INFLUENCE OF ENVIRONMENTAL FACTORS ON WETLAND AVIAN SPECIES IN PAYA INDAH AND PUTRAJAYA WETLANDS USING HABITAT SUITABILITY MODELLING

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February 2020

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Faculty : Forestry and Environment

In Malaysia, multiple lands use has opened the way to substantial loss of wetland ecosystem, and shrinkage of the populations, habitat and food bases of avian species. However, the study of the avian populations and environmental factors affecting their diversity become eminent to understand the complexity of Malaysian wetlands ecosystem structure, and also develop appropriate management with robust monitoring tools to ensure their ecological sustainability. The study aimed to determine and compared the population and occupancy estimates of selected rail species namely *Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*, and other water and terrestrial dependent avian species in Paya Indah and Putrajaya wetlands, Peninsular Malaysia. The study also determined the environmental factors that influenced the occurrence of water birds and terrestrial birds particularly *Porphyrio porphyrio indicus* (PPI) and *Amaurornis phoenicurus (AP)*, and to develop their habitat suitability models in Paya Indah (PIW) and Putrajaya (PW) wetlands, Malaysia. Distance sampling point count technique using stratified random design was employed to survey avian (from November 2016 to December 2018) from a total of 57 and 54 point stations established around 14 and 24 lakes in PIW and PW respectively. An automatic linear modelling algorithm (ALMA) and geographic information systems were employed to compute the importance ratios of 17 environmental factors (hydrology, climatic, waterscape, and landscape factors). A total of 124,032 and 125,643 bird observations were recorded in PIW and PW from November 2016 to December 2018. The results showed that the terrestrial birds in PIW had higher observed individuals (n = 104,872), species diversity (N = 7.25), richness (R1 = 13.25), evenness (E = 0.92) as compared to the terrestrial birds in PW (n =97340; N = 7.84; R1 = 24.00, E = 0.93). All the observed bird individuals and estimated indices were significantly different except for the Pielou's J evenness index. However, PW had the highest observed water bird individuals (n=28,303) species diversity (N = 7.60), richness (R1 = 26.73), evenness (E = 0.73) as compared to the water birds in PIW (n =19,160; N = 7.10; R1 = 15.60, E = 0.79). The ALMA results showed that the maximum and minimum weights of the environmental factors are land use/land cover (LULC) and water dissolved oxygen for *Porphyrio porphyrio indicus* in PIW, while the atmospheric pressure and Normalized Dominant Water Index (NDWI) in PW. This implies that environmental factors significantly contributed to occurrence of the bird species. Also, the maximum and minimum weights of the factors are water turbidity and electrical conductivity for *Amaurornis phoenicurus* in PIW, while the atmospheric pressure and six water parameters in PW. Large areas of PW were classified more suitable for terrestrial and water birds than PIW due to the favourable atmospheric pressure, LULC, rainfall, wind speed, relative humidity and NDWI. This approach of ranking the important environmental variables criteria using ALMA is very important to conservationist as it presents them with a tool to understand which factor affects the population of birds in their respective habitats. Thus, the models' adoption as management tools coupled with a robust population monitoring database will enhance the management effectiveness of the species and wetlands. Thus, these wetland habitats need to be conserved in order to increase the population, perpetuity and sustainability of the avian species in the future.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGARUH FAKTOR PERSEKITARAN KE ATAS SPESIES AVIAN TANAH PAYA DI PAYA INDAH DAN PUTRAJAYA WETLANDS MENGGUNAKAN KAEDAH PEMODELAN KESESUAIAN HABITAT

