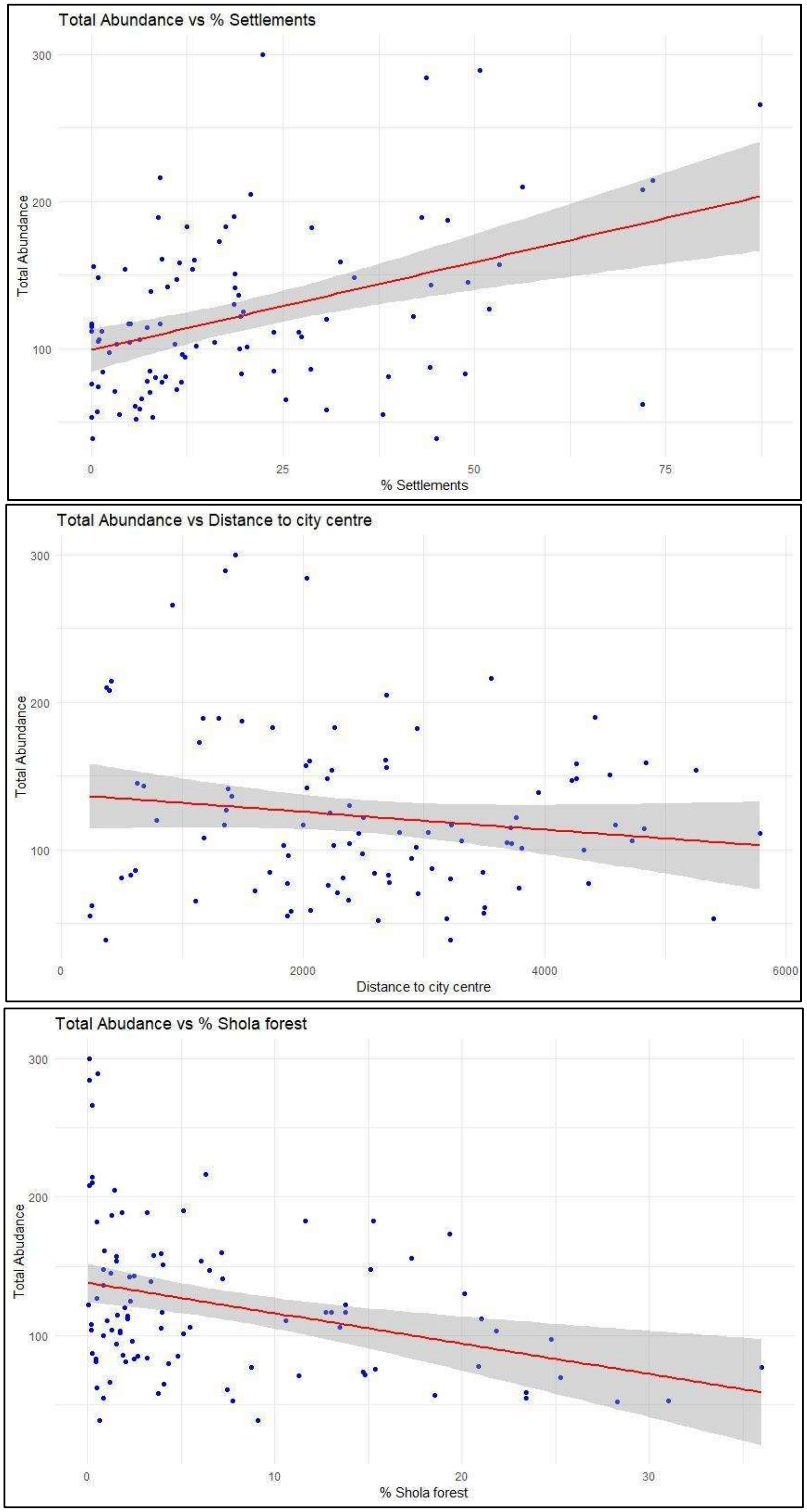

Figure 6: Plots showing the effects of the significant drivers of Total abundance. Top- % of settlements, middle- distance to city centre, bottom- % of shola forest

