ECOLOGICAL STUDIES ON THE *Nepenthes* SPECIES ALONG KAINGARAN TRAIL OF MOUNT TRUS MADI, SABAH, MALAYSIA

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ABSTRACT

This study aimed to provide an insight into the current status of the *Nepenthes* community on Mount Trus Madi and the implications to their conservation. Ten 0.01 ha *Nepenthes* plots were established along the Kaingaran summit trail. A total of five *Nepenthes* taxa were identified, namely the *Nepenthes tentaculata, N. zakriana, N. macrophylla, N. lowii* and natural hybrid *N. x trusmadiensis.* The most abundant species was *N. tentaculata* with number of individuals was more than 75% from the total number of individuals of all species. In contrast, the other four taxa have a smaller distribution and less abundant along the Kaingaran trail. All species have significantly aggregated population dispersion pattern indicating that they grow in grouped and tend to survive best in particular favourable patches. Population structure of *N. tentaculata* showed higher number of seedlings compared to juveniles and mature individuals, indicating that its population is healthy, stable and growing. Meanwhile, the N. *lowii, N macrophylla* and *N.* x *trusmadiensis* showed lower number of seedlings and juveniles that may suggesting the inability of their seeds to germinate or the seedlings and saplings to survive and grow, that may lead to uncertain regeneration. By using Generalized Estimating Equation (GEE) approach, it was found that there was a significant reduction of the abundance of *N. macrophylla* between year 2016 and 2017, suggesting it was potentially at risk of population declined. Trail impact assessment was conducted using the Generalized Linear Models (GLM) to assess the effects of the trail on the abundance and mortality of the *Nepenthes* plants at different distances from the trail. The abundances of *Nepenthes* were significantly higher along the trail than further away while their mortalities were significantly highest at the zones that furthest from the trail. Their seedling individuals that were located at furthest from the trail, were also more likely to die compared to their seedlings adjacent to the trail. Evidently, the *Nepenthes* plants in this study were preferred to grow and survived the best along the trail, where the forest gap was wider, light intensity was higher and less competition with other plants, compared to the area furthest from the trail. Correlation analysis Spearman rank correlation coefficients was used to identify the relationship between the density of *Nepenthes* and the changes in stand structures and other factors along the elevation profile. The density of *N. lowii* was significantly correlated to the vegetation type and mean tree height where they were only grow well on summit scrub vegetation which have shorter trees. Meanwhile, the density of *N. macrophylla* was significantly correlated with the total tree basal area and altitude where they were restricted to elevation above 2,500 m and was more abundant on vegetation with lower tree basal areas. These indicate that both *N. lowii* and *N. macrophylla* species displayed a very narrow habitat specificity compare to the other *Nepenthes* species. The data and findings from this study are valuable as baseline data for future study comparison and thereafter will enable further effective conservation management and monitoring plans on *Nepenthes* community in Mount Trus Madi.

