Research article

Towards identification of important plant areas (IPA) for Peninsular Malaysia. Methodology and future directions

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ABSTRACT

Malaysia is a megadiverse country and listed as one of the world's biodiversity hotspots. Land use changes and deforestation have led to the threat of, and extinction of plant species. In order to mitigate loss in population numbers, and to prevent species extinction events, Important Plant Areas (IPA) for Malaysia shall be identified. The identification of IPA is important to ensure that key natural areas are adequately protected and managed to preserve the species and its habitats. Currently, there are 1771 IPA identified globally and only seven tropical countries are actively involved excluding Malaysia. Inventory and biodiversity research are actively conducted in Malaysia, however, the initiative to identify IPA is still in its infancy. The first attempt for IPA identification was in the state of Terengganu by using herbarium database through scoring technique. In this paper, we discussed methods and criteria used in IPA identification globally. We also deliberated current IPA development in Terengganu and challenges such as collections biases and the need for a robust scoring technique to reduce judgement uncertainty. We suggested GIS based multi-criteria decision making, analytical hierarchy process and species distribution for Malaysian IPA. These strategies were considered to be effective tools in providing decision support for spatial planning aimed at plant conservation in Malaysia.

1. Introduction

Malaysia is geographically divided into two landmasses, West Malaysia (Peninsular Malaysia) and East Malaysia (Sabah and Sarawak). The total land area of Peninsular Malaysia is 131,598 sq. km whereas Sabah and Sarawak cover 200,565 sq. km. It is estimated that in 2014, Peninsular Malaysia held a total of 5.8 million ha of forested area and 12.4 million ha in Sabah and Sarawak (KATS, 2018). Malaysia spans the richest floral diversity of all tropical Asia with exceptional and endemic species (Ashton, 1990). Saw et al. (2010) estimated that there are 8,300 plant species in West Malaysia and 12,000 species in East Malaysia.

Four phytogeographical provinces, i.e. Riau Pocket, the Northern Province, the Perak Province and the Continental Intrusion, were hypothesized and explained from Peninsular Malaysia (Wong, 1998; Ashton, 1990; Corner, 1960). Kiew and Saw (2019) discussed the four phytogeographical provinces which were previously formed based on a few charismatic species. Using larger sample of 969 taxa, they affirmed both the Riau Pocket and Northern Province, and excluded the Perak Province and Continental Intrusion as distinct provinces. Similar study on plant diversity which listed 11 sites as centers of plant diversity in Peninsular Malaysia was also discussed by Davis et al. (1994). Myers et al. (2000) identified Malaysia as one of the world's biodiversity hotspots, containing extraordinary species richness and hyper-endemic plants that faced an exceptional degree of threat.

Malaysia's network of protected areas comprised of national parks, wildlife sanctuaries, state parks and protection forests within permanent reserved forests. The presence of edaphic habitats such as peat swamp, freshwater swamp, mangrove forest, coastal hill forest and limestone forest has been suggested as one of the reasons for the high diversity observed in Malaysian forests (Faridah-Hanum, 2015). Unfortunately, many of these habitats are not located within the network of protected areas. When not adequately protected, endemics and rare species are potentially at higher risk of endangerment (Wong, 1998).

Establishment of plant conservation strategies in Malaysia is in line with several policies such as the Global Strategy for Plant Conservation (GSPC), National Policy on Biological Diversity 2016–2025 (NPBD) and Malaysian National Strategy for Plant Conservation (MNSPC). Malaysia's commitment towards biodiversity conservation is observed in various multilateral environment agreements which includes the United Nations Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The NPBD provides direction and a framework for protecting the countries natural resources and consists of five goals set to be achieved by 2025. Goal number three (3) highlights Malaysia's commitment towards safeguarding all key ecosystems, species and genetic diversity through various means. Under this goal, various targets are put forward to delimit what 'safeguarding' means in this sense. Of these targets, target six highlights the need to conserve at least 20% of terrestrial areas by 2025 through the establishment of protected areas or other effective area-based conservation measures. Target seven refers to the protection of vulnerable ecosystems and habitats, of which the IPA approach is directly related. Although policies and strategies towards the identification of important sites for biodiversity exist in Malaysia, the IPA approach is novel.

2. Important plant area

IPA is the most important areas in the world for wild plant diversity that can be managed and protected as specific sites (Plantlife International, 2018). This concept was inspired by the International Bird Area (IBA) program successfully developed by Birdlife International to promote targeted bird and biodiversity conservation globally. Similarly, IPA targets specific priority areas for plant conservation. Although IPA does not constitute a legal designation, Anderson (2002) highlighted that identified IPA can be used to support and underpin existing conservation legislation; therefore serves as a guide for practical conservation methods.

In order to be qualified as an IPA, a minimum of one of the following IPA criteria must be fulfilled, i.e. presence of threatened species, botanical richness or threatened habitats (Plantlife International, 2018). In Europe, North Africa and the Middle East, identification of important sites for plant diversity has been successfully achieved (Anderson et al., 2016). In realization that the program is still lacking in the tropics, the criteria were revised. Further enhancements to the criteria were made by incorporating new elements to be scientifically robust and applicable globally (Darbyshire et al., 2017). Tropical IPA involves countries such as Indonesia, Bolivia, Cameroon and other tropical countries that are expected to reach their IPA identification target by 2020.

Various methods were used for IPA identification (Williams, 2009). However, there are two main methods that can be used to identify key sites for conservation of biodiversity namely a scoring procedure (ranking system) or a problem-solving procedure (complementarity approaches) (Marignani and Blasi, 2012; Abellán et al., 2005). A scoring procedure considers value in each grid corresponds to its importance in biodiversity (Walsh, 2016) that is based on one or more criteria such as species richness, rarity or habitat. A complementarity method is the most used method among problem-solving; by means of decision support tools (Marignani and Blasi, 2012) as well as prediction modeling and algorithms (Walsh et al., 2019; Sánchez de Dios et al., 2017; Mendoza-Fernández et al., 2010; Williams, 2009; Abellán et al., 2005). The latter is frequently used when there is a need to improve IPA designation produced by the scoring method and reduce biases in IPA selection. A summary of methods used in IPA identification extracted from published journals and thesis is shown in Table 1.

The scoring procedure based on expert judgment is widely used in IPA development as the method is more easily implemented and understood (Walsh, 2016; Marignani and Blasi, 2012) compared to the complementarity approach. Studies have shown a successful IPA designation using the scoring procedure that includes a grid-based ranking system and expert judgment (Bou Dagher-Kharrat et al., 2018; Özden et al., 2016; Sérgio et al., 2012; Blasi et al., 2011; Al-Abbasi et al., 2010; Punde, 2007). However, there is no standard scoring method applied (Walsh, 2016) and the criteria used are varied between countries.

Various combinations of criteria used in IPA selections are summarised in Table 2. Based on Table 2, the most used criteria are threatened species and endemism, followed by species richness, threatened habitat and rarity. Native species, species distribution value, phylogeny, abundance, expert definition and species with a special interest are additional criteria used.

3. Current IPA development in Malaysia

The Malaysian IPA project is in its infancy. This project has been carried out at Forest Research Institute Malaysia (FRIM) since 2017, funded by the Ministry of Water, Land and Natural Resources (KATS) of Malaysia under the 11th Malaysian Plans. The objectives of this project are (i) To determine areas containing threatened plants, botanical richness and threatened habitats; (ii) To develop an IPA score index for Malaysia based on IPA criteria developed by Plantlife International; (iii) To rank and prioritize areas for IPA strategic conservation planning. A preliminary study for Malaysian IPA was carried out in Peninsular Malaysia for the state of Terengganu, Malaysia (Figure 1). Terengganu with a total area of 12,974 sq. km is situated in the eastern part of Peninsular Malaysia. A total forested area in Terengganu is 6,529.18 sq. km (Forestry Department Terengganu, 2017) which cover 50% of its land area.