4.5. Occupancy probabilities

The occupancy probability across the four urban classes were calculated for a select set of species to look at species-specific response towards the urbanization gradient. Forest specialist species like the Nilgiri Laughingthrush (NLT), Nilgiri flowerpecker (NFW), Nilgiri Flycatcher (NFC), Gray Junglefowl (GJF) and Black and Orange Flycatcher (BOF) showed a net increase in occupancy probability with decrease in urbanization (Fig 5). Whereas, urban generalist species like the House Sparrow (HC), House Crow (HC), Jungle Myna (JM) and Rock Pigeon (RP), showed a net increase in occupancy probability with increase in urbanization (Fig 5). Habitat generalist species like the Red-whiskered Bulbul (RWB), Red-vented Bulbul (RVB), Large-billed Crow (LBC), Spotted Dove (SD) and Pied Bushchat (PBC) did not show a drastic change with increase or decrease in urbanization (Fig 5).

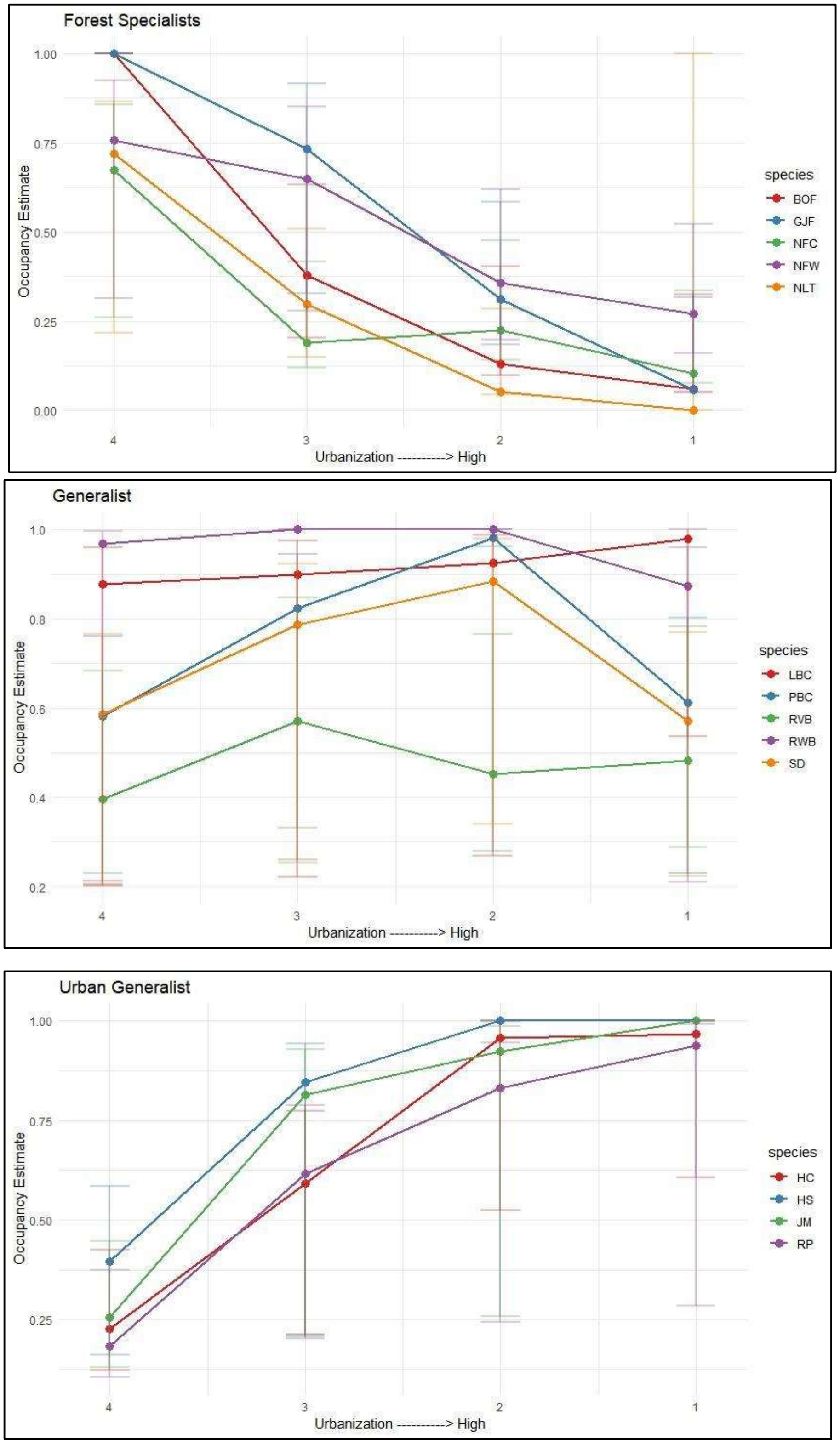

Figure 7: Plots showing the occupancy trend of forest specialist (top), Generalist (middle) and urban generalist (bottom). The points represent the occupancy estimate at each urban class and the lines represent the overall trend.

4.6. Species encounter rates

Encounter Rates of species between research grade surveys and citizen science surveys were not significantly different for 19 of the 20 species. Only Indian White-eye had significantly different encounter rates between the research grade and citizen science data.

