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Demographic Study of *Nepenthes* Species (Nepenthaceae) Recorded along the Trail to the Summit of Mount Kinabalu in Sabah, Malaysia

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Abstract: A total of 1255 pitcher plants belonging to two species were recorded from 11 plots set between 2610 m to 2970 m altitude on Mount Kinabalu, each with an area of 0.01 hectare. Of these plants, 1180 (94%) belonged to *Nepenthes villosa*, followed by *N. kinabaluensis* contained 75 (6%) plants. The density of *N. villosa* and *N. kinabaluensis* ranged from 0 to 260 and 0 to 65 plants respectively. *Nepenthes villosa* was recorded absent in P5, whereas *N. kinabaluensis* was recorded in P2, P3 and P11. Differences in density of both species between the study plots is influenced by combination of factors, which include topography, soil, habitat, different light intensities reaching the forest floor and water deficient due to exposure to wind and light intensities at higher altitudes. The I_d values were greater than 1 for both species in all plots showing contagious dispersion pattern. Size class distribution and population structure varied for both species between plots. Generally there were more seedlings and juveniles than mature plants of both species at different elevations indicating regenerating populations. In mature plants there were more male than female plants in both species.

Key words: Sabah, Mount Kinabalu, Malaysia, *Nepenthes villosa, N. kinabaluensis*, plot, altitude, population structure, dispersion pattern

Introduction

Nepenthes plant can regenerate either by vegetative shoots or seeds. The seedling has a rosette of leaves and each leaf normally bears a pitcher at its tip. Secondary rosettes also form on the stem and from the base of the stems. These rosette stage may persist for two or three years (Green, 1974); only when the stem produces leaves of full size does it begin to grow rapidly in length (Holttum, 1954) and in most species the internodes gradually lengthen with increasing age attaining 20-30 cm in length when the plant is upright. At this stage the plants only produce ground pitchers and no inflorescence. Later, the stem elongates continuously and, with the support of strong curled tendrils, it may climb up trees and begin to produce aerial pitchers which depending on species are similar or different in shape to the lower pitchers. Species capable of growing in both closed, tall canopy forest and in open habitats or in secondary vegetation, for example, *Nepenthes ampullaria, N. bicalcarata, N. macrovulgaris, N. gracilis* and *N. rafflesiana* may climb to more than 10 m tall and equal the length of the tree canopy. In open habitats, species, such as *N. ampullaria, N. bicalcarata*, may flower when a few meters tall whereas it is capable of growing to 30 m tall in dipterocarp forest. If the stem fails to find the support, for example, in *N. ampullaria* and *N. gracilis*, the stem lies on the ground, rooting abundantly at the nodes, and producing short lateral branches with dense clusters of leaves with reduced laminas and large pitchers (Macfarlane, 1908). The switch from the lower to upper pitcher type appears usually to coincide with the onset of flowering (Juniper *et al.*, 1989).

The main objectives of my study were to identify the species composition and density of *Nepenthes* recorded from the study plots, and, secondly, to determine the dispersion pattern, size class distribution and population structure of each of *Nepenthes* species recorded.

Materials and Methods

In order to accomplish the objectives of this study, a total of eleven plots, all of uniform sizes, each measuring 10 x 10 m^2, was set up along the summit trail of Mount Kinabalu from 2610-2970 m altitude. Each of the plot was subdivided into twenty five subplots, each measuring 2 x 2 m^2. The division of larger plot was necessary to determine the spatial pattern of arrangement of individuals in the population also known as the dispersion or population distribution (Brower & Zar, 1977).

In this study, all individual plants of *Nepenthes* in each plot were identified to species in the field and mapped to scale on graph paper. Every pitcher plant mapped was numbered using a plastic tag. Stem length, number of leaves and number of pitchers were measured for each plant. The life stage of each plant was recorded (Table 2) namely the seeding stage (SC1), the juvenile stage, the upright plant capable of producing only ground pitchers (SC2-SC3), the mature sterile plant which produce both upper and lower pitchers but is not reproductive (SC4-SC8), and the mature fertile male and female plant. This arbitrary classification was necessary to avoid confusion and to ease the enumeration of plants found within the study plots.

The dispersion pattern of *Nepenthes* population was computed using Morista 's Index of Dispersion (I_d), and the departure of an observed dispersion pattern from randomness was assessed statistically using Chi-square (χ^2) test (Brower & Zar, 1977).