Oleh

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Di Malaysia, pelbagai guna tanah telah mengakibatkan kehilangan ekosistem tanah paya yang amat besar, dan pengecutan populasi, habitat dan pengkalan makanan bagi spesies avian. Walau bagaimanapun, kajian mengenai populasi avian dan faktor persekitaran yang mempengaruhi kepelbagaian mereka menjadi penting bagi memahami kompleksiti struktur ekosistem tanah paya Malaysia, dan juga membangunkan pengurusan yang wajar dengan alat pemantauan yang mantap untuk memastikan kelestarian ekologikal mereka. Kajian ini bertujuan untuk menentukan dan membandingkan populasi dan anggaran penghunian bagi spesies rel terpilih, iaitu *Porphyrio porphyrio* dan *Amaurornis phoenicurus*, dan spesies avian yang bergantung pada air dan terestrial lain di Paya Indah dan Putrajaya Wetlands, Semenanjung Malaysia. Kajian ini juga menentukan faktor persekitaran yang mempengaruhi kehadiran burung air dan burung terestrial, terutamanya *Porphyrio porphyrio indicus (PPI)* dan *Amaurornis phoenicurus (AP)*, dan untuk membangunkan model kesesuaian habitat mereka di Paya Indah (PIW) dan Putrajaya Wetlands (PW), Malaysia. Teknik kiraan persampelan titik jarak jauh menggunakan reka bentuk rawak berstrata telah digunakan untuk meninjau avian (dari bulan November 2016 hingga Disember 2018) dari sejumlah 57 dan 54 stesen titik yang disasarkan di sekitar 14 dan 24 tasik, masing-masing di PIW dan PW. Algoritma pemodelan linear automatik (ALMA) dan sistem maklumat geografi telah digunakan untuk menghitung kepentingan nisbah 17 faktor alam sekitar (hidrologi, iklim, pandangan air, dan landskap). Sejumlah 124,032 dan 125,643 pemerhatian avian telah direkodkan di PIW dan PW dari November 2016 hingga Disember 2018. Hasil kajian menunjukkan bahawa avian terestrial di PIW mempunyai individu diperhati yang lebih tinggi (n = 104,872), kepelbagaian spesies (N = 7.25), kekayaan (R1 = 13.25), keserataan (E = 0.92) berbanding dengan avian terestrial di PW (n = 97,340; N = 7.84; R1 = 24.00, E = 0.93). Semua individu burung diperhati dan indeks teranggar secara signifikan adalah berbeza kecuali indeks keserataan Pielou 's J. Walau bagaimanapun, PW mempunyai individu burung air diperhati tertinggi (n = 28,303) kepelbagaian spesies (N= 7.60), kekayaan (R1 = 26.73), keserataan (E = 0.73) berbanding dengan burung air di PIW (n = 19160; N = 7.10; R1 = 15.60, E = 0.79). Hasil ALMA menunjukkan bahawa beban maksimum dan minimum faktor alam sekitar ialah penggunaan tanah/pelitup tanah (LULC) dan oksigen terbubar air untuk *Porphyrio porphyrio indicus* di PIW, manakala tekanan atmosferik dan Indeks Air Dominan Normalisasi (NDWI) di PW. Hal ini menunjukkan faktor persekitaran secara signifikan menyumbang kepada kehadiran spesies burung. Selain itu, beban maksimum dan minimum bagi faktor tersebut ialah turbiditi air dan konduktiviti elektrik untuk *Amaurornis phoenicurus* di PIW, manakala tekanan atmosferik dan enam parameter air di PW. Sebahagian besar kawasan PW telah diklasifikasikan lebih sesuai untuk burung terestrial dan air daripada PIW disebabkan tekanan atmosfera yang selesa, LULC, curahan hujan, kelajuan angin, kelembapan relatif dan NDWI. Pendekatan penarafan kriteria pemboleh ubah persekitaran yang penting ini yang menggunakan ALMA adalah sangat penting untuk penyokong pemuliharaan kerana ia mengutarakan mereka dengan suatu alat untuk memahami faktor mana yang memberikan kesan kepada populasi burung di habitat yang berkaitan. Oleh sebab itu, penerimagunaan model sebagai alat pengurusan berserta dengan pangkalan data pemantauan populasi yang mantap akan meningkatkan keberkesanan pengurusan spesies dan tanah paya. Oleh itu , habitat tanah paya ini perlu dipulihara agar dapat meningkatkan populasi dan keberterusan dan kelestarian spesies avian pada masa hadapan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

%	Percentage
°C	Degree Celsius
ha	Hectare
PIW	Paya Indah Wetland
PW	Putrajaya Wetland
HSMS	Habitat Suitability Models
ALMA	Automatic Linear Modelling Algorithm
GIS	Geographic Information System
WQI	Water Quality Index
LULC	Land Use Land Cover
IBM	International Business Machines Corporation
UNFPA	United Nations Population Fund
NWR	National Wildlife Refuge
IUCN	International Union For Conservation Of Nature
RS	Remote Sensing
GARP	Genetic Algorithm For Rule-Set Prediction
AIC	Akaike Information Criterion
ROC	Receiver Operating Characteristics Plots
SPOT	Satellite Probatoire D'observation De La Terre
MESSR	Multispectral Electronic Self-Scanning Radiometer
MOS	Marine Observation Satellite
NDVI	Normalized Difference Vegetation Index
EVI	Enhanced Vegetation Index
AVHRR	Advanced Very-High-Resolution Radiometer

