The dynamic avifaunal assemblage of a fragmented urbanised habitat at Universiti Brunei Darussalam

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Abstract

Urbanisation reshapes ecosystems and fundamentally influences species assemblages. Urban habitats are also highly dynamic with changes taking place on both spatial and temporal scales. The campus of Universiti Brunei Darussalam is an example of an urban habitat consisting of a mosaic of green spaces, fragments of kerangas forest, planted native and ornamental plants as well as building infrastructure, roads and pathways. The aim of this study is to provide an insight into the bird assemblages found within the university campus. Two survey periods were conducted in 2006/2007 and in 2019/2020 using the line transect method. A total of 49 bird species belonging to 23 families and 10 orders were recorded in this study. No evidence of differences in species richness was observed between the two surveys after exclusion of migrants. Insectivores were the most species-rich followed by omnivores, granivores, carnivores and frugivores. As predicted, there was a higher number of non-forest dependent bird species than forest-dependent species. Vegetation cover was lower in 2007 than in 2019, but species composition was similar between the surveys, and the co-occurrence of bird species was random. Even though the bird diversity was considered depauperated, it was comprised of a wide range of species classified as residents, migrants and waterbirds, indicating their ability to tolerate urbanisation. More studies are required to confirm that bird species are surviving and reproducing in this urban habitat.

Index Terms: Aves, bird diversity, ornithology, Kerangas, urban ecology, university campus

1. Introduction

Urban habitats consist of land cover, either open or forested areas converted into concrete jungles of high-rise buildings, housing settlements, pavements, and roads,[1-3] with pockets of fragmented greenery consisting of patches of intact forest remnants, native and ornamental exotic plants or a mixture of both,[4] and mowed grassy surfaces. Some examples include gardens and yards, parks, cemeteries, campus areas, golf courses, bridges, airports and landfills.[5] Habitats associated with man-made infrastructures are different from natural environments,[6] and changes to the biotic and abiotic components in the urban ecosystem are leading animals and plants to rapidly evolve to adapt to the opportunities and urgent demands of urban niches.[7] While some species will disappear from urban landscapes, others will thrive. Thus, urban habitats play an important role in restructuring bird assemblages.[8] For example, settlements are associated with increasing non-native bird species and birds using buildings as nest sites, but are to the detriment of bird species that require interior forest conditions for nesting.[9] In circumstances where there is difficulty in

securing land for conservation purposes, cities are looked upon as the last chance to save some species.[10] Besides cities, university campuses with green spaces could potentially be refugia for both plant and animal species.[10,11] For example, 14% of the total bird species found in the University of Philippines Diliman campus are Philippine endemics.[12] This calls for research into understanding how the different taxa are responding to this modified environment, and is deserving of our attention for biodiversity conservation.[11]

In this study, our main aim is to provide the first avifaunal list and a preliminary insight into the dynamic avian community within the campus of Universiti Brunei Darussalam (UBD), situated within a coastal heath forest. Heath forests, locally called kerangas, are highly threatened by urban development. These forests, although only representing 3.3% of the forest cover on Borneo,[13] are fundamental to the region's biodiversity.[14] We chose to survey birds in this fragmented and urbanised kerangas forest because they are relatively easy to observe, with many species sensitive to forest fragmentation and urbanisation.[15] Our study took place in two separate periods in 2006/2007[16] and 2019/2020.[17] First, we compare the bird richness between the two survey periods to test for the effects of temporal segregation on bird species richness and assemblages. In an urban landscape, increasing settlements are associated with increasing non-native bird species and non-forest dependent native species.[9] We predict that non-forest dependent bird species, i.e. bird species that prefer open habitats, are much more numerous than forest-dependent bird species. The modified habitat also affects other functional assemblage, such as the dietary guild. For example, a shift to increased granivores, omnivores and ground foraging bird abundances has been observed in urban habitats compared to rural habitats.[1,18,19] In this study, we describe the distribution of overall species richness and bird assemblages found within the university campus. Some studies have shown that the quality of vegetation cover has an impact on bird species richness, with a strong positive correlation between complexity of native vegetation and bird diversity and richness.[20,21] Hence, forest-dependent bird species are more affected by simplification of habitats compared to non-forest dependent species.[21] In this preliminary study, we examine both bird species diversity and vegetation cover between the two surveying periods. We expect vegetation cover to decrease due to increased urban development over time, with cascading effects on bird species.

2. Methods

2.1 Study Site

Universiti Brunei Darussalam (see ***Figure 1***) is located in the Brunei-Muara district (4º58'22.15"N, 114º53'38.27"E) of Brunei Darussalam. The area gazetted to the university (approximately 2.46 km^2) was once a tropical heath (kerangas) forest, cleared for establishing several educational, recreational, residential and administration buildings. Asphalt-surfaced roads, cemented walkways, parking lots and open surfaces devoid of vegetation are structures found within the university campus, resulting in fragmented pockets of kerangas forests set in an urban matrix and prone to catch fire.[22,23] Additional green spaces found within the campus are the botanical garden built within a kerangas fragment and a bamboo garden.

2.2 Bird Survey

We used the line transect method[24] to survey bird species richness found within the university's campus with a pair of 10 x 42 Leica binoculars. Predetermined transects (i.e., walking routes) were set up for a single observer to walk slowly and record (1) bird species seen, (2) bird behaviour (e.g., singing, perching, feeding, flying) and (3) bird foraging activities (e.g., food substrates such as insects, lizards, flowers, seeds and feeding substrates such as ground, bark, trunk, branch).[25] Birds flying above the canopy were excluded from the survey.

Two separate surveys took place in the space of 14 years, conducted by two different observers. The first survey was from September 2006 to March 2007, undertaken by Razali,[16] with a total of eleven visits on randomly set-up transects ranging between 1 km to 2 km. The second

survey took place from September 2019 to February 2020 and was conducted by Ang.[17] Three transects (ranging between 500 m to 800 m) were set up and each transect was visited 10 times across the surveying period, totalling 30 visits. All surveys started at sunrise and took 3 hours to complete. Surveys were abandoned during heavy rain and strong winds.

