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BUTTERFLY INDICATORS AND ASSEMBLAGE PATTERNS IN URBANIZED GREATER JAKARTA

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Abstract
Urban areas dominated by man-made structures can still provide habitats for butterflies. To assess urban butterfly diversity, *KupuKita*—a citizen science platform—was launched in 2021 to monitor butterflies across the Greater Jakarta region (Jakarta, Bogor, Depok, Tangerang, and Bekasi). Using a simple geotagged form with visual species lists from Papilionidae, Pieridae, and Nymphalidae families, data were collected from four habitat types: home gardens, green spaces, parks, and roadsides. Between March 2021 and November 2022, 50 species were recorded, with *Appias olferna*, *Leptosia nina*, *Eurema* sp., and *Hypolimnas bolina* being the most common. Cluster analysis based on habitat composition and vegetation identified three ecological groups—urban generalists, urban-tolerant, and rare species. Indicator species were recognized for green spaces and roads, but none for home gardens due to vegetation variability. These findings demonstrate the potential of citizen science for evaluating urbanization effects on butterfly communities.

***Keywords*: butterflies, citizen science, monitoring Greater Jakarta, urban**

Introduction

Rapid urban expansion has characterized many large cities globally (Nor *et al.* 2017). Most of the world's population resides in cities (LaPoint *et al.* 2015). Because of growing populations, built-up areas have doubled between 1989–2014 in many cities, including Jakarta (Nor *et al.* 2017), threatening food security, clean air, and clean water. However, these essential services are provided by green spaces (Solecki & Marcotullio 2013). The existence of green spaces in expanding built-up areas in many cities plays an essential role in providing ecosystem services to the urban environment, such as improved air quality, reduced noise, temperature regulation, recreation, and cultural services (Bolund & Hunhammar 1999, Solecki & Marcotullio 2013). Moreover, these areas are also vital habitats for urban biodiversity, including insects such as butterflies (Han *et al.* 2021, Lin *et al.* 2024).

Insects are abundant and diverse, comprising almost half of global biodiversity. Lepidoptera (butterflies and moths) is one of the most diverse orders of insects, playing an essential role in ecosystem functions (Gullan & Cranston 2014). In the tropics, butterflies are everywhere, including in the urban environment. They reside in urban forests, parks, and even home gardens (Koh & Sodhi 2004), providing services to the ecosystem, including pollination (Bergerot *et al.* 2010, Dylewski *et al.* 2019). Their presence is correlated with other taxa, such as birds, and their sensitivity to environmental changes makes them good indicators of ecosystem changes (Oostermeijer & van Swaay 1998, Ramírez-Restrepo & MacGregor-Fors 2017).

The Greater Jakarta area, which includes Jakarta and its satellite cities, Bogor, Depok, Tangerang, and Bekasi (Jabodetabek), is highly urbanized, containing 11.76% of the total population of Indonesia (Hasibuan *et al.* 2014). While built-up areas are more extensive in Jakarta, green spaces are more prominent in the suburbs of neighbouring cities (Zain *et al.* 2015), making Jabodetabek an ideal case study to investigate urban butterfly incidence and abundance. As urbanised areas are densely populated, utilizing human resources to help assess urban nature and ecology through citizen science is appropriate. Citizen science is an emerging trend of engaging people to contribute to science by collecting volunteer-driven data (Silvertown 2009, Mueller *et al.* 2011, Wang *et al.* 2016). Citizen science helps to fill the gaps in research data, such as species distributions, diversity, and phenological patterns (Dennis *et al.* 2017, Prudic *et al.* 2018, Squires *et al.* 2021). Online platforms such as iNaturalist (Gazdic & Groom 2019) and eButterfly (Prudic *et al.* 2017) are already available, and widely used for butterfly monitoring. However, such platforms are based on the English language, which is less useful for non-English-speaking countries such as Indonesia. To fill this gap, in March 2021, we developed KupuKita (which in Indonesian means 'our butterflies', www.kupukita.org), Indonesia's citizen science platform for urban butterfly monitoring mainly in the Greater Jakarta area (Winarni *et al.* 2023).

