

Research Article

Ecology of *Rafflesia arnoldii* (Rafflesiaceae) in Pandam Gadang West Sumatra

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ABSTRACT

Pandam Gadang has tropical forests which become the habitat of *Rafflesia* (*Rafflesia arnoldii*), which grows as a parasite of *Tetrastigma* (Vitaceae). Study on *R. arnoldii* is needed since its population continuously decreases as a result of habitat destruction of its host. The aim of the study was to determine habitat conditions, vegetation structure, and characteristics of the host species of *Rafflesia*; to identify environmental factors, and determine the *Rafflesia* habitat suitability in Pandam Gadang Koto Tinggi Village, West Sumatra. Analysis of vegetation in the habitat where *Rafflesia* grows using a circular plot. The number of individuals *Rafflesia* found was recorded and completed with observations of its morphology. Microclimate measurements were carried out together with data collection in the field. Flower morphological analysis was descriptively presented. Environmental parameters were processed with Canoco software 4.56 using Canonical Correspondence Analysis. Habitat suitability was analyzed using Maximum Entropy. The 17 *Rafflesia* individuals found on Pandam Gadang were *R. arnoldii*, known as "Cendawan Biriang", living parasitically on *Tetrastigma leucostaphylum*. The results of analysis of vegetation in the *Rafflesia* habitat showed that there were 250 individual plants consisting of 42 species and 21 genera. Seedlings most dominant was Lauraceae, belt was dominated by Moraceae, Meliaceae, and Euphorbiaceae. Trees were dominated by Euphorbiaceae, Moraceae, and Meliaceae. Existence and survival of *R. arnoldii* depended on soil pH 7-7.8, environmental humidity 83-91.8 %, and distance from the nearest river 3-27.8 m.

Keywords: Holoparasite, maximum entropy, *Rafflesia arnoldii*, *Tetrastigma leucostaphylum*

Introduction

Rafflesia is one of the Indo-Malesian plant genus that can be found in Malaysia, Indonesia, and the Philippines. 12 Of the 25 recorded species of *Rafflesia* are found in Indonesia. This plant distributes in Sumatra, Java and Borneo Islands [14]. *Rafflesia arnoldii* is one of the species recorded in Sumatra, and listed in the International Union for Conservation of Nature (IUCN) Red List Categories and has been assigned as Vulnerable (VU) [1, 2].

Rafflesia is a unique plant as it only consists of generative organs in the form of flowers. Male and female flowers are found in different individuals [2, 3]. *Rafflesia* lives as holoparasite [3, 4, 5] and

attached to the host plant through an organ called haustoria which has a root-like function [1]. The host belongs to the genus *Tetrastigma* (Vitaceae) which is liana [6]. The existence of the host plant plays significant role in the presence of *Rafflesia*. One of the factors that threaten the scarcity of *Rafflesia* is the lack of knowledge of the community to recognize host plants [7, 8]. In addition, natural disturbances such as landslides and floods have caused habitat damage, so that reduce the population of *Rafflesia* [6].

Rafflesia grows well in the forest floor of West Sumatra. There are three species in West Sumatra, named *R. arnoldii*, *R. haseltii*, and *R. gadutensis* [1, 9, 10]. In the last three years, *R. arnoldii*

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was recorded in Lima Puluh Kota, Koto Tinggi Village, Gua Aie Singkek Nagari Pandam Gadang. *R. arnoldii* was found in primary forest in Pandam Gadang which is ideal for its existence [11].

However, characteristics of the population and environmental conditions that support the occurrence of *Rafflesia* in this region has not been studied. Therefore, further studies on both aspects are crucial to support the conservation and survival of *Rafflesia*. This study aims to: (1) analyze habitat conditions and vegetation structure in the population of *Rafflesia* in the Pandam Gadang; (2) identify the environmental factors of *R. arnoldii* in Pandam Gadang; (3) determine the conservation area *in situ* using Maximum Entropy (MaxEnt) analysis. The results of this study are expected to be used as baseline data for conservation and development of the *Rafflesia* on the Pandam Gadang.