Results and Discussion

Population density: A total of 1255 pitcher plants representing two different species were enumerated from eleven study plots (2610-2970 m) on the summit trail of Mount Kinabalu (Tables 1 and 2). Two of these species were *Nepenthes villosa* and *N. kinabaluensis*. The altitude range of these two species differed. *N. villosa* occupied a wider altitudinal zone (2610-2970 m), whereas *N. kinabaluensis* was found in a narrow altitudinal zone (2645-2790 m).

The population of *N. villosa* is larger than that of *N. kinabaluensis* with total of 1180 (94%) plants compared with 75 (6%) of *N. kinabaluensis*. *Nepenthes villosa* was present in 10 of the 11 plots sampled. Both species were absent in plot 5 at 2750 m altitude. The number and percentage of *N. villosa* plant present in each plot varied considerably from 156 (13.2%) to 260 (22.1%) in P3, P4, P6, P7 and P8, to less than 10 (8.5%) plants in P1, P2, P9, P10 and P11, and it was absent in P5 (Table 1). On the other hand, *N. kinabaluensis* with a narrow altitudinal distribution range was found only in P2, P3 and P11 with 65 plants (86.5%) of the population in P11 and only 6 and 4 plants in P2 and P3 respectively. Principal component analysis (PCA) showed that P5 (2750 m) set on Mount Kinabalu has higher tree species diversity, no moss cover, steeper slope, no exposed rocked faces, the tallest tree, a higher tree basal area and deeper soil (Fig. 13a-f). The forest above and below P5 has lower tree

Table 1: The I_d, χ^2 goodness of fit test, density and dispersion pattern of *N. villosa* and *N. kinabaluensis* in 11 sampling plots from Summit Trail, Mount Kinabalu in Sabah

*Plot	Species	SP	Alt (m)	I_d	X^2	$X^2_{0.05,\ 24}$	D	DP
1	*N. villosa*	25	2610	1.31	39.7	36.4	45.0	C
2	*N. villosa*	25	2645	2.17	68.7	36.4	50.0	C
3	*N. villosa*	25	2680	2.33	393.0	36.4	260.0	C
4	*N. villosa*	25	2710	1.08	37.6	36.4	176.0	C
5	*N. villosa*	25	2750	0.00	0.0	36.4	0.0	0
6	*N. villosa*	25	2830	2.38	114.0	36.4	156.0	C
11	*N. villosa*	25	2790	2.84	316.0	36.4	70.0	C
7	*N. villosa*	25	2875	2.24	229.0	36.4	175.0	C
8	*N. villosa*	25	2910	1.88	159.0	36.4	155.0	C
9	*N. villosa*	25	2940	9.00	216.0	36.4	9.0	C
10	*N. villosa*	25	2970	1.84	93.2	36.4	85.0	C
2	*N. kinabaluensis*	25	2645	6.67	52.3	36.4	6.0	C
3	*N. kinabaluensis*	25	2680	25.00	96.0	36.4	4.0	C
11	*N. kinabaluensis*	25	2790	1.30	43.8	36.4	65.0	C

*Plot: Size of all plot sampled was 10 x 10 m^2; SP= All plots were divided into 25 subplots, each with 2 x 2 m^2 in size; D = Density; DP = Dispersion pattern.

Table 2. Size class distribution of *N. villosa* and *N. kinabaluensis* for 11 sampling plots on Summit Trail of Mount Kinabalu

