WHAT IS THE MINIMUM AREA NEEDED TO ESTIMATE THE BIODIVERSITY OF PTERIDOPHYTES IN NATURAL AND MAN-MADE LOWLAND FORESTS IN MALAYSIA AND SINGAPORE?

F.B. YUSUF[1], B.C. TAN[1] & I.M. TURNER[2]

[1]Department of Biological Sciences, The National University of Singapore, Singapore 119260; [2]National Parks Board, Singapore Botanic Gardens, 1 Cluny Road, Singapore 259569

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ABSTRACT

The present studies show that in man-made forests, six 10 m x 10 m quadrats are sufficient to give a good representation of the species diversity, as the comparatively uniform environment can provide a suitable habitat for only a limited number of species. Contrastingly, nine 10 m x 10 m quadrats are still not sufficient to capture the characteristic diversity of pteridophytes in natural forest habitats. This is due to the highly scattered distribution patterns of forest herbs, including the pteridophytes, along different gradients and microhabitats in the forest. In order to estimate the diversity of pteridophytes in natural forests more accurately, a minimal sample size of more than nine 10 m x 10 m quadrats needs to be established.

INTRODUCTION

Systematic collection and documentation of the diversity of pteridophytes in Singapore started as early as the 19th Century (Turner, 1994), and in Peninsular Malaysia in the early part of the 20th Century (Bidin, 1991). However, most of these studies concentrated on the taxonomy and species listings of pteridophytes. To date, few studies in tropical Southeast Asia have used quantitative methods to estimate the diversity of pteridophytes in a given area. Johnson (1969) appears to have been the first to conduct a quadrat survey of non-tree forest species (including pteridophytes) in this region. Her 15 quadrats in Taman Negara, Peninsular Malaysia, each of one square chain (about 0.6 km^2), yielded a low number of 7 species of ferns and fern allies. A notable recent study by Sato *et al*.,(2000) employed cubic quadrats of various sizes and numbers in an attempt to characterize the diversity of the pteridophyte flora in an oil palm plantation and three natural forests (Kepong, Pasoh and Semangkok) in Malaysia. Expectedly, the results showed that the number of quadrat cubes needed to capture the maximum pteridophyte diversity depends on the quadrat cube size used and the locally existing biodiversity. For the natural forest at Semangkok, 20 quadrat cubes of 20 m x 20 m x 20 m were needed to capture the high number of 40 species of ferns, whereas in the natural lowland forest at Kepong, the 20 quadrat cubes of 20 m x 20 m x 20 m captured a maximum number of about 28 species. In the oil palm plantation, 14 quadrat cubes of 20 m x 20 m x 20 m were needed to capture the maximum number of 18 species.

Since the objective of sampling, as opposed to documenting each and every species or individual, is to reduce the amount of labour and time involved (Chapman, 1976), the present study aimed to find out the minimum number of quadrats with a manageable area size of 10 m x 10 m that would be needed to estimate the pteridophyte diversity of natural lowland rain forest and man-made forests (oil palm and rubber plantations) in both Johor (Peninsular Malaysia) and Singapore.

STUDY SITES AND METHODS

Five sampling sites in natural and man-made forests in Johor (Peninsular Malaysia) and Singapore were selected for the present investigation. The two natural forests selected were the Gunung Pulai Forest Reserve [GPFR], situated inside the Gunung Pulai Recreation Forest (1° 36'N, 103° 34'E) in Johor, and the Bukit Timah Nature Reserve [BTNR] (103º 47'E, 1º 21'N) in Singapore. The man-made forests investigated were the oil palm and rubber plantations in the vicinity of Gunung Pulai Forest Reserve in Johor, and the rubber plantations on Pulau Ubin (1º 24' N, 103º 58' E), an island off mainland Singapore. These surveyed areas were chosen for their geographical proximity to each other, so as to eliminate the effect of climatic factors as a possible cause for the difference in the species diversity observed.

