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Mathematical Modeling of Ecological Associations and Spatial Distribution of *Nepenthes Tobaica* in Ria-Ria Village, North Sumatra: Implications for Conservation and Management

Esther Sorta Mauli Nababan[1,2*], Ridahati Rambey[2,3], Rahmawaty[2], Mohd Nazip Suratman[4,5], Abdul Rauf[2,3], Mohd Hasmadi Ismail[6], Muhammad Romi Syahputra[1], Erwin[1], Muhammad Hadi Saputra[7]

[1] Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan 20155, Indonesia
[2] Doctoral Program of Natural Resources and Environmental Management, Graduate School, Universitas Sumatera Utara, Medan 20155, Indonesia
[3] Faculty of Forestry, Universitas Sumatera Utara, Deli Serdang Regency, North Sumatra 20353, Indonesia
[4] Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam 40450, Malaysia
[5] Institute for Biodiversity and Sustainable Development (IBSD), Universiti Teknologi MARA (UiTM), Shah Alam 40450, Malaysia
[6] Faculty of Forestry and Environment, Universiti Putra Malaysia, Serdang 43400 UPM, Selangor, Malaysia
[7] Research Center for Ecology and Ethnobiology, Badan Riset dan Inovasi Nasional, Central Jakarta 10340, Indonesia

Corresponding Author Email: esther@usu.ac.id

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ABSTRACT

Nepenthes tobaica (*N. tobaica*) is a unique carnivorous plant with distinctive shapes, sizes, and color patterns. Sumatra is a global center for *Nepenthes* diversity. This study analyzes the population structure and plant associations of *N. tobaica* in Ria-Ria Village Forest, Humbang Hasundutan. Using purposive sampling with 20×20m plots, 36 vegetation species were identified. The highest Importance Value Index (IVI) was recorded for *Laplacean sp.* (91.23) at location 1, *Macadamia integrifolia* (151.03) at location 2, and *Pinus merkusii* (13099.68) at location 3. Positive associations were found between *N. tobaica* and *Laplacean sp.* (1.34) at location 1, *Pteridium aquilinum* (0.78) at location 2, and *Pinus merkusii* (96.33) at location 3. Zone 1 had the highest diversity, richness, and evenness indices, indicating favorable environmental conditions. These findings highlight key species influencing *N. tobaica* habitat suitability. Understanding these associations aids in habitat management and restoration, where indicator species can be used for conservation planning. The integration of mathematical models in this study provides a quantitative foundation for ecosystem assessments and future conservation strategies for *N. tobaica*.

1. INTRODUCTION

Indonesia is one of the world's richest biodiversity hotspots, with at least 47 distinct natural ecosystems teeming with plant and animal life, including numerous endemic species [1, 2]. Among these, *Nepenthes*, a genus of carnivorous plants, is particularly notable. Indonesia harbors approximately 15.5% of the world's flora, and its archipelago, especially Kalimantan and Sumatra, represents the global center of *Nepenthes* diversity [3, 4].

Nepenthes tobaica, an endemic species in Sumatra, is adapted to various ecological niches, often found in nutrient-poor environments where it relies on carnivory for nutrient acquisition [5, 6]. Despite its ecological significance, *nepenthes tobaica* faces increasing threats due to habitat fragmentation, land-use change, and environmental degradation, which have led to population declines [7]. Conservation efforts for this species are hindered by limited quantitative studies on its ecological interactions and habitat preferences, particularly in terms of its associations with other plant species and how these relationships influence its distribution and survival [8, 9].

While previous studies have primarily focused on the taxonomy, morphology, and habitat characteristics of *Nepenthes*, there is a lack of research that quantitatively analyzes the ecological relationships of *nepenthes tobaica* within its plant community. Understanding these associations is crucial for conservation strategies, as plant species interactions can influence habitat stability, species resilience, and potential reintroduction efforts. This study advances the understanding of *nepenthes tobaica* ecology by integrating mathematical models and ecological indices to quantify species associations and distribution patterns. The application of quantitative methods in studying *Nepenthes* ecology remains underexplored, making this approach novel in several ways. Unlike traditional qualitative descriptions, this study employs mathematical models to measure species diversity, distribution, and association. The use of the Ochiai index allows for precise determination of association strength between *nepenthes tobaica* and coexisting species. By identifying key species interactions and environmental conditions supporting *nepenthes tobaica*, this study provides actionable data for habitat conservation and management [10, 11].

To address these gaps, this study aims to analyze the population structure of *nepenthes tobaica* in the Ria-Ria Village Forest, Pollung District, Humbang Hasundutan Regency and quantify its ecological associations with other plant species using mathematical models and ecological indices. The study employs a robust quantitative framework, incorporating vegetation analysis metrics such as density, relative density, frequency, relative frequency, dominance, and the Importance Value Index (IVI) [12, 13]. The Ochiai index is used to measure species co-occurrence, while several diversity indices, including the Shannon-Wiener diversity index (H'), Margalef's species richness index, species evenness index, and Morisita's index, are applied to assess species diversity and spatial distribution. Additionally, the Basal Field Area (BFA) formula is used to quantify tree stem coverage.

By integrating these mathematical models, this research establishes a reproducible, quantitative foundation for ecological studies on *nepenthes tobaica*. The findings will not only enhance conservation strategies but also serve as a reference for future ecological research on *Nepenthes* and other carnivorous plant species.

2. RESEARCH METHODOLOGY

This research was conducted in Ria-Ria Village Forest, Pollung District, Humbang Hasundutan Regency. The method used to determine habitat conditions and their associations uses a purposive sampling method by making plots measuring 20×20 meters. Tree level vegetation in measuring plots 20×20m, pole level in measuring plots 10×10m, sapling level in measuring plots 5×5m, seedling level and lower plants are counted in measuring plots 2×2m. The nested plot shown in Figure 1 was designed to analyze the vegetation present in the study area.

