Assessing the Suitability of Habitats for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Urban Wetlands of Peninsular Malaysia

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Highlights

- Based on the habitat suitability modelling for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*, it was concluded that vast areas of Paya Indah and Putrajaya wetlands were unsuitable for the survival and sustenance of the waterbird species' populations.

- The occurrence and distribution of the waterbird species in the two urban wetlands were impacted by the landscape, climate and hydrological factors.

- The Putrajaya wetland provided a better environment for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* populations than the Paya Indah wetland.
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**Abstract:** It becomes imperative to understand the eco-climatic predictors and know the suitable habitat for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in the urban wetlands to prevent their local extinction. The study explored the habitat suitability for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* surveyed using the point count technique, and a stratified random design. The maximum entropy modelling (MEM) approach and geographic information systems employed to determine the influence of 17 eco-climatic factors on the suitable habitats for the species. Water at a minimum depth (44.30%) and rainfall (74.20%) contributed to the availability of suitable habitats for *Porphyrio porphyrio indicus* in Paya Indah and Putrajaya wetlands. Also, dissolved oxygen (56.60%) and salinity (43.50%) contributed to habitat suitability for *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. Large portions of the two urban wetlands were unsuitable for the *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* populations because of several eco-climatic factors. Thus, the models as management tools with a robust population monitoring database and framework would enhance the management effectiveness of the two species and urban wetlands.

**Keywords:** Urban Wetlands, Climate Variability, Hydrology, Rails, Peninsular Malaysia

**Abstrak:** Pemahaman terhadap ramalan eko-iklim dan mengetahui habitat yang sesuai untuk *Porphyrio porphyrio indicus* dan *Amaurornis phoenicurus* di tanah paya bandar adalah penting untuk mengelakkan kepupusan. Kajian ini meneroka kesesuaian habitat untuk *Porphyrio porphyrio indicus* dan *Amaurornis phoenicurus* di tanah paya Paya Indah dan tanah paya Putrajaya di Semenanjung Malaysia. *Porphyrio porphyrio indicus* dan *Amaurornis phoenicurus* ditinjau menggunakan teknik kiraan titik dan reka bentuk rawak berstrata. Pendekatan pemodelan entropi maksimum (MEM) dan sistem maklumat geografi...
INTRODUCTION

Urban wetlands are fragile environments with high vulnerability to ecological change and environmental stressors caused by anthropogenic activities and climatic variability or change (Kansiime et al. 2007; Ehrenfeld 2008; Brinkmann et al. 2020). The urban wetlands are one of the most diverse ecosystems across the country because of the vegetation phytosociological characteristics, unpredictable rainfall patterns, and occurrences of contiguous, different adjoining landscapes (Rajpar & Zakaria 2014). Malaysia harboured fascinating, extensive natural and artificial urban wetland habitats with a wide variety of waterbirds, especially swamphens, waterhens, moorhens and watercocks (Zakaria et al. 2009; Martins et al. 2017; BirdLife International 2020). Nine species of family Rallidae with the International Union of Conservation and Nature (IUCN) conservation status of “least concern” occur in Malaysia (Wetlands International 2018).

Purple swamphen (*Porphyrio porphyrio indicus*) and white-breasted waterhen (*Amaurornis phoenicurus*) are species belonging to one of the most diverse families of waterbirds in Peninsular Malaysia referred to as the family Rallidae (Rails, Gallinules and Coots). Apart from Malaysia, *Porphyrio porphyrio indicus* distributed in South and Southeast Asia, Oceania, the Middle East, sub-Saharan Africa, Australia and the Mediterranean basin (Bara et al. 2014; Taylor 2016; Mundkur et al. 2017). The species associated with wetlands and dense marsh vegetation containing *Phragmites* spp. and *Typha* spp. (Taylor & Van Perlo 1998; Pearlstine & Ortiz 2009). *Amaurornis phoenicurus* connected to swamppy environments and has a smaller range distributed across South and Southeast Asia (BirdLife International 2016).

The *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* do not approach the threshold for “vulnerable” under the range size criterion and classified as “least concern” (BirdLife International 2016). Habitat loss, invasive species and human interventions within the urban wetland ecosystems in Malaysia threatened the two species. The species distribution, vegetation dynamics, water and food resources, protection from predators and climatic conditions in the urban wetlands

Kata kunci: Tanah Paya Bandar, Perbezaan Iklim, Hidrologi, Rel, Semenanjung Malaysia
exacerbates the risk of local extinction (Zakaria & Rajpar 2010; Rajpar & Zakaria 2014). Even Wainger and Mazzotta (2011), Salari et al. (2014) and Gumbrecht et al. (2017) opined that the limited knowledge on the wetlands’ environmental and climatic characteristics hindered a proper understanding of the distribution and management effectiveness of their biological resources.

Based on this premise, it has become imperative that suitable habitats with immense scientific value and eco-climatic predictors for the survival and sustenance of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* populations in the urban wetlands of Malaysia determined. Habitat suitability model (HSM) development remains an effective tool for determining the ecological and microclimatic factors that influence waterbird species’ distribution within the wetlands in an urban setting. In the past three decades, the usage of HSMs to predict the likelihood of species occurrence (Hirzel & Lay 2008) or presence/absence (Rushton et al. 2004) or distribution (Franklin 1995; Guisan & Zimmerman 2000) has increased as it relates to environmental variables in a particular area. Several approaches involved in the variable selection of factors during habitat suitability modelling.

These approaches include climatic envelopes (Busby 1991; Carpenter et al. 1993; Hijmans et al. 2001), multivariate adaptive regression splines (Friedman 1991), Bayesian approach (Tucker et al. 1997), genetic algorithms (Stockwell & Peters 1999), random forest (Breiman 2001a; 2001b), artificial neural networks (Pearson et al. 2002; Thuiller 2003; Thuiller et al. 2009), generalised additive models (Thuiller 2003; Thuiller et al. 2009), generalised regression analysis and spatial prediction (Lehmann et al. 2003), generalised linear models (Thuiller 2003; Thuiller et al. 2009), classification, and regression trees (Thuiller 2003; Thuiller et al. 2009), ecological niche factor analysis (Hirzel et al. 2001; David & Stockwell 2006), maximum entropy (Phillips et al. 2006), generalised dissimilarity modelling (Ferrier et al. 2007), and support vector machines (Vapnik & Izmailov 2018).

Amidst these approaches, some employed presence only or presence and absence background data to predict species’ distribution. Hence, these approaches involved in various studies on habitat suitability modelling of waterbirds. For instance, Vallecillo et al. (2016) investigated the factors that influenced these avian groups’ distribution using the maximum entropy. Elith et al. (2006) and Aguirre-Gutiérrez et al. (2013) argued that the method offered better predictive performance, especially for presence-only data using background data and model performance evaluation. This method used the background data to account for sampling bias and to resolve non-detectability, false absences or false negatives associated with mobile organisms (Phillips et al. 2006), such as waterbird species.

Several authors employed the capability of maximum entropy to assess the habitat suitable for waterbirds across the globe. For instance, Kassara et al. (2017) predicted the suitability of wintering grounds for Eleonora’s falcons in Madagascar by integrating satellite and Global Positioning System data. Wang et al. (2019) determined the suitable habitat for conserving the red-crowned crane and migratory waterfowls in the Nenjiang River basin of Northeast China. Li et al. (2021) determined the wintering Anatidae habitats in the Gorges Reservoir Region, China. Nagy et al. (2021) explored maximum entropy with other three statistical
modelling techniques (generalised linear model, boosted regression tree gradient boosted machine) to assess the climate change impact on waterbird species in the African-Eurasian flyways. Neice and McRae (2021) mapped the habitat suitable for the Eastern Black Rail throughout its Atlantic coastal range using the maximum entropy. Therefore, this research explored the maximum entropy to determine the eco-climatic predictors and habitats suitable for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in urban wetlands (Paya Indah and Putrajaya) of Peninsular Malaysia.

