DISTRIBUTION PATTERNS OF AVIAN SPECIES IN AND AROUND URBAN ENVIRONMENTS: A CASE STUDY OF SEOUL CITY, KOREA

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Abstract

Urban ecosystem discussions often focus on vegetation diversity rather than wildlife. Even less discussion is cantered on the ecology of avian species, and not much is known about avian habitat requirements in urbanized areas. This study investigated the bird–habitat relationship in an urbanized area in Seoul, Korea. More specifically, it sought to determine a general relationship between avian species and forests by comparing the degree of adaptation observed in each species to varying conditions in urban areas. Based on observations of 11,093 birds belonging to 89 species throughout the study site, the investigators identified three significant findings: First, the bird–habitat relationship with respect to forest and urban areas can be classified into four specific types: (1) forest specialist, (2) forest-to-near-urban generalist, (3) whole-forest-to-urban generalist, and (4) urban specialist. Second, of particular interest is the identification of forest-to-near-urban generalist species. They can extend their home ranges into highly urbanized areas, but many of these species were found not far from forests. In fact, most individuals were observed <500 m from the forest border. Third, forest-to-near-urban generalists were mostly observed in >30% of the GAP (green area percentage) patches in the urban area. Knowing the habitat needs of the four bird species types will eventually help target key species during urban ecological planning. For example, we now understand that if forest-to-near-urban generalists need to be attracted to an urban environment, forest patches need to be placed, at most, 500 m apart with a GAP of > 30%.

***Keywords:** Avian species, urban environment, habitat, Korea*

1 INTRODUCTION

Urbanisation is likely the single most important driver of species extinction (Czech and Krausman, 1997). Even if wildlife species are not threatened to the level of extinction, urban expansions have driven flora and fauna to migrate to the outside of the outer edges of developed areas and have exerted negative effects on them both inside and outside of developed areas. Although avian species are less affected by urbanisation than other species because of their mobility, many avian species in developed areas have either disappeared or adapted to the adverse changes in the environment. Some avian species, such as the blackbird (Turdus merula), have been reported to increase in numbers during urbanisation (Luniak and Mulsow, 1988), but most other species have experienced decline. Yet information is scarce about how to bring diverse avian species back into urbanised areas.

To date, models explaining the relationship between bird species and habitat (bird–habitat relationships) have been developed on the basis of two major classification methods. One classifies bird species in terms of their relationship to forest edges. In this system, species are defined as forest interior species, edge species, and forest interior–edge generalist species (Bender *et al.*, 1998; Lesak *et al.*, 2011; Barbaro *et al.*, 2012). The other system classifies them according to the successional stages of the forests they inhabit: early successional species, mature forest species, and generalist species (Drapeau *et al.*, 2000; Hagan *et al.*, 1997; Imbeau *et al.*, 1999; Matsuoka *et al.*, 2012). Although the edge-based classification system has been criticised because the formation of edges (e.g., agricultural edges) is a specific phenomenon caused by human disturbance (Hunter, 1990; Imbeau *et al.*, 2003), these two main classification systems are frequently cited in applied studies on bird–habitat relationships. Additionally, a minor classification method is also sometimes used: the nesting guild concept (Hino, 1985; Newell *et al.*, 2012). This concept groups together species that exploit similar environmental resources regardless of their taxonomic classification (Simberloff, 1991). The nesting guild concept is not a broad habitat concept; it simply defines nesting places in detail (i.e. hole, canopy, bush, ground, etc.). This concept may be best used to explain the relationship between the vertical structure of a forest and bird diversity (Recher, 1969).

However, all of these classification systems were developed and tested in non-urban environments and have not been applied or tested in or near urban areas. Past studies (Hong, 2007; Kim, 2005) have attempted to address this gap by modifying Bender *et al.*'s (1998) edge-based classification system by simply adding urbanised species to the model and trying to explain conditions near the forest edges. However, they did not explain the bird distribution deep in urban zones, far away from forests. To date, there is a lack of empirical studies analysing the varying spatial sensitivities of species in urban areas as recommended by Hostetler (2001).

