Plants and Vegetation

of the

Maliau Basin Conservation Area,

Sabah, East Malaysia

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Final Report to Maliau Basin Management Committee

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1. EXECUTIVE SUMMARY

The Maliau Basin area is a tremendously valuable botanical resource for Sabah. During 2 years of botanical work, we collected over 1,100 fertile specimens, set up 35, 0.2-ha vegetation plots, and trained 8 YS staff members in botanical methods. From the tree plots, we estimate that there are ca. 1,010 tree species (> 10 cm DBH) in the basin, and we have collated a checklist of 1,800 species from ours and previous studies, which include 54 species mentioned in the IUCN red data book. A number of new species and records have been recorded at MBCA, and many more can be expected as specialists examine our collections. We have revised the forest classification system to include 12 forest types: Lowland, Floodplain, Hill, Upland clay, Riparian, Upland sandy ridge, Agathis, Montane, Heath, Short Heath, Casaurina, and Moss. The Maliau Basin is extremely valuable as a conservation resource because of i) the range of habitats represented, ii) the genetic diversity within species that occur throughout this habitat range, iii) its relative isolation from other montane conservation areas, and iv) the lowland forest it contains. It is also a unique educational and research resource.

2. CONTENTS

3. INTRODUCTION

Good introductions to the MBCA are provided by Lamb (1988), Marsh (1988), Phillipps and Lamb (1990), Wong (2001), Phillipps (2002), and on the Maliau website (www.maliau.org). In short, the Maliau Basin is a natural depression, ca. 23 km across, surrounded by steep escarpments up to 500 m high. A single river, the Maliau, drains the basin through a canyon in the south rim. The Basin is still covered by unlogged forest, ranging from high elevation moss forest (on Gunung Lutong, 1,900 m) to true lowland forest at 300 m. Yayasan Sabah, a large, semi-governmental foundation charged with managing Sabah resources for Sabah's people, set aside the Maliau Basin (physically, 39,000 ha) in 1984 as a Protected Forest Reserve, forming a pair with Danum Valley Conservation Area. Of ca. 7 Mha classed as forest in Sabah, 3 Mha are in forest reserves (both managed and conservation), including 200,000 ha of National Park, and 1Mha are managed by YS. More recently, in 1997, the MBCA (59,000 ha) has been gazetted as a Class I Conservation Area, the highest grade of conservation area in Sabah, and in some ways more effective than National Park status. Conservation status can however be downgraded by the State Assembly (Bangi island went from Class I to II, and areas of Kinabalu National Park were degazetted for copper mining). The Maliau basin sits on top of a large coal reserve, and thus represents a potentially valuable resource via exploitation. Coal exploration in the 1990s was finally halted with the government's publishing of The Maliau Conservation Area Forest Rules in 1998, but the coal and timber resources in the MB will always represent a major hurdle to preventing exploitation (see reports by Broken Hill Prospecting, and an EIA by the DPA group, 1992).

Since 1999, the Maliau Basin Project, cofunded by Danish DANCED, and YS, has been working to increase national and international awareness of the conservation, research and education value of MBCA. The botanical work described here provides background information for these public awareness exercises and for the preparation of a management plan for MBCA.

3.1. Goals for Botanical Work / Terms of Reference

The key points of the Terms of Reference for the Botanical TA in the 1999 Inception report were:

1. Review species lists.

2. Involve local organizations in further field trips.

3. Conduct surveys of under-explored areas of MBCA.

4. Deposit, identify and refer specimens to specialists.

5. Revise vegetation classification and mapping.

6. Produce report for management plan.

7. In all aspects, provide in-service training.

Two additional goals were:

8. To integrate the vegetation sampling with remote sensing data, in order to model the spatial distribution of plant biodiversity.
9. To be ready for a rapid, intensive collecting effort with additional manpower, in the event of a mast flowering.

The main expectation for the LTA (Robert Ong with assistance from Joan Perreira), as outlined by Cam Webb in 1999 were:

1. Review TOR, determine probable level of involvement of SFRC staff (including self), and propose a budget to PSC.
2. Aid in the initial interpretation of satellite images and pre-existing information, for the determination of design for sampling vegetation types.
3. Select botanically-skilled, SFRC staff members who could attend some field trips.
4. Provide safety, and botanical training for project tree climbers. Provide a short training session for all rangers associated with botanical work on the project.
5. Select botanically-skilled, SFRC staff members who could assist in the identification work of specimens at the SFRC herbarium.
6. Help locate elderly local villagers (from Inarad, Sapulut, or Kalabakan areas) who might give reliable ethnobotanical input, both in the field, and while reviewing collections.
7. Assess the possibility that soil analysis can be carried out at SFRC.
8. Facilitate the distribution of duplicate specimens to local and foreign herbaria (see proposed distribution list in Collections section of Work Plan).
9. Assist in the final interpretation of vegetation types, integrating remote sensing data and vegetation plot data. This final data should be directly usable by SFRC for their assessment of the vegetation resources in Sabah conservation areas (ITTO project).

4. GENERAL BOTANICAL COLLECTIONS

4.1. Introduction

The Maliau Basin has now become the focus of extensive general botanical collecting. Initially this was because of its `mystery value,' but more recently, because it is one of the few intact areas of forest in Sabah. We now have a large checklist of plants collected and observed in MBCA (Appendix I), but it is important to recognize that we are just still scratching the surface, especially for the trees that make up a large proportion of the botanical diversity in the area. Trees are hard to collect, due to their height, and seldom are found in a fertile condition - many species only reproduce during the irregular masting events that are a unique feature of Southeast Asian forests. The value of collecting intensively during a mast was noted in an early project report by the TA, and in fact a small mast flowering took place in Nov-Dec 2001, with fruiting in Jan-Feb 2002. Sadly, however, the TA, who was overseas, was not notified by the project botany staff, and no collecting took place. Thus a unique opportunity to collect many `difficult' species was missed. There is some hope, however, that this small mast was the first of a pair of masting events (a rare but important phenomenon), and that extensive flowering will start again shortly. *Vatica* trees were found to be flowering on the CTH plateau during the TA's Feb 2002 trip to the Basin.

4.2. Collecting History

The following is a complete record of botanical collecting at Maliau Basin, to the extent that duplicates have been deposited at SAN. Appendix I gives a nearly complete list of collections and observations, to date.

1972. Forest Department Expedition first reached Lake Linumunsut. Collections unknown.

1976. Forest Deparment. Lake Linumunsut. Peter Cockburn and Tony Lamb. 430 SAN numbers. Details in Appendix VI of Lamb (1988).

1978. Forest Department. Lake Linumunsut. K. K. Tiong (reported in Lamb 1988). Collections unknown.

1982. Tony Lamb, George Argent and Clive Marsh. Inner basin, upriver from Camp 88. ``Left NE for rim; up, down, up, and up 1st river to R." Edinburgh number series. Also N. rim with BHP (Lamb 1988).

1988. WWF-YS expedition. Orchids and fruit trees collected by Tony Lamb (used SAN #s) and W. W. Wong (1989; with collection numbers). Sightings noted by J. Guntavid (1989). Dipterocarps sightings noted by Nick Brown and Leopold Madani (1989). General checklist compiled by A. Phillips and E. Gasis (1989; without collection numbers).

1992. Phillips and Lamb (1992), with Read Beaman. Trip for EIA to NE rim. Collection numbers given. New *Casaurina*(?) and *Thismia*.

1995. John Reese, and Pelton. (Refer to Tony Lamb for details).

1996. YS-UMS-FRC expedition. Collected algae (Anton et al. 1998; without collection numbers), bryophytes (Akin and Suleiman 1998; with collection numbers), ferns (Akin 1998; without collection numbers). Rattan sightings noted (Gait et al. 1998). J. Perreira, general collections. Also S. L. Guan (FRIM), Christian Puff, Alistair Hay (UNSW), Wong K. M., each used own collection series.

1999-2002. Maliau Basin Project, botany team, general collections, MB series.

2000. Jacob Anderson (Copenhagen) Palms. Own number series.

2001 (July). de Wilde. Cucurbitaceae, Myristicaceae, general. SAN series.

2001 (April). Simon Laegaard (Aarhus). Grasses. SAN series.

2001. Axel Poulsen (UMS). Gingers. MB series.

2001. MB/FRC expedition to Lake Linumunsut. All collectors used MB series.

Additional random collections have been made by FRC staff, and a search of Brahms at SAN pulled out a number of these. Eventually the whole SAN series will be entered (currently only ca. 20% are in).

4.3. Field Methods

During the MB project, most high collections were made with tree climbers, although a `MoBot pole system' was purchased by the TA for the project, and is now at the Security gate. The presence of this pole should be advertised to potential collectors. The leading climber from FRC, Jeprin, was able to come frequently to the Maliau Basin, and made many of the high collections. He brought full rope- and spike-based climbing gear, but due to the heavy weight and slow deplotment of this equipment usually chose to `free-climb.' The TA supported him in this choice, but purchased some additional safety gear for him: a lightweight sit-harness and a long length of webbing. Most accidents are likely to occur while moving around the canopy of a tree, collecting the specimens, rather than on the ascent and descent. The harness and webbing enables the climber to attach themselves securely having reached the crown.

Several of the MB staff became good `free climbers' (Koh, and Jemehan), and were able to make collections from 5-15 m trees. Collecting from the large (50 m) emergents still remains a challenge, and requires full rope technique, or other methods (shotgun, rifle). Two members of the botany team took a climbing course, and should be capable of collecting from the largest trees.

In the field, specimens were generally pressed loosely in newspaper, tied into bundles, placed in plastic bags and covered with 70% ethanol. As many replicates as possible were made of each number, and alcohol flower collections were encouraged (although few were made in the end). Air-dried DNA vouchers were collected at first, but this was not kept up. On return to Luasong, the specimens were transferred to clean newspaper, and dried in one of two ovens purchased by the project. These are simple open-topped and bottomed boxes that force the hot air from two propane gas rings through the corrugations of the drying presses - a very efficient and simple design (Axel Poulsen arranged to have them made locally).

4.4. Herbarium Methods

Specimens were collated into MB# order at Luasong, and sent at ca. 6-month intervals to SAN. Here they were examined by SAN staff (primarily Leopold Madani and Poster), and given generic names. They were filed in family order, and were slowly matched to species. Other staff who helped at SAN included Dewol, Joel, and Patrick Lasan. Specialists, when available, looked at the specimens too (e.g., T. Lamb, orchids; Simon Laegaard, grasses). A top set was selected for the SAN collection, and others were distributed to the appropriate herbaria.

4.5. Distribution Policy

The following is the policy recommendation we made in 2000:

Main (Fertile) Specimens After discussions with members of the Forestry Research Center (Sandakan), the following distribution list was agreed upon. Specimens will be distributed to the listed institutions depending on the number of duplicates made and the institutions' position in the list. Justification is given:

1) *FRC, Sandakan*. Since the Maliau Basin is a Sabah forest reserve, it is mandatory that a duplicate of all material collected is deposited here.

2) *FRIM*. This is also a mandatory recipient herbarium for all material collected in Malaysia.

3) *Arnold Arboretum*. Harvard University is a proposed affiliate institution for the Maliau Basin project, and the university's herbarium, the Arnold, is the leading Malesian collection in North America. It is also the TA's home institution and depositing as many collections here as possible will facilitate additional determinations by the TA.

