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Research Article

Autecology of *Nepenthes* spp. in Peat Swamp and Heath Forest Pematang Gadung, West Kalimantan

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ABSTRACT
Nepenthes occur in various habitat types in West Kalimantan. But some species are categorized as vulnerable on the IUCN red list. Autecological studies of *Nepenthes* spp. are required for species management and conservation. The study aimed to analyze species diversity, distribution pattern, association, and environmental factors that correlated with *Nepenthes* spp. at peat swamp and heath forest in Pematang Gadung. Data was collected in September 2021 by purposive sampling on 60 plots measuring 3m x 3m in each habitat type. Species diversity was analyzed based on the presence and abundance of species in the plots. The distribution pattern was determined using a standardized Morisita index (Ip). Meanwhile, the association type was determined based on the Jaccard index (JI). Environmental data were analyzed by Canonical Correspondence Analysis (CCA) using Past Version 4.03. This study found six wild species in a peat swamp and four species in a heath forest. The population of *Nepenthes* spp. has clumped distribution pattern with Ip>0. *Nepenthes* spp. are associated with plants such as *Barringtonia racemosa*, *Syzygium* sp., *Nephrolepis biserrata*, and *Campnosperma auriculatum*. The result of CCA revealed that environmental factors in both habitat types affected the presence of each *Nepenthes* species. The air temperature, humidity, soil moisture, and light intensity show different influences on different species.

INTRODUCTION
Nepenthes is the only genus in the family Nepenthaceae. These plants are distributed in Southeast Asia, Seychelles, Madagascar, and Australia (Moran & Clarke 2010). According to Murphy et al. (2020) there were at least 160-180 *Nepenthes* worldwide. *Nepenthes* found in Indonesia consist of 68 species (Mansur 2013). Kalimantan, as a central distribution of *Nepenthes* in Indonesia, has 40 species, and 29 of them are reported as endemic (Dančák et al. 2022).

Nepenthes thrive in lowland tropical rainforest, mountain forest, peat forest, heath forest, limestone mountain, savanna, swamp, and lake (Mansur 2013). *Nepenthes* has leaves that are modified into pitchers as a form of plant adaptation. The pitchers have the function to trap and digest prey (Gilbert et al. 2018; Mithöfer 2022). Pitchers of *Nepenthes* produce 0.2 mL to 1.5 mL of viscous acidic liquid (pH of 3.0-5.5) and contain enzymes to digest the prey, for example, insects (Ravee et al. 2018). *Ne-*

penthes provides ecological advantages such as climate indicator in areas with high annual rainfall, humid, and low soil nutrients (Mansur 2006), absorbing carbon dioxide (CO_2) in the atmosphere (Mansur 2012), supplying nitrogen and phosphorus elements to the soil (Kissinger et al. 2015) and providing food sources for insects (Bauer et al. 2016).

Pematang Gadung Village Forest has a unique ecosystem because it is a swamp forest surrounded by a heath forest. Exploring these habitat types can potentially find endemic and new species of *Nepenthes*. Botanically, the island of Borneo is relatively well-explored in the north (Sabah, Sarawak and Brunei) (Dančák et al. 2022). In contrast, research about *Nepenthes* diversity, especially in peat swamps and heath forests in West Kalimantan, is rarely reported.

An autecological study in Pematang Gadung Village needs to be conducted. Many *Nepenthes* species are threatened due to illegal gold mining activities in this village. This study aimed to analyze *Nepenthes* spp. diversity, distribution pattern, association, and environmental factors that influence the presence of *Nepenthes* spp. in peat swamps and heath forests in Pematang Gadung.

MATERIALS AND METHODS

Study Sites

Study sites located in West Kalimantan at peat swamp (1°56'34.7"S, 110° 13'17.6"E in Pematang Gadung Village Forest about 7,004 ha), and heath forest (1°55'8.3"S, 110°16' 48.2"E outside the Pematang Gadung Village Forest area, next to a swamp forest) (Figure 1). The study site has an altitude of 2–29 meters above sea level (masl), with flat to sloping (0–8%) topography. Based on climate data from Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG), Pematang Gadung has rainfall of 3,871.2–4,352 mm/year, air temperatures of 23.2–30.3°C, air humidity 68–95% and wind speeds of 0–4 m/s.

