Long-term ecological research and its contribution to the floristic studies in tropical Asia

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Floristic studies should be based on as many specimens collected from various places as possible. However, the destruction of natural vegetation on the earth is progressing so rapidly, we have to hurry up for inventory of plants and animals on the earth. Especially in the tropical countries where we have poorer information for the biota, the intensive studies at selected places may be more effective than the traditional ways based on the collections from repeated expeditions to various places which will take long time.

Tropical rainforests in SE Asia are known for the richest floristic diversity on the earth. The floristic region 'Malesia' covers only 2% of land area, but it is believed that about 42,000 vascular plants, which is 14% of world flora, are distributed there (Roos, 1997). Of them 70% are endemic to Malesia. To cover all vascular plant flora of Malesia, Flora Malesiana project was started publishing the first volume in 1950 (van Steenis, 1950). Fifty years have already passed, but nearly 20% of species have been treated so far. Roos (1997) estimates that we need another 40 years to complete the project. Long time will be needed to collect good specimens enough for the floristic studies of Malesia.

It is doubtless that we have to try also another efficient way to reveal the floristic diversity by intensive study in smaller areas. One of good examples is a series of publication titled '*The plants of Mount Kinabalu*' (Parris *et al.*, 1992; Wood *et al.*, 1993; Beaman and Beaman, 1998). We can see about 4,000 plant species (nearly 10% of all species in Malesia) in a small area of 700km² (0.2% of Malesia). Another example is a floristic study of a small country, Brunei. The area of Brunei is about 5,765km², forests cover the 81% of the land area. The

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government managed intensive survey on flora of the country by cooperation with Royal Botanic Gardens, Kew. Helicopters are also used to visit into dense tropical rainforests efficiently. The result including not only tree species but also climbers and herbs was published in 1996 (Coode *et al.*, 1996).

From this viewpoint, a long-term ecological research also can be regarded as a way for floristic and faunistic researches. The long-term ecological research carried on at Lambir Hills National Park, Sarawak is introduced as an example. During the research, huge number of specimens of plants and animals were collected, which will be important basis for the studies of biodiversity and biogeography. It is also emphasized that through such a long-term research we can get much information of natural history about plants and animals such as plant phenology, animal seasonality, pollination biology and their mutualistic relationships, which usually cannot be obtained from dried materials.

Research Site

Lambir Hills National Park is located in the eastern Sarawak near the border of Brunei, about 30 km south of Miri City. The park covers 6,949 ha with the highest peak, Bukit Lambir 465 m above sea level. There are two dominating forest types, mixed dipterocarp forest and heath forest; the former covers 85% of the forest area and the latter is seen around the peaks and ridges.

Two permanent plots, 52 ha and 8 ha were established in the mixed dipterocarp forest. The 8 ha plot is called as Canopy Biology Plot (CBP), which was prepared to easily access to canopy level for the studies from the 3-dimensional view of the tropical rain forest. In CBP, we built two tree towers 33m and 55m tall and 200m apart, using Bornean iron wood (*Eusideroxylon zwageri*) resistant to termites' attack. These two towers were connected by nine aerial walkways at 25-30m above the ground. The main purpose of the works using this plot is to examine interrelationship between global changes of Environment such as El Nino and organization of tropical rain forest, observing plant phenology and animal seasonality. The inventory of plants and animals also has been studied through the program.

