Forest land-use in Sabah, Malaysia: an introduction to Danum Valley

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SUMMARY

The Malaysian state of Sabah occupies an area of 73 371 km^2 which is about 10% of the island of Borneo. About 60% of the land area is forested and 48% is gazetted as Permanent Forest Reserve or State or National Parks.

The largest agent of forest disturbance is the timber industry, which plays a leading role in the state economy. A statutory body, the Sabah Foundation, holds a 100-year timber concession of 973 000 ha (9730 km^2) in the southeast of the state. Of this concession 9.7% has been reserved for conservation, including 43 800 ha (438 km^2) of uninhabited, mostly lowland forest in an area called Danum Valley. Since 1986, this has been the site of a field centre and a collaborative research programme devoted to comparative study of primary forest ecology and the impacts of selective logging. The paper includes a summary account of the ecology of the Danum Valley Conservation Area.

1. INTRODUCTION

Most of the research described in this symposium has been done near the Danum Valley Field Centre, in eastern Sabah, Malaysia. The programme under which the work has been carried out has as its principal stated objective (Anon 1984*a*), 'to gain scientific understanding of the ecological processes and evolutionary mechanisms operating within tropical rainforest by studying these both under undisturbed conditions and by means of controlled experimental manipulation'. One of the supplementary objectives is 'to provide information which may contribute to improved forest management'. In practice, the dominant form of disturbance to forests in this part of Borneo is selective logging, which provides a comparative and applied perspective to studies. The aim of this paper is to describe the setting of Danum Valley and some of the challenges and opportunities it presents for ecological research. The paper begins with a review of forest land-use in Sabah followed by a brief history and ecological description of the study area. Although little of this information is original, a summary compilation may prove a useful reference, especially in making comparisons with other tropical study sites.

2. FOREST LAND-USE IN SABAH

Sabah has a land area of 73 371 km^2 and occupies about one tenth of the island of Borneo. Compared with many other parts of the Asian tropics the population density is still relatively low, averaging less than 20 persons per square kilometre. The total population in 1987 was estimated at 1.34 million, but increasing by 3.7% per annum, due largely to a high rate of immigration (Anon 1987).

In 1986, 60.1% of Sabah's land area was under forest cover, but between 1975 and 1985 this declined at a rate of 1.37% per annum (FAO 1987). In accordance with Malaysia's National Forest Policy, 45% of the land is constituted as Permanent Forest Reserve, which is divided into seven categories according to function (see Munang 1987). Of the balance of forested land, 3.4% lies within the state or national park system whereas 12% is stateland in process of alienation and destined for conversion to agricultural use.

A breakdown of the estimated remaining forest area is given in table 1. Although primary forests may still cover as much as 21.6% of the land area, this is unequally distributed among forest types. Seven hundred and twenty-five thousand hectares (ha)† (9.8% of land area) comprises montane forest, which has not been much disturbed to date. The less extensive coastal mangroves and freshwater swamp forest types are also mostly little disturbed, but primary, lowland forest on dry land now occupies only about 500 000 ha (6.8% of land area), which is a much smaller proportion of the original area of this type. Thus, although Sabah is still heavily forested by regional standards, there remains relatively little undisturbed lowland dipterocarp forest.

In recent decades, the main agent of forest disturbance in Sabah has been the timber industry (Lee 1976). Logging takes place within a system of concessions and other forest licences administered by the Sabah Forestry Department under the Forest Enactment (1986).

† 1 ha = 10^4 m^2

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Table 1. *Areas and percentages of forest types in Sabah in 1990*

(Areas are given in 1000 ha[a]. Figures in parentheses are percentages of Sabah's total land area of 7 371 100 ha.)

forest type	primary	secondary	total
mangroves	218 (3.0)	98 (1.3)	316 (4.3)
swamp and transitional forests	149 (2.0)	44 (0.6)	193 (2.6)
lowland forests (mostly dipterocarp)	500 (6.8)	2708 (36.7)	3208 (43.5)
montane forests (> 760 m ASL)	725 (9.8)	?	725 (9.8)
total forests	1592 (21.6)	2850 (38.6)	4442 (60.2)

[a]The base data for this table are taken from Chai & Yahya (1989) supplemented by FAO (1987, Table 4) and updated with figures for 1990 provided by the Sabah Forestry Department. High secondary forest includes about 1 602 000 ha of logged-over forest and 1 105 600 ha of shifting cultivation fallow. The area of montane forest (above 760 m ASL) is taken from FAO (1987, table 1). Because most of this sector is undisturbed, but no estimates of disturbed montane habitat are available, it has been assigned wholly to primary forest.