The application was done using Kepong Herbarium (KEP) database. A total of 3115 specimen records were georeferenced based on the recent topographic maps, historical topographic maps published in 1940, forest reserve maps and botanical gazetteer (Hamidah et al., 2011). Of these, 16 species were listed as Critically Endangered (CR), 63 Endangered (EN), 129 Vulnerable (VU) and 701 endemic species. The records were converted to point spatial layer to produce a species distribution map. One hundred and thirty-eight (138) spatial grids of 10x10 sq. km were

Table 1. Summary of method used in identifying IPA (+indicates included, − indicates excluded).

Author/s	Location	Scoring procedure	Complementarity
Walsh et al., (2019)	Ireland	+	+
Bou Dagher-Kharrat et al., 2018	Lebanon	+	−
Sánchez de Dios et al., 2017	Spain	+	+
Özden et al., (2016)	Cyprus	+	−
Sérgio et al., (2012)	Portugal	+	−
Marignani and Blasi (2012)	Italy	+	+
Blasi et al., (2011)	Italy	+	−
Mendoza-Fernández et al., (2010)	Andalusia	+	+
Al-Abbasi et al., (2010)	Saudi Arabia	+	−
Williams (2009)	Turks & Caicos Islands	−	+

Table 2. Summary of criteria used in identifying IPA (+indicates included, − indicates excluded).

| Reference	Species richness	Endemism	Threatened species	Rarity	Threatened habitat	Additional criterion
Walsh et al., (2019)	−	−	+	+	+	Native species, species distribution value
Bou Dagher-Kharrat et al., 2018	+	+	−	+	+	−
Sánchez de Dios et al., 2017	+	+	+	+	+	Phylogeny
Özden et al., (2016)	−	+	+	+	−	Abundance
Mendoza-Fernández et al., (2010)	−	−	+	−	+	−
Sérgio et al., (2012)	+	+	+	−	−	−
Marignani and Blasi (2012)	+	+	+	−	+	−
Yahi et al., (2012)	−	+	+	+	−	−
Blasi et al., (2011)	+	+	+	−	+	Expert definition
Al-Abbasi et al., (2010)	+	+	+	−	+	Special interest species
Williams (2009)	−	+	+	−	−	Native species, species distribution value
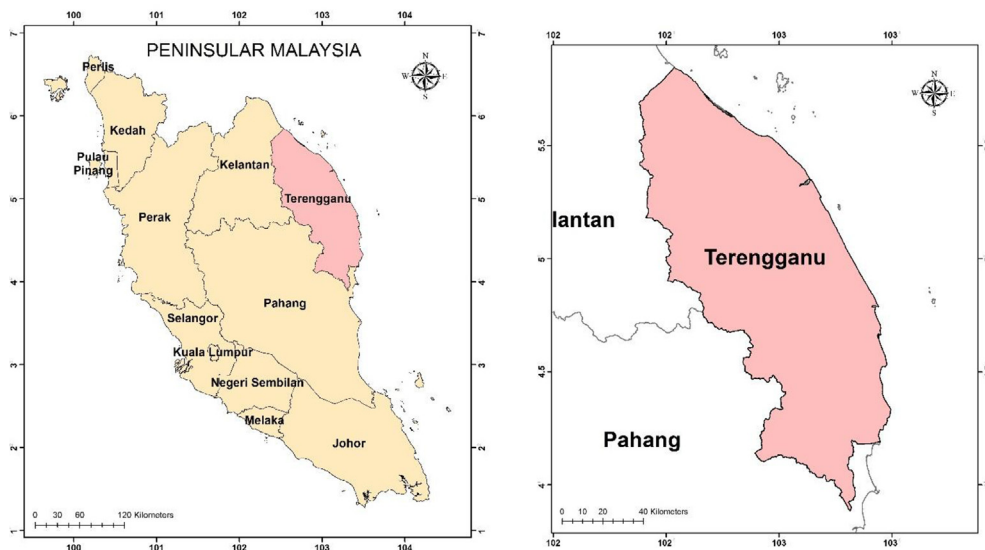
Figure 1. Study area.

generated and overlaid onto the species distribution map (Figure 2a). Figure 2b shows number of specimen records that correspond to each grid which indicates that the primary collection areas are in the central of Terengganu compared to the northern and the southern parts that recorded lesser herbarium collection. Boxes without specimen's record were excluded from the analysis.
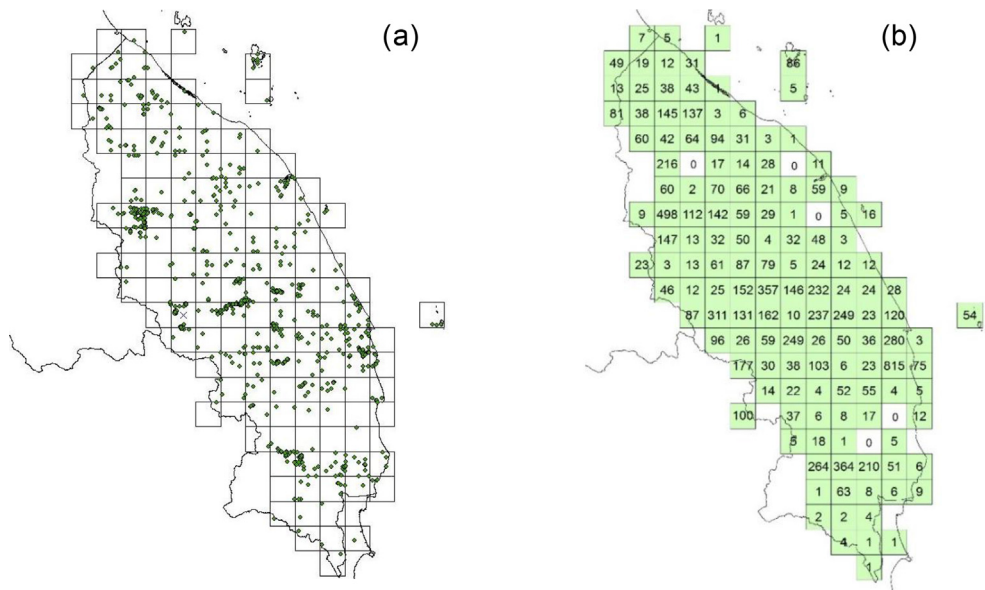

Figure 2. (a) species distribution map; (b) number of specimens in each grid.

A scoring method was used to identify IPA where threatened species, species richness and endemism were the main criteria for identification. Threatened habitat criterion was excluded in the analysis because a complete spatial data on threatened habitat was not available. Threat assessment for each species based on conservation status published in Flora of Peninsular Malaysia series (Kiew et al., 2010, 2011, 2012, 2013, 2015, 2017, 2018 & Parris et al., 2013, 2010), Malaysia Plant Red List (Chua et al., 2008) and species not yet assessed were based on IUCN Red List (www.iucnredlist.org). The scoring was assigned to each species corresponded to its threatened categories which are CR, EN, VU and endemism. Species in CR category were scored at 9, 3 for EN, 1 for VU and 6 for endemic species. Species fall outside of these categories or not evaluated were scored with 0. These scores were analyzed to produce a threatened species map. A total threatened scores were summed for each grid; for example, a grid which contains one CR species and three VU species will have a total score of twelve ((1 x 9) + (3 x 1) = 12).

