BIOTROPIA Vol. 30 No. 2, 2023: 220 - 231 DOI: 10.11598/btb.2023.30.2.1896

DIVERSITY, ECOLOGY AND CONSERVATION STATUS OF *NEPENTHES* IN WEST SUMATRA PROVINCE, INDONESIA

MUHAMMAD MANSUR[1,2*], ANDI SALAMAH[3*], EDI MIRMANTO[2] AND FRANCIS Q. BREARLEY[4]

[1]*Postgraduate Biology Study Program, Faculty of Mathematics and Natural Sciences, UniversitasIndonesia, Depok, West Java, 16404, Indonesia.*
[2]*Research Center for Ecology and Ethnobiology, Indonesian National Research and Innovation Agency (BRIN), Jalan Raya Jakarta-Bogor, Km 46, Cibinong Science Center, Cibinong, West Java, 16911, Indonesia.*
[3]*Cellular and Molecular Mechanisms in Biological System (CEMBIOS) Research Group, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, West Java, 16404, Indonesia.*
[4]*Department of Natural Science, Manchester Metropolitan University, Chester Street, Manchester, M1 5GD, UK*

Received 14 February 2023 / Revised 11 April 2023 /Accepted 12 April 2023

ABSTRACT

Nepenthes is the largest carnivorous plant genus present in Indonesia. There are 39 species of *Nepenthes* pitcher plants recorded in Sumatra from lowland to montane forests, and 34 of them are endemic; this represents the greatest species diversity of *Nepenthes* after Borneo. Field studies were conducted in 2021 and 2022 to increase our knowledge of the diversity, habitats and distributions of *Nepenthes* in West Sumatra province. Twenty-three species of *Nepenthes* were recorded from the province, consisting of 15 highland species, 4 mid-elevation species and 4 lowland species. Ecophysiological studies conducted at Bukit Malalak showed clumped distributions of *N. bongso*, *N. dubia*, *N. eustachya* and *N. rhombicaulis*. Foliar and pitcher fluid nutrient concentrations were found to be similar to those cited in other recent studies although growth rates were slightly more rapid than at Gunung Talang. Bukit Malalak is a new locality for two threatened species, namely *N. dubia* (CR) and *N. rhombicaulis* (VU), enlarging their extents of occurrence. In total, nine species from West Sumatra are threatened and conservation actions are urgently needed for these and other *Nepenthes* species remaining on the island.

Keywords: associations, carnivorous plants, diversity, ecology, foliar nutrients, Indonesian *Nepenthes*, montane forest, Red List, West Sumatra

INTRODUCTION

Nepenthes is the only genus in the Nepenthaceae family (Phillipps & Lamb 1996; Clarke 2001). *Nepenthes* are climbing lianas that produce characteristic fluid-filled pitchers extending from tendrils at the end of leaf-like phyllodes. The pitchers have a range of adaptations to attract, catch, retain and digest mostly insect prey (Moran & Clarke 2010).

The Indonesian archipelago, with a land area of 1,919,440 km^2, is in the centre of the distribution of *Nepenthes* (which extends from Madagascar to New Caledonia). In 2021, 80 species, or approximately 44 % of all *Nepenthes* (181), were recorded from Indonesia (Mansur *et al.* 2021), with diversity concentrated in Borneo and Sumatra. Over the past few decades, many new species have been described, particularly in Indonesia, Malaysia and the Philippines. In the last three years alone, three new species have been described in Sumatra: *N. putaiguneung* Al Farishy, Metusala & Jebb in Kerinci Seblat National Park (Metusala *et al.* 2020), *N. longiptera* Victoriano in Aceh (Victoriano 2021) and *N. harauensis* Hernawati, R. Satria & Chi.C.Lee in West Sumatra (Hernawati *et al.* 2022b). There are now 39 *Nepenthes* species recorded in Sumatra (Hernawati *et al.* 2022a). Mansur *et al.* (2022a) recently documented the 22 species found in the province of North Sumatra, but information from other provinces remains poor. This is particularly true of the provinces through which the Barisan Mountains run, as these are likely to harbour the highest diversity of

*Corresponding author, email: mansurhalik@yahoo.com/ salamah@sci.ui.ac.id

Nepenthes due to their topographic variation (Nerz 2005). Furthermore, there are few ecophysiological studies of *Nepenthes* species endemic to Sumatra, in contrast to those in Borneo (but see Pavlovič *et al.* 2009, 2010; Moran *et al.* 2012; Mansur *et al.* 2022b).

West Sumatra has a diverse topography, ranging from lowlands (< 500 m asl) to mountains (> 2000 m asl), with a broad range of associated microclimates and geologies. These conditions allow this province to support a high diversity of *Nepenthes* species. The estimated forest cover in West Sumatra is 1,897,911 ha, of which 41.7% is protected forest, 15.8% is production forest and 42.5% is within nature reserves and nature conservation areas (Dinas Kehutanan Sumatra Barat 2018). The aim of this study was therefore to determine the species diversity, distribution, population, habitat and ecology of *Nepenthes* in West Sumatra province.

MATERIALS AND METHODS

Field studies were conducted in October 2021 and October 2022 (totalling four weeks) in Agam Regency (Bukit Malalak and Gunung Singgalang), Limapuluh Kota Regency (Air Putih Nature Reserve, Batu Karang-Harau, Kelok Sembilan and Palupuah), Solok Regency (Gunung Talang) and around the city of Padang (Figure 1). Exploration was conducted to inventory the species of *Nepenthes* in each study location. Further study of literature, along with examination of herbarium specimens at Herbarium Bogoriense-Cibinong, took place in May and June 2022 to add information about the species of *Nepenthes* in West Sumatra; Pasaman Regency was only studied through a review of literature and herbarium specimens.

We further focused on at Bukit Malalak (00°09 S; 100°23' E) where three plots of 0.09 ha each (10 m × 90 m) were established to determine the abundance of *Nepenthes* and the tree species growing in their habitat. Each species of *Nepenthes* in the nine subplots (10 × 10 m each) and their positions (x and y) were recorded. Trees (Ø ≥ 5 cm) in each subplot were identified and their trunk diameter, total height and positions (x and y) were measured. All data collected was processed and analysed according to the Mueller-Dombois & Ellenberg method (1974) to obtain values for basal area (BA), relative frequency (RF), relative density (RD), relative dominance (RDo), and importance value index (IVI).

A few individuals of each *Nepenthes* species were numbered with small aluminium tags, and the top leaf of each individual was punched with a small hole using a paper hole-punch. After 12 months, the plants still living were re-censused and the stem length and number of leaves of each individual were re-recorded.