Over the past 40 years, production of round logs under these licences increased steadily from 226 000 m^3 in 1950 to 11 million m^3 in 1973 (Chai & Yahya 1989). For 15 years thereafter, production was relatively constant at around 10–12 million m^3 per year until after 1987 when an apparent downward trend began. In 1990, production was 8.44 million m^3, about half of which was processed locally and the balance exported in log form.

Forests in Sabah, and particularly in the eastern half of the state, are extremely rich in large trees in the family Dipterocarpaceae. Sabah alone has at least 180 species in this family, but many have similar timber properties and can thus be marketed under just a few commercial groups (Whitmore 1984). These facts combined with strong export demand for logs have encouraged extraction levels that are among the highest in the tropics (Sundberg 1983). In some concessions, these can reach 120 $m^3\,ha^{-1}$, although typical figures are rather less. During the 1980s, Yayasan Sabah cut an average about 70 $m^3\,ha^{-1}$ from its concession. Other things being equal, high levels of extraction are inevitably associated with heavy damage (Fox 1970; Nicholson 1979).

Another significant cause of forest loss and disturbance has been shifting cultivation. Most of the rural population of Sabah traditionally depends on shifting cultivation of hill rice, supplemented by assorted non-timber forest produce (see, for example Marsh & Gait (1988); De Beer & McDermott (1989)). However, the estimated 15% of Sabah's land area affected by shifting cultivation is rather lower than for Sarawak (*ca.* 25%, Hatch 1982) and some parts of Kalimantan (Potter 1990). Apart from scattered coastal and riverine settlements, eastern Sabah was almost uninhabited until about 1960.

3. YAYASAN SABAH FOREST CONCESSION

Within the overall context of forest land-use in Sabah, the forest concession belonging to Yayasan Sabah (Sabah Foundation) is both a large component of the commercial forest estate in its own right and of special interest here because it includes the Danum Valley (figure 1). Yayasan Sabah is a parastatal organization established by an enactment of the Sabah state legislature in 1966 and governed by a Board of Trustees. Its mission is to improve the livelihood of Sabahans through charitable activities and programmes, principally in the fields of education and welfare.

To fund its activities, Yayasan Sabah was, in 1970, allocated 854 700 ha of scattered timber land with which to generate revenue from log sales. In 1984, this area was expanded and consolidated into a single block of 972 804 ha. The new concession area contains six categories of land, amounting to 20% of the total area, which are likely to remain unlogged (table 2). The most important are two designated Conservation Areas: Danum Valley (43 800 ha) and Maliau Basin (39 000 ha).

4. HISTORY AND STATUS OF DANUM VALLEY CONSERVATION AREA (DVCA)

The Danum Valley Conservation Area (DVCA) is located in the upper catchment of the Segama River, of which the Danum River is a major tributary (figure 2). The area is currently uninhabited and the only nearby dwellings are the Field Centre and a temporary logging camp at Kuala Danum. Wright (1975) states that there has been no shifting cultivation in recent times upstream of Kuala Kawag, which is about 70 km by river from the edge of the DVCA. However, recent discoveries of old coffins and other artefacts at three locations within the DVCA raise the possibility that parts of it may formerly have been cultivated or at least visited regularly. A single radiocarbon test on soil charcoal fragments collected near one of the coffin sites dates to 315 ± 20 years BP (P. Becker, personal communication). Further work on this important topic is in progress.

The first outsiders to visit the upper Segama region were gold prospectors in the 1880s and 1890s (Fitch 1955). Although traces of gold are widely distributed, no significant deposit has ever been found. In the modern era, Fitch (1955) and Leong (1974) completed extensive geological surveys of the area on foot.

In 1976, an expedition, organized by the Sabah Parks Board and WWF Malaysia, carried out a 4-week survey of the Danum–Segama drainage from three

