GIS Based Multi-Criteria Decision Making for Identification of Important Plant Areas: A Case Study in Johor, Malaysia

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Abstract. Important Plant Areas (IPA) is a concept developed by Plantlife International to identify sites of exceptional botanical importance for conservation priority. The three main criteria for IPA are presence of threatened species, exceptional botanical richness and threatened habitats. Studies have shown that scoring method based on expert judgement is widely used in IPA identification as it is the easiest to understand and implement. However, reported drawbacks were uncertainty in score judgement and effect of the weighted score on each criterion was not understood. Therefore, a robust scoring system was needed to overcome this obscurity. The current study utilized Kepong Herbarium records, GIS-based multi-criteria decision making and analytical hierarchy process to identify IPA in the state of Johor, Malaysia. These techniques were considered to be effective tools in providing decision support for spatial planning aimed for plant conservation in Malaysia.

1. Introduction
Decision support systems are defined as model-based sets of procedures for processing data and judgments to assist decision making [1]. Multi criteria decision making (MCDM) is one of the most important tools for decision support systems. Over the last few decades, users for multi criteria evaluation had increased due to the fact that this method was constantly being developed and enhanced [2]. These methods are frequently used to solve real world problems [3] and has been increasingly implemented in environmental planning processes. It produces transparent result from different perspectives and systematic evaluation of alternatives [4]. There are two categories of MCDM which are the multi-attribute decision making and multi-objective decision making [5].

MCDM is a technique to assist decision-makers in selecting the best solution from a number of feasible choice-alternatives [6]. The main concern of MCDM is how to combine information from several criteria to form a single index evaluation [7]. Therefore, various techniques were developed to overcome the complex nature in MCDM. One of them was the Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s. The AHP is a decision support tool which can be used to resolves the complex decision making through a hierarchical structure of objective, criteria, sub criteria and alternative. This technique is perceived as a robust scoring technique that reduces uncertainty as AHP allows users to assign weight to each criterion according to the decision maker’s pairwise comparison of the options. The higher the weighted score, the more important of the
corresponding criterion it will be. In addition, to reduce bias in decision making, AHP incorporates useful techniques for checking consistency of the decision maker’s evaluation [8].

GIS-based multi-criteria decision-making (GIS-MCDM) can be accorded as the integration between GIS and MCDM. The advantage of the integration is that these two distinct areas of research can complement each other, such as the decision maker can combine expert judgment into GIS system for conservation [9]. The integration of GIS-MCDM methods has been applied in forestry application, i.e. in forest planning [10], identification of suitable harvest zone [11], suitability of forest road allocation [12], to map and develop a habitat suitability index for large mammals [9] and analyzing habitat parameters for elephant [13].

Important Plant Areas (IPA) is a scheme that determine the most important areas in the world for wild plant diversity that can be managed and protected as specific sites [14,15]. This program was developed by Plantlife International and inspired by the International Bird Area (IBA) program which was successfully developed by Birdlife International to promote targeted bird and biodiversity conservation globally. Similarly, IPA targets specific priority areas for plant conservation. Currently, 1,771 IPA have been identified in 16 countries across Europe, North Africa and the Middle East [16]. The IPA project is dynamic where identification for the new IPA sites can be added from time to time when supporting data become available.

In 2016, criteria for IPA were revised to facilitate the identification in the tropic. The revised criteria were developed to be scientifically robust and applicable globally including the tropics where application of IPA criteria has to date been limited [17]. Improvements to the criteria were made by incorporating new elements such as socio-economically and culturally important plants. In order to be qualified as an IPA, a minimum of one of the following key criteria must be fulfilled. The key criteria are presence of threatened species, exceptional botanical richness and threatened habitats [15].