The same dataset was analyzed to produce a species richness map (Figure 3). Species richness is defined as the number of species within a specific area (Newton, 2007). Total score in each grid were calculated using the following formula:

Scores of threatened species and species richness in each grid were totaled to generate hotspot map using ArcMap 10.4 (Figure 4a). Referring to Table 3, the grids were grouped based on standard deviation (std. dev.). The three highest range of standard deviation will become IPA (Figure 4b). Summary of the selected areas are shown in Table 4.

3.1. Challenges of current Malaysian IPA

Attempt on IPA Terengganu was aimed to gain experience, identify potential problems and suggest the best method for Malaysian IPA. We tested the KEP dataset and IPA criteria with a scoring method as this method was an elementary of IPA implementation, widely used globally (refer to Table 1) and easy to understand. We started from a basic scoring

Figure 3. Number of species in each grid.

method; from there we explored and suggested a complementarity method to overcome challenges thus improve the identification.

The biggest challenge in Terengganu IPA was the availability data on plant distribution as well as its threat status and endemicity. Referring to Figure 2(b) there are grids without or have low collecting intensity which makes impossible for analysis or inaccurate result. Therefore, more botanical studies are required in the east coast of Peninsular Malaysia to understand its floristic composition (Kiew and Saw, 2019). Besides, uncertainty to be judged for each criterion was also a challenge in this application. The utmost contributor to uncertainty is often the criteria weight (Chen et al., 2010). For example, how much score for species richness, areas with endangered or endemic plants. Furthermore, which areas were more important to conserve, either area of species richness or threatened species. From literature and experience in Terengganu IPA, we observed that a unified IPA scoring method has not been agreed in IPA applications globally.

The effect of the weighted score given by expert judgment to each criterion is not understood, therefore, a robust scoring system is needed to overcome this obscure (Sánchez de Dios et al., 2017). Uncertainty in judgment could be uncertainty associated with limited information about the condition and uncertainty associated with fuzziness on phenomena (Malczewski, 2006). Thus, a scoring process should be through effective assessment techniques, allowing decision makers to assign sufficient score for the used criteria. Furthermore, the intended scoring techniques should be able to assess the sensitivity of the final output based on variations of the input or score. Therefore, the effect of each score given to each criterion can be seen or visualized, where necessary changes can be made easily and updated from time to time.

In Terengganu IPA, the challenge has also existed in a form of bias from the herbarium database. Herbarium collections tend to exhibit under or over-representation of certain taxa depending on sites accessibility (Walsh et al., 2019), sampling methods and intensities (Sánchez de Dios et al., 2017). Identification of species richness areas is often impressed with these biases. Often, areas with huge data collections will be considered as species richness areas. Application for the state of Terengganu revealed that the selected IPA areas were confined in a protected area i.e. forest reserve and total protected areas within a species richness area.

Biases may also have been associated with expert judgment; which often based on personal experience as well as taxa and regions unfamiliarity (Cowling et al., 2003). Therefore, a complementarity approach may be used to mitigate the effects of biased data sets (Blasi et al., 2011). Walsh et al. (2019) and Sánchez de Dios et al. (2017) recommended that the scoring procedure should be applied in combination with other complimentary approaches to reduce biases. Marignani and Blasi (2012) compared the scoring procedure and complementarity approaches to identify IPA in Italy and suggested that a combination of both approaches could be an effective instrument in achieving conservation objectives.

The revised IPA criteria can be considered as an impetus for establishing Malaysian IPA. The effectiveness of criteria for sub-national needs to be evaluated therefore a possible fine-tuning is required to select more IPA areas (Walsh et al., 2019). The proposed Malaysian IPA criteria revised the global IPA criteria to suit Malaysian conditions and current policies. Sub-criteria are proposed for each criterion where scoring for each criterion will be assigned by botanist and conservationist through feedbacks from the questionnaire. Figure 5 shows the proposed criteria and sub-criteria for Malaysian IPA. Three key criteria developed by Plantlife International are remained with "endemism" as an additional important key criterion.

A conceptual framework proposed for Malaysian IPA is shown in Figure 6; where threatened species, botanical richness, endemism and threatened habitat are the main criterion. The KEP dataset will be used to fit threatened species, botanical richness and endemism criteria. In order to develop threatened habitat criterion, GIS layers and remote sensing images will be used to identify areas of peat swamp, freshwater swamp, mangrove forest, coastal hill forest and limestone areas.
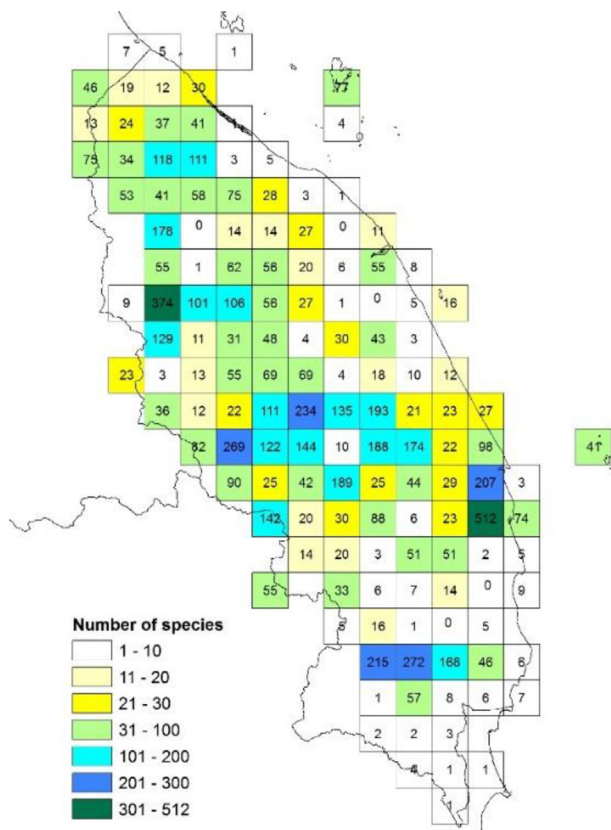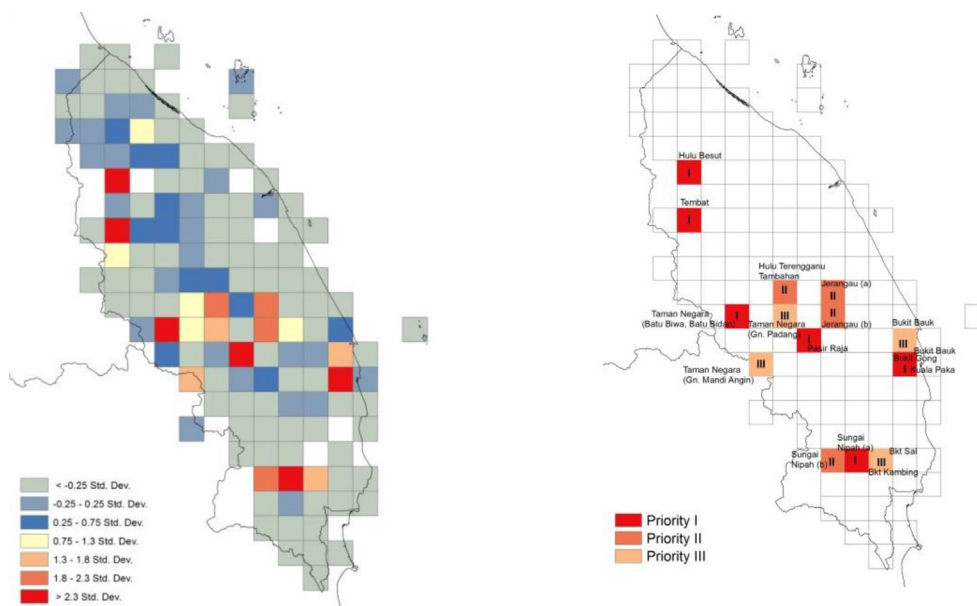
Figure 4. (a) Hotspot map (b) IPA for Terengganu.