Table 7: Paired t-test p-value for encounter rates of species between Research grade and Citizen Science data.

Species	RG	CS	T-test p-value
Rock Pigeon (rp)	27.79	41.77	0.72
House Crow (Hz)	17.50	8.71	0.36
Red-whiskered Bulbul (rwb)	26.64	20.74	0.27
Jungle Myna (jm)	20.79	13.70	0.06
Large-billed Crow (lbc)	10.18	17.98	0.67
Indian White-eye (iwe)	8.36	7.73	0.008*
Blyth's Reed warbler (brw)	4.90	4.17	0.27
Spot-breasted Fantail (sbf)	22.33	12.61	0.6
Pied Bushchat (pbc)	5.43	5.30	0.34
Red-vented Bulbul (rvb)	6.61	6.80	0.47
Nilgiri Flowerpecker (nfw)	4.98	6.04	0.1
Nilgiri Flycatcher (nfc)	7.72	6.47	0.85
Nilgiri Laughingthrush (nlt)	14.83	8.98	0.66
Indian Blackbird (ibb)	8.20	4.92	0.52
House Sparrow (hs)	44.58	39.77	0.79
Greenish Warbler (gw)	4.674	4.96	0.66
Gray Junglefowl (gjf)	2.83	4.44	0.15
Black and orange Flycatcher (bof)	4.65	4.01	0.46
Cinereous Tit (ct)	6.01	5.80	0.83
Spotted Dove (sd)	6.14	6.37	0.84

4.7. Community dissimilarity between Research grade and Citizen science data

The species-site matrices of RG and CS datasets were used to calculate the pairwise Bray-Curtis and Jaccard dissimilarity between the corresponding sites. In Bray-Curtis, grids 8 and 11 showed a 25% difference in the captured community. Whereas, all the remaining 23 grids differed less than 12% ($mean_{bray}$ = 0.08). Whereas, the overall dissimilarity between RG and CS was higher in Jaccard's ($mean_{jaccard}$ = 0.15).

