

# Tropical Rainforest Ecosystem, Land Cover, Habitat, Resource

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## 1.1 Tropical Rainforest: Myths, Delusions and Reality

One of the great human myths, which has proved to be true, says that mankind took its first steps on the branches of the “world tree”, concretely on the branches in the crowns of tropical rainforest trees. The left-behind brothers, the apes, will remain there as long as the tropical rainforest (TRF) habitat exists and effective habitat protection is in place. TRF is a stimulating environment for a human generalist’s brain to develop and achieve the stages of diversity of functions, sophistication and independence of decision which are necessary to venture successfully into the risky environment of the savannah. In the TRF, the turbulent climate of the Pleistocene offered ample opportunities and needs for phenotypic and genotypic differentiation among plants and animals, and no doubt will have stimulated the emergence of *homo spp.* The many obvious similarities in structural and functional aspects between the human brain and the TRF may be accidental, but they are astounding, not surprising, and are practical. The human brain and the TRF are similarly complex, in manifold ways diversely reacting dynamic systems; both are robust, elastic, resilient, resistant with anti-fragility potential to emerge even from chaos and to compensate damaged parts by other

parts taking over, or to repair them by auto-restoration. The brain and the TRF both conform to the Humboldt’s Amazonian concept of unity in diversity, patterned by eternal and universal natural laws (Humboldt, 1847). Silviculturally-experienced foresters know that the variability and variation of the quality and quantity of interactions between individual tree plants of the same or different species, or between temporarily passing eco-units (*sensu* Oldemann, 1990), depend on the variations of climatic and biotic factors. Added are fleeting correlations and elusive interactions between organisms, such as the effects of the hypothetical induction (Spemann, 1935; Mangold, 1982). The result is the great diversity and variation of states and processes, and the high levels of uncertainty of the future in the TRF ecosystems, and in forests and forestry generally. In stark contrast to these natural-law bound natural systems, anthropogenic financial, economic and social/political systems operate according to artificial, arbitrarily changeable and disposable rules, regulations, laws, whims and fashions. The anthropogenic systems do not possess the potential of responsive auto-restoration or dynamic auto-diversification, and possess inadequate anti-fragility potentials. Strategies must be narrowly goal-focused, but should still be system-sustainable, and need to be supported and implemented. To operate

these systems, ingenuity, expertise and free will are required, but also the gift of deception to manipulate in order to achieve set goals. The book does not include open woodlands, seashore vegetation and mangrove, and only a brief comment on plantation forests. For information on mangrove, please refer to the comprehensive description by Spalding *et al.* (2010). The history of the TRF, as we know it, began when the angiosperms evolved and became trees to form forests during the Cretaceous period ( $136\text{--}65 \times 10^6$  a BC) and successfully competed in the struggle for dominance during the largely tropical, but not tranquil Tertiary period ( $65\text{--}2 \times 10^6$  a BC). During the Plio/Pleistocene epochs ( $7\text{--}0.01 \times 10^6$  a BC) the territory which the TRF flora and fauna could occupy shrank and expanded in the rhythm of dramatic tectonic shifts, rises and falls of sea level, volcanic activities, fluctuation of air temperature with wide amplitudes and longer cold and shorter warm spells. These Pleistocene ( $2\text{--}0.01 \times 10^6$  a BC) conditions continued into the Holocene or Recent epoch (since  $0.01 \times 10^6$  a BC to today). At present, we live in one of the short periods with warmer temperatures. A very readable and sound review of these climatic oscillations and their biogeographic significance in the TRF of the Sunda region is given by Cannon *et al.* (2009), Wurster *et al.* (2010) and Pembroke (personal communication, 2012)<sup>1,2</sup>. They provide a general overview of conditions and detailed insights into processes of the environmental history of the rainforest during the Plio/Pleistocene epochs, bring the oscillating Pleistocene climate to life and explain the consequences for fauna and flora. Understanding the historic processes of the oscillations and sometimes catastrophic changes of the climate; the physiographic changes of the land surfaces; and the ecological relevance of responses by wildlife, plants and vegetation is a precondition for developing suitable management and conservation systems for the present TRF, and feasible concepts and rational strategies to strengthen the prospect of attaining survival and sustainability of life on earth in the distant future.

In my opinion, all these strong climatic, tectonic and geomorphological dynamics which characterise the historic scenarios through which the TRF progressed to its present state should have made the TRF ecosystem dynamic, robust, resilient, resistant, elastic, adaptable and an opportunistic and aggressive coloniser of newly available sites, such as land emerging from the sea when sea levels fell, or when volcanic activity pushed up fresh parent material, as in the case of the Krakatau islands. TRF had to survive under the regimen of extrinsic stochastic and unpredictably interacting causal factors. This required the creation of an intrinsic regulating network of interacting processes within a structure and physiognomy of the forest ecosystems which can stand up elastically or repair effectively if damage occurs. All this has to happen within the framework of basic natural laws which, as far as we know or surmise, originated in the Big Bang, apply universally and are unchangeable. Such a situation requires and creates stamina in all species of fauna, flora and microorganisms, and possibly the ability to adapt by acquiring new traits, which may even be saved as added codes in the genome. The ecosystem needs adequate resistance, elasticity and resilience, and the ability to adapt, restore and rehabilitate if damage has occurred. It is most improbable that the most exacting and demanding, by no means tranquillity-promoting conditions throughout the Cainozoic era (Tertiary  $65\text{--}2 \times 10^6$  a, Quaternary  $2 \times 10^6$  a to present) would result in the evolution of a TRF which is fragile; vulnerable to any kind of extrinsic impact or disturbance, especially by man; is given to cascading into collapse; has no power of resilience and elasticity; no capacity for self-repair of damaged compartments; and on any interference by humans loses its spurious “integrity” and “biodiversity”. The extraordinary similarities in many of these aspects between the human brain and the TRF, and the recent changes of scientific knowledge about it among brain researchers, as a similarly complex dynamic system add to the argument and should have opened our eyes to the fact that the TRF is indeed robust, elastic, resilient and

resistant, and can compensate for damage, but also that it can be destroyed beyond repair. Auto-restoration in both TRF and brain occurs according to the eternal primeval natural laws and the derived laws of correlations, which humans cannot change. It is a crucial difference between natural (eco)systems and (eco)systems created by man that the anthropogenic financial, economic and social/political systems operate according to rules and regulations invented by man, which can be changed or ignored (if one has the power to do so) at will.

Cannon *et al.* (2009) studied the distribution of the TRF and the climatic and geological conditions during the last maximum glaciation of the Pleistocene in Sundaland, and concluded that at the LGM (last glacial maximum), Sundaland rainforests covered a substantially larger area than currently present. Extrapolation of the model over the past million years demonstrates that the current “island archipelago” setting in Sundaland is extremely unusual given the majority of its history, and the dramatic biogeographic transitions caused by global deglaciation were rapid and brief. Compared with dominant glacial conditions, lowland forests were probably reduced from approximately  $1.3$  to  $0.8 \times 10^6$  km<sup>2</sup> while upland forests were probably reduced by half, from approximately  $2.0$  to  $1.0 \times 10^5$  km<sup>2</sup>. Coastal mangrove and swamp forests experienced the most dramatic change during deglaciations, going through a complete and major biogeographic relocation. The Sundaland forest dynamics of glacial contraction, extinction, fragmentation into refugia and interglacial expansion, driven by glacial cycles, occurred simultaneously with those in equatorial Africa. From there, some authors deduct that Sundaland evergreen rainforest communities are even now in a refugial stage. They suggest that the current interglacial biogeographic condition present in Sundaland is unrepresentative of the predominantly “glacial” phases of the Quaternary which were several centigrades cooler” (Cannon *et al.*, 2009; Wurster *et al.*, 2010). Their conclusion that, connected with the turbulent biogeographic past and the necessarily refugial character of the contemporary Sundaland rainforests, the present TRF

is highly vulnerable, however, is unconvincing. The opposite conclusion, that it is as natural ecosystem and against natural forces robust, appears more realistic and convincing. But its species and the communities which form its diverse ecosystems are vulnerable to the point of extinction against the brutal forces of destruction, rather than traditional usufruct, created by the attitudes and lifestyles of modern and postmodern mankind.

Around 400,000 years BC a new factor of perturbation and disturbance appeared. *Homo sapiens* possessed and developed to perfection tools, hunting and fishing gear and fire. Man was clearly no mere animal, but a very distinct phenomenon. Among the three unique gifts (Markl, 1986) man perfected first the extraordinary and unique gift of adaptive language, which made him distinct from animals. Animals communicate by sequences of monosyllabic, if emotionally charged, signals, supported by body gestures and facial expression. In body language and audio-signals domestic dogs and, from my own experience, in the wild – gibbon and orang hutan – as well as, according to what I read, other primate species, are absolute masters of audio-signal and body language. However, to claim that they have and use language is popularising research in pet-animal species, not sound and serious science. I have used monosyllables and emotion-expressing audio-signals successfully in remote pristine TRF in Sarawak to communicate with primates such as orang hutans and gibbons, and with birds such as hornbills, and also to trick and trap rutting deer. Second, *H. sapiens* possesses the further gift of free will to decide any way he fancies, even to his own, his social group's and the species' disadvantage. The recent results from long-term psychological–sociological research into the causes of the killing-and-raping craze in areas of currently acute violence (Congo, Somalia, Syria, Iraq, Afghanistan, Pakistan) are worrying prospects in this context for the future of the species. There are strong indications that the male genome contains a gene of lust to kill, the truly fully female genome apparently not. If this is so, and history of mankind speaks for it, these

are worrying prospects for the future of the species (Elbert, 2013), particularly since constraint systems have eroded or been wilfully destroyed. Third, man has the gift of intellectual power of abstract thinking, to “go out of himself” to create word and structural models depicting reality, myths, hopes and aspirations, as he sees and wants them, and to realise his dreams in real life. Eventually these virtual models were first put on paper and finally on computers, turning his three gifts into a combination tool which potentially is and may prove a Pandora’s box. During the development from the initial simple linear thought models to the present computerised simulation models of complex dynamic systems, *H. sapiens* accumulated more and more power to change casually or by design, and unconsciously the world in which he lived and the manner he lived in it – his lifestyle. The TRFs did not escape and suffered from intrinsic fundamental deficiencies of these anthropogenic system models, as compared to the design and functioning of natural systems. The performance of system simulation models of anthropogenic systems in the worlds of economics, finance, society and politics are determined by anthropogenic rules and laws, which depend on human free will and decision, can be changed at will, and are based on data and information which are created in real anthropogenic systems. Consequently, the anthropogenic systems as models and in reality can be manipulated, and at any time any criteria, indicators, values and targets can be changed. The system’s dynamics and trends, therefore, become unpredictable, not as a result of complexity and random chance events, but because of the effect of *H. sapiens*’ blessed gift of free will and free decision.

In science, the consequence for research and development (R&D) in the TRF is that while natural ecosystems operate by the basic laws of nature (Big Bang-created and persistent), the interacting anthropogenic systems operate by laws of convenience, free will and thought, deception and free decision. This introduces a new and different kind of unpredictability and uncertainty, and makes integration for forest management and conservation hazardous.

Integration of research in natural and economic/financial/social/political sciences requires considerable skill and understanding. The hard-science approach is based on the eternal, immutable (as far as we know) Big Bang laws; the soft-science approach has to deal with systems which are ruled and regulated by temporary, mutable laws which do not even apply globally at any time.