ABSTRAK

KAJIAN EKOLOGIKAL SPESIES* NEPENTHES *DI SEPANJANG DENAI KAINGARAN DI GUNUNG TRUS MADI, SABAH, MALAYSIA

Kajian ini bermatlamat untuk menyediakan maklumat status semasa bagi komuniti Nepenthes *di Gunung Trus Madi dan implikasi terhadap pemuliharaannya. Sebanyak sepuluh 0.01 hektar plot* Nepenthes *telah ditubuhkan di sepanjang denai puncak Kaingaran. Sejumlah lima taksa* Nepenthes *telah dikenalpasti, iaitu* Nepenthes tentaculata, N. zakriana, N. macrophylla, N. lowii *dan hibrid semulajadi* N. x trusmadiensis*. Spesies yang terbanyak ialah* N. tentaculata *dengan bilangan individunya melebihi 75% daripada jumlah keseluruhan bilangan individu bagi semua spesies. Sebaliknya, empat taksa yang lain mempunyai taburan yang lebih kecil dan bilangan individu yang lebih rendah di sepanjang denai Kaingaran. Semua spesies mempunyai pola penyebaran populasi secara berkelompok yang signifikan yang menunjukkan bahawa tumbuhan ini tumbuh secara berkelompok dan cenderung untuk hidup dengan lebih baik di tompokon sesuai yang tertentu. Struktur populasi bagi* N. tentaculata *menunjukkan bilangan anak benihnya adalah lebih banyak berbanding bilangan juvenil dan individu matangnya, yang menandakan bahawa populasi bagi spesies ini adalah sihat, stabil dan bertambah. Sementara itu, spesies* N. lowii, N macrophylla *dan* N. x trusmadiensis *menunjukkan bilangan anak benih dan juvenil yang lebih rendah menandakan ketidakmampuan biji benihnya untuk bercambah atau anak benih dan juvenilnya untuk hidup dan tumbuh, yang mungkin boleh mendorong kepada regenerasi yang tidak pasti. Dengan menggunakan pendekatan Generalized Estimating Equation (GEE), didapati bahawa terdapat pengurangan yang signifikan bagi bilangan individu* N. macrophylla *di antara tahun 2016 dan 2017, menandakan spesies ini berpotensi menghadapi risiko populasi yang merosot. Taksiran kesan denai dibuat menggunakan Generalized Linear Models (GLM) untuk menaksirkan kesan denai terhadap bilangan individu dan kematian bagi tumbuhan* Nepenthes *pada beberapa jarak dari denai yang berbeza. Bilangan individu* Nepenthes *adalah lebih tinggi di sepanjang denai berbanding yang jauh dari denai manakala bilangan kematiannya adalah lebih tinggi pada zon yang paling jauh daripada denai. Anak benihnya yang berada paling jauh daripada denai juga adalah lebih berkemungkinan besar untuk mati berbanding dengan anak benihnya yang berada di sebelah denai. Terbukti bahawa tumbuhan* Nepenthes *di dalam kajian ini lebih sesuai untuk tumbuh dan hidup di sepanjang denai, di mana kawasan ini mempunyai bukaan hutan adalah lebih luas, keamatan cahaya yang lebih tinggi serta kurangnya saingan dengan tumbuhan lain, berbanding dengan kawasan yang berjarak lebih jauh dengan denai. Analisis koefisien korelasi Spearman digunakan untuk mengenalpasti hubungan di antara kepadatan* Nepenthes *dengan perubahan struktur dirian dan faktor lain di sepanjang profil ketinggian di denai ini. Kepadatan spesies* N. lowii *mempunyai korelasi yang signifikan dengan jenis vegetasi dan purata ketinggian pokok di mana spesies ini hanya sesuai untuk tumbuh di vegetasi puncak yang mempunyai pokok yang lebih rendah. Manakala, kepadatan spesies* N. macrophylla *mempunyai korelasi yang signifikan dengan jumlah keluasan dasar pokok dan altitud di mana spesies ini adalah terbatas pada aras ketinggian melebihi 2,500 m dan tumbuh lebih banyak di vegetasi yang mempunyai keluasan dasar pokok yang lebih rendah. Ini menunjukkan bahawa kedua-dua spesies* N. lowii *dan* N. macrophylla *mempunyai kekhususan habitat yang sangat terhad berbanding dengan spesies* Nepenthes *yang lain. Data dan keputusan dari kajian ini adalah sangat*

bernilai sebagai data asas untuk kajian di masa akan datang dan seterusnya membolehkan pengurusan pemuliharaan dan pelan pemantauan yang berkesan ke atas komuniti Nepenthes *di Gunung Trus Madi.*

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a.s.l.	-	above sea level
CAMP	-	Conservation Area Management Plan
CDB	-	Convention on Biological Diversity
CI	-	confidence interval
CITES	-	Convention on International Trade in Endangered Species
DBH	-	diameter at breast height
EIA	-	Environmental Impact Assessment
FMU10	-	Forest Management Unit No. 10
GEE	-	Generalized Estimating Equation
GLM	-	Generalized Linear Model
GPS	-	Global Positioning System
GSPC	-	Global Strategy for Plant Conservation
IBM	-	International Business Machines Corporation
IPBES	-	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	-	International Union for Conservation of Nature
MPCT	-	Management Planning Core Team
QIC	-	Quasi Likelihood under Independence Model Criterion
RPG	-	Resource Person Group
SAN	-	Sandakan Herbarium
SC	-	size class
SE	-	standard error
SPSS	-	Statistical Package for the Social Sciences

