

Research Article

Distribution modeling of *Rafflesia schadenbergiana* and *Rafflesia consueloae* using multi criteria decision analysis-analytical hierarchy process in GIS

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Abstract

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The identification of potential habitats of the largest and smallest flowering parasitic *Rafflesia* in the Philippines is a prerequisite in conservation of species and preservation of their habitats which have been being degraded due to anthropogenic activities and climate change. This research aimed at revealing the possible habitat suitability for *Rafflesia schadenbergiana* Göppert ex Hieron and *Rafflesia consueloae* Galindon, Ong Fernando throughout the Philippines using Geographic Information Systems (GIS). The selection criteria in this research were based on four parameters (elevation, annual rainfall, temperature, and land use / land classification) identified during the extensive literature review. The generated map shows that the optimal growth of the *Rafflesia schadenbergiana* can be observed with a temperature range of 20–22°C while *Rafflesia consueloae* can thrive within 24°C to 25°C. The importance of these criteria was evaluated using a pairwise comparison method and the final weight was computed for each criterion. Setting up of the values suiting the subject species was followed by weighted overlay analysis. The final output is the distribution and habitat suitability of the subject species.

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Introduction

Together with other megadiverse countries, the Philippines host over two-thirds of the Earth's wildlife species (CEPF, 2001). But many of the wildlife species are on the brink of extinction. One reason is because of land degradation. Land degradation cause soil fertility loss that hinders the growth and development of *Rafflesia*. Today, there is still a need for more data on the characteristics of degraded lands to aid in the formulation of appropriate conservation of wildlife species. The biology of *Rafflesia* containing rather controversial species of plants fascinated many researchers (Hidayati and Walck, 2016). Over the past few years, there has been rekindled interest in the genus and discovery of new species. Barcelona et al.

(2009) stated that remaining tropical forest habitat has become highly degraded and fragmented as a result of human activities such as logging, mining, and land conversion for agriculture. Considering the increasing frequency of climatic extremes and destruction of the natural habitats such as the tropical forest, many studies, and efforts for the conservation of *Rafflesia* are being addressed now. *Rafflesia* is a genus of holoparasitic plants that grow in tropical rainforest of Southeast Asia including Sumatra, Java, Borneo, Peninsular Malaysia, Southern Thailand, and the Philippines (Barcelona et al., 2006; 2007).

Geographic Information Systems (GIS) plays a vital role in conserving data and optimal locations for monitoring of the habitat of a certain species. GIS is a dynamic technology and bequeaths a digital data

reserve for future monitoring program of species spatial distribution. Multi Criteria Decision Analysis (MCDA) in GIS is used to combine layers of spatial data representing the criteria and to specify how the layers are combined. The Analytical Hierarchy Process (AHP), which defines weights for criteria selected (Al-Adamat, 2008), is the method of MCDA that is implemented within GIS. Applying this tool for the assessment of the habitat suitability for *Rafflesia* can help in the conservation of the critically endangered species of largest flowering plant likewise for the smallest flowering *Rafflesia* in the Philippines. The use of GIS for identifying the optimum sites for suitability of *Rafflesia schadenbergiana* and *Rafflesia consueloae* schemes has not yet been addressed so far. This gap of knowledge stimulated us to perform research we are reporting here.

Materials and Methods

Variables

Four variables were used in the modeling process to determine the habitat suitability of the species and were sourced out from different databases and sources to wit: elevation, annual rainfall, temperature, and land use / land classification (LULC). Elevation data were extracted from Shuttle Radar Topography Mission (SRTM) 90-meter Digital Elevation Model (DEM) spatial resolution covering the whole country. The annual rainfall and temperature values derived from the interpolated data by Hijman et al. (2005) and

sourced out from WorldClim.org. LULC data were sourced out from NAMRIA on its 2010 release. The suitability modeling was performed in the ArcGIS version 10.4 environment on its model builder processing applying the Multi Criteria Decision Analysis and Analytical Hierarchy Process (Saaty, 1980).