Table 3. Classes for IPA suitability.

Priority	Score	Description
Priority I	>2.3	Highly suitable
Priority II	1.8–2.3	Moderate suitable
Priority III	1.3–1.8	Good suitable

Table 4. Summary of selected IPA.

	Area	Score
Priority I		
1.	Bukit Gong, Kuala Paka, Bukit Bauk	6.44
2.	Tembat	3.54
3.	Sungai Nipah (a)	3.10
4.	Taman Negara (Batu Biwa, Batu Bidan)	2.33
5.	Hulu Besut	2.32
6.	Pasir Raja	2.31
Priority II		
1.	Sungai Nipah (b)	2.16
2.	Jerangau (b)	1.94
3.	Hulu Terengganu Tambahan	1.93
4.	Jerangau (a)	1.88
Priority III		
1.	Bukit Bauk	1.69
2.	Bukit Kambing/Bukit Sai	1.64
3.	Taman Negara (Gn. Mandi Angin)	1.61
4.	Taman Negara (Gn. Padang)	1.26

Threat assessment for plant species will be based on Malaysia Red List and IUCN Red List. These data help to fulfill threatened plant species and endemism criteria. For the botanical richness criterion, species distribution modeling (SDM) application by Maxent is proposed. A combination of the scoring procedure and complementarity approaches will be implemented to improve the scoring technique and reduce biases. GIS-MCDM by using AHP technique is proposed for use to fulfill the needs for a robust scoring system which allows the effect of each scoring to be seen and revised if needed. SDM by means of Maxent will be used to reduce collection bias thus improving species richness areas identification. All criteria will be converted into GIS layers and integrated with AHP score. Further analysis will be then performed in GIS environment which includes the production of preliminary IPA map, revision of AHP score and production of prioritized IPA map for Peninsular Malaysia.
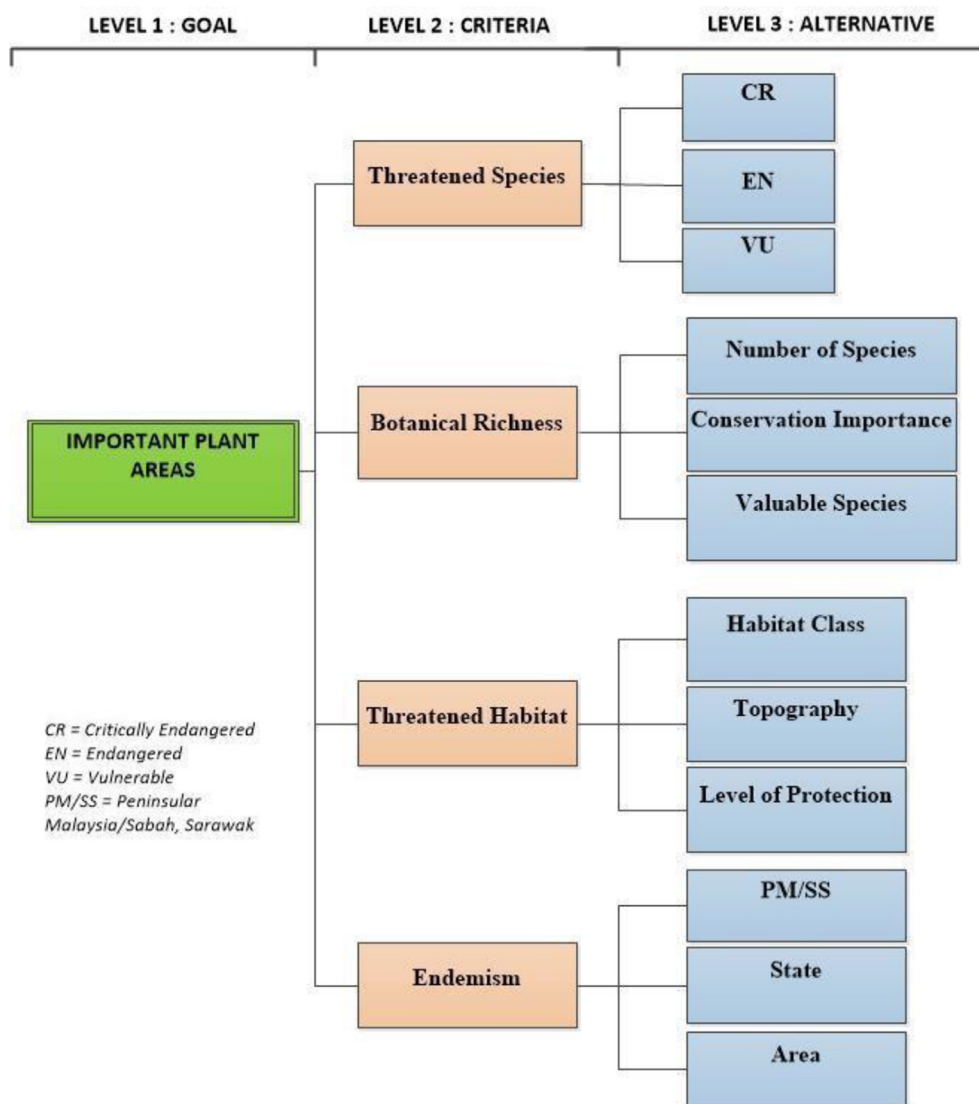
LEVEL 1 : GOAL **LEVEL 2 : CRITERIA** **LEVEL 3 : ALTERNATIVE**

CR = Critically Endangered
EN = Endangered
VU = Vulnerable
PM/SS = Peninsular
Malaysia/Sabah, Sarawak

Figure 5. Proposed criteria for Malaysian IPA.

4. Proposed methodology for Malaysian IPA

This section will discuss a potential GIS-MCDM for scoring and SDM to reduce biases from herbaria collection and also to identify species richness areas.

4.1. Analytical hierarchy process (AHP)

Decision support systems are sets of procedures for processing data and judgments to assist in decision making (Bottero et al., 2013). MCDM is one of the most important tools for decision support systems. It is a technique to assist decision-makers in selecting the best solution from a number of feasible alternatives (Jankowski, 1995) as well as frequently used to solve real-world problems (Kubler et al., 2016) and widely implemented in environmental planning processes as it produced a transparent result (Mustajoki and Marttunen, 2017). Since the last few decades, users have increased as it is constantly being developed and enhanced (Velasquez and Hester, 2013).

Various techniques were developed to handle the complex problems in MCDM such as AHP, MAUT, SMART, MACBETH and TOPSIS (Ishizaka and Siraj, 2018). However, the most often used and well-known technique is Analytical Hierarchy Model (AHP) (Dos Santos et al., 2019; Kordi and Brandt, 2012; Mohd Hasmadi, 2009; Saaty, 1990) which was developed by Thomas L. Saaty in the late 1970s. AHP is a simple technique, easy to understand and implement which can simplify complex problems (Bhushan and Rai, 2004). Kordi and Brandt (2012), reveals four steps in setting up priority using AHP. These are structuring problems as a hierarchy, pairwise comparisons matrix, consistency ratio and calculating the final weight.

