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Research article

Correlation between resident birds and anthropogenic noise and particulate matter: A case study at Kasetsart University, Bangkok, Thailand

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Abstract

Importance of the work: Urban ecosystems are among the most polluted due to anthropogenic development, with humans and wildlife being affected by this pollution.
Objectives: To examine the presence of some birds and their correlation to pollution in the kind of anthropogenic noise and particulate matter (PM).
Materials & Methods: Sixty bird species were identified in the case study, of which the individual presence of 21 common residents was analyzed for their correlation to pollution using negative binomial regression.
Results: Seven species were significantly correlated to the pollution. Five species (*Pycnonotus goiavier*, *Spilopelia chinensis*, *Pycnonotus conradi*, *Passer montanus* and *Copsychus saularis*) had a negative relationship to anthropogenic noise, while two species (*Dicaeum cruentatum* and *Columba livia*) had a negative relationship to the particulate matter levels PM10 and PM2.5. The results suggested that 14 resident bird species had adapted to living in the urban ecosystem.
Main finding: Suggested policies to minimize the impacts on bird populations on campus were: restricting vehicle access; controlling noise levels; controlling black exhaust smoke emission; and promoting car- and pollution-free travel.

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Introduction

With globalization, there has been continuous development of urban areas worldwide that has resulted in pollution, which affects both humans and wildlife and has been exacerbated by the alteration of natural processes in the urban ecosystem (Livesley et al., 2016). Many studies have investigated the impacts of human activities on wildlife, such as the loss of nesting trees (Isaksson, 2018), undesirable noise disturbance (Bayne et al., 2008), night-time artificial light disturbance and the effects of airborne pollutants (Sanderfoot and Holloway, 2017), all of which are unpredictable in urban ecosystems. Urban birds can respond to environmental changes; therefore, adaptation of migration patterns and population declines serve as useful indicators of environmental quality (Furness et al., 1993; Brown et al., 1997). These depend on birds' tolerance to urban ecosystem environments (Møller, 2008; Nemeth and Brumm, 2010; Møller et al., 2012).

Massive amounts of pollution by human activities are important factors influencing the likelihood of birds inhabiting an urban environment. For example, many of the major pollutants in urban ecosystems are caused by daily human activities, such as traffic, burning rubbish and tree felling for housing and industrialization (Francis et al., 2009; Li et al., 2016a). One common problem in urban ecosystems is noise pollution (Francis et al., 2009; Blickley and Patricelli, 2010). Anthropogenic noise is a major problem associated with the use of cars, ships, trains, planes and various human activities (Forman and Deblinger, 2000). Excessive noise has resulted in some birds migrating from urban habitats to less noisy suburban areas (Samia et al., 2015), along with population decline and behavioral changes (Peris and Pescador, 2004). The major sources of noise in urban areas are transportation systems (Blickley and Patricelli, 2010); therefore, traffic is a major cause of the increased exposure of birds to background noise. Some birds are unable to tolerate the excessive noise levels encountered in urban areas (Patricelli and Blickley, 2006). Reijnen et al. (1995) reported that the population of breeding birds declines as the background noise level increases, because loud noise masks the mating calls of birds that reduces the opportunities for some birds to breed. However, noise pollution is not the only problem in urban ecosystem, with air pollution caused by human activities also having negative effects (Bell et al., 2011; Rai, 2016).

Urban areas contain ecosystems with large concentrations of air pollutants. Many studies (Bayne et al., 2008; Benson, 2013; Sanderfoot and Holloway, 2017; Isaksson, 2018) have indicated that both birds and humans are affected by air pollution. For example, particulate matter 2.5 (PM 2.5) in urban areas is often caused by incomplete combustion of fuel in engines in cars and factories, which operate continuously, while PM10 is generated by the incineration of waste and burning of coal in power plants and these processes cause an accumulation of PM in the air. (Eeva and Lehikoinen, 2000; Belskii and Belskaya, 2013). Both sizes of particles may damage the respiratory system of birds, resulting in increased stress levels, poor immune function, decreased reproductive success and population declines (Sanderfoot and Holloway, 2017), which may be causes of avian absence when there more PM in the air. Consequently, urban ecosystems are among the most polluted due to human activities, especially anthropogenic noise and PM.

The Kasetsart University Bangkhen campus (KU) is located on the outskirts of the Bangkok metropolitan area, which was a rice field 80 years ago. Over time, the area has been developed, with rapid construction of houses. The city has expanded such that there are many additional buildings compared to the original area. This may result directly in habitat loss for a number of bird species (Dobson et al., 2006). KU is surrounded by main roads, which may cause traffic pollution, as mentioned above. Nonetheless, this area contains many green areas containing habitats for urban birds, although any avian residents would experience large quantities of PM and anthropogenic noise (Barber et al., 2010; Blickley and Patricelli, 2010; Shannon et al., 2014; United State Environment Protection Agency, 2021). Both factors might correlate the biodiversity of KU with other research. Therefore, the current study focused on the diversity of urban birds and their correlation to urban noise and particulate pollution. A case study was conducted at KU to explore the importance of birds as indicators of pollution levels in urban areas and to provide supporting information for future habitat management in the area.

Materials and Methods

Study site

The Kasetsart University Bangkhen campus (KU) is located in Bangkok, the capital city of Thailand. KU has a total area of 135.68 ha and contains many buildings and patchy green areas, including rice fields, gardens and planted forests. These green areas are very important for the urban bird community. A survey by Universitas Indonesia of the world's most environmental-friendly universities ranked KU as 45th worldwide and 1st in Thailand (UI Green Metric World University Ranking, 2021). This was largely because the area around the university has scattered green areas, which provide a habitat and food source for a variety of birds in the urban ecosystem. The diversity of animal species increases with increasing green space (Carbó-Ramírez and Zuria, 2011) (Fig. 1).