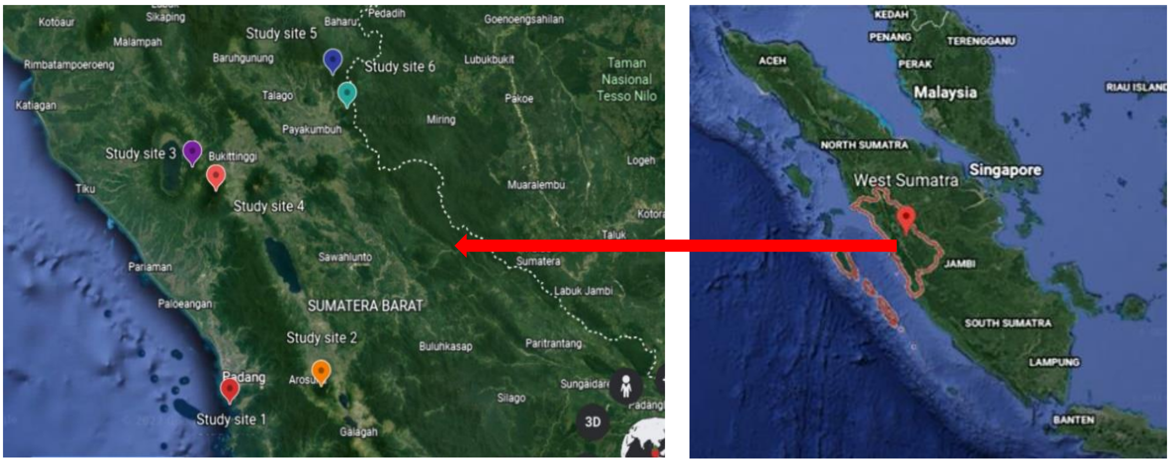

Figure 1 Map of six study sites in four regencies/cities in West Sumatra province (study site 1: around Padang city (00°60' S; 100°23' E); study site 2: Gunung Talang (00°59' S; 100°41' E); study site 3: Gunung Singgalang (00°24' S; 100°20' E); study site 4: Bukit Malalak (00°09' S; 100°23' E); study site 5: Kelok Sembilan (S: 00°04' S ; 100°42' E), Air Putih Nature Reserve and Palupuah (00°03' S; 100°41' E); study site 6: Batu Karang-Harau (00°03' S; 100°44' E).

Interspecific associations between plant species were calculated using a 2 × 2 contingency table (Ludwig & Reynolds 1988) on species that had an IVI > 10 % (Zulkarnaen *et al*. 2017). The calculated χ^2 value was then compared with the χ^2 table at the 5 % test level. If the value of χ^2 was greater than that in the χ^2 table at the 5 % test level, then there was an association between the two species, whereas if the value of χ^2 was less than that in the χ^2 table, then there was no association (Mueller-Dombois & Ellenberg 1974). The strength of the associations were then calculated using the Ochiai (1957) index with values ranging from 0 to 1, wherein the stronger the association between the two plant species, the closer the index value is to 1 (Ludwig & Reynolds 1988). Equations are presented in more detail in Mansur *et al*. (2022a). Finally, to determine the spatial distribution of each *Nepenthes* species (i.e. regular, random or clumped), Morisita's (1959) index of dispersion was calculated using a quadrat size of 10 m × 10 m.

Laboratory Procedures

Analysis of nutrient concentrations was carried out on samples of *N. bongso* Korth., *N. dubia* Danser and *N. rhombicaulis* Sh.Kurata from Bukit Malalak. Leaf samples were dried in an oven at 60 °C for three days and then ground with a pestle and mortar. Two ml of mixed acid (sulphuric acid, nitric acid and perchloric acid) was added to 0.2 g of leaf material and heated on a hotplate at 170 °C until the solution was clear; samples were then diluted to a final volume of 10 ml before analysis. Phosphorus concentration was determined using a colorimetric method, in which 1 ml of sample was added to 3 ml of distilled water and then reacted with 1 ml of P dye; the yellow colour of the sample was measured using a Shimadzu BioSpec-Mini 1240 UV-vis spectrophotometer at 450 nm. Nitrogen concentration was also determined by a colorimetric method, where 2 ml of the sample reacted with 4 ml of sodium phenoxide and 4 ml of 5% NaOCl; the blue colour of the sample was measured using a spectrophotometer as above but at a wavelength of 636 nm. Other elements were determined with atomic absorption spectrophotometry using a Shimadzu AA-6800. Pitcher fluid was analysed as above after being filtered to remove any debris.

RESULTS AND DISCUSSION

Diversity

In total, 23 species of *Nepenthes* were recorded from West Sumatra province, comprising 18 species documented during the field surveys, two species represented by herbarium specimens (*N. jamban* Chi C.Lee, Hernawati & Akhriadi: BO.1979938 and *N. lingulata* Chi C.Lee, Hernawati & Akhriadi: BO.1979937), two species documented from the region in literature records, i.e., *N. izumiae* Troy Davis, C.Clarke & Tamin (Clarke *et al*. 2003) and *N. jacquelineae* C.Clarke, Troy Davis & Tamin (Clarke 2001), and one species also indicated for the region via a credible second-hand source, namely *N. naga* Akhriadi, Hernawati, Primaldhi & M.Hambali (Putra-RSN Nepenthes Nursery, pers. comm.; Table 1). The majority of species documented are considered highland species (15), with four species each of mid-elevation and lowland species. Seven species are restricted to West Sumatra, 11 are found across other provinces of Sumatra (in addition to West Sumatra) and five are also found on other Indonesian islands. Nine species have been assessed as having a threatened status (2 × VU, 2 × EN, 5 × CR) against the International Union for Conservation of Nature (IUCN) 3.1 criteria (IUCN 2001) (Clarke *et al*. 2000a, b, c; Clarke 2014; Hernawati & Clarke 2014; Hernawati *et al*. 2014; Cross *et al*. 2020). Limapuluh Kota Regency had the greatest number of species (9), followed by Pasaman Regency (8 species), Solok and Agam Regencies (7 species each) and then Padang City, with just 2 species. We also found four natural hybrids: *N. talangensis* Nerz & Wistuba × *N. bongso* and *N. talangensis* × *N. inermis* Danser at Gunung Talang, and *N. eustachya* Miq. × *N. albomarginata* W.Lobb ex Lindl., and *N. gracilis* Korth. × *N. eustachya* in Air Putih Nature Reserve.

