Urban green spaces in Dhaka, Bangladesh, harbour nearly half the country’s butterfly diversity

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Abstract

Cities currently harbour more than half of the world’s human population and continued urban expansion replaces natural landscapes and increases habitat fragmentation. The impacts of urbanisation on biodiversity have been extensively studied in some parts of the world, but there is limited information from South Asia, despite the rapid expansion of cities in the region. Here, we present the results of monthly surveys of butterflies in three urban parks in Dhaka city, Bangladesh, over a 3-year period (January 2014 to December 2016). We recorded 45% (137 of the 305 species) of the country’s butterfly richness, and 40% of the species detected are listed as nationally threatened. However, butterfly species richness declined rapidly in the three study areas over the 3-year period, and the decline appeared to be more severe among threatened species. We developed linear mixed effect models to assess the relationship between climatic variables and butterfly species richness. Overall, species richness was positively associated with maximum temperature and negatively with mean relative humidity and saturation deficit. Our results demonstrate the importance of urban green spaces for nationally threatened butterflies. With rapidly declining urban green spaces in Dhaka and other South Asian cities, we are likely to lose refuges for threatened fauna. There is an urgent need to understand urban biodiversity dynamics in the region, and for proactive management of urban green spaces to protect butterflies in South Asia.

Key words: environmental predictor, South Asia, species richness, threatened butterflies, urban ecology
Introduction

More than half of the world’s human population currently lives in cities, compared to 14% a century ago (Tratalos et al. 2007), and the proportion is expected to further increase over the coming decades (Wei and Ewing 2018). This will exert increased environmental demands on already diminishing surrounding natural habitats (McKinney 2002, 2006; Hahs et al. 2009; Elmqvist et al. 2013; McDonnell and MacGregor-Fors 2016) through agricultural conversion, intensification and infrastructure development, and loss of natural vegetation to supply the resource demands of a growing urban population (Tratalos et al. 2007; Aguilerá et al. 2019). Given the decrease of natural habitat areas over time (Long et al. 2014), urban landscapes are becoming more important for species conservation, including butterfly conservation (Ramírez-Restrepo and MacGregor-Fors 2017; Bidau 2018; Soanes and Lentini 2019).

Since the mid-1900s, ecologists have been working to understand how urbanisation impacts biodiversity (Sanderson, Walston, and Robinson 2018) including invertebrates (Jones and Leather 2012). An increasing intensity of urbanisation often involves loss of green spaces, which leads to a decline in biodiversity (Bergerot, Julliard, and Baguette 2010; Gaston and Evans 2010; Fox 2013). However, both positive and negative effects of urbanisation on species richness have been observed, depending on the configuration and spatial scale of the impact (Gaston 2005; Goddard, Dougill, and Benton 2010; Jain, Lim, and Webb 2017; Ramírez-Restrepo and MacGregor-Fors 2017; Ibáñez-Álamo et al. 2017). Meta-analysis has revealed that 30% of studies showed an increase in invertebrate species richness, compared to 64% of studies showing a decrease along the low to medium urbanisation gradient (McKinney, 2008). However, there is very little information beyond Australia, Europe and North America and some locations in Asia (e.g. Hong Kong and Singapore). Data are particularly lacking from South Asia where urbanisation is progressing rapidly.

Butterflies are useful model organisms for studying the impacts of urbanisation because they depend on a wide range of plants, and, in many cases, their taxonomy, geographic distribution and status are relatively well known (Schulze et al. 2004; Lomov et al. 2006; Braby et al. 2021). Butterflies are mostly host-specific; females seek larval food plants for oviposition, caterpillars depend on one or a few closely associated plants on which they feed, grow and take shelter during development (Gaston 2000; Agrawal 2002; Ferrer-Paris et al. 2013; Aich et al. 2016), and a majority of butterflies rely on flowering plants as an adult food resource (Dennis 2010; Cinici 2013; Soga et al. 2015a). Therefore, butterfly diversity can be a useful proxy for plant diversity in any given area (Jain, Lim, and Webb 2017). Butterflies are sensitive to disturbances to their habitat, and may be severely affected by environmental fluctuations in abiotic factors such as temperature, light intensity, soil composition, radiation, humidity and photoperiod as well as to changes in vegetation composition and structure (Forister et al. 2010; Braby et al. 2014; Braby 2018; Whitworth et al. 2018). Even minor changes in habitat can lead to emigration or local extinction (Harrison 1989; Hanski and Thomas 1994; Hanski, Alho, and Moilanen 2000; Chowdhury et al. 2021a, b). Moreover, butterflies, alongside birds, are one of the most charismatic and conspicuous groups, widely noticed by the public (Fuller et al. 2007; Shwartz et al. 2014; Swamy, Nagendra, and Devy 2019).