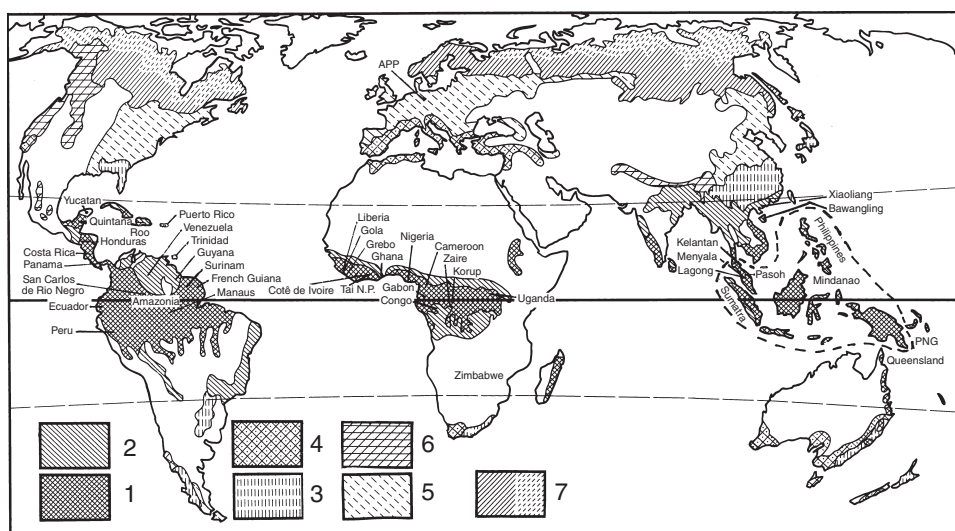
In practice, the consequences for sustainable use and development in the TRF biome were the development of anthropogenic systems in land and forest use, and in economics and politics which followed laws set by humans, which may be obeyed or not, and can be changed by free will. The result is that the TFR ecosystem is changed in ways which are not predictable and may not be compatible with sustainability. Obviously, the natural and anthropogenic ecosystems are functionally so fundamentally different that adjustment and integration can only be achieved and sustained in two ways. The human interference is either at consistent perturbation level, or at long-term episodic disturbance level. Anything more intense needs effective control by a wise and uncorruptible government and a vigilant civic society.

I conclude that the notion of a TRF that is apparently pristine, seemingly unchanging over ages, and existing in harmony and stability is a myth. Also the present interglacial warm period is by nature less uniform and climatically more oscillating than many like to believe. *H. sapiens* has added to these natural dynamics his own activities dictated by free will, and with superimposed systems that do not follow the fundamental natural laws, but which may unforeseeably change erratically and unpredictably in any direction. In this manner, mankind has manipulated the TRFs during the past 400,000 years. Modern mankind multiplied the kinds and intensities of manipulation to a point at which at least one-third of the pristine forest has gone, partly converted (see, among others, FAO, 2005, 2011) and eventually only few lucky areas, well protected by responsible governments, villages and non-governmental organisations (NGOs), or by sheer inaccessibility, will still carry TRF that may be confidently called truly pristine.

Early in the history of civilised *H. sapiens*, the “pristine” rainforest of sublime “integrity”, stability, lushness and productivity held great fascination for the forest people (see Chapter 2), scientists, explorers, adventurers, nature lovers, and lately – and most recently – for the profiteers among *H. sapiens-atrox* (“atrox”, latin for “ferocious”, has been invented by the author to point at “sapiens” being misleadingly indicating that we are “wise”). A Chinese geographer described the opulence and diversity of rainforests in South China–Vietnam, more than a millennium ago, explaining these features as containing the causal factors which safeguard harmony, in compliance with the Chinese principle of universal harmony (Wang, 1961). Alexander von Humboldt and Bopland initiated biogeographical and ecological research in TRFs in the Orinoco–Rio Negro region more than two centuries ago. Humboldt saw the unity of principles and natural laws ex-

pressed in the biodiversity and apparent in the similarities and differences between tropical and temperate, apparently pristine, forest vegetations. Committed to truth and objectivity in science and honesty and responsibility in life, he could not foresee the kind of conflicts and degradation of standards in science, commerce and politics which the timber-mining and land-grabbing tsunami of the modern/postmodern era caused in the TRF biome and globally. Myths were created, such as that the TRF is a wasted asset that cannot be managed ecologically and economically sustainably, to assist vested or new interest to promote their schemes, and to campaign against those who thought otherwise and opposed the schemes. This subject will keep cropping up throughout this book.

The contemporary rainforest biome, irregularly stretching across the equator (Fig. 1.1) is home of the zonal forest formation class of the dense, tall, evergreen, wet



**Fig. 1.1.** Locations outside Borneo mentioned in the text. The broken line delimits the Malesian Floral Region, which is characterised by a high species richness and high dominance of Dipterocarpaceae and a generally high plant species diversity with very high values of  $\alpha$ - and  $p$ -diversity. Borneo is probably the regional centre of tree-species richness and  $\alpha$ -diversity, and the Sabal area, RP 146, has the highest recorded values (Fig. 1.16; Weiske, 1982; Droste, 1995). The Malesian region is faunistically divided between east and west by the various versions of the Wallace line (not shown). APP is Auermühle, where the goal-orientated production programmes were developed (Bruenig, 1995/1996). The location on the map of FRIM, Kepong, Selangor, is west of Pasoh and south of Lagong. The zonal formations of the potential natural vegetation are: 1, superhumid to humid evergreen and semi-evergreen tropical forest; 2, humid to subhumid semi-deciduous and deciduous tropical forest; 3–7, non-tropical. Adapted from Bruenig (1987c).

forest (Champion, 1936) or the predominantly evergreen superhumid to humid, or according to Ashton (1995) “fire-sensitive aseasonal evergreen”, tropical lowland forest (Baumgartner and Bruenig, 1978). On average zonal soils and sites in the lowlands, moisture availability is adequate for the existence of mesophil evergreen tree species that can endure sporadic periods of drought stress. The latest and most reliable data on the areal extent and the state of the tropical forest are available in the series of three volumes *Conservation Atlas of Tropical Forests* prepared and published by IUCN since 1990–1991 (Collins *et al.*, 1991; Sayer *et al.*, 1992) and the latest of a series of bi-annual State Of The World Forests reports by the FAO of the United Nations (UN) (FAO, 2009, 2011). The biome includes a wide

range of conditions of geology, tectonics, evolutionary history, past and present climate, landform, exposure, atmospheric chemistry, soil and vegetation (Tables 1.1 and 1.2). There are profound differences between geographic regions. At the largest scale, there are climatic, geological and geomorphological, floristic and faunistic differences between Asia, Africa and America. At the medium scale, there are differences between climatically similar biogeographic regions, such as Borneo, Peninsular Malesia and Sumatra within Malesia (Fig. 1.1). These differences may be the result of evolution, migration of species via land, water or air routes into geographical isolation, geomorphological patterns and events, fluctuation of the habitat offering land surface, proportions and patterns of the various soil

**Table 1.1.** Climatic parameters in the humid tropics. Adapted from UNESCO (1978).

Zonal location	Equatorial belt and tropical areas with constant flow of moist air-masses outside this belt	Subequatorial to outer tropics with influence of trades, monsoons and monsoon-like alternating winds
Climate type	Tropical perhumid (wet), isotherm, non-seasonal to weakly seasonal, diurnal variation > annual variation	Tropical humid (moist), isotherm, seasonal with predominantly summer rainfall
Amount of annual isolation on the ground (kW cm <sup>-2</sup> )	South-east Asia 9.8–11.2 Congo basin 8.4–9.1 Amazon basin 7.0–8.4	~11.2
$T_m$ (°C) mean annual	28	25
Annual march of seasonal variation	3	15–20
Diurnal variation	9	20
Wind	Predominance of tropical low pressure trough, low velocities, except very high in convective bursts and squalls, local tornadoes; frontal winds moderate, high velocities rare	High velocities during summer (typhoon, hurricane, cyclone), low during dry season, strong effect of tropical convergence zone. Local frontal storms toward the end of dry season ( <i>habub</i> in Africa)
Relative humidity (mean %)	95/100 night, 60/70 daytime, occasionally 40 at noon, little seasonal variation, in episodic dry periods <40%	90/100 wet season, 60/80 dry season
Potential evaporation: actual precipitation ratio, $E_p/P_o$	<1	<1
Annual precipitation (mm), range of means and min./max.	average = 3000–4000 minimum = 50 ( $T_m + 12$ ) = 2000 maximum >10,000	average = 1300–3000 minimum = 1000 maximum = very variable

**Table 1.2.** Vegetation formations in the humid tropics in the two climates in Table 1.1. Adapted from UNESCO (1978).

	Megatherm-hydrophilous	Megatherm-tropophytic
Characteristic habitus of zonal formation:	Hygromorph-mesomorph, sclerophyll-mesophyll	Tropomorph
Zonal	Superhumid to humid, ombrophilous, predominantly evergreen equatorial wet forest and semi-evergreen wet tropical forest	Humid to subhumid, semi-deciduous and deciduous tropical forest
Edaphic formations	Littoral forest Mangrove forest and woodland Freshwater swamp forest Swamp grassland Riparian forest Peatswamp forest (with phasic communities) Simple sclerophyll, xeromorph forests on ultra-basics, podzols, skeletal and related soils	Littoral forest Mangrove forest and woodland Freshwater swamp forest Swamp grassland Riparian forest (often relic gallery) Evergreen forest (on moister, deep and well-drained soils) Sclerophyll forest (sandy terraces, podzols, and skeletal soils)
Physiographic formations	Submontane forest (wet) Montane forest (wet to moist) Alto-montane forest (moist) Alto-montane moss forest (wet, misty) Alto-montane woodland and scrub (moist)	Similar to the perhumid climate zone, except for species composition, conifers increase in southern and northern hemisphere, bamboo species become more frequent in the northern hemisphere
Degraded formations	Secondary mesophyll forest and woodland Secondary microphyll sclerophyll forest and woodland Pine forest to pine savannah Grassland ( <i>Imperata cylindrica</i> ) Karst-woodland Sclerophytic savannah	Secondary forest Savannah Pine forest, pine woodland or pine savannah Karst-woodland Sclerophytic xeromorphic savannah

and site types in the landscape, and whatever else that may induce separation of populations of species and divergence of evolution. Differences and changes of past and present activities of humans and of the interactions between vegetation, animals and humans add to the extreme heterogeneity, variability and variation of diversity at *alpha* (tree community, forest stand), *beta* (landscape) and *gamma* (region) spatial scales of the forest vegetation in the TRF biome.

Primeval TRF covered more than 90% of the biome's land surface before the advent of humankind. This forested area has been drastically modified and reduced since humankind learned to master the biotechnological problem of cutting the tall tropical evergreen forest for slash-and-burn cultivation in the very wet equatorial climate. There

is possibly hardly any TRF in the world that has not been influenced and modified in some way by humankind (Dilmy, 1965) (Table 1.3). Reality has already overtaken the estimated figures, but the trend is still unchanged (compare the detailed figures in FAO, 2005 and 2011). Commercial forestry has modified (legally and illegally logged) TRF, but understandably the area is unreliably recorded and reported (see Chapter 11.2). Probably at least one-third, but possibly more than half of the existing rainforest area, and possibly three-quarters or more of the potential production forest area have been more or less carelessly and wastefully logged since 1945, and particularly since the 1970s. Customary selective timber harvesting has increasingly turned into wholesale mining of the commercial timber stock,

**Table 1.3.** The changes of forest areas and world population, taking an optimistic and a pessimistic view. From Ist eine Klimaänderung unausweichlich? – Der Raubbau an den Wäldern ist bedrohlich. *Die Umschau* 85 (1985) 3, 153–155.