Step 1: Structuring problem as a hierarchy

Structuring the problem as a hierarchy is the first step that consists of goals, criteria and alternatives. The advantages of hierarchy decomposition are to better understand the decision to be achieved, criteria used and alternatives to be evaluated (Mu and Pereyra-Rojas, 2017). The goal is achieved through different criteria where additional hierarchical levels can be included for complex problems. Levels of the hierarchy depend on how the complex problems are structured to achieve the goal. Figure 7 illustrates three levels of AHP hierarchy based on the revised IPA criteria (Darbyshire et al., 2017). On top of the hierarchy is the goal to be achieved. The second level is IPA criteria to be compared and the third level is alternative to be evaluated in relation to the criteria.

The AHP resolves complex decision making through a set of pairwise comparisons that focuses on comparing two criteria at a time. The importance of score was determined through verbal judgement with
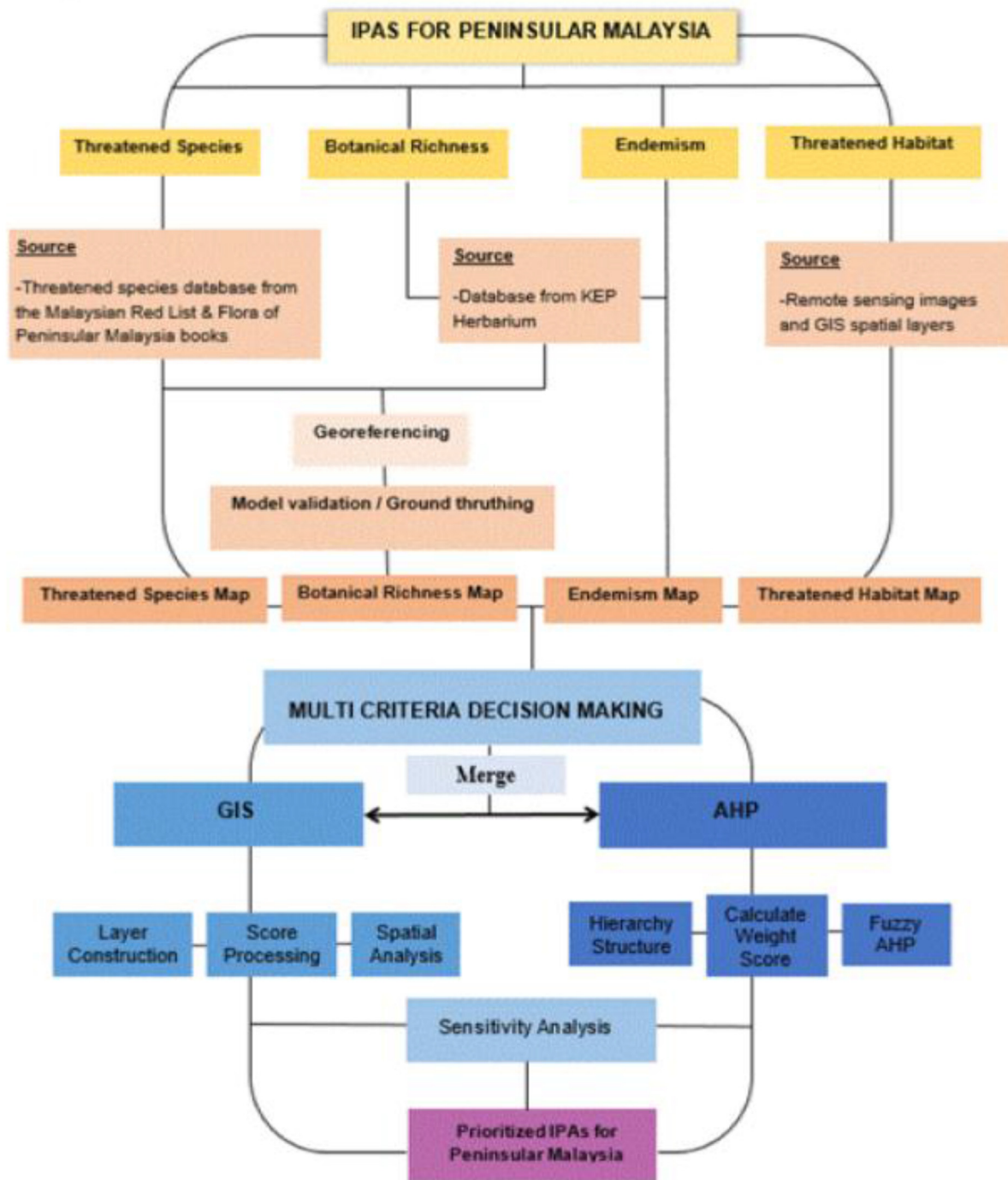
Figure 6. A conceptual framework for Peninsular Malaysia IPA.

preference scores so it can be considered as a very flexible tool to translate evaluation by decision makers into a multi-criteria ranking (Saaty, 1980). The scoring is decided on the basis of how important each criterion in reaching the goal (Kordi and Brandt, 2012). A numerical scale to indicate how much one criterion is more important than the other and their corresponding intensities are shown in Table 5. The evaluations are given on a scale of odd-numbers (1, 3, 6 and 9) and intermediated by even-numbers (2, 4, 6 and 8) value in between when compromise is needed.

To perform the pairwise comparison, a comparison matrix table is needed (Table 6). The judgment is transferred to a pairwise comparison matrix based on the numeric scale. Value in each cell is justified based on