P		Sp.	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	STR	MP	FP	Σ
1	NV	No.	19.0	12.0	5.0	6.0	0.0	0.0	0.0	0.0	42.0	1.0	3.0	45
		%	41.8	26.9	11.5	13.2	0.0	0.0	0.0	0.0	95.6	1.2	2.4	100
2	NV	No.	40.0	8.0	1.0	0.0	0.0	0.0	0.0	0.0	49.0	0.0	1.0	50
		%	80.0	16.0	2.0	0.0	0.0	0.0	0.0	0.0	98.0	0.0	2.0	100
3	NV	No.	100.0	46.0	18.0	28.0	23.0	10.0	10.0	13.0	247.0	10.0	3.0	260
		%	39.0	17.9	17.1	10.9	9.0	3.9	4.0	5.1	95.3	3.8	1.04	100
4	NV	No.	44.0	26.0	29.0	17.0	17.0	15.0	7.0	8.0	162.0	8.0	2.0	172
		%	25.9	15.6	16.8	10.2	10.2	9.0	4.4	4.8	95.0	4.6	1.2	100
5	NV	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
5	NK	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
11	NV	No.	18.0	74.0	0.0	61.0	0.0	0.0	0.0	0.0	153.0	2.0	1.0	156
		%	11.5	47.4	0.0	39.1	0.0	0.0	0.0	0.0	98.0	1.3	0.7	100
7	NV	No.	60.0	45.0	25.0	13.0	9.0	5.0	2.0	4.0	161.0	7.0	7.0	175
		%	33.9	25.5	14.1	7.4	5.1	2.8	1.1	2.2	92.0	4.0	4.0	100
8	NV	No.	44.0	37.0	28.0	11.0	4.0	1.0	2.0	1.0	125.0	15.0	15.0	155
		%	26.9	23.7	17.9	7.0	2.6	0.6	1.2	0.6	84.4	7.8	7.8	100
9	NV	No.	7.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	9
		%	77.8	0.0	0.0	22.2	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100
10	NV	No.	13.0	12.0	9.0	6.0	11.0	6.0	5.0	11.0	73.0	12.0	0.0	85
		%	20.2	14.4	10.8	7.2	12.2	7.2	5.0	2.4	85.5	14.5	0.0	100
AP	NV	No.	360.0	264.0	123.0	153.0	69.0	40.0	30.0	53.0	1092.0	55.0	33.0	1180
		%	32.4	23.8	11.1	13.7	6.3	3.6	2.8	4.8	92.0	5.0	3.0	100
2	NK	No.	3.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0	1.0	6
		%	49.8	0.0	16.6	0.0	0.0	0.0	0.0	0.0	66.4	16.6	16.6	100
3	NK	No.	1.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	3.0	1.0	0.0	4
		%	25.0	0.0	25.0	0.0	0.0	0.0	0.0	25.0	75.0	25.0	0.0	100
11	NK	No.	8.0	27.0	0.0	20.0	0.0	0.0	0.0	0.0	55.0	10.0	0.0	65
		%	12.0	40.5	0.0	32.0	0.0	0.0	0.0	0.0	84.5	15.5	0.0	100
AP	NK	No.	13.0	27.0	2.0	20.0	0.0	0.0	0.0	0.0	62.0	12.0	1.0	75
		%	17.3	36.0	2.6	36.7	0.0	0.0	0.0	0.0	82.6	16.0	1.4	100

P- Plot; Sp.- Species; STR- Sterile plant; MP- Male plant; FP- Female plant; SC- Size class; SC1:10.1-20 cm (seedling); SC2: 20.1-40cm (Juvenile); SC3: 40.1-60 cm (Juvenile); SC4: 60.1-100 cm (mature sterile); SC5: 100.1-140 cm (mature sterile); SC6: 140.1-180 cm (mature sterile); SC7: 180-250 cm (mature sterile); SC8: > 250 cm (mature sterile); No.- Number of plants; %- percentage; AP – Total number of plants recorded from all sampling plots; NV- *N. villosa*; NK – *N. kinabaluensis*

Table 3: Summary of characteristics of 11 sampling plots on the summit trail of Mount Kinabalu

P	Alt (m)	Slope (deg)	Aspect (deg)	RF (%)	GC (%)	MC (%)	MH (m)	BA (cm^2)	SH HM (cm)	SH BS (cm)	SH BRS (cm)
1	2610	30	230	29	20	49	4.7	1012	10	0	5
2	2645	10	300	17	23	52	2.0	2297	4-8	0	16-27
3	2680	10	270	5	38	56	3.3	2416	9-20	0	15-20
4	2710	34	210	0	95	5	4.2	3413	3-9	0	22-20
5	2750	24	210	0	8	0	6.1	5158	4-7	4-11	20-25
11	2790	20	120	0	95	4	5.1	3724	-	-	-
6	2830	24	330	0	20	17	5.4	4562	3-9		17-22
7	2875	14	230	0	95	0	2.8	2736	5-17	0	26-40
8	2910	8	210	0	80	12	2.6	1756	-	-	-
9	2940	16	240	95	4	1	2.2	1548	2-7	-	14-18
10	2970	10	320	0	99	0	3.9	4884	1-2	0	19-25

RF- Exposed rocked faces; GC- Undergrowth cover; MC- Moss cover; MH- Mean tree height; BA- Basal area of tree; SH – Soil horizon; HM- Humus; BS- Black soil; BRS – Brown soil; P- plot.

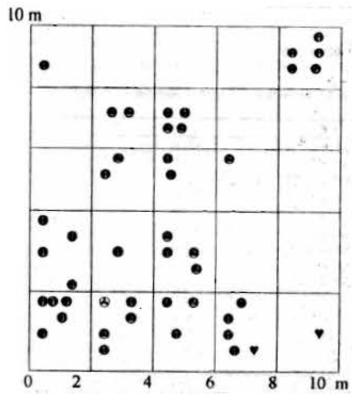

Fig. 1: CDP of *NV* in P1 (2610 m) on MK

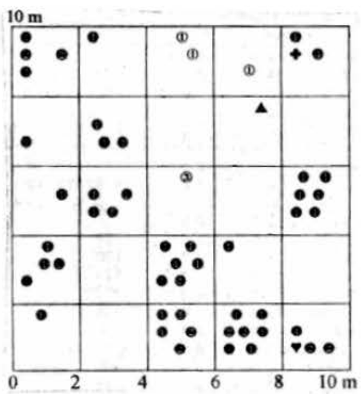

Fig. 2: CDP of *NV* (filled circle) and NK in P2 (2645 M) on MK.