In addressing the challenge of monitoring ecosystem resilience in urban areas, the selection of appropriate indicator species is essential. Butterflies, with their sensitivity to environmental changes, offer a powerful lens through which such resilience can be assessed (Pla-Narbona *et al.* 2022). Due to their association with vegetation, butterfly incidence and abundance are influenced by factors such as the availability of host plants, flowering vegetation, microclimatic conditions, and habitat connectivity. Their abundance and occurrence are also linked to human population density and the extent of urbanization (Kuussaari *et al.* 2021). A study conducted in Beijing highlighted that parks with sufficient vegetation and nectar resources play a more significant role in butterfly species richness than land cover alone (Han *et al.* 2021). A prior study in the Greater Jakarta Area suggested that there were differences in the butterfly diversity between Jakarta and its satellite cities (Winarni *et al.* 2023). However, research on urban butterflies is underexplored in Southeast Asia, particularly in understanding their potential to reveal ecosystem resilience in urban environments (Ramírez-Restrepo & MacGregor-Fors 2017, Lin *et al.* 2024). This study investigates the incidence and abundance of butterflies in the urban Greater Jakarta Area and evaluates indicator species for different habitat types, using the KupuKita platform.

Materials and Methods

The data used in this study were collected using the KupuKita platform, especially its online form <https://bit.ly/formkupukita>. The platform focused on easy-to-identify large species from three families, i.e., Nymphalidae, Papilionidae, and Pieridae, to ensure correct identification by citizens. It was based on species found in urban areas, particularly in Jakarta and its surroundings. Other butterfly families, such as Lycaenidae and Hesperiidae, were not included as butterflies in these families are small, harder to see, and can be overlooked by untrained observers (Corbet & Pendlebury 1992, Vann 2008).

Data forms featured geolocations of observers, observer information, pictorial species lists with corresponding number of individuals (from one to more than ten individuals), habitat information and category (roadside, home gardens, parks, and urban green spaces), stratum of observation habitat (understory, middle story, upper story), as well as questions on the presence of grasses and flowering plants. In the habitat category, urban green spaces were defined as large areas managed as urban forests or botanical gardens. Parks were defined as other green spaces, including recreational areas, cemeteries, and community playgrounds.

The pictorial species list was based on existing field guides for butterflies in Indonesia and Malaysia (Corbet & Pendlebury 1992, Peggie & Amir 2006), and was discussed with butterfly experts. Particularly for *Eurema*, the KupuKita platform provides only *Eurema sp.* in its pictorial species list to simplify identification, without distinguishing among individual species. Consequently, all records represent a species complex (e.g., *E. hecabe*, *E. blanda*, *E. alitha*) rather than separate species due to visual similarity. Hereafter, the *Eurema sp.* species complex will be referred to simply as *Eurema spp.* Participating citizens in Jakarta and satellite cities, Jabodetabek (abbreviated from Jakarta, Bogor, Depok, Tangerang, and Bekasi), submitted home garden observations and observations from other areas nearby (Fig. 1).