Based on literature, two main methods oftenly used to identify IPA are scoring and complementarity methods. A scoring method considers value in each grid to correspond to its importance in biodiversity [18]. A complementarity method uses decision support system tools [19] as well as prediction modelling [18,20,21]. Scoring method is the most used method as it is easy to implement. However, the drawbacks of scoring method were uncertainty in judgement and the effect of the weighted score to each criterion was not understood [20]. The question on what score should be awarded to each criterion could not be easily answered. It is a daunting task to assign scores for species richness, areas with endangered or endemic plants and threatened habitat such as mangrove, peat swamp and limestone. It is also difficult to decide which criteria deserves a higher score. Therefore, a robust scoring system is needed to overcome this obscure. The intended scoring techniques should be able to assess the sensitivity of the final output based on variations of the input or score. 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. Therefore, [18,19,20] recommended that the scoring procedure should be applied in combination with other complementarity approaches to enhance the identified conservation areas.

Malaysian IPA exercise has started since 2017. The objectives of this project are (i) to identify 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; and (iii) to rank and prioritize areas for IPA strategic conservation planning. In this paper, we focused on the second objective, which is to develop a scoring index and apply them in the state of Johor. A complementarity method that is GIS-based multi-criteria decision making (GIS-MCDM) by using Analytical Hierarchy Process (AHP) techniques are proposed. The integration fulfils the need for a robust scoring system which allows effect of each scoring to be seen and mitigate uncertainty bias in the judgement.

2. Materials and methods
2.1. The study area
The study area is in the state of Johor. Johor is a state located south of Peninsular Malaysia. It is located between latitudes 2° 52’ and 1° 15’ and longitudes 102° 26’ and 104° 19’. Johor has an area of about 19,166 sq.km and bordered by the South Chinese Sea to the east, Straits of Malacca to the west and Straits of Johore to the south, which also separates Johor from Singapore. Johor Bahru, located in
the southern region is the capital city and the most developed area while the central region of the state is still covered with forest. Sand beaches can be found at the east coast whereas muddy coast is dominant at the west coast.

2.2. Herbarium dataset
Kepong Herbarium (KEP) database was the main source of flora database in this study. A total of 13,557 botanical records from Johor were georeferenced based on the recent topographic maps, historical topographic maps published in 1940, forest reserve maps and botanical gazetteer [22]. Of these, 8 species were listed as Critically Endangered (CR), 33 Endangered (EN), 52 Vulnerable (VU) and 330 endemic species. Threat data for each species were based on conservation status published in Flora of Peninsular Malaysia series [25-33], Malaysia Plant Red List [31] and for species not yet assessed, these were based on IUCN Red List (www.iucnredlist.org).

In the ArcMap environment, the records were converted into point spatial layer to produce a distribution map. Two hundred and fifty (250) spatial grids of 10x10 sq.km were generated and overlaid onto the species distribution map (Figure 1). Figure 1 shows that the primary collection areas are in the central and northern Johor compared to the southern parts that has lesser collection. Grids without specimen records were excluded from the analysis.

2.3. Species richness area
The same dataset was analysed to produce a species richness map as shown in Figure 2. Species richness is defined as the number of species within a specific area [32]. Percentage of species in each grid were calculated using the following formula:

$$\text{Species Richness (\%) = \frac{\text{Number of species within grid}}{\text{Highest species number}} \times 100}$$
2.4. Threatened habitat

Plant habitat is at risk of being destroyed mainly because of deforestation and pollution. In this study, two threatened habitat types, i.e. mangrove and peat swamp were accounted in IPA identification for Johor. The eastern part of Johor along the coastal line from Muar to southern part of Kota Tinggi are mostly covered by mangrove forest and patches of mangrove occurred along eastern part of Kota Tinggi to Mersing [33]. Habitat of peat swamp in Air Hitam Utara Forest Reserve is the largest in the state of Johor. Distributions of peat swamp and mangrove areas in Johor are shown in Figure 3.
2.5. AHP
AHP is the most used and well-known technique in MCDM. It is also known to be a simple technique, easy to understand and implement that can simplify complex problems [34]. There are four steps in assigning score using AHP. These are structuring problems as a hierarchy, pairwise comparisons matrix, consistency ratio and calculating the final weight [35].

