IDENTIFICATION OF IMPORTANT PLANT AREAS USING GIS-BASED MULTI-CRITERIA DECISION-MAKING IN PENINSULAR MALAYSIA

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair : Prof. Gs. Ts. Mohd Hasmadi Ismail, PhD
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The Important Plant Areas (IPAs) framework developed by Plantlife International in the early 2000s aims to protect wild plants and fungi and contributes to the fifth target of the CBD Global Strategy for Plant Conservation (GSPC). In addition, national implementation contributes to the sixth target of the Malaysian National Policy on Biological Diversity 2016-2025. IPA initiative focused on plant conservation through three key criteria, i.e., presence of threatened species, exceptional botanical richness, and threatened habitats. These criteria were developed for global implementation, hence a likelihood of unsuited use of the criteria and thresholds in Malaysia.

A review of studies revealed that the IPA criteria were strict for implementation and the method used for IPA identification was varied and uncertain in determining the criterion weights. The preferred method used in IPA was the scoring method because of its simplicity, ease of use, and comprehensibility. However, the scoring method suffered from judgment uncertainty, the influence of the weighted score on each criterion was not understood, and the limited ability to complement biodiversity-related parameters. Herbarium databases were widely used in IPA identification; however, the database was associated with the biasness towards collections efforts, resulting inaccurate population counts, which would inadvertently classify areas with massive collection data as species-rich areas.

IPA identification is divided into two phases. First, identification of all potential IPAs and second, decision-making in selecting the final IPAs. This study moulded a preliminary solution in the first phase in the state of Perak to address issues of criterion weights, judgement uncertainty and biases in herbarium collections by proposing three complementarity techniques, namely multi-criteria decision-making - analytical hierarchy process (MCDM-AHP), species distribution modelling (SDM) and GIS-based multi-criteria decision-making (GIS-MCDM). The MCDM-AHP technique was used to solve criterion weights and judgment uncertainty issues. Collection bias in the herbarium database was reduced using SDM utilising the Maximum Entropy (MaxEnt) to identify the Dipterocarpaceae species richness areas in Perak. GIS-MCDM, which combined MCDM-AHP and SDM to acquire information for decision-making, was used to identify the IPAs.

As a result, on the weights and judgment uncertainty issues, threatened habitats were given the highest weight, followed by threatened species, endemism, and botanical richness. The results of species modelling revealed that 65% of the dipterocarp species richness areas were in the centre and south Perak and the remaining 35% were found in northern areas. IPA weights and indexes were incorporated into the GIS-MCDM environment, and as a result, eight dipterocarp IPAs were identified in the state of Perak. Six were in the protected areas, while two IPAs were outside of the protected areas.

This study has improved the existing method for site-based plant conservation by providing a smaller-scale map of IPAs with more significant detailed information related to threatened species, botanical richness, threatened habitats, and endemic species. GIS-MCDM used in this study enhanced the IPAs identification technique by incorporating GIS-based decision-making, species modelling, and spatial analysis. This enabled stakeholder to analyse spatial data, maps, charts, and reports in graphical formats for decision-making.

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

PENGENALPASTIAN KAWASAN PENTING TUMBUHAN MENGGUNAKAN TEKNIK PEMBUATAN KEPUTUSAN PELBAGAI KRITERIA BERASASKAN GIS DI SEMENANJUNG MALAYSIA

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Rangka kerja Kawasan Penting Tumbuhan (IPA) yang dibangunkan oleh Plantlife International pada awal tahun 2000 bertujuan untuk memelihara tumbuhan liar dan kulat, menyumbang kepada Sasaran kelima, Konvensyen Kepelbagaian Biologi. Pelaksanaannya di peringkat nasional menyumbang kepada Sasaran keenam, Dasar Kepelbagaian Biologi Kebangsaan 2016-2025. IPA memberi tumpuan kepada pemuliharaan tumbuhan menggunakan tiga kriteria utama iaitu kewujudan spesies terancam, kekayaan botani yang luar biasa, dan habitat terancam. Kriteria ini dibangunkan untuk pelaksanaan global, justeru kemungkinan kriteria dan ambangnya tidak sesuai bagi Malaysia.