While there are several studies on the occurrence of butterflies in urban areas in Europe, North America and Australia (Shapiro 2002; Matteson and Langellotto 2010; Bergerot et al. 2011; Jones and Leather 2012; Dennis et al. 2017; Braby et al. 2021; Theodorou et al. 2020), our understanding is limited from elsewhere in the world. In this study, we document the occurrence of butterflies in urban Dhaka, Bangladesh and identify some of the environmental factors associated with their distribution. While a number of studies have been conducted on butterflies in Bangladesh (Chowdhury and Hossain 2013; Khan 2014; Neogi et al. 2016; Chowdhury et al. 2017, 2021a, b; Haidar et al. 2017; Imam et al. 2020), little is known about the occurrence of butterflies in its main urban centre. Here, we (i) survey butterflies over a 3-year period in three urban green spaces in Dhaka to elucidate the status, diversity and seasonal distribution of butterflies, (ii) investigate the impact of environmental factors on butterfly species richness and (iii) understand the importance of urban green spaces for threatened butterflies in Bangladesh.

Methods

Study areas

Dhaka, the capital of Bangladesh and one of the world’s largest megacities, accommodates about 18.2 million people (Swapan et al. 2017). Its remaining natural habitats are under pressure from human impacts, such as pollution and urban development (Szabo et al. 2016; Shabriar et al. 2020). The city encompasses a limited number of green spaces within its 306.4 km² area, and here we focus on three of the largest and most diverse in terms of flowering plants: National Botanical Garden, the University of Dhaka campus and Ramna Park (Fig. 1).

The National Botanic Garden of Bangladesh is a protected area and the largest plant conservation centre in the country, with an area of about 0.85 km². It is located in Mirpur, Dhaka, beside Dhaka Zoo, and was established in 1961. The University of Dhaka campus covers 2.43 km² and is also situated near the city centre. The campus is well vegetated but more developed than the National Botanical Garden. Ramna Park is located just to the east of campus and covers an area of 0.3 km². All three study sites contain a number of vegetation layers, including canopy, shrubs and herbs which can sustain relatively high levels of biodiversity. Both the National Botanic Garden and Ramna Park also contain water bodies which add to the habitat diversity available to local butterflies.

Butterfly surveys

In each study area, survey routes were designed using existing trails to comprehensively cover all parts (area) of each green space. Paths were walked at least once a month at each location from January 2014 to December 2016, between early morning and late afternoon, excluding days with heavy rain. Each survey took between 2 and 8 h, depending on the length of the route, and to minimise timing bias, we periodically changed the survey direction. All butterflies (species occurrence, but not abundance) visible from the path (~10 m) were recorded. During the study, we used photographs to aid identification of butterflies to species level, comparing them with illustrations in a range of resources (Kehimkar 2008; Chowdhury and Hossain 2013; Bashir 2014). Collection with a net was restricted to species which could not be identified accurately using photography. In those cases, we identified them in the lab (Department of Zoology, University of Dhaka).

We collated the recently assessed national-level extinction risk for each species (IUCN Bangladesh 2015), which follow
IUCN Red List Categories and Criteria v. 3.1 (IUCN 2012a) and IUCN regional guidelines (IUCN 2012b). Extinction risk categories range from the lowest risk categories of Not Evaluated, Data Deficient, Least Concern and Near Threatened, to the threatened categories of Vulnerable, Endangered and Critically Endangered (IUCN Bangladesh 2015).