Initially, six non-contiguous quadrats of 10 m x 10 m were established in each of the five study sites. The measurement of 10 m x 10 m was selected in consideration of the morphology and distribution pattern of the plant group to be sampled. According to Causton (1988), a quadrat size of up to 0.25 km^2 is suitable for the sampling of herbaceous vegetation. Since pteridophytes are comparatively not large herbaceous plants (with some exception, like *Cyathea* sp.), and after conducting a preliminary survey at the selected study sites, a quadrat size of 10 m x 10 m was deemed suitable for this study.

In placing the quadrats, a ground survey of Gunung Pulai Recreation Forest was carried out and six seemingly undisturbed forested sites were selectively identified, each located within a reasonably homogenous topography. The non-random selective method was adopted where the quadrats were preferentially located by sight to ensure that at least one individual pteridophyte was present in each quadrat. This pre-determined layout of quadrats in the natural forests was aimed to maximize the capturing of diversity of pteridophytes using the minimal number of quadrats.

In BTNR, the 2 ha permanent plot managed by the Smithsonian Institution and the National Institute of Education (NIE) was chosen to establish the six non-contiguous quadrats. Within the Smithosonian-NIE plot, the quadrat placement was similarly pre-selected in favour of the better portion of forest cover.

In the case of the two types of man-made forests in Johor and Singapore, the location of the six non-contiguous quadrats in each of the three rather homogeneous study sites was also preferentially selected to maximize the inclusion of fern diversity within the quadrat. In actual observation, the non-random selection of quadrat site was found to be not necessary in the two types of man-made forests, the rubber and oil palm plantations, because of the similarity of pteridophytic flora found *in situ*.

In all quadrats, the pteridophyte species within hand reach were recorded. Epiphytes of the high forest canopy that could not be collected from standing on the ground were excluded because the specimens could not be identified with certainty to the species even with field binoculars. The inclusion of epiphytic pteridophytes within the height of arm length in each quadrat is equivalent to, but not exactly comparable

with, the quadrat cube method used by Sato *et al.,* (2000). The microhabitat conditions for each of the pteridophytic species collected were also recorded. To complete the diversity survey, additional collections were made from the general vicinity outside the six quadrats of each study site. After the quadrat samplings, voucher materials from each study site were prepared and identified in the Cryptogam Laboratory at the National University of Singapore and verified by comparison with authentic specimens preserved at SINU and SING herbaria.

Finally, to estimate the minimum number of quadrats needed to characterize the pteridophyte species diversity in the different forest types, a species-area curve was generated for each of the five study sites.

RESULTS

The inventory of pteridophytes present in the six quadrats in each of the five study sites yielded 18 species in GPFR, 14 species in BTNR, 18 species in the oil palm plantations in the vicinity of GPFR, 13 species in the rubber plantations in the vicinity of GPFR, and 14 species in the rubber plantations in Pulau Ubin (Table 1).

TABLE 1. Number of species, genera and families reported from the five study sites based on quadrat sampling.

Habitat	**Natural Forests**		**Man-made Forests**		
Locality	**GPFR, Johor**	**BTNR, Singapore**	**Oil palm plantation, Johor**	**Rubber plantation, Johor**	**Rubber plantation, Singapore**
Species	18	14	18	13	14
Genera	16	12	17	13	12
Families	12	10	13	11	9

Interestingly, additional collections made from the general vicinity outside the quadrats in all man-made forests showed only a small increase in the number of species in comparison with the number of species found inside the quadrats. In the oil palm plantation, only two additional species (*Selaginella willdenowii* and *Selaginella selangorensis* var. *ciliata*) were added. Similarly, in the rubber plantations in Johor and Pulau Ubin, only one species each (*Lindsaea ensifolia* and *Pteris semipinnata* respectively) was not captured by the six quadrats. Contrastingly, while the number of species found in the six quadrats was 14 at BTNR and 18 at the GPFR (Table 1), the total number of pteridophytes reported for BTNR (Wee, 1995) and the collections made from the general vicinity of established quadrats in GPFR during this study produced a high total of 95 species for BTNR and 38 species for GPFR. The listing of species of ferns and fern allies collected from the quadrats of the two types of forests investigated is given in Appendix 1.