Table 1 Habitat, distribution, elevation and conservation status of the 23 *Nepenthes* species recorded from West Sumatra province. Species in bold were recorded from the field survey

Nepenthes	**Habitat**	**Regency**					**Elevation**	**Distribution**	**IUCN Red List category**
		AG	**LM**	**PD**	**PS**	**SL**			
adnata Tamin & M.Hotta ex Schlauer	Forest		●				M/H	WS	EN [D]
albomarginata W.Lobb ex Lindl.	Forest/Shrubland		●		●		M/H	Indo	LC
ampullaria Jack	Shrubland		●				L/M	Indo	LC
bongso Korth.	Forest	●				●	H	S	LC
dubia Danser	Mossy forest	●					H	WS	CR [B1+2e]
eustachya Miq.	Forest/Shrubland	●	●		●		M	S	LC
gracilis Korth.	Shrubland		●	●		●	L	Indo	LC
harauensis Hernawati, R.Satria & Chi.C.Lee	Forest		●				H	WS	-
inermis Danser	Mossy forest					●	H	S	LC
izumiae Troy Davis, C.Clarke & Tamin	Forest/Shrubland				●		H	WS	LC
jacquelineae C.Clarke, Troy Davis & Tamin	Mossy forest				●		H	WS	CR [B2ab(v) C2a(i)]
jamban Chi C.Lee, Hernawati & Akhriadi:	Mossy forest				●		H	S	CR [B2ab(v) C2a(i)]
lingulata Chi C.Lee, Hernawati & Akhriadi:	Forest				●		M	S	CR [B2ab(v)]
longifolia Nerz & Wistuba	Forest/Riparian		●				M	S	LC
mirabilis (Lour.) Druce	Shrubland			●			L	Indo	LC
naga Akhriadi, Hernawati, Primaldhi & M.Hambali	Forest				●		H	S	VU [D2]
pectinata Danser	Forest	●			●	●	H	S	LC
reinwardtiana Miq.	Shrubland		●			●	L/M	Indo	LC
rhombicaulis Sh.Kurata	Forest	●					H	S	VU [D2]
singalana Becc.	Forest	●					H	S	LC
spathulata Danser	Forest/Mountain peak	●				●	H	S	LC
talangensis Nerz & Wistuba	Forest/Mossy forest					●	H	WS	EN [C2b]
tenuis Nerz & Wistuba	Forest		●				H	WS	CR [A2]

Notes: AG = Agam, LM = Limapuluh Kota, PD = Padang City, PS = Pasaman, SL= Solok; L = Lowland, M = Mid-elevation, H = Highland; WS = West Sumatra only, S = Sumatra only, Indo = other islands in Indonesia (in addition to Sumatra); LC = Least Concern, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, - = not yet assessed against IUCN Red List criteria.

In our survey, conducted across five regencies in West Sumatra, we recorded 23 species of *Nepenthes*, 18 of which are endemic to the island of Sumatra. This number is comparable to our survey in North Sumatra (22, including two taxa yet to be formally described; Mansur *et al.* 2022a), with 12 species common to both surveys. *Nepenthes eustachya*, *N. gracilis* and *N. pectinata* Danser are three species whose distribution is quite broad, as they are found in three regencies/cities; indeed, *N. gracilis* is widespread not only in western Indonesia, but also in Peninsular Malaysia and southern Indochina. Other species, however, are more limited, notably *N. talangensis*, which is found only on Gunung Talang (Solok Regency; Nerz & Wistuba 1997), *N. jacquelineae* in Pasaman Regency (Clarke 2001) and *N. harauensis* in Limapuluh Kota Regency (Hernawati *et al.* 2022b), all three of which are the type localities for those species, while *N. jamban*, *N. lingulata* and *N. naga* are found not only in Pasaman Regency (West Sumatra), but also in Mandailing Natal Regency (North Sumatra), on the border between West Sumatra and North Sumatra.

Population

Nepenthes population measurements were only carried out at Bukit Malalak. In the study plots, *N. bongso* generally grew as an epiphyte under a shady canopy with a small population (Plot 2), while in open areas (mountain peak), it grew terrestrially with a larger population (Plot 1). In a total plot area of 0.27 ha, seven individuals of *N.*

dubia were found: four in Plot 1 and three outside of the plot in mossy forest (mountain peak), growing terrestrially under a slightly open canopy (Table 2). *Nepenthes eustachya* was abundant in Plot 3 and grew terrestrially in shady areas. Thirteen individuals of *N. rhombicaulis* were found in Plot 1 and ten were found in Plot 2, where they grew terrestrially in shady areas. Morisita's index was greater than 1 for all species in all plots, indicating a clumped distribution; the exception was of *N. rhombicaulis* in Plot 2, which had a value of 0.80, indicating a more random distribution. These clumped distributions are in keeping with earlier studies (Adam 2002; Damit *et al.* 2017), which is likely due to similar habitat requirements for light or sufficiently moist soil, for example. More advanced statistical techniques, such as those based on Ripley's *K*, are likely to be more informative regarding spatial patterns if sufficient individuals are measured (Brearley *et al.* 2023).

Table 2 Number of individuals of four *Nepenthes* species in three plots each of 0.09 ha at Bukit Malalak, Agam Regency (Sumatra).

Nepenthes	**Elevation (m)**	**Plot**			**Total**
		1 (1586 m asl)	**2 (1329 m asl)**	**3 (1186 m asl)**	
bongso	1300–1600	64	6	0	70
dubia	1550–1600	4	0	0	4
eustachya	1150–1300	0	0	50	50
rhombicaulis	1300–1600	13	10	0	23