Percent weight determination

The modeling process involved weighted overlay analysis which is an operation under the surface analysis in ArcGIS. For unbiased assigning of relative weight to each factor influencing the habitability of the *Rafflesia* species, Saaty's (1980) Analytical Hierarchy Process was applied. The relative importance of each variable was compared to that of the others. Then, considering the corresponding weight of the factor that may range 1 to 9 followed its share in a total of 100% was calculated.

The Pairwise Comparison Matrices (PCM) involves comparing all the possible pairs of criteria to determine the priority ranking of all the criteria. The AHP method is based on creating PCM series which compare all the criteria to each other. For PCM elements, Saaty (1980) suggested a scale from 1 to 9 (Table 1) where the values of 1 and 9 indicate that the criteria are equally important and extremely important compared to the other criteria, respectively. Consistency in PCM is checked by identifying judgement errors and calculating the consistency ratio (Malczewski, 1999).

Table 1. Scales for pairwise comparison methods adapted from Saraf and Choudhury (1998).

Intensity of Importance	Definition	Explanation
1	Equal importance in pair	Two criteria contribute equally to the objective
3	Moderate importance	Judgment and Experience slightly favor one criterion over another
5	Strong importance	Judgment and Experience strongly favor one criterion over another
7	Very strong Importance	Judgment and Experience very strongly favor one criterion over another
9	Extreme importance	The evidence favoring one criterion over another is of highest possible validity
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals	Values for inverse comparison	If criterion i had one of the above numbers assigned to it when compared with criterion j, then j has the reciprocal value when compared with i

Assigning scale value

The model uses 1 to 3 by 1 evaluation scale which corresponds to classifications: (a) marginal (b) moderate and, (c) high suitability. The scale value was assigned based on the range classification of each factor (variables) while the classification was based on 1 to 5 scale. Decisions were backed with related literature information such as actual range habitability

of the species with regards to elevation and temperature, among others (Tables 2 and 3).

Model builder process flow

Figure 1 shows that variables such as elevation, rainfall, and temperature underwent reclassification processes to organize their raster values into the desired classification with reference to habitability of

the species. After reclassification, the output rasters were subjected to weighted overlay analysis along with the land use / land classification raster. Evaluation scales were set to 1 to 3 by 1 and each of the factors (variables) and scale value is assigned from its reclass value. Relative weight in the overlay analysis was also

set based on the prior computation using Saaty’s (1980) methodology. Setting up the values suiting the subject species was followed by weighted overlay analysis and habitat suitability of the subject species.

Table 2. Pairwise comparison matrix used to determine the relative importance of the criteria.

Criteria	More importance								Equal important	Less importance								Criteria
	9	8	7	6	5	4	3	2		1	2	3	4	5	6	7	8	
LULC									1									LULC
Rainfall																		Rainfall
Temperature																		Temperature
Elevation																		Elevation

Table 3. The pairwise comparison matrix of *Rafflesia schadenbergiana* and *Rafflesia consueloae*.

Criteria	Temperature	Elevation	Landcover/Landuse	Rainfall
Temperature	1	0.2	0.2	1
Elevation	5	1	1	0.2
Landcover/Landuse	5	1	1	5
Rainfall	1	5	0.2	1

