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Ecology of *Nepenthes* on Mount Talang, West Sumatra, Indonesia

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Abstract

Gunung (Mount) Talang is an active volcano in West Sumatra that has a number of *Nepenthes* species, including the endemic *N. talangensis*, but their ecology has been little been studied. This study found five species of *Nepenthes* growing in the protected forest area of Gunung Talang, namely *N. bongso*, *N. inermis*, *N. pectinata*, *N. spathulata* and *N. talangensis*. The population of *N. talangensis* is very small (23 individuals) and it grows sympatrically with *N. bongso* and *N. inermis* forming natural hybrids. *Lithocarpus conocarpus*, *Camellia lanceolata*, *Syzygium acuminatissimum*, *Adinandra dumosa* and *Dehaasia* sp. are the five most dominant tree species found in the *Nepenthes* habitat, while *L. conocarpus* and *Podocarpus nerifolius* had strong positive associations with *N. talangensis*. Growth rates of the five *Nepenthes* species were not significantly different, neither were foliar nitrogen (mean = 1.14%) or phosphorus concentrations (mean = 0.11%). We suggest that *N. talangensis* should be considered as Critically Endangered and outline some possible conservation actions.

Keywords Carnivorous plants · Conservation · Endemic species · Foliar nutrients · Indonesia

Introduction

Nepenthes is the only genus in the Nepenthaceae family, which are all classified as carnivorous plants (Phillipps and Lamb 1996; Clarke 2001). Indonesia is the center of the

global distribution of *Nepenthes* (Mansur 2013) with 79 species or 43% of the total number in the world (currently 182) (Mansur et al. 2021). Sumatra is one of the largest and most biodiverse of the Indonesian islands (Whitten et al. 1997); the Bukit Barisan Mountains, which stretch from South Sumatra to Aceh, are one of the most important contributors to Sumatra's high biodiversity, including *Nepenthes* (Lee et al. 2006). On the island of Sumatra, there are 39 species of *Nepenthes* of which more than three-quarters are endemic (Hernawati et al. 2022). The high number of *Nepenthes* species recorded in Sumatra makes it the second largest center of diversity after Borneo (Indonesia, Malaysia and Brunei Darussalam), and *Nepenthes* experts state that Sumatra is a hotspot for *Nepenthes* evolution (Wistuba et al. 2007). Indeed, the discovery of several new *Nepenthes* species from the island of Sumatra in recent years supports its importance as a key area for tropical biodiversity.

In the 1980s, half of Sumatra's landmass was tropical rain forest, but now more than half of that forest has been lost, placing Sumatran forests under some of the greatest threat in Indonesia (Margono et al. 2012). According to Global Forest Watch data, during 2001–2019, deforestation in Indonesia reached 26.8 million ha, with most of that occurring in Sumatra and Kalimantan (Lidwina 2021). Changes in the function of forest areas to non-forest areas such as oil palm plantations and gold/coal mining, along with forest fires, have reduced

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forest land so that it is predicted that the population of *Nepenthes* in their natural habitat will also decline. Nevertheless, many *Nepenthes* species are found at higher elevations which provides some protection from forest loss and land conversion. However, overexploitation for commercial purposes as ornamental plants will result in a reduction in the natural population of *Nepenthes* and there are several species, such as *N. clipeata* (Lee 2007; Mansur et al. 2021), *N. dubia* (Cheek et al. 2017) and *N. rigidifolia* (Hernawati and Akriadi 2005) whose conservation status, based on the IUCN Red List, is Critically Endangered. Indeed, Indonesia ranks second (26 species) after Brazil (28 species) for threatened carnivorous plants species. There are currently, 12 Critically Endangered species, nine Endangered species and five Vulnerable *Nepenthes* species in Indonesia (Cross et al. 2020), so it is necessary to make efforts to reduce the threat of further loss of *Nepenthes* species in Indonesia, and in Sumatra in particular.

Studies of *Nepenthes* have mostly focused on descriptions of new species, the methods they use to attract, capture and digest prey, and on the food webs contained within their pitchers (Moran and Clarke 2010). In contrast, there is a lack of basic autecological research on habitat requirements and associations of *Nepenthes* species, or on ecophysiological studies such as foliar nutrient concentrations or growth rates (Mansur et al. 2021, 2022a,b, 2023; Mansur and Brearley 2008; Osunkoya et al. 2007, 2008). Whilst *Nepenthes* show aggregated spatial patterns (Chua 1995; Damit et al. 2017), we are not aware of any studies that document the associations between *Nepenthes* and other plant species in natural habitats that might shed further light on their habitat requirements and how these might be shaped by interspecific interactions.