Category of forest	Area (million km <sup>2</sup> )				
	1965	1975	1985	2000	2050
<i>Closed natural forest (optimistic)</i>					
Equatorial tropical predominantly evergreen, wet to moist (perhumid/humid)	5.5	5.0	4.4	4.0	3.0
Tropical seasonal predominantly rain-green, deciduous, wet to moist (subhumid)	7.5	6.5	6.0	5.5	4.5
<i>Open natural forest (optimistic)</i>					
Tropical, seasonal rain-green and evergreen (alluvial, montane), moist to dry (semi-arid)	7.5	6.5	6.0	5.5	4.5
<i>Sum of tropical natural forest</i>					
Optimistic	20.5	18.0	16.4	15.0	12.0
Pessimistic	20.5	17.0	15.0	12.5	8.0
<i>Tree plantations in tropics</i>					
Forestry	0.04	0.05	0.08	0.16	?
Agriculture	0.20	0.25	0.27	0.28	?
<i>Total forest of the earth</i>					
Optimistic	38.2	36.0	34.5	33.7	30.5
Pessimistic	38.2	35.5	33.0	29.0	24.0
<i>World population (1000 millions)</i>					
Optimistic	–	4.0	5.0	5.8	7.0
Pessimistic	–	4.2	5.3	6.6	11.0

wasteful in every aspect. The guiding principle has turned from sustainable use of a common resource, imposed and enforced by government, to ruthless exploitation of a privilege to maximise outturn and private profit and minimise costs and time, and ignore the social costs. This development went parallel with the general decline of morality in the business world since the delusions took root: the market regulates itself, the Manchester Doctrine of *laissez faire*, profit maximising at the top will filter wealth down to the bottom. After the Lehmann investment banking disaster in 2008, followed by years of crisis in the anthropogenic systems of the world of finance, the weekly *Die Zeit* investigated the state of morals in banking and free markets. The representative in Europe of a leading US investment bank interviewed by *Die Zeit* quipped: “Morals in banking? Banking is about money, not morals” (*Die Zeit*, Nr 7, 2011). The commonness of market-linked amoral attitudes confirms a recent laboratory test by A. Falk and N. Szech, University of Bonn and Bamberg. They recorded the decisions of 1000 students in a 3-day free market

scenario whether to “take money (profit) and a healthy animal will die; or don’t take the money and the animal will live”. Forty-five per cent of the students chose the money if they decided in isolated seclusion; while 75% chose to take the money in an open free-market context. The deduced hypothesis is that the free market corrodes morals by making it easy to merge in the system and ignore ethics and morals without being noticed. The practical example of this in forestry is producers, sellers and buyers of illegally logged and traded tropical timber hiding in a “network” (UNEP and INTERPOL, 2013) and worrying about maximum profit and survival, but not about morals, common resources, deforestation and social costs (*Die Zeit*, Nr 21, 2013; Mizuno *et al.*, 2016). No wonder that declines of extent and value of the TRF resource continues (Bruenig, 1981, 1989b–e; Amelung and Diehl, 1992; FAO, 2011). Permanent rainforest stock and land losses are overwhelmingly caused by intentional deforestation (90%), mostly for agricultural expansion and dubious plantation schemes (see Chapters 8 and 11).

Forestry and orderly traditional or sustainable advanced logging modify the growing stock of trees and the functions of the forest within acceptable limits. They rarely cause deforestation directly but may lead to it (Chapter 2; Bruenig, 1989d,e; Amelung and Diehl, 1992). There are regional differences in the contributions to deforestation of traditional migratory (shifting) agriculture (prevailing in Asia), and of farming and husbandry (prevailing in tropical America, [Table 1.4](#)).

However, public attitudes, social scenarios and human activities changed in the course of the postmodern era of the 20th century with a neocapitalist–neoliberal era since the 1960s. This has been to the disadvantage of the world as a sustainable human habitat, with disastrous consequences for the tropical forests generally and the achievement of sustainable social forestry in particular, and at great, but unaccounted social and socioeconomic cost. One of the manifold consequences is a noticeable decline of interest and investment in scientific research and R&D activities in the TRFs. Of the 26 publications in *Plant Ecology* in 2009, only six concerned the tropics, of which only two produced new insights. Very little is known, but much speculated about the genetic structure and processes in TRF. The title and preface to the book by Wickneswari and Cannon (2011) claims it to be a guide to genetics of

tropical forests for foresters, bridging the knowledge gap between the few academic publications on TRF genetics and the problem-ridden world of TRF forestry practice. But it mainly proves that we know very little about intra-specific and intra-population genetic variation. The results of the research by Newbery and Lingenfelder (2009) in Danum Conservation Area, Sabah, indicate that there is indeed much to discover which would be management-relevant, but this research is expensive, tedious and not very rewarding. Sampling in the canopy has become expensive in the post-tree-climber era, and reliable root sampling is not easy in the TRF, as I experienced in the 1950s when I sampled root material for the taxonomic determination of a new coniferous genus. Research results and practical experience in temperate broadleaf forests, however, make the claim in the book by Wickneswari and Cannon (2011) that the major threat to genetic viability of TRF is “commercial logging” (whatever that is) at least appear premature. There is no proof and, I believe, probably never will be except in cases of conversion. If you lump the effects timber mining, forest conversion and land-grabbing for plantations, infrastructure and “development”, chances of proof of the claimed loss of genetic diversity and viability will be increased almost to certainty.

**Table 1.4.** Areas of tropical forest formations in 1850 and 1985, and changes by landuses in millions of hectares and forest area logged in Latin America (including Surinam and Guyana) (Houghton *et al.*, 1991); in Sarawak, Malesia, for 1840 (estimated from probable population densities) and 1990 (Forest Department Sarawak, undated) (see also [Table 5.1](#)).

Tropical forest formation class	Change in area							Logged forest
	1850	1985	Crops	Pasture	Fallow	Degraded	Plantation	
Evergreen	226	212	7	3	0	4	0	–14 (6%)
Seasonal	616	445	48	54	30	32	7	–171 (28%)
Open	380	211	27	101	7	34	0	–169 (44%)
Sum	1222	868	82	158	37	70	7	–354 (29%)
	1840	1990						
Evergreen in Sarawak (total land area 12.3)	12.1	8.7	0.5	0	3 <sup>a</sup>	0.2	0.2	–3.7 (30%)
								~4.5

<sup>a</sup>Secondary woodland, only partly active fallow in practised shag (shifting rotational agriculture).

In the foreword of a review of State of Tropical Forests, He Chang Hui (FAO, 2005) joins my long-time wonder at the paradox: how to reconcile the severe degradation of the tropical forest resource, the decline of forestry and research in the tropics, and the strong increase of interest and activities of the lay public (civic society) to save the tropical forests as environmental resource and habitat, and their flora and fauna, with the ineffectiveness of politics, conventions, framework declarations and forest policies to stop the destructive activities of the actual degraders. How is it possible that societies make noise, but hardly act effectively? Our knowledge, experience and capabilities were adequate half a century ago to prevent the historic turn from sustainable development to degradation, and are more than sufficient now to turn the tide and stop the plunder, but deforestation and forest degradation in the tropical forests, and also in the warm-to-cold temperate forests, continue unabated.

## 1.2 Rainforest Macro- and Mesoclimate

The original concept, persisting right into the 1930s, was that the equatorial (rainforest) climate was “everwet” or “perhumid”, unseasonal or so weakly seasonal that its ecological effects were minimal. The climate was thought to be spatially at meso- to macro-scales uniform (Köppen, 1931, A<sub>0</sub> climate). Evaluation of data from standard meteorological observations since the 19th century and new data from research stations and projects have changed this concept of the equatorial climate and its rainforest completely, even if there had been no climate oscillations or change involved. Adding new research data on the history of climate, tectonics and geomorphology during the Pleistocene and Quaternary created a new concept of equatorial climate and made us realise that in the past – and even now – the equatorial climate and the TRF are not stable and harmonious systems, but environments of turbulence, change and stress, a world of permanent change. This recognition, together with data

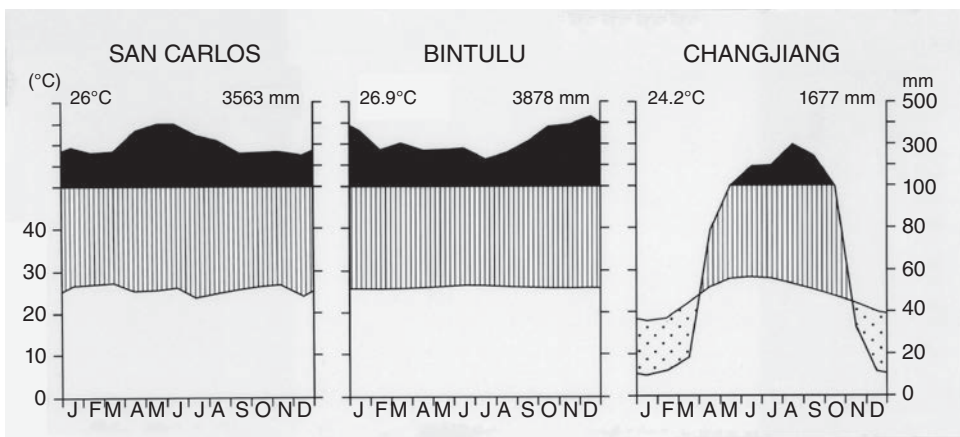
on flora, fauna and vegetation during these periods, is a most valuable contribution of actual changes and their consequences for assessing the possible effects of the most probable course of Global Climate Change (GCC).

Throughout the Plio–Pleistocene transition, Pleistocene and Holocene or Present, climate fluctuated and temperature and precipitation changed by natural causes. Cold glacial periods (lengths in the order of 100,000 years) and warm interglacials (10–15,000 years) alternated. The emergence of *H. sapiens* (more fitting would be: *H. atrox*), fire-using hunter and shifting cultivator, added to the perturbing and disturbing causal factor of change in the forest and its immediate site and environment. Eventually, the mesoclimatic conditions in the landscape would also be affected and changed. Such change was already observed three centuries ago in India, and attributed by scientists to the spreading deforestation. A global threat of climatic change towards desiccation was suspected, reforestation called for and regional cooperation of scientists in monitoring climate change suggested by botanist William Roxburgh in Calcutta. However, in India and in London the authorities, politicians with vested interests and administrators with intrinsic aversion to change did not respond rationally, but rejected the reality of impending climate change, the need and feasibility to reforest the bare lands and to establish regional cooperation to monitor the suspected climate change (Grove, 1997). Little has changed over three centuries in the attitudes of authorities and also in the disinterested lethargy of the public. In the second half of the 20th century, scientists warning the public and governments that GCC was possible, then likely and eventually highly probable to certain, fared no better in London, Washington and New York far into the 1990s.