Data collection

The point count method was used (Bibby et al., 1992) based on the randomization of 109 observation points using systematic sampling, with approximately 200 m between each point. At each point, the number of birds was counted within a circular area with a radius of 30 m (Round and Brockelman, 1998). Taxonomic classification was based on morphological characteristics. Binoculars (8 × 32) were used to confirm species identity (Issa, 2019). Where it was not possible to determine the species of a bird in the field, photographs of the bird were used to confirm identification based on the book "A Guide to the Birds of Thailand" (Lekagul and Round, 2005). Data were collected for 10 min at each sampling point because this was considered a time-efficient timeframe that allowed for a reasonable observation of both species and numbers of birds. A longer timeframe may result in more birds but not provide substantially more useful information. The survey was conducted in the morning (0630–0900 hours) because the birds were most active at that time (Vallejo et al., 2009). This study was performed from December 2019 to March 2020, which is the winter season in Thailand (Chaiyarat et al., 2019).

Environmental pollution data were used as independent variables in the analysis of the effects of noise and air pollution on birds. Noise levels were determined at each sampling point using a sound meter. Background noise measured in this way was considered as anthropogenic noise at KU, which usually emanated from the engines of vehicles, such as motorbikes, cars and buses. The background noise was in the range 26.9–71.3 dB, which includes loud sounds in the upper range and has been shown to impact bird diversity in other studies (Perillo et al., 2017). At the same time as the noise pollution survey, air pollution data, including particulate matter less than 2.5 µm (PM2.5) and particulate matter less than 10 µm (PM 10) both measured in micrograms per cubic meter at the building level, were collected from the KU Tower by the Faculty of Environment, Kasetsart University.

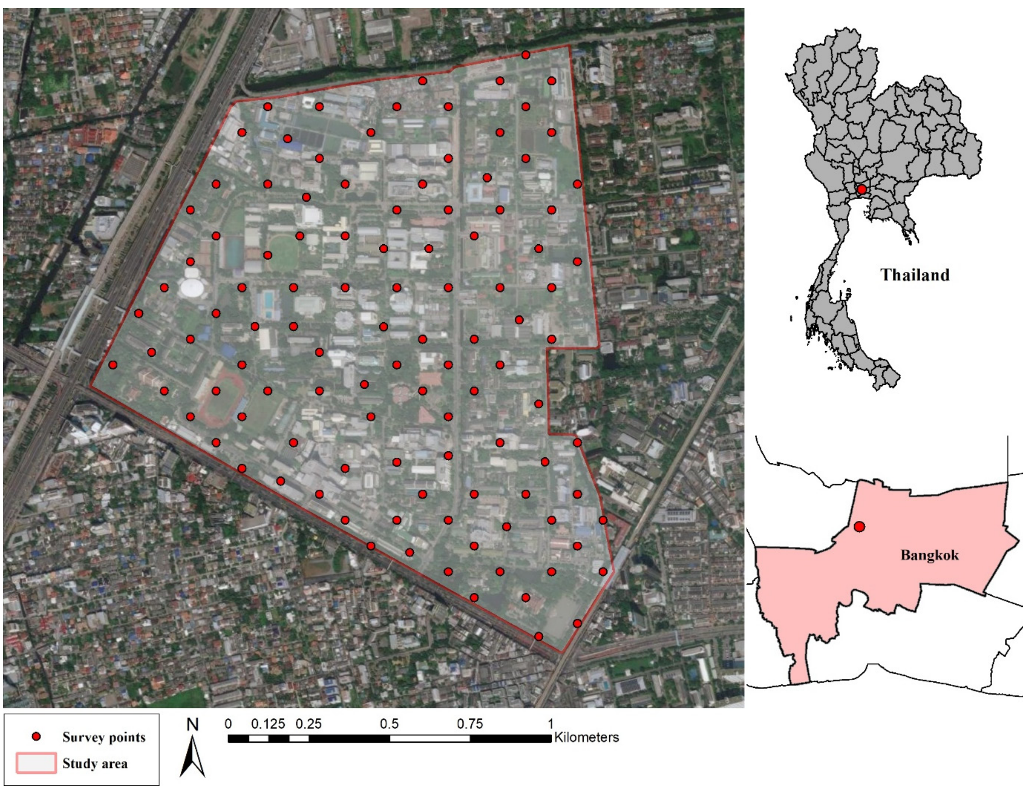

Fig. 1 Bird observation points within study area of Kasetsart University Bangkhen campus, Bangkok, Thailand

Data analysis

The abundance of birds and the dominance of a particular species is difficult to ascertain. Relative abundance (RA) was used as an index of bird species abundance in this study and was reported as the percentage abundance of all birds found in the habitat area. RA is a widely used metric because it is easy to compare between sites and habitats. In this study, this index was used to classify urban birds at KU. The RA was determined using the equation reported by Achacoso et al. (2016), which has been applied in several studies of species diversity.

Relative frequency (RF: the number of points at which a bird is found × 100 / total number of points) was determined, to indicate how often each bird species was found in the habitat area after surveying all sampling points (Volpato et al., 2009). The RF was used to infer the correlation between the birds and urban environmental pollution. A bird species was classed as being present if it had an RF greater than 10%. Only resident birds were included in the analysis because these bird species had greater numbers of samples than visitor birds; this ensured there were sufficient data for efficient and accurate modeling of the correlation of selected bird species to pollution.