Overall, the species-area curves generated for the five study sites (Figure. 1) showed an increase in the average number of pteridophyte species with the increase of the number of quadrats. However, the species-area curve for the oil palm and rubber plantations appeared to reach a plateau in its species number at the 6th quadrat. In contrast, the species-area curve for GPFR and BTNR continued to show an increase in species number up to the 6^{th} quadrat. The latter trend was observed with the addition of three more quadrats of the same size to the two forest sites (Figure. 2).

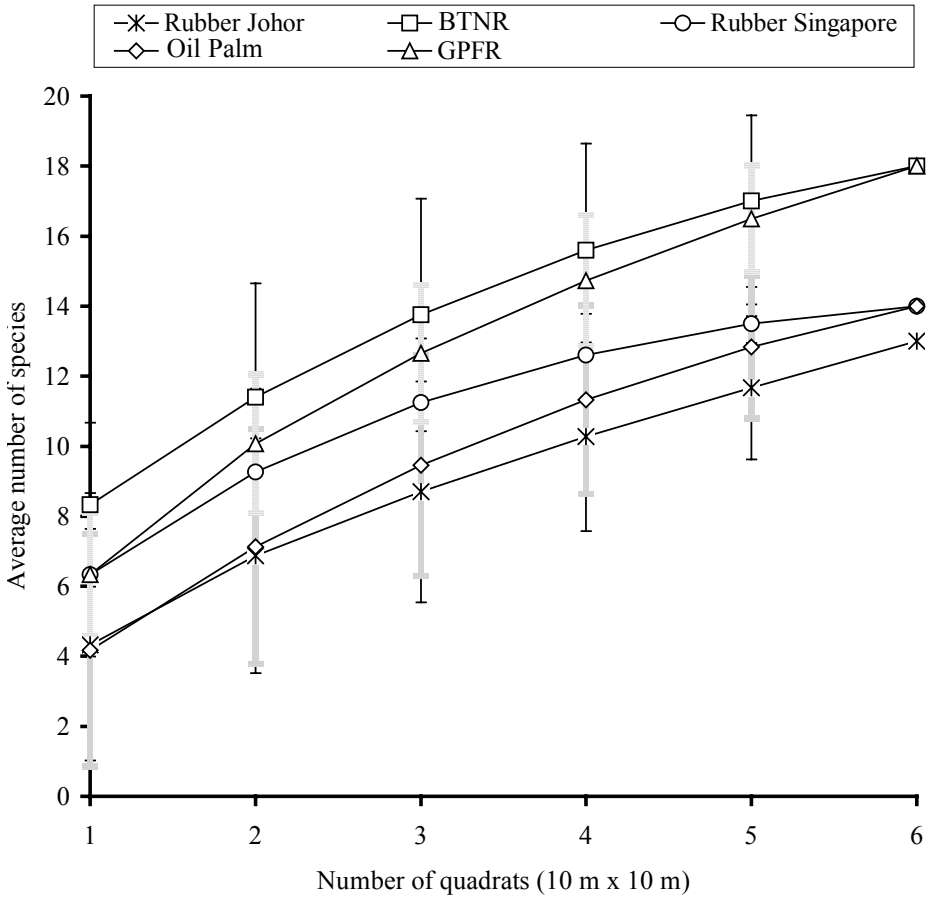

Figure 1. Changes in accumulating number of pteridophyte species with increase in sample size (6 quadrats) in natural and man-made forests in Peninsular Malaysia and Singapore.

DISCUSSION

Results from this study show that a minimum of six quadrats of 10 m x 10 m is sufficient to capture the characteristic pteridophyte diversity in oil palm and rubber plantations in Johor and Singapore. This observation was confirmed when general collections made from outside the quadrats produced only two additional species in the oil palm plantation and one additional species each from the rubber plantations in Johor and Pulau Ubin.