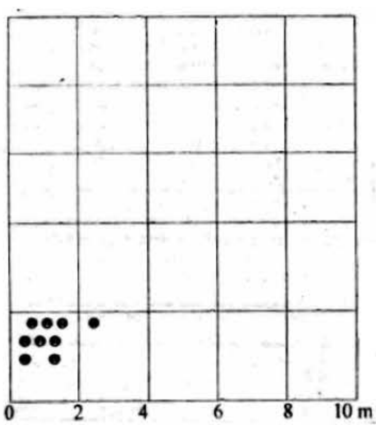

Fig. 3: CDP of *NV* in P9 (2940 m) on MK.

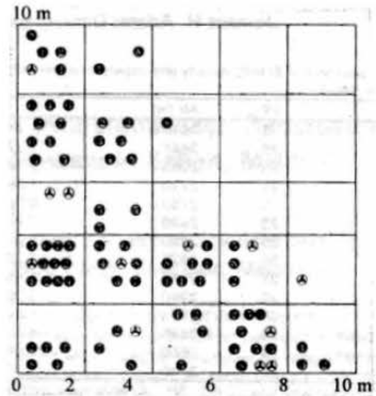

Fig. 4: CDP of *NV* in P10 (2970 m) on MK.

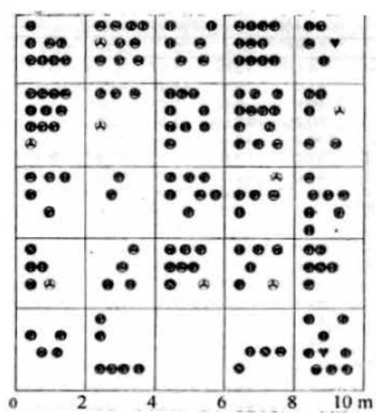

Fig. 5: CDP of *NV* in P4 (2710) on MK.

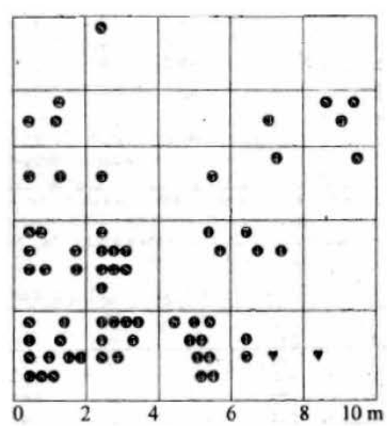

Fig. 6: CDP of *NV* in P6 (2830 m) on MK.

species diversity, often mossy, shallow slopes, sometimes rocky, tree shorter with low basal area, shallow soil depth and abundance of *N. villosa* and *N. kinabaluensis*.

The highland pitcher plants are more conspicuous in mossy forest and mountain ericaceous forest (Smythies, 1965). *Nepenthes villosa* and *N. kinabaluensis* are confined to forests on ultrabasic soils and results of this study confirm the earlier studies (Adam *et al.*, 1989, 1992, 1994; Adam and Wilcock, 1996; Kurata, 1976; Phillipps and Lamb, 1988). Pitcher plants are rare or absent in oak forest or in closed canopy, deeply shaded forests at high elevations. Adam (1997) demonstrated that pitcher plants growing in the infertile soil supplement nutrients by trapping animals especially insects. The absence or rare occurrence of pitcher plants in closed canopy forest at higher elevation is due to light and soil factors (Smythies, 1965; Adam *et al.*, 1994; Adam, 1995).

Differences in the density of *N. villosa* and *N. kinabaluensis* in the 11 study plots on Mount Kinabalu are influenced by

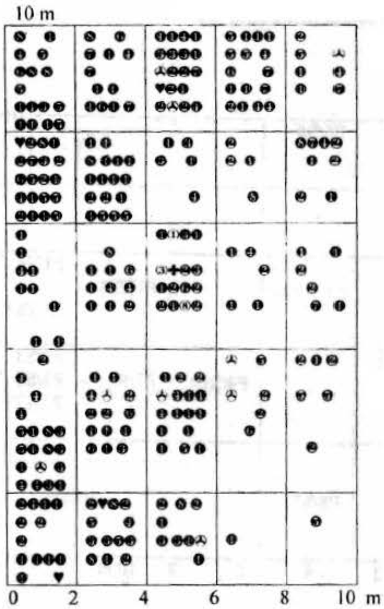

Fig. 7: CDP of *NV* and NK in P3 (2680 m) on MK.