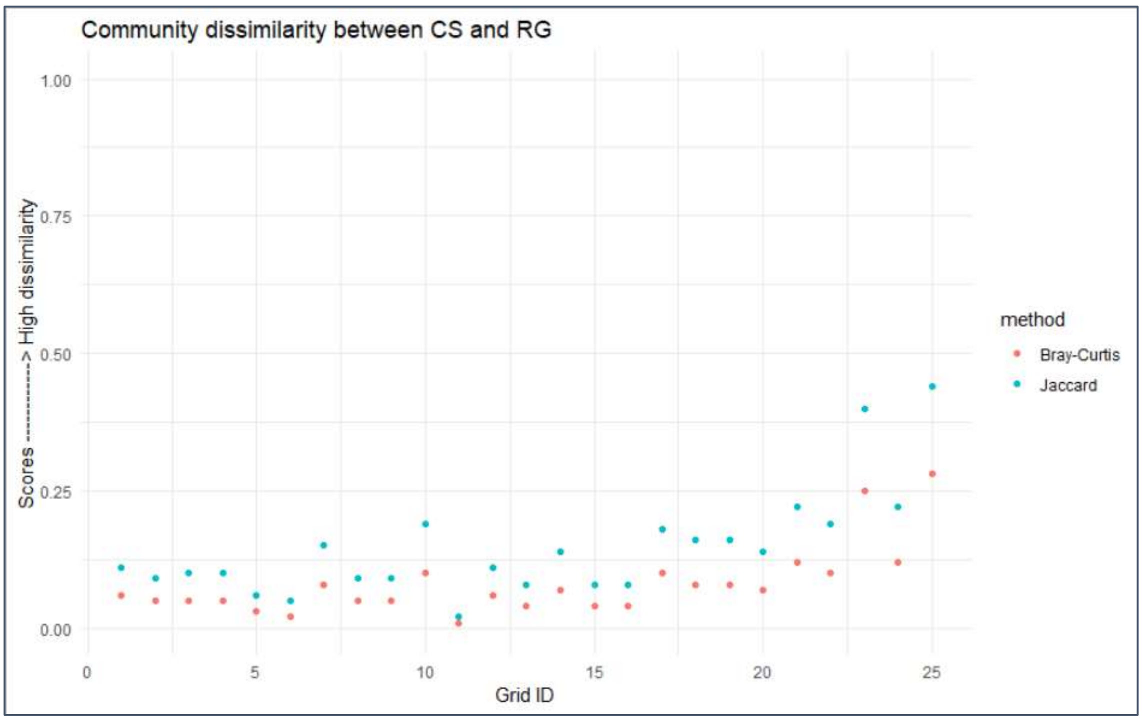

figure 8: Table showing the Bray-Curtis and Jaccard's scores between corresponding sites of RG and CS datasets.

5. Discussion

The results of the study suggest that the bird community in the Nilgiris show clear patterns in response to the current levels of urbanization. Analysing the patterns in species richness, abundance and diversity against the habitat variables indicate that settlements, and distance to a remnant shola patch were the two main variables that explained the mostamount of variance in the data.

Species and traits that are vulnerable to urbanization driven habitat modification were identified. The encounter rates of species and the community captured by research grade and citizen science datasets did not differ significantly.

5.1. Bird community response to urbanization

The observed patterns in bird species richness, abundance and composition can be summarised as follows:

Species richness had a strong negative correlation, while abundance has a slight positive correlation with increase in urban cover. Lower levels of urbanization had high species richness but the species were present in low abundances. On the other extreme, at higher levels of urbanization, numerous species present at lower levels of urbanization were either absent or occurred in extremely low abundances. Instead, very few species (House Sparrow, Rock Pigeon & House Crow) accounted for a large proportion of the abundance. Indicating that progressive urbanization may lead to numerous species, in our case forest endemics, to be replaced by a smaller set of species which are non-native to the landscape (Leveau et al., 2017). Thus, the bird communities at higher levels of urbanization were more uneven compared to communities at lower levels of urbanization.

Ordination results suggest a continuous linear change in community composition along the urbanization gradient (figure 4). This can be possibly explained by the gradual reduction of niche space with increase in urbanization (Garaffa et al., 2009; Mckinney, 2006).