Associations between environmental variables and species richness

Previous studies have documented how environmental factors such as temperature, rainfall and humidity can affect butterfly species richness (Hadley 1994; Stefanescu, Herrando, and Páramo 2004; Kati et al. 2012). To determine the influence of abiotic factors on butterfly species richness, we collected daily climate data [maximum temperature (°C), minimum temperature (°C), mean relative humidity (%) and total rainfall (mm)] from the Department of Environment, Bangladesh, which is about 5–8 km away from our study sites. Although area-specific microclimate data would help assess the detailed patterns of butterfly occurrence, climate does not greatly vary spatially within Dhaka, and these summary data are useful for detecting broad associations in butterfly abundance over time with climatic variables. We also included saturation deficit (SD), a metric of evaporative water loss due to temperature and humidity and Meyer’s ratio, which relates evaporative water loss to rainfall, as predictor variables (Prescott 1946; Hadley 1994; Kalra and Parkash 2016).

We aggregated our observation data by month for data analysis, when there were >1 survey in a certain month, we combined our observation records. We carried out statistical analyses in R (ver.s 3.6.0; R Core Team, 2019) with a significance level of 5% for all analysis. We checked the normality of data and where necessary log-transformed the data. We fitted linear mixed effect models using the ‘lme4’ package (ver. 1.0.4; Bates et al. 2013) to determine the association between environmental variables and butterfly species richness, with species richness (total number of species seen in a monthly visit) as the response variable, environmental variables as explanatory variables and location and months as random effects to account for differences between seasons and the three parks. We conducted analysis of variance (ANOVA) to test the level of significance. We first fitted an overall model encompassing all butterfly species, then developed separate models for each family to determine family-wise association. We determined minimum adequate models of butterfly species richness using multimodel inference for model selection based on the Akaike information criterion (AICc; default cut-off = 2), as implemented in the R package MuMIn (Barton and Barton 2019). This procedure involved dropping each variable, in turn, to determine the best model and reiterating this step until the model AICc could not be further improved. We also fitted a linear model to test changes in species richness with year, month and location as fixed factors. We then conducted an ANOVA using F-test to test significance level. All tests were two-tailed unless otherwise stated. We also conducted post hoc pairwise comparisons using Tukey’s tests to assess for differences in species richness due to spatial and temporal variation.

We excluded Riodinidae from all the analyses since we observed only two species.

Results

We found 137 species of butterflies (45% of all species known to occur in Bangladesh; see Supplementary Table S1), belonging to all six major families over the 3-year study period. The most species-rich was Lycaenidae with 42 species (51% of lycaenid species in Bangladesh), and conversely, Riodinidae was the least species-rich family, with two of three species occurring in Bangladesh detected represented in our study. The other families were Nymphalidae (39 species, 36%), Hesperiidae (25 species, 56%), Pieridae (18 species, 58%) and Papilionidae (11 species, 44%). Species richness declined markedly throughout the study period and in all three study areas, albeit with some fluctuation (Fig. 2). For example, in the National Botanical Garden, species richness peaked in early-summer 2014 (73 species) and was lowest in mid-winter 2016 (29 species; Fig. 2).
Of the butterfly species recorded, nearly 40% are listed as nationally threatened (53 species; IUCN Bangladesh 2015), whereas 9% (12 species) were not evaluated and only a single species was regarded as Data Deficient (Spindasis elima). Thirteen species or 57% of the Hesperiidae recorded in our study are nationally listed as threatened, whereas 19 species or 23% of the Lycaenidae are nationally threatened. The highest number of butterfly species was recorded from the National Botanical Garden (130 species, 50 threatened) and the lowest from Ramna Park (89 species, 25 threatened); 108 species (36 threatened) were recorded at the University of Dhaka campus.

The presence of a species varied dramatically in different months in all three study areas (Fig. 3). Some species were found in each month of the 3-year study period (e.g. Leptosia nina, Pieridae), whereas other species were detected only a few times (e.g. Delias descombesi, Pieridae) and some species only once (e.g. Unkana ambasa, Hesperiidae). However, across all three study areas, species listed as nationally threatened occurred in fewer months of the year than species listed as Least Concern (Fig. 4).