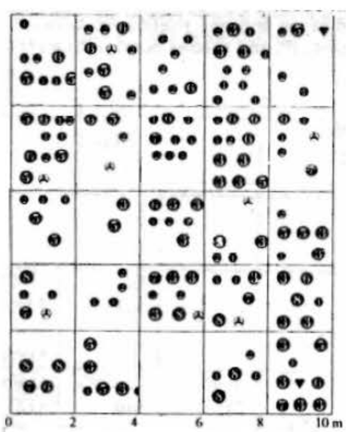

Fig. 8: CDP of NV in P4 (2710 m) on MK.

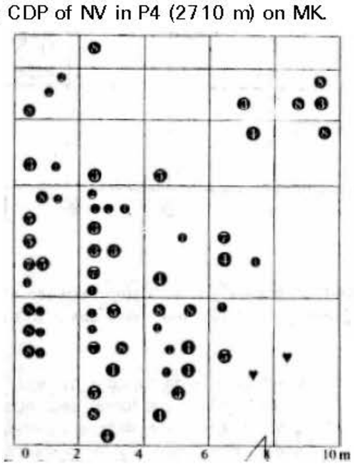

Fig. 9: CDP of NV in P6 (2830 m) on MK.

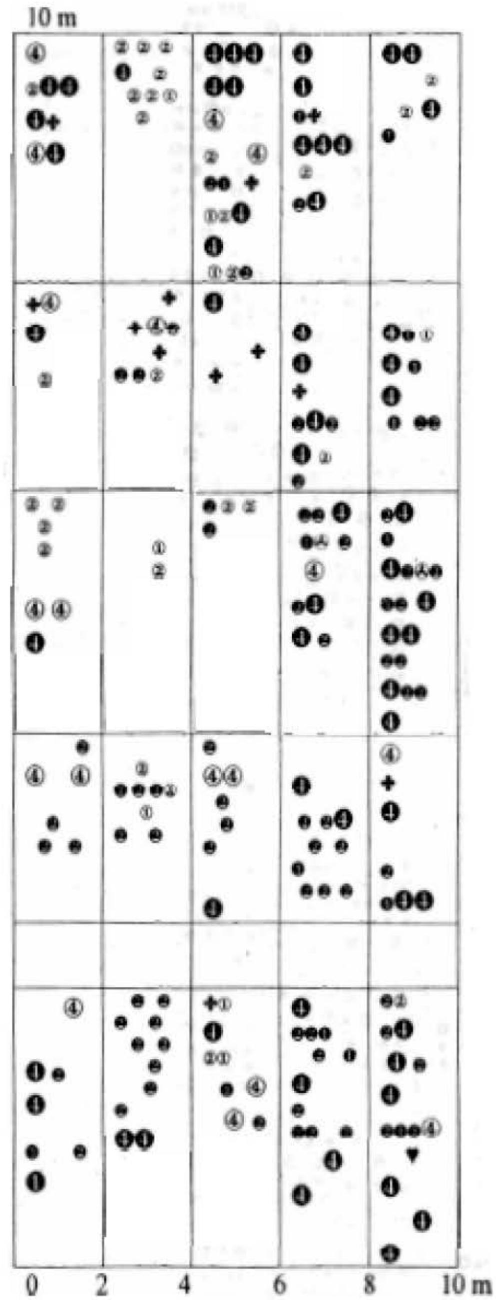

Fig. 10: CDP of NV and NK in P11 (2790 m) on MK

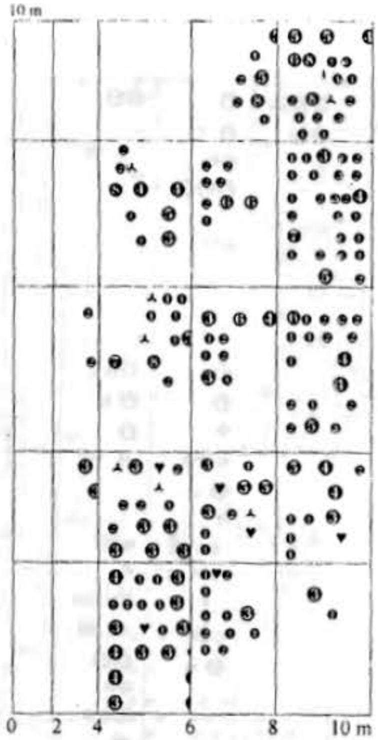

Fig. 11: CDP of *NV* in P7 (2875 m) on MK.