The correlation of birds to environmental pollution was analyzed based on a regression model with a negative binomial distribution function, using the "MASS" package in the R program (R Core Team, 2021). A negative binomial regression model is suitable for input data that contained many entries with zero (zero-inflated model). In this case, this reflected the number of survey points that did not appear to be exploited by some bird species (Zuur et al., 2009; R Core Team, 2021). In the simulation, the dependent variable was the number of individual birds determined using the point count method (focus on each species of bird), and the independent variables were environmental factors (the levels of noise, PM 2.5, PM 10). The continuous independent variable was adjusted to a standardized form (mean = 0, SD = 1) before modeling. This allowed evaluation of the effect of a variable on the number of birds present based on coefficients derived from the model, reflecting the correlation of birds to external stimuli.

Results

Bird diversity

Throughout the study period from December 2019 to March 2020, which is the winter season, 420 samples were surveyed from 109 sampling points (December = 109, January = 101, February = 101, March = 109). Sixty species of birds were identified in the KU area and were categorized as resident or non-breeding visitors. The birds represented 52 genera and 33 families in 12 orders, including 33 species of Passeriformes, followed by Coraciiformes and Columbiformes. The Columbidae and Muscicapidae families had the most species (n = 5), followed by the Estrildidae, Ardeidae, and Sturnidae (n = 4), and Cuculidae and Meropidae (n = 3). The bird with the highest RA was *Columba livia* (27.1%), followed by *Passer montanus* (11.7%), *Geopelia striata* (7.6%) and *Pycnonotus conradi* (5.8%), all of which have been reported as resident birds in urban areas, buildings, parks and rice fields (Chaiyarat et al., 2019; Yarnvudhi et al., 2022). The most frequently observed birds were *Col. livia* (85.9%), *Geo. striata* (67.6%), *Pyc. conradi* (67.4%), *Psilopogon haemacephalus* (63.6%) and *Pas. montanus* (63.6%). The next most abundant species in garden areas were *Cinnyris jugularis* and *Dicaeum cruentatum* and garden birds, such as *Ploceus philippinus*, *Merops orientalis* and *Ardeola speciosa* (Table S1).

Relationship to background noise

In total, 21 resident bird species (Table S1) were selected to provide sufficient data for modeling. The coefficients derived from the negative binomial regression model showed the correlations of the different resident bird species to background noise. Seven species of birds correlated negatively to the noise, with the most negative correlation for the resident birds, such as *Pycnonotus goiavier*. Two species of resident birds (*Cypsiurus balasiensis,* and *Col. livia*) had a positive correlation to the background noise (Fig. 2). In this study, 12 bird species were not significantly influenced by noise pollution, representing most of the total bird species analyzed. This indicated that more than one-half of the birds were highly adapted to the urban environment. Accordingly, there was no correlation of these birds to the factors mentioned above (Fig 2).

Relationship to particulate matter

Dic. cruentatum and *Col. livia* were negatively correlated to PM 10 and PM 2.5 in urban air, while *Spilopelia chinensis* and *Geo. striata* were both positively correlated to PM 10 and PM 2.5 (Figs. 3 and 4). Three species of birds were not significantly correlated to PM 2.5; however, they were affected by PM 10. *Aethopyga nipalensis* was negatively correlated, while *Acridotheres tristis* and *Anastomus oscitans* were correlated. This finding suggested that these species may only have been correlated to PM 10 and not PM 2.5. In addition, 14 and 17 species of birds did not have a statistically significant correlation to PM 10 and PM 2.5, respectively, representing most of the total species of resident birds that were analyzed. These results showed that many resident bird species may have been highly tolerant to pollution in the urban environment, such that there was no statistically significant correlation to the factors investigated (Figs. 3 and 4).

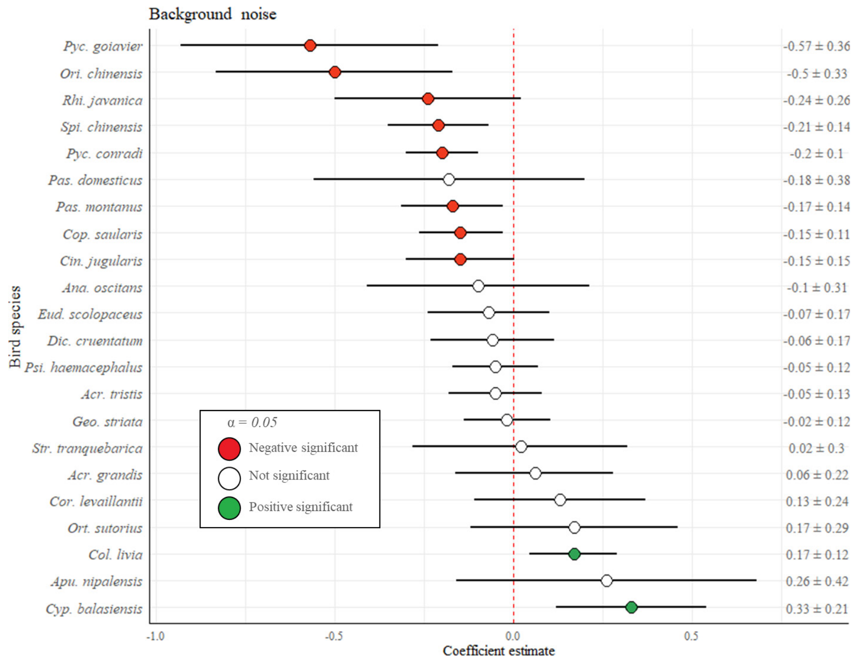

Fig. 2 Coefficient estimates of relationship of bird species to background noise based on negative binomial regression model, where horizontal bars show interval of coefficient estimates at 95% confident interval, blank dots indicate species not statistically significant to the variable ($p \geq 0.05$), red dots indicate species negatively statistically significant ($p < 0.05$ and coefficient less than 0) and green dots refer to species positively statistically significant ($p < 0.05$ and coefficient greater than 0)