Flora

The mixed dipterocarp forest of SE Asia is known for the richest diversity of tree species in the world. In 52 ha plot, all trees with diameter 1cm or more at breast height were examined. The number of trees is about 360,000 (Chai *et*

Table 1. Trees of 8-ha plot (Canopy Biology Plot), DBH ≥ 10 cm

Family	Number of trees	Number of	Number of
Dipterocarpaceae	796	7	52
Euphorbiaceae	511	21	66
Myristicaceae	191	5	40
Burseraceae	144	5	25
Lauraceae	123	11	35
Myrtaceae	123	2	22
Moraceae	112	5	27
Annonaceae	111	11	27
Rubiaceae	87	11	17
Meliaceae	85	12	34
Theaceae	83	2	4
Sapotaceae	81	3	17
Anacardiaceae	76	9	17
Sterculiaceae	76	7	16
Leguminosae	70	8	16
Olacaceae	70	3	3
Ebenaceae	70	1	18
Guttiferae	65	4	22
Tiliaceae	64	3	10
Melastomataceae	59	3	6
Flacourtiaceae	44	4	11
Bombacaceae	43	2	8
Saurauaceae	42	1	1
Fagaceae	38	3	10
Ixonanthaceae	36	1	1
Verbenaceae	34	3	6
Rhizophoraceae	32	3	5
Icacaceae	31	2	2
Ulmaceae	29	1	2
Celastraceae	27	2	4
Xanthophyllaceae	26	1	13

Table 1. Continued.

Family	Number of trees	Number of	Number of
Thymelaeaceae	16	3	4
Sapindaceae	16	3	3
Anisophylleaceae	16	1	2
Apocynaceae	15	2	2
Dilleniaceae	12	1	2
Lecythidaceae	10	1	2
Rutaceae	10	1	2
Elaeocarpaceae	9	2	4
Loganiaceae	9	1	2
Alangiaceae	7	1	2
Chrysobalanaceae	6	3	3
Proteaceae	6	1	1
Rhamnaceae	5	2	2
Combretaceae	5	1	2
Compositae	5	1	1
Myrsinaceae	4	1	3
Aquifoliaceae	4	1	2
Simaroubaceae	3	2	2
Linaceae	3	1	1
Araliaceae	2	1	1
Crypteroniaceae	2	1	1
Oleaceae	2	1	1
Staphylleaceae	2	1	1
Convolvulaceae	1	1	1
Escaloniaceae	1	1	1
Magnoliaceae	1	1	1
Oxalidaceae	1	1	1
Santalaceae	1	1	1
Symplocaceae	1	1	1
family unknown	1	—	1
	3555	195	590

al., 1995). From the plot, more than 1,200 tree species were recorded (P.S. Ashton, pers. com.). For 8 ha plot (CBP) only trees with DBH 10cm or more were examined, and the numbers of individual and species are 3,555 and 590, respectively (Table 1). Lambir Hills are located in a phytogeographical area called as 'Riau Pocket' showing high species diversity of tropical rainforest in West Malesia, probably because the area functioned as refugia in the glacial period (Wong, 1998).

The heath forest around the summit area is dominated by *Gymnostoma nobile* showing similar flora to the heath forest around Kuching. In the thicket at the summit, however, there are several interesting plants including endemic species to Lambir Hills such as *Rhododendron chamaeipytis* and *Pentaphragma lambirensis*. On sandy soils along the stream Sungei Liam Libau, a kind of heath forest is developed. A new species of Lowiaceae, *Orchidantha inouei* was discovered here, and it is also found to grow on sandy soils in Belait, Brunei (Nagamasu and Sakai, 1999).

A preliminary floristic list including not only tree species but also herbs and climbers was published but monocots and ferns were poorly studied (Nagamasu and Momose, 1997). It needs further elaboration consulting the result of 52 ha census.

The family Zingiberaceae was intensively studied as an important member on forest floor of tropical rain forest. We recognized 46 species of gingers in the Lambir Hills, of which 20 species (43%) were undescribed. So far six new species of *Amomum* were published, and the papers about other genera including a new genus are in preparation (Sakai and Nagamasu, 1998). It is doubtless many taxa are still left undescribed even in tree species.