Material and Methods

Data collection

The research was conducted in Nagari Pandam Gadang, Gunuang Omeh District, Lima Puluh Kota Regency (0° 02' 14.816" S 100° 18' 03.246" E), West Sumatra Province from August 2018 to March 2019. Purposive sampling was employed in the fieldwork based on the presence of *R. arnoldii* with a circular plot (Figure 1) [9, 12, 13]. The circular plot was used by three subplots set up according to *R. arnoldii* as center point. In each plot, the plants in vegetation were divided according to the growth level of vegetation from trees, belt and seedling. The vegetation composition was observed based on the size of the main stem diameter including trees > 10 cm, belt 2-10 cm and seedlings < 2 cm [14]. Subplots for tree vegetation are

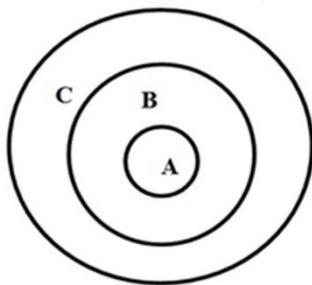


Figure 1. Scheme of observation of *Rafflesia* [18]. A = 0.001 ha (r = 1.785 m) for seedlings, B = 0.01 ha (r = 5.65 m) for beta, C = 0.1 ha (r = 17.85 m) for trees

individuals are recorded as biotic data. The abiotic data includes air temperature, soil temperature, air, and soil humidity, wind speed and light intensity. Measurements were made with 4 in 1, soil tester and thermometer. Elevation and geographic coordinate data were collected using a distance measuring instrument (meter) and Global Positioning System (GPS). The distance of *Rafflesia* with the nearest water source was measured manually using a meter.

Data analysis

Biotic data was processed by vegetation analysis including Relative Frequency (RF), Relative Dominance (RDo), and Relative Density (RD). Important Value Index (IVI) is calculated using the following formula:

$$IVI = RF_{(i)} + RDo_{(i)} + RD_{(i)}$$

The individual data of *R. arnoldii* consists of morphology, size, number, and developmental phase were analyzed in a descriptive way. In order to determine the environmental factors that affect the survival of *Rafflesia*, *Principal Component Analysis* (PCA) using *Canoco* version 4.56 was done. Habitat suitability maps were created using the *Maximum Entropy* (MaxEnt) version 4.01 program, using coordinates and exploration results. Environmental data were downloaded from *Worldclim.org* and *Fao.org* with a resolution of 1 km (30s) [15]. Distributional map of *R. arnoldii* in Pandam Gadang created using ArcGIS 10.3.

Results and Discussion

The population of *Rafflesia arnoldii*

Local people in Pandam Gadang name *R. arnoldii* as "Cendawan Biriang". A total of 17 individuals from three populations was found in Pandam Gadang in which 4 individuals in the dead condition in the form of blossoms and buds (knop). Twelve individuals were found to grow in the host root section (Table 1). There were 8 individuals with intact closed knop that were covered with bracts, knop with bracts conditions which were slightly exposed to the top 3 individuals and 1 dead knop. The largest knop diameter is 21.66 cm, still intact and covered with bracts, growing in the host root (*Tetrastigma leucostaphylum*), while the smallest knop is 8.59 cm growing at the base of the host with intact conditions covered by bra-