We may conclude: the rainforest flora, fauna and microbes have adapted during the Pleistocene and Quaternary to fluctuating, sometimes violently oscillating macroclimatic conditions. During the predominantly uniformly tropical climate of the Tertiary the angiosperms appeared and prospered, but preadapted early to invade the climatically

different subtropical and temperate biomes where they had to endure long (millenia) and medium (centuries) periods during which the temperature and moisture were considerably higher or lower than that of the present (UNESCO, 1978; Flenley, 1988; Heaney, 1991; Taylor, 1992; Verstappen, 1994; Cannon *et al.*, 2012). But they are most likely not adapted to the conditions which the continued large-scale land-cover devastation and transformation, and the concurrent excessive air, water and soil pollution are creating in the rainforest and in the adjoining biomes. The responses of authorities from the UN down to the tribal and village communities have been weak, inefficient, ineffective, narrowly interest-bound, largely verbal and with few exceptions, without action. Therefore, the macro- and meso-climatic causal processes of change will continue; social and economic decline not properly accounted for or indexed by GDP or GNP will continue; and socially sustainable development will remain a dream, particularly in the TRF biome. The climate will continue to change and oscillate and resource overuse and misuse will aggravate environmental decline.

The macro-scale atmospheric circulation systems that determine the macro- and meso-climatic conditions and events fluctuate accordingly on the scale of years to decades. The Americas are predominantly affected by the Hadley cell circulation. In Africa, South Asia and Malesia and the Australo-Pacific region, the very variable monsoonal circulation is superimposed on the Hadley cell pattern. A comprehensive description of tropical climates and climate change is given by Hendersen-Sellers and Robinson (1988). The climate is not as uniform as climate diagrams suggest (Fig. 1.2 and Table 1.1). On the contrary, meso- to macro-climatic conditions show a pronounced spatial heterogeneity, which appears to be enhanced by the consequences of human activities. Neither the original TRF climate was, nor the contemporary climate in an environment of deforestation and air and water pollution is as favourable for plants as scientists and laymen commonly assume. Stress factors include the great intensity of radiant heat influx, extreme midday moisture saturation pressure deficits, high proportion of high-intensity rainfall events, occurrence of more or less unseasonal and



**Fig. 1.2.** Climate diagram of the apparently everwet equatorial climate (examples San Carlos de Rio Negro, Amazonia, Venezuela, and Bintulu, Sarawak) and of the seasonal tropical climate with one dry season at the outer margin of the tropics (example Changjiang, Hainan) (Walter, 1973; data for San Carlos supplied by J. Heuvelodp). San Carlos de Rio Negro, Territorio Amazonas, Venezuela and Bintulu are typical of the “everwet” tropical rainforest climate. Both locations are subject to occasional, episodic drought. The seasonal tropical climate of Changjiang permits predominantly evergreen mesophyll forest only on alluvial lowland and on montane sites. Black represents logarithmic scale above 100 mm per month, supposed to denote “everwet”. Stippled below the temperature line denotes ‘dry period’.

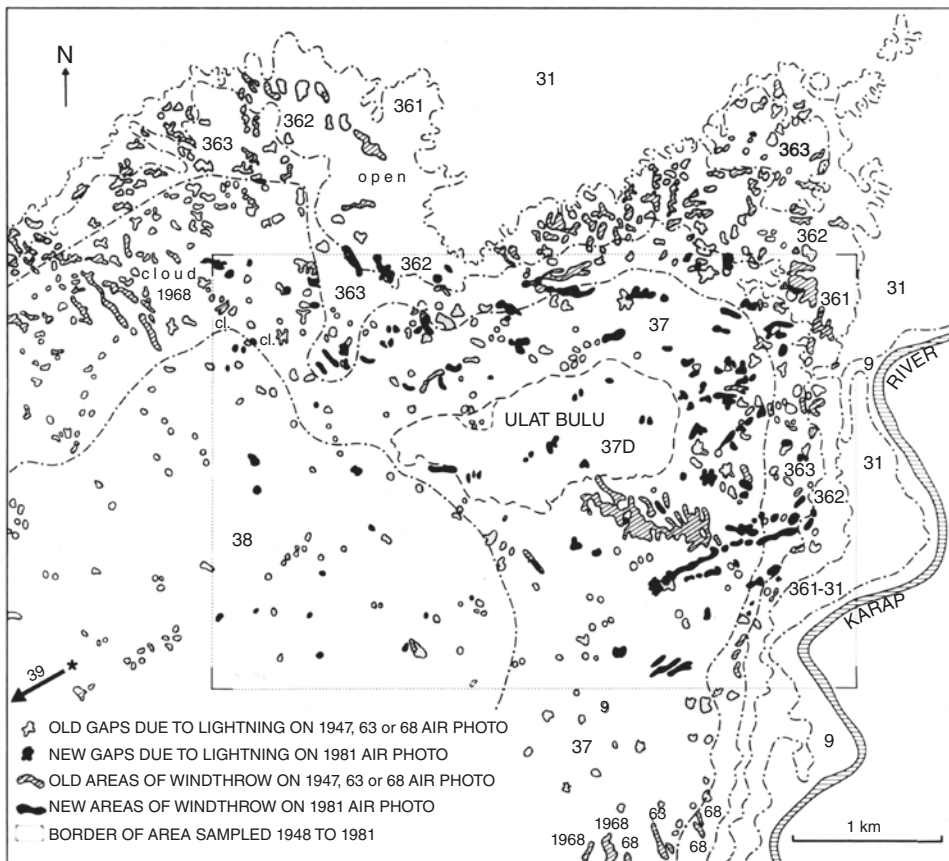
unpredictable episodically very severe and prolonged periods of drought, and the high frequency of heavy lightning strikes, storms, squalls, tornadoes and aerial micro-bursts of high velocity. Added are the consequences of particulate and gaseous pollution of the air and the toxic solutes in the surface and ground waters, which are largely ignored by the authorities in spite of warnings by scientists since the 1960s.

The occurrence of prolonged and physiologically effective drought conditions were suspected by Schulz (1960) in Surinam and proved for Sarawak by Bruenig (1966, 1969a, 1971a), for the Amazonian caatinga near San Carlos de Rio Negro by Heuvelink (1978; Bruenig *et al.*, 1979) and confirmed for Borneo by Baillie (1972, 1976), Whitmore (1984, p. 59), Wirawan (1987) and Woods (1987). The El Niño Southern Oscillation (ENSO) droughts have become a regular trend, adding to GCC an increasingly disturbing regional phenomenon with globally spreading climatic and social effects. Throughout Malesia, the obvious increase of episodic extreme events of drought, flood and storms throughout the biome, and the noticeable increase of air pollution, ranging from heavy ground-level smog and smoke to persistent stratospheric haze and strato-cirrus clouds, thin but effectively blotting out the famous tropical star display, changing essential exchange dynamics in the atmosphere and affecting the usual hydrological cycle for most of the year, are a very serious warning. So far, this is not adequately recognised and taken seriously by politicians and the public. The severity of the ecological and economic consequences, especially the effects of prolonged drought in the “ever-wet” TRF climate on forestry and agricultural gross and net productivity, and also on carbon sequestration and storage, are wilfully and wishfully ignored. On the other hand, prolonged periods of supersaturation, which are probably also increasing, will stress the TRF ecosystem (plants, animals and soils with their microbes and animals), by heavy leaching, prolonged soil water saturation, high rates of surface water runoff and erosion and low radiation.

The lightning and windthrow gaps, observable on aerial photographs of the uniform

canopy of Alan (*S. albida* Sym.) peatswamp forests in Sarawak show a noticeable spatial and temporal pattern (Figs 1.3 and 1.4; Bruenig, 1973b). There is evidence of some interaction between the canopy damage caused by lightning (causing the initial gap), and storm extending it (Fig. 1.4) and of strong fluctuations of the incidence of gap formation between years. The sizes of the lightning gaps are largest in the phasic communities 3.61–3 (tall trees forming an aerodynamically rough canopy), medium in 3.7 (tall, but smooth canopy) and smallest in 3.8 (low, dense and smooth). This gradient of disturbance may not only be caused by the gradient of crown sizes and canopy roughness, but also be connected with differences and variation in the electrical conductivity of forest and peat together. Severe and extensive storm damage in TRF is well documented (Browne, 1949; Anderson, 1961a; Whitmore, 1974, 1975a; Basnet *et al.*, 1992).

Additional climatic heterogeneity is caused by topographical features and related hydrological properties of the ground. Large plumes of clouds originate regularly in the wake of coastal mountains, stretch far inland and seed rainfall along their path (Fig. 1.5). Conversely, rain-fronts develop at inland mountains and follow fairly set paths into the lowlands. This spatial patchiness of atmospheric and soil moisture, caused by physiographic heterogeneity at small to medium scale, complicates landuse and forestry planning, and being very vexing, is usually disregarded. An illustration of the effects of the great spatial heterogeneity of climatic conditions, and accordingly of effects at a very large regional scale, is the intensity of discharge of water and sediments from land surfaces into the seas (Figs 1.6 and 1.7). The extremely high discharge of water and sediments per square kilometre land surface in the South-east Asian Archipelago is related to the very high intensities of rainfall events and high relief energy. These extremely high discharge rates are indicators of the fragility and vulnerability of the land surface, which impose severe limitations on sustainable land and forest use in the Malesian region. This, and the tendency to abnormal atmospheric circulation patterns in the region, are serious but

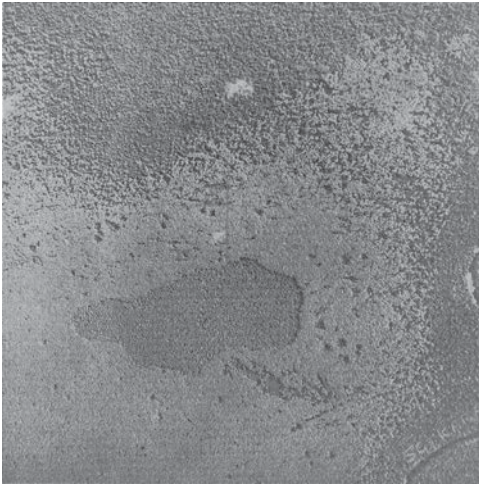


**Fig. 1.3.** Zoning of the phasic communities in the peatswamp forest. Type 9 is cultivation on the riparian fringe, rice fields and secondary forest fallow. Then follow the forest phasic community PC1 or forest type 31, PC2: 361-363, PC3: 371-373 and PC4: 3.8; outside the map area further southwest follow PC5 and 6.37D: 110-ha gap caused by lethal defoliation of alan bunga (*Shorea albida*) by an unidentified caterpillar ulat bulu before 1948 (Anderson, 1961b). The map has been drawn from a sequence of aerial photographs (1947, 1963, 1968, 1981) showing effects of disturbance events caused by lightning, windthrow and ulat bulu. Incidence and severity of the disturbance are related to differences in the canopy roughness, stature of the trees, tree-species richness and diversity. Note the concentration of gaps in the aerodynamically rough and tall canopy of 363 and adjacent 37, and the decline of gap size with crown size in 37 and 38. Karap river is a tributary of Batang Baram, Sarawak. For further explanation of forest types see Section 6.5 and Bruenig (1969b).

usually overlooked problems and are obstacles to sustainable forestry, environmental protective maintenance and sustained landuse generally. The ecologically rather favourable, but very exacting and probably worsening rainforest climate, the declining quality of soil and air (particulate, gaseous, solved and suspended pollution of air and water), and physical soil damage by careless application

of unsuitable technology have serious consequences for integrated sustainable development. The chief conditions and factors are:

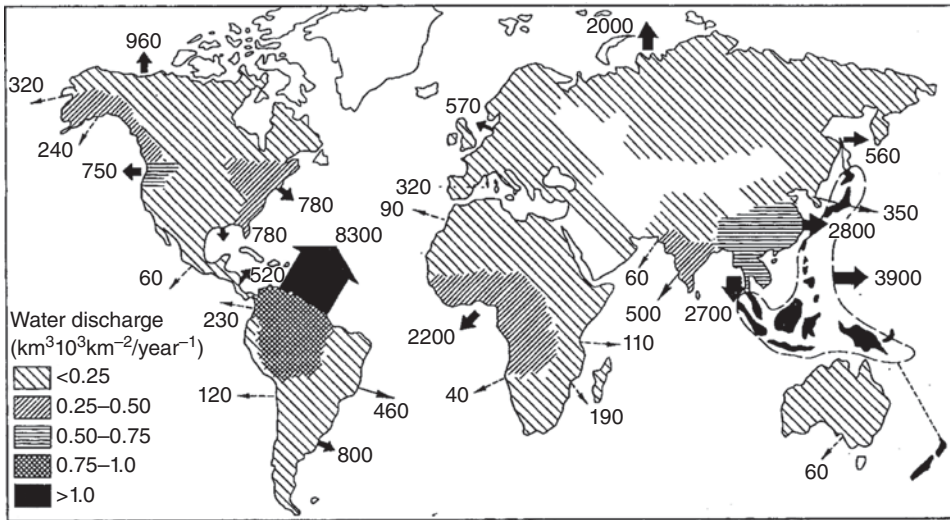
1. Heavy leaching of minerals and organic matter from the soil and heavy rates of surface and within-soil subsurface erosion.
2. No regular dry-season recovery of the nutrient regime as in deciduous tropical forests.



**Fig. 1.4.** Diversity of vegetation and of disturbances at  $\beta$ -level in peatswamp forest in the same area as shown in Fig. 1.3 (status in 1981) (courtesy Sarawak Government, 1982).



**Fig. 1.5.** Diversity of the physiography of the landscape affects heterogeneity of meso-climate: plume of clouds are regularly formed by the Peninsular Bako N.P. and, travelling far inland, affects the heterogeneity of the rainfall distribution pattern. Gunung Santubong on the left has only formed the noon cloud cap on this day, but is often also the source of very compact plumes. The plain between Bako and Santubong is a mosaic of mangrove, beech forest and kerangas forest on terraces, mostly strongly modified or converted. The Santubong hill (810 m a.s.l.) and the Bako N.P. carry a mixture of very diverse MDF and KF forests and secondary vegetation.

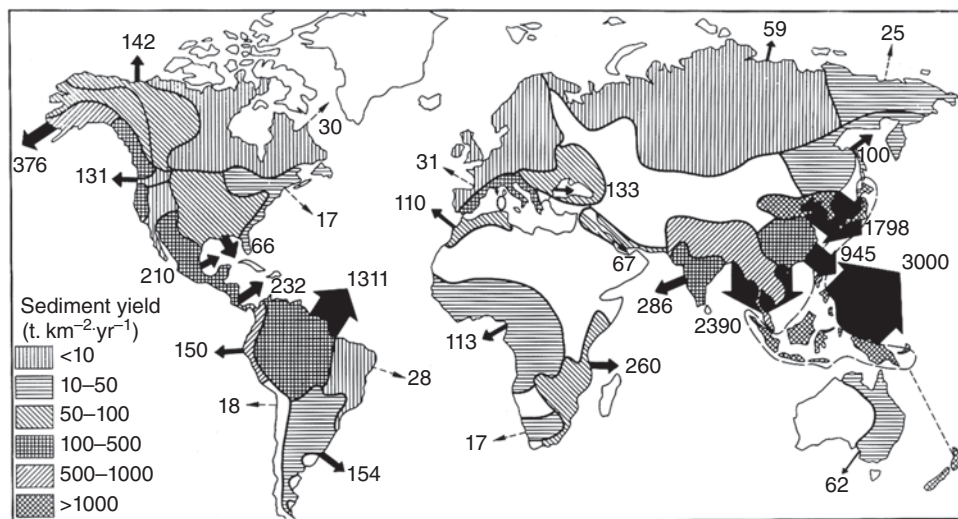


**Fig. 1.6.** Mean annual total discharge of fluvial waters from the catchment areas (regions) to the oceans (arrowed numbers) and the average rates of annual discharge (runoff) or water in cubic kilometres per 1000  $\text{km}^2$  land surface (hatching). The Amazon catchment has the highest total water yield, but the Malaysian Archipelago has the highest runoff per 1000  $\text{km}^2$  land surface (from Milliman and Meade, 1983).

3. High temperatures and consequently high intensity of physical and chemical processes on the plant surface, in the plants and in the soil.

4. Intense direct and indirect solar radiation, high temperature, generally high humidity and

occasionally, especially around midday, strong vapour saturation deficit, which individually and in combination stress and strain the plants and favour photochemical and biochemical reactions with natural and anthropogenic toxic pollutants, which may cause damage.



**Fig. 1.7.** Mean annual fluvial sediment flows from regional drainage areas in to the oceans (arrowed numbers) in million tonnes and the average rates of annual sediment yields in tonnes per square kilometre land surface (hatching). The Malesian Archipelago has the highest water runoff and by far the highest sediment yield per unit land surface ( $\text{km}^2$ ) (from Milliman and Meade, 1983).

5. Prolonged drought periods create fire risks (Goldammer and Seibert, 1989) and cause mortality among seedlings and saplings (Becker and Wong, 1993).

6. Prolonged droughts and supersaturation are likely to affect primary productivity and tree biomass growth. ENSO droughts have already caused substantial confirmed reductions of growth-ring width of trees with long recovery times in the C-layer of a mixed dipterocarp forest (MDF), and presumably also in the B- and A-layers (Newbery and Lingenfelder, 2009; see also Section 1.13), indicating reduced gross and net primary productivity and production of tree biomass in future.

7. Increase of mortality caused by drought, pests and diseases among trees in all layers, increasing the probability of substantial reduced gross and net primary productivity and production of tree biomass in future.

8. Higher rates and intensities of damaging lightning hits causing gaps which may be extended by the effects of exposure and wind.

9. Air temperature increase as the compounded result of natural oscillation (only partly due to variation of sun activities) and anthropogenic changes of the atmosphere (gaseous and particulate pollution) and the

optical and hydrological properties of the surface of the globe. Globally, in 1910–2010 the air temperature rose (“global warming”) by slightly more than  $1^\circ\text{C}$  ( $0.1^\circ\text{C}$  per decade) and in 1975–2000 about  $0.5^\circ\text{C}$ , reaching a temperature “plateau” of  $+0.6^\circ\text{C}$  above the average air temperature in 1951–1980 (previews from the 2013 IPCC report). Climate model simulations had shown such plateaux before, they can occur in simulations and in reality at any time, but are difficult to explain and impossible to predict. One thing is certain: neither in simulations nor in reality do they indicate an end of the warming trend, nor when the warming trend will return. The 2003–2010 plateau seems to be balanced by an increased warming trend in the oceans, also difficult to explain, and not boding well for the tropics (because of the increased violence of tropical storms). For the TRF, the best data-supported and statistically significant estimate of current average decadal air temperature increase rate is  $0.26^\circ\text{C}$ , measured in 1986–2007 – for over 22 years – in Danum Valley, Sabah (Newbery and Lingenfelder, 2009). In the intrinsically very volatile tropical climate put out of balance by warmer seas and drier landscapes (deforestation, building of infrastructure and

megapolitan-agroindustry complexes with weakened convectional hydrological cycling), the future environmental conditions can be assumed, but not predicted.

**10.** Insurance companies and meteorological stations record an increase in frequency and intensity of extreme climatic events, especially damaging storms, intensive rainfalls and high floods, and long rainless periods, fuelled by the increase of the surface temperature of much of the equatorial seas. These, in addition to more extremes of climatic events, create another GCC-promoting feedback loop: warmer seawater – reduced plankton – reduced CO<sub>2</sub> assimilation – more greenhouse gases retained in the atmosphere – less CO<sub>2</sub> is taken out of circulation and sedimented – warming of air and water is promoted and the rate of change accelerated.

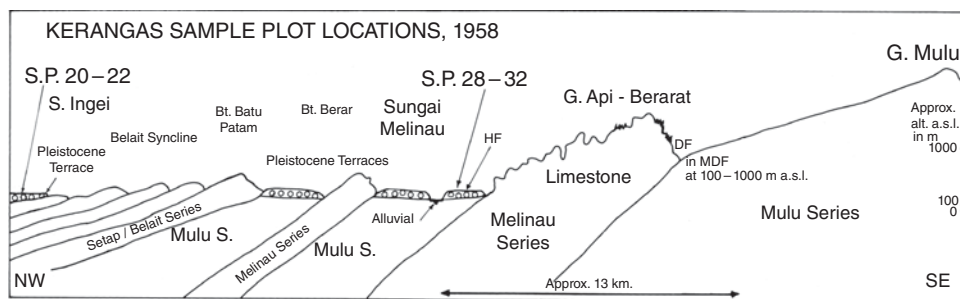
In conclusion, the equatorial tropical climate is exacting and puts severe limitations on forest utilisation, sustainable forest management and conservation. The year-round hot weather favours outbreaks of pests and diseases, especially in monocultures. The combination of constantly high temperatures and the often very high rainfall intensities that leach and erode the soils make unsustainable any harvesting and management system that does not maintain high levels of complexity and the protective functions of the canopy, and keeps soil damage at the lowest possible levels. The occasional high, episodically extreme, wind speeds blow off leaves (Wöll, 1989) and crowns (Anderson, 1961a), or throw trees or tracts of forests (Browne, 1949). Native trees are physiologically and morphologically adapted to compromise between the need for high transpiration (cooling, nutrient pumping) and the avoidance of overheating, drought and storm damage (Gates, 1965, 1968; Bruenig, 1966, 1969a,b, 1971c), but extreme conditions can overstrain even native tree species.

### 1.3 Rainforest Soils, Soil Types and Vegetation Types, Mosaics and Catenas

Rainforest soils are a rich spectrum of a great variety of taxonomic units which generally

occur in extremely heterogeneous mosaics or sometimes in substrate and landform-related catenas. Their pedological taxonomy is confusing to the non-specialist and most foresters, and like the floristic taxonomy is subject to change. For the sake of practical foresters, I retain the established and simple taxonomic terms of the 1980s, which I used in 1996–1998. The soils in rainforest can vary profoundly at a scale of a few square metres to square hectometres and hectares, according to the spatial variation of the geological substrate, geomorphology, climate and the long-term influences of vegetation (Figs 1.8–1.10). A pantropical synopsis of tropical soils and their complicated nomenclature in the various systems of classification is given by Schmidt-Lorenz (1986) and Longman and Jenik (1987). Burham gives a brief but useful regional review for South-east Asia (SEA) (Burham in Whitmore, 1975a). The forest soils of Sarawak, including the unique extensive oligotrophic medium to deep peatswamp soils and the more scattered oligotrophic podzols and podsolic soils in kerangas forests (heath forest) have been intensively pedologically studied, classified, assessed and mapped since the 1950s. A useful overview of the soils of Sarawak from an agricultural and forestry point of view is given by Andriesse (1962). A description of the great variety of soils in the humid tropics, including a critical contribution to the laterite discussion of the origin and nature of this soil, and identification of distinctive features that are important for the growth of tree species and communities, is given in the now classic reconnaissance report of the soils of the Brazilian Amazon region by Sombroek (1966). He states that any differences in forest characteristics within an area of uniform climatic conditions and non-existent or uniform anthropogenic influences, are apt to show a correlation with lower category soil differences. Among these are moisture-holding capacity, the total available amounts of the various plant nutrients and the penetration possibilities for roots.