4) *Kew/Leiden*. These are the leading Malesian collections in Europe. Depending on the plant group involved, and the specialists that exist at the herbaria, they will be assigned either 4th or 7th position.

5) *UMS*. After depositing in major Malaysian and International herbaria, we wish to help develop the small but active collecting program of UMS.

6) *Aarhus*. The Maliau project is part funded by Danish organizations and taxpayers, and we would like to contribute to Danish herbaria in return.

7) *Leiden/Kew*. See 4.

Specialist Set Where a specialist is needed to identify a particular specimen, he/she will be inserted into the above list, and will be given the specimen in return for determining its identity. Only in the case when a single copy only has been made of the specimen will the specialist be requested to return the specimen to Sandakan.

DNA material Where possible, some leaf material will be dried in silica gel and will be useful for standard DNA analysis to determine phylogenetic relationships. This material will NOT be used for pharmaceutical analysis (and is usually of too small a quantity for this purpose). Two of these vouchers will be made for each specimen. One will be distributed to FRIM, the other going to a foreign institution with interest in the taxon collected.

Vouchers Numerous sterile twig and fallen leaf collections will also be made during the project. These are usually of no interest to any herbarium. They will be identified at Sandakan, and may be stored there if the herbarium is willing. Otherwise, they will be returned to the Maliau Field Station for permanent storage in the field herbarium.

Other Collectors Specimens made by other collectors (including UMS) may be distributed according to their own criteria, except for the one requirement that a duplicate of all material collected is deposited at Sandakan.

To date this is the general policy that has been followed. Several sets of Maliau specimens have now been sent out to foreign herbaria.

4.6. Results

Over 1,100 fertile numbers were collected during the first 2 years of the project. Appendix II lists the taxa collected to date. As usual, the list over-represents herbaceous and shrubby vegetation, and under-represents trees, especially since no mast was targeted for collecting. A good range of taxa have, however, been collected, and this represents a very substantial start to what we hope will be a long-term collecting program. The Arnold Arboretum has received a large batch of specimens and is in the proccess of giving names to the taxa yet to identified. However, as is usual, there are many taxa that could not be named by staff at SAN, and could not be matched, especially in collections from the higher elevations.

4.7. IUCN Red Data Book Status

The online database of the IUCN redlist <http://www.redlist.org/search/search-expert.php> was queried on 9 Apr 2002, for all `PLANTAE' that occur in Malaysia. The resulting list was compared with the checklist for MBCA (Appendix I) and the following taxa were found to be on the Redlist:

Critical (CR), 19 spp. ``A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria (A to E) as described below."

Dipterocarpaceae: *Hopea ferruginea*, *Hopea nervosa*, *Hopea aequalis*, *Parashorea malaanonan*, *Shorea acuminatissima*, *Shorea almon*, *Shorea foxworthyi*, *Shorea hopeifolia*, *Shorea johorensis*, *Shorea leptoderma*, *Shorea platycarpa*, *Shorea smithiana*, *Shorea superba*, *Shorea waltoni*, *Dipterocarpus gracilis*, *Hopea beccariana*, *Dipterocarpus lowii*, *Hopea sangal*, *Shorea asahii*

Endangered (EN), 12 spp. ``A taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future, as defined by any of the criteria (A to E) as described below."

Dipterocarpaceae: *Dryobalanops lanceolata*, *Shorea agami*, *Shorea andulensis*, *Shorea argentifolia*, *Shorea faguetiana*, *Shorea leprosula*, *Shorea obscura*, *Shorea pauciflora*, *Dipterocarpus crinitus*, *Shorea bracteolata*, *Shorea gratissima*

Vulnerable (VU), 15 spp. ``A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future, as defined by any of the criteria (A to E) as described below."

Anacardiaceae: *Mangifera pajang*

Araucariaceae: *Agathis dammara*, *Agathis kinabaluensis*

Bombacaceae: *Durio acutifolius*, *Durio grandiflorus*, *Durio kutejensis*

Dipterocarpaceae: *Shorea macrophylla*

Illiciaceae: *Illicium kinabaluensis*

Lauraceae: *Eusideroxylon zwageri*

Meliaceae: *Aglaia rivularis*

Myristicaceae: *Horsfieldia borneensis*

Nepenthaceae: *Nepenthes lowii*

Thymelaeaceae: *Aquilaria malaccensis*, *Gonystylus bancanus*

Rutaceae: *Melicope subunifoliolata*

Low Risk (LR), 8 spp. ``A taxon is Lower Risk when it has been evaluated, does not satisfy the criteria for any of the categories: Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories: 1. Conservation Dependent (cd). Taxa which are the focus of a continuing taxon-specific or habitat-specific conservation programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within a period of five years. 2. Near Threatened (nt). Taxa which do not qualify for Conservation Dependent, but which are close to qualifying for Vulnerable. 3. Least Concern (lc). Taxa which do not qualify for Conservation Dependent or Near Threatened."

Fabaceae: *Koompassia excelsa*, *Koompassia malaccensis*

Meliaceae: *Aglaia forbesii*, *Aglaia palembanica*, *Aglaia rufinervis*

Myristicaceae:*Knema kinabaluensis*

Nepenthaceae: *Nepenthes hirsuta, Nepenthes veitchii*

4.8. New Species/Records at MBCA

The process of determining that a new species has been found is lengthy, and depends upon the time and willingness of specialist taxonomists. The final count of new species at MBCA will therefore be a changing number, and beyond the time-frame of this project. However, we are in no doubt that many new species, and important new records have been found, because i) each specialist visiting the area has found interesting taxa, if not new species, and ii) many of the taxa were not matchable in the SAN herbarium, indicating many new records for Sabah. Groups likely to contain new species include the orchids, Myrtaceae, Ericaceae and other taxa of high elevation forests.

TABLE 1. New species and/or new records at MBCA.

Taxa	Family	New Sp./Record	Recorded by	Notes
Dacrydium elatum	Podocarpaceae	NR (Borneo)	Several	1988
Mangifera bullata	Anacardiaceae	NR (Borneo)	T. Lamb/J. Bompard	1988; 750 m
Rafflesia tengku-adlini	Rafflesiaceae	2nd record	A. Phillipps	also at Gg. Trus Madi
Nephelaphyllum trapoides	Orchidaceae	NR (Sabah)	T. Lamb	AL 916 (1988)
Bulbophyllum limbatum	Orchidaceae	NR (Sabah)	T. Lamb	AL 925 (1988)
Bulbophyllum sp. nov.?	Orchidaceae	NS?	T. Lamb	AL 905 (1988)
Coelogyne sp. nov.?	Orchidaceae	NS?	T. Lamb	AL 906 (1988)
Coelogyne odoardi	Orchidaceae	NR (Sabah)	T. Lamb	
Calophyllum bursicolum	Clusiaceae	NR (Sabah)	A. Phillipps	1988
Rhododendron nervulosum	Ericaeae	2nd record	T. Lamb	1982
Nepenthes vetchii X *stenophylla*	Nepenthaceae			
Nepenthes hirsuta	Nepenthaceae	NR (Sabah)	A. Phillipps	1988
Gymnostoma sp. nov.?	Casaurinaceae	NS?	T. Lamb/G. Argent	1982
Thismia sp. nov.?	Burmanniaceae	NS?	T. Lamb	1982
Trichoasanthes postari W.J. de Wilde & Duyfjes	Cucurbitaceae	NS	W. de Wilde	SAN 144098
Benincasa sp nov.?	Cucurbitaceae	NS?	W. de Wilde	
Zehneria sp. nov.	Cucurbitaceae	NS	W. de Wilde	

5. VEGETATION MAPPING

The Maliau Basin is particularly rich in variation in vegetation types. A prime goal of the botanical work was to produce a GIS-based map of the vegetation of the Basin, in collaboration with the GIS TA, Erik Prins. The stages involved were:

1. to observe in the field variation in vegetation within MBCA, and produce hypotheses concerning the causes and distribution of this variation,
2. to split this variation into discrete classes, where possible,
3. to determine the classes that could be detected using remote sensing, and
4. to classify the remote sensing data to produce a map of vegetation types.

Stage 1 was executed by walking tours of the basin, by helicopter overflights, and by setting up vegetation plots (Section 6). Stage 2 is inherently difficult: most vegetation types intergrade with each other in nature, and assigning a `type' to any one point is usually highly subjective. Statistical cut-offs can be applied to floristic and structural data, but this is highly labor-intensive, can be applied only to the few areas where vegetation plots have been set up. Indicator species provide a simpler alternative, and we tried to identify associations of some important species with particular vegetation classes. The upshot of these concerns is that we should recognize fewer rather than more vegetation types.

The remote sensing data available were a series of Landsat images, and a set of 1970 arial photographs (produced during the Sabah Forest Inventory). The clearest and most informative was a Landsat 5 image taken in 2001, which formed the basis of the vegetation map. The arial photos were invaluable for the interpretation of variation in the spectral signature of the satellite image. As is usually the case with image analysis, some vegetation classes recognized on the ground could not be differentiated on the images and some distinctions on the images could not be interpreted as vegetation differences on the ground. The final mapping units are given in Table 2.

5.1. Previous Classification Systems

The following forest types have been proposed by previous researchers:

Tony Lamb and Anthea Phillips (Lamb and Wong 1989, Phillips and Lamb 1992)

Mossy Rim forest. Above 4,500 ft. Wide belt on N rim (150 feet), but only narrow on NE and E rim. MD3A in Forest Inventory interpretation.

Casaurina forest. Wide band, behind Moss forest, down to 2,500 ft. to 5,500 ft, on slopes of less than 25 degrees and deeply weathered sandy soils. Interspersed with high-elevation heath forest, on even more podzolic soils. *Casaurina* may be sp. nov. Other species include *Tristania*, *Podocarpus*, *Dacrydium* and *Eugenia*. MC2A, MC2B, and MC3A in Forest Inventory interpretation. Rhododendrons in understory.

Casaurina-conifer forest. Describing the area above rengas ridge, on the edge of the heath plateau. *Casaurina sumatrana*, *Phyllocladus*, *Dacrydium beccarii*, *Agathis*, *Podocarpus* sp., *Shorea platyclados*. Also occurs around Helipad 5 (NE rim?). MC2B in Forest Inventory interpretation. Forest type unrecorded from other areas of Sabah. (Lamb and Wong 1989)

Mixed lower montane forest. Oaks, chestnuts and conifers.

Heath forest. Describing the main southern heath plateau, and level benches all the way around basin, below rim. *Dacrydium beccarii*, *Tristania* spp., without *Casaurina sumatrana*, *Shorea coriacea*, *Rhododendron durionifolium* ssp. *sabahense*. *R. lanceolatum*, *R. pneumonanthum*. Similar to heath forest at Nabawan, Long Pa Sia, Bario (Sarawak), except for some species substitutions: *Dacrydium pectinatum* at Nabawan, *Rhododendron malayanum* and *R. longiflorum* at Nabawan. The same formation occurs on the northern rim at 1,300 m (visited in 1982).

Nick Brown and Leopold Madani (1989)

Lowland hill dipterocarp forest. In valley bottoms and slopes up to 700 m. *Hopea nervosa*, *Shorea fallax*, *S. johorensis*, *Dryobalanops lanceolata*.