This phenomenon of urbanization-induced biotic homogenization is well studied in birds across the world (Aronson et al., 2014; Crooks et al., 2004; Dale, 2018; Garaffa et al., 2009; Hensley et al., 2019; Isaksson, 2018; Luck & Smallbone, 2011; Mckinney, 2006; McKinney & Lockwood, 1999; Suarez-Rubio & Thomlinson, 2009). Although other studies quantify urbanization differently, it is simply understood that urbanization reduces the structural complexity of habitats, leading to the formation of homogenized concrete jungles. These environments act as structural filters, eliminating species based on their traits; thus, resulting in numerous losers being replaced by few winners as McKinney and Lockwood (1999) suggested.

5.2. Effects of urbanization on regional species pool

The stark difference in community composition across the urbanization gradient suggests that it is fair to assume that species are lost at a local scale. However, community composition at a local scale does not portray the full picture; nor does it stand true for multiple seasons or at the landscape scale (Crooks et al., 2004; Leveau et al., 2017). To fully grasp specific drivers of all species, especially rare endemic species at a larger spatial and temporal scale additional effort is required. Some studies have also shown that the local species pool is not just a subset of the regional species pool, rather urban communities have unique structure, shaped by the unique drivers of the city scape (Fournier et al., 2020). Thus, indicating the need to prove the observed patterns in species richness, abundance and diversity persist across multiple seasons and at a landscape scale.

5.3. Habitat correlates of Species richness, abundance, diversity and composition

Our linear model results indicated that the percentage of settlements, closeness to shola patches, distance to the city centre, and canopy cover strongly explained the observed patterns in richness, abundance, and diversity. Richness and diversity were lowest in urban class 1, which can be attributed to its proximity to the city centre, higher percentage of settlements, and distance from shola patches. As urbanization decreased, richness and diversity increased, likely due to the potential rise in suitable habitats and niche space (Mckinney, 2006; Suarez-Rubio & Thomlinson, 2009)

Abundance was highest in class 1, possibly because a small set of species that are extremely well adapted to urban sprawls accounted for a large proportion. Although the richness in classes 2 and 3 was similar to that in class 4, the abundance of forest specialist species was extremely low. This may be due to forest specialists being unable to persist in classes 2 and 3 due to the subsidized habitat conditions (Garaffa et al., 2009).

Overall, the drivers this study found important are similar to previous studies (Dale, 2018; Garaffa et al., 2009; Leveau et al., 2017; Tiwary & Urfi, 2016).

5.4. Non-significant results

A few of the covariates like percentage of agriculture and shola grassland did not significantly explain the observed patterns in species richness, abundance and diversity. These landscape variables accounted for extremely low proportion of the study area. The extensive tracks of agriculture and tea plantations were not part of the study area allthough they are known to have influence the response (Ramnarayan & Shanthi, 2018) in this landscape.

5.5. Functional Similarity and Species level responses

Species grouped by their common traits showed similar response towards the urbanization gradient. Habitat degradation due to urbanization is known to reduce functional heterogeneity and favour generalist species (Luck & Smallbone, 2011)

Forest specialists were negatively affected by the percentage of settlements and distance to shola. Endemic shola birds like the Nilgiri Laughingthrush, Black and orange Flycatcher and Nilgiri Flycatcher like many other narrow endemics, possess narrow niche widths (Mckinney, 2006; Suarez-Rubio & Thomlinson, 2009). Species with narrow niche widths are more often constrained by dispersal abilities (Salisbury et al., 2012). These obligatory understory insectivores require continuous understory cover to move across the landscape. The complete alteration of a landscape's structural profile due to urbanization leads to loss of both quality and quantity of natural habitat for narrow endemics (Byers & Mitchell, 2005). Thus, leading to their inevitable decrease over time.

Conversely, urban generalist species like House Sparrow, House Crow, Jungle Myna and Rock Pigeon have shown a positive increase in occupancy probability along the urbanization gradient. The homogenized urban landscape provides these species excellent food availability, primarily from abundant garbage and, in some cases, direct supplementation by humans (Tiwary & Urfi, 2016). In addition, buildings provide suitable habitat for these species to nest, roost and cover against predators (DeStefano & Johnson, 2005). In the Nilgiris, every building has multiple bird boxes, providing additional nesting sites for House sparrow and Jungle Myna, thus, resulting in exponential increase in their numbers.