Kajian literasi berkaitan aplikasi IPA melaporkan bahawa kriteria IPA adalah ketat untuk digunakan, metod yang digunakan untuk mengenalpasti kawasan adalah berbeza-beza dan ketidakpastian wujud dalam menentukan pemberat bagi setiap kriteria. Kaedah yang banyak digunakan dalam penentuan IPA ialah kaedah skor kerana ia ringkas, mudah digunakan dan difahami. Walau bagaimanapun, kaedah skor cenderung kepada ketidakpastian penilaian, pengaruh pemberat pada setiap kriteria yang tidak difahami, dan keupayaan terhad untuk melengkapi parameter biodiversiti. Pangkalan data herbarium banyak digunakan dalam pembangunan IPA, namun isu yang timbul dari penggunaan pangkalan data ini adalah berat sebelah dari segi pensampelan menyebabkan kiraan populasi yang tidak tepat iaitu kawasan yang mempunyai kutipan data yang banyak mungkin dikelaskan sebagai kawasan kekayaan spesies.

Pengenalpastian IPA dibahagikan kepada dua fasa, pertama pengenalpastian kawasan yang berpotensi sebagai IPA dan kedua keputusan akhir bagi penentuan IPA. Kajian ini merangka penyelesaian pada fasa pertama untuk menangani isu berkaitan dengan pemberat kriteria, ketidakpastian penilaian, dan berat sebelah dalam koleksi herbarium dengan mencadangkan tiga kaedah iaitu Membuat Keputusan Pelbagai Kriteria - Proses Hierarki Analitik (MCDM- AHP), Pemodelan Taburan Spesies (SDM) dan Membuat Keputusan Berbilang Kriteria Berasaskan GIS (GIS-MCDM). MCDM-AHP digunakan untuk menyelesaikan isu kriteria dan ketidakpastian penilaian. Berat sebelah pengumpulan dalam pangkalan data herbarium dikurangkan melalui SDM menggunakan Entropi Maksimum (MaxEnt) dengan mengenal pasti kawasan kekayaan spesies Dipterokarpa di Perak. GIS-MCDM yang menggabungkan MCDM-AHP dan SDM digunakan untuk mengenal pasti IPA.

Hasil akhir bagi penentuan pemberat dan ketidakpastian penilaian menunjukkan kriteria habitat terancam diberi pemberat tertinggi, diikuti dengan spesies terancam, endemisme dan kekayaan botani. Pemodelan taburan spesies pula menunjukkan 65% daripada kawasan kekayaan dipterokarpa terletak di bahagian tengah dan selatan Perak dan baki 35% di kawasan utara. Pemberat kriteria dan indeks IPA telah diintegrasikan ke dalam persekitaran GIS-MCDM. Hasilnya lapan IPA bagi kaum Dipterokarpa telah dikenalpasti di negeri Perak, enam daripadanya terletak di dalam kawasan perlindungan, sementara dua lagi berada di luar kawasan perlindungan.

Kajian ini telah menambah baik metodologi sedia ada untuk pemuliharaan berasaskan tapak bagi tumbuhan dengan menyediakan peta IPA berskala kecil dengan maklumat lebih terperinci berkaitan spesies terancam, kekayaan spesies, habitat terancam dan spesies endemik. GIS-MCDM yang digunakan di dalam kajian ini telah menambah baik pengenalpastian IPA dengan menggabungkan pembuatan keputusan ke dalam GIS, pemodelan spesies, dan analisis spatial, bagi membolehkan pihak berkepentingan menganalisis data spatial, peta, carta dan laporan dalam format grafik untuk membuat keputusan.

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I certify that a Thesis Examination Committee has met on 28 September 2022 to conduct the final examination of Hamidah binti Mamat on her thesis entitled "Identification of Important Plant Areas Using GIS-Based Multi-Criteria Decision-Making in Peninsular Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of 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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AHP	Analytical hierarchy process
Asl	Above sea level
AUC	Area under the curve
CBD	United Nations Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species
CR	Consistency ratio
CR	Critically endangered
CSV	Comma-separated value
DEM	Digital elevation model
EN	Endangered
FR	Forest reserve
FRIM	Forest Research Institute Malaysia
GIS-MCDM	GIS-based multi-criteria decision-making
GLM	Generalized linear model
GSPC	Global Strategy for Plant Conservation
HCV	High conservation values
IBA	Important Bird Areas
IPAs	Important Plant Areas
KATS	Ministry of Water, Land and Natural Resources
KEP	Kepong herbarium
MaxEnt	Maximum Entropy
MCDM	Multi-criteria decision-making
MNSPC	Malaysian National Strategy for Plant Conservation