Gunung Talang is an active volcano in West Sumatra that last erupted between 2005 and 2007. It has an area of 6150 ha with a peak height of 2,597 m asl located in Solok Regency with the status of Protected Forest. In addition to providing ecosystem services regulating water systems, preventing flooding, controlling erosion and maintaining soil fertility, the Gunung Talang forest is also predicted to have a high biodiversity, including of *Nepenthes*. Puspitaningtyas and Wawangningrum (2007) reported that there were six species of *Nepenthes* found in the Gunung Talang forest, five of which are endemic to the island of Sumatra. After fifteen years had passed, we were interested to determine how the number of *Nepenthes* on Gunung Talang might have changed, monitor the state of their current population and habitat, and conduct initial studies on their autecology.

Materials and methods

The study was conducted in the Gunung (Mount) Talang protected forest area in November 2021 and October 2022. Administratively, the research location is in Jorong Bukit

Gompong Village, Gunung Talang District, Solok Regency (Fig. 1). The mountain is about 30 km east of the city of Padang in West Sumatra.

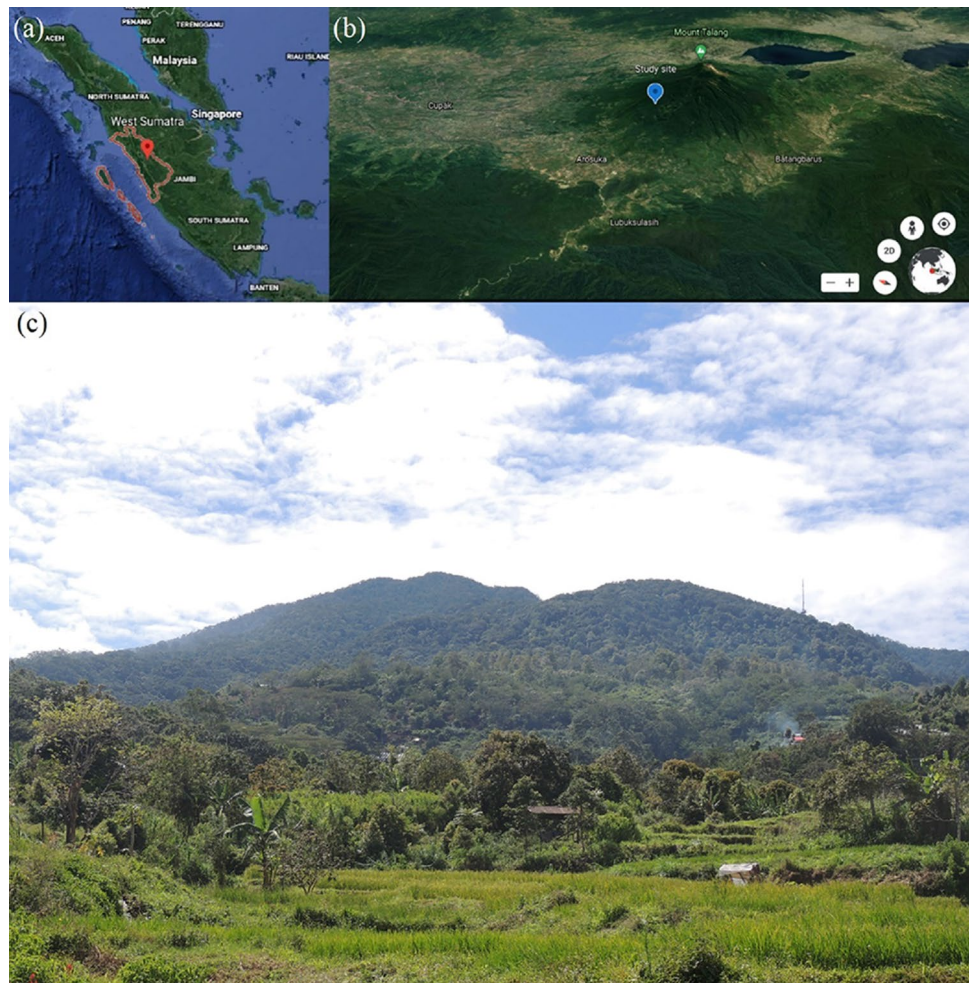
Plant exploration was carried out by following the summit trail from an elevation of c. 1500 m to c. 2300 m above sea level. Each *Nepenthes* plant found was recorded; for each individual, their coordinate position, morphological parameters (including stem length and leaf number) and leaf chlorophyll content were also determined. Leaf area was calculated as length \times width \times 0.66. Leaves from three plant samples from each species (*N. bongso*, *N. inermis*, *N. pectinata* and *N. talangensis*), namely the second leaf from the tip of the stem (estimated to be six months old), and pitcher fluid were sampled to analyze their nutrient concentrations. We also collected soil samples (c. 100 g) from three elevations where *Nepenthes* grew (2090, 2150 and 2215 m asl). Each species of *Nepenthes* was collected for herbarium vouchers that were deposited in Herbarium Bogoriense (BO), Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Indonesia. A number of plants of each 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 11 months, the plants were re-censused and the stem length and number of leaves of each individual were re-recorded.