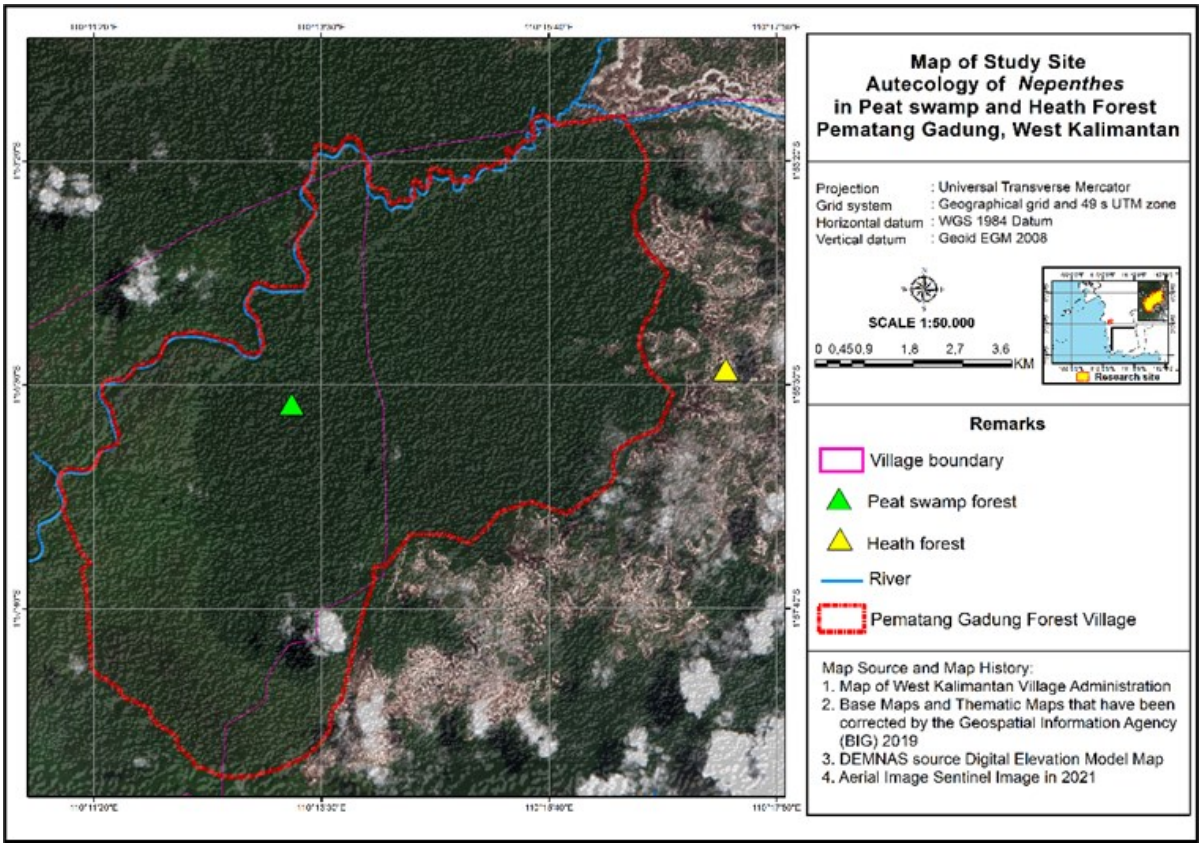

Figure 1. Map of study site in a peat swamp and heath forest Pematang Gadung.

Data Collection

This study was conducted in September 2021. The presence of *Nepenthes* spp. was selected through survey and exploration during the study. Sixty plots of 3m x3m were purposively placed in peat swamps and heath forests. Purposive sampling was chosen for an in-depth investigation to define characteristics for a purpose relevant to the study. Purposive sampling provides a sample that can logically assume to represent the population (Palinkas et al. 2015). The number of *Nepenthes* counted as one individual if more than half of the plant was in the plot. *Nepenthes* were identified using literatures (Cheek & Jebb 2001; Mansur 2006). Meanwhile, the associated plants were observed and identified using (Soepadmo et al. 1995) and websites (https://powo.science.kew.org/ and https://www.asianplant.net/).

Abiotic data collection, including air temperature, humidity, light intensity, and wind speed, was measured using a handheld 4-in-1 environment meter. Soil samples were collected in 1 kg from 10 points of each habitat type at 10–20 cm depth using a sample ring. Then prepared by removing litter residues and plant root debris for physical and chemical analysis.