Table 1. Individuals Conditions in a population of *Rafflesia* in Pandam Gadang

Population	Individuals	Diameter (cm)	Height (cm)	Grow Places at <i>Tetrastigma</i>	Conditions Individuals
I	1	10.51	4.5	Roots	Knop with brachtea slightly open at the top
	2	-	-	Roots	Former blossoming
	3	-	-	Roots	Former flowers bloom
	4	18.79	14.5	Roots	Knop fully enclosed brachtea
	5	-	-	Roots	Former flower bloom
II	6	9.55	6	The base of the stem	Knop fully enclosed brachtea
	7	10.19	5	Roots	Knop fully enclosed brachtea
	8	19.75	16	Roots	Knop fully enclosed brachtea
	9	-	-	Roots	Former flower bloom
III	10	14.01	9	Roots	Knop covered with brachtea
	11	21.66	14	Roots	Knop with a little open at the top
	12	14.33	11	The base of stem	Knop is covered with brachtea
	13	9.87	3.8	Roots	Knop with a little open top
	14	48.72	26	Roots	Flower blooms begin to wither and black
	15	20.70	7.8	The base of the stem	Whole knop
	16	8.59	5.7	The base of the stem	Whole knop
	17	8.28	4	The base of the stem	Whole knop

Table 2. Vegetation found in habitat *Rafflesia arnoldii*

Vegetation type	Number of individual	Number of species	Dominant family
Seedlings	49	8	Lauraceae
Belts	102	25	Moraceae, Lauraceae, Meliaceae, Euphorbiaceae
Trees	99	32	Euphorbiaceae, Moraceae, Meliaceae
Total	250	42	

cts. Among the 17 individuals, there were individual blooms that began to wither and blacken with flower organs still complete. Based on information from the local community, it is estimated that flowers begin to wilt after 5–6 days. The distance of the population of *R. arnoldii* from the nearest water source (river) varies between 3.8 to 27.4 m. The populations near the river are susceptible to floods and landslides.

Vegetation in *Rafflesia arnoldii* habitat

Observation of vegetation from three subplots revealed 42 species of plants belong to 21 genus. In this type of vegetation, 49 seedlings were found belong to 8 species dominated by member of Lau-

raceae. A number of 102 individuals consisted of 25 species were recorded for the belt, consists of Moraceae (4 individual), Euphorbiaceae (3), Meliaceae (2), and Lauraceae (2). A number of 99 individuals from 32 species were recorded for tree, which consists of Euphorbiaceae (7), Moraceae (5), and Meliaceae (5) (Table 2).

The seedlings and belts were dominated by coffee (*Coffea canephora*) with IVI values at 107.81% for seedlings and 52.74% for belts. The dominant tree species is *kayu surian* (*Toona surenii*) with IVI is 44.97% (Table 3). The higher IVI value indicated that the species has a high level of tolerance to the environment and population of this type [9] and indicates that the species has high

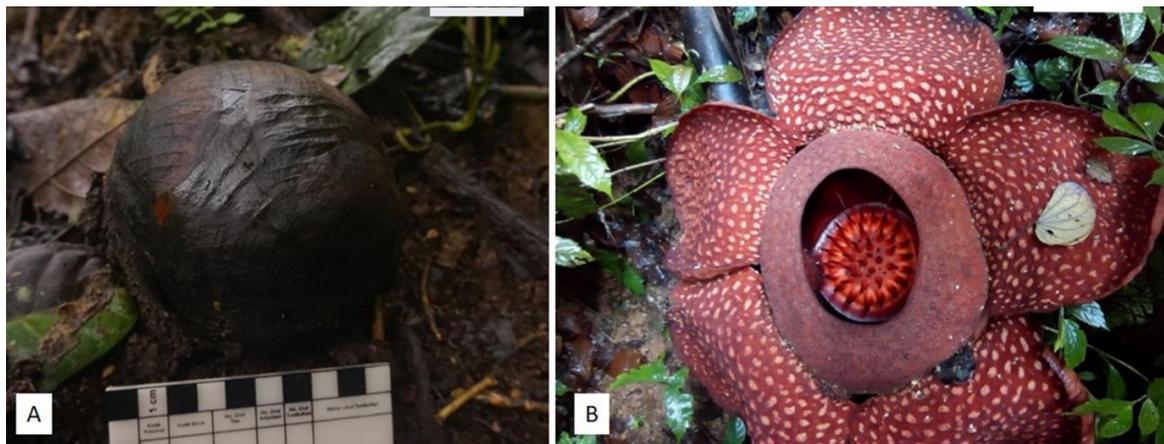


Figure 2. Morphology of *R. arnoldii* flower. Young knop still completely enclosed within bracts (A) and flowers in full bloom (B). Scale bar A = 3 cm, B = 10 cm