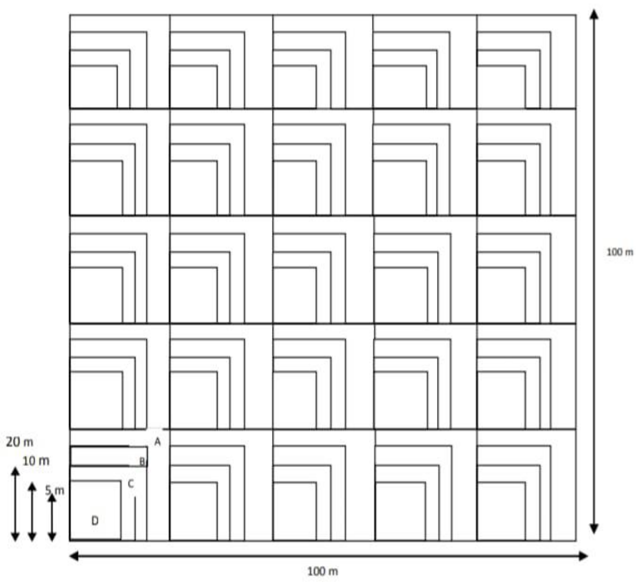

Figure 1. Shape of nested plot

Data Analysis

a. Density (K)

$$\text{Density}=\frac{\text{the number of individuals of a species}}{\text{Area of sample unit}}$$

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

b. Frequency

$$\text{Frequency}=\frac{\text{Number of Plots Found of a Species}}{\text{Total Number of Plot}}$$

$$\text{Relative Frequency (RF)}=\frac{\text{Frequency of a Type}}{\text{Total Frequency}}\times 100\%$$

c. Dominance

$$\text{Domination}=\frac{\text{Base Field Area of a Species}}{\text{Area of sample unit}}$$

$$\text{Relative Domination (RDO)}=\frac{\text{Dominance of a Species}}{\text{Dominance of the entire plot}}\times 100\%$$

d. Base Field Area (BFA)

$$\text{BFA}=\frac{\pi * R^2}{\Sigma\, all\ sample\ sub-plots}$$

where, *R* is the radius of the circle of the stem diameter; *D* is DBH. The BFA obtained is then converted m^2.

e. Importance Value Index (IVI)

For both pole and tree level: $IVI = RD + RF + RDO$

For seedling and sapling levels: $IVI = RD + RF$

Vegetation in non-*nepenthes* and *nepenthes* plots can be calculated using the Similarity Index [14].

$$\frac{2C}{A+B}$$

f. Shannon-Wiener Diversity

$$H' = \sum_{I=1}^{N}\left[\frac{Ni}{N}\ In\ \frac{Ni}{N}\right]$$

H'=Σpi in pi

$Pi=\frac{Ni}{N}$

where,

H'=Shannon-Wiener diversity

Ni=number of individuals of the n^{th} species

N=total number of individuals

The value of H 'is as follows:

H'<1=low level of species diversity

*H'*1-3=moderate level of species diversity

H'>3=high level of species diversity [15, 16]

Vegetation species richness was determined by using the richness index [14].

$$R=\frac{S-1}{In\,(N)}$$

where,

R=Index of species richness

S=Number of species

N=Total number of individuals

g. Evenness Index (Ludwig-Reynold)

$$E = \frac{H'}{In\ (S)}$$

where,
E=Index of species evenness
H'=Index of species diversity
S=number of species

h. Index of Morisita

Analysis of *nepenthes* distribution patterns using the standardized Morisita index [17].

The index is calculated with the equation:

$$I_D = \left[\frac{\sum X^2 - \sum X}{(\sum)x^2 - \sum X}\right]$$

where,
I_D=Morisita's dispersion index
N=The number of plots
X=The number of individuals found on each plot

The analysis of *N. tobaica*'s spatial distribution using the Morisita index provides insights into the species' ecology. Understanding these patterns is crucial for predicting the species' response to environmental changes and for designing effective conservation strategies.

i. Association

Association determined using Ochiai index [14].

(a) Ochiai Index (OI)= $\frac{A}{\sqrt{A=b}\ \sqrt{A+c}}$

where,
A=Number of plots where both associated species (A and B) were found
B=Number of plots where type A but not type B was found
C=Number of plots where type B was found but not type A

The association value occurs in the interval 0 to 1. The closeness of association relationship from the association index interval is shown in Table 1.

Table 1. Association on vegetation (association index)

No.	Association Index	Remark
1	1.00-0.75	Very High (ST)
2	0.74-0.49	High (T)
3	0.48-0.23	Low (R)
4	≤0.23	Very Low (SR)

3. RESULT AND DISCUSSION

Identification of Plant Species in the Habitat of Toba Semar Bag (*Nepenthes Tobaica*) in Ria-Ria Village

Based on the results of the research that has been carried out, 21 species of lower plant level vegetation were found in location 1, 13 species in location 2 and 8 species of lower plant level vegetation in location 3 around the habitat of the toba semar bag (*nepenthes tobaica*) in Ria-Ria Village, Pollung District, Humbang Hasundutan Regency. The growth of these vegetation in the village in all three locations is very good and is still very much found, indicating that the environment at the research site still supports the sustainability of the species. However, for this level of growth, eradication or burning is often carried out because the local community is dominant in their livelihoods as farmers. The lower plant level vegetation found in the three research locations in detail can be seen in Table 2.

