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Land use and oriental pied-hornbill occurrence in Singapore

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ABSTRACT

Oriental Pied-Hornbills (*Anthracoceros albirostris)* disappeared from Singapore in the 1800s but were returned in the 2000s through a combination of active reintroduction and recolonization. Since then, they have multiplied and even thrived in Singapore, spreading throughout much of the country. Singapore is extremely urban and densely populated, and here we examine where hornbills have been seen as a function of land-use. We combine citizen science data from eBird and iNaturalist with GIS information to model hornbill occurrence. We find that vegetation with no canopy, marshy habitat, and built-up areas have strong positive effects on the probability of hornbill sightings. We interpret our results with respect to larger regional patterns.

1. Introduction

Southeast Asia includes multiple biodiversity hotspots (De Bruyn et al., 2014) but also has one of the highest deforestation rates (Hughes, 2017). Within Southeast Asia, intense urbanization and deforestation have resulted in substantial biodiversity loss in Singapore in particular (Corlett, 1992; Chisholm et al., 2023). While birds may be less dependent on Singapore's nature reserves than other animals (Brook et al., 2003; but see Chisholm et al., 2023), some Singapore bird species have gone locally extinct. The Oriental Pied-Hornbill (*Anthracoceros albirostris)* disappeared from Singapore in the 1800s, and the comprehensive checklist published by Gibson-Hill (1949) did not include these hornbills, even though this species survived in Peninsular Malaysia. In March 1994, after more than a century of absence, a pair was observed at Pulau Ubin, an island in Singapore's northeast (Wong, 2011).

In 2006, Singapore's National Parks Board (www.nparks.gov.sg) and the Wildlife Reserves of Singapore (now Mandai Wildlife Reserves; www.mandai.com/en/singapore-zoo.html) started the Singapore Hornbill Project to reintroduce the hornbills to Singapore (Cremades and Ng, 2012). The team set up artificial nests in previously unoccupied areas, such as southern Bukit Timah (Cremades et al., 2011). The program established populations in Bukit Timah, Pulau Ubin, and Singapore Botanic Garden within a few years (Cremades and Ng, 2012). Some hornbills can survive well in disturbed and fragmented habitats (Marsden and Pilgrim, 2002). Their successful adaptation to Singapore's urban landscape is partly due to their use of cultivated fruits and other species found in urban parks and gardens (Lok et al., 2013; Tan, 2010), and may be aided by their ability to find food sources like other birds' nestlings in an urban environment (Loong et al., 2021).

Although the Singapore Hornbill Project was a success, the Singapore Red Data Book lists the species as "Near Threatened" (www.nparks.gov.sg/biodiversity/wildlife-in-singapore/species-list/bird) as of March 2024. Exploring the occupancy of Oriental Pied-

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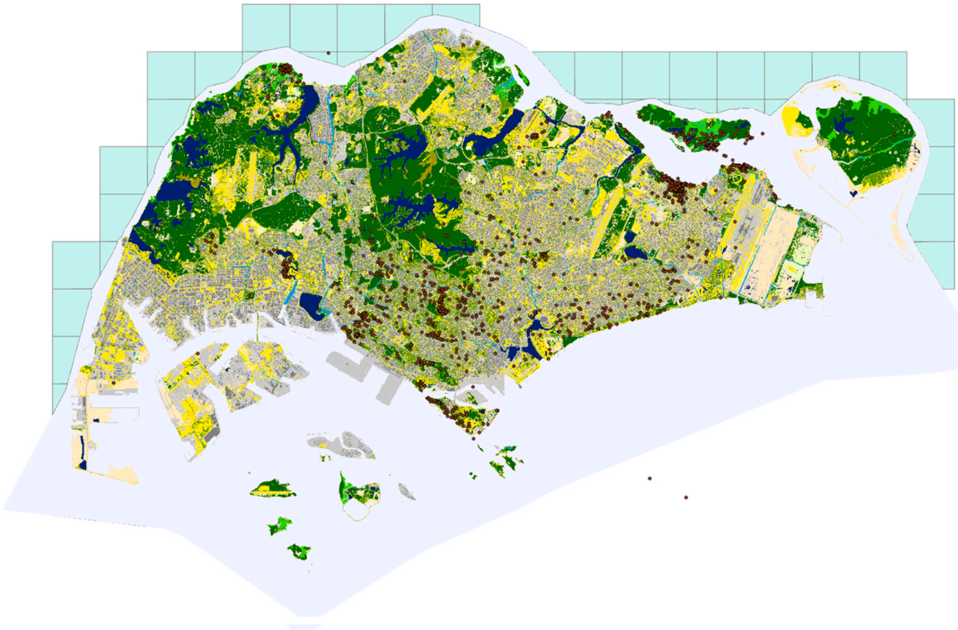