MTP	Minimum presence logistic
MyBIS	Malaysia Biodiversity Information System
NDVI	Normalised differential vegetation index
NPBD	National Policy on Biological Diversity
ROC	Receiver operating characteristic
SAN	Herbarium of Forest Research Centre, Sabah
SAR	Herbarium of Forest Research Centre, Sarawak
SDM	Species distribution modelling
SING	Singapore herbarium
Sq.km	Square kilometer
SRTM	Shuttle radar topography mission
TIPA	Tropical Important Plant Areas
VU	Vulnerable

CHAPTER 1

INTRODUCTION

1.1 General background

Malaysia, located in the Indo-Malaya region, is one of the twelve megadiverse countries in the world. The Indo-Malaya (tropical Asia) region ranked the second-highest tree species richness in the world, with 13,739 species (BGCI, 2021). The total forested area of Peninsular Malaysia is 5.69 million ha constituting about 43.3% of entire land areas, with 4.80 million ha (84.3%) of these areas gazetted as Permanent Reserve Forest (PRFs) (Forestry Department Peninsular Malaysia, 2020). Geographically, Malaysia is divided into Peninsular Malaysia to the West and Sabah and Sarawak to the East, with a total land area of 131,598 sq.km and 200,565 sq.km, respectively. In terms of tree, Malaysia comprises 9.2% (5422 species) of the world's diversity; of which 1616 (29.8%) are endemic (BGCI, 2021). Peninsular Malaysia and East Malaysia have an estimated 8,300 and 12,000 plant species, with 30% and 42% endemic to those regions, respectively (Saw et al., 2010).

Malaysia's transition from a low-income country to a high-income country profoundly affects its land-use patterns. Malaysia lost around 29.4% of its forest cover between 1973 and 2015 (Chua et al., 2022). In Peninsular Malaysia, between 1960s and 1970s, a significant land-use change occurred when vast forested areas were converted to rubber and later oil palm plantations (Saw & Sam, 2000). At present, rising land-use changes and conversion to plantations, agricultural lands, and urbanization are significant contributors to biodiversity loss in Peninsular Malaysia (Syahida-Emiza et al., 2013). Land-use changes have exerted pressure on Malaysia's biodiversity, causing many plant populations to become vulnerable where half of the nation's plant diversity faces various threats (Ministry of Natural Resources and Environment, 2016). Malaysia Plant Red List recorded nearly 28.64% of the peninsula's plants as threatened, and at least 98% of 96 endemic taxa assessed as threatened (Yong et al., 2021). Some species are experiencing extinction, such as *Begonia eiromischa* (Begoniaceae) (Kiew, 1990), *Oreogrammitis crispatula*, and *O. kunstleri* (Grammitidaceae) (Chua, 2010). Natural habitat destruction and population reductions, which result in population and species loss, appear to be ongoing and accelerating across Malaysia (Chua et al., 2022). Therefore, strategies to reduce biodiversity loss should be pursued, and one strategy regarded as clearly a priority is establishment of conservation areas (Eken et al., 2004; Sutherland, 2008).

Conservation areas are regions that harbour significant biodiversity or are critical for maintaining ecosystem services (HCV Malaysia, 2021). In Malaysia, conservation areas framework to protect biodiversity and ecosystem conducted through species-based or landscape-based approaches; which are classified as Protected Areas (Ministry of Natural Resources and Environment, 2019), High Conservation Values Areas (HCV Malaysia, 2018; HCV Malaysia, 2021), Key Biodiversity Areas (Ahmad Ruzman et al., 2021), Environment Sensitive Areas (PLANMalaysia, 2021) and Important Bird Areas (Yeap et al., 2007). Except for Important Bird Areas, which focused on bird conservation, most frameworks concentrated on the broadest aspects of environmental features such as natural, ecological, cultural values, biological, environmental and social. Plants are often underrepresented in conservation planning schemes. In areas recognised as important for fauna, plants are rarely considered in the management strategies despite their high botanical importance (Corlett, 2016; Darbyshire et al., 2017). Thus, there is a clear and urgent need to make information on plants available to decision-makers for maximum impact on environmental decision-making. Information on plants, such as threats, populations, and locations, is essential to support the existing conservation framework. Site-based plant conservation measures should complement to Malaysia's current frameworks to ensure plants are not neglected in biodiversity planning.