Phenology and general flowering

The mixed dipterocarp forest of West Malesia shows 'general flowering' with irregular intervals 2 to 10 years. We continued observation of plant phenology of 576 individuals representing 305 species in 56 families along aerial walkway systems in CBP from 1992. In Lambir Hills, a general flowering occurred in 1991 and followed in 1996. The proportion of flowering species and individuals were low (2-5%) in 1992-1995, but drastically increased in March 1996 and reached 16.9% and 21.1%, respectively (Sakai *et al.*, 1999).

During 43 months we could observe 527 effective reproductive events, of which 57% were concentrated in general flowering period. The species flowered

only in general flowering period were commonly found among species in various plant taxonomic groups, life forms, pollination systems, and fruit types. Interestingly fig-wasp-pollinated *Ficus* (8 spp.) did not include any general-flow-ering species.

Ashton *et al.* (1988) presented a hypothesis about the trigger for general flow-ering that a drop of daily minimum temperature by $\sim 2^{\circ}\text{C}$ is likely the cue. In our climatic monitoring, a drop of daily minimum temperature up to 3°C was re-corded in January 1996, 1 or 2 months before the general flowering (Sakai *et al.*, 1999).

Pollination Biology

During the observation, we could collect many flowering and fruiting speci-mens for many species and the plant visitors of 270 species from 73 families were recorded (Momose *et al.*, 1998). Among them, the plant species pollinated by social bees included the largest number (32%) and followed by beetle-polli-nated species (20%). The proportions of plants pollinated by animals and lepi-dopterans were less frequent than those in La Serva, Costa Rica (Kress and Beach, 1994).

Around CBP, several nests of a bee, *Apis dorsata*, were found only in general flowering period and after (Nagamitsu, 1998). This species is an example of im-migrating plant visitors.

Some plants have special mechanisms to attract specific pollinators. Such interesting relationships in pollination biology have been studied by the mem-bers of Canopy Biology Program Sarawak: moths and *Gnetum* (Gnetaceae) using sweet pollination drop as reward (Kato and Nagamitsu, 1995); cockroaches and *Uvaria elmeri* (Annonaceae) flowering on the ground (Nagamitsu and Inoue 1997); spider hunters and some loranthaceous hemiparasites with special mor-phology of flower and inflorescence (Yumoto *et al.*, 1997); small beetles and *Shorea parvifolia* (Dipterocarpaceae) using corolla as reward; dung beetles and *Orchidantha* (Lowiaceae) with ill-smelled flower like horse dung (Sakai and Inoue, 1999), and so on.

Otherwise, flowers were visited by diverse insects, and if plant had large flowering patches with a rich reward, social bees are dominated. In spite of high diversity of plant species, and consequent low density of the species, long-distance-specific pollinators were not common compared with Neotropics where humming birds or euglossine bees are important pollinators (Momose *et al.*, 1998).