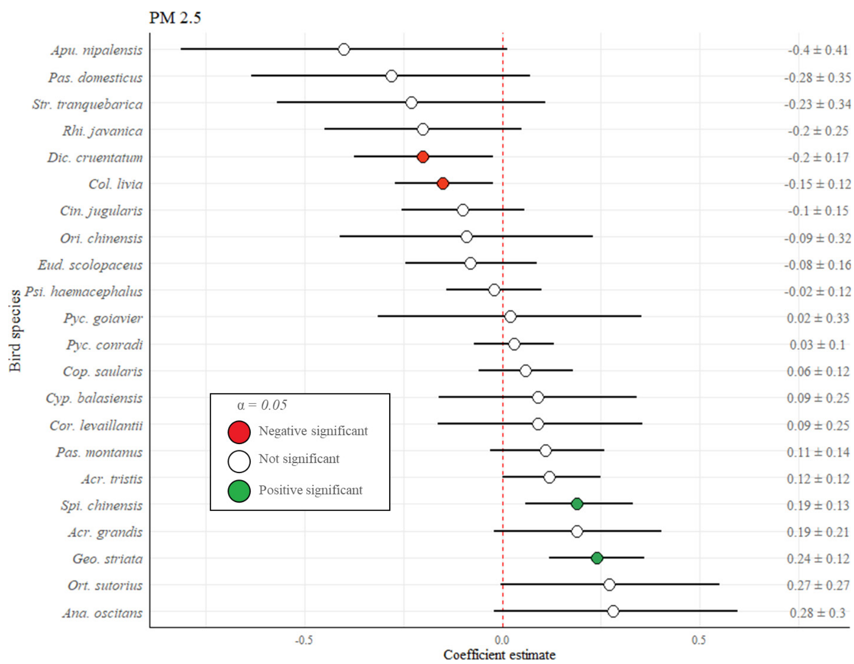

Fig. 3 Coefficient estimates of relationship of bird species to particulate matter 2.5 (PM 2.5) based on negative binomial regression model, where horizontal bars show interval of coefficient estimates at 95% confident interval, blank dots indicate species not statistically significant to the variable ($p \geq 0.05$), red dots indicate species negatively statistically significant ($p < 0.05$ and coefficient less than 0) and green dots refer to species positively statistically significant ($p < 0.05$ and coefficient greater than 0)

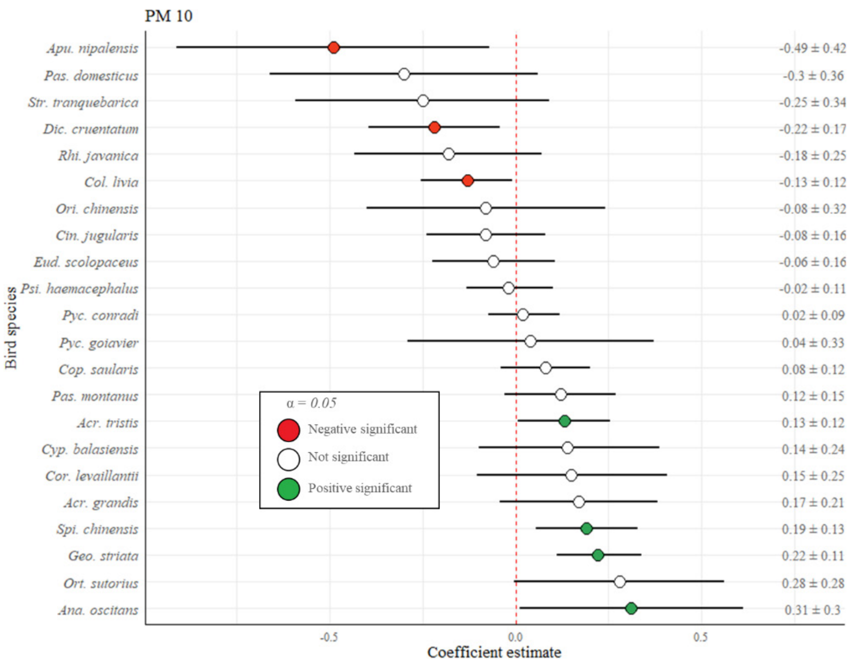

Fig. 4 Coefficient estimates of the relationship of bird species to particulate matter 10 (PM 10) based on negative binomial regression model, where horizontal bars show interval of coefficient estimates at 95% confident interval, blank dots indicate species not statistically significant to the variable ($p \geq 0.05$), red dots indicate species negatively statistically significant ($p < 0.05$ and coefficient less than 0) and green dots refer to species positively statistically significant ($p < 0.05$ and coefficient greater than 0)

Discussion

Bird diversity comparison

The bird diversity results in the study area identified 53 resident species, while other public parks in Bangkok have reported varying numbers of bird species. For example, a park in Chulalongkorn University identified 40 resident birds, Suan Luang Rama IX Park 28 species and Wachirabenchatat Park, 26 species of resident birds. Comparing the diversity of birds with public areas in other provinces, the diversity of resident birds in the KU study area was less than at Suranaree University of Technology (80 species) but more than for Phutthamonthon park (35 species), as shown in Table 1. Compared with the diversity of non-breeding visitors, fewer birds were found in this study than in neighboring areas such as Chulalongkorn University, where 13 species of non-breeding

Table 1 Bird diversity on Kasetsart University Bangkhen campus (KU) and the comparison with other parks and green areas in Thailand