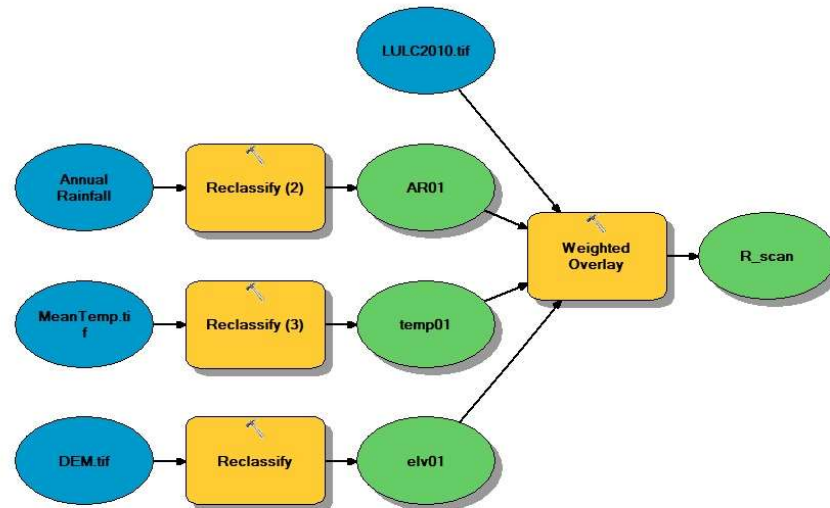


Figure 1. Flowchart of the methodology used in this research paper. (AR= Annual Rainfall, Temp= Mean Temperature, DEM = Elevation).

Results and Discussion

Land degradation rehabilitation is one of the factors to be consider when conserving wildlife species such as *Rafflesia*. Exploitation and land degradation contributes to the extinction of *Rafflesia*. Therefore, scientist and researchers consider land management to achieve good conservation practices for threatened biodiversity species (Posa et al., 2008). Barcelona (2007) described the population of *R.*

schadenbergiana wherein the species is located outside of the Mt. Kitanglad Range Natural Park. Based on their study, this species was damaged because of unsustainable ecotourism activities. The habitat of the species was converted into mountain resort where the adjacent vicinity was cleared. The clearing of the area poses threat to seed germination and exposes it to different pests (Barcelona et al. 2009). Other species such as the *Rafflesia*

philippinensis Blanco was subjected to disturbance such as pressure from tourist for hiking and exploration activities. Large scale mining operations and land conversion greatly affect the conservation of *Rafflesia* species (Posa et al., 2008). In this study, Analytical Hierarchy Process (AHP) was used to generate a habitat suitability map of the two critical species of *Rafflesia* in the Philippines. Four criteria affecting the distribution, ecology, and taxonomy of the species were defined based on the literature review and discussions with *Rafflesia* taxonomist as expert. The identification of the potential habitat and distribution of *R. schadenbergiana* and *R. consueloae* depends on the rating and the weights of each criterion. As stated in this research, opinions of interviewed experts were used to determine the weights of each criterion for the habitat suitability of *Rafflesia*. The

AHP approach was used to assess the consistency of the expert opinions by using the Consistency Ratio which must be less than or equal to 0.1. This was patterned from most literature review. Tables 4 and 5 summarizes (weights and ratings) the selection criteria for the suitability of *R. schadenbergiana* and *R. consueloae*. The Weighted Linear Combination (WLC) was used to integrate criteria. Implementing the WLC technique includes standardizing the suitability of the species, assigning weights of relative importance then combining the weights and obtaining a suitability map. Based on the outcome of the reclassification through the use of the model builder, evaluation scales were set to 1 to 3 by 1 and each of the factors (variables) and scale value is assigned from its reclass values where 1 = marginally suitable, 2 = moderately suitable, and 3 = highly suitable.

Table 4. The ratings of the four criteria for *Rafflesia schadenbergiana* Goppert ex Hieron based on the literature review and weights.

Criteria	Weight	Condition	Rating
Elevation	0.25	<600, >1400 masl	1
		600-800 masl-1271-1400 masl	2
		820-1271 masl	3
Temperature	0.0833	<18°C, >25°C	1
		18-20°C, 22-25°C	2
		20-22°C	3
Annual Rainfall	0.25	<1800 mm, >3000 mm	1
		1800-2200 mm, 2750-3000 mm	2
		22750-3000 mm	3
Landuse/Landcover	0.41667	Wetland, brushland, etc.	1
		Shrubland, Fallow	2
		Closed Forest and Open Forest	3

Table 5. The ratings of the four criteria for *Rafflesia consueloae* Galindon et al. (2016) based on the literature review and weights.