Ridge forest. Upper slopes and ridges to 950 m, descending into lowland hill dipterocarp forest. Dipterocarps (mainly non-emergent) co-dominant with oaks. *Hopea beccariana*, *Shorea platyclados*.

Coniferous forest. Low stature, above 950 m. Few dipterocarps. *Shorea platyclados*.

Heath forest. Low forest, high humidity. *Shorea venulosa* (or *coriacea*? - CW).

Saw Leng Guan and Clive Marsh (1989)

Lowland dipterocarp forest. After Burgess (1969). Lower slopes draining into Maliau river. Dense and multi-layered. Emergents include dipterocarps, Burseraceae, and Fabaceae. Smaller crowned on steep, lower slopes

Riverine forest. Restricted in extent at Maliau. *Eugenia claviflora* var. *riparis, E. perpuncticulata*, *E. rejangense*, *Tristania* cf. *grandifolia*. On alluvial soils: *Callicarpa longifolia*, *Mallotus penangensis*, *Guioa pleuroptris*, *Cinnamomum racemosa*, *Dysoxylum* cf. *acutangula*, *Rhodamnia cineria*.

Upper dipterocarp forest (lower montane). Characterized by *Shorea platyclados*. Structurally similar to lowland dipterocarp forest. At the Maliau: ca. 830 m to ca. 1,000 m. Dominated by oaks, Lauraceae, Myrtaceae, Clusiaceae, and dipterocarps (concentrated on ridges).

Agathis-Shorea platyclados/Oak-Laurel forest (lower montane). After Wyatt-Smith (1963). Corresponds to Brown's `coniferous forest' and Lamb's `Casaurina-conifer forest.' Elevation at Maliau ca. 1,000 m to ca. 1,200 m. Humus accumulation greater than lower forests. *Agathis borneensis*, *Shorea platyclados*, *S. venulosa*, *S. coriacea*, *Pyrenaria* sp. *Eugenia* spp., *Calophyllum* sp., *Actinodaphne* sp., *Litsea* sp., Fagaceae, *Casaurina sumatrana*, *Podocarpus polystachys*, *Phyllocladus hypophyllus*.

Montane Ericaceous forest. After Burgess (1969). At Maliau, above 1,200 m, e.g. at N end of Long Ridge. Right at cliff edge, trees only ca. 4 m tall, increasing in height with distance from edge, but seldom taller than 17 m. Trees crooked, mossy, small-xeromorphic-leaved, ground mossy and peaty. *Dacrydium falciforme*, *Phylloclados hypophyllus*, *Podocarpus imbricatus*, *Eugenia* cf. *hypophyllus*, *E. kinabaluensis*, *E*. cf. *ampullaria*, *Rhododendron* spp., *Vaccinium* spp., *Tristania* spp., *Actinodaphne* spp., *Litsea* spp., *Cinnamomum* spp., *Calophyllum* spp., *Casaurina sumatrana*, *Timonius* spp., *Weinmannia blumei*, *Tetractomia tetrandra*, *Embelia minutifolia*, *Elaeocarpus* aff. *palembanicus*.

Heath forest (edaphic climax). Differs from previous forest type by drier soils and less moss. *Tristania* cf. *grandifolius* (v. common). *Parastemon urophyllus*, *Prunus arborea* var. *densa, Ilex cymosa*, *Elaeocarpus pendula*, *Shorea coriacea*, *S. venulosa*.

Previous expedition reports also contain impressions of the forest types in addition to the above classifications:

1976. Peter Cockburn and Tony Lamb. Forest Department Expedition to Lake Linumunsut (Lamb 1988).

1978. Forest Department Expedition to Lake Linumunsut (Mitchell 1978).

1982. Tony Lamb and George Argent. Inner basin and NW rim (Lamb 1988).

1988. YS-WWF. Tony Lamb and W. W. Wong (1989). J. Guntavid (1989).

1992. Phillips and Lamb (1992), with Read Beaman. Trip for EIA to NE rim.

1996. YS-UMS (Maryati Mohamed et al. 1998).

5.2. Field Surveys

During our work at the Basin from 1999-2002, we covered (at least) the following routes, that form the basis for our impressions of vegetation in MBCA. GPS waypoints are available in as a GIS file (see Report by Erik Prins).

- Agathis - CTH - Waterfall - Ginseng - PUP (1999)
- Helicopter flyover of SE portion of Basin (2000)
- CTH - Plateau Waterfalls (2000)
- CTH - '88 Camp 2 - Rafflesia - Ginseng - PUP (2000)
- Helicopter trip LZ - Strike Ridge (2001)
- WSW rim logging road - Pakis (2001)
- Pakis - W rim (2001)
- WSW rim logging road - cliffs on W rim (2001)
- Strike Ridge Camp - Rim (2001)
- Strike Ridge Camp - Rafflesia - '88 Camp 2 - CTH - Agathis (2001)
- Helicopter trip: KK - NW basin - Strike ridge - S basin - LZ - CT plateau - W basin - KK (2001)
- Agathis - CTH - Bambangan - Waterfall - Ginseng - Agathis (2002)
- Agathis Nature trail (2002)
- Belian - Nature Trail (2000, 2)

5.3. Proposed Vegetation Types

After considering previous classifications for the Maliau, Borneo-wide classification systems (e.g., Whitmore 1984, Ashton 1995), and our own observations, we have proposed the following system. Note that the GIS mapping units do not correspond exactly to the full range of forest types.

TABLE 2. Proposed vegetation types from this study.

	Type	Mapping Unit	Approx. Elevation	Whitmore (1984)	Fox (1972)
1.	Lowland (LO)	Lowland (lo)	100-400	Lowland evergreen	*Rubroshorea*/belian
2.	Floodplain (AL)	Lowland (lo)	100	Lowland evergreen	"
3.	Hill (HL)	Lowland (lo)	300-800	Lowland evergreen	Selangan batu
4.	Upland clay (UC)	Upland clay (uc)	600-1200	Lower montane	Lower montane (a)
5.	Riparian (RP)	[various]	200-1000		
6.	Upland sandy ridge (SA)	Sandy ridge (sa)	600-1000	Lower montane	*Dipterocarpus*/ *Richetia*
7.	Agathis (AG)	Agathis (ag)	700-1100	Lower montane	Lower montane (b)
8.	Montane (MN)	Montane (mn)	700-1500	Lower montane	Lower montane (c)
9.	Kerangas/ Heath (HT)	Short heath (sh)	900-1600	Heath	Montane (a)
10.	Short Heath (SH)	Short heath (sh), Open crowned short heat (oc)	900-1600	Heath	Montane (a)
11.	Casaurina (CA)	Casaurina (ca)	1200-1400	Heath	Montane (d)
12.	Moss/Rim (MS)	Moss (ms)	1200-1900	Upper montane	Montane (a)
-	Naturally disturbed	Disturbed (di)			
-	Logged	[various]			

1. Lowland Forest

This is the true lowland dipterocarp forest on low elevation (100-300 m) sedimentary hills. It occurs around the full circumference of MBCA (Belian camp and between Lake Linumunsut and the boundary), and in the SSE part of the inside of the basin (Bambangan and Rafflesia area). It is characterized by a high diversity of dipterocarps, primarily in the light-demanding red seraya sections (*Shorea fallax*, *S. parvifolia*, *S. macrophylla*, *S. macroptera*), and by *Parashorea* spp. Belian (*Eusideroxylon zwageri*) and *Koompassia excelsa* are also common and striking members of this forest type. The forest is relatively highly disturbed, due to the relatively high productivity and the unstable soils on which this vegetation type occurs. As usual, the tallest trees occur on the ridges, where soil movement is relatively low. This type corresponds to Fox's (1972) Dipterocarp forest Type C (Rubroshorea/belian), although some areas at higher elevations (e.g., around the Bambangan camp) have a high density of *Parashorea malaanonan*, and may more closely represent his Type F forest (*P. malaanonan*/*Dryobalanops lanceolata*). Type site: across river from Belian camp, behind floodplain.

2. Floodplain Forests

This forest occurs on the banks of the Maliau river after it exits the basin, extending up to 300 m from the river. The terrain is truly flat, and the soils are rich. The forest has a broken canopy with many gaps separating tall trees. We have observed *Koompassia excelsa*, *Alstonia*, *Pometia pinnata*. Type site: across river from Belian camp.

3. Hill forest

Characterized by decreasing disturbance, generally sandier soils, and increasing abundance of *Agathis* and *S. laevis*. Type site: ridges around Agathis camp. The site at Lake Linumunsut may also be of this class, as judged from the vegetation plots (the TA was not able to visit in person). This type may correspond with Fox's (1972) Dipterocarp forest Type F (Selangan batu).

4. Upland clay

The large area in the W of the basin between 500 and 1000 m is a network of clay hills, without great differences in relief. Patches of dense *Agathis* trees (Type AG) occur on the hill-tops, where humus accumulates, which are very noticeable from the air. This type may correspond with Fox's (1972) Lower montane forest Type (a) (upper dipterocarp). Type site: the slopes either side of the river above Pakis camp.

5. Riparian

Limited to ten's of meters from rivers, and restricted in extent at Maliau. Common species include: *Eugenia claviflora* var. *riparis*, *E. perpuncticulata*, *E. rejangense*, *Tristania* cf. *grandifolia*. On more alluvial soils (e.g., at Rafflesia camp): *Callicarpa longifolia*, *Mallotus penangensis*, *Guioa pleuroptris*, *Cinnamomum racemosa*, *Dysoxylum* cf. *acutangula*, *Rhodamnia cineria*. Type site: the riverbanks around Belian camp. In higher areas, with rocky banks, *Dipteris lobiana* is very common.

6. Upland sandy ridge

A distinct forest type characterized by a dry, airy feeling, generally smaller trees than lower down a slope, but with a few giants persisting, and relatively sparse understory. Typical species: *Calophyllum nodosum*, *Elaeocarpus* spp, *Syzygium* spp. The TA was very excited to see this type of forest, as it corresponded almost directly to large areas of forest at Gunung Palung, in West Kalimantan, which occur on granite sandy soils. While we observed relatively few *Dipterocarpus* in this type at Maliau, the description most closely fits Fox's (1972) *Dipterocarpus*/*Richetia* forest type.

7. Agathis

Agathis trees dominate hill tops and upper slopes in the Upland clay (UC) area, and are notable even on the Landsat images. Patches are however usually small. Other species include *Shorea coriacea*, and *Gymnostoma sumatrana*, with an open understory, and often a palm sp., `silad' *Licuala grandis.* Type site: on trail from CT Hut to Waterfalls.

8. Montane

Also known as oak-conifer forest, this is a fairly diverse forest of tall stature. Type site: forest on ridge around SR campsite. Humus-rich soils, but moss accumulation not as rich as in Heath forest.

9. Heath

Also known as kerangas (usually at lower elevations). Forms on sandy, semi-level benches with thick accumulations of humus, and a build-up of moss on the stems of trees. Type site: trail in valley near junction of Jalan Babi and the AG-CTH trail. Rhododendrons and other Ercaceae are common.

10. Short Heath

When the substrate is very poor (thick layers of white sandstone), and the ground level (precluding `breaking into' clay-rich layer below the sandstone, a very short form of heath forest occurs, as epitomized by the flat bench to the E of CTH, on the route to Rafflesia and Bambangan camps (where the weather station is sited). Floristically similar to heath forest, but with fewer species and much shorter stature (ca. 5-8 m). At points in the basin (especially on the W rim), the trees become spaced out, forming an open woodland with litter exposed to direct light between the trees. This forms a distinct signature in the satellite images. It may be the result of past fire and slow recovery.