Birds' unrestricted movement compared to terrestrial wildlife has both pros and cons for ecological researchers and designers because they can easily migrate in and out of areas of urban development. On the pro side, it can be easier to bring them back to urban environments with careful creation and facilitation of their habitats, ultimately resulting in higher avian species biodiversity in the urban environment. To successfully bring avian species to urban areas requires an understanding of their habitat requirements. Unfortunately, not enough is known about avian species habitat requirements in urban environments. In an effort to bring avian species back to urban environments, ecologists and landscape planners have attempted to use forest interior species or water species as the target species for enhancing collapsed ecological conditions simply because their movements can be better predicted (Choi, 2004; Forman and Godron, 1986). Those species, however, are not particularly suited to habitats in the urban environment and consequently are not appropriate target species. At present, there are not sufficient empirical data regarding (1) which species are adapted to live in an urban area, and (2) which species can extend their home ranges to highly urbanised areas by taking advantage of urban green spots, green roofs, greenways, and other spaces created by greening efforts.

Therefore, this study tries to identify species that are more adapted to live in urban areas and to use the small-to-medium green patches typically found in urban areas. It also attempts to understand the varying degrees of adaptation of avian species to green patches of various sizes created by urbanisation. It does so by surveying the green area percentage (GAP) of various land use types and their relationships to specific avian species. Lastly, this study identifies avian species that can extend their home range to a highly urbanised area with enhanced urban green areas.

The results of this research can help open space planning of urban forests facilitate the ability of some avian species to find habitats in urban environments. To this end, 26 survey team members observed the presence and distribution of various avian species to understand bird–habitat relationships in urban areas. A total of 5,836 birds belonging to 37 species were observed during the non-breeding season, while 5,257 birds belonging to 52 species were observed during the breeding season.

2 MATERIALS AND METHODS

2.1 Study area

For a case study, this study sought a highly urbanised area bordering a major forest without minor forests or heavily planted open spaces within the urbanised area. The intent was to clearly establish the spatial relationship between the distribution (appearance) of each avian species and the distance from the forest border toward the urban core without the influence of minor forests.

The study site selected was Gangdong-gu district, Seoul, South Korea. Gangdong-gu is one of 25 administrative districts of the City of Seoul and is located in the southeastern corner of Seoul (between 37º30′N 127º11′E and 37º34′N 127º26′E; see Figure 1). The total area of the district is 24.6 km2, of which greenbelt forest covers 6 km2. The district is one of the most densely populated places in the world, with almost 20,000 people/km2 in 2006 (City of Seoul, 2006). The eastern and northern boundary (outer border) of the district shares the city boundary and borders a forest protected by strong greenbelt regulations. The western and southern boundary (inner boundary) mainly borders urbanised areas. The annual average temperature is approximately 13ºC, and the annual average precipitation is approximately 1,200 mm. The rainfall events are concentrated during the summer months: over 60% of the annual precipitation occurs between July and September.

Figure 1: Study area

2.2 Site history

Until 1950, the majority of the study area was covered with forests dominated by Mongolian oak (Quercus mongolica). Between 1950 and 1953, however, the forests were almost completely destroyed in the Korean War. After the war, the area was reforested with fast-growing exotic species. According to the vegetation mapping survey conducted in 2007 (Gangdong-gu, 2008), more than 40% of the forests are currently dominated by black locust (Robinia pseudoacacia) introduced from North America. Land use in the area has changed dramatically since the 1970s, as Seoul experienced rapid industrialisation. The urbanised area has increased from 16% in 1972 to 48% in 1985 according to the analysis of Landsat satellite imagery (Gangdong-gu, 2008). The area also has seen frequent changes in urban planning policies and regulations, and as a result, land use patches have become highly fragmented. Many small land use and development patterns have appeared throughout the study area. In the last 20 years, however, the rate of development has not increased much, and the environment seems to have stabilised. The urbanised areas are currently used mostly for commercial and residential purposes. Although a few fragmented forests are located in the urbanised area, the study site shows a sharp contrast between the highly developed urban area and the adjacent forest.