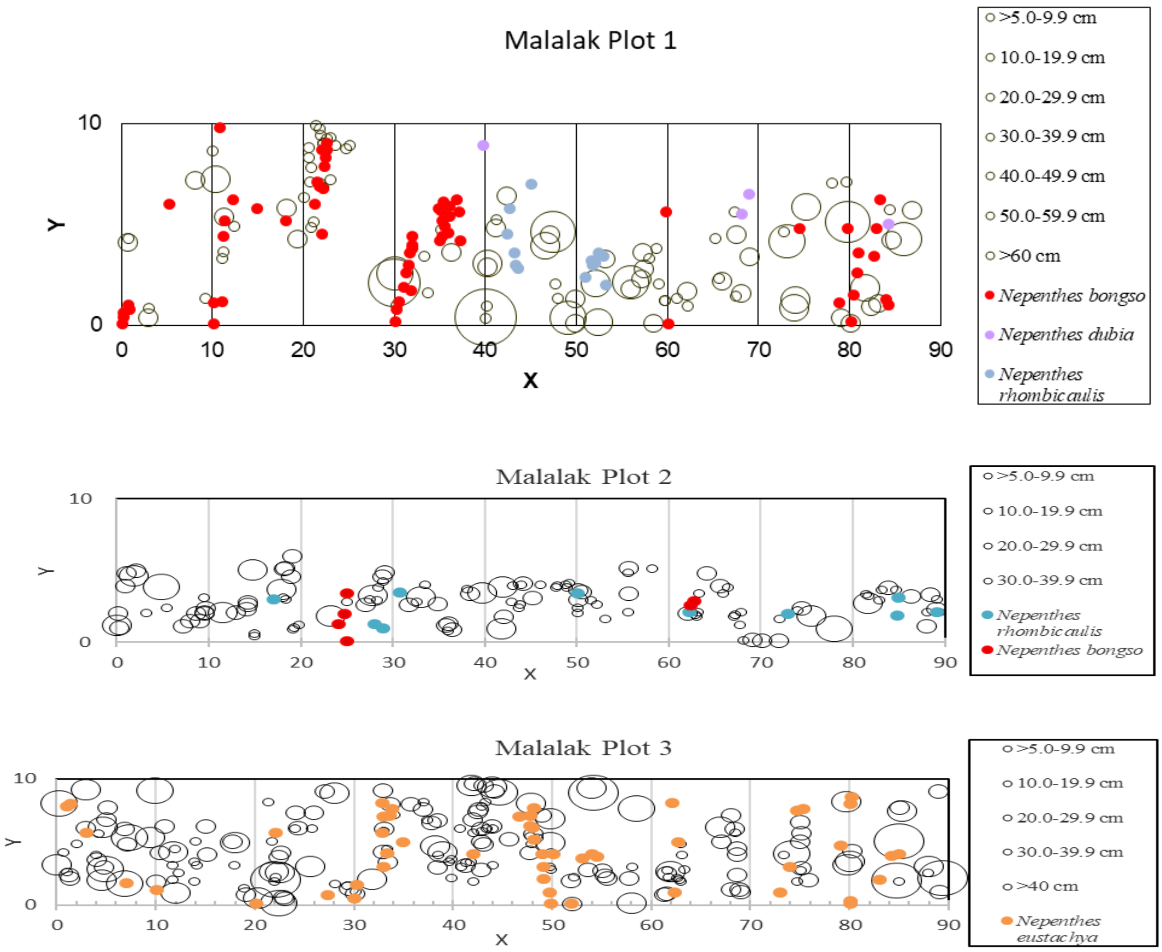

Figure 2 *Nepenthes* distributions in three 0.09 ha plots on Bukit Malalak, Agam Regency (Sumatra). Open circles show locations of each tree species with larger circles indicating trees of larger stem diameter. Coloured circles indicate locations of *Nepenthes* individuals of different species

Habitat

At the Bukit Malalak study site, *Nepenthes* plants grew in primary forest with very steep sloping. The forest's condition was intact, with few signs of human disturbance. In the total plot area of 2700 m^2, there were 416 individual trees (Ø ≥ 5 cm) recorded, comprising 34 species, 29 genera and 20 families. Myrtaceae was the most species-rich family, with eight species, five of which were *Syzygium*. The five dominant tree species in the *Nepenthes* habitat were *Ternstroemia gymnanthera* (Wight & Arn.) Bedd. (IVI = 42.1) followed by *Syzygium zeylanicum* (L.) DC. (28.5), *Myrsine avenis* (Blume) A.DC. (24.0), *Rhodoleia championii* Hook. (22.1) and *Leptospermum javanicum* Blume (19.1; Table 3).

Table 3 List of tree species and their abundance in 0.27 ha of forest plots containing *Nepenthes* species at Bukit Malalak, Agam Regency (Sumatra)

Species	Family	BA (m^2)	RD (%)	RF (%)	RDo (%)	IVI (%)
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	Pentaphylacaceae	1.330	22.1	6.04	14.0	42.1
Syzygium zeylanicum (L.) DC.	Myrtaceae	1.100	11.5	5.37	11.6	28.5
Myrsine avenis (Blume) A.DC.	Primulaceae	0.720	10.3	6.04	7.60	24.0
Rhodoleia championii Hook.	Hamamelidaceae	0.860	7.69	5.37	9.02	22.1
Leptospermum javanicum Blume	Myrtaceae	1.170	3.37	3.36	12.3	19.1
Syzygium sumatranum (Miq.) Widodo	Myrtaceae	0.760	4.33	6.04	8.01	18.4
Castanopsis costata (Blume) A.DC.	Fagaceae	0.500	4.33	6.04	5.26	15.6
Syzygium bankense (Hassk.) Merr. & L.M.Perry	Myrtaceae	0.440	4.09	4.70	4.65	13.4
Gaultheria heterophylla var. *latifolia* (Blume) Kron & P.W.Fritsch	Ericaceae	0.360	3.85	5.37	3.80	13.0
Pittosporum ferrugineum W.T.Aiton	Pittosporaceae	0.350	2.16	5.37	3.71	11.2
Carallia eugenioidea King	Rhizophoraceae	0.210	3.61	4.70	2.17	10.5
Eriosolena composita (L.f.) Tiegh.	Thymelaeaceae	0.310	3.13	3.36	3.29	9.77
Neolitsea cinnamomea (Ridl.) Kosterm.	Lauraceae	0.200	1.92	3.36	2.06	7.34
Tristaniopsis merguensis (Griff.) Peter G.Wilson & J.T.Waterh.	Myrtaceae	0.200	1.92	2.68	2.11	6.72
Heptapleurum sp.	Araliaceae	0.060	1.44	3.36	0.58	5.38
Dacrydium elatum (Roxb.) Wall. ex Hook.	Podocarpaceae	0.160	0.96	2.68	1.68	5.32
Adinandra dumosa Jack	Pentaphylacaceae	0.150	1.68	2.01	1.54	5.24
Pterophylla fraxinea D.Don	Cunoniaceae	0.170	0.96	2.01	1.76	4.74
Syzygium acuminatissimum (Blume) DC.	Myrtaceae	0.100	1.68	1.34	1.07	4.1
Calophyllum teysmannii Miq.	Calophyllaceae	0.070	0.96	2.01	0.75	3.73
Polyosma ilicifolia Blume	Escalloniaceae	0.050	1.20	2.01	0.49	3.71
Archidendron bubalinum (Jack) I.C.Nielsen	Fabaceae	0.020	0.96	2.01	0.18	3.15
Symplocos adenophylla Wall. ex G.Don	Symplocaceae	0.020	0.72	2.01	0.25	2.99
Schima wallichii (DC.) Korth.	Theaceae	0.020	0.72	2.01	0.21	2.95
Elaeocarpus mastersii King	Elaeocarpaceae	0.020	0.72	2.01	0.20	2.93
Litsea sp.	Lauraceae	0.050	0.48	1.34	0.51	2.34
Wendlandia densiflora (Blume) DC.	Rubiaceae	0.020	0.72	1.34	0.26	2.32
Lithocarpus conocarpus (Oudem.) Rehder	Fagaceae	0.020	0.72	1.34	0.23	2.29
Myrica javanica Blume	Myricaceae	0.040	0.48	1.34	0.39	2.21
Vaccinium lucidum (Blume) Miq.	Ericaceae	0.010	0.24	0.67	0.09	1.00
Rhodamnia cinerea Jack	Myrtaceae	0.010	0.24	0.67	0.07	0.98
Syzygium antisepticum (Blume) Merr. & L.M.Perry	Myrtaceae	0.010	0.24	0.67	0.06	0.98
Garcinia lateriflora Blume	Clusiaceae	0.004	0.24	0.67	0.04	0.95
Timonius flavescens (Jacq.) Baker	Rubiaceae	0.003	0.24	0.67	0.03	0.94
Grand Total		9.517				