NOAA	National Oceanic And Atmospheric Administration
LIDAR	Light Detection And Ranging
SAR	Synthetic Aperture Radar
MISR	Multi-Angular Imaging Spectro-Radiometer
LANDSAT TM	Landsat Thematic Mapper
GLMS	Generalized Linear Models
ANN	Artificial Neural Networks;
BA	Bayesian Approach
BRT	Boosted Regression Trees,
CE	Climatic Envelope
MARS	Multivariate Adaptive Regression Splines
MDA	Mixture Discriminant Analysis,
GDM	Generalized Dissimilarity Modelling
SVM	Support Vector Machine
MAXENT	Maximum Entropy
GA	Genetic Algorithm
BRT	Boosted Regression Trees
NIR	Near-Infrared And Red
LAI	Leaf Area Index
PAI	Plant Area Index
DOE-WQI	Department Of Environment-Water Quality Index
NDWQS	National Drinking Water Quality Standards
NWQS	National Water Quality Standards
NLWQS	National Lake Water Quality Criteria And Standards
TSS	Total Suspended Solids
IUNC	International Union For Conservation Of Nature

LC	Least Concern
NT	Near Threatened
VC	Vulnerable
IUCN	International Union For Conservation of Nature's
NO	Naïve Occupancy
MSI	Multi-Spectral Instrument
USGS	United States Geological Survey
LULC	Land Use/Land Cover
WGS84	World Geodetic System 1984
ERDAS	Earth Resources Data Analysis System
GDM	Geocentric Datum For Malaysia
ROC	Receiver Operating Characteristic Analysis
AUC	Area Under The Curve
AP	*Amaurornis Phoenicurus*
PPI	*Porphyrio Porphyrio Indicus*
GAM	Gross Arithmetic Mean

CHAPTER 1

INTRODUCTION

1.1 General introduction

The study of the bird populations is important for the understanding of the complexity of wetlands ecosystem structure and for providing updated information on each type of wetlands in the ecosystem (Weller, 1999; Matsinos and Wolf, 2003; Burger and Eichhorst, 2005; Amat and Green, 2010; Rahman and Ismail, 2018). Some of these bird species are distributed within one of the most varied and diverse wetland ecosystems across the country mainly due to the heterogeneity of vegetation phytosociological characteristics, unpredictable rainfall patterns and occurrence of contiguous different adjoining landscapes (Rajpar and Zakaria, 2014). But, the wetland ecosystems are threatened with a risk of extinction due to habitat loss, invasive species and human interventions (World Bank Report, 2011; Legape, 2013). Urbanization and increased agricultural activities such as oil palm plantations have largely replaced a large swath of wetlands vegetation areas (Munira et al., 2011; Russi et al., 2013).

Despite the undue human pressure on Malaysian wetlands, the birds density and distribution are pivotal on their vegetation dynamics, availability of water and food resources, protection from predators and climatic condition (Zakaria and Rajpar, 2010; Rajpar and Zakaria, 2014). Inland wetlands most especially in highly urbanized areas are critical to birds conservation (Morganti et al., 2019). PIW and PW are examples of highly urbanized and the largest wetlands located in the Selangor State (the largest populous and most developed state) and Putrajaya (the fastest-growing region) of Malaysia respectively (Ho, 2006; Malaysian Department of Information, Ministry of Communications and Multimedia, 2015). These two homogenous wetlands due to proximity (10km) with different wetland types (natural and artificial) could convey a varied abundance distribution of bird species to their ecological and micro-climatic factors.