**MATERIALS AND METHODS**

**Study Areas**

The study undertook in the Paya Indah and Putrajaya wetlands of Peninsular Malaysia (Fig. 1). Paya Indah and Putrajaya wetlands are the largest urban wetlands in the most developed state (Selangor) and fastest-growing region (Putrajaya) of Peninsular Malaysia. Paya Indah wetland is located within 101°36.39′E to 101°36.85′E longitude and 2°51.35′N to 2°51.59N latitude, next to the administrative area of Putrajaya (Rajpar *et al.* 2017). It covers a landmass of 450 ha managed by the Department of Wildlife and National Park, Peninsular Malaysia (Salari *et al.* 2014). It comprises of 14 ex-tin mine water ponds, a disturbed forest and an undisturbed peat swamp forest (Rajpar & Zakaria 2012). It has five land use/land cover (LULC) classes – marsh swamps, a lotus swamp, a lake, an open area with scattered trees, and scrublands (Rajpar *et al.* 2017), and 20 waterbird species recorded in the wetland (Zakaria & Rajpar 2010).

![Figure 1: Paya Indah and Putrajaya wetlands of the Peninsular Malaysia.](image-url)
Putrajaya wetland is located within 101°41.90′E to 101°42.43′E longitude and 2°57.71′N and 2°57.81′N in Putrajaya of Peninsular Malaysia (Rajpar & Zakaria 2013). It covers a landmass of 200 ha with five LULC areas containing the planted area, open water, islands, inundated area and walking trails. The wetland comprises of 24 cells that primarily control the water level and trap pollutants derived from upstream sources from flowing into the catchment areas of the Chua and Bisa rivers. It comprises four vegetation classes of aquatic plants with emergent plants, fruiting trees, flowering trees and bushes, and shrubs (Rajpar & Zakaria 2013).

**Occurrence Data of the Species**

The point count technique employed to collect the occurrence data of the two studied species – *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* (Bibby et al. 2000; Wretenberg et al. 2006; Tozer et al. 2010; Lloyd & Doyle 2011). The bird survey spanned from November 2016 to January 2019. Fifty-seven and 54 count stations in Paya Indah and Putrajaya wetlands placed based on their visibility, using binoculars with at least 100 m intervals apart to avoid the double count of the same avian species in the same count station. Also, the double count avoided by involving two survey teams simultaneously within the same period at adjacent count stations. The bird count surveys in each count station with a maximum variable radius of 100 m for 10 min conducted from 0730 am to 1100 am. Hutto and Young (2002) recommended the ten-minute counts to reduce the number of birds ignored.

These surveys carried out four times within a week during the 26 consecutive months. The bird survey in each point count station done 20 times and pooled for analysis. The abundance dataset of each studied waterbird species pooled to understand its trend and avoid its random fluctuation. Because of the inability to reach the actual locations of the *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*, the distance between the observer and waterbird species measured at each count station using the Hypsometer (TruePulse R 200x model). The occurrence sites estimated based on the direction and distance between the observer and the studied waterbird species. The efficient design ensured a reduced bias with improved data accuracy and precision (Dunn et al. 2006). The data recorded in the survey are the name of the lake, species observed on the lake, the total number sighted, vegetation type, land use and time sighted.

**Data Acquisition and Modelling**

This study involved four stages of the modelling process (Fig. 2).
Figure 2: Framework for habitat suitability modelling of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands of Peninsular Malaysia.

**Data acquisition**

Satellite imageries and climatic/hydrology data downloaded and collected to provide the primary source of data required as explanatory variables. The collection of ground truth points required for model validation. Sentinel 2A MSI Level-1C satellite imageries sourced from the United States Geological Survey (USGS) archives at scales of 10 m resolutions via Global Visualisation Viewer. These images captured during the driest month (9 April 2018) to minimise the interference from cloud cover and to depict the state of LULC and water coverage of the sites. The satellite data used as the principal source of data for the extraction of LULC, Normalized Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI).

Climatic factors (relative humidity, rainfall, wind speed, atmospheric pressure and atmospheric temperature) got from the three recording stations of the National Climate Center, Malaysian Meteorological Department, Malaysia. These recording stations are Kuala Lumpur International Airport, Sepang; Petaling Jaya; and Pusat Pert., Serdang. The distance between the recording stations and the study sites varied from 4.30 km to 27.73 km. The hydrological data (electrical conductivity, dissolved oxygen, water quality index) (House & Ellis 1987; Breaban
et al. 2012), turbidity, temperature, salinity, pH, minimum depth and maximum depth) collected from the National Hydraulic Research Institute of Malaysia.

Three factors (water quality index, minimum depth and maximum depth) not included in the habitat suitable modelling for the two studied species in Putrajaya wetlands. This limitation caused by non-available data at the National Hydraulic Research Institute of Malaysia and the National Climate Center, Malaysian Meteorological Department, Malaysia. The hydrological and climatic data collected from November 2016 to January 2019 to coincide with the study period. However, the seventeen eco-climatic factors (Table 1) are LULC, NDVI, NDWI, electrical conductivity, dissolved oxygen, water quality index, turbidity, temperature, salinity, pH, minimum depth, maximum depth, relative humidity, rainfall, wind speed, atmospheric pressure and atmospheric temperature.

**Table 1**: Attributes of the environmental factors in Paya Indah and Putrajaya wetlands.

| Parameters                        | Paya Indah                   | Putrajaya                   |
|-----------------------------------|------------------------------|------------------------------|
| **Climatic**                      |                              |                              |
| Atmospheric pressure (Hpa)        | 1009.203–1009.325            | 1009.436–1009.935            |
| Wind Speed (m/s)                  | 1.487–1.618                  | 1.361–1.383                  |
| Rainfall (mm)                     | 9.976–10.691                 | 8.525–9.027                  |
| Relative Humidity (%)             | 27.855–77.530                | 76.958–78.016                |
| Atmospheric temperature (°C)      | 27.741–27.773                | 27.309–27.564                |
| **Hydrological**                  |                              |                              |
| Water temperature (°C)            | 24.45–30.79                  | 29.94–30.72                  |
| pH                                | 5.73–9.05                    | 7.35–7.58                    |
| Dissolved oxygen (mg/L)           | 4.47–8.22                    | 6.12–7.35                    |
| Electrical conductivity (uS/cm)   | 15.49–41.18                  | 59.78–152.31                 |
| Salinity (ppt)                    | 0.50–5.04                    | 0.03–0.08                    |
| Turbidity (NTU)                   | 2.02–23.73                   | 12.67–76.85                  |
| Maximum depth (m)                 | 3.12–20.74                   | Not Determined               |
| Minimum depth (m)                 | 0.65–5.92                    | Not Determined               |
| Water quality index               | 50.66–80.24                  | Not Determined               |
| Land use/land cover classes (LULC)|                              |                              |
| Marsh swamp/lotus swamp/grassy vegetation | 310.24 (19.64)            | 345.38 (24.31)               |
| Semi-closed secondary forest      | 391.77 (24.80)               | 395.79 (27.87)               |
| Shrubland                         | 372.75 (23.60)               | 0.00 (0.00)                  |

(Continued on next page)
Table 1 (Continued)

| Parameters                                      | Wetlands          |
|------------------------------------------------|-------------------|
|                                                 | Paya Indah | Putrajaya |
| Bare ground/built-up areas                      | 131.54 (8.33)   | 367.61 (25.88) |
| Lakes                                           | 373.25 (23.63)  | 311.57 (21.94) |
| Normalised difference water index (NDWI)        |               |           |
| Water areas                                     | 1175.23 (74.40) | 1255.79 (88.41) |
| Non-water areas                                 | 404.32 (25.60)  | 164.56 (11.59) |
| Normalised difference vegetation index (NDVI)   |               |           |
| Vegetated areas                                 | 1159.96 (73.44) | 1139.86 (80.25) |
| Non-vegetated areas                             | 419.59 (26.56)  | 280.49 (19.75) |

Note: Each cell in LULC, NDWI and NDVI signifies “land cover area in hectares” (proportion in %).