There was a significant decline in species richness from September to February within all the study areas, across 3 years ($F = 3.71, df = 11, P = 0.002$). Amongst the study areas, there was a significant decline of species richness over the years in both Ramna Park and University of Dhaka campus ($F = 37.49, df = 2, P \leq 0.001$; see the supplementary section for full model output). In comparison to 2014, recorded species richness was significantly lower in both 2015 and 2016 ($F = 47.27, df = 2, P \leq 0.001$). Results of pairwise comparisons of years and months across the locations are in the Supplementary Material.

**Figure 2:** Number of months in each year that butterfly species occurred in three urban green spaces in Dhaka. Each row represents a species, and the cells are coloured (gradient) according to the number of months in which that species was observed in that year, where ‘12’ means that the butterfly was observed throughout the year, and ‘0’ indicates that the butterfly was not observed in any month of that particular year. Species are organised in descending order of monthly occurrence for 2014 in National Botanic Garden (left-most column). NBG, the National Botanical Garden; DU, University of Dhaka campus; Ramna, Ramna Park; NE, Not Evaluated; DD, Data Deficient; LC, Least Concern; VU, Vulnerable; EN, Endangered for the Bangladesh National Red List.
There were significant associations between butterfly species richness and some of the environmental variables (Table 1 and Fig. 5). Our overall model showed that butterfly species richness was positively associated with maximum temperature and negatively related to relative humidity and SD. However, there were clear differences among families. For example, maximum temperature (positive) and mean relative humidity (negative) were significantly associated with species richness in Lycaenidae, whereas SD (negative) was significantly associated with species richness in Hesperiidae (Table 1). We could not detect any significant association between species richness and minimum temperature or Meyer’s ratio for any family, and species richness in the Pieridae was not associated with any environmental variable (Table 1).

### Discussion

Our study showed that nearly half of Bangladesh’s butterfly species were recorded in urban green spaces in the country’s capital, Dhaka, highlighting the importance of the city for supporting a wide range of butterfly species. The butterfly community assemblages were reasonably similar among the study areas, with 84 of the 137 species (61%) being detected in all those parks, and 106 species (77%) occurring in at least two parks. Some species were very commonly observed, (e.g. L. nigra, Eurema hecabe and Catopsilia pomona) in all three study areas, and these species might be regarded as reasonably tolerant of urbanisation and a high level of human disturbance (Aronson et al. 2016). In contrast, species such as Appias indra, Appias albina and Pieris canidia were observed only once or twice, suggesting these species are rarer or irregular visitors, likely not breeding in the green spaces, and possibly not well-adapted to living in managed urban habitats. Indeed, some of these species have been described as vagrants or migrants in Bangladesh by previous authors (Larsen 2004; Bashar 2014; Chowdhury et al. under review), and suitable larval food plants might not be present in urban green spaces.
In this study, we did not observe several butterfly species previously reported from Dhaka by Larsen 2004: Cupha erymanthis and Iambrix salsala, which were reportedly common; Graphium nomius, Eurema brigitta, Petrelaea dana, Parantica aglea and Parantica melaneus were reportedly uncommon; and Miletus chinensis, Loxura atymnus and Belenois aurora were only once observed in Dhaka. However, we found some species such as Baeoris unicolor and Telicota bambusae that were absent from Larsen’s (2004) list. Similar discrepancies occurred when comparing our Dhaka species list to the national-level IUCN Red List Assessments (IUCN Bangladesh 2015). There are 12 species in our inventory which were not evaluated by the national Red List and one species which was assessed as Data Deficient (Selima). These findings suggest considerable temporal dynamics in the species that are present in Dhaka’s urban green spaces, and that urban areas may complement non-urban habitats for some butterfly species.