Note: BA = basal area, RD = relative density, RF = relative frequency, RDo = relative dominance, IVI = importance value index

Interspecific Associations

The Ochiai Index showed that *N. bongso* was positively associated with *N. dubia* and strongly positively associated with *Ternstroemia gymnanthera* in Plot 1 (Table 4). In Plot 2, *N. rhombicaulis* was positively associated with *N. bongso*, but they were weakly associated in Plot 1. *Nepenthes rhombicaulis* was also strongly positively associated with five species with a very high Ochiai index in Plot 2 and, in Plot 3, *N. eustachya* had positive associations with seven species with a very high Ochiai index (Table 4). Adam (2002) also found positive associations between *N.* × *kinabaluensis* Sh.Kurata and *N. villosa* Hook.f. and *Leptospermum recurvum* Hook.f. (Myrtaceae) in montane forest in northern Borneo, so it would be valuable to determine the traits of the trees that *Nepenthes* tend to associate with. Furthermore, understanding which habitats and which particular tree species or communities certain *Nepenthes* species associate with may provide further insight into where these *Nepenthes* species may be found in other localities.

Table 4 Chi-square (χ^2) and Ochiai Index (OI) values showing inter-specific associations between *Nepenthes bongso* (Plot 1), *N. rhombicaulis* (Plot 2), and *N. eustachya* (Plot 3) and other *Nepenthes* species and the ten tree species with the greater IVIs at Bukit Malalak, Agam Regency (Sumatra)

Species	**Plot 1: Association with *N. bongso***		**Plot 2: Association with *N. rhombicaulis***		**Plot 3: Association with *N. eustachya***	
	Chi-squared (χ^2)	**Ochiai Index (OI)**	**Chi-squared (χ^2)**	**Ochiai Index (OI)**	**Chi-squared (χ^2)**	**Ochiai Index (OI)**
Nepenthes dubia	+	0.61 (High)	Absent	Absent	Absent	Absent
Nepenthes bongso	NA	NA	+	0.74 (High)	Absent	Absent
Nepenthes rhombicaulis	-	0.25 (Low)	NA	NA	Absent	Absent
Ternstroemia gymnanthera	+	**0.88 (Very high)**	+	**0.88 (Very high)**	+	0.67 (High)
Syzygium zeylanicum	Absent	Absent	-	0.44 (Low)	+	**0.94 (Very high)**
Myrsine avenis	+	0.50 (High)	+	**0.88 (Very high)**	+	**0.88 (Very high)**
Rhodoleia championii	-	0.25 (Low)	+	**0.77 (Very high)**	+	**0.82 (Very high)**
Leptospermum javanicum	+	0.53 (High)	Absent	Absent	Absent	Absent
Syzygium sumatranum	Absent	Absent	Absent	Absent	+	**1.00 (Very high)**
Castanopsis costata	Absent	Absent	+	**0.80 (Very high)**	+	0.56 (High)
Syzygium bankense	Absent	Absent	-	(Low)	+	**0.75 (Very high)**
Gaultheria heterophylla	+	**0.89 (Very high)**	+	0.66 (High)	+	**0.75 (Very high)**
Pittosporum ferrugineum	Absent	Absent	-	0.00 (Very low)	+	**0.82 (Very high)**

Growth Rates

Leaf production rates and stem growth rates were quite variable within species. There were no significant differences in the rates among the four species measured over one year (only one individual of *N. bongso* could be measured, because the others died; Table 5). The mean stem growth rate was significantly greater on Bukit Malalak (42.1 ± s.e. 4.8 cm yr^{-1}) than on Gunung Talang (29.9 ± 3.6 cm yr^{-1}) ($t = 2.06$, $p = 0.05$), although the leaf production rate was not (9.8 ± 1.2 leaves yr^{-1} versus 7.3 ± 0.6 leaves yr^{-1}, respectively; Mansur *et al.* in review); this could be due to the lower elevation of the plants studied on Bukit Malalak or simply the fact that different species were measured at each site (with the exception of *N. bongso*). It would be interesting to further examine the possible trade-offs between leaf and stem production rate and plant survival (Mansur & Brearley 2008), as has been done in tropical tree seedling studies (Brearly *et al.* 2016).

Nutrient Concentrations

Macronutrient concentrations in the leaves were greater than those in the *Nepenthes* pitcher fluid, and there were no significant differences in nitrogen or potassium concentrations between species, but phosphorus was greatest in the leaves of *N. dubia* and least in *N. rhombicaulis*. The concentrations of foliar magnesium were not significantly different between the three species; however, calcium was greatest in *N. bongso* and sodium was greatest in *N. dubia* and least in *N. bongso*. Pitcher fluid concentrations were variable, and there were few significant differences among species, although *N dubia* had notably lower P, K and Mg concentrations (Table 6). Our ecological studies on Bukit Malalak showed that the habitat of *Nepenthes* was an infertile Latosol (unpubl. data), indicated by the presence of a large number of *Syzygium* species and *Tristaniopsis merguensis* (Griff.) Peter G.Wilson & J.T.Waterh. This compares with more fertile volcanic Andosols as found on other mountains in the region, such as Gunung Singgalang and Gunung Talang. However, these differences were not reflected in the foliar N, P or K concentrations when compared with material from Gunung Talang (Mansur *et al.* in review), although N was greater and K was lower than the species from North Sumatra (Mansur *et al.* 2022b). In contrast, less Mg was noted in the leaves from Bukit Malalak than those from Gunung Talang (but more than those from North Sumatra) and less Ca but more Na was found in the *Nepenthes* leaves from Gunung Talang and North Sumatra. If the plants obtain sufficient nutrients from their insect prey, this may be one reason nutrient concentrations in the sampled leaves do not differ between locations despite contrasting soil fertilities. Indeed, we earlier showed that foliar N concentrations of *Nepenthes* did not vary along elevation gradients, although there was an impact on foliar P concentrations (Mansur *et al.* 2022b). Determinants of foliar nutrient concentrations will differ by species and locality. How they influence the performance of different *Nepenthes* species would be valuable further research.