Data Analysis

The composition of the *Nepenthes* species and the Important value index (IVI) are calculated using the formula (Mueller-Dombois & Ellenberg 1974) as follows:

$$\text{Density} = \frac{\text{No. of individuals of a species}}{\text{Sampling plot area}}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of species}}{\text{Density of all the species}} \times 100\%$$

$$\text{Frekuensi (F)} = \frac{\text{No. of plot of occurrence of species}}{\text{total of plot}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{frequency of all the species}} \times 100\%$$

Important value index (IVI) = RD + RF

The Shannon-Wiener formula calculates the diversity index species (H') (Shannon 1948), dominance index (D) is calculated to determine the degree of species dominance (Odum 1993). The evenness index (e) estimates the distribution of individual species within a community (Krebs 1989). The formulas used were as follows:

$$H' = -\sum \left(\frac{ni}{N}\right) ln \left(\frac{ni}{N}\right)$$

$$D = \sum_{i=i}^{n} \left(\frac{ni}{N}\right)^2$$

$$e = \left(\frac{H'}{ln\, S}\right)$$

Where: ni is the number of individual species, N represents the number of individuals of the whole species, and S represents the number of species.

The distribution pattern of *Nepenthes* was analyzed using a Standardized Morisita Index (Ip) (Krebs 1989). Using the formulas:

$$I_d = n\left[\frac{\sum x^2 - \sum x}{(\sum x)^2 - \sum x}\right]; Mu = \frac{\sum \chi^2 0.975 - n + \sum xi}{\sum xi - 1}; Mc = \frac{\sum \chi^2 0.0255 - n + \sum xi}{(\sum xi) - 1}$$

$$\text{If } Id \geq Mc \geq 1, Ip = 0.5 + 0.5\left(\frac{Id - Mc}{n - Mc}\right)$$

$$\text{If } Id > Mc > 1, Ip = 0.5\left(\frac{Id - Mc}{Mc - 1}\right)$$

$$\text{If } 1 > Id > Mu, Ip = -0.5\left(\frac{Id - Mu}{Mu - 1}\right)$$

$$\text{If } 1 > Mu > Id, Ip = -0.5 + 0.5\left(\frac{Id - Mu}{Mu}\right)$$

Where: Id is the Morisita index, n is the number of observation plots, x is the number of *Nepenthes* individuals in plots, Mu is the uniformity index, χ^2 0.975 is the chi-square table with a confidence interval of 97.5%, Mc is the clumping index, χ^2 0.0025 is the chi-square table with a confidence interval of 2.5%.

Association analysis was determined using a 2x2 contingency table, and the degree of association was calculated using the Jaccard index (JI) (Mueller-Dombois & Ellenberg 1974). Using the formula:

$$JI = \frac{a}{(a+b+c)}$$

Where a: a is the number of plots found Nepenthes and others species, b is the number of plots found Nepenthes, c is the number of plots found others species.

Canonical Correspondence Analysis (CCA) using Past software version 4.03 was used to examine the correlation between environmental conditions and the existence of *Nepenthes* (Hammer et al. 2001).

RESULTS AND DISCUSSION

Habitat Characteristics of *Nepenthes*

Peat swamp forest is characterized by relatively dense canopy cover, wet soils, low light intensity, and rich leaf litter on the forest floor. Peat swamp is naturally often waterlogged and the water surface and peat surface are highly acidic (Page et al. 1999; Tanjung et al. 2020). The Pematang Gadung Village Forest area is a coastal peat dome located between the Pawan and Pesaguhan Rivers. The floral composition of the peat swamp forest consists of *Aglaia rubiginosa* (Hiern) Pannell, *Baccaurea* sp., *Combretocarpus rotundatus* (Miq.) Danser, *Cratoxylum glaucum* Korth., *Diospyros* spp., *Pandanus* spp., and *Syzygium* spp. In this area, *Gonystylus bancanus* (Miq.) Kurz was also found. This species is a peat swamp endemic plant, categorized as an endangered species.

In contrast, heath forest has low canopy cover with high light intensity, located close to illegal gold mining sites. The forest floor is covered with white quartz sand; trees have small trunk sizes with tight branches (Whitten et al. 1987). The trees commonly found in this area include *Baeckea frutescens* L., *Cratoxylum glaucum* Korth., *Melaleuca cajuputi* Maton & Sm. ex R. Powell, *Rhodomyrtus tomentosa* (Aiton) Hassk, and *Tristaniopsis obovata* Benn. Ferns and Cyperaceae species are also found, such as *Dicranopteris linearis* (Burm.f.) Underw. and *Scleria biflora* Roxb.