the following question; "How important is botanical richness as compare to threatened species in determining IPA?". Similarly, "How important is botanical richness as compare to threatened habitat in determining IPA?". Referring to Table 6, if the decision maker considers threatened habitat is strongly more important than botanical richness area, the threatened habitat cell will contain the value of 5. This means that the ratio for the importance of threatened habitat versus the importance of botanical richness is five (threatened habitat/botanical richness = 5). Conversely, the importance of botanical richness relative to the importance of threatened habitat will yield the reciprocal of this value (botanical richness/threatened habitat = 1/5). When the importance of a criterion is compared to itself, the input value is 1 which indicates that
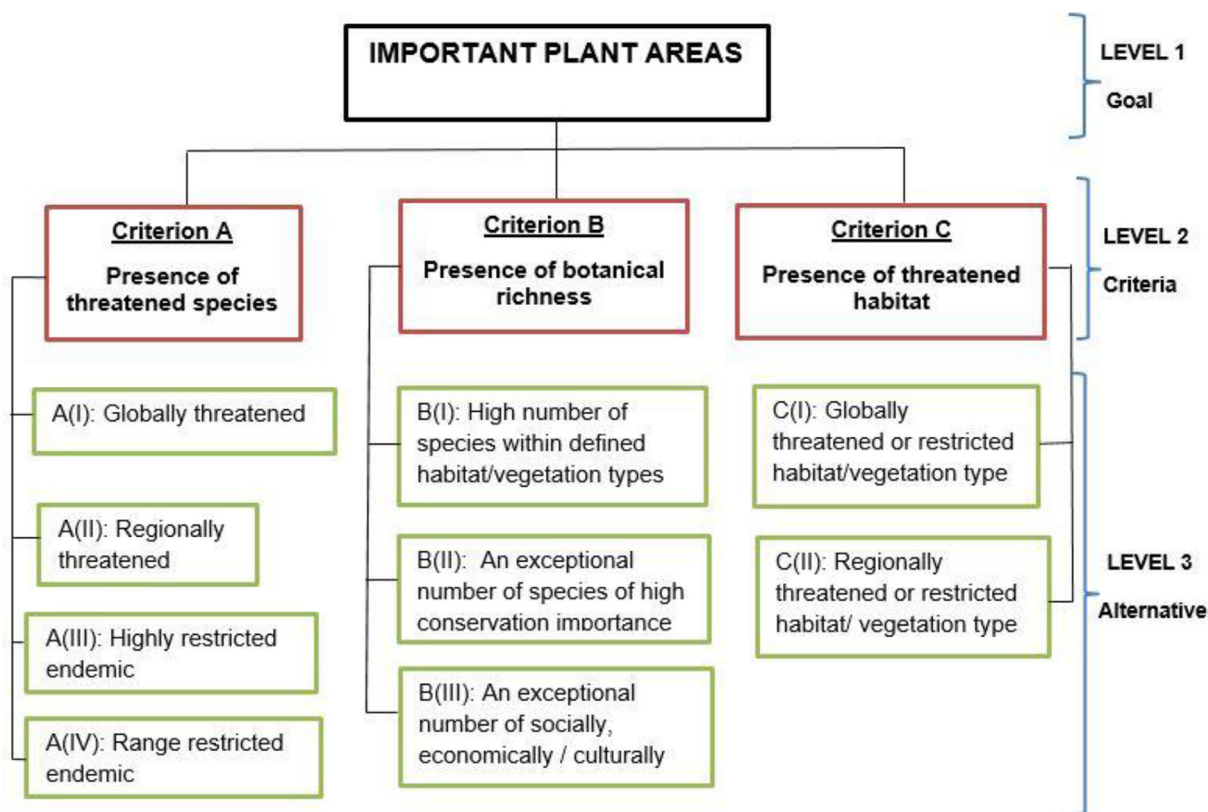
Figure 7. Three levels of AHP hierarchy. The structured hierarchy is a summary of a revised IPA criteria mentioned by Darbyshire et al. (2017).

Step 2: Pairwise comparisons matrix

Table 5. AHP numerical scale developed by Saaty (1980).

Numeric Value	Verbal Judgement
1	Equal importance
3	Moderately more important
5	Strongly more important
7	Very strong more importance
9	Extremely more importance
2,4,6,8	Intermediate values between adjacent scale value

Table 6. A comparison matrix table.

IPA	Botanical Richness	Threatened species	Threatened Habitat
Botanical Richness	1.00	1/3	1/5
Threatened Species	3.00	1.00	3.00
Threatened Habitat	5.00	1/3	1.00

the importance of itself will always be equal. For example, botanical richness versus botanical richness, threatened species versus threatened species as well as threatened habitat versus threatened habitat. This evaluation eventually transferred to a comparison matrix table as shown in Table 6.

Step 3: Consistency ratio

Once the pairwise comparison was structured, the next step is to determine the consistency ratio (CR) in the matrix. The pairwise matrix is developed by the subjective preference of individuals. Therefore, some inconsistencies may arise in the judgement due to the limitation of our brain in processing information (Hwang and Yoon, 1981). In AHP, some inconsistencies are expected and allowed. AHP calculates CR by comparing the consistency index (CI) of the matrix (decision maker's judgement) versus a random-like matrix (RI) to calculate inconsistency. RI is the average CI of 500 randomly generated pairwise comparison matrix (Mu and Pereyra-Rojas, 2017).

$$CR = \frac{CI}{RI}$$

Saaty (1980) indicated that CR of 0.10 or less is acceptable while CR

higher than 0.10 indicated that inconsistence judgement occurred. Therefore, the matrix needed to be revised and corrected.

Step 4: Calculating the final weight

The final weight of the alternatives with respect to each criterion is calculated in the final step. Similarly, a pairwise comparison technique is needed to calculate the weight for each alternative in the third level of the hierarchy.

4.2. GIS-based multi-criteria decision making

In broadest term GIS is a tool that allows the process of spatial data into information and make a decision about the earth (Myers et al., 2000). It provides a way which enables decision makers to make better decision through analysis and spatial information. GIS software provides basic functions such as overlay, union and intersects to apply for MCDM. For example, overlay operations can be used to identify suitable areas for conservation when it satisfied a set of locational criteria. However, when selections comprise preferences with scoring criteria, expert judgment and complex relationship, integrating MCDM into GIS is a great way to improve the limited capabilities.

GIS-based multi-criteria decision making (GIS-MCDM) is established on the concept of integrating GIS and MCDM. Basically, GIS-MCDM is a collection of a methods and tools to transform and combine geographic data and judgement to acquire information for decision making (Malczewski and Rinner, 2015). GIS techniques play an important role in analysing decision problems while MCDM provides full ranges of method for structuring decision problems and for designing, evaluating and prioritizing alternative decisions (Malczewski, 2006). Rationale behind the integration of GIS-MCDM is that these two distinct areas of research can complement each other (Boroushaki and Malczewski, 2010). By integrating the AHP with GIS environment, identified IPA can be easily changed, revised and presented in a form of map. Advantage of this integration is that decision maker can combine expert judgement into GIS system to conserve areas of insufficient research-based studies (Reza et al., 2013). The process of decision making will be improved through GIS-MCDA as the system allows users to analyze spatial information, maps, charts and reports in visual forms.

The development of integrated MCDM and GIS methods has emerged in recent years whereby data is prepared spatially using GIS software and analysis is performed using one of MCDM techniques (Mohd Hasmadi, 2009). The GIS-MCDM technique enables decision-makers to evaluate the relative priorities of conserving forest areas based on a set of preferences, criteria and indicators of the area (Phua and Minowa, 2005). Several successful applications resulting from the use of GIS-MCDM for forestry in Malaysia were discussed by Phua and Minowa (2005) for forest planning, Mohd Hasmadi (2009) for suitable harvest zone, Norizah and Mohd Hasmadi (2012) for suitable forest road allocation, Reza et al. (2013) to map and develop a habitat suitably index for large mammals and Suhaida et al. (2015) to analyze habitat parameter for elephant.

4.3. Species distribution model

SDM, also known as ecological niche modeling is a way of processing data using computer algorithms to generate predictive maps of species distribution in geographic space. A common application for SDM is to predict species range with climate data as a predictor. SDM creates probability models of species distribution at varying levels including landscapes, regions, and continents based on the presence, absence or abundance of species obtained from museum vouchers and/or field surveys and environmental predictors (Guisan and Thuiller, 2005). Comprehensive inventories and comprehensive plant assessments are often not feasible, as on the ground inventories of all species are time and resource consuming. For Malaysian IPA, SDM is seen as a suitable method to accelerate the process of determining species richness areas.

Maxent (ver. 3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent/) is one of the most widely used SDM software. It is a presence-only method, enabling scientists to utilize the abundant data sources of herbaria collections. The use of this software reduces the costs of sampling the species throughout their geographic range (Gomes et al., 2018). This modeling software holds great promise for SDM because it often achieves substantially superior performance in species prediction compared to other traditional linear models (Elith et al., 2011). Models generated by Maxent are easily understandable and interpretable by humans and this model performed well with a small sample size (Phillips et al., 2004).