11. Casaurina

The possibly unique forest formation at high elevations described by Tony Lamb, and visible in arial photos. Casaurina (*Gymnostoma sumatrana*, or possible *Gymnostoma* sp. nov. `red-fruit') forms more than 50% of the stand. The only place this type was observed by the TA was in the trail from SR to the rim, in a flat-bottomed gully. The trees have crowns that do not cast a lot of shade, and some native grass species were found here.

12. Moss

This is a subtype of the montane forest that forms just below the rim, where cloud moisture is nearly constant. It is characterized by extremely twisted stems, covered to shoulder-height with deep moss blankets. It stands on the hard lip of the basin, which, where seen, is white sandstone. Species present include: *Calophyllum* spp., *Podocarpus neriifolius*, *Ilex* spp., *Rapanea* spp., *Lithocarpus lucidus*, *Chionanthus* cf. *cuspidatus*, the delicate liana *Embelia myrtillus* Kurz., *Weinmannia* spp., *Drymis piperata*, *Eugenia bankense*, *Syzygium* spp., *Vaccinium* spp., *Rhododendron* spp., *Tristaniopsis* sp., *Dacrydium elatum, Disepalum anomalum, Prunus* spp., *Tetractomia tetrandra*, *Naturally disturbed*

Disturbed scarp slopes. Light demanding species with palms. Tend to be E-facing.

5.4. Notes from Sample Routes with Interpreted Vegetation Type

Agathis to CTH

Left AC (489,594/519,303), followed level ridge [HL]. Tall forest on clay ridge and slope. *S. parvifolia*. Lots of Fagaceae. (P-1A, P-1B). This is the green forest on Landsat. 500 m. Medium humus. At 489,129/519,808 start a steep stope, where forest changed both on TM and on ground (HL/SA). Climbed slope to sharp ridge (488,708/519,891). Followed ridge, past bad step, to lookout (488,463/520,257; can see entrance road to AC). *S. laevis* on ridge. Then down a shallow (dip?) slope [SA], and back up a slippery ridge [MN] ending in a long (old) ladder (488,096/520,698) and hillock (lunch). Shallow slope for ca. 300 m, then rim appears on L [MN]. Follow rim to (486,943/520,526), then peal to R, following ridge. Soon enter kerangas [HT] (486,734/520,888). Slowly downhill, in and out [HT] of kerangas, to streams, and Camel trophy hut (486,430/523,207).

CTH to Waterfall-crossroads

Start in kerangas [HT/AG]. Then a view to L of tall riverbank forest (485,946/523,855). Cross our river (slow-moving; 485,853/523,987). Descend slightly into agathis-casaurina [AG] forest (485,531/524,219). Then into an area of yellow clay soil, steeper ridge/valley, with *Shorea* sp. (485,402/524,368) [UC]. Sharp change in soil to grey sand, and an amazing stand of nearly pure *Agathis*, with *Tetramerista glabra* and a palm sp., `silad' *Licuala grandis* (485,314/524,638) [AG]. Climb shallowly to a kerangas ridge, where the trail goes also R and L (485,328/524,720). I go ahead, and trail descends slowly to a sharp edge (485,334/524,797). Here the soil changes to yellow clay, and the land falls v steeply to waterfall below. In slope forest, see 3 spp. dipt., and hear hornbill overhead [UC].

CTH to Rafflesia

Lv CTH (486,430/523,207), W. Enter short ker [SH] (487,329/523,219; 1060 m). W to jct to Bambangan, then N to rim (486,941/525,084; 1010 m). Into montane for [MN]. Sharp ridge [SA]; MD2B; 487,264/525,508), down to river (old '88 camp II). Up (MC2A) to edge of cliff

(487,917/526,202; 1050 m) [UC], then L. Follow rigde [SR] ca. 300 m, then R, and down v. steep ridge (MD2B). At 800 m (488,658/527,176) still on ridge, but running shallow (MC2A). Finally steep drop (LD2B) [DI] to C88 (FT9; LC1B; 488,974/527,711; 500 m). Behind camp the forest is v disturbed [DI]. I think the whole slope is an old (200-500 yr.) mudslide. The surface is so slippery, still. Trees just cannot stay standing for long. Yes, the whole C88 area confirms this: the boulder field in river, the `lake' above, the helipad flat. Across river: LO.

Rafflesia to Ginseng

28-4-00. (Camp 88) Leave Camp 88, hike up steep slick slopes to ridge. Follow ridge ca. 200 m then L, across small gully and onto different ridge. Down steep, past scary cliff, to river (w waterfall below). Up, and onto ridge. Follow ridge S for long way, cliff to L. Cross one river (not far down) - beatiful spot. Past river, into GP granite forest [SA]. Cross 2nd river, and up into ca. kerangas, finally to peak (491,504/526,433; 840 m). Luba palms (*Eugeissona* cf. *utilis*) over edge of cliff all the way. Now on trail to Waidi camp. Follow ridge then into undulating area (mull soils) [UC]. Jnct w trail to Camel. Down, steep (still mull). Waidi Camp, up through steps (Mor soils). Onto plataeau (huge belian), then to ridge (GP upper granite) [SA]. Junction with ridge to Belian camp (according to Henry; 491,457/523,621; 850 m). Ridge to rim, R, then L. Forest down to PUP is very close to GP low granite [SA]. Check later area with limestone(?) in sandstone. PUP (492,037/520,062).

5.5. The Ecology of the Vegetation Types

The network of influences on the vegetation types is complicated (Fig. 2), with high variablity in substrate, elevation and topography leading to extremely variability in vegetation on small spatial scales. The distribution of vegetation types can be displayed with respect to elevation and substrate (Fig. 3). A semi-subjective classification, based on expected floristic similarity, is shown in Fig. 1. When all plots have been analysed, an objective classification can be performed.

5.6. Plasticity Within Species

On of the most striking botanical features of the Basin is the range in morphology that accompanies variation in habitat, for some species. In particular, *Gomphia serratus, Parastemon* *urophyllus, Lithocarpus lucidus, Chionanthus* cf. *cuspidatus* and *Tetractomia tetrandra*, can all be found in lowland or hill forest all the way up to moss forest, but differ greatly in morphology, with leaves becoming smaller and thgicker with increasing elevation. Whether this is an expression of plasticity in a widespread genotype, or variation in genotype across the habitats, is not known. This phenomenon would be a great topic for further research. If the variation is caused by different genotypes, then this increases greatly the number of phylogenetic entities, or `species' at MBCA, with associated increase in conservation value.

5.7. Remote Sensing Classification and The Vegetation Map

A major output of the project has been a vegetation map of the Basin. A supervised classification of a Landsat image was chosen as the most useful and appropriate format for this map, and it was produced by Erik Prins, with input from the TA. As with classifying the vegetation itself, it was challenging to reduce continuous variation in spectral signature to discontinuous classes. Using data from a number of sources:

1. Sabah Forest Inventory (1971): mapped interpretation of forest timber resources from aerial photographs,
2. The original aerial photographs,
3. Landsat 5 Image (taken 1999). (30 m resolution),
4. Landsat 7 Image (taken 9 July 2000). (15 m resolution),

and especially the on the ground experience and observations of the TA, the GIS system (Erdas Imagine) was taught to recognize the spectral signature of the major vegetation types (see Table 2). The final map was based on a Landsat 7 image. See Erik Prins' report for full details. A number of classes that could be recognized in the field could not be differentiated spectrally on the image, and vice versa. Further work in mapping vegetation might be based on Quickbird, IKONOS, or hyperspectral images. These have the potential to resolve the signatures of individual species. Already, in the Landsat 7 image, there were areas in the lowlands, where distinct, pale-crowned trees can be detected, probably *Parashorea*, or *Koompassia* trees. Obtaining further landsat images will be vital in monitoring encroachment into the park by logging operations.

6. VEGETATION PLOTS

In order to i) sample tree diversity in a systematic fashion, and ii) provide an independent assessment of the vegetation classification system, a series of tree plots were established at 11 sites within MBCA. See Fig. 6. for sample locations.

6.1. Field Methods

At each sample location, at least 3 plots will be made. Their precise location was chosen (stratified randomly) to sample local variation in topography (ridge, slope, gully). They were up to 500 m from the campsite. Each plot was 50 m x 20 m for trees > 10 cm DBH, and 50 m x 40 m for trees > 30 cm DBH, and was laid out rapidly using a 50 m tape, a sighting compass, and a 10 and 20 m line. The beginning and end of the centerline were marked with plastic flagging, as was the perimeter of the plot. All trees greater than 10 cm DBH were tagged with aluminium tags and nails, measured for diameter, and located to within one of the ten 10 m x 10 m subplots. Plots contained up to 120 trees, and could usually be completed in one day.

Each tree was identified as follows. Towards the end of the sampling, when extensive experience had been gained, some species were able to be identified by sight. This was also the case when skilled members of SFRC attended trips. For each tree that could not be identified with 100% confidence either to species or as the same species as another tree in the plot, three to six leaves were collected. If the tree was climbable, a tree-climber would retrieve a twig. When the tree was to tall or the bole too wide or slippery, leaves would be knocked out of the crown with a slingshot. These would be used to identify the correct, old fallen leaves on the ground. The leaves were then stapled together, with a small piece of cardboard, on which was written, with India ink, the plot number and the tree number. At the end of the day, leaf bundles were pressed between newspaper, several to each sheet, and the sheets soaked in alcohol, as described in the methods on general collecting.

In a field notebook (with ``Write-in-the-Rain" paper if possible), details of each tree were recorded: leaf arrangement, compound/simple, leaflet number and arrangement, bark surface texture and color, inner-bark color, exudate details. If possible, a field determination was also recorded. Periodically, sterile vouchers were taken to SFRC for matching with herbarium collections.

A set of additional data was collected for each plot, including: topographic position, aspect, mean canopy height, and GPS location (see Appendix III). Soil samples were also taken at each plot. Three locations along the mid-line were sampled: 10 m, 25 m, and 40 m. An auger was used to extract soil from two layers: 0-15 cm, and 30-45 cm. Samples from the three locations of each layer were bulked together, providing two soil samples per plot. These were analyzed for basic chemistry and texture at the lab at FRC.

6.2. Herbarium Methods

At the herbarium, plots were processed one at a time. Each species that was obviously a new record for that plot would be placed in a folded sheet of newspaper, and given a unique morphotype number. This number was written on the sheet, entered directly into a morphotype database (with type tree; ``morpho.dat''), and recorded alongside the tree record in the field notebook. Common and speciose genera (e.g. Myrtaceae, Dipterocarpaceae...) were placed aside and left to the end, so multiple trees of the same species could be placed in the same sheet.

When all trees in a plot were filed, the sheets were filed into the family folders accumulating collections for all plots. When all plots had been processed in this way, general matching was started, moving through the families in alphabetical order. Where multiple morphotypes from multiple plots had been created for the same species, these `synonyms' were reduced to a single morphonumber: the lowest number was generally chosen as the final morphonumber, and this was recorded in the `synonym_of' column of the synonym records in the morpho.dat database. The physical sheets of the replicate morphotypes were tucked inside the sheet of the main morphotype. This preliminary matching could take place in the Luasong herbarium.