Year	Season	Number of species			Location	Habitat	References
		R	N	Total			
2019–2020	Winter	53	7	60	Kasetsart University (BKK)	Buildings and green patches	This Study
2018–2019	All season	40	13	53	Chulalongkorn University (BKK)	Parks and buildings	Yarnvudhi et al. (2022)
2016–2017	All season	80	14	94	Suranaree University of Technology (NMA)	Parks, green patches and buildings	Naithani et al. (2018)
2018	Summer and rainy	21	-	21	Suan Kwan Mueang, Suan Si Mueang, and Sana Chang Phueak (YLA)	Public parks	Pangsuban and Nikom (2021)
2013	All season	28	6	34	Suan Luang Rama IX (BKK)	Public parks and buildings	Chaiyarat et al. (2019)
2013	All season	35	4	39	Phutthamonthon (NPT)	Public parks, wetlands and buildings	Chaiyarat et al. (2019)
2013	All season	25	3	28	Queen Sirikit (BKK)	Public parks and buildings	Chaiyarat et al. (2019)
2013	All season	26	3	29	Wachirabenchatat (BKK)	Public parks and buildings	Chaiyarat et al. (2019)

R = resident or presumed resident; N = non-breeding visitor; BKK = Bangkok; NMA = Nakhon Ratchasima; YLA = Yala; NPT = Nakhon Pathom visitors were found, because the current study was conducted only during the winter season. Therefore, only winter visitors could be found (Table 1). According to the results, the diversity of birds in Kasetsart University is greater compared to the nearby park area, although only one study was conducted during one season (Chaiyarat et al., 2019; Yarnvudhi et al., 2022). However, the diversity of birds that can be found in urban areas depends on many factors, such as patch size, habitat condition, season and various environmental factors, including urban pollution that directly and indirectly affects bird livelihood (Suarez-Rubio and Thomlinson, 2009; Livesley et al., 2016; Hamza and Hanane, 2021).

Relationship to background noise

Urban ecosystems are extremely challenging habitats for urban wildlife (Kang et al., 2015), with ongoing human activities directly and indirectly affecting the environment of these ecosystems (Bayne et al., 2008; Benson, 2013; Sanderfoot and Holloway, 2017; Isaksson, 2018). Many studies have described the effects of human activities on urban birds, especially the background noise arising from human activities (Gidlöf-Gunnarsson and Ohrström, 2010), most notably from traffic (planes, trains, ships). Within urban areas, the noise levels are often higher due to human activity. Some birds cannot tolerate excessive noise levels (Francis et al., 2009; Phillips et al., 2018); however, other bird species are less sensitive to increased noise levels. For these bird species, urban noise may be superseded by other factors, such as food sources and habitat suitability (Ferger et al., 2014). Even within the same species, birds living in urban areas can be more tolerant to noise than those living in suburban areas, because disturbances in urban ecosystems can prevent birds from adapting to these environments (Møller, 2008; Nemeth and Brumm, 2010; Møller et al., 2012).

In this study, the numbers of *Col. livia* and *Cyp. balasiensis* were higher in areas with more noise intensity. Ciach and Fröhlich (2016) found that birds such as *Col. livia*, *Corvus frugilegus*, *Parus major*, *Gymnorhina* sp., *Coloeus monedula*, *Turdus merula* and *Passer domesticus* congregated in the same areas (those providing food) and benefited from the predator warning signals made by other species. In the current study, *Col. livia* and *Cyp. balasiensis* exhibited colony behavior within the same species and occasionally with other species. This behavior may have resulted from interdependence that protects individuals from danger during foraging and mating in urban ecosystems (Murton et al., 1972; Hails and Turner, 1984).

Bird relationship to particulate matter

Both humans and birds are harmed by air pollution, because clean air is essential for respiration (Sanderfoot and Holloway, 2017; O'Dell et al., 2019). High levels of air pollution can result in lung disease in exposed organisms. There have been many studies of the impacts of urban pollution on bird habitats, with most urban pollution-related problems reported as due to the release of airborne toxic gases from industrial processes (Dauwe et al., 2006); ground-level ozone (O_3, which directly damages society, food sources, nesting areas and shelter) (Liang et al., 2020) and airborne PM emitted from traffic and waste incineration (Sanderfoot and Holloway, 2017; Cascio, 2018; Sanderfoot and Gardner, 2021).

Birds are exposed to more PM than humans because they have a higher respiratory rate and spend more time in the open air (Li et al., 2016b; O'Dell et al., 2019). In particular, ultra-fine particles (PM2.5) are small enough to lodge in the deepest parts of the lungs and affect the respiratory system (Black et al., 2017). Sanderfoot and Holloway (2017) used fluorescent microspheres to study particle accumulation in adult *Col. livia* and found that particles less than 3 μm in diameter tended to diffuse into the respiratory system of birds more readily than particles greater than 6 μm in diameter. They concluded that the presence of some birds may have been more correlated to PM 2.5 than PM 10. This conclusion was consistent with the results of the current study, which found that the presence of 66.6% of the bird species was correlated to PM 10, while 80.1% was correlated to PM 2.5. Almost all the birds investigated in the current study were able to sense the presence of PM. However, two species (*Dic. cruentatum* and *Col. livia*) correlated negatively to both PM 10 and PM 2.5, perhaps because these species may be more affected by both forms of particulate matter. This also suggested that although larger particles do not disperse well in birds' respiratory systems, some birds are still able to detect dust particles in the air (Sanderfoot and Holloway, 2017). Therefore, the presence of these birds could be considered as a good indicator of urban air quality (Brown et al., 1997).