In man-made agroforests, like the oil palm and rubber plantations, it is not surprising that a small number of six quadrats is sufficient to capture the diversity of pteridophytes. Often, agricultural landscape is associated with homogeneity of the vegetation that consists frequently of monoculture with high habitat uniformity that lacks variation in its micro-habitats. This uniformity allows a limited suite of species to colonize and survive in a rather even and predictable distribution pattern. Furthermore, in the case of the man-made forests in Johor, the regular maintenance of the plantations in the form of weeding out the non-crop vegetation also attributes to the low diversity of the pteridophytic flora.

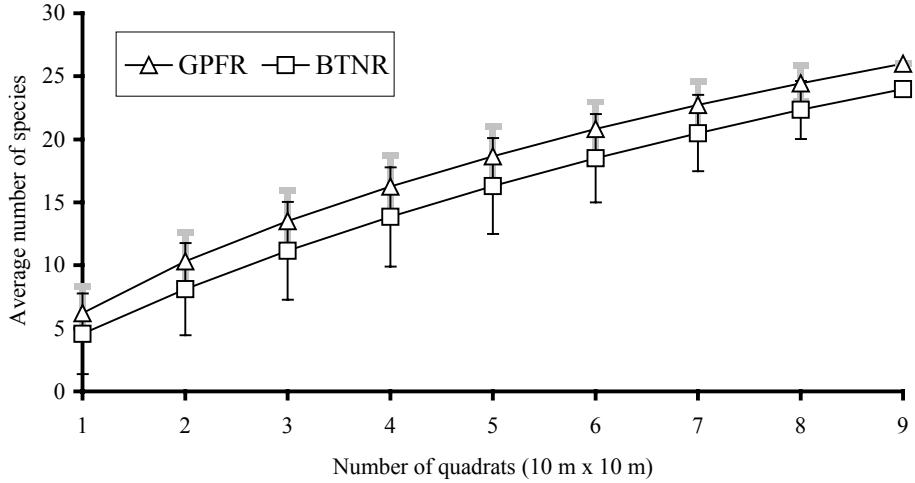

Figure 2. Changes in the accumulating number of pteridophyte species with increase in sample size (9 quadrats) in the natural lowland forest in GPFR and BTNR.

The scenario appears to be different in natural lowland forests. In the case of lowland Dipterocarp forests at GPFR and BTNR, additional collections in the vicinity outside the six quadrats resulted in a notable increase in the number of species. Based on the general collections made in GPFR, the six quadrats captured only 32% of the known diversity of pteridophytes at GPFR. Likewise, only 13% of the BTNR pteridophytes reported by Wee (1995) were captured by the six quadrats. The addition of three more quadrats in GPFR and BTNR only increased the percentage of captured species diversity to 46% (26 species) in GPFR, and 22% (24 species) in BTNR. This indicates clearly that even nine quadrats of 10 m x 10 m are still far from adequate in giving a good estimation of the total pteridophytic diversity of the lowland rainforests in GPFR and BTNR.

The big differences seen in the percentage of pteridophyte diversity captured by the same number of quadrats in the two natural forests (GPFR: 32% and 46%, BTNR: 13% and 22%) are partly due to the fact that the forested area surveyed in BTNR is ca 164 ha, while the forested area surveyed in GPFR during the present study is the 8 ha of core forest around the station office. In addition, the pteridophyte flora of BTNR has been explored, studied and documented for decades by the resident staff at the Singapore Botanic Gardens since the time of British rule, resulting in the large number of species recorded from this nature reserve. In the case of the latter, the present study is a first attempt to document the pteridophyte flora of the pristine forest reserve at GPFR in Peninsular Malaysia.

The inadequacy of nine quadrats to estimate the total pteridophyte diversity of GPFR and BTNR can further be attributed to the patchy, widely spaced, and sporadic distribution pattern of pteridophytes in many lowland rain forests, making it difficult to capture the maximum representative diversity using a small quadrat size or a small number of quadrats. Understandably, the widely scattered pattern of distribution of pteridophyte species in the region is also a reflection of the heterogeneity of lowland rainforest. Similar patchy distribution in tropical rainforests is also observed in other ground vascular herbs (Kiew, 1978; Poulsen, 1996; Lum, 1999).