Criteria	Weight	Condition	Rating
Elevation	0.25	<197-200 masl, >800-2933 masl	1
		200-300 masl, 500-800 masl	2
		300-500 masl	3
Temperature	0.0833	12.10-22, 27-28.20	1
		22-24, 25-27	2
		24-25	3
Annual Rainfall	0.25	1029-1897 mm, 3000-5066 mm	1
		1897-1993 mm, 2380-3000 mm	2
		1993-2380 mm	3
Landuse/Landcover	0.41667	Wetland, brushland, etc.	1
		Shrubland, Fallow	2
		Closed Forest and Open Forest	3

According to Barcelona et al. (2008), *Rafflesia schadenbergiana* was first collected on Mt Parág near Mt Apo in Mindanao in 1882. In 1994, a flower bud was found in the vicinity of Mt. Temlofung in South Cotabato (Pascal, 2006). The third one was at the foot of Mt Kitanglad. Despite search efforts in recent times,

Rafflesia was not encountered for more than 100 years and was even thought to be extinct (Barcelona et al., 2006). The distributional area of the largest *Rafflesia* of the Philippines, therefore, seems to cover a large part of Mindanao (Barcelona et al., 2006). Based on Figure 2, the yellow in the map depicts the suitable

elevation for *R. schadenbergiana* wherein the species probably can be found. Green and red are the elevation which the species possibly cannot grow because of the elevation lower than 600 meters above sea level (masl) and higher than >1400 masl. Barcelona et al. (2008) reported that *R. schadenbergiana* is mostly found in a secondary forest within an elevation of 820–1,271 masl. The rainfall and temperature were affected by the elevation; as the elevation goes up, the temperature

goes down likewise with the rainfall availability. The species is highly suitable from an annual average rainfall of 2220–2750 mm; that is, *R. schadenbergiana* is most likely not suitable to grow with an annual average rainfall amount ranging from <1800 mm to >3000 mm. The species can thrive up to 18–25 °C. The generated map shows that the optimal growth of the species can be observed with a temperature range of 20–22°C.

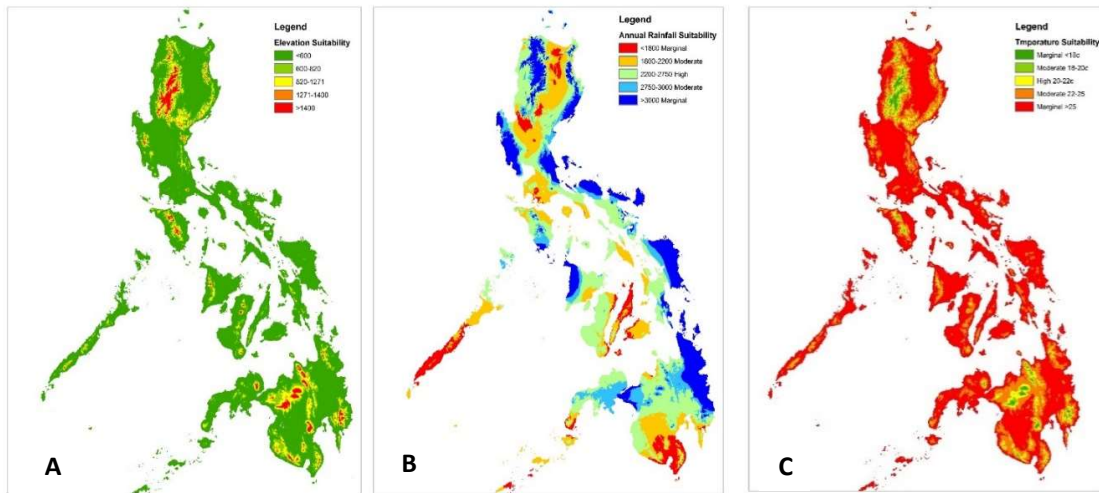


Figure 2. A) elevation, B) rainfall and C) temperature suitability of *R. schadenbergiana* (ArcGIS version 10.1).