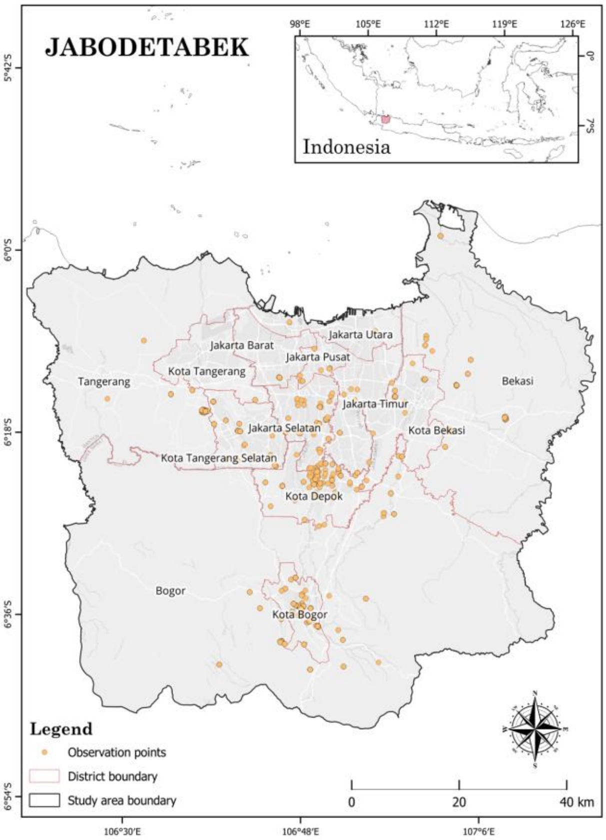

Figure 1. The study area, Jabodetabek, with observation points

In this study, we used data obtained between March 2021 and November 2022. Observers provided images of the habitat and butterflies observed. Data were then validated by the KupuKita team. Observations were made alone by each participant. Butterfly observations were conducted using a combination of Pollard walks (Pollard 1977) and point count methods, where observers walk around or stand on a point and record the butterflies observed within 50 m for 10-15 minutes (Winarni *et al.* 2023). The distance between points was approximately 50-100 m. The same species already recorded at a point was not re-recorded, and only one observer submitted the data when observers were in groups to avoid double-counting. None of the butterflies was captured or harmed.

We then calculated butterfly abundance at different habitat types based on Encounter Rates (ER = total butterfly encounter/total number of observations) (Fewster *et al.* 2009). We summarized the presence of grasses and flowering plants at each habitat type identified by observers. We also carried out hierarchical clustering of butterfly encounter rates at different habitat types to define butterflies' responses to different habitat conditions in Jakarta and its satellite cities. Then, we determined the misclassification rate of this grouping with Discriminant Function Analysis. In addition, we analyzed species indicators for each habitat type using the multipatt function in the R package *indicspecies* (De Cáceres 2013, De Caceres *et al.* 2016). Indicator species values integrate data on relative abundance and frequency of occurrence within specific habitats, helping to narrow a large pool of species to a select few that best represent the defining characteristics of each group. Analyses were carried out using the R 4.2.3 packages "vegan", "ggplot2", and "circlize".

Results

From March 2021 to November 2022, 150 observers contributed 2301 submissions. Within this timeframe, we identified a total of 50 species, belonging to the Nymphalidae, Papilionidae, and Pieridae families (Sup. Table 1, Sup. Table 2). Notably, submissions were most plentiful from home gardens, comprising 37.7% of the total, while roadside submissions were the least frequent at 10.9%. Among the four habitats, home gardens were more prominent for the presence of grasses (35.76%) and flowering plants (38.31%). On the other hand, roadsides had the least abundance of grasses (11.41%) and the least number of flowering plants (10.52%) (Fig. 2).

Similar to Winarni *et al.* (2023), this study confirmed the four most common species: *Appias olferna*, *Leptosia nina*, *Eurema* sp., and *Hypolimnas bolina*. Interestingly, these four species were prevalent across all habitat types, although their distribution varied. *Appias olferna*, *L. nina*, and *H. bolina* were most abundant in home gardens, whereas *Eurema* sp. was predominantly found along roadsides. The KupuKita platform includes only *Eurema sp.* and does not list different *Eurema* species to simplify identification. Records of *Eurema* on the KupuKita platform were entered only as *Eurema* sp., representing species complexes rather than individual species. Additionally, species like *Catopsilia pomona* and *Junonia orithya* were also notably abundant in roadside habitats (Sup. Table 2).