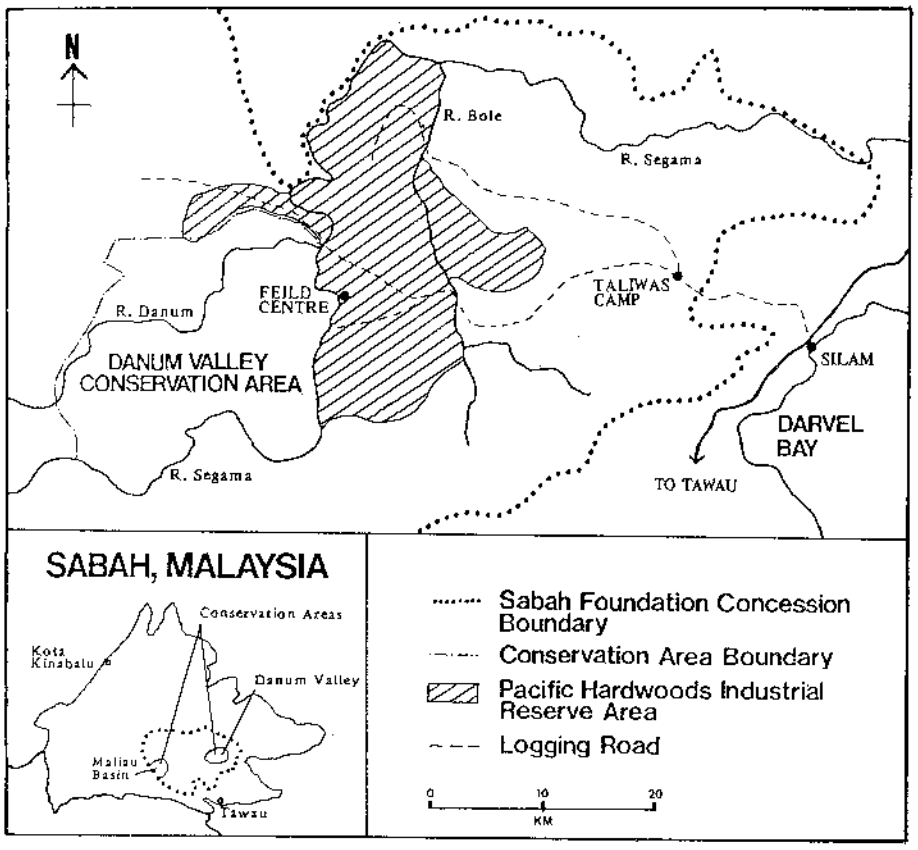

Figure 1. Map showing Danum Valley Conservation Area within Sabah Foundation's Forest Concession.

camps. The expedition report provides a useful ecological overview of the area and recommended the establishment of a National Park to encompass the entire Danum River catchment south to the Segama River (Kiew 1976).

Steps to implement this recommendation began with an amendment in 1979 to the Yayasan Sabah Enactment to permit excision of timberland from the Foundation's concession for conversion to park status. However, not all the proposed area lay within the original Yayasan Sabah concession and some 20 000 ha in the headwaters of Danum were licensed and logged between 1978 and 1983. Apparently, to forestall the risk of a similar fate to any released Yayasan Sabah concession lands, the trustees of the organisation resolved, in 1980, that the remainder of the area would be retained but managed as a special status zone for purposes of wildlife conservation. The title '*Danum Valley Conservation Area*' has since gained acceptance and was formalized in a Management Plan for the Yayasan Sabah concession (Anon 1984*b*), which was endorsed by the State Cabinet. Nevertheless, protection of the area rests ultimately on the goodwill of the Yayasan Sabah trustees and the Forestry Department plus perceived public support, rather than on any legally recognized status.

In 1981, a Conservation Section was established within the Yayasan Sabah Forestry Division, with a brief to develop Danum Valley for 'wildlife conservation, research and education'. Facilities in the field were clearly needed and, in 1982, a site was chosen at Kuala Palum Tambun. Road access was completed in September 1984, followed by a suspension foot bridge across the Segama. A simple set of buildings was built and opened in August 1986. Since then, two further phases of development of Danum Valley Field Centre (DVFC) have expanded the facilities to accommodate about 20 long-term researchers, 35 temporary visitors and 20 permanent staff. Additional facilities for tourists are currently being planned at a site 10 km away on the Danum River (see figure 2).

Table 2. *Categories of forest within New Yayasan Sabah Concession Area (NYSCA) scheduled to remain unlogged*

category of forest	area/ha	(%)
total NYSCA	972 804	100.00
conservation areas	82 800	8.50
Danum Valley = 43 800 ha; 4.5%		
Maliau Basin = 39 000 ha; 4.0%		
proposed virgin jungle reserves	1705	0.20
unworkable areas	97 280	10.00
(steep/non-commercial)		
road side reserves	500	0.05
riparian reserves	4000	0.40
water catchments	5550	0.60
total	191 835	19.75
other lands physically within, but not legally part of NYSCA		
virgin jungle reserve	26 876	
water catchment	2590	
total	29 466	