The development of habitat suitability models (HSMs) remains an effective tool to resolve the fundamental research gap of determining the ecological and microclimatic factors that significantly influence the birds distribution within homogenous wetlands in an urbanized setting. In the past three decades, the usage of HSMs has increased to predict the likelihood of species' occurrence or presence/absence or distribution as it relates to environmental variables in a particular area (Franklin, 1995; Guisan and Zimmermann, 2000; Rushton et al., 2004; Hirzel and Lay, 2008). Different approaches had been employed in the variable selection or weighting of factors during the habitat suitability modelling. Some of these approaches are generalized additive models, generalized linear models, multivariate adaptive regression splines, Bayesian approach, artificial neural networks, climatic envelop, fuzzy logics, boosted regression trees, generalized dissimilarity modelling, genetic algorithm, mixture discriminant analysis, classification and regression trees, ecological niche factor analysis, maximum entropy, support vector machine (Busby, 1991; Carpenter et al., 1993; Stockwell and Peters, 1999; Hijmans et al., 2001; Pearson et al., 2002, Hirzel et al., 2002, Thuiller, 2003; Lehmann et al., 2003; Phillips et al., 2006; David and Stockwell, 2006; Ferrier et al., 2007; Sutton et al., 2007; Thuiller et al., 2009).

These study explored the integration of birds presence and absence data with associated environmental variables to predict their habitat suitability using the Automatic Linear Modelling Algorithm (ALMA) and Geographic Information System methods. Yang (2013) introduced the Automatic Linear Modelling Algorithm, a form of a regression model with various model selection methods (such as forward stepwise, best subsets, include all predictors) to rank the independent variables based on the computation of predictor importance coefficient (referred to importance ratios in this study). These predictor importance coefficients are relative values, sum up to 1.0 and rank each independent (predictor) variable according to its importance to the model (IBM Corporation, 2011). The novel variable selection capability of ALMA was integrated with geospatial techniques to determine the influence of environmental variables on the occurrence of the birds.

1.2 Problem Statement

Malaysia has lost more than half of its wetlands to agricultural development and urbanization (Zakaria and Rajpar 2009; Dahl et al., 1991). Despite heavy wetland losses, the wetlands in Malaysia remains one of the most important migration, wintering and breeding areas for wetland-dependent birds in North America, supporting over 60% of the total Pacific Flyway waterfowl population (Central Valley Joint Venture, 2006). Hence, documentation on this current status of birds and the environmental factor affecting their occurrences in these wetlands is crucial. This will help conservationists manage their wetlands to conserve an attract avian communities.

Avian diversity faces growing pressures from human actions, including habitat conversion and degradation, habitat fragmentation, climate change, harvesting and pollution (Tittensor et al., 2014). As a result, global assessments showed that avian communities extinction risk is increasing on average while population sizes are declining (Pimm et al., 2014; Tittensor et al., 2014). Such assessments have usually focused on some bird’s species, so might not reflect broader biodiversity (Collen et al., 2009). Furthermore, most have concentrated on the global status of species, whereas the long-term security of many ecosystems especially in changing environments is likely to depend upon local avian biodiversity (Isbell et al., 2011; Hooper et al., 2012; Cardinale et al., 2012).

Average trends in local avian diversity remain unclear: analyses of temporal changes in assemblages have suggested no systematic change in species richness (Vellend et al., 2013; Dornelas et al., 2014), The spatial analysis provides an alternative source of evidence on how ecological or environmental affect avian diversity, (Alkemade et al., 2009; Gibson et al., 2011; Mendenhall et al., 2014). The prevalence of published spatial analysis makes it possible to go beyond particular taxa or regions (Gibson et al., 2011; Mendenhall et al., 2014) to develop global, taxonomically and habitat suitability representative models. Furthermore, the unwillingness of many researchers to share their raw data makes it impossible to consider multiple aspects of diversity, rather than the single, simple metrics of most existing models (Alkemade et al., 2009) which cannot capture all key aspects of diversity (Pereira et al., 2013). Hence, this study aims at addressing this gap by acquiring a comprehensive dataset of birds in PIW and PW for 26month and understand their environmental influence on bird population and diversity.

Land-use/Land cover changes are currently a major threat to bird diversity across southeast Asia (Forcey et al., 2011) and severe impacts from climate change should also be expected (Forcey et al., 2014). Birds have also been shown to be responding to climate change (Crick, 2004, Devictor et al., 2012), inclusively in the southeast Asia region (Hamilton et al., 2014). However, much remains to be explored regarding the effects of changes in land use/landcover and climate on Malaysian wetlands bird assemblages across the region.

The knowledge basis on the effects of climate change is even scarcer. The lack of long-term bird diversity monitoring, particularly in southeast Asia (Malaysia), makes it difficult to evaluate the impacts of climate change on biodiversity and to disentangle them from those of other drivers of change. Hence, it is important to understand the impacts of these climatic factors on the bird population of wetland birds.