2.3 Data

Green area percentage of land use patches

The green area percentage (GAP) of various urban land use types was studied to examine the relationship between varying habitat conditions and bird distribution. Two contrasting major land use types—urban and forest—were examined. Other minor land use types (e.g., water, wetlands, agricultural) were excluded. Determining the detailed GAP of each land use patch was necessary because of the highly fragmented nature of the landscape patches in the study area. Through the Korean War and ensuing rapid industrialisation, Seoul has seen dramatic changes in land use pattern. The population of Korea has migrated and concentrated around Seoul and the surrounding metro area where economic opportunities were abundant. About one third of Korean population currently lives in the Seoul Metropolitan Area. The area, initially spread by sprawl, underwent development through frequent changes in the urban planning policies and regulations. The land-use patches as a result have been highly fragmented. Many small land use and development patterns have appeared throughout the study area.

While surveying and creating the land use map of the study area with the intention of obtaining GAP values, particular attention was paid to gathering detailed information on the small green patches. The map was created using a two-tiered land use and land cover classification system, similar to the one developed by Gill *et al.* (2008). First, landscape patches were delineated from an existing 1:1,000-scale topographic map with field validation. Next, all the patches in the study area were classified into 29 land use types (e.g., detached house, high-rise multi-unit housing, commercial, industrial, school, park). The minimum mapping unit was 1,000 m2. Patches smaller than 1,000 m2 were merged with larger neighbouring patches. Thereafter, the GAPs of all the patches were assessed on site. The GAP field survey was conducted between January 24 and 26, 2006.

Bird survey

The bird communities were surveyed using a modified line transect method (Colin *et al.* 1992) in two different seasons: breeding season (survey date: April 30, 2006) and non-breeding season (survey date: January 1, 2006). Unlike the conventional line transect method, the modified line transect method employs zigzag walks along the transect lines to count birds in hidden areas behind large urban structures. DeGraaf *et al.* (1991) and Jokimäki and Suhonen (1998) reported that this method could reduce the underestimation error of urban bird surveys. For both seasons, the surveys were conducted between 06:00 a.m. and 12:00 p.m., only when it had not rained or snowed for three days prior to the surveys. Teams consisting of two surveyors (with a total of 13 teams for each survey) observed areas within approximately 25 m of the transect lines on either side and recorded the species and behaviours of all birds observed. Bird locations were recorded on topographic maps for overlay analysis with the land use map.

Water species such as ducks and sandpipers were excluded because the main objective was to observe avian species distribution patterns relative to the forest area.

2.4 2.4. Analysis methods

Each bird species' appearance pattern for various GAPs was examined to see if there were any significant differences in each species' preference for particular GAPs. For classification, GAP data was grouped into 10% intervals.

In addition, multiple 50-m-wide buffers were created from the forest borders to see the distribution of birds in relation to the distance from the forest borders (Figure 2). These buffers were created both inside and outside of the forest borders. The site is comprised of up to five buffer zones (250 m) on the inside and up to 38 buffer zones (1,900 m) on the outside of the forest border (Figure 2).

The minimum habitat size essential for the sustainable reproduction of birds differs depending on species and is not clearly known, but it is generally assumed to be 40 ha for carnivorous species and 2 ha for granivorous species (Forman, 1995). In Korea, the size has been suggested to be a little smaller. Park (1994) suggested 1 ha as the minimum habitat size for small, forest interior granivorous species in an urban area. Therefore, the natural forest and planted park patches that were bigger than 1 ha were classified as forests. If the size of fragmented forest and planted woodlands in a built-up area was smaller than 1 ha, the patch was classified as urban. For both analysis methods, ESRI's ArcGIS software was used.