Birds as pollution indicators

When noise and air pollution in large cities are investigated, the impacts on human health are often the focus; however, noise and air pollution also present serious threats to wildlife and to birds in particular (Lovett et al., 2009). Some species of birds thrive in urban ecosystems and these urban species often exhibit prominent phenotypic differences in their behavior, physiology and morphology (Isaksson, 2018; Bressler et al., 2020). These phenotypic changes are linked to specific drivers of urban selection, such as food items and tolerance to air pollution, light, noise and human disturbances (Bayne et al., 2008; Benson, 2013; Sanderfoot and Holloway, 2017; Isaksson, 2018). The correlation of urban birds to noise and air pollution has been evaluated in other studies (Møller, 2008; Nemeth and Brumm, 2010; Møller et al., 2012). Birds can serve as environmental indicators because their presence or absence can indicate the impacts of noise pollution and climate (Brown et al., 1997). Most birds are susceptible to even slight changes in ecosystems (Canterbury et al., 2001). In summary, birds are widely distributed throughout a range of habitats and can be used to measure the quality of various ecosystems (Brown et al., 1997).

In the current study, nine species of birds were correlated to noise pollution. Seven species had a negative correlation and were absent from areas with excessive noise levels. The bird species that could be used as sound pollution indicators in ecosystems were *Pyc. goiavier*, *Rhipidura javanica*, *Spi. chinensis*, *Pyc. conradi* and *Pas. montanus*, while *Dic. cruentatum* and *Col. livia* both had negative correlations to PM 10 and PM 2.5. In areas with high levels of PM, the abundance of these birds decreased. Therefore, either species could serve as an indicator of the level of air pollution. *Col. livia* correlated to both noise and PM; thus, in areas with high-intensity noise, there was a greater chance of *Col. livia* being present. In agricultural areas, gardens and water bodies, which are unsuitable habitats with relatively low levels of noise, these birds are present in small numbers.

Management implications

It is difficult to implement bird habitat management policies in urban ecosystems because the demand for human habitation is overwhelming. However, some degree of environmental management is possible in urban environments. The current study identified that some birds correlated to both noise and PM, which are considered the results of human activities. KU has large volumes of car traffic that is partly responsible for the high level of background noise, resulting in the disappearance of some bird species from the area. Based on the current result, impacts on bird populations could be minimized by: restricting traffic flows around the campus; screening cars on site to prevent noise levels from exceeding the legal threshold, based on the Enhancement and Conservation of National Environmental Quality Act, B.E. 2535 (1992) that states that the loudness of cars should not exceed 85 dB at a distance of 7.5 m or 100 dB at 0.5 m; controlling the emission of black exhaust smoke according to the Enhancement and Conservation of National Environmental Quality Act, B.E. 2535 (1992); reducing open burning of biomass (a major source of PM) to reduce dust emissions; and promoting non-motorized and pollution-free travel, where emission-free travel (electric cars, bicycles, walking) should be preferred over cars. In addition, more studies should be conducted of the effects of other sources of environmental pollution, such as airborne toxins, water pollution and soil contamination, because extremely polluted urban ecosystems may impact both human health and urban wildlife.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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References

Achacoso, S., Walag, A.M.P., Saab, L.L. 2016. A rapid assessment of foliage spider fauna diversity in Sinaloc, El Salvador City, Philippines: A comparison between habitats receiving different degrees of disturbance. Biodiversity 17: 156–161. doi.org/10.1080/14888386.2016.1258331

Barber, J.R., Crooks, K.R., Fristrup, K.M. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends Ecol. Evol. 25: 180–189. doi.org/10.1016/j.tree.2009.08.002

Bayne, E.M., Habib, L., Boutin, S. 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of Songbirds in the Boreal Forest. Conserv. Biol. 22: 1186–1193. doi.org/10.1111/j.1523-1739.2008.00973.x

Bell, J.N.B., Power, S.A., Jarraud, N., Agrawal, M., Davies, C. 2011. The effects of air pollution on urban ecosystems and agriculture. Int. J. Sust. Dev. World 18: 226–235. doi.org/10.1080/13504509.2011.570803

Belskii, E.A., Belskaya, E.A. 2013. Bird population in birch forests of the Southern Urals affected by industrial pollution: Report 1. Reactions of species and the community. Contemp. Probl. Ecol. 6: 315–322. doi.org/10.1134/S1995425513030025

Benson, E. 2013. The urbanization of the Eastern Gray Squirrel in the United States. J. Am. Hist. 100: 691–710. doi.org/10.1093/jahist/jat353

Bibby, C., Burguess, N.D., Hill, D.A. 1992. Bird Census Techniques. Academic Press. London, UK.

Black, C., Gerriets, J.E., Fontaine, J.H., Harper, R.W., Kenyon, N.J., Tablin, F., Schelegle, E. S., Miller, L.A. 2017. Early life wildfire smoke exposure is associated with immune dysregulation and lung function decrements in adolescence. Am. J. Cell Mol. Biol. 56: 657–666. doi.org/10.1165/rcmb.2016-0380OC

Blickley, J.L., Patricelli, G.L. 2010. Impacts of anthropogenic noise on wildlife: Research priorities for the development of standards and mitigation. J. Int. Wildl. Law Policy. 13: 274–292.