Three plots of 0.09 ha each (30 m \times 30 m) were established to determine the abundance of *Nepenthes* and the species of trees growing in their habitat. Each species of *Nepenthes* in the 27 subplots (10 m \times 10 m each) was recorded along with their position (x and y co-ordinates). Tree species ($\varnothing \geq 5$ cm) in each subplot were recorded and their stem diameter, height, and position (x, y) noted. All data collected was processed and analyzed according to the Mueller-Dombois and Ellenberg method (1974) to obtain values for Basal Area (BA), Relative Frequency (RF), Relative Density (RD), Relative Dominance (RDo), and Importance Value Index (IVI). Morisita's (1959) index of dispersion was calculated for each species in each plot. The calculation of associations between plant species was carried out using a 2 \times 2 contingency table (Ludwig and Reynolds 1988; Sutomo et al. 2011; Handayani et al. 2019) on plant species that had an IVI value greater than 10% (Zulkarnaen et al. 2017). The calculated chi-square (χ^2) value was then compared with the chi-square (χ^2) table at the 5% test level, which is 3.84. If the value of χ^2 was greater than that in the χ^2 table, 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 between them (Mueller-Dombois and Ellenberg 1974). The strength of the association was then calculated using the Ochiai (1957) index (OI):

$$OI = a/(\sqrt{a+b})(\sqrt{a+c})$$

a = The number of sampling units (i.e. each 10 m \times 10 m subplot) where both species occur.

Fig. 1 Location **a** and **b** and photo **c** of Gunung (Mount) Talang, West Sumatra, Indonesia. (Photo Credit: M. Mansur)



b = The number of sampling units where species a occurs but not species b.

c = The number of sampling units where species b occurs but not species a.

The Ochiai index value ranges from 0 to 1 with the stronger the association between the two plant species the closer the index value is to 1 (Ludwig and Reynolds 1988).

Leaf and soil samples were dried in an oven at 60 °C for three days, then ground with a pestle and mortar. Two ml of mixed acid (sulfuric acid, nitric acid, and perchloric acid) was added to leaves or soil (0.2 g) and heated on a hotplate at a temperature of 170 °C until the solution was clear with a white precipitate. Samples were then diluted to a final volume of 10 ml before analysis. Determination of P was done by a colorimetric method, where 1 ml of the sample was added to 3 ml of distilled water and then reacted with 1 ml of P dye with the yellow color of the sample measured using a Shimadzu BioSpec-Mini 1240 UV-Vis spectrophotometer at a wavelength of 450 nm. Nitrogen was also determined by a colorimetric method, where 2 ml of the sample was reacted with 4 ml of Na-phenate and 4 ml of 5% NaOCl with the blue color of the sample measured using

a spectrophotometer as above at a wavelength of 636 nm. Determination of other elements (Ca, K, Mg and Na) was by atomic absorption spectrophotometry using a Shimadzu AA-6800. The pH of the pitcher fluid was measured using an ATC pH-2011 portable meter.

Data were analysed using Minitab 19.2 using one-way ANOVAs with Tukey's post hoc tests with a significance level of 0.05.

Results and discussion

Diversity

In a previous study, it was found that there were six species of *Nepenthes* in the Gunung Talang area, namely *N. bongso*, *N. gracilis*, *N. inermis*, *N. pectinata*, *N. spatulata* and *N. talangensis* (Puspitaningtyas and Wawangningrum 2007), but at the time of this study, only five species were found (Fig. 2), with *N. gracilis* not observed. *Nepenthes gracilis* generally grows in open areas in the lowlands and is widespread across Borneo, Sumatra, Sulawesi, the Malay

peninsula and Indochina (Phillipps and Lamb 1996; Mansur 2013), so there is little concern regarding its conservation. *Nepenthes spathulata* has also been recorded from Gunung Singgalang (Mansur et al. 2023) indicating that it is also found in West Sumatra, in addition to provinces further south (Clarke 2001). *Nepenthes pectinata* and *N. spathulata* grow at an elevation between 1500 to 2100 m above sea level (asl) in shaded areas. *Nepenthes bongso* and *N. talangensis* grow at an elevation of 2150 to 2200 m asl in mossy forest with a shaded canopy, while *N. inermis* grows at an elevation of 2150 to 2300 m asl in mossy forest with a slightly open canopy (Table 1). As well as Gunung Talang, *N. pectinata* was also found on Gunung Panglubao, Gunung Singgalang, Gunung Talakmau (Cheek and Jebb 2001), and Gunung Malintang (Herbarium Bogoriense: BO); *N. spathulata* was also found on Gunung Tanggamus (Lampung), South Sumatra, Jambi and Bengkulu (Clarke 2001), and Gunung Pesagi (BO); *N. bongso* was also found on Gunung Kerinci, Gunung Marapi, Gunung Singgalang (BO) and Gunung Gadut (Clarke 2001) and *N. inermis* was also found in Gunung Belirang (Clarke 2001), whereas *N. talangensis* is endemic to Gunung Talang, and thus, particularly important to study.