Fig. 1. Map of selected study area of selected 3.0 km grids including Sentosa, excluding the Southern Islands and Bukom island.

Hornbills, and relating hornbill sightings to land-use, has general implications to their reintroduction and colonization into urban environments.

Species distribution modelling (SDM) investigates relationships between species observations and environmental variables, assuming a functional relationship (Miller, 2010), and often using geographical information systems (GIS; Trisurat et al., 2013). Other studies of the Oriental Pied-Hornbills in Singapore used sighting density maps derived from citizen science platforms to explore population distribution (Strange and O'Dempsey, 2022). Citizen or community science platforms, such as eBird (Sullivan et al., 2009) and iNaturalist, can serve as repositories for observations of hornbills, especially in urban areas with high human density and many participants. These platforms include metadata such as date, time and location, which allow the validation of observations through the citizen science community. Although there are potential biases, these databases can offer a viable alternative to other scientific records (Tiago et al., 2017). Oriental Pied-Hornbills are morphologically conspicuous and loud, and because high human population density correlates to sampling density (Prudic et al., 2017), hornbills in Singapore are a suitable object for citizen science studies. This affords us the opportunity to use citizen science data to model where hornbills occur.

Here, we use data from citizen science platforms to model the occurrence of Oriental Pied-Hornbills as a function of land-use variables in Singapore. We hypothesize hornbills will thrive within grids with certain environmental features, and that these features should therefore be considered in conserving Oriental Pied-Hornbills, especially in urban environments. We then compare these qualitative features to Oriental Pied-Hornbill sightings in the region.

2. Materials and methods

We utilized the citizen science platforms, iNaturalist (www.inaturalist.org/) and eBird (ebird.org), and downloaded records of oriental hornbill sightings with spatial information from within Singapore. We excluded specific areas and data due to inaccessibility, such as islands and the ocean (Fig. 1). Data from eBird (https://doi.org/10.15468/dl.pdf5eq) for Oriental Pied-Hornbills for the selected areas of Singapore (downloaded on August 31, 2022) yielded 5195 approved observations from the eBird Basic Dataset (eBird Basic Dataset, 2022) from 1 January 2010–31 July 2022. We downloaded 1089 research-grade sightings from iNaturalist using the query 'species = Anthracoceros albirostris, location = Singapore', from September 2011 to August 2022, from most parts of Singapore, on August 24, 2022 (Fig. 1).

We obtained geographical coordinates of sightings from the metadata of each sighting in the downloaded raw data and used those to map sightings on ArcGIS Pro 3.1.1 (www.esri.com). For land cover data, we included the high-resolution map by Gaw et al. (2019), loaded as a base map of Singapore's national ecosystem cover. ArcGIS Pro 3.1.1 was used as the software to convert the raster map to polygon. The Coordinate Reference Systems used was the localized datum SVY21, commonly used in Singapore (SiReNT, 2020).

An earlier study performing generalized linear models (GLM) using a 2014 map made public by the Singapore Urban Redevelopment Authority (URA; https://www.ura.gov.sg/Corporate) revealed that a grid size of 2.5 km produced the best models (AIC = 199.7; BIC = 219.6; all other grid sizes produced models with AIC > 289.7; BIC > 311.1; Yahya, 2023). In the current analysis, we limited our analysis to 2 km and 3 km square grids, generated as shapefiles and layered onto the Gaw et al. (2019) map in ArcGIS. We obtained a list of spatial features in each grid by using the union tool in ArcGIS pro followed by the spatial join tool with the option *join*

Table 1
Initial main and interaction effects for GLM, before stepwise deletion of effects.