When this reduction of synonyms was finished, matching with collections in the FRC herbarium was started. Leopold, Poster and Joel were mainly responsible for this.

After entering all data and identifications, multivariate analysis were used to identify vegetation types based on species groupings, and to determine the nature of variation in soil components.

6.3. Other Forest Plots/Transects at MBCA

1972. Forest Department Forest Inventory Correlation plots. Lake Linumunsut (reported in Lamb 1988). Data not recovered.

1978. Two 0.25 ha plots at Lake Linumunsut. Vouchers may or may not have been collected. (Mitchell 1978). Data not recovered.

1982. Tree plots by Sabah Society forester Encik Awang Hazani in inner basin (Lamb 1988). Data not recovered.

1988. Nick Brown made a long transect for dipterocarp species (Brown 1989).

1996. Four transects (20 m wide, length unreported!) near CTH (Gait et al. 1998).

199x. FRC plots near CTH (Ong et al. 199X).

6.4. Results

35 plots were made, at 11 locations, and data was collected for 2782 trees (Appendix III and IV). At the time of this report, 1595 trees had been matched to morphotype. Using these identified trees, basic estimates of total biodiversity were made (Table 3).

TABLE 3. Species richness estimates from 7 locations

				Species	Richness	Metrics
habitat	plots	trees	spp	S/100t	1st 100	Chao1
Lowland (LO)	10	589	210	35.6	56.1	365.3
Upland clay (UC)	2	190	118	62.1	65.3	353.4
Sandy ridge (SA)	1	74	53	71.6	34.9	195.9
Hill (HL)	3	190	99	52.1	55.4	175.9
Heath (HT)	3	182	77	42.3	44.2	146.0
Riparian (RP)	1	67	34	50.7	22.4	53.0
Short heath (SH)	3	302	14	4.6	5.2	20.8

The Chao 1 metric estimates the total number of species in that forest type. For the whole of MBCA, across all habitats, we observed 440 tree species greater than 10 cm DBH, but also estimated that there are a total of 1010 species, using the `Chao 2' metric, treating each habitat type as a replicate sample. The total vascular plant diversity at the site could be as high as 2-3,000 species.

A simple ordination was performed (using NMDS; Fig. 5). Three major groups of species could be identified in the ordination, corresponding to kerangas/heath [HT], hill [HL], and lowland [LO] types. Further classification will be made when more of the samples have been identified. The soil samples were also ordinated (Fig. 4), and showed a similar pattern of variation to the tree plots.

These data provide a solid basis for further research at MBCA, and reinforce the notion of the great diversity of habitats at MBCA.

7. COUNTERPART ORGANIZATIONS AND CAPACITY BUILDING

Interactions with Forest Research Centre were exemplary. The staff were incredibly helpful, and the herbarium and larger environment are a great place to work. We hope that the staff at FRC got as much out of the collaboration as we did.

Unfortunately, the collaboration with University of Malaysia, Sabah did not develop, as hoped.

Our own botany team staff have matured greatly, and now represent a very able resource for the future. They know how to collect, set up plots, process specimens, climb trees, and interact with scientists. They also have significant taxonomic knowledge. Se below for our recommendations for their future.

8. INTERPRETIVE MATERIAL AND NATURE TRAIL

An important part of the success of eco-tourism in the MBCA will be the availability of user-friendly interpretive material. The completion of a full set of interpretive material is beyond the scope of our work, but we did set up nature trails at both Agathis and Belian camps, and provide here some preliminary notes that can be later incorporated into an interpretive booklet. The two nature trails are described in basic detail.

8.1. On the drive in

Visitors might be asked to notice a number of very obvious plants in the secondary, degraded forest on the drive in from the Security gate:

Duabanga moluccana. This is the tall tree, with an unbranched bole and horizontal branches. The leaves are opposite each other, rectangular in shape, and tend to be heavily holed by insects.

Neonauclea. The other common oppositely-leaved tree, with large oval-shaped leaves and a prominant, oval stipule protruding from between the terminal pair of leaves.

Macaranga spp. These are the shortish trees with large, `fig-leaf' shaped leaves. There are many species.

Octomeles sumatrana. In the lowland, wetter areas (only) you will see these tall, unbranched trees, with alternate, egg-shaped, pointed leaves which are usually very heavily eaten by insects.

Caesalpinia latisiliqua. Throughout the disturbed forest there is a climber with very distinctive bright red legume pods.

8.2. Agathis camp

The nature trail here is a lovely walk. The full map of the nature trail is being prepared separately, but in note form:

Leave camp. Gingers. Cross river by log. Point X. R: strangling fig. Cross river. Note dipping rocks. Through plot P1C. R: *Elaeocarpus* stilts. L: *Selaginalla*. L: *Artocarpus* (cempedak). L: liana, climbing, falling climbing. L: *Shorea parvifolia*. R: large *Dialium*. L: tampoi merah. L: lg melapi bunga (*S. confusa*). R: seraya daun mas. Gap, note bamboo. R: termite nest. L: seraya punai (*S. parvifolia*). R: signs of gaharu hunters. Trail turns to L in gully. R: kapur paji. L: majau. Cross stream, note *Dipteris biloba*. L: kempas. R: *Dillenia* w stilts. R: jelutong, R: seraya minyak. Trail splits - L to Giant *Agathis*. Turn R. R: termite nest. Hilltop: note *Agrostystachis*. R: giant *Irvingia*. R: strangling *Ficus* (tree gone). R: *Agathis*. Streambank: Marantaceae. Cross stream. R: tampoi kuning. R: tongkat ali. L: mempening (Lithocarpus). Cross stream. L: rotan merah. L: Marantaceae sp diff. L: rambutan. Crossing trail: liana you can drink from (kelait). Junction with point X. R to `skyline loop', L to return.

8.3. Belian camp

The route starts directly across the river from the proposed bridge site site. Up. Disturbed area. R: large urat mata (Parashorea malaanonan). R: menggaris with two fig roots. R: urat mata. L: urat mata. R: belian. Top of rise. R: Heretiera borneensis. R: seraya punai with birds nest fern. R: belian. Look far to L: huge menggaris. Gap with tree fall. L: belian. A large Irvingia on L. L: seraya minyak. L: majau. R: Scaphium (kembang semangkok). L: huge dipterocarp (S. pauciflora). Climb to a small gap. Gingers near trail. Followed by an area of disturbance by wild pigs that have been `hoovering' up the fruits of a forest oak. L: menggaris. Follow the ridge to the open clearing that is the dancing ground of an argos pheasant. Just before a very large gap, watch for a trail to the left, at Quercus tree. Skirt the hillside. L: seraya kuning siput. Here is a large pig mud wallow. Turn left and follow the trail back onto the ridge, passing a tree used as a rubbing post. Note a stand of belian trees to the right. R: Sindora velutinata. R: Bambangan. Descend the ridge, following the stream on the left, then cross the stream. You are now in the alluvial flats again. Follow ahead. R: pulai. Cross the stream again at a very interestingly-shaped meander. A giant Koompassia, complete with strangling fig, lies to the right, between two temporary streams. Cross the mud channel here. Turn L on trail and return to bridge. The whole trail should take ca. 1 hour at an easy pace.

The benefit of a layout like the one we made is that i) both alluvial bench and steep lowland hills were sampled, ii) a trail could be extended from the top of the loop up to the rim of the Maliau Basin, providing a strenuous hike through pristine forest for active visitors. The trail is now only lightly marked, and it is important that it be followed soon and marked more permanently.

8.4. Special Species Accounts

Conifers Because the forest at MB is generally high elevation, the conifers play an important and often striking role in the forest. There are not a great number of species, and they are mostly quite distinct. Here is a simple key to the main conifers at MB:

1. Leaves broad, flat
  2. Leaves apparently pinnate — *Phyllocladus hypophyllus* Hk. f.
  2. Leaves apparently simple
    3. Leaves opposite
      4. Leaves snapping when bent in two
        5. Leaves large, elliptical — *Agathis borneensis* Warb
        5. Leaves small, oval — *Agathis orbicula* de Laub.
      4. Leaves flexing when bent in two — *Nageia wallichiana* (Presl.) O. K.
    3. Leaves alternate
      6. Leaves spirally arranged, oblong — *Podocarpus polystachys* R. Br. ex Endl.
      6. Leaves scimitar-shapped — *Falcatifolium falciforme* (Parl.) de Laub.

1. Leaves scale-like
  7. Some twigs with flat elliptically outlined sprays of scales
  Dacrycarpus imbricatus (Bl.) de Laub.
  7. Twigs without such sprays
    8. All scales tightly held to the twig — *Dacrydium elatum* (Roxb.) Wall. ex Hook.
    8. Some scales raised away from twig
      9. Scales fine — *Dacrydium beccarii* Parl. in DC. Prod.
      9. Scales thick, stout — *Dacrydium pectinatum* de Laub.

Dipterocarps MBCA contains a large number of dipterocarp species (at least the 74 included in the checklist), and as the major tree group in Borneo, and the major timber resource, they form a group of interest to many people. They are often hard to tell apart, but an interpretive key to the major sections could be easily made for the species at MBCA, and would empower visitors to know and take more care of the major economic resource of Sabah.

Orchids Everyone loves orchids for their exquisite flowers. They are especially diverse and accessible in the heath and short-heath forest of the CTH plateau, and specific orchid tours could be led to this area. We noted the greatest flowering of orchids there in April-May 2000. There are a number of good introductory guides to orchids that might be made available to visitors.

Rhododendrons There are also always rhododendrons flowering in the heath forest, the commonest probably being *R. borneense*, *R. durionifolium*, and *R. javanicum*, and their various subspecies. Argent et al. (1988) wrote a great guide to these showy plants, but the common species at MBCA could also be photographed and displayed in the field center.

Nepenthes These are another group that people will come to MBCA especially to see. Again, the heath forest is the place to see them, and a botanical tour could easily be made to this area. Several good guides are already available in the Lusaong library. We have records of 9 species at MBCA: *Nepenthes* cf. *mirabiles*, *Nepenthes gracilis*, *Nepenthes hirsuta*, Nep*enthes lowii*, *Nepenthes reinwardtiana*, *Nepenthes stenophylla*, *Nepenthes tentaculata*, *Nepenthes veitchii*, *Nepenthes veitchii X stenophylla*.

Rafflesia tengku-adlinii A parasite on the *Tetrastigma* liana, this plant is very attractive and interesting. The liana itself appears to grow in heavily disturbed sites, and we know of two places where the liana and parasite can be found: on the trail down to Bambangan Camp, and in the disturbed forest on the hill behind Rafflesia camp. Several rangers know the sites, and should be frequently questioned about the flowering status.

9. CONSERVATION COMMENTS

The Maliau Basin is an outstanding conservation resource. At the most generic level, it has value because it is one of the few large areas of intact forest in Sabah and Borneo. It also contains a sizeable area of lowland forest - the most threatened forest type in Borneo (estimated by Derrick Holmes of the World Bank to be completely gone in 10 years). However, MBCA is perhaps most valuable for its great range of forest types in a relatively small area. This diversity of forest types definitely will cause an increased diversity of species, perhaps higher in total than if the whole area were lowland forest (the most species rich forest type). The diversity of forest types has a downside: that each is fairly small in area, and may not contain self-sustaining populations of the taxa there. However, for migratory animals, this diversity of forest types actually may increase the overall security of food resources, with different areas having different phenology. In addition the intra-specific diversity of genotypes is notable in many species (see 5.6).