Table 2. Undergrowth plant community around *nepenthes tobaica* in Ria-Ria Village, Pollung District, Humbang Hasundutan Regency

Local Name	Latin Name	Family	Loc-1	Loc-2	Loc-3
Andaliman	*Zanthoxylum acanthopodium*	Rutaceae	-	+	-
Adulpak	*Homalanthus populneus*	Euphorbiaceae	+	-	-
Andor Andor	*Jasminum pubescens*	Oleaceae	+	+	-
Appapaga	*Centella asiatica*	Mackinlayaceae	+	-	-
Arsam	*Pteridium aquilinum*	Dennstaedtiaceaae	+	+	-
Attalobung	*Pennisetum purpereum*	Poaceae	+	-	-
Bunga Paet	*Eupatorium perfoliatum*	Asteraseae	+	-	-
Bunga Pansur	*Russelia equisetiformis*	Balsaminaceae	+	-	-
Hail Hail	*Elaeagnus trifloral* roxb	Elaeagnaceae	+	-	-
Hari Moting	*Clidemia hirta*	Melastomaceae	+	+	-
Haure	-	-	-	-	-
Holpu Holpu	*Arundina graminifolia*	Orchidaceae	+	+	-
Ilalang	*Imperata cylindrica*	Poaceae	+	+	+
Karamunting	*Rhodomyrtus tomentosa*	Myrtaceae	-	-	+
Keladi	*Caladium* sp.	Araceae	+	+	-
Markisa Siuh	*Passiflora edulis*	Passifloraceae	-	+	-
Pagit-Pagit			-	-	+
Pakis	*Diplazium esculentum*	Athyriaceae	+	+	-
Pakis Keras	*Struthiopteris spicant*	Blechnaceae	-	-	+
Pakis Bunga Danau	*Polypodiophyta* sp.	Polypodiaceae	-	-	+
Pengusir Tikus			-	-	+
Petiper			-	-	+
Podom Podom	*Mimosa pudica*	Fabaceae	+	-	-
Resam	*Dicranopteris* sp.	Gleicheniaceae	-	+	-
Ria Ria	*Carex sp.*	Poaceae	+	-	-
Rumput Manis	*Hierochloe odorata*	Poaceae	+	+	-

Sae Sae	*Gaultheria leucocarpa*	Ericaceae	+	+	-
Sijukkot	*Lactuca indica*	Asteraceae	-	+	-
Simarbadak Badak	*Platycerium Bifurcatum*	Polypodiaceae	+	-	-
Sanggar	*Themeda gigantea*	Poaceae	+	-	-
Sapilpil	*Cyperus rotundus*	Cyperaceae	+	-	-
Sanduduk	*Melastoma melabathricum*	Melastomataceae	+	-	+

Remark: Exists (+), None (-)

Table 3. Tree community around *nepenthes tobaica* in Ria-Ria Village, Pollung District, Humbang Hasundutan Regency

Local Name	Latin Name	Family	Loc-1	Loc-2	Loc-3
Alpukat	*Persea americana*	Lauraceae	-	+	-
Api api	*Laplacean sp.*	*Acanthaceae*	+	-	-
Bane	*Basillicum polystachyon*	Verbenaceae	+	-	-
Bintatar	*Celtis tetrandra*	Cannabaceae	+	-	-
Hapas	*Exbulandia populnea*	Malvaceae	+	-	-
Haumbang	*Morinda tinctoria roxb*	Rubiaceae	+	-	-
Ingus ingus	*Macaranga gigantea*	Euphorbiaceae	+	-	-
Kaliandra merah	*Calliandra calothyrsus*	Fabaceae	-	+	-
Mabar	-	-	+	-	-
Makadamia	*Macadamia integrifolia*	Proteaceae	-	+	-
Pinus	*Pinus merkusii*	Pinaceae	+	+	+
Simartolu	*Schima wallichii*	Theaceae	+	-	-
Suhul suhul	*Macaranga gigantea*	Euphorbiaceae	+	-	-

Remark: Exists (+), None (-)

Table 4. Environmental factors of the Toba Semar Pockets Habitat (*nepenthes tobaica*)

Sites	Location 1 Ria-Ria	Location 2 Ria-Ria	Location 3 Ria-Ria
Altitude (mdsl)	1468.8	1528.0	1443.6
Lux	197	188	
T (°C)	22.16	20.98	21.33
RH (%)	86.00	78.00	50.00
Soil texture	Clay	Clay	
Slope (%)	46.63	62.15	
Slope category	Extreme slopes	Extreme slopes	
Land use	Agroforestry	Agroforestry	Agroforestry

Note: T: Temperature, RH: Humidity

At the tree growth level, 10 tree species were found in Site 1, 4 tree species in Site 2, and 1 tree species in Site 3 that grew around the habitat of the toba semar bag (*nepenthes tobaica*) in Ria-Ria Village, Pollung District, Humbang Hasundutan Regency. These species grow well in the research location and coexist with the toba semar bag (*nepenthes tobaica*). The vegetation at the tree level found in detail can be seen in Table 3.

Vegetation found around *nepenthes tobaica* habitat, both at the understorey and tree level, plays an important role in supporting the survival of this species. Understory plants such as Arsam (Pteridium aquilinum) and Appapaga (Centella asiatica) can help maintain soil moisture in *nepenthes tobaica* habitats. This is important considering that the pouch plant needs a moist environment to grow optimally. On the other hand, trees such as Pinus (Pinus merkusii) and Simartolu (Schima wallichii) provide shade that protects the pouch semar from direct sunlight, while creating a microclimate that supports its growth [18-20].

Environmental factors are factors that greatly affect the growth of toba semar bags (*nepenthes tobaica*) in a habitat. In this study, toba semar pouches (*nepenthes tobaica*) were found in 3 locations with altitude variations between 1443.6 to 1528 meters above sea level. The temperature at the research site ranged from 20.98°C to 22.16°C with humidity ranging from 50% to 86%. Temperature and humidity conditions in this location are within the normal range of Nepenthes growth. Nainggolan et al. [6] stated that this plant can survive in air temperature and air humidity of 20-32°C and 67-93% respectively. Light intensity at the sites ranged from 188 to 197 lux, the soil type at the three sites had a clay texture, which could affect drainage. Nepenthes generally grows on nutrient-poor soils but with high moisture [16]. The extreme slope level (46.63-62.15%) indicates that this habitat is located in a steep area, which is in accordance with the ecological characteristics of Nepenthes in the wild, especially on cliffs and mountains. All sites were in agroforestry areas, which provided partial shading benefits while minimizing habitat disturbance. The environmental factors in which the toba antlered pouch (*nepenthes tobaica*) was found can be seen in detail in Table 4.