Table 3. Five species of plants with the highest Importance Value Index in the habitat of *Rafflesia arnoldii* in Pandam Gadang

Vegetation	Species	Family	INP (%)
Seedings	<i>Coffea canephora</i>	Rubiaceae	107.81
	<i>Laportea stimulans</i>	Urticaceae	55.81
	<i>Villebrunea rubescens</i>	Urticaceae	50.10
	<i>Cinamomum burmannii</i>	Lauraceae	24.33
	<i>Ficus disticha</i>	Moraceae	23.83
Belta	<i>Coffea canephora</i>	Rubiaceae	52.74
	<i>Toona surenii</i>	Meliaceae	34.11
	<i>Laportea stimulans</i>	Urticaceae	24.62
	<i>Cinnamomum burmanii</i>	Lauraceae	18.45
	<i>Ficus ampelas</i>	Moraceae	14.53
Trees	<i>Toona surenii</i>	Meliaceae	44.97
	<i>Shorea</i> sp.	Dipterocarpaceae	26.24
	<i>Aglia argentea</i>	Meliaceae	25.94
	<i>Ficus fistulosa</i>	Moraceae	16.08
	<i>Macaranga gigantea</i>	Euphorbiaceae	13.06

dominance in *Rafflesia* population in Pandam Gadang.

Abiotic Factors of *Rafflesia arnoldii* habitat

Three populations of *R. arnoldii* were found at 800 to 1,024 m asl. Air humidity range between 83–91.8%. This condition probably caused by the dense canopy cover which could maintain the air humidity. The soil has a pH with a range between 7–7.8 and classified as neutral to alkaline, while soil is moist ranges with range of slackness from 65 to 97.4%. The highest humidity is found in the habitat of the second population with a value of

91.3–97.4%. Measurement of the distance of population to water sources ranging from 3 to 27.8 m. The third population is the furthest from the river at distance range from 26 to 27.8 m, while the first population has the nearest distance from 3 to 3.8 m. The result was reported contrast to other locations *R. arnoldii* grows at lower altitude of 490–558 masl, has relatively acidic soil pH of 5.5 [12].

The results of abiotic parameters observation are presented in Table 4. Light intensity varies from 130 to 803 lux, with the first population has the highest light intensity (800–803 lux) and the third population has the lowest (130–137 lux). The

Table 3. Physical parameters of the environment in Pandam Gadang

Abiotic factors	Population		
	1	2	3
Elevation (m asl)	800-806	1.003-1.010	1.021-1.024
ambient temperature (°C)	23.4-25.8	21-23.2	19.1-21
Humidity (%)	85 –86.6	83–87.1	86.3–91.8
Wind speed (m / s)	1.5–2	0	0
pH land	7–7.2	7–7.4	7–7.8
Soil moisture (%)	65–68	91.3–97.4	68–71
Soil temperature (°C)	19.4–22	20–23.2	19–22.1
Light intensity (lux)	800–803	200–208	130–137
The distance of population from the river (m)	3–3.8	3.6–4	26–27.8

Table 5. Plant species climbed by *Terastigma leucostachyum* in Pandam Gadang

Vegetation	Species	Family
Seedlings	<i>Laportea stimulans</i>	Urticaceae
	<i>Coffea canephora</i>	Rubiaceae
Belts	<i>Camptosperma</i> sp.	Anacardiaceae
Trees	<i>Laportea stimulans</i>	Urticaceae

Table 6. Fauna around the *Rafflesia* population in Pandam Gadang and their activities