The biogeographic position of MBCA also contributes to its value. While high elevation forest on sedimentary rock in itself is not rare, MBCA is one of the easternmost mountains of its type (most mountains further east are granitic or ultrabasic in origin). It is thus some-what isolated, and probably has a drier climate than other sedimentary mountains further west. Eastern Sabah also appears to be a unique biogeographic province (Ashton 1990, Wong 1998), with a dividing line for some groups running from Gg. Mulu to Ulu Padas, the boundary of Meligen Sandstone (T. Lamb, A. Phillipps, pers. comm.). All these factors will contribute to a higher probability of local speciation in upland taxa than are relatively isolated from their nearest populations outside MBCA.

In terms of alpha-diversity, the lowlands are the richest (although our analyses indicate that the upland clay vegetation is also very rich), and the most threatened regionally. Being on the boundary of the park, these are also the most endangered by fire and poaching. It seems clear, therefore, that they should be the focus of most of the conservation effort. The interior of MBCA will then take care of itself.

The zonation of the area is an issue for the management plan, but one that should not consume too much time or be too rigid. The difficult terrain in MBCA will take care of most `casual' visitors, and the impact of the few who might make it in is unlikely to be serious. If a `most-valuable' core zone were to be chosen, it should probably be the lowland forest inside the basin, but this is also the area most likely to be needed for tourism. Rather than zonation, the simple prevention of heavy impact beyond the Maliau Falls trail should be sufficient to preserve the area.

We feel that it is especially important to link the conservation and management plans for MBCA with those for Danum Valley. Together, these sites make an unsurpassed pair of conservation areas, including all the major vegetation sites in Sabah (except mangroves). As a research offering, they are also strengthened by being put together. If the logged forest between can be left to regenerate, the whole arc from Danum to Maliau would be a superb conservation area, and we support all plans to present this as a World Heritage area.

10. CONTINUING BOTANICAL WORK AT MALIAU

We hope that botanical work at MBCA has only just started. We have just begun to scratch the surface of plant diversity there, and offer some suggestions here for further work.

10.1. Continued Collecting

The most important aspect of further botanical work at MBCA is that the databases must be maintained, and that labels and fieldnotes must be produced for SAN. There are several of the botanically-inclined permanent staff (Koh, Linus) who would be able to do this, and they should be taught the methods. Specimens must continue to be sent out to specialists, as this is the only way that new species will be discovered.

10.2. World Ecosystem Reference Station

MBCA is perfect for a station in a network of ecosystem monitoring sites. Tree survival and growth rates can be monitored to give important forest dynamics information. See Oliver Phillip's RAINFOR project <http://www.geog.leeds.ac.uk/projects/rainfor>. Phenology should also be monitored. Suitable networks to approach include: US Long-term Ecological Research <http://lternet.edu>, International LTER <http://www.ilternet.edu>, Organization of Biological Field Stations <http://www.obfs.org/index.html>, International OBFS <http://www.iobfs.org>, Global Terrestrial Observing System <http://www.fao.org/gtos>, World Network of Biosphere Reserves <http://www.unesco.org/mab/wnbr.htm>, Center for Tropical Forest Science <http://www.ctfs.si.edu>.

10.3. `Open' Research

Encouraging `open' research is vital to the healthy use of MBCA by scientists. Fields of study especially suited to MBCA are: ecology, systematics, ecosystem science. The assets of MBCA that will be attractive to scientists are: Great habitat diversity, genetic diversity, pre-existing plot network, good collections and field herbarium, remaining lowland forest, large areas of montane forest, outstanding GIS resources, and a globally-unique basin structure, with valleys matching variation in vegetation.

10.4. Herbarium at Field Studies Center

The following items/design features are needed (the set-up at Luasong can be used as a template):

- Drying ovens x 2 (including stoves, gas bottles, cardboard, felt or foam, frames; already purchased, and at Luasong, but need cleaning/mending)
- Waist-high, large tabletop, for sorting
- Cubby-holes, or actual herbarium cabinets
- Computer dedicated to specimen database
- Storage space for field equipment
- Good working lights
- (Optional) Stereo/dissecting microscope
- The above to be housed in an air-conditioned room

The laboratory area should include a separate `shack' for the drying ovens. A space of ca. 3 m x 3 m is sufficient, with concrete floor and basic walls. It should be isolated enough from the main lab that a fire in the drying oven would not threaten the rest of the structures. The ovens are listed above, and will be left at the lab after the end of the project. The drying shack can be used also to house litter and soil drying equipment (Tulgren funnels, etc.).

An air-conditioned room in the main laboratory should be designed as a herbarium. I suggest a room of at least 5 m x 4 m. Specimen storage pigeon-holes can line each long wall. These can be open, and each should be 35 cm wide, 45 cm deep, and ca. 35 cm tall. A high (standing-height) work space should fill the center of the room, with a lower work-desk at one end, large enough to support a computer. Several fluorescent lights should be supported over the work table, and a large window should fill one end of the room.

10.5. Canopy Research

MBCA is no better as a site for canopy research than Danum, and considerably harder to move around in. However, canopy research is `sexy' and can draw in positive attention. Developing a canopy walkway for visitors will also be a major asset. Note, however, our advice that the alluvial, disturbed bench on the other side of the river from Belian camp is not a good site for a public canopy walkway - it will be too hot, as the forest is too open and broken. A site further up the hill is suggested.

10.6. Potential Major Research Opportunities

Besides the joining of an ecosystem monitoring network, MBCA would be an excellent site for a major research program, such as a 50-ha plot site, managed by the Center for Tropical Forest Science. Suitable contacts can be provided by the TA.

10.7. Future of Botanical Team

As mentioned above, the botany team are a well-trained unit that can be used in education, training, and research. They might also be trained to carry out basic monitoring research, such as phenology on the trees along the Nature trails. There is no reason to let any of them go from the team - the current number (6) is optimal, especially if two parties of scientists or visitors need to be accompanied at once.

10.8. Rapid, intensive collection during mast flowering

Because most species in these forests only flower with the masting cycles of the dipterocarps, every 3-7 years, our fertile collections will be poor if we do hit get another mast in the next 2 years. However, the last mast in the area was in 1996, so there is a good chance that we may see a mast. If this occurs, it will be beneficial to increase the general collecting intensity during the 4-5 months of flowering, and the ca. 2 weeks of fruiting. I propose that we put aside funds for adding 3 extra team members (two of whom will be tree climbers), whose job it would be to collect constantly during the mast. Other sampling work would continue, though added attention would be made to getting fertile specimens in plots.

The TA has recently established a web-site for communal monitoring of masting activity: Mastwatch <www.phylodiversity.net/mastwatch>, and it is hoped that researchers at the Maliau will contribute to this site.

10.9. Palynology

Early work after the 1988 expedition found pollen from *Alangium*, *Barringtonia*, *Brownlowia*, *Casaurina*, *Cephalomappa*, *Dacrydium*, *Durio, Florshuetzia*, *Gonystylus*, *Lycopodium*, *Picea*, *Pinus*, *Rhizophora* and *Stenochlaena* in the Tanjonmg formation rocks (Marsh 1988). Work was carried out by labs at Sarawak Shell. While not directly relevent to conservation at the Maliau, the great range of rock ages exposed at the Maliau makes it a great site for further palynological work.

10.10. Bioprospecting

There has been much talk over the past 10 years of the potential for pharmaceutical collaborations to fund conservation activities. There have been notable successes, but in general the model has not been the panacea for conservation that it has been proposed to be. Instead, the concept of valuation of genetic resources has lead to a deterioration in relations between researchers and conservationists and natural resource departments in biodiversity-rich countries. Accusations of `biopiracy' fly, and it has become nearly impossible to conduct non-commercial research in many countries, let alone remove botanical specimens. It is the opinion of the TA that the drawbacks of promoting bioprospecting far outweigh the possibility of mutual benefit, and thus this should be a strategy employed at MBCA only with extreme care. This said, the great diversity of the site means that the chances of discovering useful bioactive compounds is as high as anywhere could be.

11. EDUCATIONAL OPPORTUNITIES IN BOTANY AT MBCA

We are in full agreement that perhaps the most beneficial long-term role for MBCA may be as a site for Sabahan education. If travel costs were not prohibitive, this could be for secondary school students as well and college students, but visits by the latter are more likely. The botany program has much to offer college students, especially those training in forestry. The plot methodology employed is simple, and the students are encouraged to add plots to the network. The staff on site, especially the MT, are fully versant with the methods, and can direct the students. The network would be best served by adding plots in unvisited areas, but this will necessitate serious logistical investment, and so adding more lowland plots will also be valuable (since this is the most diverse forest type).

12. COLLECTED RECOMMENDATIONS FOR MANAGEMENT PLAN

Tourism

1. *Cheap tourism*. We recommend that there eventually be at least some cheap option for foreign tourists. Even though at the time these tourist may not be the most thoughtful or influential, I am convinced that a place like the MB makes a lasting impression and changes people, slowly.
2. *Interpretive material*. A consultant be hired to complete quality interpretive material.
3. *TV*. The TV should be removed from the main living area at Agathis. It is understood that the staff have a right to recreation, but for many foreign tourists, having violent, loud films playing while they eat their dinner will seriously detract from the quality of their experience.
4. *Tree numbers*. Similarly, the large tree numbers painted on the nature trail should be removed.

Research

5. *Specimen database*. It is of utmost importance that the main botanical specimen database be maintained, and that labels continue to be produced for specimens. There are several of the botanically-inclined permanent staff who would be able to do this, and they should be taught the methods.
6. *Herbarium at Belian*. The vouchers currently at SAN should be brought back to the MB field center, to become a simple, but quite comprehensive field herbarium.
7. *Permanent Senior Scientist*. In light of all the scientific needs for collection of long-term data, the hosting and briefing of visiting scientists, and the need for further proposals, there is a great need for a permanent senior scientist to be based at the Field Center.
8. *GIS Station*. All users of MB, especially scientists and educators, will benefit greatly from access to the considerable GIS data already compiled. There should be a computer in an easily accessible location, loaded with basic GIS software, and a simple `ABC' of GIS should be written and made available.
9. *Porters for scientists*. Successful scientific work in the MBCA will depend heavily on moving supplies and equipment into the Basin. A reasonably priced option must be

developed for portering. The history of portering prices will make this difficult, but a solution must be found.

10. *Biodiversity Enactment*. The current development of the Sabah Biodiversity Enactment is a very positive step for Sabah, but recent experience has also made it clear that such institutions can curtail positive activities in a serious way. Every possibility should be taken for MBCA staff and scientists to be involved in discussions about the council's rulings.
11. *Publication of results*. I personally hope that the remaining month of funding for the botany TA be made available in late 2002 for further herbarium work, and the writing of a paper for Sandakania containing the main botanical finding of this report.

Long term conservation.