Bressler, S.A., Diamant, E.S., Tingley, M.W., Yeh, P.J. 2020. Nests in the cities: Adaptive and non-adaptive phenotypic plasticity and convergence in an urban bird. Proc. R. Soc. B 287: 20202122. doi.org/10.1098/rspb.2020.2122

Brown, R.E., Brain, J.D. Wang, N. 1997. The avian respiratory system: A unique model for studies of respiratory toxicosis and for monitoring air quality. Environ. Health Perspect. 105: 188–200. doi.org/10.1289/ehp.97105188

Canterbury, G.E., Martin, T.E., Petit, D.R., Petit, L.J., Bradford, D.F. 2001. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conserv. Biol. 14: 544–558. doi.org/10.1046/j.1523-1739.2000.98235.x

Carbó-Ramírez, P., Zuria, I. 2011. The value of small urban greenspaces for birds in a Mexican city. Landsc. Urban Plan. 100: 213–222. doi.org/10.1016/j.landurbplan.2010.12.008

Cascio, W.E. 2018. Wildland fire smoke and human health. Sci. Total Environ. 624: 586– 595. doi.org/10.1016/j.scitotenv.2017.12.086

Chaiyarat, R., Wutthithai, O., Punwong, P., Taksintum, W. 2019. Relationships between urban parks and bird diversity in the Bangkok metropolitan area, Thailand. Urban Ecosyst. 22: 201–212. doi.org/10.1007/s11252-018-0807-1

Ciach, M., Fröhlich, A. 2016. Habitat type, food resources, noise and light pollution explain the species composition, abundance and stability of a winter bird assemblage in an urban environment. Urban Ecosyst. 20: 547–559. doi.org/10.1007/s11252-016-0613-6

Dauwe, T., Janssens, E., Eens, M. 2006. Effects of heavy metal exposure on the condition and health of adult great tits (*Parus major*). Environ. Pollut. 140: 71–78. doi.org/10.1016/j.envpol.2005.06.024

Dobson, A., Lodge, D., Alder, J., et al. 2006. Habitat loss, trophic collapse, and the decline of ecosystem services. Ecology 87: 1915–1924. doi.org/10.1890/0012-9658(2006)87[1915:HLTCAT]2.0.CO;2

Eeva, T., Lehikoinen, E. 2000. Recovery of breeding success in wild birds. Nature 403: 851–852. doi.org/10.1038/35002672

Enhancement and Conservation of National Environmental Quality Act, B.E. 2535. 1992. Royal Thai Government Gazette. https://portal.mrcmekong.org/assets/v1/documents/Thai-Law/Enhancement-and-Conservation-of-National-Environmental-Quality-Act-(1992).pdf, 14 February 2022.

Ferger, S.W., Schleuning, M., Hemp, A., Howell, K.M., Böhning-Gaese, K. 2014. Food resources and vegetation structure mediate climatic effects on species richness of birds. Global Ecol. Biogeogr. 23: 541–549. doi.org/10.1111/geb.12151

Forman, R.T.T., Deblinger, R.D. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) Suburban Highway. Conserv. Biol. 14: 36–46.

Francis, C.D., Ortega, C.P., Cruz, A. 2009. Noise pollution changes avian communities and species interactions. Curr. Biol. 19: 1415–1419. doi.org/10.1016/j.cub.2009.06.052

Furness, R.W., Greenwood, J.J.D., Jarvis, P.J. 1993. Can birds be used to monitor the environment? In: Furness, R.W., Greenwood, J.J.D. (Eds.). Birds as Monitors of Environmental Change. Springer International Publishing. Dordrecht, the Netherlands, pp. 1–41.

Gidlöf-Gunnarsson, A., Ohrström, E. 2010. Attractive “quiet” courtyards: A potential modifier of urban residents’ responses to road traffic noise? Int. J. Environ. Res. Public Health 7: 3359–3375. doi.org/10.3390/ijerph7093359

Hails, C., Turner, A.K. 1984. The breeding biology of the Asian Palm Swift *Cypsiurus balasiensis*. IBIS 126: 74–81.

Hamza, F., Hanane, S. 2021. The effect of microhabitat features, anthropogenic pressure and spatial structure on bird diversity in southern Tunisian agroecosystems. Ann. Appl. Biol. 179: 195–206. doi.org/10.1111/aab.12690

Isaksson, C. 2018. Impact of urbanization on birds. In: Tietze, D.T. (Ed.). Bird Species. Springer International Publishing. Cham, Switzerland, pp. 235–257.

Issa, M.A.A. 2019. Diversity and abundance of wild birds species’ in two different habitats at Sharkia Governorate, Egypt. J. Basic Appl. Zool. 80: 34. doi.org/10.1186/s41936-019-0103-5

Kang, W., Minor, E.S., Park, C., Lee, D. 2015. Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. Urban Ecosyst. 18: 857–870. doi.org/10.1007/s11252-014-0433-5

Lekagul, B., Round, P.D. 2005. A Guide to the Birds of Thailand, 2nd ed. Saha Karn Bhaet Co., Ltd., Bangkok, Thailand.

Li, X., Yang, Y., Xu, X., Xu, C., Hong, J. 2016a. Air pollution from polycyclic aromatic hydrocarbons generated by human activities and their health effects in China. J. Cleaner Prod. 112: 1360–1367. doi.org/10.1016/j.jclepro.2015.05.077

Li, Z., Courchamp, F., Blumstein, D.T. 2016b. Pigeons home faster through polluted air. Sci. Rep. 6: 18989. doi.org/10.1038/srep18989

Liang, Y., Rudik, I., Zou, E.Y., Johnston, A., Rodewald, A.D., Kling, C.L. 2020. Conservation cobenefits [*sic*] from air pollution regulation: Evidence from birds. PNAS 117: 30900–30906. doi.org/10.1073/pnas.2013568117

Livesley, S.J., McPherson, E.G., Calfapietra, C. 2016. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. J. Environ Qual. 45: 119–124. doi.org/10.2134/jeq2015.11.0567

Lovett, G.M., Tear, T.H., Evers, D.C., Findlay, S.E.G., Cosby, B.J., Dunscomb, J.K., Driscoll, C.T., Weathers, K.C. 2009. Effects of air pollution on ecosystems and biological diversity in the eastern United States. Ann. N. Y. Acad. Sci. 1162: 99–135. doi.org/10.1111/j.1749-6632.2009.04153.x