Nepenthes thrive in peat swamps and heath forests, growing in the ground or climbing a host tree. Generally, *Nepenthes* are vines or subscandent scrubs that grow and attach to adjacent trees using looped tendrils. We did not find differences in *Nepenthes* habits in either peat swamp or heath forest.

Species Richness

We recorded four species from the heath forest, *Nepenthes ampullaria* Jack, *Nepenthes gracilis* Korth., *Nepenthes mirabilis* (Lour.) Druce, and *Nepenthes rafflesiana* Jack. These species are also found in peat swamp forest and we recorded two other species from this forest, *Nepenthes bicalcarata* Hook.f. and *Nepenthes* x *hookeriana* Lindl. (Figure 2). *N. bicalcarata* is an endemic species to Borneo. The latest species is a hybrid of *N. ampullaria* and *N. rafflesiana* (Clarke 2001). *N. bicalcarata* has never been reported to be found in Ketapang Regency (Sunardi & Mansur 2021), so it is the first report of *N. bicalcarata* from Ketapang Regency. *N. reinwardtiana* Miq. can be found in a peat swamp and heath forests (Rantau et al. 2019; Wulandari et al. 2020) but has not been found in this study. *N. reinwardtiana* prefers to grow in open areas (Hariyadi 2013). Nevertheless, degradation in the heath forest due to illegal gold mining may cause this species to be absent at the study site.

Figure 2. *Nepenthes* spp. found in Pematang Gadung Village Forest, West Kalimantan (A) *N. ampullaria*; (B) N. *bicalcarata*; (C) *N. gracilis*; (D) *N. mirabilis*; (E) *N. rafflesiana*; (F) *N.* x *hookeriana*

Diversity and Distribution Pattern of *Nepenthes* spp.

The most common species found in the peat swamp forest Pematang Gadung Village are *N. ampullaria*. This species, with a density value of 3,370 ind/ha, is predominant since it has the highest (IVI 115.13%) in the peat swamp forest (Table 1). Generally, *N. ampullaria* is abundant in humid conditions, with high water availability and shaded areas (Moran et al. 2003; Nurhadi et al. 2018). This kind of condition is found in Pematang Gadung Village Forest.

Furthermore, a community of *Nepenthes* in the heath forest was dominated by *N. gracilis*, (4,241 ind/ha, IVI 170.36%) (Table 1). This species thrives in heath forest probably because heath forest in Pematang Gadung has lower canopy cover and higher light intensity (479–1987 lux) than in peat swamp forest. *N. gracilis* prefers to grow in conditions with high light intensity. According to Armanda, et al. (2020), *N. gracilis*

Table 1. Density and IVI of *Nepenthes* spp. in peat swamp and heath forest.

Site	Species	D (ind/ha)	RD (%)	RF (%)	IVI (%)
Peat swamp	*N. ampullaria*	3,370	64.31	50.82	115.13
	N. bicalcarata	148	2.83	4.92	7.74
	N. gracilis	130	2.47	3.28	5.75
	N. mirabilis	296	5.65	8.20	13.85
	N. rafflesiana	1,222	23.32	31.15	54.47
	N. x *hookeriana*	74	1.41	1.64	3.05
Heath	*N. ampullaria*	56	1.18	2.78	3.95
	N. gracilis	4,241	89.80	80.56	170.36
	N. mirabilis	37	0.78	2.78	3.56
	N. rafflesiana	389	8.24	13.89	22.12

Remarks: D: density; RD: relative density; RF: relative frequency; IVI: important value index

dominates in heath forests because this species is often more adaptable than others.

N. ampullaria and *N. rafflesiana* prefer to thrive in shaded habitats with high soil moisture. We found these species more abundant in the peat swamp forest compared to the heath forest. In this study, we reported that *N. bicalcarata* was found in peat swamps. The density of *N. bicalcarata* in peat swamp forests is poor (148 ind/ha). In contrast, *N. bicalcarata* is not found in heath forests, probably due to high temperatures. *N. bicalcarata* grow optimally at 18–29°C (Mansur 2006).

N. x *hookeriana* was rarely found in the peat swamp forest (74 ind/ha, IVI 3.05%) and absent in the heath forest. This species is usually found in limited quantities among the parent species. *N. mirabilis* in the heath forest has the lowest density (37 ind/ha); it might be due to competition with the other species, primarily the dominant species, *N. gracilis*.