CONCLUSION

For adequate estimation of the pteridophyte diversity in a man-made forest, such as the oil palm and rubber plantations in southern Malaysia and Singapore, a minimum number of six quadrats of 10 m x 10 m is sufficient. However, a total of nine quadrats of 10 m x 10 m is still insufficient to capture the overall pteridophyte diversity in the natural lowland forest in Johor (Malaysia) and Singapore. A minimum of more than nine quadrats of 10 m x 10 m is suggested for any similar studies in natural forests in the future.

REFERENCES

BIDIN, A. 1991. Fern and fern-allies of Peninsular Malaysia, pp. 62–66. In: KIEW, R. (Ed). The state of nature conservation in Malaysia. Malayan Nature Society.

CAUSTON, D.R. 1988. Introduction to vegetation analysis. Unwin Hyman.

CHAPMAN, S.B. 1976. Methods in Plant Ecology. Blackwell Scientific Publications.

JOHNSON, A. 1969. A forest quadrat in the National Park: the flora other than trees. Malayan Nat. J. 22: 152–158

KIEW, R. 1978. Floristic components of the ground flora of a tropical lowland rain forest at Gunung Mulu National Park, Sarawak. Pertanika 1: 112–119.

LUM, S. 1999. Tropical Rainforest, pp. 24–34. In: BRIFFETT, C. & CHEW, H.H. (Eds). State of the natural environment in Singapore. Nature Society, Singapore.

POULSEN, A.D. 1996. Species richness and density of ground herbs within a plot of lowland rainforest in North-West Borneo. J. Trop. Ecol. 12: 177–190.

SATO, T., S.L. Guan and A. Furukawa. 2000. A quantitative comparison of pteridophyte diversity in small scales among different climatic regions in Eastern Asia. Tropics 9(2): 83–90.

TURNER, I.M. 1994. The inventory of Singapore's biodiversity, pp. 47–52. In: WEE, Y.C. & NG, P.K.L. (Eds). A First Look at Biodiversity in Singapore. National Council on the Environment, Singapore.

WEE, Y.C. 1995. Pteridophytes, pp. 61–70. In: CHIN, S.C., CORLETT, R.T., WEE Y.C. & GEH, S.Y. (Eds). Rain Forest in the City: Bukit Timah Nature Reserve,Singapore. Gardens' Bulletin Singapore Supplement 3. National Parks Board, Singapore.

Appendix 1. Distribution of pteridophyte species in natural and man-made forests in Johor (Peninsular Malaysia) and Singapore based on quadrat sampling (9 quadrats in natural forest and 6 quadrats in man-made forest).

FAMILY	GENERA AND SPECIES	QUADRATS				
		NATURAL FOREST		MAN-MADE FOREST		
		GPFR	BTNR	OP	RP	RU
Adiantaceae	*Adiantum latifolium* Lam.	-	+	+	-	-
	Pityrogramma calomelanos (L.) Link	-	-	+	+	-
	Syngramma alismifolia (C. Presl) J. Sm.	+	-	-	-	-
	Taenitis blechnoides (Willd.) Sw.	+	+	+	+	+
Aspleniaceae	*Asplenium longissimum* Bl.	-	-	+	-	+
	Asplenium nidus L.	+	+	-	-	+
	Asplenium tenerum G. Forst. var. *retusum* C. Chr.	+	-	-	-	-
	Asplenium sp. 1	-	-	-	+	-
Blechnaceae	*Blechnum cf. orientale* L.	-	-	-	+	+
	Blechnum finlaysonianum Hook. & Grev.	+	+	-	-	-
	Stenochlaena palustris (Burm. f.) Bedd.	-	+	+	+	+
Cyatheaceae	*Cyathea contaminans* (Hk.) Copel.	-	+	-	-	-
	Cyathea squamulata (Bl.) Copel.	+	+	-	-	-
Davalliaceae	*Davallia denticulata* (Burm. f.) Mett.	-	-	+	+	+
	Scyphularia triphylla (Hook.) Fée	+	-	-	-	-
Dennstaedtiaceae	*Lindsaea divergens* Hook. & Grev.	+	-	-	-	-
	Lindsaea ensifolia Sw.	-	+	+	-	-
	Microlepia speluncae (L.) T. Moore	-	+	+	+	-