Morphology

The morphology of the five species studied was different, according to their respective characters. The upper pitchers of *N. inermis* and *N. talangensis* resemble a funnel (infundibular) and *N. inermis* is notable by the lack of a peristome. The lower pitchers of *N. bongso*, *N. pectinata* and *N. spathulata* are oval (ovoid) and the upper pitchers are trumpet-shaped. In other locations in Sumatra, both the lower and upper pitchers of *N. spathulata* are ovoid in the basal portion and cylindrical above as are the upper pitchers of *N. pectinata* (when produced), while the lower pitchers of both *N. bongso* and *N. pectinata* are variable in shape (Clarke 2001). *Nepenthes bongso* had the greatest stem diameter, stem length, internode length, peristome width and pitcher height. *Nepenthes pectinata* had the largest leaves and *N. inermis* had the smallest leaves, while *N. talangensis* had the greatest chlorophyll content compared to other species (Table 2). The pH of the pitcher fluid of *N. bongso*, *N. inermis*, *N. spathulata* and *N. talangensis*, was the same, namely between 4.3 and 4.5, whilst *N. pectinata* had a pH closer to neutral of 6.2. (Table 3).



Fig. 2 **a** *Nepenthes bongso* Korth., **b** *Nepenthes inermis* Danser, **c** *Nepenthes pectinata* Danser, **d** *Nepenthes spathulata* Danser and **e** *Nepenthes talangensis* Nerz & Wistuba found on Gunung (Mount) Talang (Sumatra) (Photos a, b, c & e by M. Mansur, photo d by Yusran E. Ritonga)

Table 1 Elevation, number of individual found and Morisita's index of dispersion of five *Nepenthes* species in three plots each of 0.09 ha on Gunung (Mount) Talang (Sumatra) as well as their IUCN conservation status

<i>Nepenthes</i>	Elevation (m)	Plot			Sum	Morisita's Index			Conservation status (IUCN)
		1 2215 m asl	2 2150 m asl	3 2090 m asl		Plot 1	Plot 2	Plot 3	
<i>bongso</i>	2150–2200	1	1	0	2	–	–	–	LC
<i>inermis</i>	2150–2300	3	3	0	6	3.0	9.0	–	LC
<i>pectinata</i>	1500–2100	0	0	36	36	–	–	1.4	LC
<i>spathulata</i>	1500–2100	0	0	2	2	–	–	9.0	LC
<i>talangensis</i>	2150–2200	4	5	0	9	1.5	5.4	–	EN

EN Endangered, LC Least Concern

Table 2 Morphology of five *Nepenthes* species in their natural habitat on Gunung (Mount) Talang (Sumatra)

Parameter	<i>Nepenthes</i>				
	<i>bongso</i>	<i>inermis</i>	<i>pectinata</i>	<i>spathulata</i>	<i>talangensis</i>
Stem diameter (mm)	7.3±0.88 a	4.2±0.15 b	6.2±0.52 ab	6.0±2.00 ab	6.7±0.12 a
Stem length (cm)	216±92.0 a	175±66.4 ab	119±15.5 ab	19.6±2.9 b	92.6±3.6 ab
Node length (cm)	13.1±1.6 a	4.6±0.3 bc	2.6±0.4 c	5.1±3.8 bc	6.2±0.4 b
Leaf area (cm ²)	77.5±20.1 ab	12.5±2.5 b	91.3±13.7 a	57.7±24.3 ab	53.7±3.4 ab
Chlorophyll (SPAD meter units)	53.8±4.8 ab	43.8±5.0 ab	41.5±2.1 b	41.1±3.2 ab	56.2±2.7 a
Pitcher height (cm)	18.6±2.5 a	6.2±0.5 b	10.7±1.0 b	13.0±5.5 ab	10.3±0.6 b
Pitcher width (cm)	6.1±0.70 a	4.0±0.92 a	5.5±1.65 a	3.0±0.80 a	5.4±0.25 a
Peristome width (mm)	15.5±3.6 a	No peristome	4.3±0.6 c	8.8±0.3 abc	9.0±0.7 b
Inflorescence length (cm)	–	7.4	18.0	–	13.8

Values are mean ± standard error with letters indicating significant differences (at $p < 0.05$) with a Tukey's test

Table 3 Concentrations of nutrients (% dry weight for leaves and soil and volume for pitcher fluid) and pitcher pH in four species of *Nepenthes* on Gunung (Mount) Talang (Sumatra)