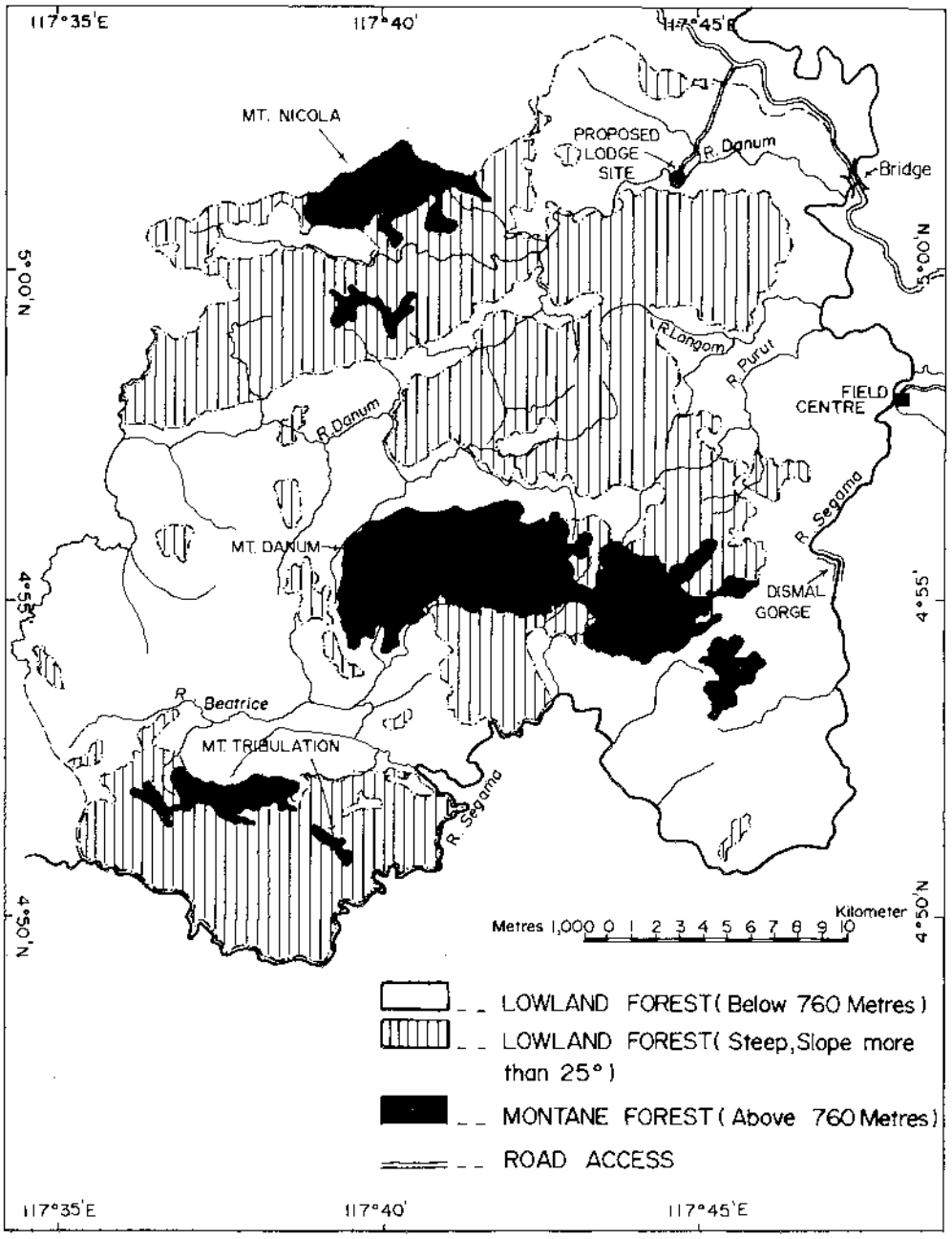

Figure 2. Map of Danum Valley Conservation Area showing main features of drainage and topography.

Concurrently with the planning of the DVFC, negotiations between the Sabah Forestry Department, Yayasan Sabah, and the Universiti Kebangsaan Malaysia – Sabah Campus led to the signing in September 1984 of a Memorandum of Understanding for a Danum Valley Rain Forest Research and Training Programme. A supplementary agreement between these bodies and the Royal Society (U.K.) provided a framework for collaborative involvement by British scientists. Both agreements were renewed in 1990 with an additional signatory – the Sabah Ministry of Tourism and Environmental Development. These organizations constitute the principal members of the Danum Valley Management Committee which acts as a governing body for the programme. To date, about 70 studies have been completed or are in progress.

5. ECOLOGY OF THE DANUM VALLEY CONSERVATION AREA

(*a*) *Physiography and geology*

Most of the DVCA occupies rugged terrain at moderate elevation in a complex and actively eroding landscape. Nine per cent of the area lies above 760 m above sea level (ASL) (the conventional lower limit for montane forest) and another 36% is at lower elevation but on slopes exceeding 25° (figure 2). Three major summits are Mt Nicola (917 m) in the Brassey Range on the northern perimeter, the more isolated Mt Danum (1093 m) in the centre, and Mt Tribulation (861 m) in the upper Segama highlands to the south-west.

The dense vegetation cover of the region has

allowed only the general geology to be accounted for (Fitch 1955; Leong 1974; Muhamad *et al.* 1989). Three main formations have been described: Crystalline Basement, Chert-Spillite and Kuamut.