These also hold true in Bornean upland forests and are the primary features used in forest soil mapping for forest management planning in Germany. However, uncertainties

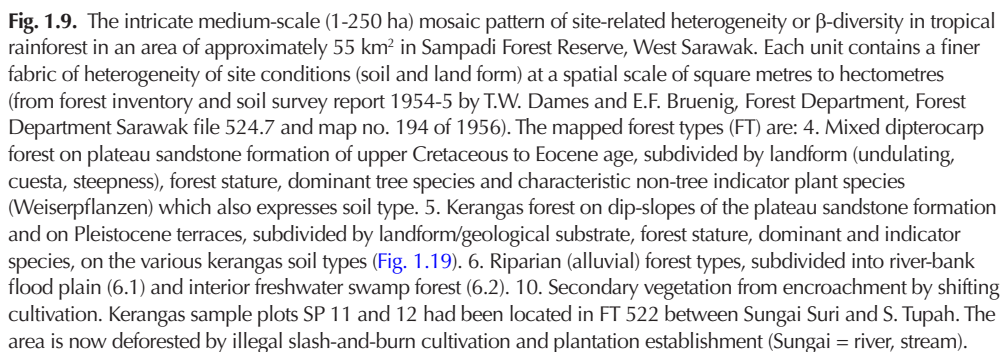


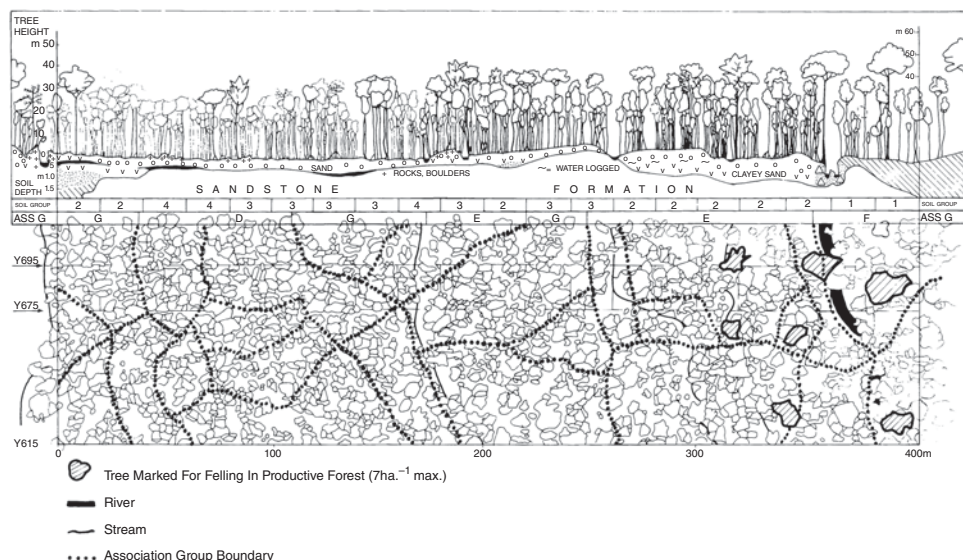
**Fig. 1.8.** Diversity of geologic substrate along a 13-km transect from Gunung Mulu in north-eastern Sarawak westwards to Sungai Ingei, Ulu Belait, in south-western Brunei, an example of the heterogeneity of parent material and topography at landscape scale. In this case it was formed by a strong uplift of a Miocene and Pliocene Tertiary synclinal trough in which rather varied argillaceous and arenaceous materials had been deposited. Older materials, including limestone, broke through the surface. New heavy erosion and sedimentation in the trough and uplifting of the edges created several levels of Pleistocene and Holocene deposits. This geologically and geomorphologically diverse and active landscape supports a great variety of very different tropical soils. SP 20-22 and 28-32 indicate the location of kerangas sample plots of 1959 (Bruenig, 1966, 1968). The plot HF of Proctor *et al.* (1983a,b) and Newbery and Proctor (1984) is adjacent to RP 28 and 29. DF is their MDF plot.

remain, mainly caused by human ignorance and by the openness of the system of interacting factors of soil, geomorphology, climate, flora, fauna, vegetation and physio-ecology (Bruenig, 1970a; Ashton and Bruenig, 1975; Weiske, 1982; Newbery, 1985, 1991; Newbery *et al.*, 1986; Ashton and Hall, 1992). In the 1950s, Dutch soil scientists surveyed forest and agricultural soils for the Departments of Agriculture and Forestry, Sarawak, and produced a basic classification scheme (Andriesse, 1962; Dames, 1962) on which the currently used classification could be built (Tie Yiu Liong, 1982). The diagnostic field and laboratory parameters used for upland soils are: soil organic matter, drainage, Munsell colour, presence of cemented spodic, oxic, argillic or cambic horizons, soil texture, nature of cation exchange complex, pH and parent material. Peats are classified by depth, substrate, vegetation, ground water table and ash content. These parameters accord broadly to the soil properties that Somerbroek used to differentiate between types, and are key indicators of sustainable productivity: moisture-holding capacity (soil organic matter, SOM), rootability (soil texture, horizons), nutrients (Munsell colour, cation exchange capacity (c.e.c.) and pH). For forestry planning, soil and site data have been

incorporated in the forest inventory procedure in Sarawak since the mid-1950s (Bruenig, 1961b, 1963, 1965a). This information, as elsewhere in the world, was in later years hardly applied in forestry and agricultural planning and development (Ashton and Bruenig, 1975). The very strong timber orientation of the FAO forest inventory in Sarawak in the 1970s (Bruenig, 1976) and the lack of a comprehensive integrated multisectoral spatial information system (Bruenig, 1992b) blocked further advancement towards sustainability and facilitated the mushrooming of unregulated timber exploitation.

The typical “zonal” mesophytic TRFs grow on red-yellow, heavy-textured clays to moderately textured, more or less sandy clay loams. Structure, water-holding capacity, depth of rootability and content and distribution of SOM vary widely. Their combination determines fragility of the soil and sets the limits for sustainable forest modification and manipulation. Mixed dipterocarp forest (MDF) soils (cambisols, acrisols, ferralsols, udult ultisols) in Sabah have generally  $Mg_2+$  and  $K+$  as dominant cations and, on average, an effective cation exchange capacity (e.c.e.c.) of 80% of c.e.c. In contrast, the sandy and very acid (pH <3–4.5) kerangas





**Fig. 1.10.** Pattern at small spatial scale (order of metres to 100 m<sup>2</sup> = small-gap size) of terrain and soil type and canopy structure along a 20-m wide east-west transect in Sabal Forest Reserve, Sarawak, 1963. The rooting systems and depths on the various soil types correspond to conditions shown in Fig. 1.14. The profile of forest and soil (top) runs between Y675 and 695 from X 0 to 400 (in metres). The mixed dipterocarp forest (X 360-400, soil group 1) is part of the area that was selectively logged in 1978 and had the highest tree-species richness in 1990 recorded in Sarawak, described in Sections 1.8, 2.8 and 6.3; Tables 1.6 and 6.2. Soil groups are: (1) deep sandy-clayey loam, ultisol, (2) medium deep sand over clayey sand, podzol, (3) medium deep sand over hard Bh (Ortstein) or sandstone, podzol, (4) shallow sand, podzol. D.E.F.G: association groups of trees  $\geq 30$  cm diameter, 30 nearest neighbour FANTASM-B divisive classification (Bruenig *et al.*, 1979; Weiske, 1982). Dotted line: boundary between association groups. Canopy projection: crowns of A- and upper B-layer trees. Thick-lined crowns: merchantable trees marked for felling in selection silviculture management in 1.5 ha production forest (MDF and *Agathis* KF on soil groups 1 and 2).

and padang soils have AF+ and 30% e.c.e.c. (humult ultisol/ferralsol) or Fe<sub>3</sub>+ and 10% e.c.e.c. (arenosol/podzol) (Lagan and Glauner, 1994). The very acid sandy humult ultisols, podzols and oligotrophic peat soils (Anderson, 1961a) are absolute forest soils (Bruenig, 1969c). Therefore, they will be an important component of the eventual permanent forest estate, at least in some parts of the biome, such as Borneo, Guyana-Surinam and Amazonia. These soils are inherently infertile and extremely fragile. This excludes agriculture and constrains forestry severely (Bruenig, 1966, 1969c; Klinge, 1969). In Borneo, these infertile upland soils are mainly podzolic arenosol, podzolic stagnic gleyic clay or excessively drained sandy podzol (spodosol) and the related kerangas peatbogs or kerapah (Bruenig, 1966, 1989c).

The kerangas and kerapah soils and the analogous Amazonian and Guyana-Surinam caatinga soils (Klinge, 1969) differ in some essential ecologically important features from the clay-loam and clay soils (ultisols, oxisols, acrisols, ferralsols) under MDF (Dames, 1962) in Malesia, the Tierra Firme forest soils in the Neotropics in the Amazonian-Central American region, and the equivalent soils under “climax” forests in the equatorial African region. The main features of relevance to forest management and conservation (Bruenig, 1966, 1974; Bruenig and Schmidt-Lorenz, 1985) are:

1. extremely low nutrient content and very high acidity;
2. extremely unbalanced water regime, oscillating between parched-dry and supersaturated states;