Vegetation Analysis and Association of *Nepenthes Tobaica* at Understory, Seedling, Sapling, Pole, and tree Levels

The results of vegetation analysis show that the vegetation composition at the research site consists of 36 species. The many types of species found at the research site indicate that the research site still has a balanced ecosystem, so it still has quite abundant diversity. The results of vegetation analysis and associations with the highest IVI value in the plant community around the habitat in Ria-Ria Village in detail can be seen in Table 5.

Table 5. IVI and association of *nepenthes tobaica* in plant communities surrounding habitat in Ria-Ria Village, Humbang Hasundutan Regency, North Sumatra, Indonesia

Scientific Name	Family	IVI	OI	Association Category	Association
Location-1 Undergrowth					
Pteridium aquilinum	Dennstaedtiaceaae	63.95	0.96	S	+
Nepenthes tobaica	Nepenthaceae	18.93	0.21	NS	+
Gaultheria leucocarpa	Poaceae	15.25	0.51	NS	+
Themeda gigantea	Polypodiaceae	22.26	0.21	NS	+
Cyperus rotundus	Cyperaceae	43.9	0.86	NS	-
Location-2					
Nepenthes tobaica	Nepenthaceae	22	0.62	S	+
Dicranopteris sp.	Gleicheniaceae	74.65	0.61	NS	+
Imperata cylindrica	Poaceae	17.07	0.47	NS	+
Melastoma melabathricum	Melastomataceae	11.85	0	S	+
Pteridium aquilinum	Dennstaedtiaceaae	20.6	0.78	S	+
Location-3					
Nepenthes tobaica	Nepenthaceae	162.65			
Melastoma melabathricum	Melastomaceae	35.78	0.5	NS	+
Pagit-Pagit		17.89	0.35	NS	+
Imperata cylindrica	Poaceae	134.84	0.54	NS	+
Struthiopteris spicant	Blechnaceae	216.84	0.84	NS	+
Location-1 Seedling					
Avicennia germinans	Acanthaceae	58.23	0.67	NS	+
Basillicum polystachyon	Verbenaceae	20.42	0.43	NS	+
Macaranga gigantea	Euphorbiaceae	33.04	0.15	NS	-
-	-	18.5	0.15	NS	-
Saurauia blumeana Spreng	Gigantea blume	46.04	0.15	NS	-
Location-2					
Pinus merkusii	Pinaceae	98.1	0.29	NS	+
Macadamia integrifolia	Proteaceae	151.03	0.12	NS	-
Calliandra calothyrsus	Fabaceae	30.2	0	NS	-
Persea americana	Lauraceae	20.67	0	NS	+
Location-3					
Saurauia blumeana Spreng	Actinidiaceae	128.28	0.35	NS	+
Schima wallichii	Theaceae	36.67	0.46	NS	+
Silum		49.6	0.62	NS	-
Location-1 Stakes					
Avicennia germinans	Acanthaceae	61.24	0.75	NS	-
Celtis tetrandra	Cannabaceae	20.69	0.38	NS	-
Morinda tinctoria roxb	Rubiaceae	22.01	0.43	NS	+
Syzygium myrtifolium	Myrtaceae	19.69	0.37	NS	+
Leptospermum javanicum	Myrtaceae	19.63	0.53	NS	-
Location-2					
Macadamia integrifolia	Proteaceae	37.57	0.08	NS	-
Homalanthus populneus	Euphorbiaceae	8.47	0	NS	+
-	-	14.02	0.08	NS	+
Leptospermum javanicum	Myrtaceae	103.17	0.82	NS	+
Neonauclea calycina.	Rubiaceae	15.08	0	NS	+
Location-3					
Antiapi		15.08	0.29	NS	+
Erythrina variegata	Fabaceae	14.02	0.2	NS	+
Obat Gula		60.32	0.2	NS	+
Helicteres hirsute	Malvaceae	15.08	0.29	NS	+
Pinus merkusii	Pinaceae	65.61	0.71	NS	-
Location-1 Pole					
Laplacean sp.	Acanthaceae	84.04	0.84	NS	-
Morinda tinctoria Roxb	Rubiaceae	32.04	0.48	NS	+
-	-	25.72	0.3	NS	+
Pinus merkusii	Pinaceae	29.53	0.52	NS	+
Quersus salicina	Fagaceae	28.45	0.48	NS	+
Location-2					
Macadamia integrifolia	Probaceae	52.96	0.16	NS	-
Pinus merkusii	Pinaceae	27.67	0.5	NS	+
-	-	28.85	0.2	NS	+
Calliandra calothyrsus	Fabaceae	28.22	0	NS	+
Coffea canephora pierre	Rubiaceae	109.79	0	NS	+
Location-3					
Pinus merkusii		13099.68	0.58	NS	+
Location-1 Tree					
Laplacean sp.	Acanthaceae	91.23	1.34	S	+

Exbulandia populnea	Malvaceae	17.54	0.5	S	+
-	-	21.05	0.35	NS	+
Pinus merkusii	Pinaceae	14.04	1.04	S	+
Schima wallichii	Theaceae	17.54	0.8	S	+
Location-2					
Pinus merkusii	Pinaceae	98.1	0.29	NS	+
Macadamia integrifolia	Proteaceae	151.03	0.12	NS	-
Calliandra calothyrsus	Fabaceae	30.2	0	NS	-
Persea americana	Lauraceae	20.67	0	NS	+
Location-3					
Pinus merkusii	Pinaceae	96.33	0.58	NS	+

Note: S: Significant, NS: Not Significant

Table 5 presents the IVI and Association of *nepenthes tobaica* in Plant Communities Surrounding Habitat in Ria-Ria Village, Humbang Hasundutan Regency, North Sumatra, Indonesia. The table is divided into multiple locations and vegetation types (undergrowth, pole, and tree).

Nepenthes tobaica, the focus species, is present in all three locations within the undergrowth category, with its Importance Index varying across locations and being highest in Location-3. While most species exhibit a positive association with *N. tobaica*, the majority of these relationships are not statistically significant. However, there are a few significant associations, both positive and negative. The dominant species differ among locations, with Pteridium aquilinum, Dicranopteris sp., and Struthiopteris spicant having the highest IVI in Location-1, Location-2, and Location-3 undergrowth, respectively. The comprehensive data provided in the table includes vegetation layers (undergrowth, pole, and tree), showcasing the rich plant community structure and biodiversity in the study area, with the varying associations and importance indices suggesting a complex ecological relationship between *N. tobaica* and other plant species within its habitat.