Crystalline Basement

The oldest rocks in the region make up the crystalline basement, a group of metamorphic and igneous rocks of Lower Triassic or earlier age. Outcrops, probably fault bounded, occur in the central southern region extending east to Dismal Gorge. Isolated blocks also occur in the southwest and northeast of the area. Regionally, the basement lithologies are highly diverse (Leong 1974). Igneous bodies have locally intruded the metamorphic rocks and contact aureoles are sometimes present. Ultramafic serpentinite rocks may also be part of the crystalline basement and surface in the Mt Danum and Mt Nicola massifs. They form part of an intermittent ultramafic zone in Sabah extending in an arc from Banggi Island in the north to the islands of Darvel Bay.

Chert–Spillite Formation

Ranging from late Cretaceous to early Tertiary in age and unconformably overlying the crystalline basement or in fault contact with it, is the Chert–Spillite formation. Most outcrops have undergone disturbance or are not *in situ* due to slumping, faulting and volcanic activity that occurred during the Miocene. The formation outcrops as a belt across the central region of the DVCA, extending east to within 2 km of the Field Centre. The formation lithologies include radiolarian chert, volcanic breccia agglomerate, spillite keratophyre, basalt, pillow lava, tuff, minor rhyolite and dacite, epidote hornfels, epidosite ophicalcite, some altered and schistose volcanic rocks and associated dolerite (Leong 1974).

Kuamut Formation

Regions of comparatively low relief in the DVCA are mostly occupied by the Lower to Upper Miocene Kuamut formation. Deposits occur extensively near the DVFC in the River Palum Tambun catchment, extending north to River Danum and beyond. They are also in the western–central region and an outlier south of Dismal Gorge. The formation consists of a melange of slumped sedimentary and volcanic rocks with interbedded sandstone, mudstone and tuffs, known collectively as slump breccia. Near to the DVFC, the sedimentary blocks consist of sandstone, radiolarian chert, shale and siltstone; locally the sandstone contains deposits of charcoalified wood.

The volcanic rocks in the melange can be broadly divided into three groups: pillow and non-pillow basalt, tuff and tuffite, and agglomerate. A good example of pillow lava can be seen close to the DVFC reception centre and is characteristic of a submarine lava extrusion.

(*b*) *Soils*

According to a regional soil survey mapped at 1:250000 scale, the DVCA encompasses seven soil associations, of which more than 85% of the area is covered by just two, the Mentapok Association and the Bang Association (Wright 1975). Most of the rugged landforms of the DVCA correspond to the Mentapok Association. These soils are derived mainly from basic and intermediate igneous rocks of the basement complex and consist of chromic and orthic luvisols, euthric cambisols and lithosols.

Soils close to the DVFC are classed in the Bang Association which is developed over rocks of the Kuamut Formation. The majority of these soils are orthic acrisols, developed on sandstone and mudstone. Other rock types within the slump breccia, including ultrabasic, basic and intermediate igneous rock, tuffaceous rocks and chert, produce cambisols, lithosols and luvisols. The five other Associations found particularly in the northwestern part of the DVCA are Rumidi, Brantian, Kretam, Bidu-Bidu and Gumpal.

Cambisols derived from basic and intermediate igneous rocks in the Bang Association are stony and only moderately deep. Chemically, they are saturated with base exchangeable calcium values of up to 50 meq%. Cation exchange capacities can be high (40 > meq%) with available phosphorous levels between 250 to 670 p.p.m.

By contrast, the orthic acrisols of the Bang Association are much deeper, with clay percentages of 30% to 60% in the argillic horizon and 30–35% in the alluvial horizons. Acidity ranges from pH 5.3 to 4.0. The dominant cation is said to be magnesium with variable base saturation percentage from low to medium (Wright 1975).

There are important differences within the Bang Association between soils derived from sedimentary and ultrabasic rocks. Soils derived from the same parent rock but at different localities also show considerable variation, emphasizing the heterogeneity of this Association and the importance of local factors in pedogenic processes (Sinun 1991).

(*c*) *Climate*

Rainfall

The running annual rainfall average at DVFC after 5 years of records currently stands at 2822 mm, which is drier than most northern parts of Sabah east of the Crocker Range, e.g. Sandakan airport (1982–1988, 3051 mm), but wetter than the eastern seaboard (Lahad Datu 2062 mm, 1960–1983). This pattern (figure 3) is greatly influenced by the edge effects of two monsoons; the wetter northeast monsoon from November to March and the drier but more consistent southwestern monsoon in June and July. Although the onset of both monsoons is quite variable, there is a general trend for a drier period in the inter-monsoon months of April and September. During the data collection period there were 6 months that received less than 100 mm, reflecting the Field Centre's location close to the drought prone east of Sabah (Walsh 1990).