LIST OF SYMBOLS

%	-	percent
°	-	degree
°C	-	degree Celcius
=	-	equal to
<	-	less than
>	-	more than
≤	-	less than or equal to
≥	-	more than or equal to
π	-	pi = 3.14159
Σ	-	summation
sp.	-	unspecified species
ha	-	hectare
m	-	meter
km	-	kilometer
cm	-	centimeter
mm	-	millimeter
I_d	-	Morisita's Index of Dispersion
χ^2	-	Chi-square test
Exp(B)	-	exponential parameter estimates

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CHAPTER 1

INTRODUCTION

1.1 Background and Justification of the Research

Around one million threatened animal and plant species are facing an accelerating global rate of species extinction within the next decades that was caused by the human actions (IPBES, 2019). This global biodiversity loss issue has been addressed over many years and numerous initiatives have been implemented internationally and locally to tackle it. The Aichi Biodiversity Target 12 specifically aims to prevent the extinction of known threatened species and to improve their conservation status.

For the plant kingdom, the Global Strategy for Plant Conservation (GSPC), adopted by the Convention on Biological Diversity (CDB), provides a flexible framework consisting of 16 targets for plant conservation to be achieved by year 2020. Guided and encouraged by this framework, many countries have effectively developed their national responses and strengthened their plant conservation activities to contribute to the to the implementation of GSPC (Sharrock *et al.,* 2018). In Malaysia specifically, the Malaysia National Strategy for Plant Conservation has been developed to strategise the existing national conservation efforts in a more holistic manner (Ministry of Natural Resources and Environment & FRIM, 2009).

The tropical pitcher plant, or scientifically known as *Nepenthes*, is one of the most interesting plants, and it has gained worldwide popularity due to its bizarre, carnivorous, jug-shaped leaf extension. It has become one of the most sought-after plants in horticulture, which has led to the indiscriminate collection of this plant in the past, deteriorating its natural wild populations (Simpson, 1995; Phillipps *et al.,* 2008; Jennings & Rohr, 2011). Because of their unique carnivorous characteristics and high commercial value, over half of the carnivorous plant species around the

world, including *Nepenthes* genus, are listed as threatened by the International Union for the Conservation of Nature (IUCN) (Jennings & Rohr, 2011). Most of the highland *Nepenthes* species have narrow endemism and a very restricted extents of occurrence, where majority of the them are confined to a single mountain summit or highland range (Clarke, 1997; Gray *et al.,* 2017; Robinson *et al.,* 2019).

The second highest mountain in Malaysia, Mount Trus Madi, is the home to many rare and endemic flora including *Nepenthes*. Out of about 1,600 of plant taxa listed in this mountain, a total of 250 taxa (16%) are endemic to Borneo, including 68 taxa that are endemic to Sabah and four hyper-endemic taxa confined to the Trus Madi highlands (Sabah Forestry Department, 2013a). Although there is an increasing interest in hiking activities due to their upgraded facilities in the recent years, there is still very limited research on assessing how summit trails affect the biodiversity, including *Nepenthes*, on this mountain.

Knowledge of the current distribution and population dynamics of the threatened plants is essential in managing mitigation measures and implementing a monitoring programme in the Trusmadi Forest Reserves (Sabah Forestry Department, 2013a). However, the studies of the ecology, population sizes, distribution and regeneration dynamics for certain *Nepenthes* species is still grossly deficient, (Simpson, 1995; Clarke & Moran, 2011) including the *Nepenthes* community in Mount Trus Madi. Some studies have been done in the past years, but a comprehensive study of their current population sizes in the wild, especially of the rare and threatened species, is still lacking.

Therefore, a solid baseline data on the *Nepenthes* on Mount Trus Madi is needed to assess their current population sizes and condition. The data and findings from this study will be valuable as the baseline data for monitoring and managing this threatened plant. Future sampling data can be compared to this baseline data to detect changes and evaluate trends in its populations.