Table 5 Growth rates of four *Nepenthes* species in their natural habitat at Bukit Malalak, Agam Regency (Sumatra) over an twelve-month period (Oct 2021 to Oct 2022). Also shown are the environmental conditions and survival rates. Values are mean ± standard error

Nepenthes	**Plot**	**Conditions**	**No. of individuals**	**Survival (%)**	**No. of new leaves produced**	**Length of new stem produced (cm)**
bongso	2	Slightly shaded	1	33	5.0	24.6
dubia	1	Fairly open	3	100	9.7 ± 0.3	48.9 ± 7.8
eustachya	3	Shaded	3	100	13.3 ± 2.9	52.2 ± 8.0
rhombicaulis	2	Slightly shaded	4	100	8.5 ± 1.6	33.7 ± 7.6

Table 6. Nutrient concentrations in leaves and pitcher fluid of three *Nepenthes* in Bukit Malalak, Agam Regency (Sumatra). Values are mean ± standard error with letters indicating significant differences (at $p < 0.05$) with a Tukey's test

Element	Leaves (%)			Pitcher fluid (mg l^{-1})		
	bongso	***dubia***	***rhombicaulis***	***bongso***	***dubia***	***rhombicaulis***
N	1.09 ± 0.02 a	1.01 ± 0.01 a	1.36 ± 0.22 a	0.97 ± 0.22 a	3.52 ± 1.44 a	1.09 ± 0.04 a
P	0.10 ± <0.01 ab	0.14 ± 0.02 b	0.08 ± 0.01 a	5.04 ± 0.03 a	0.18 ± 0.05 a	4.51 ± 2.35 a
K	1.32 ± 0.02 a	1.08 ± 0.18 a	1.10 ± 0.05 a	721 ± 363 a	6.72 ± 1.23 a	283 ± 163 a
Ca	0.16 ± 0.02 b	0.05 ± 0.01 a	0.09 ± 0.02 a	491 ± 27 b	294 ± 4.6 ab	172 ± 86 a
Mg	0.14 ± 0.01 a	0.12 ± 0.01 a	0.13 ± <0.01 a	92 ± 11 c	4.9 ± 0.2 a	50 ± 5.6 b
Na	0.42 ± 0.04 a	0.92 ± 0.14 b	0.70 ± 0.02 ab	0.85 ± 0.03 a	1.48 ± 0.07 a	516 ± 296 a

Conservation Status

Of the 23 species reported from West Sumatra, nine have threatened conservation status, namely *N. dubia* (CR), *N. jacquelineae* (CR), *N. jamban* (CR), *N. tenuis* (CR), *N. adnata* Tamin & M.Hotta ex Schlauer (EN), *N. talangensis* (EN), *N. tenuis* Nerz & Wistuba (EN), *N. naga* (VU) and *N. rhombicaulis* (VU). At nearly 40 % of the known species in the province, this is a worryingly high proportion. Our research extends the ranges of *N. jamban* and *N. lingulata* from their type locality in North Sumatra (Lee *et al.* 2006) to West Sumatra based on herbarium collections deposited at Herbarium Bogoriense (BO) by Wewin Tjiasmanto and that of *N. naga* through personal communication (Putra). Previously, *N. dubia* was only known to grow on Gunung Talakmau, Pasaman and West Pasaman Regencies, at an elevation of 1800 to 2700 m asl (Clarke 2001), and Mandailing Natal Regency, North Sumatra (Sahal, pers. comm.). Our research also extends the known range of *N. dubia* to include Bukit Malalak, thereby increasing the size of the small, originally documented population and its extent of occurrence (EOO). This is positive, as species with larger ranges and population sizes are less prone to extinction; this species is currently listed as critically endangered, satisfying the Red List criteria B1+2e, i.e. it has a small geographic range and small population size (Clarke *et al.* 2000a; Cross *et al.* 2020). The EOO of *N. rhombicaulis* is also extended, having been formally documented only from Gunung Pangalubao near Lake Toba in North Sumatra, about 300 km distant. This species is currently assessed as Vulnerable under the Red List criterion D2, i.e. it has a restricted area of occupancy (Clarke *et al.* 2000b). Cross *et al.* (2020) listed *N. tenuis* as CR under criteria A2, i.e. a greater than 80% reduction in population over the last 10 years. They further considered that it might be extinct; however, we found this species growing in the Batu Karang-Harau area, albeit with a very small population of about 20 individuals. Despite extending the range and population of these species, they are still threatened, as we discuss below. The other six species are listed as threatened because of their restricted ranges and an observed decline in their population in the cases of *N. jacquelineae*, *N. jamban* and *N. talangensis* (Clarke *et al.* 2000c; Cross *et al.* 2020).

Nepenthes harauensis has only recently been described (Hernawati *et al.* 2022b) and has not yet been formally assessed for the IUCN Red List; nevertheless, the restricted range of this species coupled with the rapid rate of environmental change in Sumatran ecosystems strongly suggests that it is likely to be threatened in its natural environment and would likely fall under the Endangered category if formally assessed (although we would need a better estimate of of its populations' size and trajectory). Other species that might be found in West Sumatra province include *N. putaiguneung*, which was recently described from an unknown location in the extensive Kerinci Seblat National Park (Metusala *et al.* 2020), as well as *N. aristolochioides* Jebb & Cheek, which is known from three locations in the park where it is under threat from collectors (McPherson 2009), underlining the problems of plant conservation even in formally protected areas (Linkie *et al.* 2010). With the exception of the two latter species, most of the other species described from Sumatra (Hernawati *et al.* 2022a) and not recorded from the North (Mansur *et al.* 2022a) or West Sumatra provinces (in this study) are found in the very north of the island in Aceh or in the more central Jambi province.