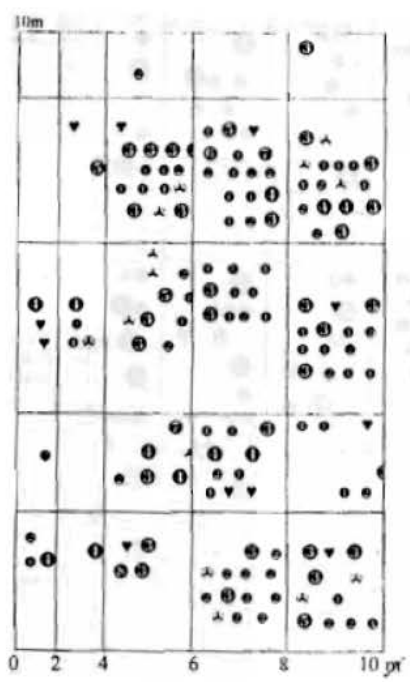

Fig. 12: CDP of NV in P8 (2910 m) on MK.

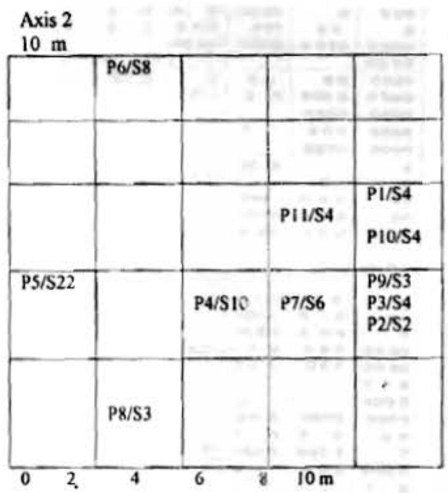

Fig. 13a: PCA ordination showing relationship between altitude (alt) of plots (P) and species number (S) on MK.

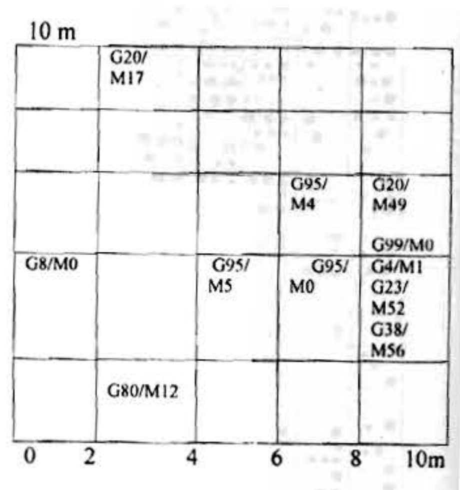

Fig. 13b: PCA ordination showing relationship between alt. Of P and % ground cover (G) and moss cover (M) on Mt. Kinabalu.

a combination of factors, which include topography, soil, habitat and different light intensities reaching the forest floor due to the density and forest canopy height and water deficient particular for plots located on exposed ridge, due to both the high rate water loss from the soil, constant exposure to wind from the western part of the island, and high light intensities at high

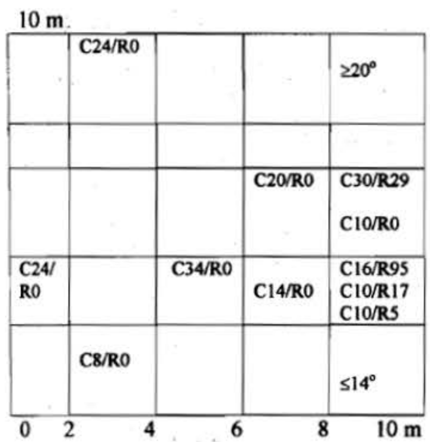

Fig. 13c: PCA ordination showing relationship between alt. Of P and slope ©and % of rock faces on MK.

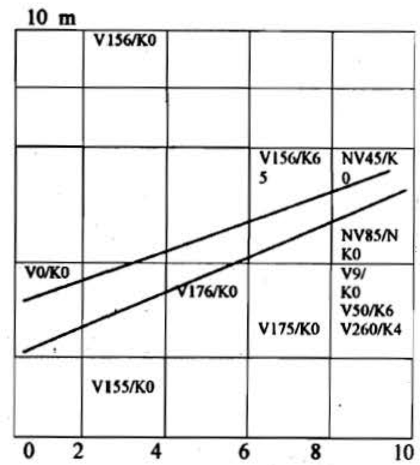

Fig. 13e: PCA ordination showing relationship between altitudes and density of *N. villosa* (V) and N. Kinabaluensis (K) in plots on Mt. Kinabalu.