Diversity of *Nepenthes* in the peat swamp forest of Pematang Gadung is slightly higher compared with the heath forest. The diversity of *Nepenthes* is categorized as medium (H'= 1.04) in the peat swamp forest and low (H'= 0.39) in the heath forest (Figure 3a). This data is supported by the values of the dominance and evenness index (Figure 3b, 3c). High diversity, evenness, and density of species in the community indicate the availability of niches, so it is important to maintain their sustainability (Benayas et al. 1999). To avoid their extinction and ensure the availability of genetic material for development efforts, ex-situ conservation and cultivation are necessary.

High dominance index (0.81) makes *Nepenthes* diversity low in heath forests (Figure 3b). A high dominance value indicates that the habitat has low species diversity with an uneven number of species distribution. However, the dominant species with a high IVI score need conserving to maintain species composition. Decreasing species diversity will reduce competition between species and increase competition for each species. *Nepenthes* in peat swamp and heath forest is categorized as having an uneven distribution of the number of species with a value of (e) ≤ 0.50 (Figure 3c). Diversity and low evenness in the community caused by species dominance may indicate competition for resources and limited niches to occupy (Wilsey & Polley 2004).

Nepenthes spp. have a clumped distribution pattern (Ip >0) in both peat swamp and heath forest of Pematang Gadung (Table 2). These results are in line with reports from previous studies elsewhere (Payung et al. 2021; Apriyanto et al. 2021). *Nepenthes* tends to be clumped and thrive in forests with acidic soils that are nutrient-poor and seasonally wet (Damit et al. 2017).

Table 2. Distribution pattern of *Nepenthes* spp. in peat swamp and heath forest.

Species	Peat swamp		Heath	
	Ip	Distribution Pattern	Ip	Distribution Pattern
N. ampullaria	0.52	Clumped	0.58	Clumped
N. bicalcarata	0.73	Clumped	-	-
N. gracilis	0.51	Clumped	0.50	Clumped
N. mirabilis	0.64	Clumped	0.03	Clumped
N. rafflesiana	0.53	Clumped	0.55	Clumped
N. x *hookeriana*	0.50	Clumped	-	-

Remarks: Ip: standardized Morisita index value

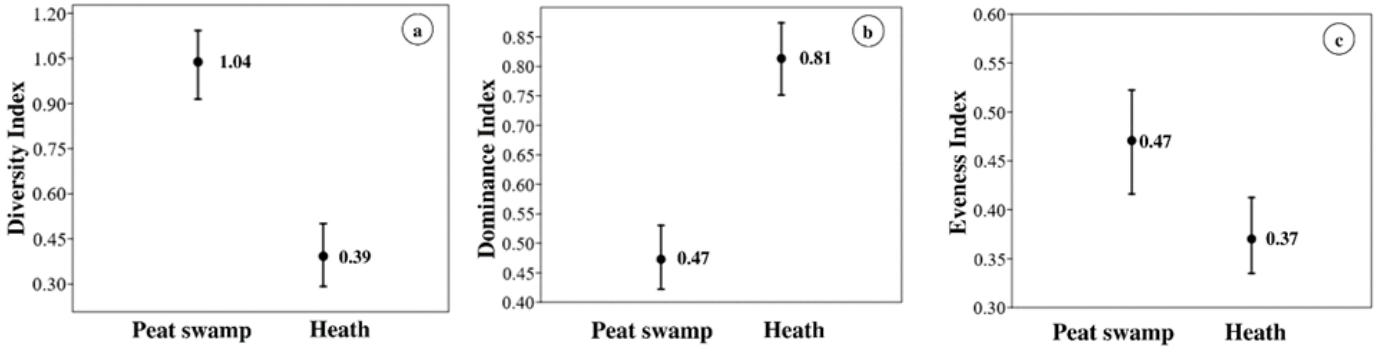

Figure 3. (a) Diversity index value; (b) Dominance index; (c) Evenness index; bar line in graph shows error bar.

Clumped distribution occurs due to generative reproduction supported by environmental conditions. When released and carried by the wind, *Nepenthes* seeds that are thread-shaped with thin wings will fall not far from the *Nepenthes* parent. It is because trees near the *Nepenthes* can restrict the movement of their seeds. Vegetative reproduction in *Nepenthes* also caused clumped distribution patterns. Vegetative reproduction in *Nepenthes* with developing basal shoots that arise from axillary buds along stems at ground level (Lam et al. 2020).