Seasonality plays a key role in determining migration in insects, and when the surrounding environment becomes unsuitable, insects tend to migrate (Dingle 2014; Chowdhury et al. 2021a, b, in review). Migratory individuals exploit seasonal resources at their peak condition, and in that way, avoid resource depression (Alerstam, Hedenström, and Åkesson 2003). In this study, there were several species which were detected only a few times or at specific times of the year. Nearly 50% (66 of the 137 species) of recorded butterflies in this study were described as migrants by previous authors (Williams 1930; Larsen 2004) and by new analyses (Chowdhury et al. in review). The percentages of migratory butterflies recorded in our studies, were highest among Papilionidae (73%, 8 species), whereas none were from the Riodinidae. For other families, migrants varied from 31% to 72%: Pieridae (72%, 13 species), Nymphalidae (62%, 24 species), Hesperiidae (32%, 8 species) and Lycaenidae (31%, 13 species). The high proportion of migratory species suggests that a large part of the butterfly community might depend on a combination of an influx from non-urban populations and local habitat quality of the parks, i.e. both landscape-scale connectivity and local patch quality.

Although we did not formally quantify disturbance, butterflies seemed to prefer less disturbed habitats within the green spaces, aligned with evidence that disturbance can reduce species richness in urban habitats (Biswas and Mallik 2010; Kati et al. 2012; Jain, Lim, and Webb 2017). During our field survey, we found that high butterfly species richness seemed to coincide with areas less frequently visited by people in both the National Botanical Garden and Ramna Park (pers. obs.). At the University of Dhaka campus, butterfly richness peaked in the Curzon Hall area, which is one of the least disturbed parts of the campus (Chowdhury et al. 2017). Butterflies at the University of Dhaka campus were also concentrated inside and surrounding the small Botanical Garden, perhaps drawn by a high diversity or concentration of potential larval and adult food resources planted there (Bartel, Haddad, and Wright 2010; Soga and Koike 2012; Curtis et al. 2015).

Butterflies are sensitive to environmental changes and a small variation in environmental parameters can sometimes result in major changes in their populations (Thomas et al. 2004a,b; Rosin et al. 2012; Casner et al. 2014), and environmental variables may impact patterns of butterfly species richness (Hadley 1994; Hill et al. 2001, 2003; Roy and Thomas 2003; Stefanescu, Herrando, and Páramo 2004). Here, we found maximum temperature to be positively associated with temporal variation in species richness, and mean relative humidity and SD negatively associated. However, there were marked differences among families. These results contrast with a previous short-term study at the University of Dhaka campus, where associations between butterfly species richness and rainfall, but not temperature and humidity were detected (Chowdhury et al. 2017). This may be because the previous study considered only 1 year and one study site. A long-term study at the population level, and more targeted in terms of collecting microclimate