Scientific Name	Local Name	Activities and Findings
<i>Sesarmidae</i> (geosearmid)	<i>Kepiting</i>	walk in litter
<i>Sus scrofa</i>	<i>Babi Hutan / kondiak</i>	create nest and the traces of
<i>Macaca fascicularis</i>	<i>Karo</i>	climbing trees around population
<i>Presbytis melalophus</i>	<i>Simpai</i>	climbing trees around population
<i>Ratufa affinis</i>	<i>Tupai</i>	climb a tree around the population
<i>Ratufa bicolor</i>	<i>Tupai</i>	climb the tree supporting host
<i>Macaca nemestrina</i>	<i>Baruak</i>	climb a tree around the population
<i>Drosophila colorata</i>	<i>Lalat</i>	wilted on flowers
<i>Chrysomya megacephala</i>	<i>Lalat</i>	wilted on flowers
<i>Sarcophaga haemorrhoidalis</i>	<i>Lalat</i>	withered on flowers

difference in light intensity in each population is caused by the presence of land clearing, where light emitted by the sun directly into the forest floor increases ambient temperature. The results obtained indicate that third population has the lowest light intensity. It can be assumed that *R. arnoldii* prefers shelter, this also evidenced by the highest number of 8 individuals founded (Table 1). Light intensity on of the physical factors of the environment that role in the proliferation of habitat *Rafflesia* [14, 13], and helps the development or *R. arnoldii* [12].

Morphology of *Rafflesia arnoldii*

Flower of *Rafflesia* consists of two phases, in buds termed as knop and fully bloom (Figure 2A).

Knop is the initial stage of development of flowers which is globular and has brown bracts. The bracts protect the young flower by covering the internal organs before they starting to bloom. The young knop will develop to adult knop marked by its size that is getting bigger, and it the bracts began to open and the strands of the perigone lobe change the color to pink or orange. The adult knop has a complete flower section can be distinguished between the inside and outside. The second stage is fully blooming flower show distinct five perigone lobes (Figure 2B). The diameter of fully blooming flower of *R. arnoldii* has 64.65 cm diameter with five intact perigone lobes strands and there are white patches on the surface. This result consistent by the research who reported that *R. arnoldii* had

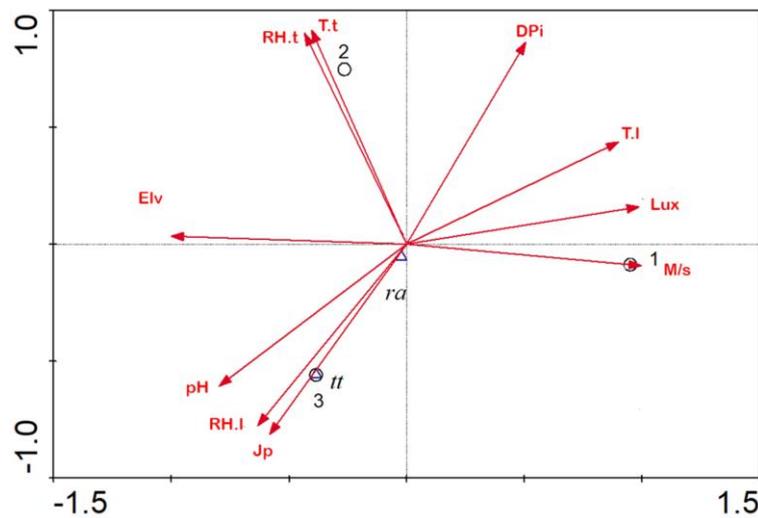


Figure 3. Ordinary Canonical Correspondence Analysis (CCA) population in Padang Pandam shows the first and third axis of environmental factors. Elv: Elevation, Dpi: host plant diameter, T.l: environmental temperature, RH.l: environmental humidity, M/s: wind speed, pH: soil pH, T.t: soil moisture, Lux: light intensity, Jp: distance of population from the river, tt: *T. leucostaphylum*, ra: *R. arnoldii*