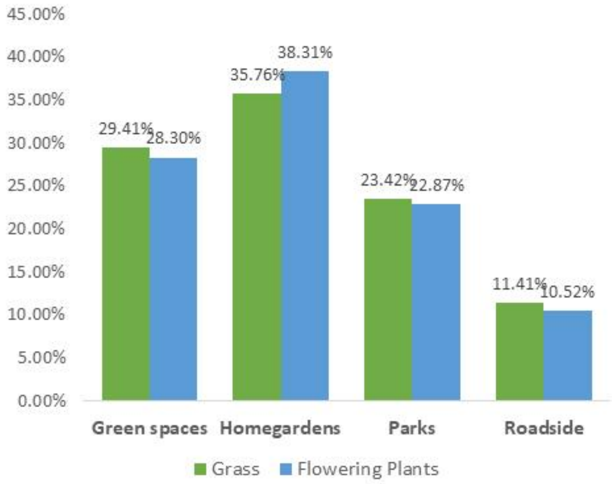

Figure 2. Proportions of grass and flowering plants in different habitat types

The cluster analysis identified three groups of butterflies in the overall butterfly community in Jakarta and its satellite cities (Fig. 3). Members of Cluster 1 were 32 rare/sporadic species, including *Pachliopta aristolochiae*, *Graphium doson*, etc. Cluster 2 was urban-generalist species, composed of species with the highest ER in all habitat types; the common species, *Appias olferna, Leptosia nina, Eurema* sp., and *Hypolimnas bolina*. Cluster 3 included 14 species of the urban-tolerant/frequent species group, including *Delias hyparete*, *Graphium agamemnon,* and *Papilio demoleus*. With discriminant function analysis, this grouping was 94% correctly assigned to their cluster membership. While urban-generalists and urban-tolerant/frequent species were likely present in all habitat types, rare/sporadic species were mostly present in home gardens (100%), green spaces (87.5%), and parks (93.8%), but less likely to be present on roadsides (59.4%) (Sup. Table 1, Sup. Table 2, Fig. 3). Among the rare species, only three species, *Danaus chrysippus*, *Junonia athlites*, and *Ariadne ariadne,* were likely to be more abundant on the roadsides.

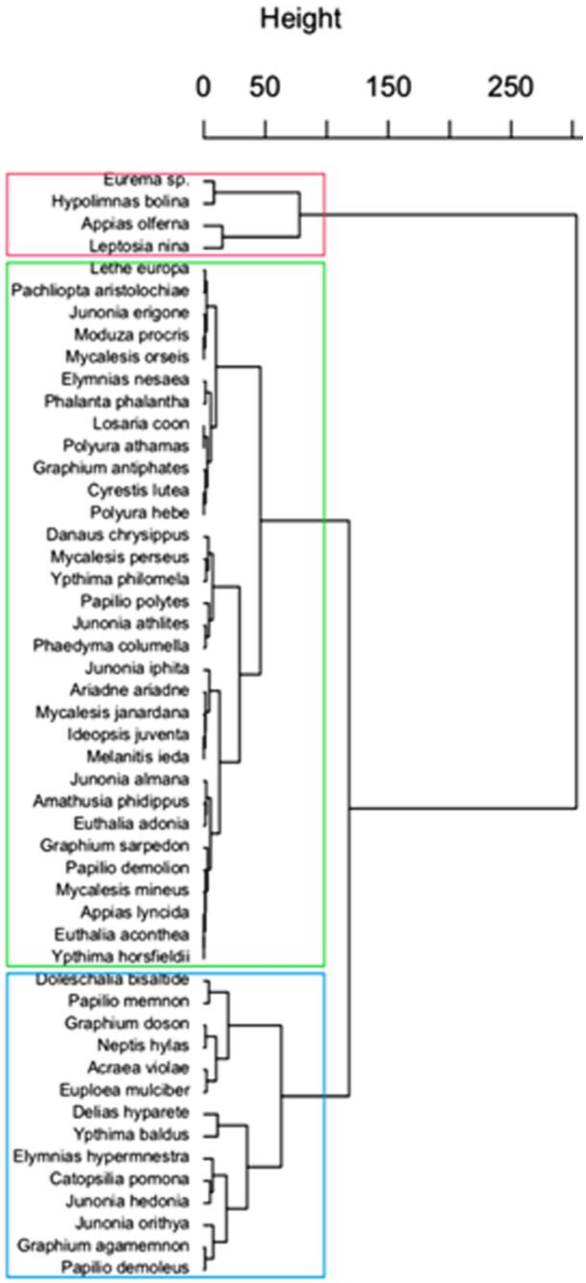

Figure 3. Dendrogram of cluster analysis of butterfly species found in the Greater Jakarta areas showing 3 clusters

Eighteen of the 50 species recorded were associated with only one habitat type. Twelve species were associated with green spaces, four were associated with roads, and two were associated with a combination of habitats (Sup. Table 3). Among the twelve species associated with green spaces, the three most dominant species in Jabodetabek, *Leptosia nina*, *Eurema* sp., and *Hypolimnas bolina* were included. The four species associated with roadsides were *Danaus chrysippus*, *Catopsilia pomona*, *Junonia orithya*, and *Junonia athlites*. The two species associated with a combination of habitats (green spaces and parks) were *Papilio polytes* and *Junonia iphita*.