Nepenthes spp. Association with other Plants

Associations influence the occurrence of each species in its habitat. *Nepenthes* spp. in peat swamps and heath forests may have a positive association with a plant species and negative association with the other (Table 3). Positive associations between species indicate differences in resource use and non-competitive interactions between species, while negative associations occur due to competition that can inhibit the presence and abundance of other species (Maire et al. 2012; Sritharan et al. 2021). The positive association between *Nepenthes* species and other plants indicates that these plants can be a climbing tool for *Nepenthes*. In addition, other plants also contribute litter to the pitchers of *N. ampullaria*, which is a semi-detritivorous species.

N. mirabilis tends to coexist with *Barringtonia racemosa* in peat swamp forests (JI 0.60). *N. mirabilis* also associates with other species in peat swamp forests, such as *Poikilospermum suaveolens*. This species was found in plots with low canopy cover, where light can reach the forest floor. In this study, *N. mirabilis* often occupied open areas close to river, whereas *N. ampullaria* did not thrive in these niches. Habitat specification occurs to avoid competition with dominant species (Calatayud et al. 2020). Therefore, associations in species with low abundance suggest that the species may not compete with dominant species for the same resources.

The endemic species, *N. bicalcarata* is positively associated with *Antidesma coriaceum*. *Antidesma coriaceum* is often found in plots where *N.*

Table 3. Chi-square (χ^2) statistic and association index of *Nepenthes* spp. with other plants in peat swamp and heath forest.

Nepenthes-other plant	Chi-square (χ^2)	Association type	JI
N. ampullaria-Macaranga caladiifolia Becc [1]	4.76	Positive	0.34
N. ampullaria-Tetrameristra glabra Miq. [1]	4.01	Positive	0.13
N. ampullaria-Cratoxylum glaucum Korth. [1]	5.43	Negative	0.07
N. ampullaria-N.rafflesiana [1]	23.32	Negative	0.08
N. ampullaria-Syzygium sp. [2]	29.49	Positive	0.50
N. bicalcarata-Antidesma coriaceum Tul. [1]	19.32	Positive	0.33
N. bicalcarata- Simaba borneensis (Noot.) Feuillet [1]	8.82	Positive	0.25
N. gracilis-Nephrolepis hirsutula (G.Forst.) C.Presl [1]	6.59	Positive	0.40
N. gracilis-Curculigo latifolia Dryand.ex W.T.Aiton [1]	4.83	Positive	0.11
N. gracilis-Cratoxylum glaucum Korth. [2]	22.76	Negative	0.45
N. gracilis-N. mirabilis [2]	13.98	Negative	0.02
N. gracilis-N. rafflesiana [2]	9.22	Negative	0.15
N. mirabilis-Barringtonia racemose (L.) Spreng. [1]	34.74	Positive	0.60
N. mirabilis-Poikilospermum suaveolens (Blume) Merr. [1]	4.70	Positive	0.17
N. mirabilis-Nephrolepis biserrata (Sw.) Schott [2]	28.97	Positive	0.50
N. mirabilis-Scleria biflora Roxb. [2]	4.14	Positive	0.10
N. rafflesiana-Cratoxylum glaucum Korth.[1]	10.82	Positive	0.39
N. rafflesiana- Sandoricum koetjape Merr.[1]	4.46	Positive	0.11
N. rafflesiana-Pternandra rostrata (Cogn.) M.P.Nayar [1]	6.51	Negative	0.05
N. rafflesiana-Baeckea frutescens L.[2]	7.37	Positive	0,25
N. rafflesiana- Willughbeia sp.[2]	5.68	Positive	0.18
N. x *hookeriana-Campnosperma auriculatum* (Blume) Hook.fil.[1]	29.49	Positive	0.50
N. x *hookeriana- Stemonurus secundiflorus* Blume [1]	9.15	Positive	0.17

Remarks: Chi-square table 3.84; 1: peat swamp; 2: heath; JI: Jaccard Index

bicalcarata thrive. This species was also found to be used as a climbing tool for *N. bicalcarata*. This report supports previous information on *N. bicalcarata* in West Kalimantan (Sunardi & Mansur 2021).

Nepenthes spp. exhibited negative associations with some plants. *Cratoxylum glaucum* is a common tree in a peat swamp and heath forest, which has negative associations with *N. ampullaria* and *N. gracilis*. We assume that the dominant species compete for the same resources in these niches. Negative associations in forest communities are found in the most common species with a wide distribution and low habitat specificity (Sritharan et al. 2021). *N. rafflesiana* and *C. glaucum* tends to be found in the same plot, suggesting no competition between both species. In addition, *N. rafflesiana* is not a dominant species in peat swamp forests, so it is unlikely to compete with *C. glaucum*. *Nepenthes* abundance and vegetation composition influence the associations that occur within habitats. *N. ampullaria* in heath forest associated with *Syzygium* sp. This species grows on the forest floor under the shade of *Syzygium* sp. Meanwhile, *N. mirabilis* is associated with *Nephrolepis biserrata* and *Scleria biflora*. This result is aligned with the report from Hidayat et al. (2018) that *N. mirabilis* is often found growing together with Cyperaceae and ferns.