A Pareto diagram at Figure 2, visually represents the IVI and association of *nepenthes tobaica* with other plant species. The bars represent IVI values for different species in descending order, while the line shows the cumulative percentage of IVI values. This helps identify the most important species and demonstrates the potential application of the Pareto principle (80/20 rule).

Figure 3 displays the relationship between the Importance Value Index and the Ochiai Index for plant species associated with *nepenthes tobaica*. It shows how a species' ecological importance correlates with its association strength with *N. tobaica*, reveals species distribution patterns, identifies key species with high IVI and OI values, highlights unusual species (outliers), and may indicate groups of species with similar ecological roles. The range of IVI and OI values shown reflects the diversity of ecological importance and association strengths within the community.

Pareto diagram in Figure 4 showing the IVI and association of *nepenthes tobaica*. The diagram visually represents the relative importance and association of different factors related to *nepenthes tobaica*, a species of pitcher plant. These frequencies are compared across the three study locations and broken down by the plants' growth stages (understory, seedling, sapling, pole, and tree).

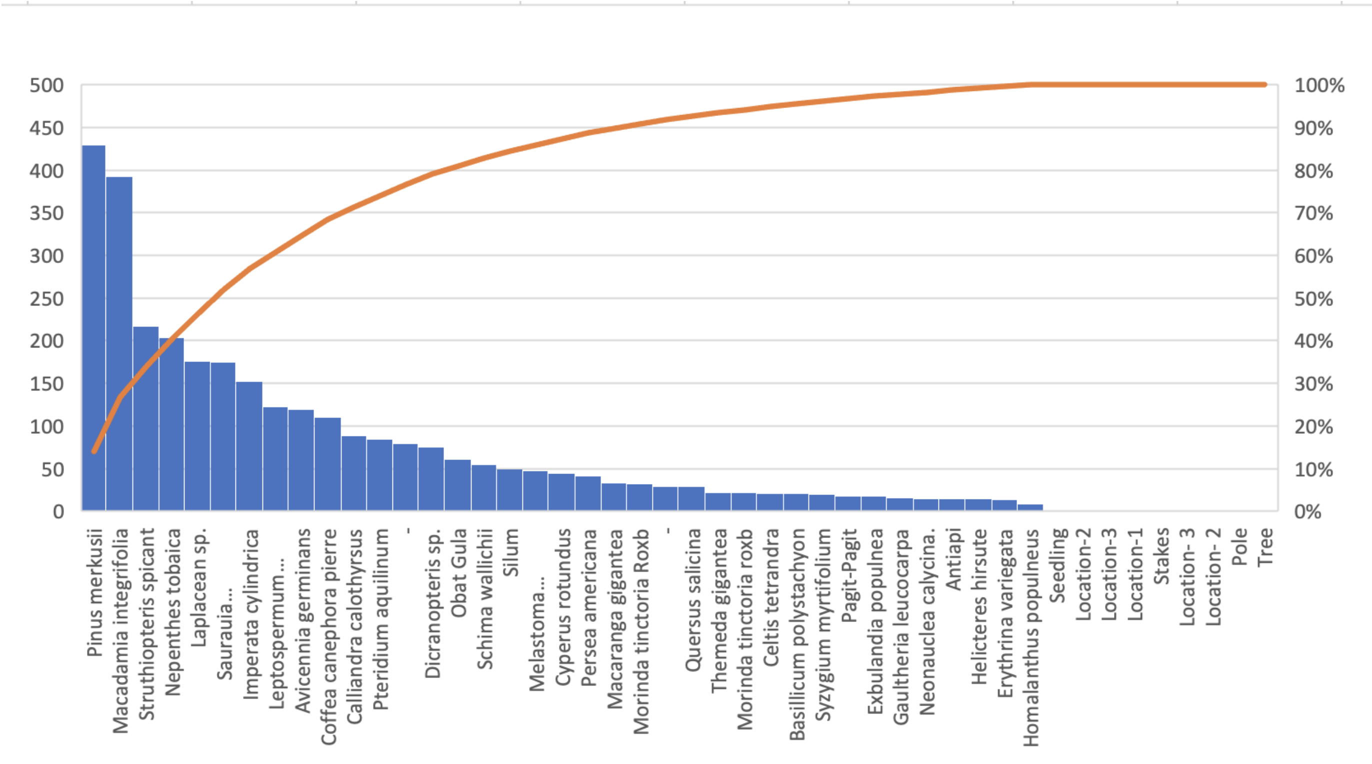

Figure 2. Pareto diagram of the IVI and association of *nepenthes tobaica*

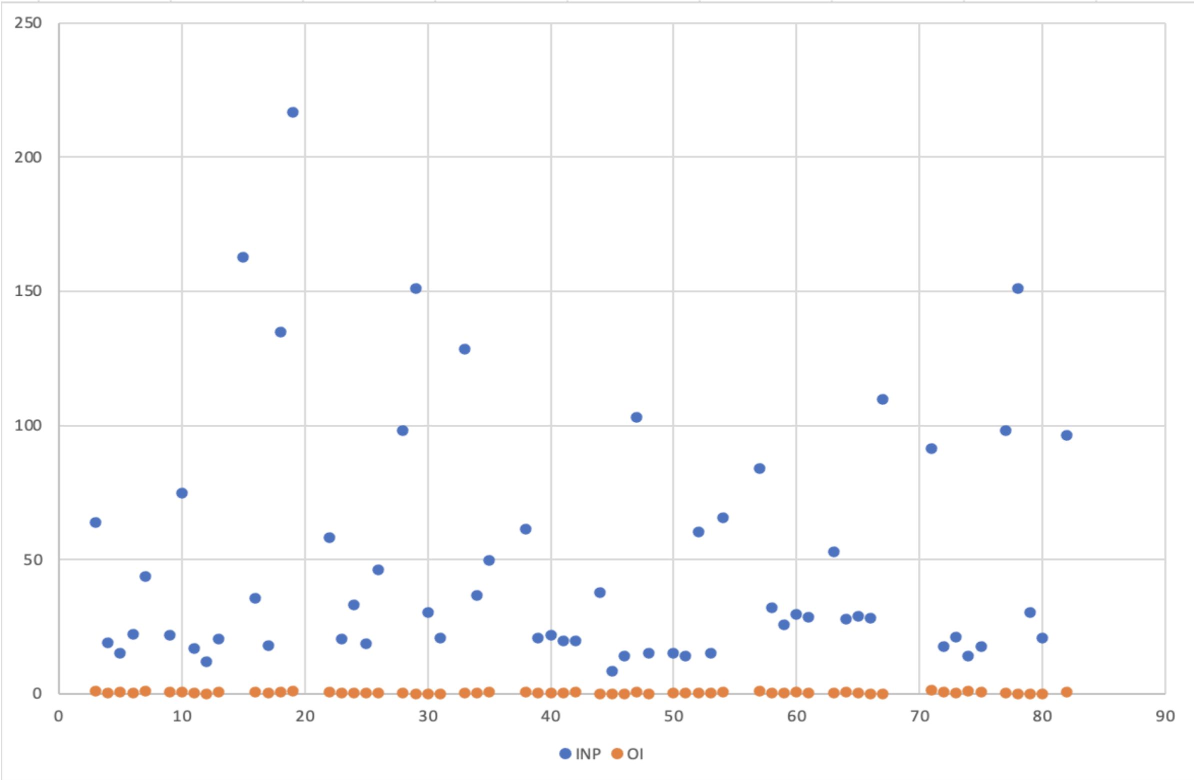

Figure 3. Scatter plot to visualize the relationship between IVI and OI values for different species

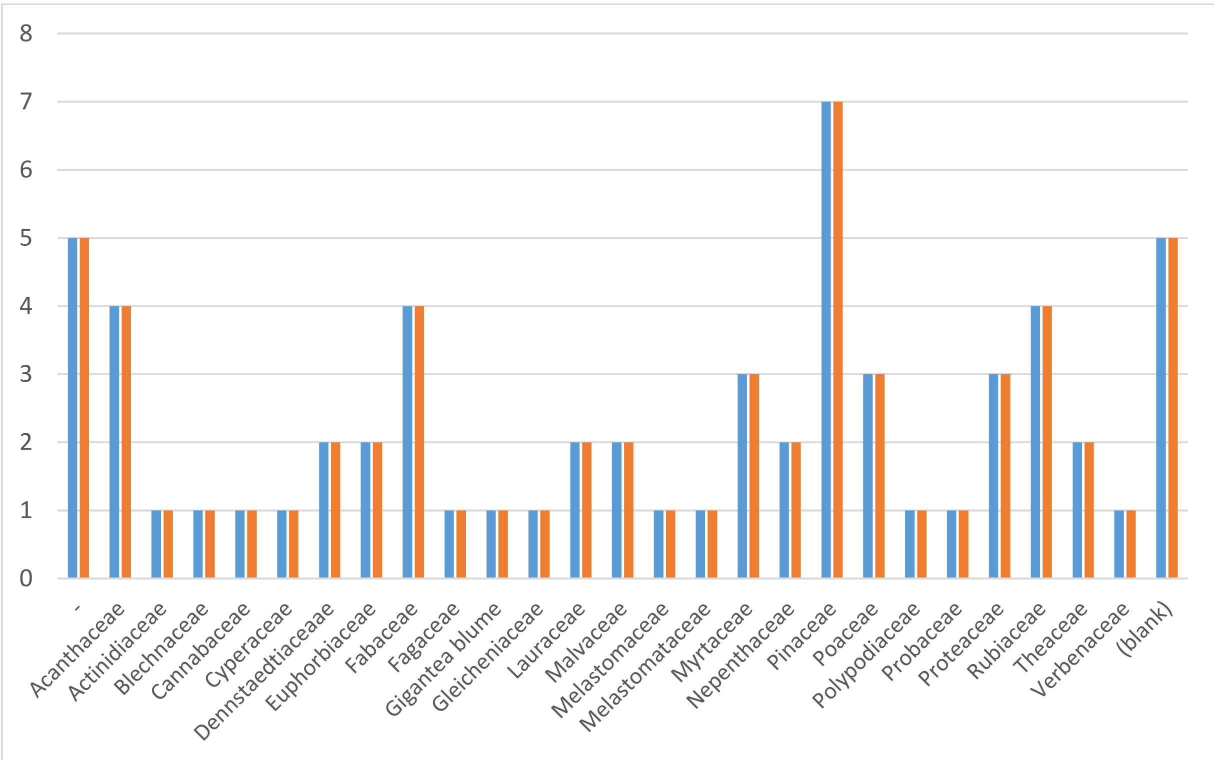

Figure 4. Diagram of count of association

Vegetation and Association Analysis of *N. Tobaica* at the Undergrowth Level

In the population at Site 1, 5 species of understory plants were found with the highest IVI values, namely Pteridium aquilinum (63.95), Cyperus rotundus (43.90), Themeda gigantea (22.26), *Nepenthes tobaica* (18.93), and Gaultheria leucocarpa (15.25). At the understory level, Pteridium aquilinum species from the Dennstaedtiaceae family had the highest association value with a value of 0.96, which was positive and real. The lowest association value was found in Cyperus rotundus species with an association value of 0.86, negative and not real.

The highest Index of Importance (IVI) in the understory population at Site 2 was found in Dicranopteris sp. (74.65), *Nepenthes tobaica* (22.00), Pteridium aquilinum (20.60), Imperata cylindrica (17.07) and Melastoma melabathricum

(11.85). Based on the calculation results, the highest association value was found in the Pteridium aquilinum species with a value of 0.78, which was positive and not real.