In this study water birds refer to the bird species that entirely depend on wetlands for a variety of activities such as foraging, nesting, loafing and moulting, whereas, terrestrial birds refer to bird species that do not entirely depend on wetland habitat but may visit the wetland occasionally in search of food, shelter and perch (Rajpar & Zakaria 2009; 2010).

1.3 Importance of Study

1.3.1 Justification of the study

Estimating the bird population and diversity in man-made marsh wetland is an important tool to understand the avian assemblages, population trends and the current status of biodiversity in the wetland or habitats, for effective conservation and better management in the future. Accurate population estimates and detailed information about habitat use of marsh bird species in Malaysia are lacking. No detailed study has been carried out in man-made marshes wetlands to determine the population and diversity of avian communities. Due to the important role that birds play in maintaining ecosystems and supporting biodiversity, many seek their protection to manage biological threats and efficiently protect the environment (Stevenson and Fanshawe, 2002). Birds fulfil many ecological functions in their habitats. For instance, they are bioindicators of healthy ecosystems (Mistry et al., 2008, Slabbekoorn and Ripmeester, 2008). In addition, insectivorous species and raptors regulate disease vectors, including mosquitoes and rodents. Scavenger birds, such as the Pied Crow (*Corvus albus*), contribute to biomass recycling and to some degree reduce levels of disposable wastes. Frugivorous birds play an important role in seed dispersal of fleshy fruit-producing plants environment (Stevenson and Fanshawe, 2002). Birds are also important in plant pollination as demonstrated by sunbirds, which participate in crossbreeding of flowering plants, especially those with the bird-pollination syndrome (Judd, 2008). These ecosystem services are important for many communities, and to ensure that birds can fulfil these biological roles at an appropriate level for current and future generations, hence, there is a pressing need to study the population and how environmental factors affect the bird diversity in Malaysian wetlands, especially in urban areas as higher bird population leads to a better habitat or ecosystem which directly or indirectly improves the urban communities.

In this study, the bird/avian population is the size of each bird species per hectare while diversity is a variation in bird species inhabited man-made marsh wetland. Determining the bird population and diversity provide information on population size, population changes over a specific period across different wetlands or habitats, the impact of wetland or habitat loss and degradation in different wetlands or habitats (Githiru & Lens, 2006; Norvell et al., 2003). For this purpose, a distance sampling point count method was chosen because it was more appropriate technique and extensively used to determine the avian population and diversity in different habitats (Buckland et al., 2008; Harrison & Kilgo, 2004). This method provides a uniform way of counting birds over time across the locations, reduces bias in estimates of avian populations and each point count station represents an independent data that can generate a large sample size and a robust data set (Thomas et al., 2010; Wilson et al., 2000).

With global increases in human population growth, there is a need for research regarding the relationship between environmental factors affecting wetlands and bird diversity (Mattison, 2005; Crossman, 2013). Human-induced changes to bird diversity have occurred more rapidly in the past 50 years than at any other time in history, and the forces driving such changes are steady, showing no evidence of decline over time (Millennium, 2005). In the past, conservation efforts have largely focused on conserving individual species and habitats. More recently, conservation ecologists have focused on wetland services or the goods and services from ecological systems that benefit people (Millennium, 2005).

Hence, the development of habitat suitability models remains an effective tool to resolve this fundamental research gap. Over the years, different approaches had been employed in the variable selection or weighting of factors during the habitat suitability modelling of birds. For instance, the Analytic hierarchy process (Zhang et al., 2016, Tian et al., 2016), maximum entropy (Vallecillo et al., 2016), etc had been applied to investigate the factors influencing the distribution of these avian groups. Amidst these methods, Elith et al. (2006) and Aguirre-Gutiérrez et al. (2013) argued that the maximum entropy method offered better predictive performance, most especially for presence-only data. However, Yang (2013) introduced the Automatic Linear Modeling Algorithm (ALMA), a forward stepwise model selection method to rank the independent variables based on the computation of importance ratios. It is an extension of the multiple linear regression functions in the Statistical Package for Social Sciences software that can explore both the species' presence and absence data. Also, it has not been applied in any studies related to habitat suitability modelling. In this study, the novelty of variable selection capability of ALMA was integrated with geospatial techniques to determine the influence of environmental variables on the occurrence of the Avian community and some selected rails species (*Porphyrio porphyrio indicus* and *Amaurornis phoenicurus*). The research aimed at developing robust habitat suitability models towards improved conservation of these Avian communities in the Paya Indah and Putrajaya Wetlands of Peninsular Malaysia.