### Table 1: Models of butterfly species richness across three study sites in Dhaka

| Variable          | Estimation | SE   | T    | P     | R²   |
|-------------------|------------|------|------|-------|------|
| Overall           | 5.29       | 2.02 | 2.62 | 0.02  | 0.42 |
| Log (Tmax)        | 1.01       | 0.44 | 2.25 | 0.02  |      |
| Log (Tmin)        | -0.44      | 0.28 | -1.58| 0.11  |      |
| Log (Rain)        | 0.05       | 0.03 | 1.49 | 0.14  |      |
| Log (RHmean)      | -0.81      | 0.31 | -2.69| 0.01  |      |
| Log (SD)          | -0.20      | 0.11 | -1.92| 0.05  |      |
| Log (MR)          | -0.01      | 0.03 | -0.51| 0.61  |      |
| **Pieridae**      |            |      |      |       |      |
| Intercept         | 2.73       | 2.50 | 1.10 |      0.27|
| Log (Tmax)        | 0.92       | 0.53 | 1.76 | 0.08  |      |
| Log (Tmin)        | -0.47      | 0.33 | -1.43| 0.15  |      |
| Log (Rain)        | 0.003      | 0.04 | 0.08 | 0.93  |      |
| Log (RHmean)      | -0.62      | 0.38 | -1.61| 0.11  |      |
| Log (SD)          | 0.05       | 0.12 | 0.46 | 0.64  |      |
| Log (MR)          | -0.002     | 0.03 | -0.08| 0.93  |      |
| **Lycaenidae**    |            |      |      |       |      |
| Intercept         | 4.69       | 4.36 | 1.08 |      0.43|
| Log (Tmax)        | 2.14       | 0.91 | 2.35 | 0.02  |      |
| Log (Tmin)        | -0.85      | 0.58 | -1.46| 0.14  |      |
| Log (Rain)        | -0.004     | 0.07 | -0.06| 0.95  |      |
| Log (RHmean)      | -1.51      | 0.68 | -2.32| 0.02  |      |
| Log (SD)          | -0.36      | 0.22 | -1.68| 0.09  |      |
| Log (MR)          | 0.02       | 0.05 | -0.33| 0.74  |      |
| **Nymphalidae**   |            |      |      |       |      |
| Intercept         | 7.39       | 2.73 | 2.72 | 0.66  |      |
| Log (Tmax)        | 0.83       | 0.60 | 1.38 | 0.17  |      |
| Log (Tmin)        | -0.59      | 0.38 | -1.56| 0.11  |      |
| Log (Rain)        | 0.10       | 0.04 | 2.27 | 0.02  |      |
| Log (RHmean)      | -1.33      | 0.42 | -3.22| 0.001 |      |
| Log (SD)          | -0.31      | 0.15 | -2.16| 0.03  |      |
| Log (MR)          | 0.0001     | 0.004| -0.004| 0.99 |      |
| **Hesperiidae**   |            |      |      |       |      |
| Intercept         | -2.07      | 3.89 | -0.53| 0.53  |      |
| Log (Tmax)        | 1.26       | 0.86 | 1.45 | 0.15  |      |
| Log (Tmin)        | 0.45       | 0.53 | 0.84 | 0.39  |      |
| Log (Rain)        | 0.04       | 0.06 | 0.54 | 0.59  |      |
| Log (RHmean)      | -0.26      | 0.59 | -0.43| 0.66  |      |
| Log (SD)          | -0.61      | 0.21 | -2.93| 0.003 |      |
| Log (MR)          | -0.09      | 0.05 | -1.74| 0.08  |      |
| **Papilionidae**  |            |      |      |       |      |
| Intercept         | -1.59      | 2.51 | -0.64| 0.25  |      |
| Log (Tmax)        | 1.19       | 0.54 | 2.21 | 0.03  |      |
| Log (Tmin)        | -0.13      | 0.34 | -0.41| 0.68  |      |
| Log (Rain)        | -0.05      | 0.04 | -1.29| 0.20  |      |
| Log (RHmean)      | 0.0001     | 0.39 | 0.00 | 0.99  |      |
| Log (SD)          | -0.08      | 0.13 | -0.64| 0.52  |      |
| Log (MR)          | 0.01       | 0.03 | 0.36 | 0.71  |      |

*aWe used linear mixed effect models with environmental data as fixed factors and location and year as random factors: Tmax maximum temperature; Tmin minimum temperature; rain, total rainfall; RHmean, mean relative humidity; MR, Meyer’s ratio.

*bSignificant association.
data, specific to the time of day and locations being surveyed is required to understand these patterns in more detail.

The richness and distribution of butterfly species fluctuate in accordance with their life cycle and are tied to seasonal changes (Roy and Thomas 2003). When compared with temperate butterflies, seasonal variation does not typically have a large impact on tropical areas and/or areas without a pronounced dry season (Hill et al. 2003; Koh and Sodhi 2004; Koh, Sodhi, and Brook 2004, Hamer et al. 2005). In Bangladesh, the pronounced dry season lasts from November to March, and the rainy season from mid-May to mid-July. We recorded the maximum number of butterfly species during the transition period between the dry and rainy seasons. Indeed, flowering activity peaks in the dry season (Bawa, Kang, and Grayum 2003), whereas fungal infections tend to rise in the rainy season, leading to high mortality in butterflies (Abdala-Roberts et al. 2019). In all three study areas, butterfly species richness peaked in April–May and was lowest in September–November. Other studies on tropical species similarly find that diversity tends to be lower during the rainy season (Hawkins and Porter 2003; Christensen and Hellmann-Clausen 2009; Abrahamczyk et al. 2011), although some studies reported the opposite result (Devries and Walla 2001; Hamer et al. 2005). A possible explanation for the contrasting results could be that human intervention in the form of watering provides more food resources and thereby, attracted more butterflies in our study areas than in surrounding areas during the dry season. It should be noted that watering of plants is not a common practice in Dhaka; however, some small patches (e.g. the botanic garden at the University of Dhaka campus) are watered during the dry season.