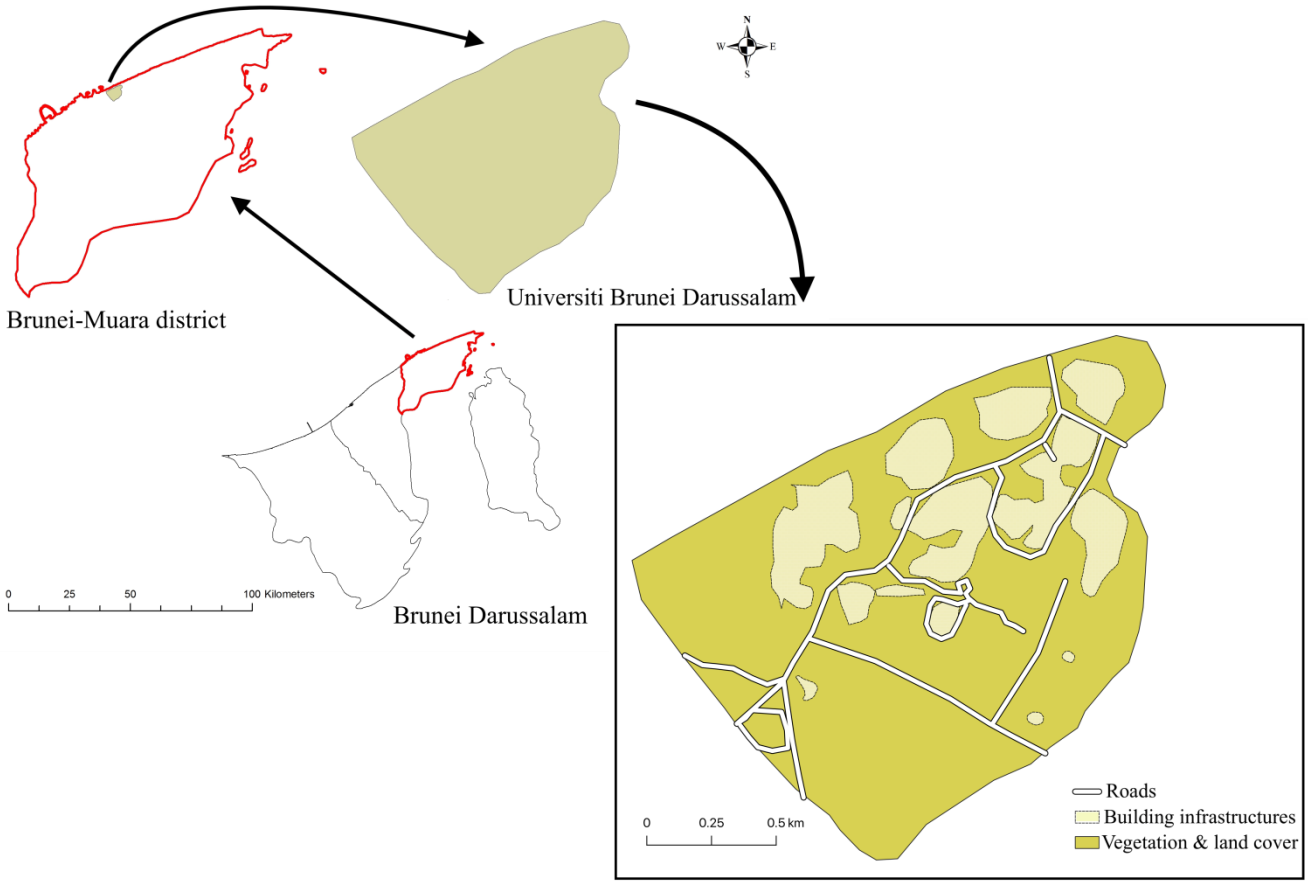

Figure 1. A map of Universiti Brunei Darussalam.

Birds were identified to the species level following the nomenclature classification based on Birds of the World.[26] Resident bird species are individuals that are found and breed locally, while migrants are non-breeding and transient individuals that forage to continue their migrating journey. Bird species were categorized into ecological guilds based on diet[27-29] and the use of forest habitats.[30] The diet guilds were classified into 5 groups, namely insectivores (diet consisting of mainly insects), frugivores (diet consisting of mainly fruits and figs), granivores (diet consisting of mainly seeds), omnivores (diet consisting of nectar, seeds, fruits and insects) and carnivores (diet consisting of fish, small-mammals, birds, and frogs). Likewise, habitat-use was classified into two categories: (1) forest-dependent species (i.e., primarily found in forest habitat consisting of tall trees and shrub-like undergrowth) and (2) non-forest dependent (i.e., primarily found in non-forested habitats such as open areas, grassy vegetation, gardens and settlement buildings).

2.3 Vegetation Cover

The normalised difference vegetation index (NDVI) was used to evaluate the changes in vegetation cover over time in the study area. The ratio between the measured canopy reflectance in the red and near infrared bands was used to determine the NDVI.[31] We have selected cloud-free satellite images (LANDSAT 5 and 8) of four different years 2007, 2011, 2014 and 2019 from the USGS earth explorer. Using the ArcGIS

raster calculator, we calculated the NDVI and extrapolated it to the study area using the delineated study area boundary.

2.4 Data Analysis

All statistical analyses and graphs were performed and plotted in R 4.1.2,[32] unless stated otherwise. We tested for any differences in (1) species richness, (2) habitat use, and (3) dietary guild categories between the two surveying periods using Fisher's Exact Test. A student's *t*-test was conducted to compare species richness between the two habitat-use categories (forest-dependent and non-forest dependent). We determine the similarity in bird composition between the surveys using the *jaccard.test* function.[33]

3. Results

3.1 Temporal Sampling Effects

In the 2006/2007 survey, 44 bird species were observed while only 31 bird species were seen in 2019/2020 survey (see ***Figure 2a*** and ***Table 1*** in the Appendix). There were significant differences in total bird species richness between the surveys conducted in 2006/2007 and 2019/2020 (Fisher's Exact Test $P = 0.004$), but when migrants were excluded from the analysis the significance disappeared (Fisher's Exact Test $P = 0.252$).

There were no significant differences in species richness of the bird species that were categorised as forest-dependent between the two surveying periods (Fisher's Exact Test $P = 1.00$). On the other hand, the species richness of bird species categorised as non-forest dependent showed significant differences between the surveying periods (Fisher's Exact Test $P = 0.001$). However, the significance decreased when migrants were removed (Fisher's Exact Test $P = 0.061$).

Birds were classified into ecologically functional groups based on diet preferences, and no significant differences were found in frugivore (Fisher's Exact Test $P = 1.00$), granivore (Fisher's Exact Test $P = 1.00$), omnivore (Fisher's Exact Test $P = 0.590$) and carnivore (Fisher's Exact Test $P = 0.182$) richness between the two survey periods. Insectivore species richness was different between the two surveys (Fisher's Exact Test $P = 0.049$), with more insectivores detected in the 2006/2007 survey (21 species). However, the significance of the difference disappeared when migrants were omitted from the analysis (Fisher's Exact Test $P = 1.00$).