Few species did not show such significant rise or decline in occupancy probability across the urbanization gradient. These generalist species like Red-whiskered bulbul, Large-billed Crow, Red-vented Bulbul have wide dietary and special niche widths, allowing them to successfully occur in similar numbers along the urbanization gradient (DeStefano & Johnson, 2005).

5.6. Research grade vs Citizen science data

The primary dataset used in this study was collected by citizen volunteers. The question that arises is "Is there difference in accuracy between citizen science generated data and researcher generated data?". To answer this question, encounter rates of individual species from the citizen science and research grade data were compared. Although, the number of individuals encountered by research grade surveys were marginally higher, there was no statistically significant difference. Only Indian white-eye had a statistically significant difference in encounter rates between the two datasets. This may be attributed to the small size and drab colour of the species. The communities captured by the two datasets also did not vary significantly as well.

From the results, it can be assumed that the citizen science datasets are 'good enough' and comparable to the research grade data. However, numerous studies (Aceves-Bueno et al., 2017; Crall et al., 2011; Gardiner et al., 2012; Kosmala et al., 2016) that have use far more complex measures to test for accuracy, have suggest that citizen science datasets are less accurate and such assumptions cannot be made from preliminary results. The results of Kosmala et al., (2016) suggest that only 60 to 70% accuracy was found between citizen science and research grade data across the terrestrial projects. Crall et al., (2011) strongly recommend that strict measures in both data collection and post-hoc correction are put in place to account for accuracy biases in citizen science datasets. Highlighting the need for more robust analysis to rigorously test for accuracy between the datasets in this study.

However, (Hochachka et al., 2012) suggest that to ensure less biased data the data collection protocol should be simple and easy for the volunteers, allowing for less room to commit errors.

On the other hand, the errors in accuracy and biases are often related to the taxa being studied In many cases taxa that the volunteers have already had experience with leads to less errors (Dickinson et al., 2010). Both these measures were accounted for in the design and implementation of this study, which might be one of the reasons behind a lower variation between the citizen science and research grade datasets.

5.7. Conservation implications and Way forward

Overall, the results of this study suggest that differences in individual species shape the local bird community of the urban landscape. To understand the non-random filtering of species traits, it is crucial to understand trait specific responses (Crooks et al., 2004; Suarez-Rubio & Thomlinson, 2009) and identify the most sensitive traits. The need for further research is evident, particularly studies that span multiple seasons and cover larger spatial scales to fully understand the long-term and regional impacts of urbanization on bird communities. Additionally, I recommend that citizen volunteers are a good option to monitor the bird community across large special and temporal scales.

In conclusion, this study emphasizes the critical need to consider both habitat complexity and species-specific traits in urban planning and conservation efforts. Protecting and restoring natural habitats like shola patches within urban landscapes can mitigate the negative impacts of urbanization and support a more diverse and resilient avian community. Our findings serve as a call to action for incorporating biodiversity conservation into urban development strategies, ensuring that urban ecosystems can support a rich tapestry of life even as human populations continue to grow and expand.