1.3.2 Justification for choice of waterbirds (*Porphyrio porphyrio indicus* and *Amaurornis phoenicurus)*

Purple Swamphen (*Porphyrio porphyrio indicus*) and White-breasted Waterhen (*Amaurornis phoenicurus*) are important species of the family Rallidae (Rails, Gallinules, and Coots) in Peninsular Malaysia. Globally, a lot of research had been undertaken most especially in the areas of their estimated population, habits, habitats, foods, nesting and reproduction, and potential ecological impacts in different habitats (del Hoyo *et al.,* 1996; Taylor and Van Perlo, 1998; Gopakumar and Kaimal, 2008; Pearlstine and Ortiz, 2009; Buden and Retogral, 2010; BirdLife International, 2012; Taylor, 2016; Moreno-Opo and Pique, 2018; Chen *et al.,* 2019). These different habitats of Purple Swamphen and White-breasted Waterhen include natural and man-made wetlands, rivers, lakes, reservoirs, ponds, freshwater swamps, mangroves and tidal mudflats, coral reefs, rice fields, grasslands, sewage farms, etc. Given the uncertainty in the population trends of the two species within severely fragmented areas in recent times (BirdLife International, 2015; BirdLife International, 2016b), it is highly expedient to consider their current estimated populations in different urban wetlands despite their present “least concern” status on the IUCN Red data list (BirdLife International, 2016a; BirdLife International, 2016b). Also there are insufficient baseline data and the diversity of this species within most tropical wetlands especially Malaysian wetlands remains a major issue in its management effectiveness (Leveau et al., 2018). Having established some of the concerns from BirdLife International, (2019), they suggested that the following should be done on this species;

- This species should be fully protected, included in the appropriate category in the national catalogues and have a National Recovery Plan.
- Also there should be ***a continuous monitoring*** scheme for this species, Key sites should be adequately protected, as should smaller sites and appropriate restoration, ***conservation and enhancement measures applied***.
- Also, restrictions on hunting at important sites are also needed and **monitoring** should be standardised throughout its range.

- Research should focus on ***mortality and migration caused by environmental factors and habitat use***. (de Vergara and Ripoll, 1999).

Hence, it was highly imperative to establish the influence of environmental variability on their natural relics and distribution areas with immense scientific value.

1.3.3 Justification of study site selection

Continuous human development and urbanization have changed most natural habitats, including wetlands. Hence, the current trend of landscaping, and particularly for new townships, incorporates artificial habitat as one of its primary components to treat the effluent and maintain the water quality and environmental health. Comparative studies of avian community composition in different habitats, including urbanized areas, can improve our knowledge of the general patterns and processes that characterize bird species and communities. A number of studies that describe avian responses to urbanization (conducted mainly in temperate areas) suggest that urbanization affects landscape heterogeneity and consequently, the distribution, abundance and resources upon which birds depend (Marzluff, 2001; Jokimaki et al., 2002; Blair, 2004; Chace and Walsh, 2004; Manhaes and Alan, 2005), hence Paya Indah Wetland and Putrajaya Wetland were chosen because of its uniqueness in avian diversity and its location in Malaysia.

1.4 General Aims and Research objectives

The research aimed at comparing the population estimate of avain species, and developing robust habitat suitability models towards improved conservation of avain species in Paya Indah Wetland and Putrajaya Wetland of Peninsular Malaysia.

The objectives were as follows;

- To determine the population size, occupancy modelling, and diversity of terrestrial birds, waterbirds, and selected waterbird species (*Porphyrio porphyrio* and *Amaurornis phoenicurus)* in Putrajaya Wetland and Paya Indah Wetlands of Peninsular Malaysia;
- To examine environmental factors that influence the population and diversity of terrestrial birds, waterbirds, and selected species (*Porphyrio porphyrio* and *Amaurornis phoenicurus)* within Paya Indah Wetland and Putrajaya Wetland.
- To develop habitat suitability models for terrestrial birds, waterbirds, and selected species (*Porphyrio porphyrio* and *Amaurornis phoenicurus)* within Paya Indah and Putrajaya Wetland in the study area.

This study, therefore, provides policymakers and conservationists of the wetlands with scientific information about the ecological status of birds and how their population and diversity can be affected by wetland environmental characteristics.

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