3.2 Taxonomic-Level Species Richness and Bird Assemblages

The total number of bird species found in this study was 49 (see ***Figure 2a*** and ***Table 1***), and comprised 10 orders and 23 families (see ***Figure 3***). The most diverse order was Passeriformes containing 13 families (see ***Figure 3a***), and 32 bird species (see ***Figure 3b***). The families Nectariniidae, Dicaeidae, Pycnonotidae, Zosteropidae, Passeridae and Sturnidae were composed of omnivores sunbirds, spiderhunters and flowerpeckers, bulbuls, white-eyes, tree sparrow and starlings (see ***Figure 3c***). Meanwhile, the Estrildidae were represented by the seed-eating (granivore) munias (see ***Figure 3c***). We also documented the occurrence of the primarily insectivorous Cisticolidae, Corvidae, Hirundinidae, Motacillidae, Muscicapidae, and Timaliidae (see ***Figure 3c***).

Forest-dependent birds were significantly lower in numbers compared to non-forest dependent birds ($t = -3.49$, $d.f. = 2$, $P = 0.037$, see ***Figure 2b***). Resident birds, which forage and breed locally, were found across the five dietary guilds. Insectivores had the highest number of species, followed by omnivores, granivores, carnivores and finally frugivores (see ***Figure 2c***). A small number of migrants were observed (9 species), comprised of only 2 dietary guilds – insectivores and carnivores (see ***Figure 2c***). Among the migrants, only one species was classified as a forest-dependent insectivore, i.e. the Forest Wagtail (*Dendronanthus indicus*) (see ***Table 1***).

Eight species of birds were classified as waterbirds that inhabit and require waterbodies or wetlands for foraging and nesting. Of the eight waterbirds, the Bar-tailed Godwit (*Limosa lapponica*), also a migrant, was classified as

Near-Threatened according to the IUCN Red List. The White-breasted Waterhen (*Amaurornis phoenicurus*) and Purple Heron (*Ardea purpurea*) were the only resident waterbirds (see ***Table 1***).

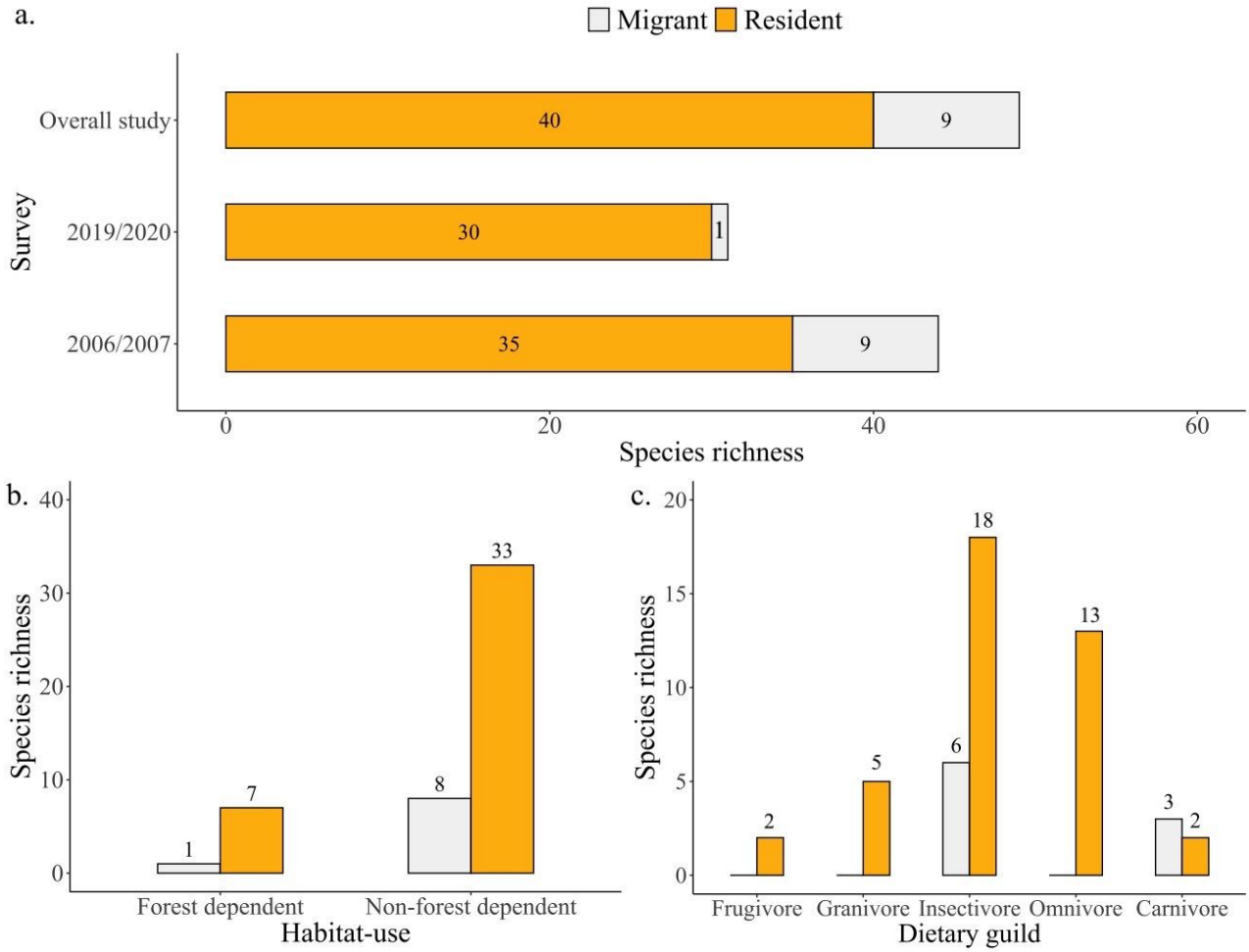

Figure 2. Species richness distribution of resident and migrant birds:
a. per survey and overall study; b. habitat-use; c. dietary guild categories.