Examples of Maxent application for IPA identification published by Williams (2009) for the Turks and Caicos Islands represented the first Maxent application for IPA identification. In this study, three endemics species and the IUCN Red List species were applied as the main criterion for the establishment of the IPA where six IPAs finally identified. Raes et al. (2009) studied the botanical richness and patterns of endemism in Borneo by applying Maxent to generate estimates of species richness, endemicity and floristic regions. One species richness area and two endemicity hotspots were identified in this study.

5. Conclusion

Scoring procedure and problem-solving approaches are common methods used in IPA identification. The scoring procedure yields consistent and easy to understand results. However, the main drawback of this technique is reported as being insufficiently robust especially when the effect of the score cannot be seen (Sánchez de Dios et al., 2017). Bias is an important factor influencing IPA. Therefore, if possible these obstacles must be eliminated or reduced. Many other studies have demonstrated an enhancement of IPA selection when combining scoring procedure and complementarity approaches. Walsh et al. (2019); Marignani and Blasi (2012) and Sánchez de Dios et al. (2017) recommended this approach to be implemented in IPA selection.

Efforts are now being made to develop IPA for Peninsular Malaysia using the complementarity method that is GIS-MCDM and SDM. These methods previously have provided, through a range of data on environmental properties as well as advanced techniques to further understand biodiversity and strategies to protect critical sites. The Peninsular Malaysian IPA exercise documented here not only establishes a national spatial planning procedure, but also provides a rational tool for decision-makers to gazette more protected areas. The early stage of this exercise demonstrated the usefulness of IPA identification by using the complementarity method and ultimately provides a rationale and framework for important plant areas protection.

Declarations

Author contribution statement

M. Hamidah: Conceived and designed the experiments; Performed the experiments.

I. Mohd Hasmadi: Conceived and designed the experiments; Wrote the paper.

L. S. L. Chua: Conceived and designed the experiments; Wrote the paper.

K. H. Lau, I. Faridah-Hanum: Analyzed and interpreted the data; Wrote the paper.

W. S. Y. Wong: Conceived and designed the experiments; Performed the experiments. Analyzed and interpreted the data.

H. Z. Pakhriazad: Analyzed and interpreted the data.

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References

Abellán, P., Sánchez-Fernández, D., Velasco, J., Millán, A., 2005. Conservation of freshwater biodiversity: a comparison of different area selection methods. Biodivers. Conserv. 14 (14), 3457–3474.

Al-Abbasi, T.M., Al-Farhan, A., Al-Khulaidi, A.W., Hall, M., Llewellyn, O.A., Miller, A.G., Patzelt, A., 2010. Important plant areas in the arabian peninsula. Edinb. J. Bot. 67 (1), 25–35.

Anderson, S., 2002. Identifying Important Plant Areas: A Site Selection Manual for Europe, and a Basis for Developing Guidelines for Other Regions of the World, p. 52.

Anderson, S., Darbyshire, I., Halski, B., 2016. Important plant areas. In: RBG Kew, State of the World's Plants Report-2016. Retrieved from. https://stateoftheworldsplants.com/2016/report/sotwp_2016.pdf. (Accessed 6 September 2018).

Ashton, P., 1990. Plant conservation in the Malaysian region. In: Yap, L.S.W., S.K (Eds.), *Proceedings of the International Conference on Conservation of Tropical Biodiversity*. Kuala Lumpur, Malaysia. Malayan Nature Society.

Bhushan, Navneet, Rai, K., 2004. The Analytic Hierarchy Process. Strategic Decision Making: Applying the Analytic Hierarchy Process, pp. 11–21.

Blasi, C., Marignani, M., Copiz, R., Fipaldini, M., Bonacquisti, S., Del Vico, E., Zavattero, L., 2011. Important plant areas in Italy: from data to mapping. Biol. Conserv. 144 (1), 220–226.

Boroushaki, S., Malczewski, J., 2010. Using the fuzzy majority approach for GIS-based multicriteria group decision-making. Comput. Geosci. 36 (3), 302–312.

Bottero, M., Comino, E., Duriavig, M., Ferretti, V., Pomarico, S., 2013. The application of a multicriteria spatial decision support system (MCSDSS) for the assessment of biodiversity conservation in the province of varese (Italy). Land Use Pol. 30 (1), 730–738.

Bou Dagher-Kharrat, M., El Zein, H., Rouhan, G., 2018. Setting conservation priorities for Lebanese flora—identification of important plant areas. J. Nat. Conserv. 43 (January), 85–94.

Chen, Y., Yu, J., Khan, S., 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environ. Model. Software 25 (12), 1582–1591.

Chua, L.S.L., Suhaida, M., Hamidah, M., Saw, L.G., 2008. Malaysia Plant Red List. Peninsular Malaysian Dipterocarpaceae, p. 230.

Corner, E.J.H., 1960. The Malayan flora. In: Purchon, R.D. (Ed.), *Proceedings of the Centenary and Bicentenary Congress of Biology*. Kuala Lumpur. University of Malaya Press, Malaysia.

Cowling, R.M., Pressey, R.L., Sims-Castley, R., Le Roux, A., Baard, E., Burgers, C.J., Palmer, G., 2003. The expert or the algorithm? - comparison of priority conservation areas in the Cape Floristic Region identified by park managers and reserve selection software. Biol. Conserv. 112 (1–2), 147–167.

Darbyshire, I., Anderson, S., Asatryan, A., Byfield, A., Cheek, M., Clubbe, C., Radford, E.A., 2017. Important Plant Areas: revised selection criteria for a global approach to plant conservation. Biodivers. Conserv. 26 (8), 1767–1800.

Davis, S.D., Heywood, V.H., Hamilton, A.C., 1994. Centres of Plant Diversity: a Guide and Strategy for Their Conservation. World Wide Fund for Nature (WWF) and IUCN.

Dos Santos, P.H., Neves, S.M., Sant'Anna, D.O., Oliveira, C. H. de, Carvalho, H.D., 2019. The analytic hierarchy process supporting decision making for sustainable development: an overview of applications. J. Clean. Prod. 212, 119–138.

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E., Yates, C.J., 2011. A statistical explanation of MaxEnt for ecologists. Divers. Distrib. 17 (1), 43–57.

Faridah-Hanum, I., 2015. Forest Biodiversity. Importance of Species Composition Studies. Universiti Putra Malaysia.

Forestry Department Terengganu, 2017. Forestry Department Terengganu. Yearly Report 2017.

Gomes, V.H.F., Ijff, S.D., Raes, N., Amaral, I.L., Salomão, R.P., Coelho, L.D.S., Ter Steege, H., 2018. Species Distribution Modelling: contrasting presence-only models with plot abundance data. Sci. Rep. 8 (1), 10038.

Guisan, A., Thuiller, W., 2005. Predicting species distribution: offering more than simple habitat models. Ecol. Lett.

Hamidah, M., Chua, L.S.L., Suhaida, M., Yong, W.S.Y., Kew, R., 2011. Botanical Gazetteer for Peninsular Malaysia. Research Pamphlet No. 131.

Hwang, H.L., Yoon, K., 1981. Multi Attribute Decision Making. Methods and Application. A State of the Art Survey. Springer Verlag. Berlin, New York.

Ishizaka, A., Siraj, S., 2018. Are multi-criteria decision-making tools useful? An experimental comparative study of three methods. Eur. J. Oper. Res. 264 (2), 462–471.

Jankowski, P., 1995. Integrating geographical information systems and multiple criteria decision-making methods. Int. J. Geogr. Inf. Syst. 9 (3), 251–273.