Understandably, more birds can live in a larger patch than in a smaller patch (Burkey, 1995; Diamond, 1975; Forman, 1995). The number of observed individuals in each buffer area was normalised based on the size of each buffer as a percentage of individuals. In addition to species in and around water bodies, rarely observed species (< 10 individuals observed in the two surveys) were excluded to reduced generalisation error.

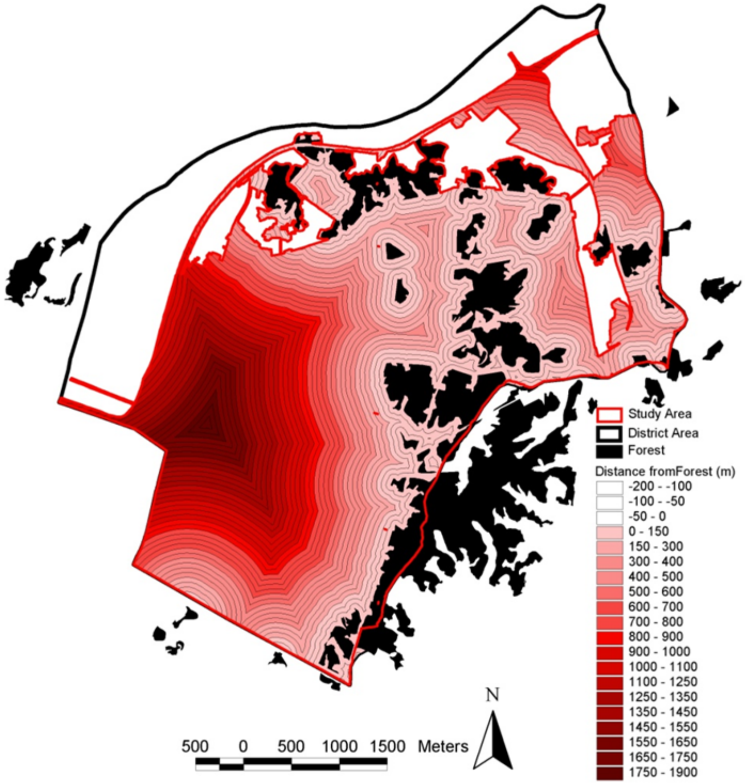

Figure 2: Distance buffering from the forest border for spatial analysis

3 Results

3.1 Land use and GAP

Of the total district area (24.6 km2), about 6 km2 is covered with water. Slightly over 0.01 km2 is covered by agricultural uses and grasslands. Forested areas cover 2.7 km2 and the urban area cover 15.9 km2. A total of 1,593 land use patches were delineated in the urban area. The mean size of the patches was 0.010 km2, with a standard deviation of 0.017 km2.

Because the study area is heavily developed, GAPs for patches are small compared to less developed areas. The GAPs of 980 patches (53.0% of the study area) is ≤ 10%, and the GAP of 143 patches (8.6% of the study area) is 11%–20% (Table 1).

Table 1: Green Area Percentage (GAP) Distribution Showing Number of Patches in Each GAP Interval and Total Area of Each GAP Interval in the Study Area

Green Area (%)	No. of Patch	Area(□)
≤ 10	980	9,860,557
11~20	146	1,608,444
21~30	82	1,327,119
31~40	44	1,232,713
41~50	16	249,755
51~60	8	163,826
61~70	4	58,779
71~80	5	19,088
81~90	1	26,804
91~100	893	4,053,226
Total	2,179	18,600,311

3.2 Distribution of birds

In the non-breeding season survey (January 2006), a total of 5,836 birds belonging to 37 species were observed. The most abundant species was the tree sparrow (Passer montanus; 2,018 individuals), which is known as an urbanised species in Korea. This species was mainly observed in small urban green open spaces and gardens. The second most abundant species was the magpie (Pica pica; 719 individuals), which is also known as an urbanised species in Korea (Choi 2004).