**Image Pre-processing**

The Sentinel 2A bands had already been atmospherically corrected with the bands in the dataset containing true top of atmosphere reflectance integer units. The raster subjected to geometric and radiometric corrections using histogram equalisation, haze and noise reduction functions in ERDAS Imaging 2014 software (ERDAS 2014). The spatial reference systems (World Geodetic System 1984) of the wetlands’ satellite imagery datasets and vector data (places, roads, lakes, boundaries) transformed and projected to the Malaysian local projected coordinate system (Selangor GDM 2000).

**Creation of Factor Maps/Data Conversion**

This study used four criteria (hydrology, climatic, waterscape, landscape) and seventeen factors to model the influence of eco-climatic factors on the spatial heterogeneity of waterbirds in Peninsular Malaysia. The two factors for landscape (LULC and NDVI; a measure of vegetation cover, forage availability and human activity) and one factor for waterscape (NDWI; a measure of water availability) selected, as suitability factors based on the studies by Hirzel *et al.* (2001); Brotons *et al.* (2004); Soulliere *et al.* (2007); Tian *et al.* (2008) and Tang *et al.* (2011). The NDVI and NDWI extracted from the Sentinel 2A imagery. Also, the pixel-based image classification using the supervised classification method employed to determine the LULC (a measure of safe shelter and forage availability for waterbirds) on the wetlands.

The United States Geological Survey (USGS) Land Classification Scheme (Anderson *et al.* 1976) changed into five and four LULC classes for the analysis based on the present LULC scenario in Paya Indah and Putrajaya wetlands. Paya Indah wetlands had a semi-closed secondary forest, shrub lands, marsh
swamp/Lotus swamp/grassy vegetation, lakes and bare grounds/built-up areas. The Putrajaya wetland had a semi-closed secondary forest/aquatic herbaceous vegetation, marsh swamp/aquatic grassy vegetation, lakes, bare ground/built-up areas. A field survey carried out to gather ground-truthing to allow for accurate assessment. Hand-held GPS (GPS Map 78s, GARMIN) used to collect coordinates of points representing the different LULC classes. Ground truthing performed in April 2018 to collect a total of 190 ground control points in the study area during the season, similar to the acquisition of satellite datasets. The ground control points used as training samples during the LULC classification of the wetlands.

Error matrices and kappa statistics computed using the accuracy assessment tool in ERDAS Imagine 2014 software (ERDAS 2014). The presence and hydrology/hydrological data converted to delimit text and .asc file formats. The factor files (continuous and raster data) of the hydrological and climatic parameters created using the inverse difference interpolation method according to the procedure of Knight et al. (2005).

**Construction of Habitat Suitability Model (Model Development and Validation)**

The habitat suitability models (HSM) of the two waterbird species and their eco-climatic predictors were constructed and determined using the maximum entropy modelling approach (Phillips et al. 2006). The presence/absence data (number of individual waterbirds detected and non-detected, 75%) and the 17 eco-climatic factors served as the dependent and independent variables. Twenty-five per cent of the presence data (abundance of the waterbirds) and the 1000 background or pseudo-absence points were employed to validate the models (Phillips et al. 2006). For this study, a minimum contribution of 10% set as the level for an ecologically meaningful contribution of the eco-climatic factors to habitat suitability of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*.

Each of the generated HSM (a continuous raster file) reclassified into five suitability classes from highly non-suitable (1) to highly suitable (5) based on the waterbird habitat suitability continuum framework developed by Dong et al. (2013) using Jenk’s natural breaks (Jenk 1967). The habitat suitability map for each species categorised into five suitability classes (based on Jenk’s Natural Breaks Classification): Highly suitable, suitable, moderately suitable, non-suitable and highly non-suitable. According to Hosmer and Lemeshow (2000), the area under the curve value within the range of 0.50 to 0.70, 0.70 to 0.90, and greater than 0.90 showed that the model accuracy is low, moderate and high. The area under the curve value of > 0.75 is considered more accurate, acceptable, and suitable for predicting species distribution (Elith 2000; Vanagas 2004; Phillips et al. 2006; Lobo et al. 2008).
RESULTS

Fig. 3 presented the fitted habitat suitability models for studied species in Paya Indah and Putrajaya wetlands. The four models had a robust performance, with the area under the curve values greater than 0.50 of a random model. The area under the curve values for *Porphyrio porphyrio indicus* in Paya Indah and Putrajaya wetlands were 0.987 and 0.939. Also, the area under the curve values for *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands were 0.896 and 0.993.

Table 1 shows the eco-climatic predictors of habitat suitable for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. The range of electric conductivity (15.49uS/cm–41.18uS/cm), dissolve oxygen (4.47 mg/L–8.22 mg/L), turbidity (2.02 NTU–23.73 NTU), water temperature (24.45°C–30.79°C), salinity (0.50 ppt–5.04 ppt), minimum water depth (0.65 m–5.92 m), maximum depth (3.12 m–20.74 m), relative humidity (27.855%–77.530%), rainfall (9.976 mm–10.691 mm), wind speed (1.487 m/s–1.618 m/s) and atmospheric temperature (27.741°C–27.773°C) offered suitable habitats for the two species (Table 1).

Table 2 presents the eco-climatic factors’ contribution to the habitat suitability modelling of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. Based on the maximum entropy modelling result, minimum water depth (m) had the highest contribution (44.30%) to the habitat suitable for *Porphyrio porphyrio indicus* in Paya Indah wetland, followed by dissolved oxygen (24.90%). In Putrajaya wetland, rainfall (mm) had the highest contribution (74.20%) to the habitat suitable for *Porphyrio porphyrio indicus* in Paya Indah wetland, followed by pH (11.10%). The landscape and waterscape factors did not influence the habitat suitability for *Porphyrio porphyrio indicus* in the Putrajaya wetland. However, three and two eco-climatic factors predicted the habitat suitability for *Porphyrio porphyrio indicus* in Paya Indah and Putrajaya wetlands.