3.3 Bird Composition and Assemblages of the Two Surveys

A total of 8 species were classified as forest-dependent within the foraging guilds, including frugivores, insectivores and omnivores (see ***Figure 4a***). No granivore and carnivore species were classified as forest-dependent. A migrant insectivore, the Forest Wagtail (*Dendronanthus indicus*) was only observed in the earlier survey (2006/2007). Two forest-dependent insectivore bird species, the Little Pied Flycatcher (*Ficedula westermanni*) and the Oriental Honey Buzzard (*Pernis ptilorhynchus*), were observed in the recent survey (2019/2020), but were not observed in the earlier survey (2006/2007) (see ***Table 1***). The remaining 5 forest-dependent species: 2 frugivores, the Little Green Pigeon (*Treron olax*) and Pink-necked Green Pigeon (*Treron vernans*); and 3 omnivores, the Red-eyed Bulbul (*Pycnonotus brunneus*), Orange-bellied Flowerpecker (*Dicaeum trigonostigma*) and Little Spiderhunter (*Arachnothera longirostra*); were observed in both survey periods.

Within the non-forest dependent category of resident birds (41 species), insectivores (21 species) had the highest number of species followed by omnivores (10 species), granivores and carnivores (5 species). Two species of granivores, the Chestnut Munia (*Lonchura*

atricapilla) and the Zebra Dove (*Geopelia striata*); six species of omnivores (a waterbird – the White-breasted Waterhen (*Amaurornis phoenicurus*), the Asian Glossy Starling (*Aplonis panayensis*), Yellow-vented Bulbul (*Pycnonotus goiavier*), Olive-backed Sunbird (*Cinnyris jugularis*), Brown-throated Sunbird (*Anthreptes malacensis*) and the naturalized Eurasian Tree Sparrow (*Passer montanus*)); eleven species of insectivores (the Sunda Pygmy Woodpecker (*Picoides moluccensis*), Blue-throated Bee-eater (*Merops viridis*), Raffles's Malkoha (*Rhinortha chlorophaea*), the White-breasted Woodswallow (*Artamus leucorynchus*), Pied Triller (*Lalage nigra*), Pied Fantail (*Rhipidura javanica*), Common Iora (*Aegithina tiphia*), Oriental Magpie Robin (subsp. *musicus*) (*Copsychus saularis musicus*), Pacific Swallow (*Hirundo tahitica*), Yellow-bellied Prinia (*Prinia flaviventris*) and Ashy Tailorbird (*Orthotomus ruficeps*)); and two carnivores, the Collared Kingfisher (*Todiramphus chloris*) and the migrant Intermediate Egret (*Ardea intermedia*); were found in both surveys (21 species, see ***Table 1***). There were no frugivore species categorised as non-forest dependent (see ***Figure 4b***).

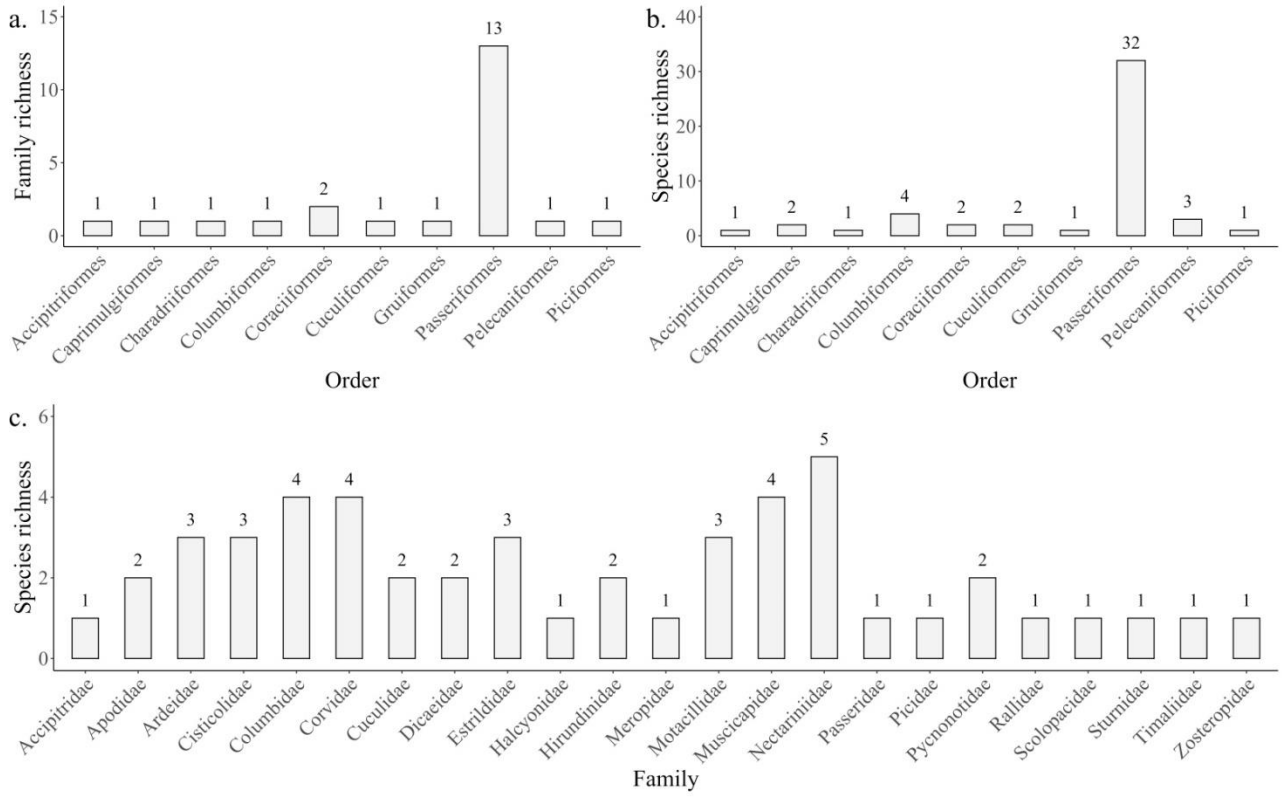

Figure 3. Distribution of species within each taxonomic class:
a. number of Family grouped within Order; b. number of bird species grouped within Order;
c. number of bird species grouped within Family.