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8. Appendix

Checklist of birds recorded during the study period across the 4 urban classes

S.no	Common Name	Scientific Name	1	2	3	4
1	Indian Spot-billed Duck	*Anas poecilorhyncha*		✓		
2	Indian Peafowl	*Pavo cristatus*	✓	✓	✓	✓
3	Gray Junglefowl	*Gallus sonneratii*	✓	✓	✓	✓
4	Painted Bush-Quail	*Perdicula erythrorhyncha*			✓	
5	Rock Pigeon	*Columba livia*	✓	✓	✓	✓
6	Nilgiri Wood-Pigeon	*Columba elphinstonii*			✓	✓
7	Spotted Dove	*Spilopelia chinensis*	✓	✓	✓	✓
8	Asian Emerald Dove	*Chalcophaps indica*	✓	✓		✓
9	Gray-fronted Green-Pigeon	*Treron affinis*			✓	
10	Greater Coucal	*Centropus sinensis*	✓	✓	✓	✓
11	Jacibin Cuckoo	*Clamator jacobinus*		✓		
12	Asian Koel	*Eudynamys scolopaceus*		✓		
13	Eurasian Moorhen	*Gallinula chloropus*		✓		
14	White-breasted Waterhen	*Amaurornis phoenicurus*	✓	✓	✓	✓
15	Red-wattled Lapwing	*Vanellus indicus*	✓	✓		
16	Pin-tailed Snipe	*Gallinago stenura*	✓	✓		
17	Common Sandpiper	*Actitis hypoleucos*		✓		✓
18	Green Sandpiper	*Tringa ochropus*		✓		
19	Wood Sandpiper	*Tringa glareola*		✓		
20	Little Cormorant	*Microcarbo niger*		✓		✓
21	Little Egret	*Egretta garzetta*	✓	✓	✓	✓
22	Indian Pond-Heron	*Ardeola grayii*	✓	✓	✓	✓
23	Eastern Cattle Egret	*Bubulcus coromandus*		✓		
24	Medium Egret	*Ardea intermedia*		✓		
25	Oriental Honey-buzzard	*Pernis ptilorhynchus*			✓	✓
26	Crested Serpent-Eagle	*Spilornis cheela*		✓		
27	Crested Goshawk	*Accipiter trivirgatus*			✓	
28	Shikra	*Accipiter badius*			✓	
29	Brahminy Kite	*Haliastur indus*		✓		
30	Common Buzzard	*Buteo buteo*		✓		

31	Rock Eagle-Owl	*Bubo bengalensis*			✓	
32	Eurasian Hoopoe	*Upupa epops*	✓	✓	✓	✓
33	Common Kingfisher	*Alcedo atthis*				✓
34	White-throated Kingfisher	*Halcyon smyrnensis*	✓		✓	✓
35	Asian Green Bee-eater	*Merops orientalis*				✓
36	Chestnut-headed Bee-eater	*Merops leschenaulti*				✓
37	Coppersmith Barbet	*Psilopogon haemacephalus*		✓	✓	✓
38	White-cheeked Barbet	*Psilopogon viridis*	✓	✓	✓	✓
39	Brown-capped Pygmy Woodpecker	*Yungipicus nanus*			✓	✓
40	Malabar Flameback	*Chrysocolaptes socialis*				✓
41	Streak-throated Woodpecker	*Picus xanthopygaeus*		✓		✓
42	Eurasian Kestrel	*Falco tinnunculus*		✓		
43	Rose-ringed Parakeet	*Psittacula krameri*	✓	✓	✓	✓
44	Vernal Hanging-Parrot	*Loriculus vernalis*	✓	✓	✓	✓
45	Orange Minivet	*Pericrocotus flammeus*		✓	✓	✓
46	Indian Golden Oriole	*Oriolus kundoo*		✓		
47	Bar-winged Flycatcher-shrike	*Hemipus picatus*			✓	✓
48	Spot-breasted Fantail	*Rhipidura albogularis*	✓	✓	✓	✓
49	White-browed Fantail	*Rhipidura aureola*	✓	✓	✓	
50	Ashy Drongo	*Dicrurus leucophaeus*	✓	✓	✓	✓
51	Brown Shrike	*Lanius cristatus*				✓
52	Long-tailed Shrike	*Lanius schach*	✓	✓	✓	✓
53	House Crow	*Corvus splendens*	✓	✓	✓	✓
54	Large-billed Crow	*Corvus macrorhynchos*	✓	✓	✓	✓
55	Cinereous Tit	*Parus cinereus*	✓	✓	✓	✓
56	Indian Yellow Tit	*Machlolophus aplonotus*			✓	
57	Ashy Prinia	*Prinia socialis*	✓	✓	✓	✓
58	Blyth's Reed Warbler	*Acrocephalus dumetorum*	✓	✓	✓	✓
59	Dusky Crag-Martin	*Ptyonoprogne concolor*			✓	
60	Hill Swallow	*Hirundo domicola*	✓	✓	✓	✓
61	Barn Swallow	*Hirundo rustica*		✓		
62	Red-rumped Swallow	*Cecropis daurica*				✓
63	Yellow-browed Bulbul	*Acritillas indica*			✓	✓
64	Square-tailed Bulbul	*Hypsipetes ganeesa*		✓	✓	✓
65	Red-whiskered Bulbul	*Pycnonotus jocosus*	✓	✓	✓	✓
66	Red-vented Bulbul	*Pycnonotus cafer*	✓	✓	✓	✓
67	Tytler's Leaf Warbler	*Phylloscopus tytleri*			✓	✓
68	Tickell's Leaf Warbler	*Phylloscopus affinis*		✓	✓	✓
69	Green Warbler	*Phylloscopus nitidus*	✓	✓	✓	✓
70	Greenish Warbler	*Phylloscopus trochiloides*	✓	✓	✓	✓