In the breeding season survey (April 2006), a total of 5,257 birds belonging to 52 species were observed. As with the non-breeding season observations, tree sparrows and magpies were the most abundant (2,138 individuals) and second most abundant (549 individuals) species recorded, respectively.

Across the two surveys, a total of 59 species were observed. Of those, 31 species had more than 10 individuals. Thirty individuals of Siskin (Carduelis spinus) were observed, but only in one small area as one group. Because of the limited distribution and potential resulting bias toward the analysis, these species were excluded. As a result, a total of 30 species were used to reduce the generalisation error due to rare observation of species.

3.3. Avian species distribution along the forest–urban gradient

When the observations were analysed for each of the 50-m buffers along the forest border, bird species distribution patterns varied. Some species were mostly observed inside the forests (i.e. Picus canus, Dendrocopos kizuki, Sitta europaea etc.), while other species (i.e. Streptopelia orientalis, Anthus hodgsoni, Turdus naumanni eunomus etc.) were observed in the forests as well as in urban areas close to the forests. Some other species showed no such preference and inhabited both forest and urban areas (i.e. Parus major, Pica pica etc.), while several other species strongly preferred urban areas (i.e. Columba livia var. domestica, Hirundo rustica etc.). Interestingly, many other species commonly known as forest interior species were observed both in the forests and the urban area (i.e. Anthus hodgsoni, Parus palustris etc.).

Although the appearance patterns varied, four distinct appearance categories were found among the bird species: (1) forest specialists, (2) forest-to-near-urban generalists, (3) whole-forest-to-urban generalists, and (4) urban specialist. Figure 3 shows the characteristics of each type. Forest specialist species were concentrated in the forest and hardly appeared in the urban core. These species were hard to find in a highly urbanised area, even if urban greenness was considerably enhanced. Forest-to-near-urban generalist species were found from inside the forest to the nearby urban area. These species had difficulty penetrating urban areas more than 500 m away from the forest boundary. Whole-forest-to-urban generalist species were found throughout the study area, but the density was slightly higher in the forest near the forest border. Urban specialist species were rarely seen in the forest, and most individuals were scattered throughout the entire urban area.

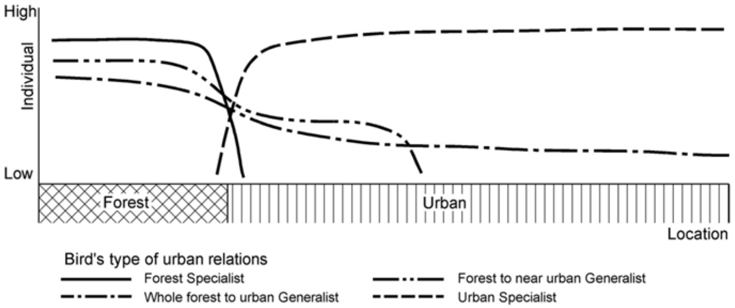

Figure 3: Depiction of the spatial relationships of observed bird appearance patterns along the forest-to-urban spectrum

Figure 4 combines observations of each species for each distance buffer. The study results show that many species have appearance patterns that are contrary to their widely known habitats. For example, the tree sparrow, domestic pigeon, and magpie are commonly considered urban specialist species in Korea (Choi 2004). However, this study's results show that the magpie did not follow the urban specialist pattern. Furthermore, the great tit is known as a forest interior species (JS Kim 1999), but it was found to be of the whole-forest-to-urban-generalist type. The classification type of each bird species is shown in Table 2.