Dominant species of *Nepenthes* are negatively associated with some other *Nepenthes*. It indicates that the dominant species found in peat swamp (*N. ampullaria*) and heath (*N. gracilis)* tend to compete for nutrients and insect prey. Therefore, different *Nepenthes* species were rarely found in the same plot at the research location.

Correlation between Environment Factor Affecting the Abundance of *Nepenthes* spp.

Air temperature and air humidity are essential factors for *Nepenthes*' growth. The measurements of environmental factor in peat swamp forest show that the average air temperature is 24.8 °C with an average air humidity of 81.3%. Meanwhile, the average air temperature in the heath forest is higher at 29.8 °C with an air humidity of 73.8%. *Nepenthes* growth in air temperature ranges from 23°C–31°C (Mansur 2006), with air humidity ranging from 67–90% (Nainggolan et al. 2020).

Precipitation is one of the environmental factors affecting the existence of *Nepenthes*. *Nepenthes* is predominantly found in the rainfall range between 3500–4000 mm/year (Sartika et al. 2017). Ketapang Regency rainfall for 2020-2021 ranges from 3871.2–4352 mm/year. Heavy rainfall also supports the availability of water in both habitat types, which can support the growth of *Nepenthes*.

Based on CCA analysis, environmental factors correlate with the presence of *Nepenthes* spp. in peat swamps (Figure 4a) and heath forests (Figure 4b). In peat swamp forest, showed a positive correlation between *N. mirabilis* and *N. gracilis* to light intensity. Both species in the study site are often found in open canopy cover with the light intensity reaching to forest floor. The existence of *N. rafflesiana* is influenced by the air temperature. *N. ampullaria* and *N. bicalcarata* are affected by air humidity. Meanwhile, *N.* x *hookeriana* had a low correlation with air humidity.

The CCA ordination graph in the heath forest suggests that soil temperature, air temperature, and light intensity are highly correlated with *N. gracilis*. This species can thrive in heath forest with high light intensity from 479-1987 lux, high air temperature of 29.8 °C and soil temperature from 27-30°C. Meanwhile, *N. ampullaria* is influenced by high soil moisture, similar to conditions in peat swamp forests that are often waterlogged. *N. rafflesiana* has a low correlation with environmental factors in the heath forest. This species is generally found in shaded areas, but some individuals are found in open areas.

The results of soil fertility analysis in the *Nepenthes* habitat showed that the nutrient content and pH were low, with 2.9 in the peat swamp forest and 3 in the heath forest. *Nepenthes* spp. in the peat swamp forest grows on soil with a silty loam texture, while in the heath forest, *Nepenthes* spp. grows on sandy soil. The high percentage of sand fraction in the heath forest causes the soil's capacity to bind water significantly lower. Low porosity impacts the ability of nutrients to be released from soil colloids due to infiltration. The percentage of soil texture fraction, sand, dust, and clay also affected the nutrient content.

In the peat swamp forest, the C-organic content is categorized as very high at 40.14% due to the high organic matter contained in the peat soil. Total N in peat soil is relatively high at 1.67%. However, most of it is contained in lipoproteins, so it cannot be utilized directly by plants. Meanwhile, the C-organic content in heath forest is high at 3.3%, with a low total N content of 0.15%. Cation exchange capacity was very high at 171.32 in the peat swamp and low at 11.18 in the heath forest. Both habitats had low base saturation values of <20%.