Numerous international environmental initiatives have been launched to aid in selecting biodiversity conservation areas, either focused on identifying or developing networks of areas important for biodiversity. For the plant in situ conservation, the Important Plant Areas (IPAs) concept developed by Plantlife International in the early 2000s, which currently benefits the plant conservation efforts in 70 countries worldwide (Couch et al., 2019), is considered optimal for implementation (Salma et al., 2019). The concept was inspired by the International Bird Areas (IBA) concept and is defined as the most important area in the world for wild plant diversity that can be managed and protected (Plantlife International, 2018). IPA initiative focuses on identifying critical areas for plant conservation using three key criteria, i.e. presence of threatened species, exceptional botanical richness, and threatened habitats (Anderson, 2002; Anderson et al., 2016; Darbyshire et al., 2017). The IPA identification is divided into two stages. The first stage identifies all potential IPAs that meet one or more criteria, while the second involves the national IPA constituency selecting the most critical sites (Anderson, 2002; Darbyshire et al., 2017).

Over the last two decades, there has been an increasing number of IPAs in Europe, North Africa, and the Middle East. This framework, unfortunately, is not widely used in tropical countries. Realising this implementation gap, further improvements and revisions were made to suit the needs of the tropical countries (Darbyshire et al., 2017), which are now known as Tropical Important Plant Areas (TIPA). In addition, further improvements to the criteria have been rendered by introducing new elements such as socio-economic and culturally significant plants, which are currently implemented in the tropical countries such as Bolivia, Guinea (Couch et al., 2019; Couch et al., 2020), Indonesian New

Guinea, Mozambique, Uganda, the British Virgin Islands (Dani Sanchez et al., 2019), and Cameroon (Cheek et al., 2021).

In Malaysia, the forested areas are conserved in the network of national parks, wildlife sanctuaries, state parks, and protection forests within the Permanent Reserve Forest. Therefore, strategic conservation efforts are needed to safeguard plants outside these protected areas. IPAs can be established on any land regardless of its status, including protected areas, private and state lands; thus, this framework can be used to identify important plants outside the existing network of protected areas. Although IPAs do not constitute a legal designation, the identified IPAs can be used as multiple-used areas to support and complement existing Protected Areas and Protection Forests. Likewise, it underpins the approaches of High Conservation Values Areas, Key Biodiversity Areas, and Important Bird Areas.

IPA framework directs in situ plant conservation and may assist Malaysia in determining plant conservation areas by providing clear evidence of the biodiversity value of a site. Findings arising from this study could help stakeholders and decision-makers to identify conservation actions, site protection, and management for these crucial plant areas.

1.2 Problem statements

Even though plants are essential components that support the diversity of other organism and humans, the conservation of plant diversity has received significantly less attention than animal (Oldfield, 2010; Goettsch et al., 2015; Corlett, 2016; Darbyshire et al., 2017). Peninsular Malaysia has implemented frameworks for the protection of important biodiversity and ecological areas; however, a framework for in situ plant protection is still lacking. The plant protection framework is crucial for plant conservation, underpins the existing biodiversity frameworks and assists decision-makers in determining conservation zones that enable conservation measures to be adequately addressed (Kjetil Bevanger, 2019).

The floristic province of Peninsular Malaysia has been studied throughout the years, i.e., phytogeography and floristic composition (Corner, 1960; Ashton, 1990; Wong, 1998; Kiew & Saw, 2019), centre for plant diversity (Davis et al., 1994), hotspots areas (Myers et al., 2000) and regional species intensity index (Ng et al., 2022); however detailed spatially explicit analysis of floristic compositions are still lacking. These information gaps need to be rapidly filled because plant habitats are already exposed to numerous threats (Yong et al., 2021; Chua et al., 2022) with three extinct species in Peninsular Malaysia. Therefore, further research is needed at a finer scale to ensure that key natural areas are adequately protected and managed to preserve the species and its habitats.