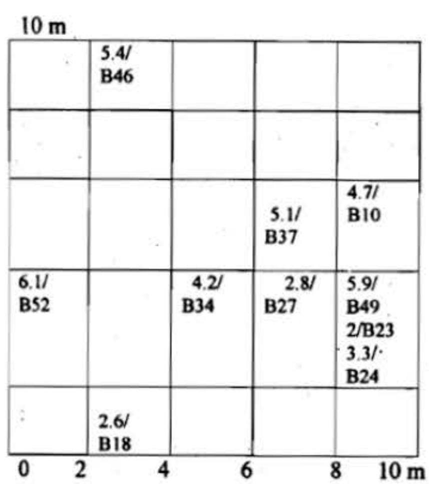

Fig. 13d: PCA ordination between alt., tree height, basal area (B) (m^2) on MK.

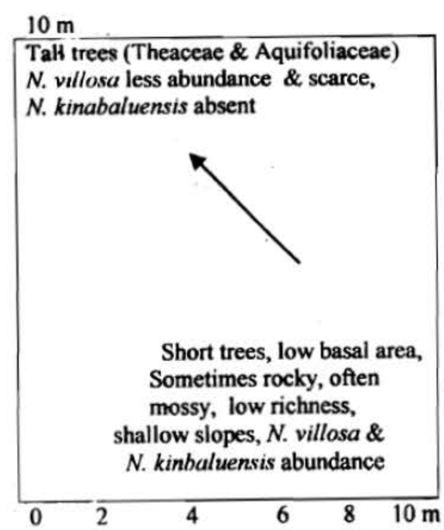

Fig. 13f: PCA ordination showing relationship between observed ecological factors and altitude on Mt. Kinabalu

altitudes. The absence of these two species in P5 is related to very high tree basal area (BA= 52 m^2) and, the plot is located below the ridge thus the area is not exposed to wind and high light intensity. The tree species in the plot are tall with a dense canopy that permits little light to reach the forest floor thus may deter the germination of seeds of these two species or their growth (Som, 1988).

Factors such as shallow soil and exposed rock, lack of forest floor vegetation create unfavorable dry conditions for the growth of *N. villosa* in P9 and vice versa in P3, P4, P11, P7 and P8 where plants show a strong tendency to grow well in parts of the plot with a gentle terrain, deep soil profile, presence of floor vegetation cover and moss cover, which create moist conditions at ground level, thin forest canopy that allows a certain amount of light to reach the forest floor, required for germination and growth of pitcher plants (Table 3). *Nepenthes villosa* was totally absent in parts of the plots with very dense undergrowth cover, and a dense canopy. The observations clearly show that lights is one of the important factors required for the establishment of *Nepenthes villosa*.

Som (1988) reported that the high humidity and moist conditions are the two factors, favoring growth of *Nepenthes* species. In P1, *N. villosa* population comprised mostly of small plants (Fig. 1). Factors that may deter or slow down the growth and account for the low density of these plants include steep slopes, active erosion, shallow soils and a high percentage of barren rock faces (Fig. 2). In this plot, *N. villosa* grew in the limited area of land on well developed soil. The poor establishment of *N. villosa* and *N. kinabaluensis* in P2 were due to water deficiency due to the constant wind exposure and high light intensity on the summit of exposed ridge (Fig. 2). In P3, fewer *N. villosa* was recorded from the shaded and steep section of the plot, but was commonly on the gentle section (Fig. 7). The influence of topography on the establishment of *N. villosa* plants was evident in P4 (Fig. 8), P6 (Fig. 9), P7 (Fig. 11), P10 (Fig. 4), and P11 (Fig. 9), where plants tend to grow on the gentle section of the plot with forest opening. It was absent from steep slopes (34°) and shallow gullies. In these areas of the plot, erosion was active thus preventing the development of the soil and the establishment of pitcher plants.