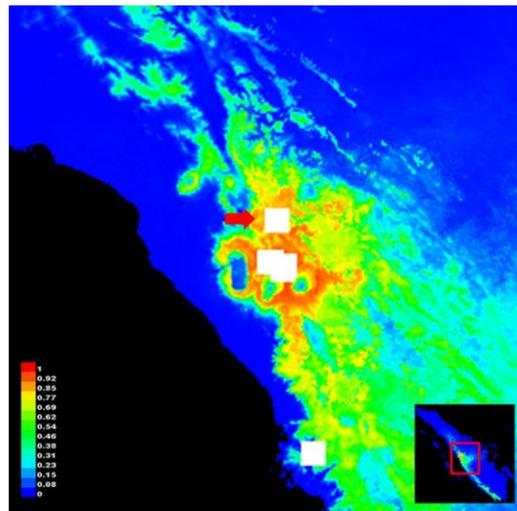


Figure 4. Habitat suitability modeling *R. arnoldii* at Pandam Gadang (red arrow)

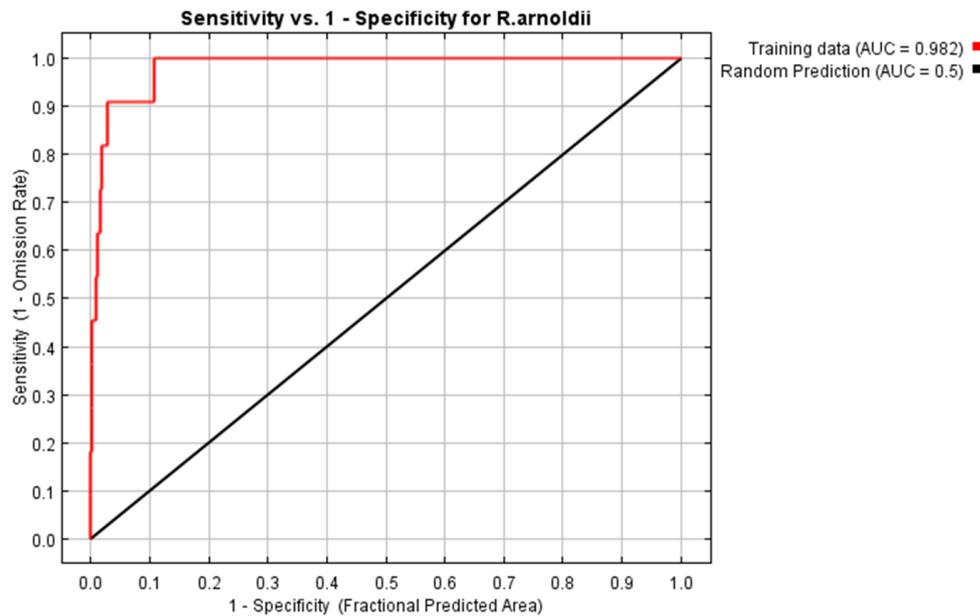
small white (wart) patches on the perigone lobe, and was the largest size compared to the other *Rafflesia* species [1, 2].

Based on the recent observation, the strands of the perigone lobe have the largest and smallest widths which are 28 cm long and 24 cm wide and 25 cm long and 22 cm wide. The observed perigone tube height ranging from 22 to 23.5 cm while disk height ranging from 11 to 13 cm bearing 51 processes.

Host plants: *Tetrastigma leucostaphylum*

Hosts plant recorded during the study is *T. leu-*

costaphylum with diameter at breast height (DBH) at the smallest class at 1.73-1.88 cm, while the largest class at 6.13–6.73 cm. *Tetrastigma leucostaphylum* usually reproduces generatively but vegetative host proliferation was also recorded during the study, covering the stem and branches of the young shoots of the host stem. Host plant always climb trees right in the population *R. arnoldii*. The results of the identification of host tree species *T. leucostaphylum* originated in more than one species (Table 5). The host tree is usually the closest one to *T. leucostaphylum*. Therefore, it is assumed the host tree play an important role in sta-

Figure 5. Area Under the Curve (AUC) value in modeling *R. arnoldii* habitatTable 7. Environmental factors and its contribution in the habitat of *R. arnoldii* in Pandam Gadang