IPA framework can be utilised in Malaysia to assist in identifying key natural areas to ensure that these areas are adequately protected and managed to preserve species and their habitats. However, IPA framework was designed for global use; therefore, the criteria and thresholds may not be considered ideal in all countries (Darbyshire et al., 2017). For the implementation in Malaysia, methods and protocols must be refined to accommodate national capacities in identifying the critical areas for plants.

Studies have shown that the scoring method is preferred for selecting potential IPAs because of its simplicity and ease of understanding. This method assigns a rating to each grid based on its biodiversity significance, where grids that are important regions for plant diversity are given high values. The scoring method has been successfully used to identify IPAs of Al-Abbasi et al. (2010); Blasi et al. (2011); Sérgio et al. (2012); Özden et al. (2016); Bou Dagher-Kharrat et al. (2018); Sayadi et al. (2022). It has, however, several drawbacks in that it does not have a standard scoring method (Walsh, 2019), suffers from judgment uncertainty, the influence of the weighted score on each criterion is not understood (Sánchez de Dios et al., 2017), and it has limited ability to complement biodiversity-related parameters (Ribeiro et al., 2017). Even though criterion weights are critical aspects influencing IPAs designation, the method focused on resolving judgement uncertainty and determining appropriate criterion weight remains unexplored. A scoring method is beneficial when comprehensive data on plants and habitats are available. In cases where the data is scarce, the scoring method should combine additional complementarity methods to improve analytical sensitivity (Marignani & Blasi, 2012; Sánchez de Dios et al., 2017; Walsh et al., 2019).

In a tropical country with a megadiverse, detailed species data is lacking and almost impossible to gather through plant inventories, which require high cost, is labour intensive, and time-consuming. Nevertheless, the herbarium database remains the most practical and popular plant data source for biodiversity analysis (Lavoie, 2013). The main challenge and limitation are collection bias (Raes et al., 2009; Daru et al., 2018; Meineke & Daru, 2021). Herbarium databases are useful in the identification of IPA, but such collections tend to exhibit under or over-representation of specific taxa because of the bias towards sites that are accessible (Walsh et al., 2019), sampling methods and intensities. Herbarium databases are also biased in temporal coverage (Meineke & Daru, 2021). As a result, old records may not have precise information on the locality and current land use (Sánchez de Dios et al., 2017). These biases led to the distribution data challenges, particularly in poorly inventoried or surveyed areas. This causes inaccurate population counts (Magurran, 2004), which would inadvertently but inappropriately classify areas with massive collection data as species-rich areas (Sánchez de Dios et al., 2017).

IPA identification in this study considered difficulties or limitations of data on species distributions, population sizes, threats, and resources to gather such data. This study utilised three methods to address the concerns raised in IPA applications which are (i) Criterion weights and judgement uncertainty and (ii) Biases in herbarium collections. First, the multi-criteria decision-making – Analytical Hierarchy Process (MCDM-AHP) method was used to resolve the criterion weights and judgement uncertainty issues, and species distribution modelling (SDM) was applied to enhance the quality of species richness areas identification. Finally, results from MCDM-AHP and SDM were integrated into the GIS environment utilising the GIS-MCDM. The combination of MCDM-AHP and SDM has yet to be tested in any IPA development and is regarded as a valuable tool for decision-making in spatial planning aimed at plant conservation in Malaysia.

1.3 Research questions

With all the issues stated earlier. The following research questions are formed:

1. What approach and criteria are applicable for identifying Malaysian IPA?

2. How much weight should be assigned to score Malaysian IPA criteria?

3. What is the appropriate method to reduce biases from herbarium data so that species richness areas can be defined more precisely?

4. Can the developed criterion weight and index determine Malaysian IPAs?

1.4 Aim and objectives

This research aims to identify significant areas for plant conservation using the IPA framework. The objectives are as follows:

1. To propose an appropriate methodology for the development of Malaysian IPA;

2. To develop a protocol for Malaysian IPA criterion weights and index;

3. To improve the identification of species richness areas; and

4. To produce an IPA using the developed criterion weights and index.

1.5 Scope of the study

The IPA designation was divided into two phases. This study focused on the first phase, which involved the development of methodology and criteria weights protocol to identify the prospective IPAs. The second stage, in which stakeholders and decision-makers assessed the final IPAs, was not cover in this study.