Main Effects	Interaction Effects
Builtup	Builtup:Marsh
Mangrove	Builtup:Vegetation with No Canopy
Marsh	Marsh:Vegetation with No Canopy
Pervious	
Sea	
Vegetation with Canopy	
Vegetation with No Canopy	
Vegetation with Structure with Canopy	
Vegetation with Structure without Canopy	
Water	

Table 2
Optimized final models for probability in hornbill sighting as response variable for the grid scale of 2.0 km, and 3.0 km squares with predictor variables.

Model	Explanatory Variables	AIC	BIC	Estimate	Standard Error	Pr(>|z|)
Null Model (2 km)	No variables	415.96	419.74	−0.64	0.12	5.54e−08***
2 km		308.44	323.53			
	Intercept			−2.50	0.29	2e−16***
	Built-up			3.03	0.81	0.000175 ***
	Vegetation without canopy			16.24	2.28	9.49e−13***
	Marsh			9.80	4.60	0.033 **
Null Model (3 km)	No variables	206.74	209.74	−0.11	0.16	0.511
3 km		141.37	153.36			
	Intercept			−2.31	0.41	1.51e−08***
	Built-up			5.52	1.48	0.000199 ***
	Vegetation without canopy			17.42	4.31	5.24e−05***
	Marsh			21.21	10.17	0.037072*

one to one to record sightings. The bounding area of map was defined by selecting the grids with the Select function on ArcGIS, followed with removal of grids made up entirely of sea, or inaccessible areas such as the military sites.

For each grid square we calculated the percentage land-use of the total area, as determined by the Gaw et al. (2019) map, which lists thirteen land-use notations (Table A1). To facilitate a simpler yet robust ecosystem cover, we combined some land-use types into variables "built-up", "water", and combined freshwater marshes and freshwater swamp forests into "marsh" because these constituted a total of only 0.4 % of Singapore's total area (Table A1).

We constructed GLM for grid sizes 2.0 km and 3.0 km with binomial error distribution (McCullagh and Nelder, 1989) in R Studio version 2023.06.0 (R Development Core Team, 2023), where sighting was a binary response variable, i.e., we did not include the number of sightings within a grid. We initially included the ten land-use categories as main predictors, and interaction terms between three pairs of predictors (Table 1). We enhanced model performance with stepwise logistic regression by iterative deletion of predictors based on statistical significance (Kassambara, 2018). We chose the candidate model with the lowest AIC and BIC (Burnham and Anderson, 2002). We predicted marginal effects of the selected model with other effects held constant at their mean values using the R package *sjPlot* with the function plot_model (Lüdecke, 2023).

3. Results

After stepwise deletion of non-significant predictors (Table B1), both optimized GLM for 2.0 km and 3.0 km grid size contained similar significant predictors and neither included any significant interaction terms. For either grid size, percentages of land that were built-up, marsh, or vegetation without canopy were significant predictors of hornbill sightings (Table 2). The 3.0 km grid sized produced the lowest AIC (141.37) and BIC (153.36), values less than half those of the 2.0 km grid size (Table 2). We therefore consider the 3.0 km grid size for the rest of our analysis (Burnham and Anderson, 2002).

We summarized statistics of grids with and without sightings (Table B2). Hornbills were sighted in grids with higher percentages of most land-uses except sea. Interestingly, grids with hornbill sightings had, on average, about twice the percentages of built-up land-use (26.85 %), vegetation without canopy (10.50 %), and marsh cover (0.92 %), as grids without sightings (10.95 %; 5.02 %, and 0.50 %, respectively; Table B2).