The highest IVI value in the population at Site 3 for the lower plant level was found in the species Struthiopteris spicant (216.84), *Nepenthes tobaica* (162.65), Imperata cylindrica (134.84), Melastoma melabathricum (35.78) and Pagit-pagit (17.89). At the lower plant level, species with the highest association value were found in Struthiopteris spicant with a value of 0.84, positive and not significant.

Vegetation and Association of *N. Tobaica* at Seedling Level

The highest IVI value at the seedling level in location 1 was found in Avicennia germinans (58.23), Saurauia blumeana Spreng (46.04), Macaranga gigantea (33.04), Basillicum polystachyon (20.42) and sp1 (18.50). Based on the calculation results, it was found that the species with the highest association value was Avicennia germinans with an association value of 0.67, positive and not real. The lowest association value was found in 3 species, one of which was Macaranga gigantea with a value of 0.15, was negative and not real.

The highest IVI value at the seedling level in the population at Site 2 was found in the species Macadamia integrifolia (151.03), Pinus merkusii (98.10), Calliandra calothyrsus (30.20) and Persea americana (20.67). At the seedling level, 2 species were found to be associated and 2 species were not associated with *N. tobaica*. The species with the highest association value was found in Pinus merkusii species with a value of 0.29, positive and not significant, while the species with the lowest value was found in Macadamia integrifolia species with a value of 0.12, negative and not significant.

The highest IVI value at the seedling level in the population at Site 3 was found in the species Saurauia blumeana Spreng (128.28), Silum (49.60) and Schima wallichii (36.67). At the seedling level population in location 3, the highest association value was found in Silum species with a value of 0.62, negative and not real. The lowest association value was found in Saurauia blumeana Spreng species with a value of 0.35, positive and not significant.

Vegetation and Association Analysis of *N. Tobaica* at Stake level

In the population at location 1, the highest IVI value at the sapling level was found in the species Avicennia germinans (61.24), Morinda tinctoria Roxb (22.01), Celtis tetrandra (20.69), Syzygium myrtifolium (19.69) and Leptospermum javanicum (19.63). Based on the calculation results, the highest association value was found in Avicennia germinans species with a value of 0.75, negative and not real. The lowest association value was found in Syzygium myrtifolium species with a value of 0.37, positive and not significant.

The highest IVI values at the sapling level in the population at Site 2 were found in the species Leptospermum javanicum (103.17), Macadamia integrifolia (37.57), Neonauclea calycina (15.08), sp2 (14.02) and Homalanthus populneus (8.47). In the sapling level population at Site 2, the highest association value was found in the species Leptospermum javanicum with a value of 0.82, positive and not significant. The lowest association value was found in 3 species, one of which was Macadamia integrifolia with a value of 0.08, negative and not significant.

The highest IVI value at the sapling level in the population at location 3 was found in Pinus merkusii species (65.61), sugar medicine (60.32), Helicteres hirsute (15.08), Antiapi (15.08) and Erythrina variegata (14.02). In the sapling level population at Site 3, the highest association value was found in Pinus merkusii species with a value of 0.71, which was negative and not significant.

Vegetation and Association Analysis of *N. Tobaica* at Pole level

In the population at location 1, the highest IVI value at the pole level was found in Laplacean sp. (84.04), Morinda tinctoria Roxb (32.04), Pinus merkusii (29.53), Quersus salicina (28.45) and sp3 (25.72). Based on the calculation of the highest association value found in Laplacean sp. with a value of 0.84, is negative and not real. The highest IVI value at the pole level in the population at location 2 was found in the species Coffea canephora pierre (109.79), Macadamia integrifolia (52.96), sp4 (28.85), Calliandra calothyrsus (28.22), and Pinus merkusii (27.67). At the pole level population in location 2, the highest association value was found in Pinus merkusii and Leptospermum javanicum species with a value of 0.50, positive and not significant. The lowest association value was found in Macadamia integrifolia species with a value of 0.16, negative and not significant.

In the population at location 3 at the pole level, 1 species was found, namely Pinus merkusii with an IVI value of 13099.68. At location 3 for the pole level, 1 species was found to be associated with *N. tobaica* with a value of 0.58, which is positive and not real.

Vegetation and Association Analysis of *N. Tobaica* at Tree Level

In the population at location 1, the highest IVI value at the tree level was found in Laplacean sp. (91.23), sp5 (21.05), Exbulandia populnea (17.54), Schima wallichii (17.54) and Pinus merkusii (14.04). Based on the calculation results, the highest association value was found in Laplacean sp. species with a value of 1.34, positive and real.

The highest IVI values at the tree level in the population at Site 2 were found in the species Macadamia integrifolia (151.03), Pinus merkusii (98.10), Calliandra calothyrsus (30.20) and Persea americana (20.67). In the tree-level population at Site 2, 2 species were found to be associated with *N. tobaica* and 2 species were not associated with *N. tobaica*. The highest association value was found in Pinus merkusii species with a value of 0.29, positive and not significant. The lowest association value was found in Macadamia integrifolia with a value of 0.12, negative and not significant.

In the population at location 3 at the tree level, 1 species was found, namely Pinus merkusii with an IVI value of 96.33. At location 3 for the tree level, 1 species was found to be associated with *N. tobaica* with a value of 0.58, which is positive and not significant.

Index of Diversity, Richness, Evenness of Species, and Morisita Index in Ria-Ria Village

Based on the calculation results, the values of the Diversity Index, Richness, Evenness of Species, and Morisita Index were found in the three research locations. The values obtained in the three locations are different, this shows that the three locations have different environmental conditions such as lighting, humidity, and soil structure that support the growth of diverse species. The values of Diversity Index, Richness, Evenness of Species, and Morisita Index in Ria-Ria Village in detail can be seen in Table 6.