The highest daily rainfall recorded so far at DVFC is 177.2 mm (29 March 1988) with three other falls exceeding 100 mm in the 5-year period. Measurable

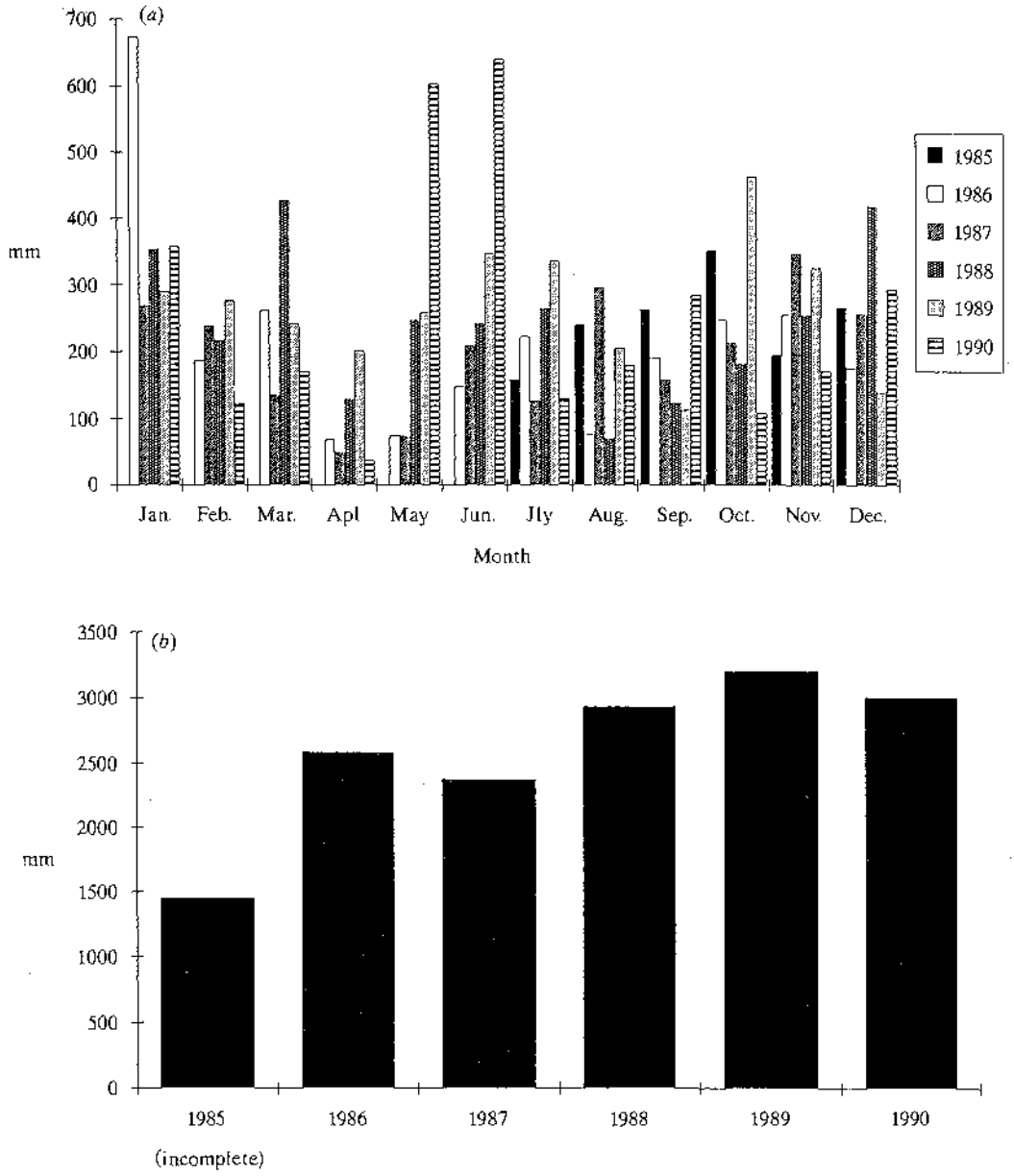

Figure 3. Rainfall at the Danum Valley Field Centre, July 1985–December 1990. (a) Monthly; (b) annual.

rain is received on an average of 220 days per year, falling mainly in the afternoon and evening. There are often considerable variations in daily totals between rain gauges 2 km apart, reflecting the local passage of thunder cells.

Temperature and relative humidity

Recorded temperatures at the Field Centre are typical of a wet equatorial climate, with a mean annual temperature of 26.7°C, mean maximum temperature of 30.9°C and mean minimum of 22.5°C (Walsh 1990). Also typical of a rain forest environment where extremes are absent is the highest recorded temperature, 36.0°C, and the lowest 18.2°C. Relative humidity at 08h00 showed very little fluctuation with an annual mean of 94.5% and 72% at 14h00, falling to as low as 57% during the dry month of May 1986 (Walsh 1990). However, consideration must be given to the location of the meteorological station in a large clearing adjacent to the Segama river. Mean maximum and mean minimum temperatures in the nearby forest during parts of 1987 and 1989 were 28.4 and 21.2°C, respectively (Brown 1990).