Literature cited

- Ashton, P. S., T. J. Givnish and S. Appanah. 1988. Staggered flowering in the Dipterocarpaceae: new insights into floral induction and the evolution of mast fruiting in the aseasonal tropics. *American Naturalist* 132: 44-46.
- Beaman, J. H. and R. S. Beaman. 1998. The plants of Mount Kinabalu. 3. Gymnosperms and non-orchid monocotyledons. Royal Botanic Gardens, Kew.
- Chai, E. O. K., H. S. Lee and T. Yamakura. 1995. Preliminary results from the 52-hectare long term ecological research plot at the Lambir National Park, Sarawak, Malaysia. *In* Long Term Ecological Research of Tropical Rain Forest in Sarawak. Seng, L. H., P. S. Ashton and K. Ogino (eds.) Pp. 42-58. Ehime University.
- Coode, M. J. E., J. Dransfield, L. L. Forman, D. W. Kirkup and Idris M. Said (eds.). 1996. A checklist of the flowering plants and gymnosperms of Brunei Darussalam. Ministry of Industry and Primary Resources, Brunei Darussalam.
- Kato, M. and T. Nagamitsu. 1995. Floral and pollination biology of *Gnetum* (Gnetaceae) in a lowland mixed dipterocarp forest in Sarawak. *American Journal of Botany* 82: 862-868.
- Kress, W. J. and J. H. Beach. 1994. Flowering plant reproductive systems. *In* La Serva, Ecology and Natural History of a Neotropical Rain Forest. McDade, L. A., K. S. Baawa, H. A. Hespenheide and G. S. Hartshorn (eds.) Pp. 161-182. University of Chicago Press, Chicago.
- Momose, K., T. Yumoto, T. Nagamitsu, M. Kato, H. Nagamasu, S. Sakai, R.D. Harrison, T. Itioka, Abang A. Hamid and T. Inoue. 1998. Pollination biology in a lowland dipterocarp forest in Sarawak, Malaysia. I. Characteristics of the plant-pollinator community in a lowland dipterocarp forest. *American Journal of Botany* 85: 1477-1501.
- Nagamasu, H. and K. Momose. 1997. Flora of Lambir Hills National Park, Sarawak, with special reference to the Canopy Biology Plot. *In* General Flowering of Tropical Rainforests in Sarawak. Inoue, T., and Abang A. Hamid (eds.) Pp. 20-67. Center for Ecological Research, Kyoto University.
- Nagamasu, H. and S. Sakai. 1999. *Orchidantha inouei* (Lowiaceae), a new species from Borneo. *Nordic Journal of Botany* 19: 149-152.
- Nagamitsu, T. 1998. Community ecology of floral resource partitioning by eusocial bees in an Asian tropical rainforest. Ph. D. dissertation, Kyoto University.

- Nagamitsu, T. and T. Inoue. 1997. Coakroach pollination and breeding system of *Uvaria elmeri* (Annonaceae) in a lowland mixed-dipterocarp forest in Sarawak. *American Journal of Botany* 84: 208-213.
- Parris B. S., R. S. Beaman and J. H. Beaman. 1992. The plants of Mount Kinabalu. 1. Ferns and fern allies. Royal Botanic Gardens, Kew.
- Roos, M. 1997. Flora Malesiana: progress, needs and prospects. *In* Plant Diversity in Malesia III. Dransfield, J., M. J. E. Coode and D. A. Simpson (eds.) Pp. 231-246. Royal Botanic Gardens, Kew.
- Sakai, S. and H. Nagamasu. 1998. Systematic studies of Bornean Zingiberaceae. I. *Amomum* in Lambir Hills, Sarawak. *Edinburgh Journal of Botany* 55: 45-64.
- Sakai, S. and T. Inoue. 1999. A new pollination system: dung-beetle pollination discovered in *Orchidantha inouei* (Lowiaceae, Zingiberales) in Sarawak, Malaysia. *American Journal of Botany* 86: 56-61.
- Sakai, S., K. Momose, T. Yumoto, T. Nagamitsu, H. Nagamasu, Abang A. Hamid and T. Nakashizuka. 1999. Plant reproductive phenology over four years including an episode of general flowering in a lowland dipterocarp forest, Sarawak, Malaysia. *American Journal of Botany* 86: 1414-1436.
- Van Steenis, C. G. G. J. 1950. Flora Malesiana vol. 1 Noordhoff-Kolff N.V., Djakarta.
- Wong, K. M. 1998. Patterns of plant endemism and rarity in Borneo and the Malay Peninsula. *In* Rare, Threatened, and Endangered Floras of Asia and the Pacific Rim. Peng, C. I. and P. P. Lowry II (eds.) Pp. 39-169. Institute of Botany, Academia Sinica, Taipei.
- Wood, J. J., R. S. Beaman and J. H. Beaman. 1993. The plants of Mount Kinabalu. 2. Orchids. Royal Botanic Gardens, Kew.
- Yumoto, T., T. Itino and H. Nagamasu. 1997. Pollination of hemiparasites (Loranthaceae) by spider hunters (Nectarinidae) in the canopy of a bornean tropical rain forest. *Selbyana* 18: 51-60.