Study results on habitat characteristics of *Nepenthes* are essential data in species management and necessary for conservation purposes. *Nepenthes* is a protected plant species under Law Number 5 of 1990 and Minister of Environment and Forestry Regulation on Permen LHK/P.20 Year 2018. *N. ampullaria*, *N. gracilis*, *N. mirabilis*, and *N. rafflesiana* as the least concern (LC) species by IUCN. In contrast, endemic species *N. bicalcarata* is categorized as vulnerable (VU) (Schnell et al. 2000). Five spe-

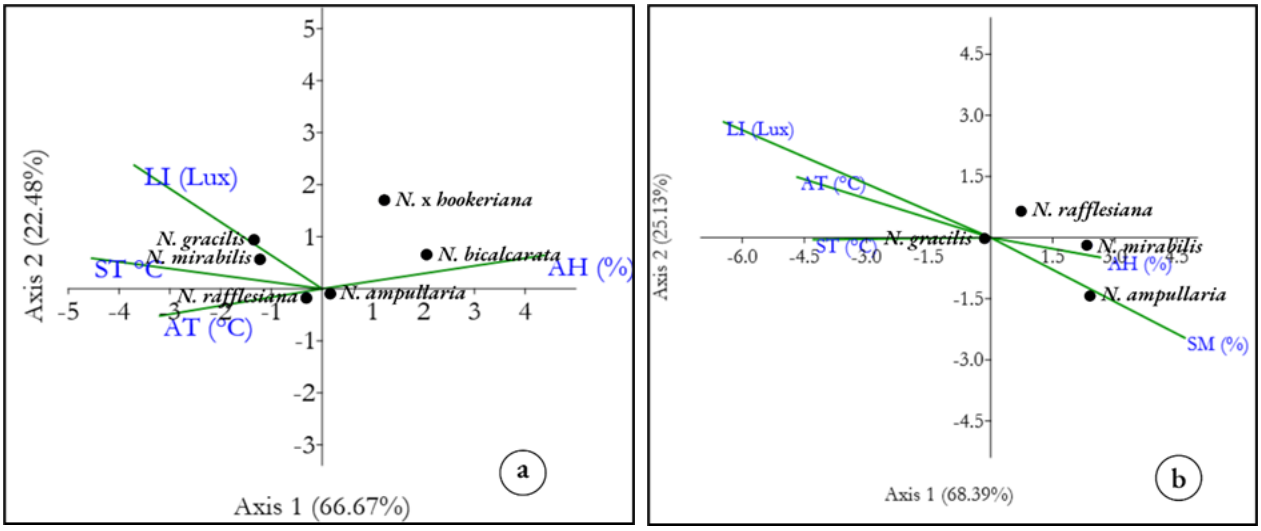

Figure 4. Correlation between environmental factors and the existence of *Nepenthes* spp. (a) peat swamp forest; (b) heath forest. AH: air humidity; AT: air temperature; LI: light intensity; SM: soil moisture; ST: soil temperature.

cies of *Nepenthes* excluding *N.* x *hookeriana* are also listed as restricted for all trade activities.

N. bicalcarata requires special attention in conservation. This species found in small quantities with a density of 142 ind/ha. Based on IUCN, the annotation of this species needs updating, and its population is considered unspecified. Consequently, further exploration and data collection of *N. bicalcarata* is required. The distribution of *N. bicalcarata* only covers the western and northern parts of Borneo (including Malaysia and Brunei Darussalam). Over the last 30 years, peat swamp forest was converted into oil palm plantations and has decimated 60% of the *N. bicalcarata* population in Borneo (Clarke et al. 2018).

Nepenthes spp. in the Pematang Gadung is threatened by illegal gold mining activities. In-situ conservation of *Nepenthes* species should be implemented in Pematang Gadung Forest Village by restricting forest clearing, illegal logging, and mining area occupation. Monitoring activities of *Nepenthes* spp. discovery points in study site is also crucial. Ex-situ conservation through captive breeding and cultivation techniques, both conventional and tissue culture, can be applied by considering the characteristics of the *Nepenthes'* habitat.

CONCLUSIONS

Based on the results of autecological studies, the population of *Nepenthes* in peat swamp and heath forest has clumped distribution and are often found close to other plants like *Barringtonia racemosa* and *Syzygium* sp. The factors that most influence the presence of *N. gracilis* include light intensity, air temperature, and soil temperature. Meanwhile, the presence of *N. ampullaria* is affected by high soil moisture. The Pematang Gadung Forest has a high potential for *Nepenthes* due to the presence of an endemic species of *N. bicalcarata*. Accordingly, conservation activities are very important to be carried out in this forest to maintain the existing diversity of *Nepenthes*.

AUTHOR CONTRIBUTION

NU, S, and NSA designed research; NU has been tasked with sampling and observing the existence of *Nepenthes* spp. and its autecological factors in the field, data analysis, and manuscript writing. S and NSA supervised the identification process in the laboratory, data analysis, manuscript writing, and editing

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CONFLICT OF INTEREST

There is no conflict of interest in this research

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