Table 6. Values of diversity index, richness, evenness of species, and Morisita index in Ria-Ria Village

	Understory	Seedling	Stake	Pole	Tree
Location 1					
Total Type	22	7	10	10	10
H'	2	1.6	1.52	1.33	1.81
Category	Medium	Medium	Medium	Medium	Medium
Dmg	2.45	5.15	5.09	2.35	4.04
Category	Low	High	High	Low	Medium
J	2.56	1.95	0.3	0.58	0.2
Category	High	Sedang	Low	Low	Low
Morisita	0	0.23	0.37	0.42	0.2
Category	Random	Clump	Clump	Clump	Clump
Location 2					
Total Type	16	5	7	9	4
H'	1.66	1.03	1.34	1.73	1.15
Category	Medium	Medium	Medium	Medium	Medium
Dmg	2.38	1.25	1.76	2.24	1.19
Category	Low	Low	Low	Low	Low
J	0.61	0.74	0.75	0.83	1.04
Category	Low	Low	Low	Low	Medium
Morisita	0.33	0.45	0.36	0.25	2.49
Category	Clump	Clump	Clump	Clump	Clump
Location 3					
Total Type	9	3	6	1	1
H'	1.08	0.91	1.15	0	0
Category	Medium	Low	Medium	Low	Low
Dmg	1.5	0.72	1.58	0.35	0.43
Category	Low	Low	Low	Low	Low
J	0.52	1.31	0.72	0	0
Category	Low	Medium	Low	Low	Low
Morisita	6.88	11.53	11.32	25	25
Category	Clump	Clump	Clump	Clump	Clump

Note: H': Shannon's diversity index, Dmg: Margalef's species richness index, J: Evenness index

In the population of location 1, all growth stages have moderate diversity, namely understorey (2.00), seedling (1.60), sapling (1.52), pole (1.33), and tree (1.81) (Table 6). The species richness value in the Site 1 population at the understory (2.45) and pole (2.35) levels was low. At the tree level (4.04) is medium and at other levels, namely seedlings and saplings, is high. The species evenness index at the lower plant level (2.56) is high. At the seedling level (1.95) is categorized as low and at other levels, namely saplings, poles and trees are categorized as low. In the location 1 population, almost all growth levels have a clump growth pattern, namely at the seedling level (0.23), sapling (0.37), pole (0.42) and tree (0.20), only at the lower plant level (0.00) including random.

In the population of location 2, all growth stages have moderate diversity, namely understorey (1.66), seedling (1.03), sapling (1.34), pole (1.73), and tree (1.15). The value of species richness in the population of location 1 at all growth stages is in the low category. The species evenness index at almost all levels is in the low category, namely understory (0.61), seedling (0.74), sapling (0.75) and pole (0.83). At the tree level (1.04) is medium. Growth pattern of all growth stages including clumps.

In the population of location 3, the diversity value at the lower plant level (1.08) and saplings (1.15) is medium. The other levels were low, namely seedlings, poles and trees. Species richness at all growth stages is low. The species evenness index at almost all levels is low, namely at the lower plant level (0.52), saplings (0.72), poles (0.00) and trees (0.00). Growth pattern at all growth levels including clumps.

Based on Table 6, it can be concluded that location 1 has the highest H' value at the lower plant level (2.00) which indicates higher diversity than other locations. Similarly, species richness (Margalef Index) shows the highest species richness at Site 1, especially at the seedling level (5.15), while the lowest species richness is at Site 3 with a value of 1.19 at the tree level. This may be due to environmental pressure or human disturbance. Mansur et al. [20] stated that changes in land functions into agricultural land, settlements and other functions besides reducing the habitat area of a species can also affect changes in surrounding environmental factors so that many vegetation species are unable to survive. The highest species evenness index was also found at the lower plant level in location 1 (2.56), which indicates a more even distribution of species than other locations.

4. CONCLUSION

This study identified 36 species of vegetation across three research locations. The highest Importance Value Index (IVI) at location 1 was recorded at the pole level for *Laplacean sp.* (91.23), while in location 2, *Macadamia integrifolia* exhibited the highest IVI at both the seedling and tree levels (151.03). At location 3, *Pinus merkusii* had the highest IVI (13099.68). Positive and significant species associations were found in *Laplacean sp.* (1.34) at location 1 and *Pteridium aquilinum* (0.78) at location 2, whereas no significant positive associations were observed at location 3. The highest species diversity, richness, and evenness indices were recorded in zone 1, suggesting that the environmental conditions in this zone are more favorable for vegetation growth.

The findings align with previous studies highlighting the role of specific plant associations in shaping *Nepenthes* habitats. Prior research has demonstrated that *Nepenthes* species often thrive in nutrient-poor environments, where their interactions with surrounding vegetation can influence competition and resource availability. This study builds on those findings by providing a quantitative framework for assessing such associations. The absence of significant associations at location 3 suggests that habitat degradation may disrupt ecological networks, reinforcing previous conclusions that land-use changes can negatively impact *Nepenthes* populations. Future research should further examine how habitat disturbances alter plant community dynamics and whether certain species serve as indicators of habitat quality.

The study underscores the importance of sustainable land-use practices for *N. tobaica* conservation. The identification of key associated species provides valuable insight for habitat restoration efforts. Specifically, conservation strategies should prioritize the preservation of *Laplacean sp.* and *Pteridium aquilinum*, as their strong associations with *N. tobaica* suggest that they may contribute to habitat stability. Additionally, maintaining high species diversity, as observed in zone 1, could support ecosystem resilience and ensure favorable growth conditions for *N. tobaica*. Given the increasing threats from habitat modification, conservation policies should integrate ecological data into land management plans, emphasizing the protection of vegetation structures that sustain *Nepenthes* populations.

Beyond *N. tobaica*, this study demonstrates the broader applicability of mathematical models in conservation research. By integrating ecological indices with quantitative analysis, the approach offers a replicable method for assessing plant associations, species interactions, and habitat quality. Future research should expand this framework to other *Nepenthes* species and examine long-term ecological trends, particularly in response to climate change and anthropogenic pressures. Investigating how environmental variables such as soil composition and hydrology influence species associations would further enhance conservation strategies.

Overall, this research provides essential ecological insights into *N. tobaica*, offering a robust foundation for habitat management and conservation planning. The use of mathematical models to quantify ecological relationships enhances our ability to predict species distributions and assess habitat quality, ultimately informing more effective conservation strategies for *N. tobaica* and other vulnerable plant species.

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