1.2 Objectives

This study aims to contribute to the knowledge gap at this reserve by providing an insight into the current status of the *Nepenthes* community on Mount Trus Madi and the implications for its conservation. This aim is achieved by fulfilling these objectives:

i. to provide the baseline data of the *Nepenthes* community on Mount Trus Madi by determining the species composition, population dispersion pattern and population structure of each *Nepenthes* species along the Kaingaran summit trail.

ii. to analyse the changes in *Nepenthes* abundance, including its mortality and possible linkages to the trail impact.

iii. to identify the correlation between the density of *Nepenthes* and the changes in stand structures along the elevation profile of Kaingaran summit trail of Mount Trus Madi.

CHAPTER 2

LITERATURE REVIEW

2.1 The *Nepenthes* Species

Nepenthes is a genus of tropical pitcher plants, belonging to the monotypic family Nepenthaceae. They are widely known for their carnivorous and unusual jug-shaped leaf extension to trap and digest fauna for nutritional benefit. These plants are dioecious and grows in the form of terrestrial or epiphytic climbers or shrubs (Cheek & Jebb, 2001).

Nepenthes is widely distributed in the Malesian region with higher diversity found in Borneo, the Philippines and Sumatra. Some outlying species also occurs in Madagascar, Seychelles, Sri Lanka, India, Indochina, Solomon Islands, New Caledonia and Australia (Cheek & Jebb, 2001). The number of *Nepenthes* species worldwide is continuously increasing, with 74 species about two decades ago (Jebb & Cheek, 1997) to currently about 150 species (Cheek *et al.,* 2018). Several new species, as well as new locality records, are being discovered almost every year. Out of this total, 39 species are found in Borneo and 22 species in Sabah. Six are endemic to Sabah, with four endemic to Mount Kinabalu (*N. burbidgeae, N. edwardsiana, N. rajah, N. villosa*), one endemic to Mount Trus Madi (*N. macrophylla*) and one obligate ultramafic species (*N. macrovulgaris*) (Lamb *et al.,* 2007).

Nepenthes is divided into two major groups based on the altitudes of their habitats. The lowland species are found below 1,000 m elevation, whereas highland species are found above 1,000 m a.s.l. (Clarke 2001). These plants grow in a variety types of habitats and tends to live in open stunted forest that is fairly sunny with nutrient-poor acid soils (Phillipps *et al.* 2008). Lowland species can be commonly found in disturbed secondary forests, peat swamp forests and heath forests (also

known as *kerangas* forests). Some *Nepenthes* are also present in limestone and ultramafic substrates. Most highland species are confined to montane vegetation, usually in open, mossy, stunted, ridge-top forests (Cheek & Jebb 2001).

2.2 Studies of *Nepenthes* in Malaysia and Sabah

Nepenthes has fascinated many plant enthusiast including scientific researchers due to their unique morphology and carnivorous mechanism. Several published studies on its taxonomy and ecology were done by some notable researchers in the past decades contributing to the knowledge of this extraordinary plant. *Nepenthes* taxonomy had been revised by several botanists including Hooker (1873), Macfarlane (1908), Danser (1928) and Jebb and Cheek (1997). The most recent major monograph of Nepenthaceae by Cheek and Jebb (2001) recognises 83 species from Malesia region.

Charles Clarke has been studying the ecology of pitcher plants in Southeast Asia for nearly three decades since 1989, primarily on the structure, assembly and dynamics of the communities of fauna with *Nepenthes* (Clarke, 2002b). Apart from his ecological studies, he also published five books on *Nepenthes* entitled the *Nepenthes* of Borneo (Clarke, 1997), *Nepenthes* of Sumatra and Peninsular Malaysia (Clarke, 2001b), A Guide to the Pitcher Plants of Sabah (Clarke, 2001a), A Guide to the Pitcher Plants of Peninsular Malaysia (Clarke, 2002a) and A Pocket Guide: Pitcher Plants of Sarawak (Clarke & Lee, 2004). These pictorial and informative books have complement the taxonomic revision of *Nepenthes*, broaden the discussion of its ecological context and hence, become a collection of excellent references, not only for plant scientist but also interested laymen.