As regards *Amaurornis phoenicurus*, dissolved oxygen (mg/L) had the highest contribution (56.60%) to its habitat suitability in Paya Indah wetland, followed by water quality index (31.70%). At Putrajaya wetland, salinity (ppt) had the highest contribution (43.50%) to the habitat suitable for *Amaurornis phoenicurus*, followed by LULC (27.90%). Thus, three eco-climatic factors predicted the habitat suitability for *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. A few eco-climatic factors had no significant influence on the suitable habitat for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. The eco-climatic factors are: the waterscape (NDWI), landscape (NDVI), climatic (relative humidity, wind speed, atmospheric pressure, atmospheric temperature) and hydrological (electric conductivity, turbidity, water temperature).
Table 2: The contribution of eco-climatic to the habitat suitability modelling of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands.

| Criteria          | Factors                              | *Porphyrio porphyrio indicus* |              |              | *Amaurornis phoenicurus* |              |              |
|-------------------|--------------------------------------|------------------------------|--------------|--------------|--------------------------|--------------|--------------|
|                   |                                      | Paya Indah                  | Putrajaya    | Paya Indah   | Putrajaya                | Paya Indah   | Putrajaya    |
|                   |                                      | Factor contribution (%)     | Rank         | Factor contribution (%) | Rank         | Factor contribution (%) | Rank         |
| Hydrology         | Electric conductivity (uS/cm)         | 0.00*                       | 9            | 1.40*        | 5                        | 0.00*        | 4            | 0.00*        | 7            |
|                   | Dissolved oxygen (mg/L)              | 24.90*                      | 2            | 4.90*        | 4                        | 56.60*       | 1            | 0.50*        | 6            |
|                   | Water quality index                  | 4.10*                       | 4            | NA           | NA                       | 31.70*       | 2            | NA           | NA           |
|                   | Turbidity (NTU)                      | 0.00*                       | 9            | 0.00*        | 6                        | 0.00*        | 4            | 6.00*        | 4            |
|                   | Water temperature (°C)               | 0.00*                       | 9            | 0.00*        | 6                        | 0.00*        | 4            | 2.40*        | 5            |
|                   | Salinity (ppt)                       | 0.60*                       | 7            | 8.40*        | 3                        | 0.00*        | 4            | 43.50*       | 1            |
|                   | pH                                   | 0.70*                       | 6            | 11.10*       | 2                        | 0.00*        | 4            | 0.00*        | 7            |
|                   | Minimum Depth (m)                    | 44.30*                      | 1            | NA           | NA                       | 0.00*        | 4            | NA           | NA           |
|                   | Maximum Depth (m)                    | 23.30*                      | 3            | NA           | NA                       | 0.00*        | 4            | NA           | NA           |
| Climatic          | Relative humidity (%)                | 2.00*                       | 5            | 0.00*        | 6                        | 0.00*        | 4            | 0.00*        | 7            |
|                   | Rainfall (mm)                        | 0.00*                       | 9            | 74.20*       | 1                        | 0.00*        | 4            | 19.60*       | 3            |
|                   | Wind speed (m/s)                     | 0.00*                       | 9            | 0.00*        | 6                        | 0.00*        | 4            | 0.00*        | 7            |
|                   | Atmospheric pressure (Hpa)           | 0.00*                       | 9            | 0.00*        | 6                        | 0.00*        | 4            | 0.00*        | 7            |

(Continued on next page)
### Table 2 (Continued)

| Criteria          | Factors                              | P. porphyrio porphyrio indicus | A. phoenicurus |
|-------------------|--------------------------------------|-------------------------------|---------------|
|                   | Paya Indah                           | Putrajaya                     | Paya Indah    | Putrajaya |
|                   | Factor contribution (%)              | Rank                          | Factor contribution (%) | Rank | Factor contribution (%) | Rank | Factor contribution (%) | Rank |
| Climatic          | Atmospheric temperature (°C)         | 0.00<sup>ns</sup>             | 9             | 0.00<sup>ns</sup> | 6     | 0.00<sup>ns</sup> | 4     | 0.00<sup>ns</sup> | 7     |
| Waterscape        | Normalised Difference Water Index    | 0.00<sup>ns</sup>             | 9             | 0.00<sup>ns</sup> | 6     | 0.00<sup>ns</sup> | 4     | 0.00<sup>ns</sup> | 7     |
| Landscape         | Normalised Difference Vegetation Index | 0.00<sup>ns</sup>             | 9             | 0.00<sup>ns</sup> | 6     | 0.00<sup>ns</sup> | 4     | 0.00<sup>ns</sup> | 7     |
|                   | Land use/land cover                  | 0.10<sup>*</sup>              | 8             | 0.00<sup>ns</sup> | 6     | 11.70<sup>*</sup> | 3     | 27.90<sup>*</sup> | 2     |

Notes: * signifies the parameter is significant (Factor contribution ≥ 10%) while ns signifies the parameter is non-significant (Factor contribution < 10%); "NA" means "Not Assessed".
Figure 3: Habitat suitability models of (A) *Porphyrio porphyrio indicus* and (B) *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands of Peninsular Malaysia.

Fig. 3 and Table 3 present the habitat suitability models and their attributes for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. From the habitat suitability map for *Porphyrio porphyrio indicus*, the highly non-suitable area occupied the highest wetland area (1459.56 ha; 92.40%) in the Paya Indah wetland. The highly suitable area occupied the lower wetland area (5.61 ha; 0.36%). For *Porphyrio porphyrio indicus* in Putrajaya wetland, the highly non-suitable area occupied the highest wetland area (959.24 ha; 67.54%), while there was no wetland coverage for the highly suitable area. The highly non-suitable area for *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands occupied the highest wetland area (1507.54 ha; 95.44%) and (701.46 ha; 49.39%). The highly non-suitable area by *Amaurornis phoenicurus* occupied the lower wetland area (<1%) in the two urban wetlands.
Table 3: Attributes of habitat suitability models for PPI and AP in Paya Indah and Putrajaya wetlands.

| Suitability classes     | Porphyrio porphyrio indicus | Amaurornis phoenicurus |
|-------------------------|------------------------------|------------------------|
|                         | Paya Indah                   | Putrajaya              |
|                         | Area (Ha) | Proportion (%) | Area (Ha) | Proportion (%) | Area (Ha) | Proportion (%) | Area (Ha) | Proportion (%) |
| Highly suitable         | 5.61      | 0.36           | 0.00      | 0.00           | 2.83      | 0.18           | 0.73      | 0.05           |
| Suitable                | 17.54     | 1.11           | 162.66    | 11.45          | 16.90     | 1.07           | 241.08    | 16.97          |
| Moderately suitable     | 28.07     | 1.78           | 196.06    | 13.80          | 41.08     | 2.60           | 350.73    | 24.69          |
| Non-suitable            | 68.77     | 4.35           | 959.24    | 67.54          | 1507.54   | 95.44          | 701.46    | 49.39          |
| Highly non-suitable     | 1579.55   | 100.00         | 1420.35   | 100.00         | 1579.55   | 100.00         | 1420.35   | 100.00         |
| Specific locations/     | Southwest Grebe, Northern    | Upper West, Upper East,|
| lakes with the          | Teratai, Eastern Sendayan,    | Southern Upper North   |
| suitable habitat        | Southeastern Kemoning         | Western/Eastern Sendayan,|
|                         |                                | Southeastern Kemoning   |
|                         |                                | Upper West, Upper East,|
|                         |                                | Lower East, Central     |
|                         |                                | Wetland                 |
DISCUSSION

Since the 20th century began, the decline in the range and population size of waterbird species attributed to the loss of suitable habitat and excessive human activities such as hunting, agriculture, and urbanisation (BirdLife International 2004). BirdLife BHDTF (2013) opined that the sufficient and large suitable areas for birds are essential for sustaining a healthy population in the long term. In this study, large portions of the two urban wetlands are unsuitable for the survival and sustenance of Porphyrio porphyrio indicus and Amaurornis phoenicurus populations. The small suitable habitat for the two species in Paya Indah and Putrajaya wetlands calls for urgent attention despite the initial scientific notion of their wide range in Malaysia and conservation status of “least concern” to prevent their local extinction. The ambient ecological and climatic factors attributed to this less suitable habitat. This assertion corroborated the findings of Esper et al. (2012), Ismail and Rahman (2013) and Jordan (2017) that habitat characteristics and climatic factors affected the distribution, breeding activities, and suitable habitat for waterbirds.