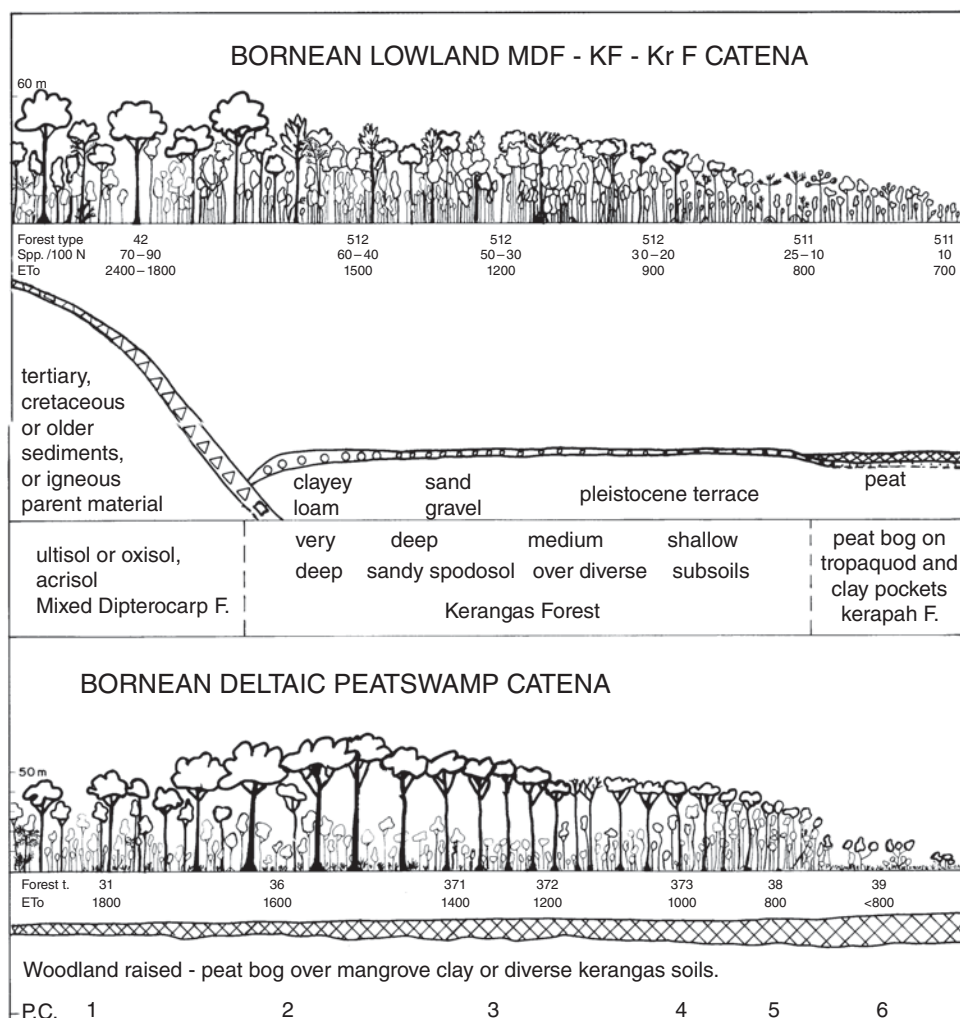
3. in kerangas/caatinga a thick layer of litter overlying usually also thick, fibrous, very acid surface raw humus or in kerapah peat, rich in non-hydrolysable polyphenols (tannins) and allelopathic compounds (Bruenig, 1966; Bruenig and Sander, 1983);
4. shallow to deep, bleached eluvial albic, usually sandy, in kerapah also clayey, soil horizon;
5. often overlying a reddish-brown, hardened, illuvial humic or humic-iron pan;
6. discharge of tea-coloured strongly humic “black-water” (hence the name “Rio Negro” for the river draining the extensive caatinga areas in Amazonia); and
7. possible toxic ( $H_2$ ) reaction to fertilising must be considered in rehabilitation or restoration projects.

The peatswamp soils of Sarawak were described by Anderson (1961a, 1964, 1983) who commented on the diversity of their geomorphic features. The surface topography may be flat or dome-shaped, the substrate topography bowl-shaped, flat or undulating, and its chemical and physical properties varied in nature (Fig. 1.11). Anderson suspected that the almost permanent waterlogging at the periphery and periodic or episodic drought in the centre were the major determinants of the vegetation types rather than the nutrient contents of the peat and substrate, which show no clear catena sequence of variation. The organo-chemical nature of the peat may influence abundance and distribution patterns of individual species, such as ramin (*Gonystylus bancanus* (Miq.) Kurz), within the various phasic communities *sensu* Anderson (1961a) more than nutrients (Bruenig and Sander, 1983). The same applies in principle to kerangas forests (Bruenig, 1966; Riswan, 1991; Section 1.7) where the hydrological features of the soil and terrain determine the forest vegetation type and physiognomy. Site hydrology and nutrient status possibly affect kind and pattern of the diversity of tree and non-tree flora within the vegetation-soil type. For the suspected role of unusual mineral elements see Proctor (1989).

The interaction of moisture, aeration, nutrients, SOM (living and dead), biological

soil life and, in soils on extreme parent materials, toxic conditions, determine the soil's suitability and capacity to support plant growth and carry forest vegetation. The primary productivity of the plants determines the amount of food available to the soil organisms. The soil organisms maintain crumb structure, porosity and thereby aeration, rootability, infiltrability, absorptivity and water-holding capacity of the soil, and contribute to the conservation and cycling of nutrients. The important role and abundance of mycorrhiza (Mikola, 1980) in TRFs was realised by Möller (1922, 1929) in the 1880s during ecological research in Brazilian Atlantic rainforest. His understanding of mutualism and symbiosis helped to design sustainable silvicultural management systems, especially for the restoration of degraded lands and forests, in Germany (Möller, 1922, 1929; Bruenig, 1984a, 1989a) and also a century later in TRFs of China (Yang and Insam, 1991).

Even the non-specialist can notice the distinct  $\beta$ -diversity of insects, leeches, insects (mosquitos), soil animals and mushrooms between different types of TRF with different soil and site conditions, which are accentuated by different forestry and non-forestry regimes. A long-term ecological study in MDF in the Kinabatangan Valley, Sabah, included a soils study of the effects of reduced-impact logging (RIL) on decomposers in the Deramakot and Tangkulap Forest Reserves (Hasegawa *et al.* (2013), pp. 63–88). This very comprehensive, thorough and scientifically well designed 6-year study compared soil organismic life in a relic of pristine MDF in sustainably managed forest with supervised RIL (Demarakot FR), with that in customarily exploited forest (timber-mined/customarily logged, TM/C) in Tangkulap F.R., of this 4500 ha illegally logged. Microflora and meso- and macro-fauna of the loamy ultisols were enumerated and monitored in each area in one 2-ha plot and four 0.2-ha plots, but in Tangkulap FR in one 2-ha plot and three 0.2-ha plots. Guild-specific methodologies were well chosen, applied and described. The overall conclusion after 6 years of field research confirms that orderly forest management affects the state and processes of soil biology but is sustainable,



**Fig. 1.11.** The change of canopy structure with site in Borneo. Forest types according to Bruenig (1969b) in the upland (almost flat or undulating lowland to upper hillforest on dry land) forest catena (see Figs 1.23 and 1.24) and Anderson (1961a, 1983) in the peatswamp catena. SPP/1 OON: number of tree species  $\geq 1$  cm diameter in 100 random individuals. ETa: Evapotranspiration rate. Top: mixed dipterocarp forest (type 42), *Agathis*-bearing kerangas (type 513), typical kerangas (type 512), poor kerangas (511), kerapah or related very poor types (510). Bottom: deltaic peatswamp forest, mixed ramin-bearing peatswamp forest (type 31 and PC1), *Shorea albida* phasic communities alan (PC2), alan bunga (PC3), padang alan (PC4), mixed (PC5) and open padang (PC6). The crowns have been pictorially depicted by a continuous outline. In reality the mostly cauliflower- or broccoli-shaped crowns are an open compound of subcrowns with more or less bunched leafage that transmit light particularly well if the sun is high around noon, but intercept more in the morning and afternoon.

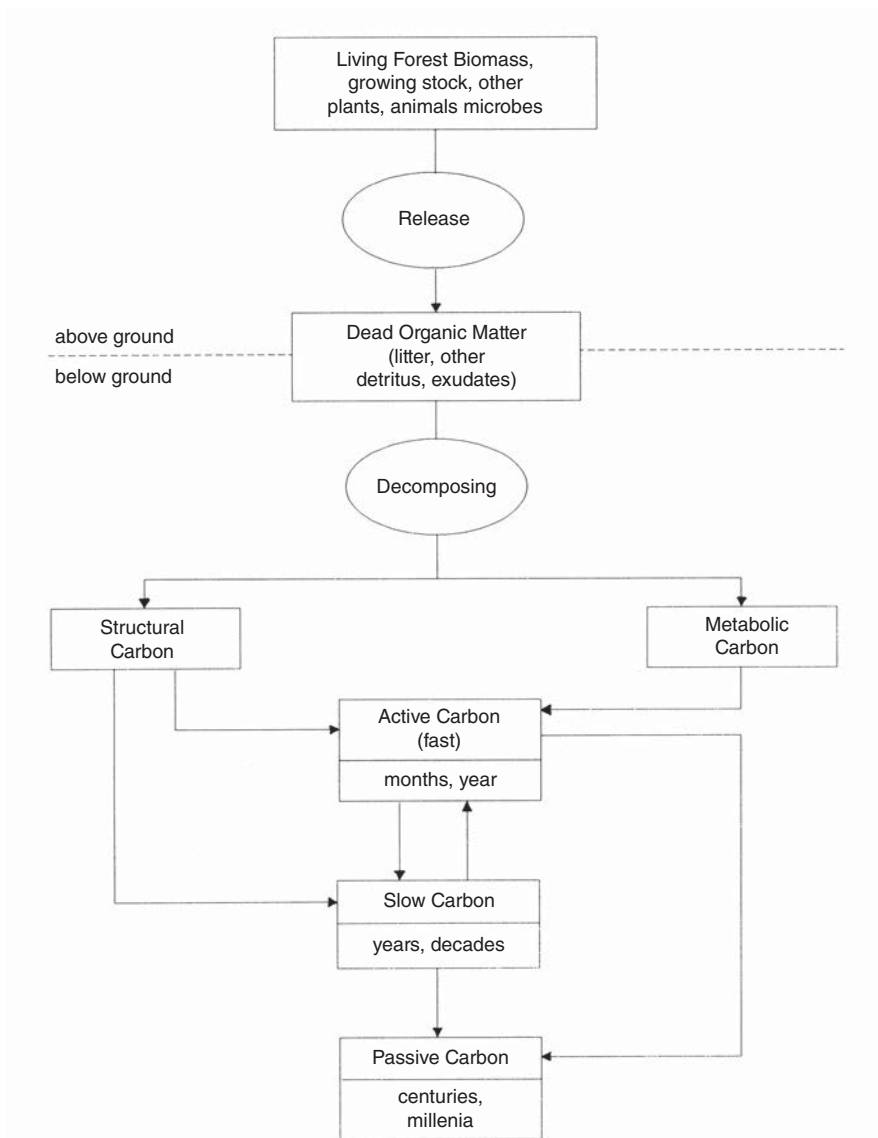
while TM/C is destructive and not sustainable. The significantly different impacts of RIL and TM/C cause long-term differences in the quality and quantity of transfers of energies and matters to the decomposers in

the soil. The decomposer soil organisms are resistant and resilient to management and harvesting impacts to a certain site-specific threshold, but need food in the form of litter to recover. Transgressing the threshold, as in

TM/C, will cause lasting change of soil biology and possible damage to the soil as a habitat of trees. The study touched on the key problem of restoring the functions of the demolished and degraded TRF ecosystem: what potentials are left in the damaged soils to restore the functions and processes which are essential in reconstructing the growing stock and protective canopy of timber trees? Their crowns and roots are the resources needed to restore the damaged soils and the interaction between the two compartments. Impacting on the protective and productive canopy as little as economically and technically possible and ecologically feasible is crucial to maintaining adequate functionality in ecological and social terms. Recent studies of the effects of TM/C logging or alternative RIL suggest that the reduced canopy opening by RIL is also beneficial to insect life.