Seventeen non-forest dependent bird species were not observed during the recent survey (2019/2020). These were the endemic granivorous Bornean Dusky Munia (*Lonchura fuscans*) and Spotted Dove (*Spilopelia* chinensis); the insectivore disturbance specialist Bold-striped Tit-babbler (*Mixornis bornensis*); the insectivorous Rufous-tailed Tailorbird (*Orthotomus sericeus*), the Plaintive Cuckoo (*Cacomantis merulinus*) and Asian Palm Swift (*Cypsiurus balasiensis*); and the migratory insectivores White-throated Needletail (*Hirundapus caudacutus*), Asian Brown Flycatcher (*Muscicapa dauurica*), Barn Swallow (*Hirundo rustica*), Eastern Yellow Wagtail (*Motacilla tschutschensis*) and Richard's Pipit

(*Anthus richardi*); the omnivorous Yellow-breasted Flowerpecker (*Prionochilus maculatus*), Crimson Sunbird (*Aethopyga siparaja*) and Hume's White-eye (*Zosterops auriventer*); a carnivorous waterbird, the Purple Heron (*Ardea purpurea*); and migrants, the Near-Threatened Red-listed Bar-tailed Godwit (*Limosa lapponica*) and the Chinese Pond Heron (*Ardeola bacchus*) (see ***Table 1***).

Meanwhile, only 3 species were not observed in the earlier survey (2006/2007): namely an omnivore, Van Hasselt's Sunbird (*Leptocoma brasiliana*), a granivore, the Scaly-breasted Munia (*Lonchura punctulata*), and an insectivore, the Oriental Magpie Robin (subsp. *pluto*) (*Copsychus saularis pluto*) (see ***Table 1***).

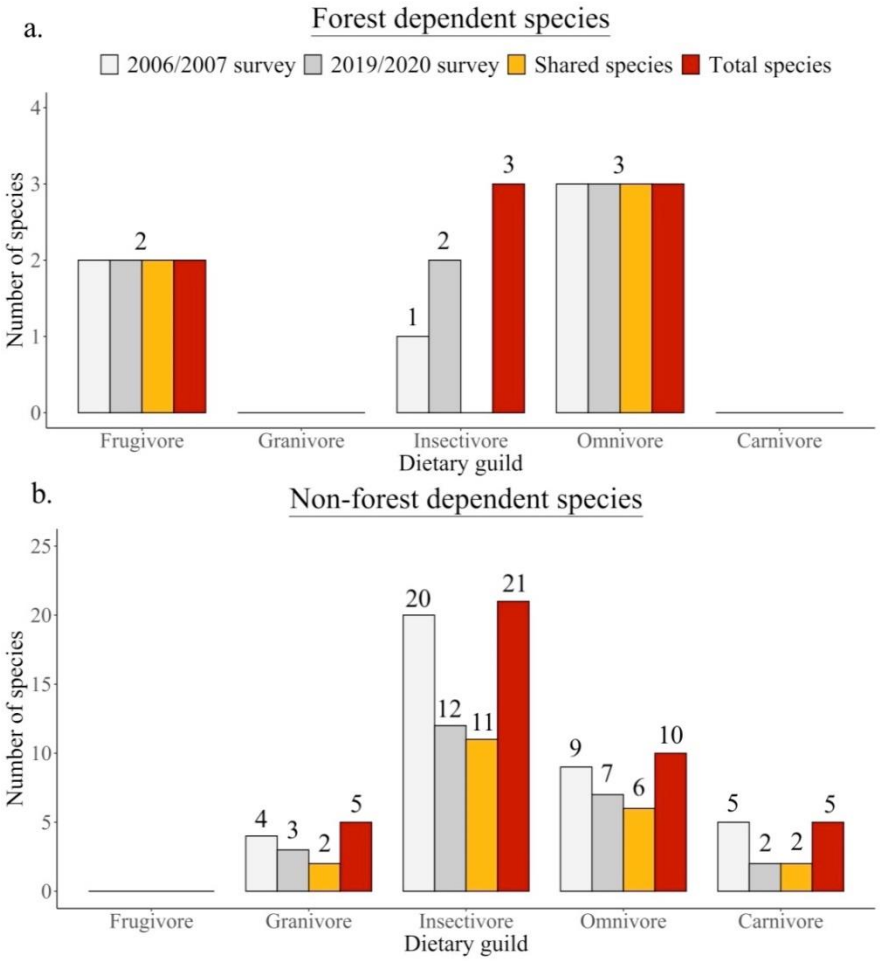

Figure 4. Barplots illustrating species richness at different dietary guild within:
a. forest-dependent category; b. non-forest dependent category.
Counts of bird species in 2006/2007 survey (shaded in light grey), counts of bird species in 2019/2020 survey (shaded in darker grey), counts of shared number of species between the two surveys (shaded in yellow), and total number of species (shaded in red)

3.4 Vegetation Cover and Bird Species Richness

The vegetation cover in 2007 was lower (NDVI = 0.243, see ***Figure 5***) than in 2011 (NDVI = 0.465, see ***Figure 5***). In both 2014 and 2019, the vegetation cover decreased again (0.364, 0.333, see ***Figure 5***). The Jaccard similarity coefficient (JC) showed similarity in species composition between the 2006/2007 and 2019/2020 surveys (JC = 0.531, P = 0.077) with twenty-six bird species (53%) shared between the two surveys (see ***Figure 4*** and ***Table 1***).

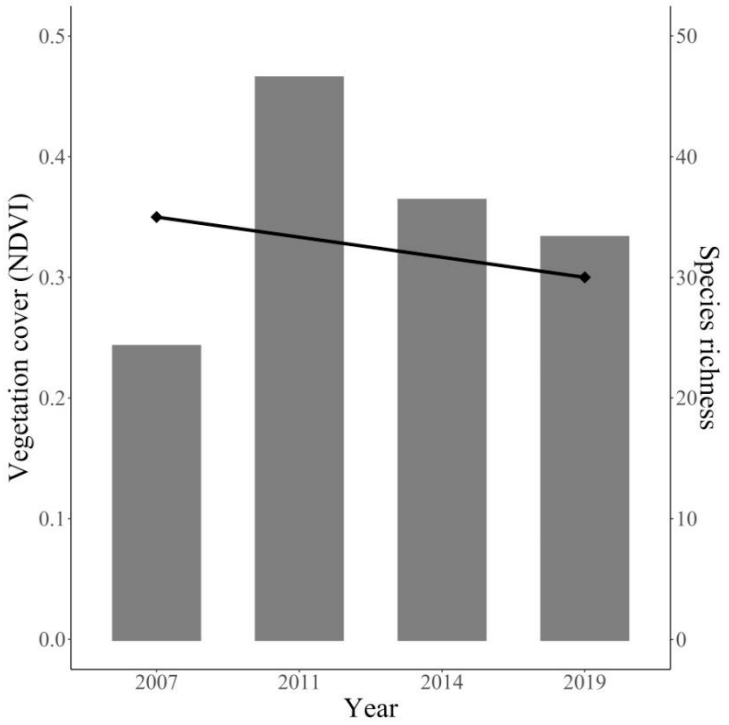

Figure 5. Distribution of vegetation cover (NDVI, bar plot shaded in grey) across the different years (2007, 2011, 2014 and 2019) and bird species richness (black line) taken from surveys in 2006/2007 and 2019/2020.