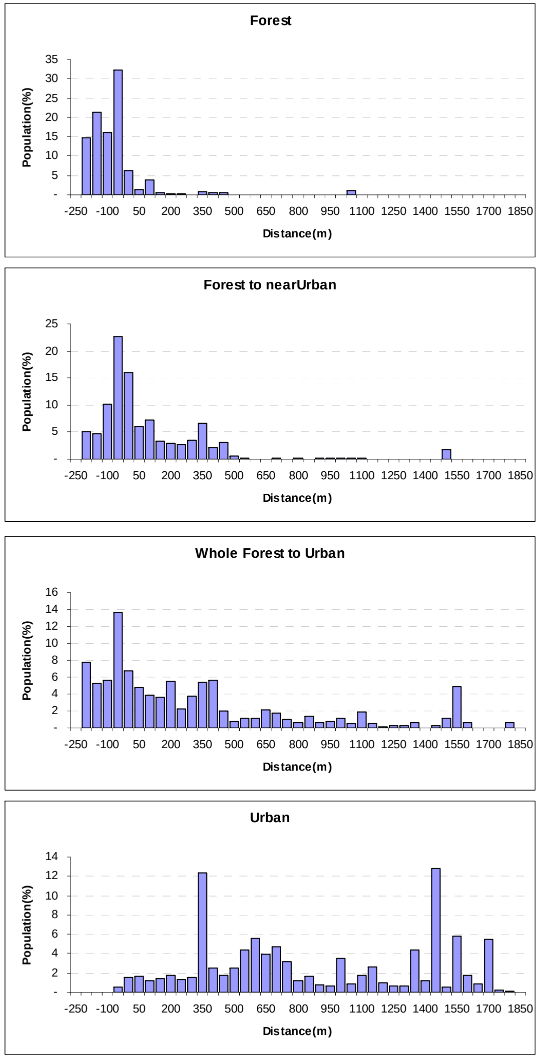

Figure 4: Observed percentage of each classification type for each buffer from the forest border

Table 2: Bird Species Appearance Pattern Classifications Across Forest and Urban Areas

Appearance Pattern Classifications	Species
Forest specialist (10)	blue and white flycatcher (*Cyanoptila cyanomelana)*, grey-faced woodpecker (*Picus canus)*, coal tit (*Parus ater)*, brambling (*Fringilla montifringilla)*, nuthatch (*Sitta europaea)*, great spotted woodpecker (*Dendrocopos major)*, Japanese pygmy woodpecker (*Dendrocopos kizuki)*, yellow-throated bunting (*Emberiza elegans)*, ring-necked pheasant (*Phasianus colchicus)*, varied tit (*Parus varius)*
Forest-to-near-urban generalist (12)	Tristram's bunting (*Emberiza tristrami)*, hawfinch (*Coccothraustes coccothraustes)*, long-tailed tit (*Aegithalos caudatus)*, jay (*Garrulus glandarius)*, marsh tit (*Parus palustris)*, goldcrest (*Regulus regulus)*, Korean crow tit (*Paradoxornis webbiana)*, Rufous Tturtle dove (*Streptopelia orientalis)*, Naumann's thrush (*Turdus naumanni naumanni)*, dusky thrush (*Turdus naumanni eunomus)*, crowned willow warbler (*Phylloscopus occipitalis)*, olive-backed (Indian tree) pipit (*Anthus hodgsoni)*
Whole-forest-to-urban generalist (5)	Brown-eared bulbul (*Hypsipetes amaurotis)*, great tit (*Parus major)*, Daurian redstart (*Phoenicurus auroreus)*, yellow-browed warbler (*Phylloscopus inornatus)*, magpie (*Pica pica)*
Urban specialist (3)	Tree sparrow (*Passer montanus)*, domestic pigeon (*Columba livia* var. *domistica)*, house swallow (*Hirundo rustica)*

The relationship between the appearance percentage of each classification type and GAP for each land use patch is shown in Figure 5. As expected, forest specialists prefer a higher GAP. What notable also is that urban generalists appear more in higher GAP areas. Both forest-to-near-urban and whole-forest-to-urban species appeared evenly through different GAPs.

Whole-forest-to-urban generalists were mainly observed in the 40%–60% GAP, but a relationship between whole GAP intervals and observed bird species regarding preferences for specific GAP intervals was not observed. Forest-to-near-urban generalists were mostly observed in urban patches with GAP intervals greater than 30%. This 30% level may be used as a GAP management guideline for urban patches to enhance urban bird diversity.