There is inadequate information on the influence of microclimatic and ecological variables on habitat suitability for Porphyrio porphyrio indicus and Amaurornis phoenicurus in any urban wetland. However, this study revealed the occurrence and distribution of Porphyrio porphyrio indicus and Amaurornis phoenicurus in Paya Indah and Putrajaya wetlands, influenced by a few landscapes, climatic and hydrological factors. In contrast, waterscape (NDWI; a measure of water availability) had no significant influence on the two species distribution in both wetlands. For the first species (Porphyrio porphyrio indicus), the landscape of Putrajaya wetland contained a more suitable habitat for its populations than the Paya Indah wetland due to varying eco-climatic predictors. Three hydrological factors (minimum depth, dissolved oxygen, and maximum depth) contributed to Porphyrio porphyrio indicus distribution in the Paya Indah wetland. The climatic (rainfall) and hydrological factors (water pH) contributed to Porphyrio porphyrio indicus distribution in the Putrajaya wetland. Paya Indah and Putrajaya wetlands have experienced one form of human activities or the other over the years. Zakaria and Rajpar (2010) and Hassen-Aboushiba (2015) reported that tin mining and agricultural activities, coupled with tourism infrastructural development, were the major anthropogenic activities in the Paya Indah wetland. Also, urban sprawl and water purification/supply are among the drivers of landscape dynamics in Putrajaya Wetland. The anthropogenic activities within the two urban wetlands associated with the varied eco-climatic predictors related to habitat suitability for Porphyrio porphyrio indicus. This view supported Bai et al. (2013) and Li et al. (2018) that the wetlands converted to other land use types could influence their microclimates and alter their hydrological cycle.

In Paya Indah wetland, the minimum and maximum depths of the lakes contributed to making Paya wetland a less suitable habitat for the Porphyrio porphyrio indicus populations, as this affects the wetlands’ habitat characteristics, forage availability and bird locomotion. It aligned with the views of Rajpar and Zakaria (2011) that water depth influenced the occurrence, diversity, and distribution
of waterbirds in the Paya Indah wetland. Fluctuation in water level might alter habitat characteristics and cause changes in waterbirds communities (Lee et al. 2006; Johnson et al. 2007). Besides the limiting access to foraging habitats, water depth also affects the net energy intake of Porphyrio porphyrio indicus because foraging efficiency decreases with increasing water depth. Gawlik (2002) showed that the locomotion of wading birds foraging prey in the water column slowed down in deep water as water resistance increases with depth.

Rainfall was the only climatic variable that influenced the habitat suitable for Porphyrio porphyrio indicus in the Putrajaya wetland. The lower amount of rainfall in Putrajaya wetland than Paya Indah wetland contributed to the suitability of the habitat for the survival and sustenance of Porphyrio porphyrio indicus populations. This assertion supports the findings of Wormworth and Mallon (2014) that rainfall is a limiting factor to the birds’ distribution because of their direct impact on wetland habitats. Water pH is also a contributory factor to the suitable habitat for Porphyrio porphyrio indicus in the Putrajaya wetland. Water pH (ranging between 7.2 and 9.2) in Putrajaya wetland was alkaline but tended towards the neutral level during the entire study period. The neutral waters in the Putrajaya wetland connected to its more suitable habitat for Porphyrio porphyrio indicus than the Paya Indah wetland. Longcore et al. (2006) reported that a water pH in the alkaline range supported higher macro-invertebrates and attracted more waterbirds to the water bodies. Also, Minns (1989) considered pH an indicator of overall productivity that could cause habitat diversity with a significant influence on the species richness of phytoplankton (food for Porphyrio porphyrio indicus).

Water salinity contributed to a more suitable habitat for Amaurornis phoenicurus in the Putrajaya wetland than in the Paya Indah wetland. The direct relationship between water salinity and food resources in urban wetlands associated with water salinity. According to Ma et al. (2010), water salinity determined the spatial heterogeneity of aquatic animals and zoobenthos and influenced the locality of foraging sites by waterbird species. But, the landscape (LULC; a measure of vegetation cover, forage availability and human activity) had a significant influence on the suitable habitat for Amaurornis phoenicurus in the two urban wetlands. It depicted the roles of anthropogenic activities (the driver of LULC), forage availability, and vegetation cover in the occurrence and distribution of Amaurornis phoenicurus. Van Niekerk (2010), Mundava et al. (2012), Tanalgo et al. (2015), Catford et al. (2017) and Marasinghe et al. (2020) opined that anthropogenic pressure poses a threat to the population growth and habitat suitability of waterbirds. Hence, our findings support the findings made by Rajpar and Zakaria (2014) and Jahanbakhsh et al. (2017) that vegetation covers affected habitat selection, distribution and diversity of waterbirds in Putrajaya wetland, Malaysia and Parishan International wetland, Iran.

The dissolved oxygen was the only eco-climatic (hydrological) factor that influenced the habitat suitability of both species (Porphyrio porphyrio indicus and Amaurornis phoenicurus) in the Paya Indah wetland. For this reason, the dissolved oxygen link to Porphyrio porphyrio indicus and Amaurornis phoenicurus distribution is non negligible. According to Sathe et al. (2001), dissolved oxygen
is vital in regulating the metabolic processes of aquatic plants. It is an indicator of ecosystem health in a wetland ecosystem. Previous studies observed a significant relationship between dissolved oxygen and waterbirds (Thapa & Saund 2012; Sulai et al. 2015; Haq et al. 2018).

Thus, the influence of eco-climatic variability on the urban wetlands' vegetation composition, structure, hydro-morphological properties, and consequently the populations' distribution and sustainability of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* is significant. According to Sekercioglu et al. (2012), Porte and Gupta (2017), and Mundkur et al. (2017), this global phenomenon had broad impacts on the distribution, morphology, carrying capacities and seasonal variations of urban wetlands connected to the feeding and breeding activities of waterbird species such as *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*.

**CONCLUSIONS**

Our findings revealed that large portions of the two urban wetlands were not suitable for the survival and sustenance of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* populations. Notwithstanding, the Putrajaya wetland offered a more suitable habitat to the *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* populations as to the Paya Indah wetland. The habitat suitability associated with the favourable rainfall, water pH, salinity, and LULC of Putrajaya wetland to *Porphyrio porphyrio indicus*. *Porphyrio porphyrio indicus* thrived more in urban wetlands with lower rainfall, neutral pH, higher dissolved oxygen, shallow water depth, and marsh swamp/lotus swamp/grassy vegetation interspersed with semi-closed secondary forest. *Amaurornis phoenicurus* experienced high survival and suitable habitat with lower rainfall, higher dissolved oxygen, higher water quality index, lower salinity, and marsh swamp/lotus swamp/grassy vegetation interspersed with semi-closed secondary forest in urban wetlands. Landscape, climatic and hydrological factors influenced the occurrence and distribution of *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands. Thus, the developed habitat suitability models gave a better understanding of the current extent to which eco-climatic factors contributed to the habitat suitable for *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus* in Paya Indah and Putrajaya wetlands of Peninsular Malaysia. The models as management tool adopted with a robust population monitoring database and framework will enhance the management effectiveness of the two species and urban wetlands.