	<i>Nepenthes</i>	pH	N	P	K	Ca	Mg	Na
Leaves	<i>bongso</i>	–	1.15±0.08 a	0.091±0.027 b	1.21±0.08 a	0.359±0.191 a	0.139±0.001 a	0.172±0.17 a
	<i>inermis</i>	–	1.01±0.01 a	0.090±0.052 a	1.01±0.19 a	0.147±0.057 a	0.161±0.014 b	0.343±0.22 ab
	<i>pectinata</i>	–	1.36±0.54 a	0.129±0.001 a	1.75±0.11 b	0.197±0.028 a	0.155±0.002 ab	0.518±0.01 ab
	<i>talangensis</i>	–	1.04±0.03 a	0.137±0.017 a	1.26±0.161a	0.201±0.124 a	0.150±0.004 ab	0.696±0.03 b
Pitcher Fluid	<i>bongso</i>	4.47±0.06 a	0.007±0.001 a	0.003±<0.001 b	0.003±0.002 a	0.027±0.001 a	0.001±0.001 a	0.02±<0.01 a
	<i>inermis</i>	4.27±0.24 a	0.010±0.001 a	0.003±<0.001 b	0.202±0.013 b	0.044±0.006 b	0.024±0.009 a	0.01±<0.01 a
	<i>pectinata</i>	6.23±0.14 b	0.012±0.003 a	0.003±<0.001 b	0.005±0.002 a	0.036±<0.001 ab	0.004±<0.001 a	0.03±0.01 b
	<i>talangensis</i>	4.32±0.25 a	0.023±0.014 a	0.0002±<0.0001 a	0.060±0.051 ab	0.043±0.003 b	0.011±0.005 a	0.04±0.04 ab
Soil			1.69±0.21	0.073±0.009	2.11±0.22	–	–	–

Values are mean ± standard error with letters indicating significant differences (at $p < 0.05$) with a Tukey's test

Population

In the plot area of 0.27 ha, only two individuals of *N. bongso* and *N. spathulata* were recorded whereas we found six individuals of *N. inermis*, 36 individuals of *N. pectinata* and nine individuals of *N. talangensis* (Table 1). Outside the plots, we also found one individual of *N. bongso* and 14 individuals of *N. talangensis*. Although *N. bongso*, *N. inermis* and *N. spathulata*, have very small populations, these three species can be found in other locations in West Sumatra, therefore, their conservation status, according to the IUCN, is classified as Least Concern. On the other hand, *N. pectinata* is found quite abundantly on Gunung Talang and is widespread in West Sumatra and North Sumatra (Cheek and Jebb 2001; Mansur et al. 2022a, 2023).

The *N. talangensis* population is very small and confined to Gunung Talang, therefore, the IUCN classifies it as an Endangered (C2b) species as assessed in 2000 (Clarke et al. 2000). At the time of this study, the population of *N. talangensis* was very small and threatened, with only 23 individuals found in the study site (nine individuals in the plot, 14 individuals outside the plot), therefore, we suggest

to increase the Red List status of the species to 'Critically Endangered' (A2a, B2a,b(v), C2b) with the necessity to carry out *ex-situ* conservation efforts by means of cultivation so that its population is maintained.

Habitat

At the study site, *Nepenthes* plants grew in primary forest with sloping to very steep topography on Andosol soils and the forest was slightly disturbed by humans. In a plot area of 0.27 ha, 35 tree species ($\varnothing \geq 5$ cm) were recorded, which were dominated by *Lithocarpus conocarpus* (Fagaceae), *Camellia lanceolata* (Theaceae) and *Syzygium acuminatisimum* (Myrtaceae) with IVIs of 47.2, 34.6 and 27.1%, respectively (Table 4).

Distribution and associations

Within the three plots, *N. inermis* and *N. talangensis* generally grow in clusters (Median Morisita's index was 5.5) while *N. pectinata* has a relatively broader and more randomly distribution (Morisita's index = 1.4) (there were

Table 4 List of tree species and their abundance in 0.27 ha of *Nepenthes* habitat on Gunung (Mount) Talang, Sumatra