71	Large-billed Leaf Warbler	*Phylloscopus magnirostris*			✓	✓
72	Western Crowned Warbler	*Phylloscopus occipitalis*				✓
73	Indian White-eye	*Zosterops palpebrosus*	✓	✓	✓	✓
74	Indian Scimitar-Babbler	*Pomatorhinus horsfieldii*	✓		✓	✓
75	Puff-throated Babbler	*Pellorneum ruficeps*	✓			
76	Brown-cheeked Fulvetta	*Alcippe poioicephala*			✓	✓
77	Nilgiri Laughingthrush	*Montecincla cachinnans*		✓	✓	✓
78	Jungle Babbler	*Argya striata*	✓	✓	✓	✓
79	Velvet-fronted Nuthatch	*Sitta frontalis*			✓	✓
80	Jungle Myna	*Acridotheres fuscus*	✓	✓	✓	✓
81	Nilgiri thrush	*Zoothera dauma neilgherriensis*				✓
82	Indian Blackbird	*Turdus simillimus*	✓	✓	✓	✓
83	Oriental Magpie-Robin	*Copsychus saularis*	✓	✓	✓	✓
84	Nilgiri Sholakili	*Sholicola major*		✓	✓	✓
85	Nilgiri Flycatcher	*Eumyias albicaudatus*	✓	✓	✓	✓
86	Gray-headed Canary-Flycatcher	*Culicicapa ceylonensis*		✓	✓	✓
87	Tickell's Blue Flycatcher	*Cyornis tickelliae*		✓	✓	✓
88	Indian Blue Robin	*Larvivora brunnea*	✓		✓	✓
89	Malabar Whistling-Thrush	*Myophonus horsfieldii*			✓	✓
90	Black-and-orange Flycatcher	*Ficedula nigrorufa*	✓	✓	✓	✓
91	Kashmir Flycatcher	*Ficedula subrubra*			✓	✓
92	Blue Rock-Thrush	*Monticola solitarius*			✓	
93	Blue-capped Rock Thrush	*Monticola conclorhyncus*				✓
94	Pied Bushchat	*Saxicola caprata*	✓	✓	✓	✓
95	Nilgiri Flowerpecker	*Dicaeum concolor*	✓	✓	✓	✓
96	Purple Sunbird	*Cinnyris asiaticus*		✓	✓	✓
97	Scaly-breasted Munia	*Lonchura punctulata*				✓
98	Black-throated Munia	*Lonchura kelaarti*				✓
99	House Sparrow	*Passer domesticus*	✓	✓	✓	✓
100	Gray Wagtail	*Motacilla cinerea*	✓	✓	✓	✓
101	White-browed Wagtail	*Motacilla maderaspatensis*	✓	✓	✓	
102	Nilgiri Pipit	*Anthus nilghiriensis*			✓	✓
103	Common Rosefinch	*Carpodacus erythrinus*	✓	✓	✓	✓