KATS (Minstry of Water Land and Natural Resource) (Ed.), 2018. Forest Area by Region (1990-2014). Retrieved September 6, 2018, from. http://www.nre.gov.my/en-my/Forestry/Pages/Forest-Area-By-Region.aspx.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2018. Flora of Peninsular Malaysia Series II: Seed Plants, 7. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2017. Flora of Peninsular Malaysia Series II: Seed Plants, 6. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2015. Flora of Peninsular Malaysia, Series II: Seed Plants, 5. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2013. Flora of Peninsular Malaysia, Series II: Seed Plants, 4. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2012. Flora of Peninsular Malaysia, Series II: Seed Plants, 3. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E., Boyce, P.C. (Eds.), 2011. Flora of Peninsular Malaysia, Series II: Seed Plants, 2. Forest Research Institute Malaysia.

Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E., Boyce, P.C. (Eds.), 2010. Flora of Peninsular Malaysia, Series II: Seed Plants, 1. Forest Research Institute Malaysia.

Kiew, R., Saw, L.G., 2019. Corner's Riau Pocket and other phytogeographical provinces in Peninsular Malaysia. Gardens' Bull. Singap. 71 (suppl.2), 525–538.

Kordi, M., Brandt, S.A., 2012. Effects of increasing fuzziness on analytic hierarchy process for spatial multicriteria decision analysis. Comput. Environ. Urban Syst. 36 (1), 43–53.

Kubler, S., Robert, J., Derigent, W., Voisin, A., Le, Y., 2016. A state-of the-art survey & testb e d of fuzzy AHP (FAHP) applications. Expert Syst. Appl. 65, 398–422.

Malczewski, J., 2006. GIS-based multicriteria decision analysis: a survey of the literature. Int. J. Geogr. Inf. Sci. 20 (7), 703–726.

Malczewski, J., Rinner, C., 2015. Multicriteria Decision Analysis in Geographic Information Science.

Marignani, M., Blasi, C., 2012. Looking for important plant areas: selection based on criteria, complementarity, or both? Biodivers. Conserv. 21 (7), 1853–1864.

Mendoza-Fernández, A., Pérez-García, F.J., Medina-Cazorla, J.M., Martínez-Hernández, F., Garrido-Becerra, J.A., Sánchez, E.S., Mota, J.F., 2010. Gap Analysis and selection of reserves for the threatened flora of eastern Andalusia, a hot spot in the eastern Mediterranean region. Acta Bot. Gall. 157 (4), 749–767.

Mohd Hasmadi, I., 2009. Developing policy for suitable harvest zone using multi criteria evaluation and GIS-based decision support system. Int. J. Econ. Finance 1, 105–117.

Mu, E., Pereyra-Rojas, M., 2017. Practical Decision Making: an Introduction to the Analytic Hierarchy Process (AHP) Using Super Decisions V2.

Mustajoki, J., Marttunen, M., 2017. Comparison of multi-criteria decision analytical software for supporting environmental planning processes. Environ. Model. Software 93, 78–91.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858.

Newton, A., 2007. Forest ecology and Conservation : a handbook of techniques. https://doi.org/10.1093/acprof:oso/9780198567448.001.0001.

Norizah, K., Mohd Hasmadi, I., 2012. Developing priorities and ranking for suitable forest road: allocation using Analytic Hierarchy Process (AHP) in peninsular Malaysia. Sains Malays. 41 (10), 1177–1185.

Özden, O., Mustafa Kemal, M., Salih, G., 2016. Important Plant Areas along the Kyrenia Mountains, Cyprus, 10. International Scientific Publications, pp. 349–359.

Parris, B.S., Kiew, R., Chung, R.C.K., Saw, L.G. (Eds.), 2013. Flora of Peninsular Malaysia, Series II: Seed Plants, 2. Forest Research Institute Malaysia.

Parris, B.S., Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. (Eds.), 2010. Flora of Peninsular Malaysia, Series I: Ferns and Lycophytes, 1. Forest Research Institute Malaysia.

Phillips, S.J., Dudík, M., Schapire, R.E., 2004. A maximum entropy approach to species distribution modeling. In: Twentyfirst International Conference on Machine Learning ICML 04, 69, p. 83.

Phua, M.H., Minowa, M., 2005. A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. Landsc. Urban Plann. 71 (2–4), 207–222.

Plantlife International, 2018. Important Plant Area (IPA) Criteria. Retrieved April 26, 2018, from. http://www.plantlifeipa.org/criteria.

Punde, S., 2007. Prioritising Areas for Forest Conservation in the Konkan Region of the Western Ghats Hotspot (India) – a Pilot Study, p. 34.

Raes, N., Roos, M.C., Slik, J.W.F., Van Loon, E.E., Steege, H. Ter., 2009. Botanical richness and endemicity patterns of Borneo derived from species distribution models. Ecography 32 (1), 180–192.

Reza, M.I.H., Abdullah, S.A., Nor, S.B.M., Ismail, M.H., 2013. Integrating GIS and expert judgment in a multi-criteria analysis to map and develop a habitat suitability index: a case study of large mammals on the Malayan Peninsula. Ecol. Indicat. 34 (October 2017), 149–158.

Saaty, T.L., 1980. The Analytic Hierarchy Process. New York. McGraw-Hill International Book Co, New York.

Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. 48 (1), 9–26.

Sánchez de Dios, R., Cabal Ruano, C., Domínguez Lozano, F., Sainz Ollero, H., Moreno Saiz, J.C., 2017. The role of criteria in selecting important areas for conservation in biodiversity-rich territories. Divers. Distrib. 23 (4), 368–380.

Saw, L.G., Chua, L.S.L., Suhaida, M., Yong, W.S.Y., Hamidah, M., 2010. Conservation of some rare and endangered plants from Peninsular Malaysia. Kew Bull.

Sérgio, C., Garcia, C.A., Hespanhol, H., Vieira, C., Stow, S., 2012. Bryophyte diversity in the peneda-gerês national park (Portugal): selecting important plant areas (IPA) based on a new survey and past records cecília. Bot. Complut. 36, 39–50.

Suhaida, A., Alias, M.S., Salman, S., 2015. Analysing elephant habitat parameters using GIS, remote sensing and analytic hierarchy process in peninsular Malaysia. Pertanika J. Sci. Technol 23 (1), 37–50. Retrieved from. http://www.pertanika.upm.edu.my/.

Velasquez, M., Hester, P.T., 2013. An analysis of multi-criteria decision making methods. Int. J. Oper. Res. 10 (2), 56–66.

Walsh, A., Sullivan, C.A., Waldren, S., Finn, J.A., 2019. Development of a scoring method to identify important areas of plant diversity in Ireland. J. Nat. Conserv. 47 (June 2018), 1–11.

Walsh, Aidan, 2016. Methods for the Identification of Important Areas of Plant Diversity in Ireland. Trinity College Dublin.

Williams, S., 2009. The Identification and Conservation of Important Plant Areas: a Case Study from the Turks and Caicos Islands. Department of Biology. Retrieved from. http://www.iccs.org.uk/wp-content/thesis/consci/2009/Williams.pdf.

Wong, K.M., P.L.I., 1998. Patterns of plant endemism and rarity in Borneo and the Malay peninsula. In: In, Cheng, I.P., Porter (Eds.), Rare, Threatened and Endangered Floras of Asia. Institut of Botany, Academia Sinica Monograph, Taipei, pp. 139–169.

Yahi, N., Vela, E., Benhouhou, S., De Belair, G., Gharzouli, R., 2012. Identifying important plants areas (key biodiversity areas for plants) in northern Algeria. J. Threat. Taxa 4 (8), 2753–2765.