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REFERENCES

Aguirre-Gutierrez J, Carvalheiro L G, Polce C, van Loon E E, Raes N, Reemer M and Biesmeijer J C. (2013). Fit-for-purpose: Species distribution model performance on evaluation criteria – Dutch hoverflies as a case study. *PLoS ONE* 8(5): e63708. https://doi.org/10.1371/journal.pone.0063708

Anderson J, Hardy E, Roach J and Witmer R. (1976). *A land use and land cover classification system for use with remote sensor data*. Washington DC: Scientific Research Publishing. https://doi.org/10.3133/pp964

Bai J H, Lu Q Q, Zhao Q Q, Wang J J and Ouyang H. (2013). Effects of alpine wetland landscapes on regional climate. *Advances in Meteorology* 2013: 972430. https://doi.org/10.1155/2013/972430

Bara M, Merzoug S E, Khelifa R, Bouslama Z and Houhamdi M. (2014). Aspects of breeding ecology of the purple swamphen *Porphyrio porphyrio* in the wetland complex of Guerbes-Sanhadja, Northeast of Algeria. *Ostrich* 85: 185–191. https://doi.org/10.2989/00306525.2014.971901

Bibby C, Jones M and Marsden S. (2000). *Expedition field techniques-bird surveys*. Cambridge: Bird Life International Publication.

BirdLife BHDTF. (2013). *Setting conservation objectives for birds. Interim Position on standards and approaches for defining the Favorable Conservation Status of birds (focus on the national/sub-national level)*. EU Birds and Habitats Directives Task Force. 19 pp.

BirdLife International. (2004). *Birds in Europe: Population estimates, trends and conservation status*. Cambridge, UK: BirdLife International.

_______. (2016). *Amaurornis phoenicurus*. The IUCN red list of threatened species. https://doi.org/10.2305/IUCN.UK.20163.RLTS.T22692640A95217833.en. (accessed on 30 October 2018).

_______. (2020). Country profile: Malaysia. http://www.birdlife.org-/datazone/country/malaysia. (accessed on 24 April 2020).

Breaban I G, Ghetue D and Paiu M. (2012). Determination of water quality index of Jijia and Miletin ponds. *Bulletin UASVM Agriculture* 69(2): 160–167. https://doi.org/10.15835/buasvmcn-agr:8745

Breiman L. (2001a). Random forests. *Machine Learning* 45(1): 5–32. https://doi.org/10.1023/A:1010933404324

_______. (2001b). Statistical modeling: The two cultures. *Statistical Science* 16: 199–231. https://doi.org/10.1214/ss/1009213726

Brinkmann K, Homann E and Buerkert A. (2020). Spatial and temporal dynamics of urban wetlands in an Indian megacity over the past 50 years. *Remote Sensing* 12: 662. https://doi.org/10.3390/rs12040662
Brotons L, Thuiller W, Miguel B and Hirzel A H. (2004). Presence-absence versus presence-only modelling methods for predicting bird habitat suitability. *Ecography* 27: 437–448. https://doi.org/10.1111/j.0906-7590.2004.03764.x

Busby J R. (1991). Bioclim, a bioclimatic analysis and prediction system. In Margules C R and Austin M P (eds.), *Nature conservation: Cost effective biological surveys and data analysis*. Canberra: CSIRO, 64–68.

Carpenter G, Gillison A N and Winter J. (1993). A flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity and Conservation* 2: 667–680. https://doi.org/10.1007/BF00051966

Catford J A, Roberts J, Capon S J, Froend R H, Windecker S M and Douglas M M. (2017). Wetland Vegetation of Inland Australia. In Keith D A (Ed.), *Australian vegetation*, 3rd ed. Cambridge: Cambridge University Press, 490–515.

David R B and Stockwell D. (2006). Improving ecological niche models by data mining large environmental datasets for surrogate models. *Ecological Modelling* 192: 188–196. https://doi.org/10.1016/j.ecolmodel.2005.05.029

Dong Z, Wang Z, Liu D, Li L, Ren C, Tanga X. *et al.* (2013). Assessment of habitat suitability for waterbirds in the West Songnen Plain, China, using remote sensing and GIS. *Ecological Engineering* 55: 94–100. https://doi.org/10.1016/j.ecoleng.2013.02.006

Dunn E H, Bart J, Collins B T, Craig B, Dale B, Downes C M, Francis C M, Woodley Sand Zorn P. (2006). *Monitoring bird populations in small geographic areas* (Special Publication). Canada: Canadian Wildlife Service.

Ehrenfeld J G. (2008). Exotic invasive species in urban wetlands: Environmental correlates and implications for wetland management. *Journal of Applied Ecology* 45(4): 1160–1169. https://doi.org/10.1111/j.1365-2664.2008.01476.x

Elith J, Graham C H, Anderson R P, Dudík M, Ferrier S, Guisan A, Hijmans R J, Huettmann F, Leathwick J R, Lehmann A, *et al.* (2006). Novel methods improve prediction of species’ distributions from occurrence data. *Ecography* 29: 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

Elith J. (2000). Quantitative methods for modelling species habitat: comparative performance and an application to Australian plants. In S Ferson and M Burgman (Eds.), *Quantitative methods for conservation biology*. New York: Springer, 39–58. https://doi.org/10.1007/0-387-22648-6_4

ERDAS. (2014). ERDAS imagine 2014. Peachtree Corners Circle Norcross: Hexagon Geospatial.

Esper J, Frank D C, Timonen M, Zorita E, Wilson R J S, Luterbacher J and Buntgen U. (2012). Orbital forcing of tree-ring data. *Nature Climate Change* 2(12): 862–866. https://doi.org/10.1038/nclimate1589

Ferrier S, Manion G, Elith J and Richardson K. (2007). Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions* 13(3): 252–264. https://doi.org/10.1111/j.1472-4642.2007.00341.x

Franklin J. (1995). Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. *Progress in Physical Geography* 19(4): 474–499. https://doi.org/10.1177/030913339501900403

Friedman J H. (1991). Multivariate adaptive regression splines. The *Annals of Statistics* 19: 1–67. https://doi.org/10.1214/aos/1176347963

Gawlik D E. (2002). The effects of prey availability on the numerical response of wading birds. *Ecological Monographs* 72(3): 329–346. https://doi.org/10.1890/0012-9615(2002)072[329:TEOBA]2.0.CO;2
Guisan A and Zimmermann N E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling* 135: 147–186. https://doi.org/10.1016/S0304-3800(00)00354-9

Gumbricht T, Roman-Cuesta R M, Verchot L V, Herold M, Wittmann F, Householder E, Herold N and Murdiyarso D. (2017). Tropical and subtropical wetlands distribution version 2. https://doi.org/10.17528/GIFOR/DATA.00058

Haq R U, Eiam-Ampai K, Ngoprasert D, Sasaki N and Shrestha R P. (2018). Changing landscapes and declining populations of resident waterbirds: A 12-year study in Bung Boraphet Wetland, Thailand. *Tropical Conservation Science* 11: 1–17. https://doi.org/10.1177/1940082917750839

Hassen-Aboushiba A B. (2015). Assessing the effects of aquatic vegetation composition on waterbird distribution and richness in natural freshwater lake of Malaysia. *American Journal of Life Sciences* 3(4): 316–321. https://doi.org/10.11648/j.ajls.20150304.20

Hijmans R J, Guarino L, Cruz M and Rojas E. (2001). Computer tools for spatial analysis of plant genetic resources data 1. DIVA-GIS. *Plant Genetic Resources News* 127: 15–19.