Species	Family	BA (m ²)	RD (%)	RF (%)	RDo (%)	IVI (%)
<i>Lithocarpus conocarpus</i> (Oudem.) Rehder	Fagaceae	2.00	17.10	10.75	19.38	47.23
<i>Camellia lanceolata</i> (Blume) Seem	Theaceae	1.86	9.03	7.53	18.02	34.58
<i>Syzygium acuminatissimum</i> (Blume) DC	Myrtaceae	0.76	10.00	9.68	7.38	27.06
<i>Adinandra dumosa</i> Jack	Pentaphylacaceae	0.24	7.10	8.06	2.36	17.53
<i>Dehaasia</i> sp.	Lauraceae	0.35	6.45	6.99	3.35	16.79
<i>Podocarpus neriiifolius</i> D.Don	Podocarpaceae	1.09	1.61	2.69	10.52	14.82
<i>Litsea</i> sp.	Lauraceae	0.42	5.48	4.30	4.03	13.82
<i>Lithocarpus bancanus</i> (Scheff.) Rehder	Fagaceae	0.62	3.23	4.30	5.97	13.50
<i>Polyosma ilicifolia</i> Blume	Escalloniaceae	0.29	4.52	5.38	2.84	12.73
<i>Illicium tenuifolium</i> (Ridl.) A.C.Sm	Schisandraceae	0.16	6.13	4.84	1.57	12.54
<i>Exbucklandia populnea</i> (R.Br. ex Griff.) R.W.Br	Hamamelidaceae	0.64	0.97	1.61	6.24	8.82
<i>Castanopsis argentea</i> (Blume) A.DC	Fagaceae	0.42	2.58	1.61	4.11	8.31
<i>Drypetes</i> sp.	Putranjivaceae	0.12	3.87	3.23	1.15	8.24
<i>Garcinia celebica</i> L	Clusiaceae	0.17	2.90	2.69	1.67	7.26
<i>Gaultheria heterophylla</i> var. <i>latifolia</i> (Blume) Kron & P.W.Fritsch	Ericaceae	0.26	1.61	2.15	2.48	6.25
<i>Eriosolena composita</i> (L.f.) Tiegh	Thymelaeaceae	0.03	2.90	2.69	0.27	5.86
<i>Xanthophyllum</i> sp.	Polygalaceae	0.26	0.97	1.61	2.54	5.12
<i>Leptospermum javanicum</i> Blume	Myrtaceae	0.12	1.61	1.61	1.18	4.41
<i>Illicium sumatranum</i> A.C.Sm	Schisandraceae	0.05	1.61	2.15	0.52	4.29
<i>Neolitsea cassifolia</i> (Blume) Merr	Lauraceae	0.02	1.61	2.15	0.18	3.95
<i>Symplocos</i> sp.	Symplocaceae	0.02	1.29	2.15	0.20	3.64
<i>Heptapleurum</i> sp.	Araliaceae	0.19	0.65	1.08	1.83	3.55
<i>Pterophylla fraxinea</i> D.Don	Cunoniaceae	0.04	0.87	1.62	0.40	2.98
<i>Elaeocarpus</i> sp.	Elaeocarpaceae	0.04	0.97	1.61	0.36	2.95
<i>Magnolia sumatrana</i> var. <i>glauca</i> (Blume) Figlar & Noot	Magnoliaceae	0.04	0.97	1.08	0.43	2.47
<i>Dacrycarpus imbricatus</i> (Blume) de Laub	Podocarpaceae	0.02	0.65	1.08	0.22	1.94
<i>Melicope accedens</i> (Blume) T.G.Hartley	Rutaceae	0.02	0.65	1.08	0.21	1.93
<i>Engelhardia spicata</i> Lechen ex Blume	Cunoniaceae	0.01	0.65	1.08	0.12	1.84
<i>Rhodoleia championii</i> Hook	Hamamelidaceae	0.02	0.32	0.54	0.15	1.01
<i>Thomsonaria corymbifera</i> (Miq.) Rushforth	Rosaceae	0.01	0.32	0.54	0.13	0.99
<i>Wendlandia densiflora</i> (Blume) DC	Rubiaceae	0.01	0.32	0.54	0.08	0.94
<i>Fagraea blumei</i> G.Don	Gentianaceae	<0.01	0.32	0.54	0.03	0.89
<i>Cinnamomum</i> sp.	Lauraceae	<0.01	0.32	0.54	0.03	0.89
<i>Timonius wallichianus</i> Valetton	Rubiaceae	<0.01	0.32	0.54	0.02	0.88
Sum		10.33	100.00	100.00	100.00	300.00

BA Basal Area, RD Relative Density, RF Relative Frequency, RDo Relative Dominance, IVI Importance Value Index

insufficient individuals of *N. bongso* and *N. spathulata* to examine their distribution) (Table 1 and Fig. 3). *Nepenthes inermis* grows epiphytically on fallen tree trunks in gaps with open canopies on hilltops or small cliffs. *Nepenthes talangensis* lives sympatrically with *N. bongso* and *N. inermis* with a high to very high index of association (Table 5), therefore, hybrid species among these species were found at the study site, namely *N. talangensis* × *N. bongso* and *N. talangensis* × *N. inermis*, also known as *N. × pyriformis* (Clarke 2001) (Fig. 4). The Ochiai Index showed that *N. talangensis* was positively associated with

N. bongso and *N. inermis* as well as with other species such as *Lithocarpus conocarpus* and *Podocarpus neriiifolius* (Table 5), it was strongly associated with *Dehaasia* sp. in Plot 1 but not Plot 2. In Plot 3, *N. pectinata* had positive associations with four species with a very high Ochiai index (Table 5). The clumped distribution of *Nepenthes* is likely due to similar habitat requirements for e.g. light or sufficiently moist soil. The more random distribution of *N. pectinata* suggests less precise habitat requirements which may also be a reason for its broader distributional range across Sumatra. Associations between species illustrate

Fig. 3 a, b and c *Nepenthes* distribution in three 0.09 ha plots on Gunung Talang, West Sumatra, Indonesia. Open circles show locations of each tree species with larger circles indicating trees of larger diameter. Coloured circles indicate locations of *Nepenthes* individuals of different species