(*d*) *Vegetation*

Present knowledge of the flora of the DVCA is based on general botanical collecting work in the vicinity of the Field Centre (e.g. Smith 1987; Campbell & Argent 1988; Burtt 1989), and at the three WWF expedition camps (Kiew 1976), combined with the much more detailed but localized studies reported elsewhere in this volume.

Most of the DVCA is lowland, evergreen dipterocarp forest (*sensu* Whitmore 1984). Taking a conventional altitudinal limit of lowland forest of 760 m ASL, 91% of the Conservation Area can be considered

lowland and the balance as 'lower montane' (figure 2). However, this is a crude distinction which ignores the local influences of substrate, drainage and exposure.

The only formal classification of vegetation to have been made is that of the 1969–1972 Sabah Forest Inventory (Forestal International 1973). This work was based on photo-interpretation of slope, crown size and crown density combined with sample enumerations of large trees. Fifteen strata are distinguished in the DVCA with a total gross commercial volume estimate of 9.2 million m^3. Dipterocarps make up 88% of the total volume of large trees in the DVCA and dominate the estimates for every stratum, except small-crowned, very dense, montane forest.

Within a finer classification of Sabah forests based on dominant dipterocarp species (Fox 1970), most of the DVCA falls within the *Parashorea malaanonan* (Type A) category, which predominates over much of the upper Segama region and coastal areas of eastern Sabah. Certainly, *Parashorea malaanonan* and *P. tomentella* together with *Shorea johorensis* and other *Rubroshorea* spp. dominate the upper canopy around the DVFC (see Newbery, this symposium). Fox considers this type of forest to be characteristic of somewhat lower rainfall areas on reasonably fertile soils, such as those developed over slump breccia deposits.

Qualitatively, at least four variants in the lowland vegetation can be distinguished in the vicinity of the DVFC. Besides the *Parashorea malaanonan* type, there is an obvious riverine and streamside association of low diversity dominated by small trees in the genera *Saraca*, *Eugenia*, *Pterospermum*, *Leea* and *Dillenia*. Along the Segama River, but rarely on smaller streams, *Octomeles sumatrana* also forms scattered clumps. A notable pure stand of this species can be seen at Kuala Danum.

Away from the immediate riparian strip, and above flood level is a zone about 200 m wide in which large trees are relatively scarce and the understorey contains a high density of vines. Similar conditions predominate in the valley bottom of smaller steams. Along the Segama, climber tangles of up to 2 ha in size are common and conceivably represent an arrested succession from former cultivation sites.

Further inland on ridges and apparently correlated with surface outcropping of the chert-spillite formation, the forest has a rather open understorey. With a strong representation of *Rubroshorea* spp. and *Dipterocarpus* spp., this may correspond to Fox's Type D forest.

At higher elevations, the vegetation is quite different. On Mt Danum, slopes in excess of 25° with shallow soils developed from ultramafic parent materials, begin sharply at about the 500 m contour. Above this elevation the forest canopy does not exceed 25 m, and is dominated by smaller-crowned trees among which *Dacrydium* spp. and other gymnosperms, e.g. *Phyllocladus hypophyllus*, *Podocarpus* spp., are prominent. On nearby Mt Nicola, very stunted vegetation also descends to around 500 m elevation, apparently for similar edaphic reasons. Kiew (1976), whose team investigated Mt Tribulation in the extreme upper reaches of River Segama, reported mossy, upper montane vegetation from as low as 760 m, although this is not an ultramafic mountain. Another peculiarity of forests in Danum Valley is the apparent paucity of palms compared to areas further west in Sabah or elsewhere in Borneo (J. Bransfield & T. C. Whitmore, personal communication). Much more work remains to be done on detailed vegetation patterns of the region.

(*e*) *Vertebrate fauna*

Knowledge of the fauna of the DVCA has accumulated from diverse studies, few of which have been specifically concerned with the discovery of additional species. Thus the number of vertebrate species recorded in table 3 is undoubtedly incomplete, but probably not by more than 10–15% for each class (except perhaps reptiles and volant mammals).

Two general points about mammals should be stressed. Firstly, sightings to date include all of Borneo's largest land mammals, including elephant, Sumatran rhinoceros, banteng, clouded leopard, sun bear, orang utan, proboscis monkey and eight other primates. For several of these species, eastern Sabah and adjacent parts of East Kalimantan may hold the largest or only remaining populations in Borneo (Payne *et al.* 1985). A second and related point is that, with the exception of rhino, mammals have been very little hunted in the DVCA. Thus the site has regional significance for conservation and for the opportunity to study relatively undisturbed wildlife populations.