The butterfly species richness of Dhaka, one of the most densely populated and polluted cities globally, appears to be surprisingly high, since we recorded 45% of the 305 butterfly species known from Bangladesh, and 40% of our recorded butterfly species are listed as nationally threatened. Our findings suggest that urban green spaces can provide suitable habitats for biodiversity including threatened species (Ives et al. 2016; Soanes and Lentini 2019) and that to conserve butterflies in a tropical urban setting, it is important to take specific conservation measures (Gordon et al. 2009; Dennis et al. 2017; Soanes et al. 2019; Chowdhury et al. 2021a, b). During our survey, we observed mating or earlier (immature) stages for only a limited number of species of butterflies. Moreover, we observed some species only a few times of the year or a few times over the overall study period, suggesting that those species are probably migrants and not breeding in our study areas. Overall, it is concerning that the species richness at our study sites declined so dramatically over such a short time frame, and that the decline is most severe among threatened species. This highlights the higher vulnerability of the latter group, and suggests that the IUCN Red List is a useful tool to guide butterfly conservation action in Bangladesh. Future studies could investigate which butterfly species are successfully breeding in the urban green spaces by studying hostplant utilisation and distribution. If some of the nationally threatened species are breeding in these green spaces, special care needs to be taken in terms of management of these spaces to continue to provide viable habitat.

Insects are declining globally, and several recent studies have documented the rapid decline in both species richness

Figure 5: Relationships between selected environmental variables and butterfly species richness. Here, trend lines show the relationships between environmental variables and species richness, and grey shading represents the 95% confidence interval. We used our model-fitted data to create this plot.
and abundance in the Anthropocene (Fox 2013; Hallmann et al. 2017; Habel et al. 2019; Ubach et al. 2020; Didham et al. 2020). Habitat degradation, deforestation, agricultural intensification, land-use change, insecticide use, climate change, nitrification, invasive and ornamental species, and light pollution are all factors affecting insect populations worldwide (Wagner 2020; Chowdhury et al. 2021a, b). Dhaka is now considered as one of the most polluted cities in the world (Rahman, Mahamud, and Thurston 2019), and it is possible that butterflies are declining in response to increasing pollution levels, intensified use of insecticide/pesticides, increased fogging to control dengue fever, and seasonal mowing. A long-term study is required to investigate how these variables influence butterflies in the world’s most polluted and densely populated cities and how impacts from pollution on butterflies can be mitigated.

There is an urgent need for proactive management of urban green spaces to protect butterfly species from an extensive decline and to allow them to thrive in cities. Measures include increasing butterfly species-specific larval food plant diversity (Madre et al. 2014), increasing flower diversity to cater to a range of butterflies with varying flower-feeding niches (generalists to specialists; Jain, Kunte, and Webb 2016), reducing habitat fragmentation (Gibb and Hochuli 2002; Rosin et al. 2012; Neame, Griswold, and Elle 2013; Haddad et al. 2015) through increasing connectivity between habitat patches (Angold et al. 2006; Sattler et al. 2010; Shanahan et al. 2011; Jain et al. 2020), reducing anthropogenic disturbances and pollution, and management intensity (Aguilera et al. 2019; Chowdhury et al. 2021a, b), and increasing green spaces (Fuller and Gaston 2009; Soga et al. 2015b; Stott et al. 2015; Theodorou et al. 2020). Moreover, the establishment of a vegetation corridor or increased functional connectivity between patches to aid the movement of butterflies across Dhaka city, including butterfly gardens can provide feeding and breeding opportunities for generalist species and stepping stones for others (Jain et al. 2020). Adult butterflies may not always occur in the same areas where the earlier life stages developed, so it is also important to allocate and maintain resources across a variety of habitats, including larval host plants and nectar-producing flowers (Janz 2005; Kitahara, Yumoto, and Kobayashi 2008; Braby et al. 2021; Chowdhury et al. 2017, 2021a, b).

**Data availability**

We have attached the species list as supplementary section, and all the other datasets that we collected during the field surveys or generated during the analysis will be provided upon request.

**Supplementary data**

Supplementary data are available at JUECOL online.

**Conflict of interest statement.** None declared.

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