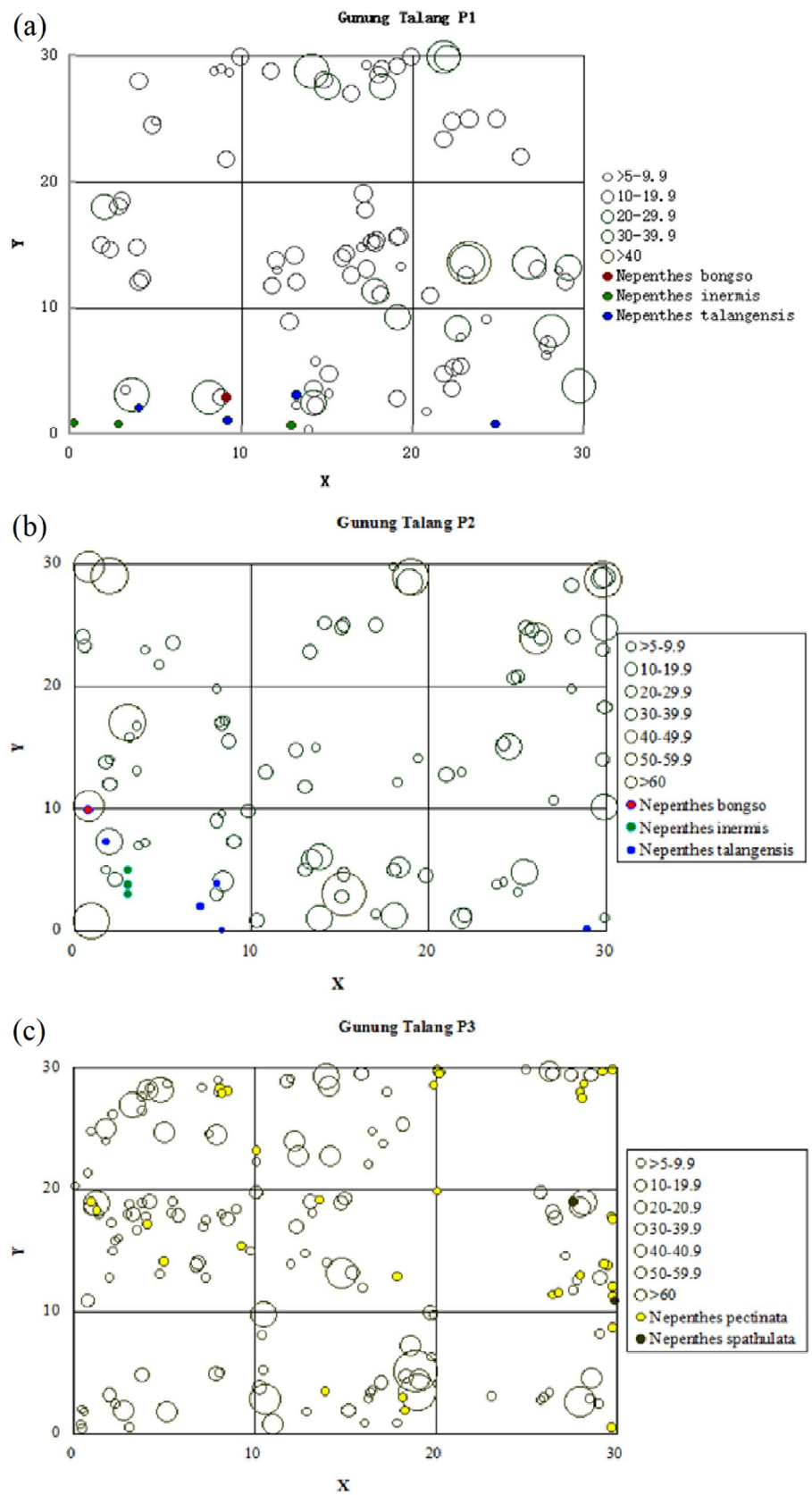


Table 5 Chi-square (χ^2) and Ochiai Index (OI) values showing associations between *Nepenthes talangensis* (Plots 1 and 2) and *Nepenthes pectinata* (Plot 3) with other *Nepenthes* species and the ten tree species with the greatest IVIs (See Table 4) on Gunung (Mount) Talang (Sumatra)