6. PACIFIC HARDWOODS INDUSTRIAL RESERVE AREA

Almost all the land east of the River Segama as far as Mt Silam on the coast is commercial forest reserve within the Yayasan Sabah concession, and is an important study area for the programme. Rights to log 40 000 ha inland from Silam were first acquired in 1958 by an American-owned company called Kennedy Bay Sdn Bhd. This firm was bought by Weyerhaueser Corporation in 1966, and in 1970 obtained other further timberland to the west as far as the Bole River.

Table 3. *Numbers of vertebrate species recorded within 10 km of the DVFC*

class	no. of species	authority
fish	34	D. Samat & F. K. Chin (personal communication)
amphibians	42	Inger *et al.* (1987, personal communication)
reptiles	42	R. Stuebing & H. Voris (personal communication)
birds	243	F. Lambert and others (personal communication)
mammals	77	L. Emmons & A. Johns (personal communication)

In 1976, Kennedy Bay (under Weyerhaueser management) came to an agreement with Yayasan Sabah which resulted in the formation of two joint-venture companies: Pacific Hardwoods Sdn Bhd, which was to be a timber processing company, producing plywood and sawn lumber, and its logging arm called Silam Forest Products Sdn Bhd. As part of the agreement, Kennedy Bay pooled its remaining coupe areas while Yayasan Sabah contributed an additional 29 248 ha of its concession east of the Segama River. This was designated an Industrial Reserve Area (IRA) to supply logs for Pacific Hardwoods. The mills were opened in 1984/5 and have an annual input capacity of around 280 000 m^3. In 1987, Yayasan Sabah bought out Weyerhaueser's interest, bringing both firms under wholly local ownership.

Since 1970, annual coupe areas of around 2700 ha have moved steadily westwards from Taliwas (figure 1). The location of these is known and the topography and roads mapped at scale 1:12 500. Thus secondary forests of differing age up to 21 years can be located with confidence for research purposes. With only three more years at this rate of assured coupe in the IRA, a second IRA of 70 000 ha has been designated further west near the Kuamut River. In the longer term, the company plans to supplement the supply of logs from natural forest with plantations of light industrial hardwoods.

From the start, Kennedy Bay Company used conventional tractor logging methods on moderate terrain while employing the cable yarding, or 'high-lead', technique on steeper slopes. These result in different patterns of disturbance (Marsh *et al.* 1987). During cable yarding, an area of about 20 ha around the spar tree is completely flattened and heavy damage extends outwards along radial corridors corresponding to the main winch line positions. Tractor logging, on the other hand, results in a near-random mosaic of skid tracks, broken trees and undamaged patches. Cable yarding causes much less soil compaction because only a single access road is required to the spar tree. Thus erosion damage and nutrient leaching are presumed to be less, although this may be partly negated if logs are dragged from one valley slope through a stream and up the other slope (Burgess 1989). Extraction intensities by Kennedy Bay Company using either method have been high, averaging 118 $m^3\,ha^{-1}$ over twenty years since 1970, but varying considerably between coupes (range 73–166 $m^3\,ha^{-1}$). Thus the residual forest is severely disturbed.

7. DISCUSSION

This paper has described a pervasive challenge to South-east Asian dipterocarp forests, namely selective logging, and the circumstances of a research site in Malaysian Borneo devoted particularly to elucidating its consequences. Although there already exists a large body of forestry research on the subject, much of this is narrowly focussed on the practical problems of regenerating trees with known commercial value. Changes in underlying ecological processes and effects on the fauna and non-timber tree components of the flora have inevitably been a lower priority. However, these are stock-in-trade to ecologists for whom logging and silviculture can be viewed as open experiments, albeit often large-scale, lengthy and unplanned.

Some short-term effects of logging and recovery processes fall within the timeframe of conventional research funding, namely 2–3 years, and can therefore be studied through time at one site. Others, such as plant successional processes, require monitoring over much longer periods or else must be inferred from comparative studies at sites of differing age since logging. Hence, the vital need for reliable data on the date and severity of disturbance.

For research of this kind, a large adjacent tract of primary forest provides not only an invaluable object of study in its own right, but also a control by which to measure the effects of change elsewhere. The value of Danum Valley from both scientific and conservation perspectives is greatly enhanced by the near absence of other forms of human disturbance, particularly hunting and shifting cultivation. This is a serendipitous feature of this part of Sabah, which contributes to its richness in large mammals.

The case for the establishment and maintenance of field stations for fundamental studies in tropical rain forest has been stated recently by Rubinoff & Leigh (1990), in relation to the Smithsonian Tropical Research Station, Panama. They point to emerging contrasts as well as similarities in ecological processes both at regional and continental levels (e.g. Gentry 1991). What is needed is a network of sites with facilities to support a range of different disciplines and thus facilitate broadly founded comparative insights. Danum Valley Field Centre and the programme associated with it is intended to provide one such site.

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