The ultrabasic endemics are characterized by being able to obtain calcium even at low concentration, being the characteristic of these sites; the heavy metal ion concentration may serve to exclude competitors, rather than providing a specific need for endemic (Kruckenberg, 1954). Brooks (1987) explained the unusual floristic composition and poor species composition of forest on ultrabasic formation as attributable to the "serpentine factor" which includes chromium, nickel and magnesium toxicity, and low calcium content and other nutrient deficiencies. This study shows that *N. kinabaluensis*, particularly *N. villosa* which are found on ultrabasic soil, associated with *Leptospermum recurvum*. It is known that *L. scoparium* recorded from ultrabasic area in New Zealand has a high calcium content (Lyon *et al.*, 1971) that reduces chromic ion toxicity (Brooks, 1987; Proctor, 1971). This may explain its tolerance to serpentine soils (Brook, 1987). A similar explanation may be applicable but research is needed to explain the successful establishment of *N. villosa, N. kinabaluensis* and *L. recurvum* on Mt. Kinabalu.

Dispersion pattern: Table 1 summarizes the results on density and dispersion pattern of *N. villosa* and *N. kinabaluensis* enumerated from 11 plots using Morista's Index of Dispersion (I_d) and Chi-square test (χ^2). The actual dispersion pattern of these species is illustrated in Fig. 1-12.

The I_d values *N. villosa* in 10 of the 11 plots were all greater than 1, ranging from 1.08 (P4; 2710 m) to 9.00 (P10, 2940 m). I_d values greater than 1 indicate the contagious dispersion pattern of *N. villosa* populations (Brower and Zar, 1977). The χ^2 for *N. villosa* in all plots ranged from 37.60 (P4) to 229.3(P7), and χ^2 values of all plots were greater than $X^2_{0.05,\ 24}$= 36.4. These results show the dispersion pattern of *N. villosa* in the study plots was significantly different from random. Since their I_d values were greater than 1, the dispersion pattern of *N. villosa* in these plots is therefore contagious (Fig. 1-12). Following the same argument, the dispersion pattern for *N. kinabaluensis* populations recorded in P3 (2680 m), P11 (2790 m) and P2 (2645 m). Factors influencing the contagious pattern of distribution of *N. villosa* and *N. kinabaluensis* include gentle terrain, deep soil profile, low tree basal area, low tree height which allow enough light to reach the forest floor, presence of undergrowth and moss cover that create a wet and humid soil environment.

Size class distribution (SCD): The stem length of two species present in the plots were grouped into eight size classes (Table 2). In a regenerating population, larger number of plants fall within the small size classes, with increasing size representing successive mortality as the plants grow older. The SCD of *N. villosa* and *N. kinabaluensis* on the summit trail on Mount Kinabalu were similar (Table 2). Both show a general decline in number with increasing size. Populations with few seedlings could be interpreted as being in decline.

Population structure: *Nepenthes* populations comprise of individual plants of different ages or life stages. In this study, four life stages were recognized namely seedlings (SC1), juvenile (SC3-SC4), mature sterile (SC4-SC8), matured fertile (Table 2). Pitcher plants are dioecious, male and female flowers are borne on different plants.

Populations of *N. villosa* and *N. kinabaluensis* had relatively larger number of seedlings and juvenile plants compared to mature sterile. Thus the populations of these two species at different elevations on this mountain are regenerating. The mature sterile have low number of fertile plants. There are more male than female plants in *N. villosa* and *N. kinabaluensis* with a ratio of 5:3 and 12:1. The higher number of male plants than the female plants may possibly be a reproductive strategy of both species as to ensure the ample pollens produced by the hundreds of male flowers in each inflorescence successfully pollinate the thousands of ovules in the flowers on female inflorescence. Large number of female plants are not vital since each female inflorescence is capable of producing thousands of seeds.

Nepenthes villosa and *N. kinabaluensis* were recorded in plots from altitude 2610-2970m and 2645-2790 m respectively located on ultrabasic rock formation on Mount Kinabalu. The population density of these two species varied considerably between plots. These differences may be attributed to a combination of local factors which include light intensity, soil, topography, slope inclination, erosion processes due to steep slopes, rock faces, and lack of vegetation cover. The dispersion pattern of both species in the plots studied was significantly contagious. The SCD of stems showed considerable variation between species; generally larger number of plants fell into small size class with a decline with increasing size, indicating regenerating population. Population structure generally comprised a low number of fertile plants with more male plants than female and a larger number of seedlings and juvenile plants compared to matures plants.

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Key to Fig. 1-13:
MK- Mount Kinabalu; NV-*N. villosa*; NK-*N. Kinabaluensis*; CDP-Contagious Dispersion Pattern
①❶ : 1-10 m ②❷: 10.1-40 cm ③❸ : 40.1-60 cm ④❹ : 60.1-100 cm ⑤❺ : 100.1-140 cm ⑥❻ : 140.1-180 cm
⑦❼ : 180.1-250 cm ⑧❽ : 250.1-500 cm. ☮ Male plant bearing male inflorescence ♥: Female plant bearing female inflorescence