Hirzel A H, Helfer V and Metral F. (2001). Assessing habitat-suitability models with a virtual species. *Ecological Modelling* 145: 111–121. https://doi.org/10.1016/S0304-3800(01)00396-9

Hirzel A Z and Lay G L. (2008). Habitat suitability modelling and niche theory. *Journal of Applied Ecology* 45: 1372–1381. https://doi.org/10.1111/j.1365-2664.2008.01524.x

Hosmer D and Lemeshow S. (2000). *Applied logistic regression*. New York, NY: Wiley-Interscience. https://doi.org/10.1002/0471722146

House M A and Ellis J B. (1987). The development of water quality indices for operational management. *Water Science and Technology* 19: 145–154. https://doi.org/10.2166/wst.1987.0076

Hutto R L and Young J S. (2002). Regional landbird monitoring: Perspectives from the Northern Rocky- Mountains. *Wildlife Society Bulletin* 30: 738–758.

Ismail A and Rahman F. (2013). Does weather play an important role in the early nesting activity of colonial waterbirds? A case study in Putrajaya Wetlands, Malaysia. *Tropical Life Sciences Research* 24(1): 1–7.

Jahanbakhsh G M, Khorasani N, Morshed J, Daneshkar A and Naderi M. (2017). Factors influencing abundance and species richness of overwintered waterbirds in Parishan International Wetland in Iran. *Applied Ecology and Environmental Research* 15(4): 1565–1579. https://doi.org/10.15666/aeer/1504_15651579

Jenks G F. (1967). The data model concept in statistical mapping. *International Yearbook of Cartography* 7: 186–190.

Johnson K G, Allen M S and Havens K E. (2007). A review of littoral vegetation, fisheries, and wildlife responses to hydrologic variation at Lake Okeechobee. *Wetlands* 27(1): 110–126. https://doi.org/10.1672/0277-5212(2007)27[110:AROLVF]2.0.CO;2

Jordan D P. (2017). Waterbirds in a changing world: Effects of climate, habitat and conservation policy on European waterbirds. PhD dissertation, University of Helsinki, Helsinki, Finland.

Kansiime F, Kateyo E, Oryem-Origa H and Mucunguzi P. (2007). Nutrient status and retention in pristine and disturbed wetlands in Uganda: Management implications. *Wetland Ecological Management* 15: 453–467. https://doi.org/10.1007/s11273-007-9054-6
Kassara C, Gangoso L, Mellone U, Piasevoli G, Hadjikyriakou T G, Tsiopelas N, Giokas S, López-López P, Urios V, Figuerola J, et al. (2017). Current and future suitability of wintering grounds for a long-distance migratory raptor. Scientific Reports 7: 8798. https://doi.org/10.1038/s41598-017-08753-w

Knight Y, Yu B, Jenkins G and Morris K. (2005). Comparing rainfall interpolation techniques for small subtropical urban catchments. In Proceedings of Scientific Conference, Modelling and Simulation (pp. 1674–1680), University of Western Australia, Nedlands.

Lee C W, Kim G Y, Jang J D, Bhandari B B and Joo G J. (2006). Water level fluctuation and habitat use pattern of wintering waterbirds in the Junam Reservoir Area, South Korea. Journal of Bioscience 7(2): 79–92.

Lehmann A, Overton J M and Leathwick J R. (2003). GRASP: Generalized regression analysis and spatial prediction. Ecological Modelling 160: 165–183. https://doi.org/10.1016/S0304-3800(02)00354-X

Li X, Cheng R, Xiao W, Sun G, Ma T, Liu F, Liu X, Qian F and Pan K. (2021). Assessment the suitability of wintering anatidae habitats before and after impoundment in the three gorges reservoir region. Sustainability 13: 4743. https://dx.doi.org/10.3390/su13094743

Li X, Mitra C, Dong L and Yang Q. (2018). Understanding land use change impacts on microclimate using Weather Research and Forecasting (WRF) model. Physics and Chemistry of the Earth, Parts A/B/C 103: 115–126. https://doi.org/10.1016/j.pce.2017.01.017

Lloyd J D and Doyle T. (2011). Abundance and population trends of mangrove landbirds in southwest Florida. Journal of Field Ornithology 82: 132–139. https://doi.org/10.1111/j.1557-9263.2011.00315.x

Lobo J M, Enez-Valverde A J and Real R. (2008). AUC: A misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17: 145–151. https://doi.org/10.1111/j.1466-8238.2007.00358.x

Longcore J R, McAuley D G, Pendelton G W, Bennatti C R, Mingo T M and Stromborg K L. (2006). Macroinvertebrate abundance, water chemistry, and wetland characteristics affect use of wetlands by avian species in Maine. Hydrobiologia 567: 143–167. https://doi.org/10.1007/s10750-006-0055-x

Ma Z, Cai Y, Li B and Chen J. (2010). Managing wetland habitats for waterbirds: An international perspective. Wetlands 30: 15–27. https://doi.org/10.1007/s13157-009-0001-6

Marasinghe S, Simpson G D, Newsome D and Perera P. (2020). Scoping recreational disturbance of shorebirds to inform the agenda for research and management in Tropical Asia. Tropical Life Sciences Research 31(2): 51–78. https://doi.org/10.21315/tlsr2020.31.2.4

Martins C O, Rajpar M N, Nurhidayu S and Zakaria M. (2017). Habitat selection of Dendrocygna javanica in heterogeneous lakes of Malaysia. Journal of Biodiversity Management and Forestry 6(3): 1–6. https://doi.org/10.4172/2327-4417.1000183

Minns C K. (1989). Factors affecting fish species richness in Ontario lakes. Transactions of the American Fisheries Society 76: 332–334.

Mundava J, Caron A, Gaidet N, Couto F M, Couto J T, De Garine-Wichatitsky M and Mundy P J. (2012). Factors influencing long-term and seasonal waterbird abundance and composition at two adjacent lakes in Zimbabwe. Ostrich 83(2): 69–77. https://doi.org/10.2989/00306525.2012.692726
Mundkur T, Langendoen T and Watkins D. (2017). The Asian Waterbird Census 2008–2015: results of coordinated counts in Asia and Australasia. Ede: Wetlands International.

Nagy S, Breiner F T, Anand M, Butchart S H M, Rke M F, Fluet-Chouinard E, Guisan A, Hilarides L, Jones V R, Kalyakin M, et al. (2021). Climate change exposure of waterbird species in the African-Eurasian flyways. Cambridge: Cambridge University Press, 1–26. https://doi.org/10.1017/S0959270921000150

Neice A A and McRae S B. (2021). Mapping habitat suitability for the Eastern Black Rail throughout its Atlantic coastal range using maximum entropy (MaxEnt). Avian Conservation and Ecology 16(1): 23. https://doi.org/10.5751/ACE-01919-160123

Pearlstine E V and Ortiz J S. (2009). A natural history of the purple swampphen (Porphyrioporphyrio). Gainsville: Institute of Food and Agricultural Sciences, University of Florida. https://doi.org/10.32473/edis-uw317-2009

Pearson R G, Dawson T P, Berry P M and Harrison P A. (2002). SPECIES: A spatial evaluation of climate impact on the envelope of species. Ecological Modelling 154: 289–300. https://doi.org/10.1016/S0304-3800(02)00056-X

Phillips S J, Anderson R P and Schapire R E. (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Porte D S and Gupta S. (2017). Assessment of distribution patterns of wetland birds between unpolluted and polluted ponds at Ratanpur, District Blaspur, Chhattisgarh, India. Indian Journal Science Research 12(2): 204–215.