Møller, A.P. 2008. Flight distance of urban birds, predation, and selection for urban life. Behav. Ecol. Sociobiol. 63: 63–75. doi.org/10.1007/s00265-008-0636-y

Møller, A.P., Diaz, M., Flensted-Jensen, E., et al. 2012. High urban population density of birds reflects their timing of urbanization. Oecologia 170: 867–875. doi.org/10.1007/s00442-012-2355-3

Murton, R.K., Coombs, C.F.B., Thearle, R.J.P. 1972. Ecological studies of the feral pigeon *Columba livia* Var. II. Flock behaviour and social organization. J. Appl. Ecol. 9: 875–889. doi.org/10.2307/2401910

Naithani, A., Suwanwaree, P., Nadolski, B. 2018. Bird community structure of Suranaree University of Technology Campus, Nakhon Ratchasima Province, Thailand. Pakistan J. Zool. 50: 1257–1265. dx.doi.org/10.17582/journal.pjz/2018.50.4.1257.1265

Nemeth, E., Brumm, H. 2010. Birds and anthropogenic noise: Are urban songs adaptive? Am. Nat. 176: 465–475. doi.org/10.1086/656275

O'Dell, K., Ford, B., Fischer, E.V., Pierce, J.R. 2019. Contribution of wildland-fire smoke to US PM2.5 and its influence on recent trends. Environ. Sci. Technol. 53: 1797–1804. doi.org/10.1021/acs.est.8b05430

Pangsuban, S., Nikom, J. 2021. Bird diversity in urban areas, Yala, Thailand. Ann. Romanian Soc. Cell Biol. 25: 1107–1114.

Patricelli, G.L., Blickley, J.L. 2006. Avian communication in urban noise: Causes and consequences of vocal adjustment. The Auk 123: 639–649. doi.org/10.1093/auk/123.3.639

Perillo, A., Mazzoni, L.G., Passos, L.F., Goulart, V.D.L.R., Duca, C., Young, R.J. 2017. Anthropogenic noise reduces bird species richness and diversity in urban parks. Ibis 159: 638–646. doi.org/10.1111/ibi.12481

Peris, S.J., Pescador, M. 2004. Effects of traffic noise on paserine populations in Mediterranean wooded pastures. Appl. Acoust. 65: 357–366. doi.org/10.1016/j.apacoust.2003.10.005

Phillips, J.N., Gentry, K.E., Luther, D.A., Derryberry, E.P. 2018. Surviving in the city: Higher apparent survival for urban birds but worse condition on noisy territories. Ecosphere 9: e02440. doi.org/10.1002/ecs2.2440

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org/, 14 February 2022.

Rai, P.K. 2016. Biodiversity of roadside plants and their response to air pollution in an Indo-Burma hotspot region: Implications for urban ecosystem restoration. J. Asia Pac. Biodivers. 9: 47–55. doi.org/10.1016/j.japb.2015.10.011

Reijnen, R., Foppen, R., Braak, C.T., Thissen, J. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. J. Appl. Ecol. 32: 187–202. doi.org/10.2307/2404428

Round, P.D., Brockelman, W.Y. 1998. Bird communities in disturbed lowland forest habitats of Southern Thailand. Nat. Hist. Bull. Siam Soc. 46: 171–196.

Samia, D.S.M., Nakagawa, S., Nomura, F., Rangel, T.F., Blumstein, D.T. 2015. Increased tolerance to humans among disturbed wildlife. Nat. Commun. 6: 8877. doi.org/10.1038/ncomms9877

Sanderfoot, O.V., Gardner, B. 2021. Wildfire smoke affects detection of birds in Washington State. Ornithol. Appl. 123: 1–4. doi.org/10.1093/ornithapp/duab028

Sanderfoot, O.V., Holloway, T. 2017. Air pollution impacts on avian species via inhalation exposure and associated outcomes. Environ. Res. Lett. 12: 083002. doi: 10.1088/1748-9326/aa8051

Shannon, G., Angeloni, L.M., Wittemyer, G., Fristrup, K.M., Crooks, K.R. 2014. Road traffic noise modifies behaviour of a keystone species. Anim. Behav. 94: 135–141. doi.org/10.1016/j.anbehav.2014.06.004

Suarez-Rubio, M., Thomlinson, J.R. 2009. Landscape and patch-level factors influence bird communities in an urbanized tropical island. Biol. Conserv. 142: 1311–1321. doi.org/10.1016/j.biocon.2008.12.035

UI Green Metric World University Ranking. 2021. Overall rankings 2021. https://greenmetric.ui.ac.id/rankings/overall-rankings-2021/, 14 February 2022.

United State Environment Protection Agency. 2021. Particulate matter (PM) basics. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics, 14 February 2022.

Vallejo Jr., B.M., Aloy, A.B., Ong, P.S. 2009. Distribution, abundance and diversity of birds in Manila's last greenspaces. Landsc. Urban Plan. 89: 75–85. doi.org/10.1016/j.landurbplan.2008.10.013

Volpato, G.H., Lopes, E.V., Mendonça, L.B., Boçon, R., Bisheimer, M.V., Serafini, P.P., Anjos, L.D. 2009. The use of the point count method for bird survey in the Atlantic forest. Zoologia 26: 74–78. doi.org/10.1590/S1984-46702009000100012

Yarnvudhi, A., Leksungnoen, N., Siri, S., et al. 2022. Monetary evaluation of supporting ecosystem services as a habitat provider for birds in Thailand urban park. Biodiversitas 23: 4747–4758. doi.org/10.13057/biodiv/d230942

Zuur, A., Ieno, E.N., Walker, N., Saveliev, A.A., Smith, G.M. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer. New York, NY, USA.