Predicted marginal probabilities of hornbill sightings were positively related to all three significant land-use predictors (Fig. 2). All else being equal, probability of hornbill sighting rose fairly steadily with percent built-up cover (Fig. 2a). The probability of hornbill sightings also rose from roughly 25 % to more than 90 % as percent vegetation without canopy rose to roughly 50 % (Fig. 2b). The strongest effect was due to marsh cover, which increased the probability of hornbill sighting from roughly 50 % to 100 % as marsh cover rose to about 25 % (Fig. 2c).

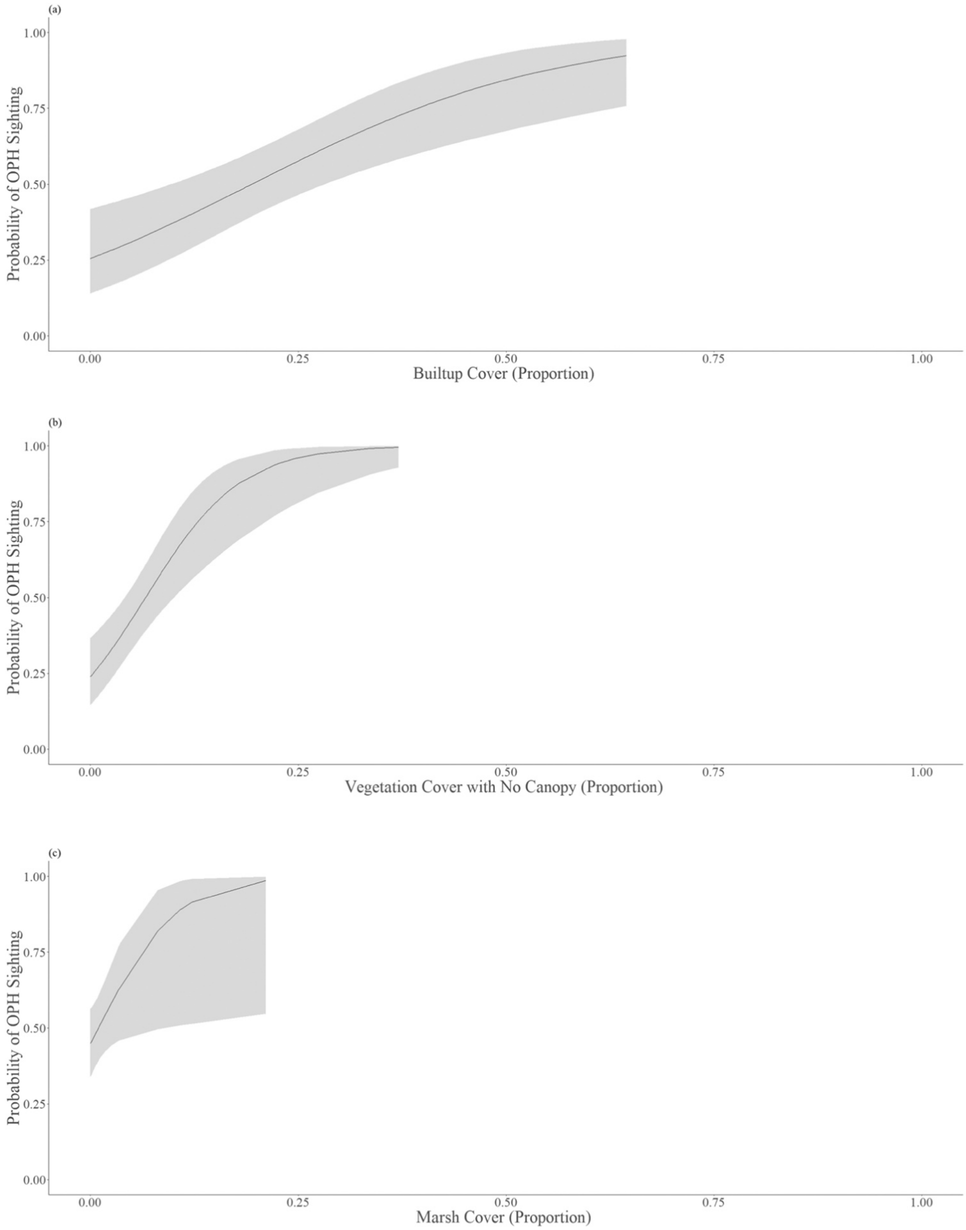

Fig. 2. Marginal relationships between the predicted probability of hornbill sightings and land use for (a) built-up; (b) vegetation without canopy; and (c) marsh. Curves derived from GLM model for 3.0 km grids (Table 2); shaded regions show 95 % confidence intervals around each curve. X-axes constrained to observed values with hornbill sightings.