4. Discussion

A total of 49 bird species were observed on the campus of Universiti Brunei Darussalam after pooling both survey periods. No significant differences in bird richness and ecological assemblages were found between the two survey periods. A higher number of non-forest dependent species than forest-dependent species was found. Vegetation cover in 2007 was lower than in 2019 and there was no evidence of differentiation in bird composition between the two surveying periods.

4.1 Temporal sampling effects

A higher number of bird species was recorded in 2006/2007 (35 resident and 9 migrant species) compared to 2019/2020 (30 resident and 1 migrant species). It is difficult to determine if the presence or absence of particular bird species was due to observational bias, as the surveys were conducted by two different observers, and the transects visited were different in the two surveying periods. The higher number of migrants observed in the first survey (2006/2007) may be attributed to the predetermined transects being conducted in more open habitat than in the second survey (2019/2020). While the additional insectivores (3 species), omnivores (1 species) and granivores (1 species) recorded during the latter survey may have been attributed to transect routes being set up along forested/vegetation areas. Species that were encountered in the first survey and not encountered in the second survey, or vice-versa, may also be attributed to chance encounters. How transects are placed along the habitat mosaics, as well as the length of the transects is known to affect the species observed.[34] However that may be, the university campus is located within a kerangas forest, albeit a fragmented one, and is a species-rich humid biome which should support a higher number of species than do arid biomes.[35] Moreover, a study in the Yucatan Peninsula, Mexico has shown that mature and fragmented forests have a higher number of bird species than the surrounding mosaic-modified landscape, such as golf courses and agricultural fields.[36]

4.2 Campus-Wide Bird Composition and Assemblages

In this study, a total of 49 bird species were recorded from the UBD campus. The low number of birds, i.e. between 20 and 55 species, is similarly to what has been seen in other campuses within the Southeast Asian region.[37-41] Only four non-forest dependent bird species (i.e., species that prefer open-habitats as opposed to forest dependent which prefer forested habitats) were shared between our study and these campuses. These urban exploiters were: granivores – the Zebra Dove (*Geopelia striata*); and omnivores – the non-native Eurasian Tree Sparrow (*Passer montanus*), the Olive-backed Sunbird (*Cinnyris jugularis*) and Yellow-vented Bulbul (*Pcynonotus goiavier*). The endemic granivore (also a non-forest dependent species), the Dusky Munia (*Lonchura fuscans*), was observed in both our study and at Universitas Lambung Mangkurat in Kalimantan, Borneo. The introduced house sparrow, imported from its native home in Europe, was found predominantly in urban habitats such as housing estates, city areas, parks and gardens. The aforementioned species can exploit a wide variety of resources and are adapted to the disturbances and hazards of the urban environment. For example, house sparrows are able to nest in crevices or on ledges of buildings.[18]

The number of non-forest dependent bird species (41 species of the total 49 species) was significantly higher compared to forest-dependent bird species (8 species). The non-forest dependent bird species are more conspicuous compared to the forest-dependent species, hence they are more readily observed.[34] Furthermore, our study showed that insectivores were the most diverse (16 species), suggesting that these species are able to exploit urban habitats and that arthropods are often diverse and abundant in an urban environment.[42] Only two frugivores were sighted during both surveys: the Little Green Pigeon (*Treron olax*) and the Pink-necked Green Pigeon (*Treron vernans*). The low number of frugivores is a characteristic of an urban habitat, with the presence of these frugivores possibly attributed to resources obtained from ornamental plants and planted exotic tree species.[28]

The next most diverse diet guilds were omnivores (10 species) and granivores (5 species). Unfortunately, we were not able to define the abundance based on presence and absence data, and thus we are unable to determine whether there was an increase in the granivore and omnivore populations between the surveys. Bird species that feed mainly on grains and seeds (granivores) and those having broad diet niches, such as the omnivores (diet comprising a mixture of fruits, seeds, insects and nectar), are likely to be abundant in an urban habitat with intermediate levels of disturbances.[43] Positive associations were found between increasing urbanisation intensity and granivores and cavity nesting species, i.e. larger clutch sizes and more fledglings per clutch,[44] indicating a shift in traits in response to urban disturbances. In addition, this response has been hypothesised to be due to the abundance of seed production by ornamental plants.[1] Furthermore, the university campus contains abundant lawn grasses and weeds alongside path walks, unattended parking lots and open spaces, supplying large quantities of small seeds which act as supplemental food resources[18] for granivore and omnivore ground forgers. Changes in the food composition come about because there are more seeds in urban landscapes, as well as anthropogenic food due to littering, improper waste handling or deliberate feeding.[21] These opportunities are exploited by generalist granivores and omnivores, hence affecting both the density and composition of bird assemblages and also increasing bird diversity.[43]

Among the granivores and omnivores, the Spotted Dove (*Spilopelia chinensis*), Zebra Dove (*Geopelia striata*) and Eurasian Tree Sparrow (*Passer montanus*) are urban-tolerant alien species that are found mainly in human-altered habitats, suggesting that seeds are plentiful in human-modified areas, as these largely constitute their diet.[45] These alien species are well adapted to human-altered landscapes and are usually dominant in rural to urban transition areas,

highlighting the structural changes such as simpler food webs and reduced ecosystem complexity.[9,46] Physical alteration of the natural environment provides novel food and nesting resources, as well as reduced predation risk. These factors make the urban environment habitable for these disturbance-tolerant, non-native bird species.[47] Retention of native vegetation was found to be associated with the persistence of native faunal species, hence demonstrating the importance of retaining native vegetation in an urban landscape.[48]

One open habitat disturbance specialist, the Bold-striped Tit-Babbler (*Mixornis bornensis*) was encountered during the 2006/2007 transect survey, perching on a 2 m tree and gleaning insects. It was not encountered in the second survey (2019/2020), and this may be attributed to the sparse distribution of this species.[34] The presence of a Kalimantan subspecies of the Oriental Magpie Robin (*Copsychus saularis pluto*) was noted in the second survey. This could have been an escapee from one of the bird singing competitions that have been popular since 2017, or even earlier, when competitors from other regions of Borneo meet in Brunei.[49]