Discussion

Urban butterfly community and response to urbanization. Community participation is instrumental in uncovering butterfly species richness and diversity in the urbanized Greater Jakarta Area (Dennis *et al.* 2017, Prudic *et al.* 2018). Interestingly, most of the data submitted were from home gardens, with all 50 species found in this common urban habitat. Using citizen scientists, we were able to cover normally restricted areas, such as home gardens (Fontaine *et al.* 2016). Community participation also enables data collection on aspects of the urban ecology of butterflies, such as species richness and diversity, and the prediction of population trends (Wang *et al.* 2016, Prudic *et al.* 2018). Citizen science data inevitably carry potential biases. To minimize these, we provided a butterfly-watching field guide and organized occasional training sessions, where participants could also share photographs via a WhatsApp group to receive support, exchange information (Colom 2021), and assist with data validation (Silvertown 2009).

This study revealed the response of butterflies to different urban habitat types. The three clusters of butterflies in Jakarta's greater area may indicate the level of response to the urban environment. Previously divided into adapter and avoider, this study improves our understanding of the response of butterflies to urban habitats (Winarni *et al.* 2023).

The response of wildlife to urbanization has been described as exploitation, adaptation, or avoidance (Blair 1996, McKinney 2006). Based on the relative importance of natural and developed areas in an urban landscape, Fischer *et al*. (2015) described wildlife as dwellers, utilizers, or urban avoiders. However, these terms are usually applied to birds, mammals, and plants (Blair 1996, McKinney 2006, Fischer *et al.* 2015) and rarely to butterflies (Konvicka & Kadlec 2011). Konvicka and Kadlec (2011) used three terms for the butterfly community in Prague, i.e., urban avoider, suburban adaptable, and urban tolerant, based on their linear response to the core of the city. Han *et al*. (2012) suggested that there were four different responses of butterflies in urban parks in Beijing, China. Based on abundance, there were typical generalists, rebound specialists, selective generalists, and typical specialists. Butterflies are highly associated with the presence of vegetation, notably host plants and nectar sources (Corbet & Pendlebury 1992, Bergerot *et al.* 2010, Han *et al.* 2021). In this study, the four most common species occupied all habitat types in abundance, suggesting that they are generalists and can adapt to various intensities of urbanization (Koh & Sodhi 2004). *Appias olferna, Leptosia nina, Eurema* sp., and *Hypolimnas bolina* were the most common species, found across the different intensities of urbanization, from green spaces to roadsides, where the urbanization level is usually higher. *Appias olferna*, *L. nina*, and *Eurema* sp. belong to Pieridae, while *H. bolina* belongs to Nymphalidae. *Leptosia nina* and *Eurema* sp. were common in Asian cities such as Dacca, Metro Manila, and Kolkata (Nair *et al.* 2014, Islam *et al.* 2016, Nacua *et al.* 2020).

Urban tolerant/frequent species represent species that were less common but still tolerant to different habitat types, including roadsides. This group included 14 species, such as *Papilio demoleus* and *Papilio memnon*, two of the most common Papilionidae in urban ecosystems (Nisa *et al.* 2013). Additionally, *Junonia hedonia* are often abundant in urban green spaces, while *Acraea violae* and *Junonia orithya* are frequent visitors to roadsides.

The third group of urban butterflies in Jabodetabek was a group of rare/sporadic species. All of the members in this group were recorded in home gardens, indicating that home gardens are potentially rich in nectar plants attracting these rare/sporadic species. Such situations also occur in other Asian home gardens, such as those in Sri Lanka and India (Karunarathna *et al.* 2012, Sarma *et al.* 2012). Uncommon species also occasionally visited parks (i.e., *Mycalesis perseus, Mycalesis mineus*). However, contrary to Konvicka and Kadlec (2011), rare or sporadic species might not exhibit a linear relationship with the city core if they are mostly found in home gardens. Such differences suggested that butterflies may show a more detailed response to different environmental conditions (Ries & Debinski 2001).