4. Discussion

Our presence-only data, derived from citizen science observations, reveal factors in land use that predict occurrence of Oriental Pied-Hornbills. Overall, the percentages of built-up land, vegetation without canopy, and marsh cover within 3.0 km grids were positive predictors of the sighting of Oriental Pied-Hornbills in Singapore. These findings largely agree with published Oriental Pied-Hornbills' habitat criteria (Kemp, 1995). Oriental Pied-Hornbills tend to live at forest edges, near coastal mangroves and other waterways, and on forested islands (Ng et al., 2011). Vegetation without canopy and marsh cover are likely near forest edges and waterways. However, we found that percent built-up land-use was also positively related hornbill sightings. In fact, the percentage of built-up area was twice a high in grids with hornbill sightings as in grids without sightings. The map we used to categorize land use (Gaw et al., 2019) does not include beach habitat. An earlier study (Yahya, 2023) found that beach cover was also a strong predictor of hornbill sightings. That positive relationship may also be due to hornbills living in coastal lowlands, where beaches are nearby.

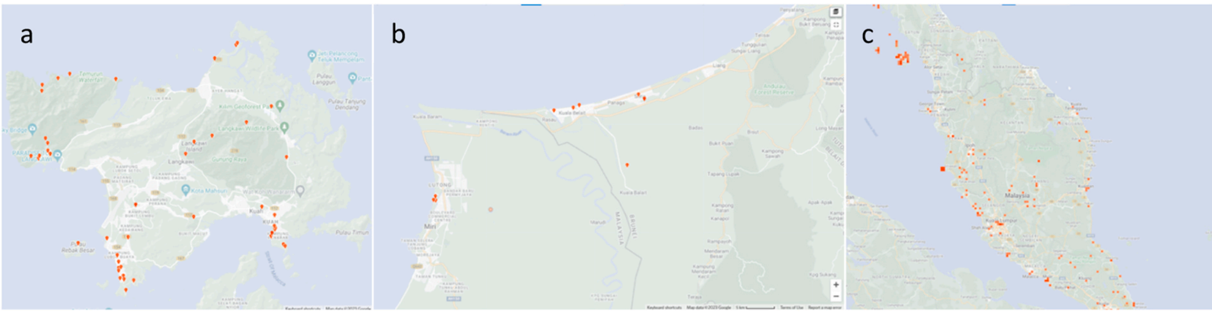

Fig. 3. Maps of all records of Oriental Pied-Hornbill observations on iNaturalist in (a) Langkawi, Malaysia; (b) the west coast of Sarawak and Brunei; (c) Peninsular Malaysia. Red markings indicate research grade observations.

One explanation for these patterns is sampling bias. People frequent open areas like parks with little canopy cover and areas near marshes or beaches. Hornbills are easy to see and identify. Frequent sightings in built-up areas might also indicate a sampling bias where there are more people. Studies with small samples often suffer from observation bias (Pearson et al., 2006). However, both Singapore's built-up areas and nature reserves are frequently visited by birdwatchers and other nature observers. Because our study occurred in a country where many citizen and community scientists could contribute observations (Lloyd et al., 2020; Hall et al., 2021), we were able to include over 6000 records. We also limited our study to the occurrence, rather than the frequency, of hornbill sightings. These approaches should have reduced more egregious sampling biases.