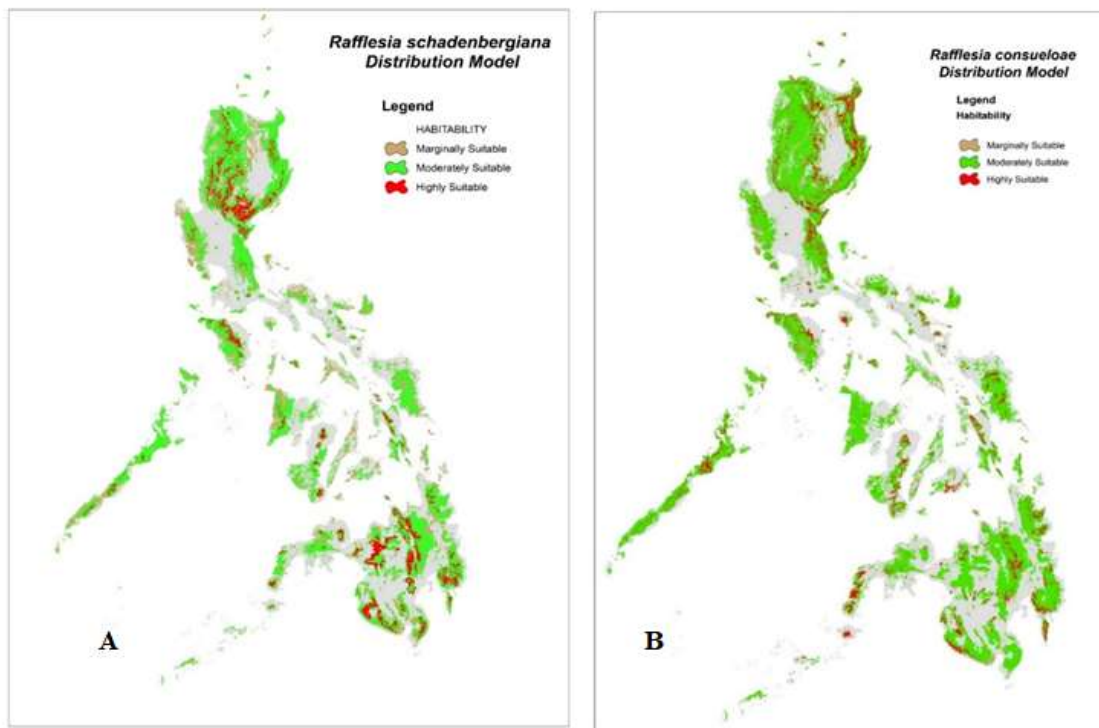


Figure 3. Generated habitat suitability maps of A) *Rafflesia schadenbergiana* and B) *Rafflesia consueloae* (ArcGIS version 10.1).

Galindon et al. (2016) discovered the smallest species of *Rafflesia* in Mt. Balukbok, with an elevation of 325 masl, in Barangay Fatima, Municipality of Pantabangan in the province of Nueva Ecija. This species is currently known only from two mountain sites with remnants of tropical lowland evergreen rain forests (Galindon et al., 2016). Such mountain sites are Mt. Balukbok and Mt. Pantaburon which are about two kilometers apart within the Pantabangan-Caranglan Watershed. *R. consueloae* thrives in an elevation

ranging from 300 and 500 meters (Figure 4). Like many *Rafflesia*, it is restricted to the roots of *Tetrastigma sp.* Galindon et al. (2016), stated that the extent of occurrence of the two small populations of *R. consueloae* is less than 100 km² apart. The generated habitat suitability map of *R. consueloae* shows that the growth is favored with annual rainfall and temperature ranges from 1,993 mm to 2,380 mm and 24°C to 25°C, respectively (Figure 4). Factors such as temperature and elevation also matter for this species.