A preliminary study was conducted in Terengganu; however, the final IPA identification was conducted in Perak, which focused on the Dipterocarpaceae plant family. The dipterocarps was selected because Malaysia is the dipterocarp hotspot area (Chua et al., 2022), and they are dominant in the forests and occur in almost all habitats (Symington, 2004). Perak is home to 115 dipterocarp species, the third highest in Peninsular Malaysia (Yong et al., 2021). The state of Perak is one of Malaysia's richest states in terms of biodiversity and has a high number of Critically Endangered taxa (Chua et al., 2010). The primary source flora database was obtained from Kepong Herbarium (KEP) and additional information on the distribution was compiled from the SING herbarium and other literature.

1.6 Significance of study

Malaysia is aware of the issues associated with the loss of natural habitats and remains committed to conserving its biodiversity. The commitments are reflected in the ratification of several multilateral environmental agreements, such as the United Nations Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Malaysia's National Policy on Biological Diversity 2016-2025 (NPBD) provides the overall guidance for biodiversity conservation and management in the country. The policy aligns with the United Nations Sustainable Development Goals, specifically the CBD Strategic Plan for Biodiversity 2011-2020. IPA framework can assist Malaysia in meeting Target 6 of the NPBD, highlighting the protection of at least 20% of terrestrial areas by 2025 (Ministry of Natural Resources and Environment, 2016). Internationally, the IPA framework contributes to the fifth target of the CBD Global Strategy for Plant Conservation (GSPC) by providing information on plants to monitor the conservation status and lobbying for the protection of conservation sites.

IPA is regarded as one avenue for plant conservation in Malaysia, alongside the Malaysia Red List. The Malaysia Red List assessments are used to meet IPA's threatened species criterion for the site-based conservation effort. IPAs can complement existing legally conserved areas such as Protection Forests under the Permanent Reserved Forests and Protected Areas in the same manner as Key Biodiversity Areas, High Conservation Value Areas, and Important Bird Areas. Designation of these multiple-use areas is considered complementary and mutually supportive since it offers the necessary site-based protection for biotic assemblages and the ecosystem. Site-based conservation safeguards abiotic ecosystem components such as water, soil, and air, all of which are necessary for the life of flora, fauna and humans. As part of the determination of site-based conservation measures, it is intended that a variety of biodiversity attributes associated with the site, such as areas of species richness, endemic species, threatened species, and threatened habitats, will be identified.

This research demonstrated the use of MCDM-AHP, SDM and GIS-MCDM for Malaysian IPA. These combined techniques are expected to improve and enhance the existing methodology for site-based plant conservation efforts. In addition, this study utilised species distribution modelling (SDM) to reduce biases and limitations associated with the herbarium database. SDM technology is expected to reduce biases, therefore filling in gaps in low collection intensity or unexplored botanical areas, thus supporting the IPA botanical richness criterion.

1.7 Organisation of the thesis

The thesis was organized as follows:

Chapter 1 presents an overview of the entire study. It comprises the general background, problem statements, research questions, aim and objectives, scopes of the study, significance of the study, and organisation of the thesis.

Chapter 2 comprises a literature review on biodiversity and conservation areas. This chapter also reviews issues, challenges and previous studies that have been conducted on IPA, GIS-MCDM, MCDM-AHP and SDM. From the review, research gaps are identified, and the design of the study is developed based on the findings.

Chapter 3 explains the research methods used to conduct this study. The research framework is presented first. Then, this chapter describes four phases of the study, which are arranged according to the research objectives. The phases include proposing an appropriate IPA methodology for Malaysian IPA, developing a protocol for Malaysian IPA criterion weights and index, identification of species richness areas and lastly, producing an IPA using the developed criterion weights and index.

Chapter 4 describes in detail the results and output obtained from the four phases of the study. This chapter highlights challenges and the proposed methods for Malaysian IPA. Further, this chapter also presents criterion weights and index derived from data obtained through questionnaire surveys of Malaysian biodiversity experts. Results of species richness modelling areas in Perak and finally eight IPAs areas identified using GIS-MCDM.

Chapter 5 discusses the overall research findings of the study. This chapter is divided into four phases and written in response to the research objectives and research questions.

Chapter 6 summarises the overall research findings, which are concluded by looking into the significant findings, the contributions of this study, the drawbacks endured, and several recommendations for future studies in plant conservation.

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