12. *Major NGO sponsorship*. None of the major international conservation NGOs (CI, TNC, WWF) has `claimed' MBCA, but each might be quite interested in doing so. The benefits would be the possibility of long-term funding and public awareness. The regional contacts of these organizations should be contacted and courted.
13. *More counterpart organizations*. Besides the collaboration with the Harvard Herbarium, several other collaborative agreements should be sought, for institutional prestige and transparency that they can afford. Possible institutions are Aarhus, the Asian BRC. and above all the Royal Society.
14. *Network membership*. The global value of MBCA as an ecosystem monitoring station is very high.
15. *General research*. While it cannot be claimed that further scientific research is fundamental to the conservation of MBCA, there is no doubt that the international awareness and prestige created by good research is beneficial to conservation. Non-destructive research of all types should therefore be encouraged.
16. *Bufferzone*. Institutional logging agreements are hard to alter, but every effort should be made to secure the expansion of the bufferzone on the side facing the Benta wawasan project. Some of the most valuable lowland forest in MBCA is very close to this boundary, and will be poached for timber. Additionally, any action to decrease the

logging activities in the Imbak valley, and between Imbak and MBCA will be very beneficial for maintaining large contiguous areas of lowland forest.

13. ACKNOWLEDGMENTS

Our most sincere thanks go to Tony Greer, Tony Lamb, Robert Ong, Joan Perreira, Anthea Phillipps, Axel Poulsen, Erik Prins, Jadda Suhaimi. Thanks to Hans Moeller and Waidi Sinun, for facilitating our work (and for their patience). The support staff have been excellent: Esperanza Sulit, Peter Buron, Aslan Budi, Alan Khoo, Ibu Naemah, Abel. Many thanks to our field staff: Henry (especially!), Jemehan, Jeprin, Koh, Linus, Aslan, Edward, and all the other permanent staff we have interacted with at Luasong and MBCA. And to anyone I've failed to mention - thanks, you know who you are. We thank Yayasan Sabah and the Malaysian Government, for permission, via the DANCED-YS MOU, to work in such a wonderful place.

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APPENDIX I. MASTER SPECIES CHECKLIST FOR MBCA

Refer to MS Excel spreadsheet: ``appendixI_checklist.xls"

APPENDIX II. LIST OF FERTILE MB-SERIES COLLECTIONS

Refer to MS Excel spreadsheet: ``appendixII_MBseries.xls"

APPENDIX III. SUMMARY DATA FOR TREE PLOTS

Refer to MS Excel spreadsheet: ``appendixIII_plots.xls"

APPENDIX IV. LIST OF TREES IN TREE PLOTS

Refer to MS Excel spreadsheet: ``appendixIV_trees.xls"

APPENDIX V. SOIL DATA FOR VEGETATION PLOT LOCATIONS

Refer to MS Excel spreadsheet: ``appendixV_soil.xls'

APPENDIX VI. DATABASES CREATED

Contents	*Format*	*Filename*	*Maintained by*	*Provided as*
Fertile Spec. Database	MS Access	specimens.mdb	Sidkan Ali	specimens.mdb
Total Plant Checklist	Applix SS	checklist.as	Cam Webb	AppendixI_checklist.xls
Fertile Specimens List	Applix SS	MB_fertile.as	Cam Webb	AppendixII_fertile.xls
Plot Summary Information	Applix SS	plots.as	Cam Webb	AppendixIII_plots.xls
Tree Plots with Morphotypes	Applix SS	trees.as	Cam Webb	AppendixIV_trees.xls
Soil Samples	Applix SS	soil.as	Cam Webb	AppendixV_soil.xls

Databases can be downloaded from http://www.phylodiversity.net/cwebb/maliau

APPENDIX VII. RESOURCES FOR FURTHER BOTANICAL WORK

Physical

Long-arm pruner (MoBot design)

2 x drying oven (open-top design)

2 x Two-burner propane stove

Cardboard spacers

Foam padding

Newspaper

4 x pair of pressess, with straps

Herbarium at Luasong with shelving and work-bench

Assorted botanical books (ca. 40% complete set of currently available books)

DBH tapes

hand pruners

Aluminium tags (ca. 500 remaining)

Soil auger

Human Resources

2 x staff trained in rope-technique

2 x staff confident in `free-climbing' small trees

6 x staff capable of collecting and pressing specimens

1 x staff with high level of botanical training

FIGURES

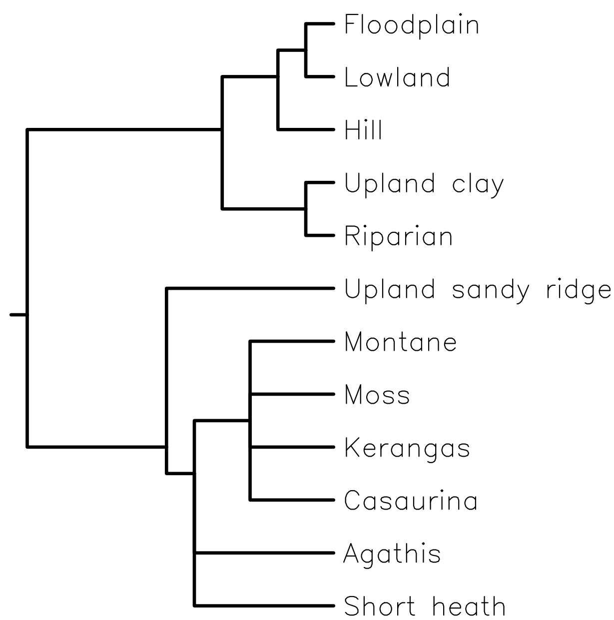

FIGURE 1. Semi-subjective classification of major vegetation types.

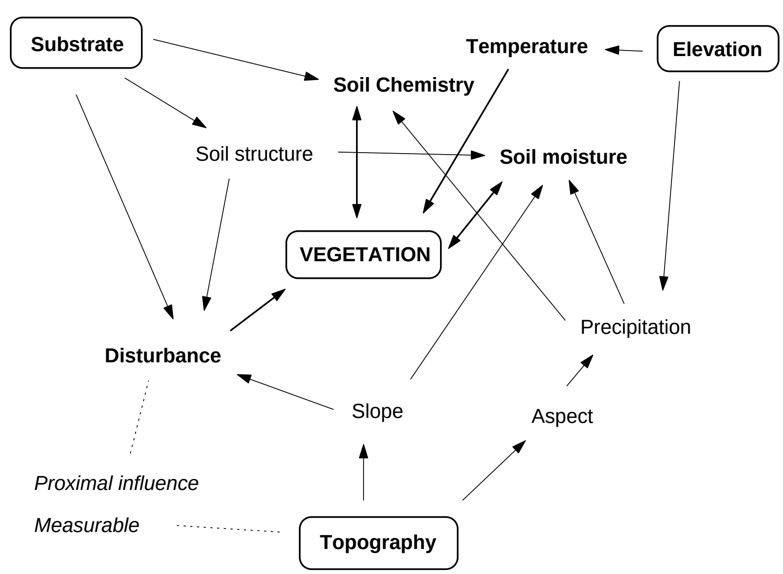

FIGURE 2. Network of influence of measureable factors on vegetation.

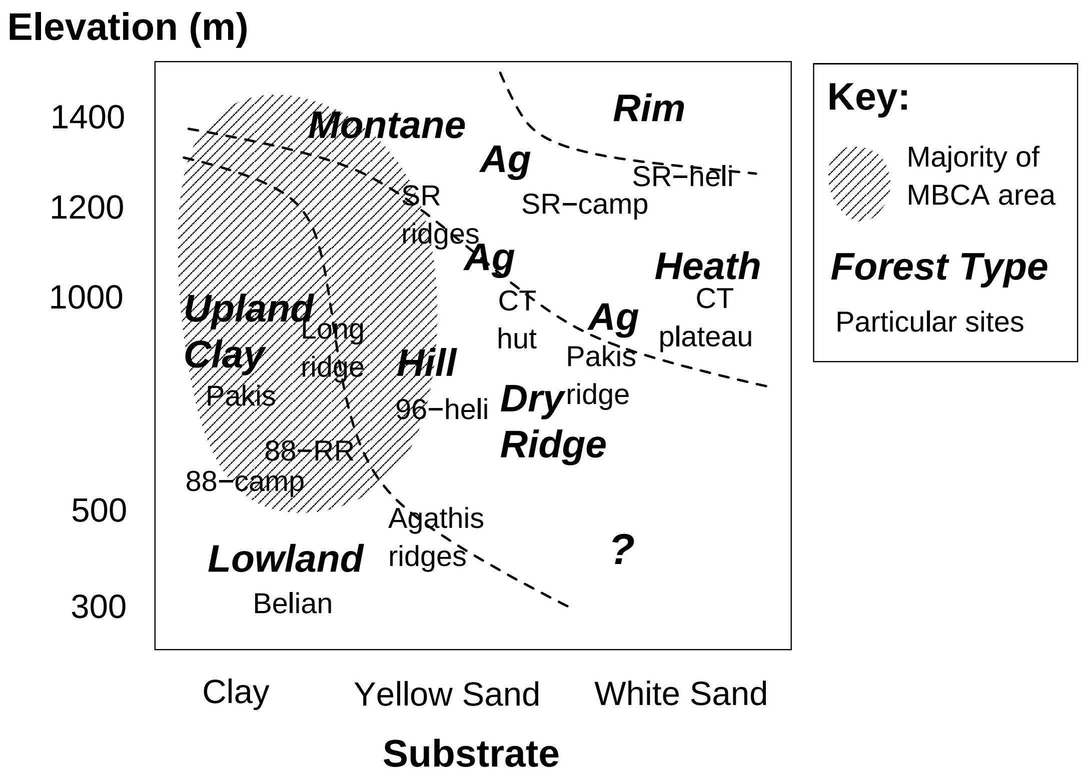

FIGURE 3. Influence of elevation and substrate on vegetation type.