Although rates of land-use change are very high in Indonesia (Margono *et al.* 2012; Austin *et al.* 2019), many rare and often endemic species remain in the Sumatran mountains due to the protected status of some localities, combined with their poor accessibility. Many of these species are not in *ex-situ* cultivation and a stochastic environmental event or agricultural invasion could rapidly cause the extinction of the entire global population of some of these locally endemic species. Conservation needs and responsibilities are therefore extremely high. Further exploration and formal records would add to the quality of existing assessments. Beyond assessing their conservation status, the key threats to the majority of *Nepenthes* in Indonesia are land-use change and collection for the horticultural trade (Clarke *et al.* 2018; Cross *et al.* 2020), so practical conservation methods need to address these challenges that will only be successful with the support of local communities and governments. These fascinating restricted range and threatened *Nepenthes* species in Sumatra need further study, especially regarding their distribution and population status. A more detailed exploration of the mountainous regions of Sumatra may well find further populations, as we have done here.

Figure 3 *Nepenthes* species recorded from West Sumatra: (a) *N. adnata* (lower pitcher), (b) *N. albomarginata* (lower pitcher), (c) *N. ampullaria* (rosette pitcher), (d) *N. bongso* (lower pitcher), (e) *N. dubia* (upper pitcher), (f) *N. eustachya* (lower pitcher), (g) *N. gracilis* (upper pitcher), (h) *N. harauensis* (lower pitcher), (i) *N. inermis* (upper pitcher), (j) *N. izumiae* (upper pitcher), (k) *N. jacquelineae* (upper pitcher), (l) *N. jamban* (upper pitcher), (m) *N. lingulata* (upper pitcher), (n) *N. longifolia* (upper pitcher), (o) *N. mirabilis* (upper pitcher), (p) *N. naga* (upper pitcher), (q) *N. pectinata* (rosette pitcher), (r) *N. reinwardtiana* (upper pitcher), (s) *N. rhombicaulis* (upper pitcher), (t) *N. singalana* (upper pitcher), (u) *N. spathulata* (upper pitcher), (v) *N. talangensis* (upper pitcher), (w) *N. tenuis* (upper pitcher). Photos a & p by Putra, Photos b–i, n, o, q–s, v & w by M. Mansur, Photos j–m by Sahal, Photo t by Sunardi, Photo u by Yusran E. Ritonga. Authorities are noted in Table 1

CONCLUSION

Our research documented 23 species of *Nepenthes* in West Sumatra province through direct observation (18 species) and the remainder through herbarium specimens, literature review and second-hand information. Of that total, 18 species are endemic to Sumatra, nine of which are threatened with extinction (2 × VU, 2 × EN and 5 × CR). We examined *Nepenthes* at one of our study sites (Bukit Malalak) in more detail and compared ecological patterns and processes with those occurring elsewhere. *Nepenthes* species require further observation, especially regarding their distribution and population, and additional exploration on poorly known Sumatran mountains will lead to new discoveries in this fascinating plant genus.

ACKNOWLEDGMENTS

This research was funded by grants from Beauval Zoo (France) and Chester Zoo (UK). Thanks to Phillip Esseen, Paul Leach, Nicolas Leroux, Johanna Rode-Margono and Stuart Young for help and support of this research. Special thanks to Sunardi, Heru Hartantri, Yusran E. Ritonga, Putra, Rhima and Daniel Ferdinan for their assistance during the fieldwork. We thank the reviewers for their comments that improved the manuscript.

REFERENCES

Adam J. 2002. Demographic study of *Nepenthes* species (Nepenthaceae) recorded along the trail to the summit of Mount Kinabalu in Sabah, Malaysia. Pakistan Journal of Biological Sciences 5(4): 419-426. DOI: 10.3923/pjbs.2002.419.426

Austin KG, Schwantes A, Gu Y, Kasibhatla PS. 2019. What causes deforestation in Indonesia? Environmental Research Letters 14(2): 024007. DOI: 10.1088/1748-9326/aaf6db

Brearley FQ, Mansur M, Eichhorn MP. 2023. Spatial patterning of *Gonystylus brunnescens* in eastern Borneo. Folia Oecologica 50(1): 55-59. DOI: 10.2478/foecol-2023-0004

Brearley FQ, Saner P, Uchida A, Burslem DFRP, Hector A, Nilus R, Egli S. 2016. Testing the importance of a common ectomycorrhizal network for dipterocarp seedling growth and survival in tropical forests of Borneo, Plant Ecology & Diversity 9(5-6): 563-576. DOI: 10.1080/ 17550874.2017.1283649

Clarke CM. 2001. *Nepenthes* of Sumatra and Peninsular Malaysia. Natural History Publications, Kota Kinabalu, Sabah, Malaysia.

Clarke CM 2014. *Nepenthes naga*. The IUCN Red List of Threatened Species 2014: e.T48994529A49009797. https://dx.doi.org/10.2305/IUCN.UK.2014-1.RLTS.T48994529A49009797.en. Accessed on 29 March 2023.

Clarke CM, Davis T, Tamin R. 2003. Nepenthes izumiae (Nepenthaceae): a new species from Sumatra. Blumea 48(1): 179-182. DOI: 10.3767/ 000651903X686141

Clarke CM, Cantley R, Nerz J, Rischer H, Wistuba A. 2000a. *Nepenthes dubia*. The IUCN Red List of Threatened Species 2000: e.T39657A10254648. https://dx.doi.org/10.2305/IUCN.UK.2000.RLTS.T39657A10254648.en. Accessed on 30 December 2022.

Clarke CM, Cantley R, Nerz J, Rischer H, Wistuba A. 2000b. *Nepenthes rhombicaulis*. The IUCN Red List of Threatened Species 2000: e.T39693A10251994. https://dx.doi.org/10.2305/IUCN.UK.2000.RLTS.T39693A10251994.en. Accessed on 04 February 2023.

Clarke CM, Cantley R, Nerz J, Rischer H, Wistuba A. 2000c. *Nepenthes talangensis*. The IUCN Red List of Threatened Species 2000: e.T39701A10256061. https://dx.doi.org/10.2305/IUCN.UK.2000.RLTS.T39701A10256061.en. Accessed on 04 February 2023.

Clarke C, Cross A, Rice B. 2018. Conservation of carnivorous plants. In: Carnivorous plants: physiology, ecology, and evolution. Eds: AM Ellison L Adamec. Oxford University Press, UK. pp. 375-388. DOI: 10.1093/oso/9780198779841.003.0027

Cross AT, Krueger TA, Gonella PM, Robinson AS, Fleischmann AS 2020. Conservation of carnivorous plants in the age of extinction. Global Ecology and Conservation 24: e01272. DOI: 10.1016/ j.gecco.2020.e01272

Damit A, Nilus R, Suleiman M. 2017. Population structure and dispersion pattern of *Nepenthes* along the Kaingaran trail of Mount Trus Madi, Sabah, Borneo. Sepilok Bulletin 25 & 26(1): 1-11.