Rajpar M N and Zakaria M. (2011). Effects of water level fluctuation on waterbirds distribution and aquatic vegetation composition at natural wetland reserve, Peninsular Malaysia. ISRN Ecology 2011: 324038. https://doi.org/10.5402/2011/324038

_____. (2012). Avian community parameters of a freshwater wetland ecosystem in Peninsular Malaysia. Asia Life Sciences 21(2): 409–428.

_____. (2013). Assessing an artificial wetland in Putrajaya, Malaysia, as an alternate habitat for waterbirds. Waterbirds 36(4): 482–493. https://doi.org/10.1675/063.036.0405

_____. (2014). Effects of habitat characteristics on waterbird distribution and richness in wetland ecosystem of Malaysia. Journal of Wildlife and Parks 28: 107–122.

Rajpar M N, Zakaria M, Ozdemir I, Ozturk M and Gucel S. (2017). Avian assemblages at Paya Indah Natural Wetland Reserve, Malaysia. Expert Opinion on Environmental Biology 6(3).

Rushton S P, Ormerod S J and Kerby G. (2004). New paradigms for modelling species distributions? Journal of Applied Ecology 41(2): 193–200. https://doi.org/10.1111/j.0021-8901.2004.00903.x

Salari A, Zakaria M, Nielsen C C and Boyce M S. (2014). Quantifying tropical wetlands using field surveys, spatial statistics and remote sensing. Wetlands 34: 565–574. https://doi.org/10.1007/s13157-014-0524-3

Sathe S S, Khabade S and Hujare M. (2001). Hydrobiological studies on two manmade reservoirs from Tasgaontahashil (Maharashtra). Ecological Environment and Construction 7(2): 211–217.

Sekercioglu C H, Primack R B and Wormworth J. (2012). The effects of climate change on tropical birds. Biological Conservation 148: 1–18. https://doi.org/10.1016/j.biocon.2011.10.019

Soulliere G J, Potter B A, Coluccy J M, Gatti R C, Roy C L, Luukkonen D R, et al. (2007). Upper Mississippi River and Great Lakes Region joint venture waterfowl habitat conservation strategy. Fort Snelling, Minnesota: U.S. Fish and Wildlife Service.
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Stockwell D R B and Peters D. (1999). The GARP modelling system: Problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science* 13: 143–158. https://doi.org/10.1080/13658819921391

Sulai P, Nurhidayu S, Aziz N, Zakaria M, Barclay H and Azhar B. (2015). Effects of water quality in oil palm production landscapes on tropical waterbirds in Peninsular Malaysia. *Ecological Research* 30(5): 941–949. https://doi.org/10.1007/s11284-015-1297-8

Tanalog K C, Pineda J A F, Agravante M E and Amerol Z M. (2015). Bird diversity and structure in different land-use types in lowland south-central Mindanao, Philippines. *Tropical Life Sciences Research* 26(2): 85–103.

Tang Z Y, Fang J Y, Sun J Y and Gaston K J. (2011). Effectiveness of protected areas in maintaining plant production. *PLoS ONE* 6(4): 1–8. https://doi.org/10.1371/journal.pone.0019116

Taylor B and Van Perlo B. (1998). *Rails: A guide to the Rails. Crakes, Gallinules and Coots of the World*. Sussex: Pica Press.

Taylor B. (2016). Purple Swamphen (*Porphyrio porphyrio*). In del Hoyo J, Elliott A, Sargatal J, Christie D A, de Juana E, eds. *Handbook of the birds of the world alive*. Barcelona: Lynx Edicions.

Thapa J B and Saund T B. (2012). Water quality parameters and bird diversity in Jagdishpur Reservoir, Nepal. *Nepal Journal of Science and Technology* 13(1): 143–155. https://doi.org/10.3126/njst.v13i1.7453

Thuiller W, Lafourcade B, Engler R and Araujo M B. (2009). BIOMOD: A platform for ensemble forecasting of species distributions. *Ecography* 32: 369–373. https://doi.org/10.1111/j.1600-0587.2008.05742.x

Thuiller W. (2003). BIOMOD: optimising predictions of species distributions and projecting potential future shifts under global change. *Global Change Biology* 9: 1353–1362. https://doi.org/10.1046/j.1365-2486.2003.00666.x

Tian B, Zhou Y X, Zhang L Q and Yuan L. (2008). Analysing the habitat suitability for migratory birds at the ChongmingDongtan Nature Reserve in Shanghai, China. *Estuarine, Coastal and Shelf Science* 80: 296–302. https://doi.org/10.1016/j.ecss.2008.08.014

Tozer D C, Nol E and Abraham K F. (2010). Effects of local and landscape-scale habitat variables on abundance and reproductive success of wetland birds. *Wetlands Ecology and Management* 18(6): 679–693. https://doi.org/10.1007/s11273-010-9187-x

Tucker K, Rushton S R, Sanderson R A, Martin E B and Blaiklock J. (1997). Modelling bird distributions – a combined GIS and Bayesian rule-based approach. *Journal of Landscape Ecology* 12: 77–93. https://doi.org/10.1007/BF02698209

Vallecillo S, Maes J, Polce C and Lavalle C. (2016). A habitat quality indicator for common birds in Europe based on species distribution models. *Ecological Indicators* 69: 488–499. https://doi.org/10.1016/j.ecolind.2016.05.008

Van Niekerk J H. (2010). Assemblages and movements of waterfowl at cattle feedlots across Gauteng, South Africa. *Ostrich* 81: 31–37. https://doi.org/10.2989/00306525.2010.455816

Vanagas G. (2004). Receiver operating characteristic curves and comparison of cardiac surgery risk stratification systems. *Interactive CardioVascular and Thoracic Surgery* 3: 319–322. https://doi.org/10.1016/j.icvts.2004.01.008

Vapnik V and Izmailov R. (2018). Rethinking statistical learning theory: Learning using statistical invariants. *Machine Learning* 108: 381–423. https://doi.org/10.1007/s10994-018-5742-0
Wainger L and Mazzotta M. (2011). Realizing the potential of ecosystem services: a framework for relating ecological changes to economic benefits. *Environmental Management* 48: 710–733. https://doi.org/10.1007/s00267-011-9726-0

Wang Z, Zhang B, Zhang X and Tian H. (2019). Using MaxEnt model to guide marsh conservation in the Nenjiang River Basin, Northeast China. *Chinese Geographical Science* 29(6): 962–973. https://doi.org/10.1007/s11769-019-1082-7

Wetlands International (2018). *Wetland international annual report*. https://www.wetlands.org/publications/the-source-annual-review-and-accounts-2018/

Wormworth J and Mallon K. (2014). Bird species and climate change: The global status report version 1.0. World Wide Fund for Nature. 75 pp.

Wretenberg J, Lindstrom A, Svensson S, Tierfelder T and Part T. (2006). Population trends of farmland birds in Sweden and England: similar trends but different patterns of agricultural intensification. *Journal of Applied Ecology* 43: 1110–1120. https://doi.org/10.1111/j.1365-2664.2006.01216.x

Zakaria M and Rajpar M N. (2010). Density and diversity of waterbirds and terrestrial birds at Paya Indah Wetland reserve, Selangor Peninsular Malaysia. *Journal of Biological Sciences* 10: 658–666. https://doi.org/10.3923/jbs.2010.658.666

Zakaria M, Rajpar M N and Sajap S A. (2009). Species diversity and feeding guilds of birds in Paya Indah Wetland Reserve, Peninsular Malaysia. *International Journal of Zoological Research* 5(3): 86–100. https://doi.org/10.3923/ijzr.2009.86.100