Besides resident bird species, a total of nine migrants were recorded in this study and one species was categorized as near-threatened (the Bar-tailed Godwit, *Limosa lapponica*). Sampling in this study was conducted between the months of September to March, which corresponds to the peak activity period for migratory water birds.[50] This may indicate that the university campus, with its forest patches[51] and proximity to the coast, provides a wintering and/or stopover habitat.[52] Eight of the migrant species were classified as non-forest dependent. A similar trend of increasing numbers of migrants that primarily use open habitats was found in a study in Costa Rica.[53] Migratory bird species have been shown to have specific habitat requirements for their breeding and winter grounds, while stopover/en-route sites will consist of habitat types different from the sites used during the breeding or wintering season.[51,54] Migratory individuals usually stop to rest and refuel before returning to their migratory routes.[55] The selection of stopover sites is non-random and influenced by (1) food abundance, (2) competition between species, (3) predator pressure, and (4) reproductive opportunities.[54] There is still a lack of understanding of the importance and selection of stopover/enroute sites by migratory birds,[56] especially in Borneo and the wider region.

Waterbirds are defined as birds living on or near water, and are ecologically dependent on wetlands.[57] A total of 2 resident and 6 migratory waterbird species were present within the campus grounds. Waterbirds play a key role in providing ecosystem services, such as dispersing both plant and animal propagules to other wetland areas, as bioindicators of the heath of aquatic ecosystems, and in pest control, and play a part in nutrient and biogeochemical cycling.[58] Furthermore, the presence of water bodies has been found to increase the richness of bird species associated with woodland habitats, due to the better foraging opportunities near water resources.[59]

4.3 Vegetation Cover and Bird Species Richness

Vegetation cover based on the NDVI was lowest in 2007, due to repeated fires that occurred in 2005.[60] An increased in vegetation cover in 2011 may be attributed to fast growing plant species such as grasses and creepers,[61] and exotic *Acacia* tree species.[62,63] A decrease in the NDVI in later years may have been attributed to infrastructure expansion within the university campus.[64] The bird species compositions show moderate similarity coefficients (JC = 0.531, P = 0.077) between the two survey periods, suggesting that co-occurrences of species are random, with the 53% (26 bird species) of shared species not affected by the different time periods of the two surveys. The types of bird species seen in this study could have been influenced by the presence of old trees from nearby forest fragments or mature planted trees, as these provide resources such as food, shelter and nesting sites.[65] Increased vegetation cover is associated with increased bird species diversity.[18,19] Furthermore, a study in Queensland, Australia found a positive associated between bird species richness and the

total number of retained mature trees within vegetated streets.[55] That can also be said for the high number of bird species (between 75 and 95 species) that were seen in other Southeast Asian university campuses.[66-69] Here, green spaces within the campuses consist of old mature native trees species[66,67,69] and the presence of a mixture of different habitats, such as mangroves and peat swamp forests.[68]

5. Conclusions and Future Directions

From this study, insectivorous birds have the highest richness among the foraging guilds, and the presence of granivores indicates the progression of the university campus landscape to a more urbanised environment. An additional sign of urbanisation is the occurrence of alien/non-native species occupying the new disturbed open-habitat niche. Meanwhile, the presence of migratory bird species has raised questions about the suitability of the habitat and whether stopover sites like the campus grounds are functionally important to these migrants. To start with, year-round bird census within the campus will provide fundamental population-based information that could help to evaluate the occurrence of migrants. Even though bird diversity was much lower in the university campus compared to intact undisturbed kerangas forests,[16,70] the presence of the large insectivore Oriental-Honey Buzzard, forest-dependent frugivore pigeons and migrant bird species suggests that resources such as food, shelter and nesting are available, and that we need to understand factors that could ameliorate further species loss in an urban habitat. For example, investigating the effects of green urban spaces, planted flora species and food availability on the distribution of insectivores and frugivores should be evaluated in future studies. The coastal heath forests of Borneo deserve to be protected, and the challenge for the future will be to balance the need for forest conservation and further urban development.

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Appendix

Table 1. List of birds observed in Universiti Brunei Darussalam campus. Nomenclature based on Birds of the World.[26]

Dietary guilds abbreviations taken from Wong,[27] Lim and Sodhi[28] and Yong et al.[29]:
Ins (insectivore) – diet mainly arthropod-based;
Fru (frugivore) – diet mainly on fruits and figs;
Gra (granivore) – diet mainly seeds and grains;
Omn (omnivore) – significant proportions of fruits, nectar and arthropod;
Carni (carnivore) – mostly fish, crustacean, reptile and amphibian.
Habitat-use categories taken from Posa[30]:
Forest-dependent species are found primarily in forest habitat (Forest);
Non-forest dependent species are found in non-forested habitat (Non-forest).
Each bird species' threat-level classification is based on IUCN Red-List categories
(*NT* – Near Threatened and *LC* – Least Concern).
Migrant, waterbird and endemic species are indicated with a superscript symbol at the end of the common name:
⊙ = migrant species; ◇ = waterbird species; ✱ = Bornean endemic;