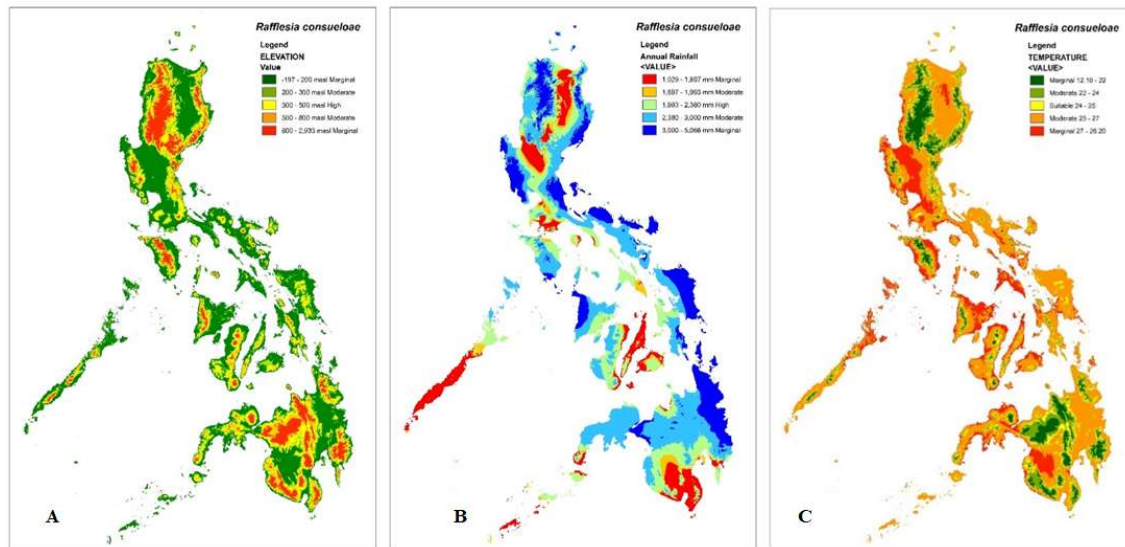


Figure 4. A) elevation, B) rainfall and C) temperature suitability of *R. consueloae* (ArcGIS version 10.1).

The highly suitable elevation is 300–500 masl, the moderately suitable is about 200–300 masl for the minimum and 500–800 masl for the maximum, and the marginally suitable elevation ranges from <197–200> 800–2933 masl. Galindon et al. (2016) reported that the First Gen Hydro Power Corporation that operates the Pantabangan hydroelectric facilities in the area helps provide support in monitoring the surrounding forests and their biodiversity. However, there is a need to ensure the continued protection of the *R. consueloae* populations and another biodiversity in the area as some local people still hunt wildlife and forest fires are likely during the dry season (Galindon et al., 2016). Vertebrates are also needed in the distribution of *Rafflesia consueloae* but due to land conversion and habitat destruction in Nueva Ecija, wild animals are also threatened by these activities.

Overall, generation of suitability maps of the two species should be supported by management of land or habitat to ensure the conservation of the *Rafflesia* species. Land management is vital in restoration of some *Rafflesia* species. Pelsler et al. (2018) stated that by revealing the environmental condition can assist the conservation management of *Rafflesia* species. Habitat fragmentation and land degradation is a significant conservation factor because the Philippine tropical

rainforest, to which most *Rafflesia* species is confined, has been reduced to an estimated 3–6% of its original cover (Mittermeier et al. 1998; Ong et al. 2002). The government together with the communities should help in the restoration of degraded lands in the Philippines.

Conclusion

The results indicate the conformity of the generated maps with the secondary data reviewed in which the usual habitat of the two species is in the mid-elevation. Possible occurrences of the species in the country were narrowed down based on elevation, temperature, rainfall amount, and type of land cover type present. The possibility of the species to be found in the area using the four parameters will be essential in the discovery of some populations and habitats of the two species being studied. The result shows the distribution of the *Rafflesia* species throughout the Philippine archipelago by using the MCDA-AHP within GIS. This will also serve as basis in the management of some degraded forest in the country. More studies should be conducted to know the precise possible distribution, ecology, habitat, and taxonomy of *Rafflesia* including its host (*Tetrastigma sp.*). Some

parameters such as the slope, aspect, soil properties, and other factors that affect the growth and distribution of *Rafflesia* should be included in the criteria.

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