Another prominent book on *Nepenthes* entitled Pitcher Plants of Borneo by Phillipps and Lamb which was first published in 1996. The updated and expanded second edition of the book was later published in 2008 (Phillipps *et al.,* 2008). Lamb *et al.* (2007) also discussed the distribution and conservation of *Nepenthes* species in Sabah during the Sarawak *Nepenthes* Summit conference held at Kuching, Sarawak. This paper highlighted the distribution of 22 *Nepenthes* species in Sabah, which out of this, six are endemic to the state and four endemic to Mount Kinabalu (Lamb *et al.,* 2007).

Nepenthes plot-based studies were mostly done by Jumaat Adam who had established several ecological *Nepenthes* plots throughout Malaysia. Some of these plots were located at Mount Kinabalu, Sabah (Adam, 2002a); Weston Sipitang, Sabah (Adam, 2002b); Bangi, Selangor (Adam *et al.,* 2004) and Rantau Abang, Terengganu (Adam *et al.,* 2011). The objectives of these studies were mostly similar which were to identify the *Nepenthes* species composition, population structure and population dispersion pattern. The results from these studies are summarised in Table 2.1 below. The methods and plot design that they have used in these studies were able to capture the overall population condition and their findings may be considered as the baseline data of a *Nepenthes* community in their study areas.

Table 2.1: Summary of the findings from Adam's plot-based studies.

Study area	Species (abundance)	Population dispersion pattern	Population structure
Mount Kinabalu, Sabah	*N. villosa (1180)* *N. kinabaluensis (75)*	All species are aggregated	Higher number of seedlings for both species
Weston Sipitang, Sabah	*N. albomarginata (52)* *N. rafflesiana (40)* *N. ampullaria (20)*	All species are aggregated	Varied.
Bangi, Selangor	*N. gracilis (147)* *N. mirabilis (15)*	All species are aggregated	Higher number of mature individuals for both species
Rantau Abang, Terengganu	*N. ampullaria (40)* *N. gracilis (490)* *N. rafflesiana (350)*	All species are aggregated	Varied.

2.3 Mount Trus Madi

Mount Trus Madi located within the protected area of Nuluhon Trusmadi Forest Reserve covering an area of 74,736 hectares. The reserve, also known as Trus Madi Conservation Area or Forest Management Unit No. 10 (FMU10) Tambunan, is classified as Class One Protection Forest under the management of the Sabah Forestry Department (Sabah Forestry Department, 2013b).

2.3.1 Vegetation

The reserve is generally covered with closed canopy forests except areas that have been logged and affected by frequent landslides (Sugau, 2011). The mountain is covered with three vegetation zones above 1,500 m elevation, which are lower montane forest, upper montane forest and summit scrub zones. The characteristics of each zone are summarised in Table 2.2 based on vegetation survey on Mount Trus Madi by Kitayama *et al.* (1993).

The lower montane forest covers an area of 41,970.98 ha and dominates mainly the northern part of the forest reserve (Figure 2.1). The upper montane forest occupying an area of 2,219.66 ha and the summit scrub zone occupies an area of 29.90 ha including the peak of Mount Trus Madi. The other vegetation types found in the forest reserve below 1,500 m a.s.l. are the upland mixed Dipterocarp forest (32,127.40 ha) and a small fragment of lowland mixed Dipterocarp forest (637.62 ha) (Sugau *et al.,* 2013).

Table 2.2: Vegetation zones of Mount Trus Madi.

Vegetation Zones	Lower montane forest	Upper montane forest	Summit scrub
Elevations	From 1,500 m to 1,850/ 2,000 m a.s.l.	From 1,850/ 2,000 m to 2,500 m a.s.l.	From 2,500 m to 2,642 m (peak)
Range of tree heights	30 m to 45 m	12 m to 17 m	Less than 5 m
Dominant species	Below 1,700 m: *Eugenia* and *Litsea* Above 1,700 m: *Dacrycarpus imbricatus, Phyllocladus hypophyllus,* a few *Eugenia* species and *Schima wallichii.*	*Tristania, Phyllocladus hypophyllus, Dacrydium beccarii* and the oaks (*Castanopsis, Lithocarpus* and *Quercus*).	*Leptospermum flavescens, Xanthomyrtus flavida* and *Tristania* species.

Source: Kitayama *et al.,* 1993