Index	Order	Family	Common name	Scientific name	IUCN Red-List Category	Habitat-use Category	Dietary guild	2006/2007 Survey	2019/2020 Survey
1	Piciformes	Picidae	Sunda Pygmy Woodpecker	*Picoides moluccensis*	*LC*	Non-forest	*Ins*	X	X
2	Coraciiformes	Halcyonidae	Collared Kingfisher	*Todiramphus chloris*	*LC*	Non-forest	*Carni*	X	X
3	Coraciiformes	Meropidae	Blue-throated Bee-eater	*Merops viridis*	*LC*	Non-forest	*Ins*	X	X
4	Cuculiformes	Cuculidae	Plaintive Cuckoo	*Cacomantis merulinus*	*LC*	Non-forest	*Ins*	X	
5	Cuculiformes	Cuculidae	Raffles's Malkoha	*Rhinortha chlorophaea*	*LC*	Non-forest	*Ins*	X	X
6	Caprimulgiformes	Apodidae	White-throated Needletail⊙	*Hirundapus caudacutus*	*LC*	Non-forest	*Ins*	X	
7	Caprimulgiformes	Apodidae	Asian Palm Swift	*Cypsiurus balasiensis*	*LC*	Non-forest	*Ins*	X	
8	Columbiformes	Columbidae	Spotted Dove	*Spilopelia chinensis*	*LC*	Non-forest	*Gra*	X	
9	Columbiformes	Columbidae	Zebra Dove	*Geopelia striata*	*LC*	Non-forest	*Gra*	X	X
10	Columbiformes	Columbidae	Little Green Pigeon	*Treron olax*	*LC*	Forest	*Fru*	X	X
11	Columbiformes	Columbidae	Pink-necked Green Pigeon	*Treron vernans*	*LC*	Forest	*Fru*	X	X
12	Gruiformes	Rallidae	White-breasted Waterhen◇	*Amaurornis phoenicurus*	*LC*	Non-forest	*Omn*	X	X
13	Charadriiformes	Scolopacidae	Bar-tailed Godwit⊙◇	*Limosa lapponica*	*NT*	Non-forest	*Carni*	X	
14	Accipitriformes	Accipitridae	Oriental Honey Buzzard	*Pernis ptilorhynchus*	*LC*	Forest	*Ins*		X
15	Pelecaniformes	Ardeidae	Intermediate Egret⊙◇	*Ardea intermedia*	*LC*	Non-forest	*Carni*	X	X
16	Pelecaniformes	Ardeidae	Purple Heron◇	*Ardea purpurea*	*LC*	Non-forest	*Carni*	X	
17	Pelecaniformes	Ardeidae	Chinese Pond Heron⊙◇	*Ardeola bacchus*	*LC*	Non-forest	*Carni*	X	
18	Passeriformes	Corvidae	White-breasted Woodswallow	*Artamus leucorynchus*	*LC*	Non-forest	*Ins*	X	X

Index	Order	Family	Common name	Scientific name	IUCN Red-List Category	Habitat-use Category	Dietary guild	2006/2007 Survey	2019/2020 Survey
19	Passeriformes	Corvidae	Pied Triller	*Lalage nigra*	*LC*	Non-forest	*Ins*	X	X
20	Passeriformes	Corvidae	Pied Fantail	*Rhipidura javanica*	*LC*	Non-forest	*Ins*	X	X
21	Passeriformes	Corvidae	Common Iora	*Aegithina tiphia*	*LC*	Non-forest	*Ins*	X	X
22	Passeriformes	Muscicapidae	Asian brown flycatcher⊙	*Muscicapa dauurica*	*LC*	Non-forest	*Ins*	X	
23	Passeriformes	Muscicapidae	Little Pied Flycatcher	*Ficedula westermanni*	*LC*	Forest	*Ins*		X
24	Passeriformes	Muscicapidae	Oriental Magpie Robin (*musicus*)	*Copsychus saularis musicus*	*LC*	Non-forest	*Ins*	X	X
25	Passeriformes	Muscicapidae	Oriental Magpie Robin (*pluto*)	*Copsychus saularis pluto*	*LC*	Non-forest	*Ins*		X
26	Passeriformes	Sturnidae	Asian Glossy Starling	*Aplonis panayensis*	*LC*	Non-forest	*Omn*	X	X
27	Passeriformes	Hirundinidae	Barn Swallow⊙◇	*Hirundo rustica*	*LC*	Non-forest	*Ins*	X	
28	Passeriformes	Hirundinidae	Pacific Swallow	*Hirundo tahitica*	*LC*	Non-forest	Ins	X	X
29	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	*Pycnonotus goiavier*	*LC*	Non-forest	Omn	X	X
30	Passeriformes	Pycnonotidae	Red-eyed Bulbul	*Pycnonotus brunneus*	*LC*	Forest	Omn	X	X
31	Passeriformes	Cisticolidae	Yellow-bellied Prinia	*Prinia flaviventris*	*LC*	Non-forest	Ins	X	X
32	Passeriformes	Zosteropidae	Hume's White-eye	*Zosterops auriventer*	*LC*	Non-forest	Omn	X	
33	Passeriformes	Cisticolidae	Rufous-tailed Tailorbird	*Orthotomus sericeus*	*LC*	Non-forest	Ins	X	
34	Passeriformes	Cisticolidae	Ashy Tailorbird	*Orthotomus ruficeps*	*LC*	Non-forest	Ins	X	X
35	Passeriformes	Timaliidae	Bold-striped Tit-babbler	*Mixornis bornensis*	*LC*	Non-forest	Ins	X	
36	Passeriformes	Dicaeidae	Orange-bellied Flowerpecker	*Dicaeum trigonostigma*	*LC*	Forest	Omn	X	X
37	Passeriformes	Dicaeidae	Yellow-breasted flowerpecker	*Prionochilus maculatus*	*LC*	Non-forest	Omn	X	

Index	Order	Family	Common name	Scientific name	IUCN Red-List Category	Habitat-use Category	Dietary guild	2006/2007 Survey	2019/2020 Survey
38	Passeriformes	Nectariniidae	Crimson Sunbird	*Aethopyga siparaja*	*LC*	Non-forest	Omn	X	
39	Passeriformes	Nectariniidae	Van Hasselt's Sunbird	*Leptocoma brasiliana*	*LC*	Non-forest	Omn		X
40	Passeriformes	Nectariniidae	Olive-backed Sunbird	*Cinnyris jugularis*	*LC*	Non-forest	Omn	X	X
41	Passeriformes	Nectariniidae	Brown-throated Sunbird	*Anthreptes malacensis*	*LC*	Non-forest	Omn	X	X
42	Passeriformes	Nectariniidae	Little Spiderhunter	*Arachnothera longirostra*	*LC*	Forest	Omn	X	X
43	Passeriformes	Passeridae	Eurasian Tree Sparrow	*Passer montanus*	*LC*	Non-forest	Omn	X	X
44	Passeriformes	Motacillidae	Forest Wagtail⊙	*Dendronanthus indicus*	*LC*	Forest	Ins	X	
45	Passeriformes	Motacillidae	Eastern Yellow Wagtail⊙◇	*Motacilla tschutschensis*	*LC*	Non-forest	Ins	X	
46	Passeriformes	Motacillidae	Richard's Pipit⊙◇	*Anthus richardi*	*LC*	Non-forest	Ins	X	
47	Passeriformes	Estrildidae	Chestnut Munia	*Lonchura atricapilla*	*LC*	Non-forest	Gra	X	X
48	Passeriformes	Estrildidae	Dusky Munia✱	*Lonchura fuscans*	*LC*	Non-forest	Gra	X	
49	Passeriformes	Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	*LC*	Non-forest	Gra		X