Variable	Description	Percentage of Contribution (%)
<i>bio19</i>	Precipitation of coldest quarter	42.7
<i>chy3</i>	Light intensity in March 2018	16.9
<i>chy12</i>	Light intensity December 2018	13.1
<i>bio15</i>	Precipitation seasonality	12.7
<i>bio7</i>	Temperature annual range (<i>bio5-bio6</i>)	4.1
<i>chy2</i>	Light intensity in February 2018	3.8
<i>bio2</i>	Maximum and minimum temperature ranges	2.9

bilizing the ambient temperature, humidity and light intensity of the *R. arnoldii* habitat. The ability of the host to wrap (belt) around the surrounding plants that forms the second and third associations can form a dense canopy around the population, the light will be blocked by the canopy entering [2].

The lack of public knowledge about *R. arnoldii* host plant is one of the threats to existence. In one sub-population, the host has been found as a dead plant because it has been cut down by the locals. The breakdown of the stem or host root infected with *R. arnoldii* will certainly disrupt the development of *R. arnoldii* directly because it will cause the cessation of nutrient supply from the host [16, 13].

Fauna activity

From the observation, six large mammals, two rodents (*Rodentia*) and three insects were found

(Table 6). The foul aroma of *R. arnoldii* invite the insects and ants. Various types of insects such as flies (*Drosophila colorata*, *Chrysomya megacephala*, *Sarcophaga haemorrhoidalis*) were found and actively visited the late flowers. Other insects such as black ants (*Euprenolepisare* sp.) were found on the dead knop and considered as source of deadly threats to knop. The previous research stated that black ants were found on the bractea of the dead knop [17].

Principal Component Analysis (PCA)

Based on PCA, the presence of *Rafflesia* in Pandam Gadang is largely due to some environmental factors. There are three environmental factors which are positively correlated which include the distance of the population from the river (Jp), humidity (RH.1), and soil pH (pH) (Figure 3). The presence of individuals at one ordinance with certain environmental parameters shows the influ-

ence environmental factors on the occurrence of the plant [18].

Habitat suitability model of *Rafflesia arnoldii*

Land clearing such as deforestation found in two populations of *R. arnoldii* is a threat to quality of habitat for *R. arnoldii*. The map of habitat suitability model of *R. arnoldii* generated from the MaxEnt program (Figure 4) and considered as still very good. This also indicated by the results of the data used are very suitable, with the position of the blue line on the black line (line with random data). The color produced in the population is red to near red which shows a value close to 1 so that the probability value and suitability of modeling a habitat are said to be good [18]. The Maximum Entropy model produced a habitat suitability map named Area under the Curve (AUC) with a value at 0.982 that approaches 1 indicates the suitability of habitat *R. arnoldii* very well (Figure 5). AUC analysis showed a number that approaches one has a prediction model with good probability. After the previous research mentioned that variables were used to predict and contribute to each habitat [19, 20].

Jackknife test was used to determine the most important environmental factors for the existence of *R. arnoldii*. The main variable that significantly affect the type of MaxEnt modeling is the coldest rainfall (high) at 42.7% followed by light intensity (Table 7). The relationship between environmental factors and species in habitat a can be seen by contribution of each parameter from the results of MaxEnt analysis [21, 22].

Conclusion

Rafflesia species at the study site is *R. arnoldii* R. Br. known by the local as Cendawan Biriang. The only host plant recorded is *T. leucostaphylum*. The results of vegetation analysis in *R. arnoldii* habitat in Pandam Gadang showed that 260 individuals belong to 43 species and 22 genus have been recorded. The seedlings are dominated by Lauraceae, belts by Moraceae, Meliaceae, Euphorbiaceae, and Lauraceae, while trees are dominated by Euphorbiaceae, Moraceae, and Meliaceae. Environmental factors that influence *R. arnoldii* populations are soil pH 7-7.8 (pH), humidity 83-91.8% (RH.I) and distance of the population from the river 3-27.8 m (Jp). The level of

suitability habitat of *R. arnoldii* in the study site show that habitat models were still very good.

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