2.5.1. IPA hierarchy
AHP structures the problem as a hierarchy. Additional hierarchical levels can be structured to dissolve complex problems. The advantages of hierarchy decomposition are to better understand the decision to be achieved, criteria used and alternatives to be evaluated [36]. Figure 4 illustrates the structure of AHP elements for IPA. Identification of important plant areas is achieved through different criteria that are threatened species, botanical richness, threatened habitat and endemism.

![Figure 4. AHP hierarchy for important plant areas.](image)

2.5.2. Pairwise comparisons matrix
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 preference scores (as shown in Table 1). 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?”.

| 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 |

2.5.3. Consistency ratio (CR)
Inconsistencies may arise in the judgement due to the limitation of our brain in processing information. The pairwise matrix is susceptible for inconsistency because it is subjective and based on individual preferences. In AHP, some inconsistencies are expected and allowed. CR of 0.10 or less is acceptable while CR higher than 0.10 indicated that inconsistence judgement occurred [8].
2.5.4. Calculating the final weight

The final weight of the alternatives with respect to each criterion was calculated in the final step. Similarly, a pairwise comparison technique used to calculate the weight for each alternative in the third level of the hierarchy. Hierarchy of IPA, final weights of each criterion and alternatives is shown in Figure 5.

| LEVEL 1: GOAL | LEVEL 2: CRITERIA | LEVEL 3: ALTERNATIVE |
|---------------|-------------------|---------------------|
|               | Threatened Species | CR (w = 0.480)     |
|               |                   | EN (w = 0.405)      |
|               |                   | VU (w = 0.115)      |
|               | Botanical Richness| Species < 20% (w = 0.115) |
|               |                   | Species 20-40% (w = 0.265) |
|               |                   | Species 40-80% (w = 0.366) |
|               |                   | Species 80-100% (w = 0.375) |
|               | Threatened Habitat| Habitat Class (w = 0.466) |
|               |                   | Topography < 200 (w = 0.271) |
|               |                   | Topography 200-750 (w = 0.251) |
|               |                   | Topography > 750m (w = 0.012) |
|               | Endemism           | PM/SS (w = 0.407)   |
|               |                   | State (w = 0.593)   |

Figure 5. Hierarchy of IPA and final weights in each level.

3. Results and discussion

Hotspot Analysis (Getis-Ord Gi*) in spatial statistic tool in ArcGIS was executed where the final weights of the four criteria were totalled to identify the hotspot areas. This extension uses vector data to identify the locations of statistically significant hotspot and coldspot in data. The Hotspot Analysis tool calculates the Getis-Ord Gi* statistic for each feature in a dataset. This tool works by looking at each feature within the context of neighbouring features. A feature with a high value is interesting, but may not be a statistically significant hotspot. To be a statistically significant hotspot, a feature will have a high value and be surrounded by other features with high values as well. The resultant Z score indicates areas of high or low values cluster spatially. Hotspot map which was grouped based on standard deviation (std. dev.) is shown in Figure 6. The three highest range of standard deviation will become IPA which were grouped into Priority I, Priority II and Priority III as shown in Figure 7. Summary of IPA identified is shown in Table 2.
The biggest challenge of herbarium dataset is collection bias. Bias existed in the form of under or over-representation of certain taxa which usually depends on sites accessibility, species of interest, sampling methods and intensities. In this study, the existence of bias in herbarium collection is clearly shown in distribution of the botanical records map (Figure 1). Based on the map, there are grids which are without or have low species distribution, which mean data analysis is almost impossible. Similarly, areas with huge data collections will be perceived as areas with high richness, when the facts that there are not, leading to inaccuracy. Therefore, these obstacles must be eliminated or reduced.
Table 2: Summary of IPA areas.