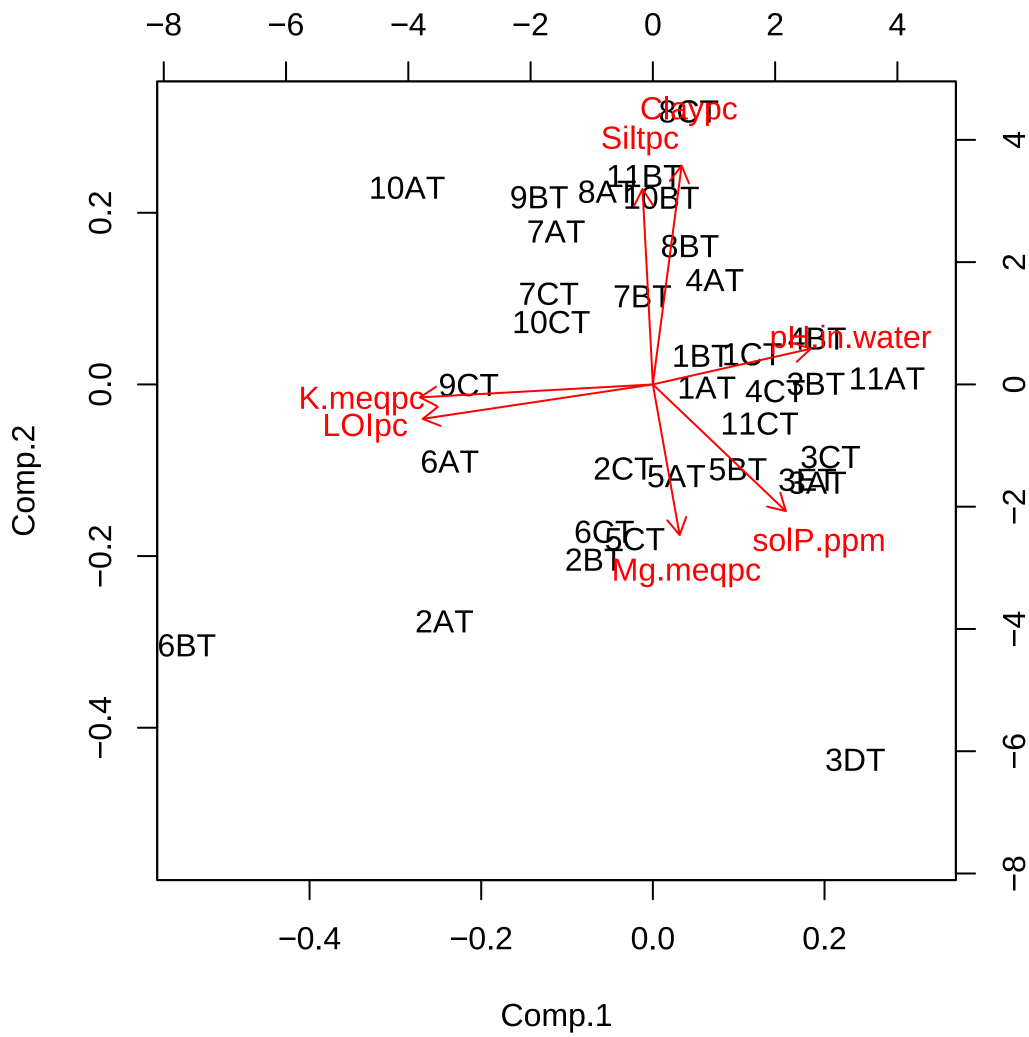

FIGURE 4. Principle component analysis biplot of soil factors and plots (Top soil).

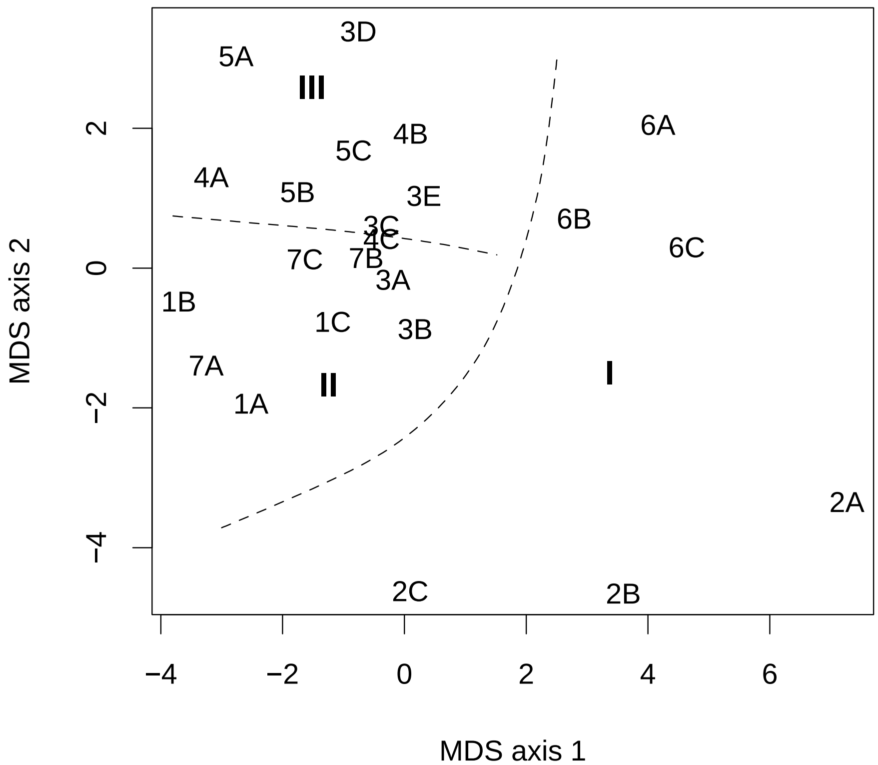

FIGURE 5. Ordination of plots 1A to 7C.

Based upon log-scaled species abundances, using multidimensional scaling. Three broad associations are visible: I. kerangas/heath plots, II. *Agathis*/hill forest, III. lowland forest.

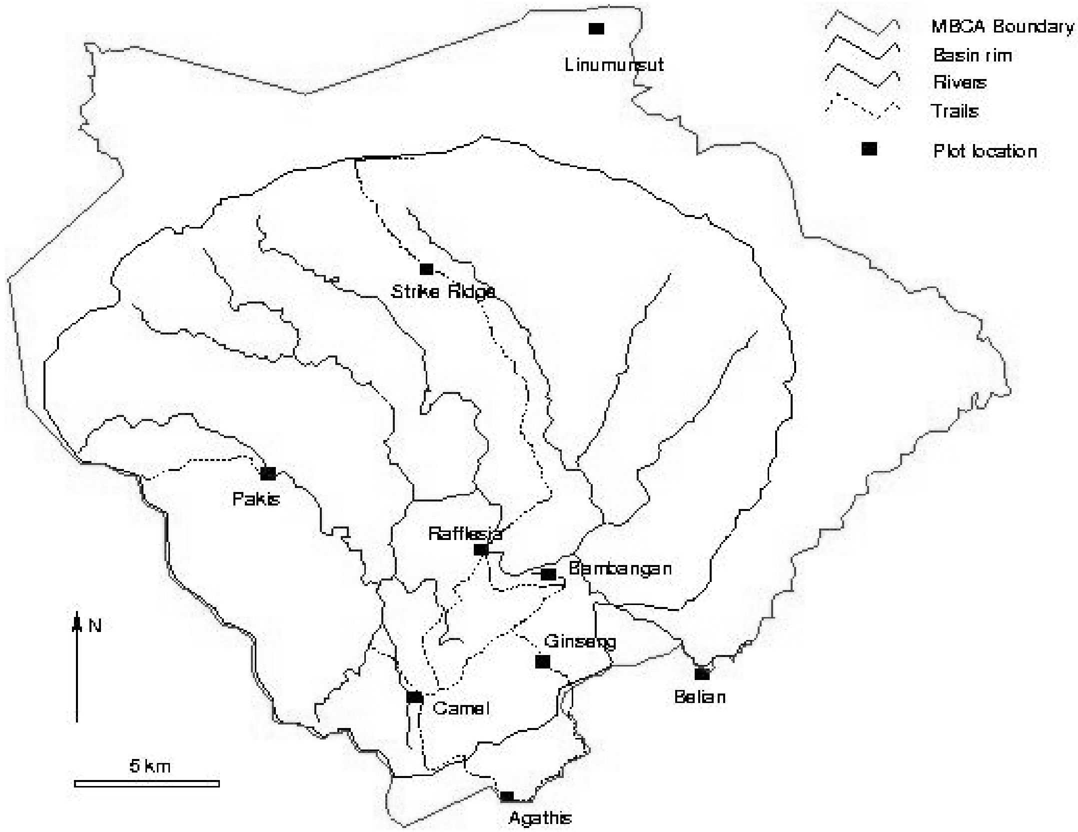

FIGURE 6. Map of Maliau Basin showing location of study plots.

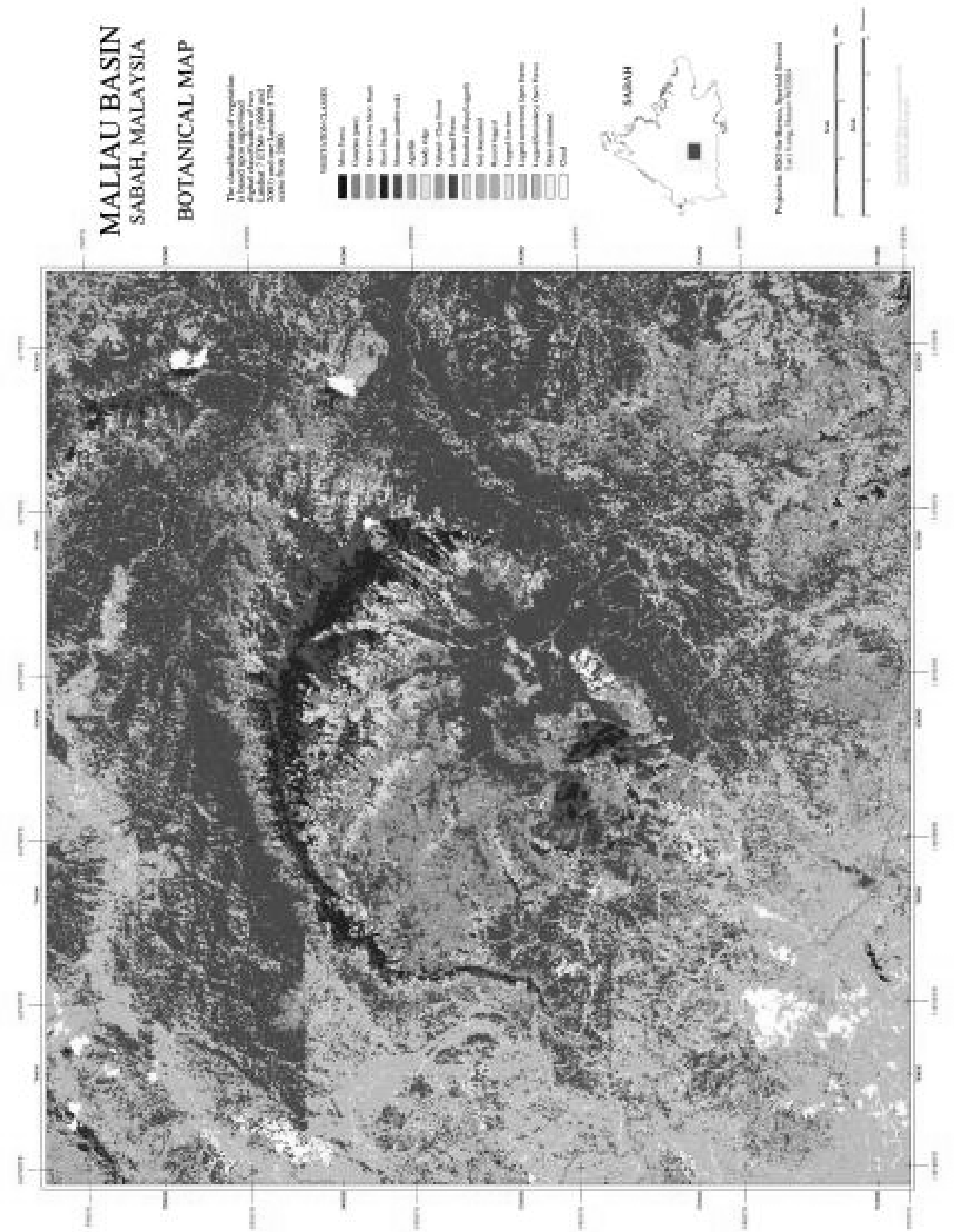

FIGURE 7. Classified Landsat image.

Primary classes: purple - short heath, red - montane, yellow - sandy ridge, pale green - upland-clay, dark-green - lowland. See images produced by Erik Prins for full-size map.