Dinas Kehutanan Sumatra Barat. 2018. Sekilas hutan Sumbar [A glimpse at the forests of West Sumatra] https://dishut.sumbarprov.go.id/details/pages/1#:~:text=Sumatera%20Barat%20terletak%20di%20pesisir,sekitar%2042%2C2%20ribu%20km2. Accessed on 30 Jan 2023.

Hernawati N, Clarke CM 2014. *Nepenthes adnata*. The IUCN Red List of Threatened Species 2014: e.T39638A19630641. https://dx.doi.org/10.2305/ IUCN.UK.2014-1.RLTS.T39638A19630641.en. Accessed on 29 March 2023.

Hernawati N, Clarke CM, Lee C. 2014. *Nepenthes tenuis*. The IUCN Red List of Threatened Species 2014: e.T39703A21845410. https://dx.doi.org/10.2305/IUCN.UK.2014-1.RLTS.T39703A21845410.en. Accessed on 29 March 2023.

Hernawati, Zuhud EAM, Prasetyo LB, Soekmadi R. 2022a. Synopsis of Sumatran *Nepenthes*. Biodiversitas 23(8): 4243-4255. DOI: 10.13057/biodiv/d230848

Hernawati, Satria R, Lee CC. 2022b. *Nepenthes harauensis*, a new species of Nepenthaceae from West Sumatra. *Reinwardtia* 21(1): 19-23. DOI: 10.14203/reinwardtia.v21i1.4306

IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

Lee CC, Hernawati, Akhriadi P. 2006. Two new species of *Nepenthes* (Nepenthaceae) from North Sumatra. Blumea 51(3): 561-568. DOI: 10.3767/000651906X622120

Linkie M, Rood E, Smith RJ. 2010. Modelling the effectiveness of enforcement strategies for avoiding tropical deforestation in Kerinci Seblat National Park, Sumatra. Biodiversity and Conservation 19(4): 973-984. DOI: 10.1007/s10531-009-9754-8

Ludwig JA, Reynold JS. 1988. Statistical Ecology: a Primer on Methods and Computing. John Wiley and Sons, New York, USA.

Margono BA, Turubanova S, Zhuravleva I, Potapov P, Tyukavina A, Baccini A , Goetz S & Hansen MC. 2012. Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. Environment Research Letters 7(3): 034010. https://dx.doi.org/10.1088/1748-9326/7/3/034010

Mansur M, Brearley FQ. 2008. Ecological studies on *Nepenthes* at Barito Ulu, Central Kalimantan, Indonesia. Jurnal Teknologi Lingkungan 9(3): 271-276. DOI: 10.29122/jtl.v9i3.471

Mansur M, Brearley FQ, Esseen PJ, Rode-Margono EJ, Tarigan MRM. 2021. Ecology of *Nepenthes clipeata* on Gunung Kelam, Indonesian Borneo. Plant Ecology and Diversity 14(3-4): 195-203. DOI: 10.1080/17550874.2021.1984602

Mansur M, Salamah A, Mirmanto E. 2022a. Diversity of *Nepenthes* species in North Sumatra province. Berita Biologi 21(3): 199-209. DOI: 10.14203/beritabiologi.v21i3.4389

Mansur M, Salamah A, Mirmanto E, Brearley FQ. 2022b. Nutrient concentrations in three *Nepenthes* species (Nepenthaceae) From North Sumatra. Reinwardtia 21(2): 55-62. DOI: 10.14203/reinwardtia.v21i2.4391

Mansur, M, Salamah A, Mirmanto E, Brearley FQ. Ecology of *Nepenthes* on Mount Talang, West Sumatra, Indonesia. Tropical Ecology (in review).

Metusala M, Al Farishy DD, Jebb MHP. 2020. *Nepenthes putaiguneung* (Nepenthaceae), a new species from highland of Sumatra, Indonesia. Phytotaxa 454(4); 285-292. DOI: 10.11646/phytotaxa.454.4.6

Moran JA, Clarke CM. 2010. The carnivorous syndrome in Nepenthes pitcher plants: current state of knowledge and potential future directions, Plant Signaling and Behavior 5(6): 644-648. DOI: 10.4161/psb.5.6.11238

Moran JA, Clarke CM, Gowen BE. 2012. The use of light in prey capture by the tropical pitcher plant *Nepenthes aristolochioides*. Plant Signaling & Behavior 7(8): 957-960. DOI: 10.4161/psb.20912

Morisita M. 1959. Measuring of the dispersion of individuals and analysis of distribution patterns. Memoirs of the Faculty of Science, Kyushu University, Series E (Biology) 2(4): 215-235.

Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York, USA.

Nerz J. 2005. Sumatra, a centre of evolution in the genus *Nepenthes*?! Acta Botanica Gallica 152(2): 262-263. DOI: 10.1080/12538078.2005.10515483

Nerz J, Wistuba A. 1994. Five new taxa of Nepenthes (Nepenthaceae) from North and West Sumatra. Carnivorous Plant Newsletter 23(4): 101-114.

Ochiai A. 1957. Zoogeographic studies on the soleoid fishes found in Japan and its neighbouring regions. Bulletin of Japanese Society of Scientific Fisheries 22(9): 526-530. DOI: 10.2331/suisan.22.526

Pavlovič A, Singerová L, Demko V, Hudák J. 2009. Feeding enhances photosynthetic efficiency in the carnivorous pitcher plant *Nepenthes talangensis*. Annals of Botany 104(2): 307-314. DOI: 10.1093/aob/mcp121

Pavlovič A, Singerová L, Demko V, Šantrůček J & Hudák J. 2010. Root nutrient uptake enhances photosynthetic assimilation in prey-deprived carnivorous plant *Nepenthes talangensis*. Photosynthetica 48(2): 227-233. DOI: 10.1007/s11099-010-0028-1

Phillipps A, Lamb A. 1996. Pitcher-Plants of Borneo. Natural History Publications, Kota Kinabalu, Sabah, Malaysia.

Victoriano M. 2021. A new species of *Nepenthes* (Nepenthaceae) and its natural hybrids from Aceh, Sumatra, Indonesia. Reinwardtia 20(1): 17-26. DOI: 10.14203/reinwardtia.v20i1.3932

Zulkarnaen RN, Peniwidiyanti, Rivai RR, Helmanto H, Wanda IF. 2017. Struktur dan asosiasi komunitas tumbuhan bawah di Resort Cikaniki, Taman Nasional Gunung Halimun Salak [Structure and associations of understorey plants at Cikaniki resort, Gunung Halimun Salak National Park]. Jurnal Ilmu Alam dan Lingkungan 8(2): 21-30. DOI: 10.20956/jal.v8i16.2985