FAMILY	GENERA AND SPECIES	QUADRATS				
		NATURAL FOREST		MAN-MADE FOREST		
		GPFR	BTNR	OP	RP	RU
Dryopteridaceae	*Pleocnemia irregularis* (C. Presl) Holtt.	-	+	+	-	-
	Tectaria barberi (Hook.) Copel.	+	+	-	-	-
	Tectaria singaporeana (Wall. ex Hook. & Grev.) Copel.	+	+	-	-	-
Gleicheniaceae	*Dicranopteris linearis* (Burm. f.) Underw.	-	+	-	+	+
Grammitidaceae	*Ctenopteris blechnoides* (Grev.) W.H. Wagner & Grether	+	-	-	-	-
Hymenophyllaceae	*Cephalomanes singaporeanum* Bosch	+	-	-	-	-
	Microgonium sp.	+	-	-	-	-
	Selenodesmium obscurum (Blume) Copel.	+	-	-	-	-
Lycopodiaceae	*Lycopodium cernuum* L.	-	+	+	+	-
Nephrolepidaceae	*Nephrolepis auriculata* (L.) Trimen	-	+	+	+	+
	Nephrolepis sp.	-	+	-	-	-
Polypodiaceae	*Goniophlebium percussum* (Cav.) W.H. Wagner & Grether	-	-	+	-	-
	Drymoglossum piloselloides (L.) Presl	-	-	-	-	+
	Drynaria sparsisora (Desv.) T. Moore	+	-	-	-	-
	cf. Phymatosorus sp.	-	-	-	-	+
Schizaeaceae	*Lygodium cf. longifolium* (Willd.) Sw.	+	-	-	-	-
	Lygodium cf. flexuosum (L.) Sw.	-	-	-	-	+
	Lygodium sp. 1	-	-	+	-	-
	Lygodium sp. 2	+	+	-	+	-
	Schizaea dichotoma (L.) Sm.	+	-	-	-	+
	Schizaea digitata (L.) Sw.	-	-	-	-	+

FAMILY	GENERA AND SPECIES	QUADRATS				
		NATURAL FOREST		MAN-MADE FOREST		
		GPFR	BTNR	OP	RP	RU
Selaginellaceae	*Selaginella roxburghii* (Hk. & Grev.) Spring	+	+	-	-	-
	Selaginella willdenowii (Desv.) Baker	+	-	-	-	-
Thelypteridaceae	*Christella subpubescens* (Bl.) Holtt.	-	-	+	-	-
	Cyclosorus sp.	-	+	-	-	-
	Mesophlebion beccarianum (Ces.) Holtt.	+	-	-	-	-
	Pronephrium rubicundum (Alderw.) Holtt.	+	-	-	-	-
	Pronephrium triphyllum (Sw.) Holtt.	-	+	+	+	-
	Sphaerostephanos heterocarpus (Bl.) Holtt.	+	+	-	-	-
Vittariaceae	*Vittaria ensiformis* Sw.	-	-	+	-	-
	Vittaria ensiformis var. *latifolia* Holtt.	-	-	-	+	-
	Vittaria elongata Sw.	+	+	+	-	+
Woodsiaceae	*Diplazium crenatoserratum* (Bl.) T. Moore	-	+	-	-	-
	Diplazium tomentosum Bl.	+	-	-	-	-
	Total number of species	25	23	17	13	14

GPFR	Gunung Pulai Forest Reserve, Johor
BTNR	Bukit Timah Nature Reserve, Singapore
OP	Oil palm plantation, Johor
RP	Rubber plantation, Johor
RU	Rubber plantation, Singapore