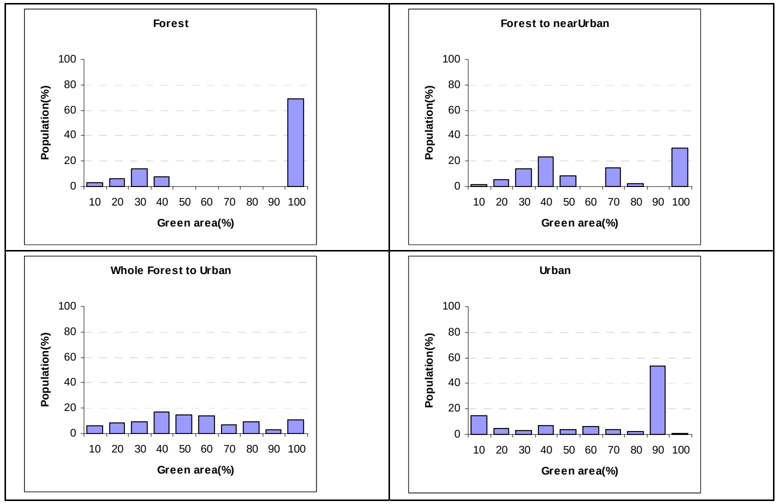

Figure 5:Observed GAP for each land use patch and pattern classification

4 Discussion and Conclusions

This study investigated bird–habitat relationships in an urbanised area and obtained results that may lead to more effective urban green space planning strategies for encouraging greater avian species diversity in urban areas. Although the two major classification systems currently used for understanding bird–habitat relationships—one based on forest edges and interiors and the other based on forests' successional stages—work well in forested and undisturbed-to-slightly disturbed natural areas, the present study suggests that they are much less effective when applied to urbanised areas. In contrast, the present research developed a bird–habitat relationship classification system based specifically on an urbanised area. The four relationship patterns identified were: 1) forest specialists, 2) forest-to-near-urban generalists, 3) whole-forest-to-urban generalists, and 4) urban specialists.

Furthermore, many planning and design attempts to enhance urban ecosystems have adopted target species based on the two existing (non-urban) classification systems. The present research, however, indicates that the target species successfully used in less developed areas are not necessarily appropriate for urbanised areas. For example, some of the woodpeckers currently used as target species are not suitable for urban species diversity management planning in Korea (Choi, 2004; KM Kim, 2002). Unless urbanised areas are completely converted into forests, woodpeckers may not be able to extend their home range into highly urbanised areas. Birds in urban areas clearly have different habitat requirements and adaptive behaviours. Our study indicates that forest specialists will always find habitat in the forests. These species will not venture into green patches in the urban environment, even when they are intentionally augmented. The whole-forest-to-urban generalist does not need human help to find urban habitat, and urban specialists are already in the urban environment. Forest-to-near-urban generalist species, however, cannot extend their home range deep into highly urbanised areas, without the help of human intervention. Few of these species were found far from major forests, and most individuals were observed less than 500 m from the forest border. Knowing that these species tend to stay near (less than 500 m away) major forests, planners could possibly place these forests at a maximum of 500 m apart to help distribute these species throughout an urbanised area. In addition, these forest-to-near-urban generalists were observed mostly in patches with GAPs lower than 30% in the urban area. Newly introduced forests could be effective when they create GAPs greater than 30%. We believe that the forest- to-near-urban generalist classification offers the most effective target species to increase biodiversity in urban environments.

In summary, the results of this study suggest some ideas on how to manage urban green infrastructure in order to increase bird diversity lost because of urbanisation: 1) if planners are to increase the number of forest-to-near-urban generalists in urban areas, major forests should be placed or preserved no more than 500 m apart, considering the influx distance (500 m) of forest-to-near-urban generalists, and 2) each development unit should secure a GAP greater than 30%.

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