Alternatively, Oriental Pied-Hornbills could genuinely be tolerant of human disturbance. The positive relationships we found between relatively open and built-up areas and hornbill sightings could reflect the ease with which hornbills have taken to living in Singapore. Anecdotal evidence supports this latter explanation. People in Singapore regularly see hornbills in housing estates and near blocks of flats – or perched on rooftops and balconies. Some facets of living in Singapore may make hornbills' lives easier, including the cultivated fruit (Lok et al., 2013; Tan, 2010), and the ease with which they find other birds' nestlings to eat (Loong et al., 2021). There may be fewer large avian predators that prey on Oriental Pied-Hornbills in Singapore compared to less urban areas as well.

We can compare the distribution of Oriental Pied-Hornbill sightings regionwide on iNaturalist to the patterns we found in Singapore. We focus on three sites: Langkawi, Peninsular Malaysia; Miri, Eastern Malaysia; and Brunei. We used all observations as of October 05, 2023 (Fig. 3). In Langkawi, sightings were abundant on the three beaches, along lowland coastal areas, and a few sightings ($n = 4$) were in the Wildlife Park in the center of the island (Fig. 3a). We found similar patterns in Miri, Malaysia, and in Brunei, where almost all sightings were near coasts and beaches (Fig. 3b). On a larger scale in Peninsular Malaysia, almost all sightings are in coastal regions. Inland sightings are generally along waterways and other wetlands, in low forests, and typically less than 50 m elevation (Fig. 3c). We cannot ascertain from these iNaturalist maps the degree of canopy cover, but sightings near beaches suggest that Oriental Pied-Hornbills often live in relatively open, low areas outside of Singapore, too. Wee et al. (2024) found a similar pattern, where MaxEnt models predicted the highest probabilities of Oriental Pied-Hornbill occurrences along the coasts of Sarawak or north of Loagan Bunut National Park (elevation 36 m) near Long Lama (see Fig. A.4 in Wee et al., 2024).

Identifying land-use features that allow hornbills to thrive can facilitate developing guiding principles in selecting a conservation area. Piasau Nature Reserve in Malaysia (https://piasaunaturereserve.com.my) may be one such successful case. Piasau was formerly a residential area for oil industry workers, and its vegetation includes inland coastal forest and sandy beach vegetation. Located at the beach near Miri River and 5 km north of Miri City, it was planned as a tourist resort (Konijnendijk, 2018). However, because of the presence of a breeding pair of Oriental Pied-Hornbills, it was converted into a nature park to facilitate Oriental Pied-Hornbill conservation. As a former residential area, much of Piasau is built up, and parts have vegetation without canopy.

The century-plus disappearance of Oriental Pied-Hornbills demonstrated that intense urbanization could drive this species locally extinct. However, while still near threatened in Singapore, their return shows that they are resilient and can thrive in an urban environment. The patterns we describe highlight the importance of urban land-use in conservation and management plans for Oriental Pied-Hornbills. For example, if Oriental Pied-Hornbills live in open vegetative habitat, near marshy areas or other wetlands, and are often seen near beaches (Yahya, 2023), then nesting boxes near those areas should be particularly effective.

5. Conclusion

We describe a model that estimates land-use that predicts the probability of Oriental Pied-Hornbill sightings. Percent built-up, marsh, and vegetation without canopy, are positively associated with hornbill sightings. Oriental Pied-Hornbills outside of Singapore are often found near water and beach habitat, and in very low elevation forests (e.g., Fig. 3), which is broadly consistent with our findings. The positive relationship between built-up land use and hornbill sightings shows that Oriental Pied-Hornbills at the very least tolerate urban environments. Our analysis demonstrates that citizen science data can be valuable in predicting species occurrence, especially in urban environments with lots of participants. Conservation managers can use similar analyses for predicting land-use important to other urban wildlife. Our study will also assist conservation managers in land-scarce Singapore where there are many competing land uses.

Ethical approval

This study was purely observational; animals were not handled, manipulated, or fed in any way. Many of the observations were carried out by community scientists in Singapore.

Declaration of Competing Interest

The authors have no competing financial or non-financial interests that are directly or indirectly related to this study.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e03060.

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