| No | Area                                                                 | Z-score | Threatened species | Endemic species | Threatened habitat |
|----|----------------------------------------------------------------------|---------|--------------------|-----------------|-------------------|
| 1  | Taman Negara Endau Rompin (A) (Jasin River & Mt. Janing area)        | 3.63    | 11                 | 63              | -                 |
| 2  | Panti FR                                                              | 3.077   | 22                 | 68              | -                 |
| 3  | Ulu Sedeli Selatan/Sg Kayu FR                                        | 2.77    | 10                 | 34              | -                 |
| 4  | Gunung Arong FR                                                      | 2.75    | 12                 | 23              | Peat swamp        |
| 5  | Kluang FR                                                            | 2.47    | 12                 | 57              | -                 |
| 6  | Labis Tengah & Timur FR                                              | 2.44    | 4                  | 39              | -                 |
| 7  | Gunung Ledang FR                                                     | 2.35    | 11                 | 37              | -                 |
| 8  | Labis Utara & Sungai Segamat FR                                       | 2.36    | 1                  | 29              | -                 |
| 9  | Labis Tengah FR                                                      | 2.29    | 12                 | 25              | -                 |
| 10 | Panti FR                                                             | 2.24    | 6                  | 12              | -                 |
| 11 | Soga & Banang FR                                                     | 1.98    | 3                  | 12              | Mangrove          |
| 12 | Kuala Sedeli area                                                    | 1.83    | 3                  | 4               | Mangrove & Peat swamp |
| 13 | Sungai Pulai/ Pulau Kukup FR                                         | 1.35    | 2                  | -               | Mangrove          |
| 14 | Sungai Johor/Belungkor/Sg. Lembam FR                                 | 1.14    | -                  | -               | Mangrove          |
| 15 | Air Hitam Utara FR                                                   | 1.12    | -                  | -               | Peat swamp        |

Notes: FR indicates Forest Reserve

Species distribution modelling is seen as a solution to overcome comprehensive ground truthing, which are time and resource consuming. There are studies demonstrated on enhancement of conservation areas utilizing species distribution modelling in Ireland using logistic regression [37], Spain implementing a null model [20] and Turks and Caicos Island by means of Maxent [38].

It is proven that AHP is a simple and easy to understand technique for scoring. Although Saaty’s provided a numerical scale as indicated in Table 1, yet uncertainties arise during the pairwise matrix processes. The main contributor to uncertainty is often the criteria weight. For example, the score one should assign for species richness, areas with endangered or endemic plants. Adding to the complexity is the question in which areas are more important to conserve; area of species richness or area with threatened species. These questions are subjective to different perspective, hence the need of experts’ consensus. Nevertheless, AHP techniques are foreseen to be continuously applied and guided by collective weighted scores determined by experts in biodiversity conservation.

The accuracy of this work is very much dependent on geo-reference processes. Geo-referencing are time consuming and require skilled GIS individuals. In this study, herbarium records in the late 19th and 20th which were without coordinates and locality notes were excluded from the analysis. If the herbarium records associated with locality notes or GPS information, they will be converted to a spatial layer for further GIS analysis. The accuracy of the georeferenced data were varied by 100 sq.km based on the availability of information therefore field verification is necessary.

4. Conclusion

Identification of IPA based on criteria is necessary for prioritizing areas for conservation. In this study, the use of GIS-based MCDM and herbarium dataset allows integration of geoinformation technique and biodiversity experts into forest conservation planning in the state of Johor. The primary advantage of the integration is the identified IPA areas can be easily visualised in map form when there are variations of input or score from the decision maker. Additionally, the effect of each score given to
each criterion can be seen or visualized in the form of a map and can be updated when additional herbarium records become available. This technique helps to reduce cost and time involved in early planning stage of identifying potential areas for conservation[10]. Further study by means of species distribution modelling is needed to identify critical areas, especially areas that are weakly botanized. The identified IPA does not come with legal designation. However, the identified areas in this study can be used to support and underpin existing legislation and considered as multiple used areas, i.e. Key Biodiversity Areas or High Conservation Value Forest. The multiple used conservation areas will certainly enhance the degree of protection of the identified areas.

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