Butterflies as indicators for habitat types. Our results suggest that a multispecies group is a good indicator of green spaces and roadsides. There were variations among different habitats. Green spaces were represented by 12 species, from the three families considered here, covering understory species such as *Leptosia nina*, *Ypthima baldus*, *Mycalesis perseus*, to middle-story species such as *Hypolimnas bolina*, *Euploea mulciber*, *Doleschalia bisaltide*, to *Graphium agamemnon*. Other studies suggested that different urban ecosystems offer different favourable habitats for butterflies according to plant incidence and diversity (Dylewski *et al.* 2019, Sing *et al.* 2019). Landscape features and vegetation type affect butterfly richness in green spaces. Green open spaces are usually planted with a variety of plants, including trees (Sing *et al.* 2019, Azahra *et al.* 2022, Lin *et al.* 2024). Roadside habitats were represented by four butterfly species, and only two species were selected as indicator species for green spaces and parks. Roads are sometimes considered a measure of urbanization (Kuussaari *et al.* 2021). Roadsides are usually covered by grasses and other weedy plants such as *Plantago* spp. and *Ipomoea* spp., which are the preferred hosts of *Junonia orithya* (Peggie & Amir 2006, Biricik 2011, Winarni *et al.* 2023). *Catopsilia pomona*, which is common in Southeast Asia and known for its migratory behaviour in India and Australia (Chaianunporn & Khoosankurat 2018, Dunn 2021, Gokul & Ramesh 2021), is frequently observed flying high along roadsides (Winarni *et al.* 2023).

Interestingly, while there are butterfly species indicators for the combination of green spaces and parks, none of the species acted solely as indicator species for home gardens. Indicator species selection was based on the relationship of a species with one or more sites (Mahata *et al.* 2023). Green spaces and parks are potentially similar in the variety of plants and are usually managed, which may include the species indicator (Lange-Kabitz *et al.* 2021). *Papilio polytes* and *Junonia iphita* were rare/sporadic species, which were never recorded on roadsides, but both were associated with green spaces and parks. Home gardens, however, typically fall somewhere between other habitats in terms of plant diversity. Home gardens in the tropics, although usually planted by personal preference, tend to have complex vertical structures with different life forms, from vines to tall canopy trees (Niñez 1987, Soemarwoto 1987, Huai & Hamilton 2009). Home gardens in Jakarta and its satellite cities may suggest different conditions, such as the host plant diversity, with potentially fewer plant species than in rural areas (Soemarwoto 1987, Campera *et al.* 2021). Home gardens in an area of Bogor (one of Jakarta's satellite cities) can host as many as 149 plant species, while in other areas, fewer than 100 species occur (Ali *et al.* 2021), highlighting the role of personal preferences in shaping plant species richness. Home gardens are usually grown with ornamental plants, but also often provide food and medicinal resources for the inhabitants, such as various fruiting trees and spices (Soemarwoto 1987, Eichemberg *et al.* 2009, Huai & Hamilton 2009).

Home gardens to support urban butterfly populations. Urbanization has dramatically impacted green spaces due to increasingly built-up areas (Nor *et al.* 2017). In other studies, urbanization mainly produced a negative effect on butterflies and even caused the local extinction of several butterfly species (Ramírez-Restrepo *et al.* 2017, Ramírez-Restrepo & MacGregor-Fors 2017). Despite the growing impact of urbanization, home gardens are important for supporting multipurpose agroecosystems and providing economic, ecological, and social functions (Huai & Hamilton 2009), and therefore, serve as a bridge between biodiversity and society, linking ecological richness with daily human life (Pendl *et al.* 2022).

Regarding ecological functions, home gardens contribute to biodiversity conservation, by preserving genetic materials, maintaining soil fertility and soil structure, and providing carbon storage (Kumar 2006, Huai & Hamilton 2009) and providing habitat to many wildlife species, including butterflies. Home gardens offer refuge when natural habitats are unavailable (Fontaine *et al.* 2016). Although diversity tends to be lower, butterfly species richness could be higher in home gardens than in other habitat types in urban Jakarta and its satellite cities. Higher species richness in home gardens is likely a consequence of habitat characteristics such as caterpillar host plants, adult butterfly nectar plants, water resources, canopy openings, and interspersion of habitat components (Maryam & Pramukanto 2020, Pendl *et al.* 2022).

Indonesian home gardens called "pekarangan" are usually enriched with diverse plants, including fruiting trees, vegetables, herbs, and spices (Soemarwoto 1987, Arifin & Nakagoshi 2011). High butterfly species richness in home gardens in this study proved that home gardens might function as additional urban habitats for butterflies in urban areas, and initiatives related to the growing expansion of such areas beyond gazetted green spaces should be endorsed.

Author contributions
All the authors contributed equally.

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