	Plot 1: Association with <i>N. talangensis</i>		Plot 2: Association with <i>N. talangensis</i>		Plot 3: Association with <i>N. pectinata</i>	
	Chi-squared (χ^2)	Ochiai Index (OI)	Chi-squared (χ^2)	Ochiai Index (OI)	Chi-squared (χ^2)	Ochiai Index (OI)
<i>Nepenthes bongso</i>	+	0.58 (High)	+	0.71 (High)	Absent	Absent
<i>Nepenthes inermis</i>	+	0.82 (Very high)	+	0.71 (High)	Absent	Absent
<i>Lithocarpus conocarpus</i>	+	0.82 (Very high)	+	0.50 (High)	+	0.41 (Low)
<i>Camellia lanceolata</i>	Absent	Absent	–	0.27 (Low)	+	0.80 (Very high)
<i>Syzygium acuminatissimum</i>	+	0.47 (Low)	–	0.29 (Low)	+	0.63 (High)
<i>Adinandra dumosa</i>	+	0.47 (Low)	+	0.58 (High)	+	0.35 (Low)
<i>Dehaasia</i> sp.	+	0.82 (Very high)	–	0.29 (Low)	+	0.71 (High)
<i>Podocarpus neriifolius</i>	+	0.82 (Very high)	+	0.50 (High)	+	0.35 (Low)
<i>Litsea</i> sp.	–	0.00 (Very low)	Absent	Absent	+	0.80 (Very high)
<i>Lithocarpus bancanus</i>	Absent	Absent	–	0.41 (Low)	+	0.79 (Very high)
<i>Polyosma ilicifolia</i>	+	0.52 (High)	+	0.50 (High)	+	0.61 (High)
<i>Illicium tenuifolium</i>	+	0.52 (High)	Absent	Absent	+	0.80 (Very high)

**Fig. 4** a *Nepenthes bongso* × *N. talangensis* and b *Nepenthes inermis* × *N. talangensis* found on Gunung (Mount) Talang (Sumatra) (Photo a by M. Mansur, photo b by Daniel Ferdinan)

that they have a similar ecological niche, which can cause their spatial patterns to be clustered in a habitat (Mueller-Dombois & Ellenberg 1974). Positive associations could be due to similar requirements for (or responses to) a limiting resource, or through species enhancing each other's fitness when in close association such as through facilitation (Mousaei Sanjerehei and Rundel 2020). In the case of the associations between *N. talangensis* and *L. conocarpus* and *P. neriifolius* this might be because of similar substrate requirements, lack of strong interspecific competition or through the trees enhancing growth of the *Nepenthes* plants; either way, further research on the possible reasons would be interesting.

Table 6 Growth rates of five *Nepenthes* species in their natural habitat in Gunung (Mount) Talang (Sumatra) over an eleven month period (Nov 2021 to Oct 2022). Values are mean ± standard error

<i>Nepenthes</i>	<i>n</i>	No. of new leaves produced	Length of new stem produced (cm)
<i>bongso</i>	2	6.5 ± 0.5	20.3 ± 11.7
<i>inermis</i>	2	6.5 ± 0.5	22.3 ± 0.3
<i>pectinata</i>	5	8.6 ± 1.4	43.6 ± 3.6
<i>spathulata</i>	1	4	34
<i>talangensis</i>	7	7.3 ± 1.1	23.3 ± 6.4
<i>bongso</i> × <i>talangensis</i>	1	8	38

Growth rates

Growth rates of the five species (and one hybrid) were not significantly different from one another (Leaves: $F = 0.60$, $p = 0.70$; Stem: $F = 1.75$, $p = 0.20$; Table 6); stem and leaf growth rates were correlated with each other across the taxa ($r = 0.48$, $p = 0.044$). This is in contrast to data from lowland forest of Central Kalimantan where it was found that different *Nepenthes* species had quite contrasting growth rates and it seemed that species that either produced longer stems with more leaves or produced thicker stems instead (Mansur and Brearley 2008).

Nutrient concentrations

Nitrogen (N) concentrations in the leaves of *N. bongso*, *N. inermis*, *N. pectinata* and *N. talangensis*, were generally low, with a mean of 1.14% and not significantly different

between species; similarly phosphorus (P) and calcium (Ca) concentrations did not differ between species. Potassium (K) was greatest in *N. pectinata* whereas magnesium (Mg) was greater in *N. inermis* than *N. bongso* and sodium (Na) was greater in *N. talangensis* than *N. bongso*. The mean N:P ratio was 11.7 ± 1.74 and did not differ among species. These concentrations all fell within the range of those already reported in Mansur et al. (2021, 2022b). The most abundant elements in the pitcher fluid were K (albeit very variable) and Ca as found in previous studies (Buch et al. 2013; Mansur et al. 2021). Concentrations of K and Ca in *N. inermis* pitcher fluid were greater than in other species—possibly related to its highly viscous fluid (Salmon 1993).

Conclusions

We here describe the ecology of five species of *Nepenthes* found on Gunung Talang in Sumatra including spatial patterns and associations along with leaf and pitcher nutrient concentrations. *Nepenthes talangensis* is an endemic species found only on Gunung Talang which needs to be immediately conserved considering its very small population that is threatened by over-harvesting by collectors for commercial purposes. The habitat of *Nepenthes* on Gunung Talang is still in quite good condition although conservation efforts can be improved.

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Data availability Not applicable.

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