While there are ample data available on annual fine-litter fall (on average 5–9 t ha<sup>-1</sup>), there is little quantitative evidence on the production and turnover rates of coarse litter. Rates of decay of trunks vary widely in relation to species, soil type and contact with the ground. In Sabal Forest Reserve, Research Plot (RP) 146, in Sarawak, bindang (*Agathis borneensis*) and meranti (*Shorea* spp.), cross-cut logs and whole trunks of trees felled in 1978 but not extracted, were strongly decomposed in 1990 if they were in direct contact with the ground (sandy-loamy humult ultisol and sandy podzol). Where the same trunk spanned a hollow, the wood was still firm. Browne (1949) reports that chengal (*Neobalanocarpus heimii* (King) Ashton) logs were still being extracted from the storm-thrown MDF in Kelantan, Peninsular Malesia, almost 70 years after the calamity. Trunks of belian (*Eusideroxylon zwageri* Teijsm. & Binn.) trees felled by the grandfather, who thereby established a customary property right, were still being utilised in the forest by the grandchild. The high spatial and temporal variations of decay and mortality (Section 1.11) make assessments of coarse-litter production difficult. Organic matter is the backbone of fertility and soil biology in all soil types, particularly in oligotrophic soils. Sustainability and success de-

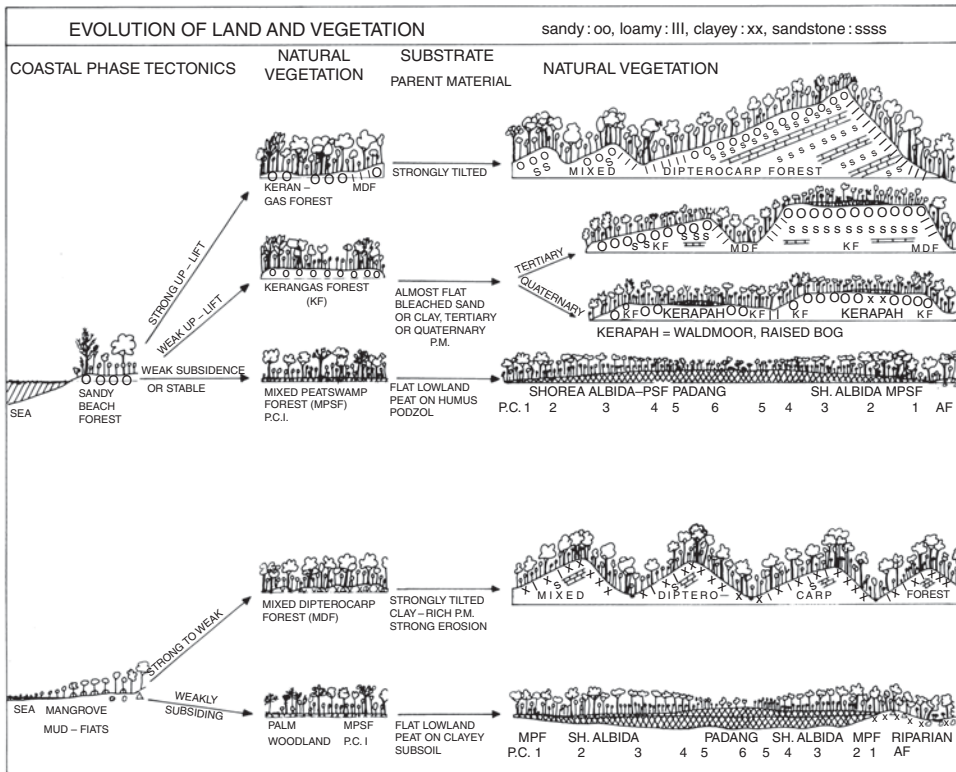
pend on the quality and suitability of its management by silvicultural close-to-nature forestry (CNF) approaches. The recycling of the organic matter of the forest ecosystem is passing through the detritus consuming food chain. Fluctuations and changes in the chemical and physical conditions of the habitat (atmosphere related to GCC) influence the activity of involved decomposers and thereby the soil water holding capacity, storage and release of nutrients, plant growth and health (Figs. 1.12, 1.13, 1.14, 1.15). Litter, moder, humus and SOM serve as reservoir and source of nutrients for the roots of living trees and as food and nutrients for soil organisms. SOM aggregates with clay minerals, improving soil porosity, crumb structure stability, crumb cohesion, soil aeration and water draining (above-field) and retention (below) capacity. As a result, the rootability and resource value for trees of any soil type is improved by above-ground mulch, infiltrated humic acids becoming SOM in the A–C soil horizons. This then forms aggregates which serve as adsorbing complex for retaining tree nutrients and trace elements (a critical factor in most tropical soils) and releasing them to roots or mycorrhiza fungi when needed. The dead organic matter (biomass), above all standing dead and fallen trees, is an important habitat for flora and fauna. The patchy deposition of coarse litter, especially trunks and crown-wood, and the heterogeneous chemical nature and differing decomposition rates of coarse and fine litter will add to faunal and floral diversity patterns and enhance the heterogeneity of chemical and physical soil conditions. These, and the diverse root exudates, will affect the activities of soil microbes and invertebrates, and influence the germination of seeds, growth of roots, establishment of seedlings and the gap dynamics above (Facelli and Pickett, 1991). The importance of microbial biomass in the soil lies in the formation and glueing of mineral soil-humus aggregates and in its role as sink, store and source of nutrients in the soil. The nutrient-preserving functions of live and dead SOM are particularly important in the hot and wet rainforest climate with high decomposition rates and heavy soil flushing by percolating water (Insam,



**Fig. 1.12.** Inputs of litter and exudates above and below ground that are directly decomposed and polymerised into persistent humous matter or pass through a chain of biological metabolism before finally entering the three sectors of the functional soil carbon pool. The system is not closed and decomposition and metabolic processes and the soil carbon pools discharge carbon in various forms into the living biomass and the environment (atmosphere, hydrosphere, lithosphere below pedosphere). Adapted from Seward and Woomer (1992, Fig. 5).

1990; Yang and Insam, 1991). The usually high SOM content (Scharpenseel and Pfeiffer, 1990; Sombroek, 1990; Kehlenbeck, 1993) accords with its important role in rainforest soils. This contrasts with the popular conviction that rainforest soils contain little

humus and the recent statement by Kira (1995) that “the accumulation of dead organic matter as the  $A_0$ -layer and soil humus decreases towards warmer habitats”. Microbes, fungi, invertebrates and other soil organisms will penetrate deep into



**Fig. 1.13.** Simplified and generalised illustration of the primary succession of vegetation and soil formation in tropical rainforest in Borneo starting with littoral deposition and proceeding in relation to tectonic movement (tilted uplifting, flat horizontal uplifting, stable, subsidence) and nature of substrate (arenaceous or argillaceous). MDF, mixed dipterocarp forest (the zonal forest formation); KF, kerangas forest (edaphic formation on well- to excessively drained soils); Kerapah, waterlogged facies of kerangas forest (woodland bog); MPF, mixed peatswamp forest (perimeter of peatswamp); Sh.albida, alan (*Shorea albida*) - phasic communities towards the peatland centre if a raised peatswamp dome is formed (Anderson, 1961a, 1964).

the soil as long as habitat and food are attractive. Deep, porous and well-aerated soils contain humus and are biologically active to a depth of several metres. Living and dead SOM are the decisive, filtering interface between the forest, the hydrosphere and, indirectly, the atmosphere. SOM, being the crucial element of chemical, physical and biological soil conditions, determines rootability and deep rooting is becoming even more vital with progressing GCC to sustain gross and net production rates during prolonged and increasingly severe drought periods, and possibly to retain nutrients during periods of heavy rainfall. Next to the leafage in the canopy (Section 1.6), SOM is the key element for ecosystem self-sustainability and sustainability of forest management in the TRF.

In most rainforest soil types the soil-aggregate structure is fragile and susceptible to breakdown and compaction. The SOM-mineral (clay/silt/sand) aggregates collapse easily under stresses from exposure, rain-splash or impact. Recovery depends fully on biological activity (roots and organisms). The benefit of soil freezing, which speeds recovery of structural and chemical status of degraded soils in cool and cold temperate climates, is absent. Restoration of porosity, crumb structure and rootability after collapse in rainforest soils is, therefore, a slow, long-term and complex process (Droste, 1995) in which, according to my horticultural experience over 60 years, much depends on the quality and quantity of input of organic matter from litter fall and mulching.



**Fig. 1.14.** Diversity of rooting: the roots of the stilted kerangas tree *Casuarina nobilis* Whitm. embrace and grow upward on a *Calophyllum sclerophyllum* Vesque. Sabal F.R., Sarawak.

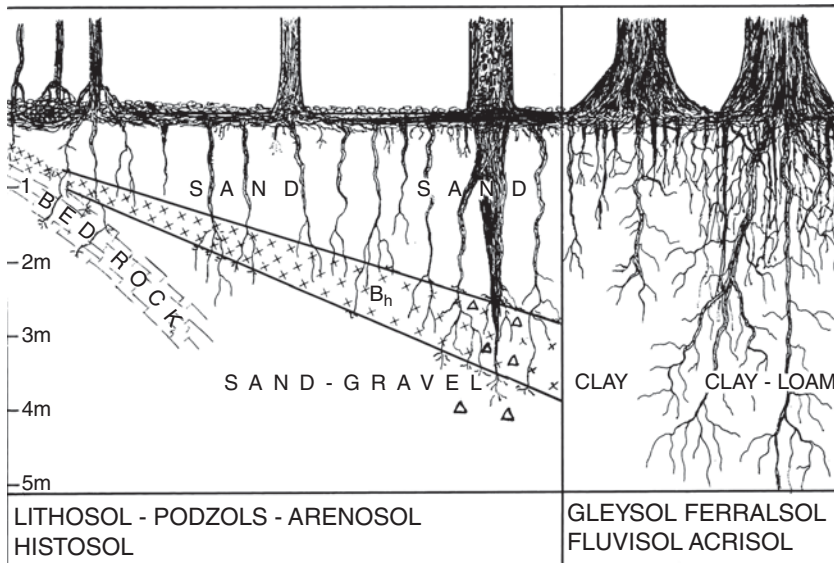
The climate-related tendency to rapid decomposition of organic matter, the sensitivity of the lateritic tropical clay and loam soils to physical impact, and the susceptibility of soils on sloping ground to erosion and internal soil slumping impose limitations on the design of low-risk and high self-sustainability forest management systems (Jentsch, 1933–1934).

After World War II, and before the timber mining tsunami and political winds changed the scenario, R&D towards sustainable forest management (SFM) intensified in those areas of TRF where peace, law and order prevailed. This condition was met in the TRF area in the British Colonial Empire, as long as it lasted. An indispensable fundamental requirement of SFM planning is an integrated soil/vegetation survey, classification and mapping. An example is Sarawak, where growing demand for timber from abroad led to the decision in 1954 to develop an SFM system, starting with the peatswamps. Enquiries came from Japan and Germany

about the suitability and availability of timber from mangrove and kerangas in Sarawak for chipping. Our mangrove forests were under SFM and in no case available for large clear-felling operations. In the case of kerangas forest we had no information except from Beccari (1904). So the Conservator of Forests, Frank G. Browne, decided to add an ecological reconnaissance of the kerangas soils and vegetation to the ongoing study of the peatswamp forests (Anderson, 1961a), and asked me to do it together with Dr Theo Dames for soils. [Figures 1.9 to 1.11](#) illustrate the fine pattern of soil/landform heterogeneity at micro- and meso-scales and in close correlation with forest vegetation type and its physiognomy. These are the scales at which soil/site/vegetation/forest growing stock information is indispensable for SFM planning. The larger scale of variation in relation to tectonics and geomorphics is illustrated in [Fig. 1.13](#). At this scale the landuse and permanent forest estate (PFE) plans are made as part of integrated regional development plans (Brüenig, 1961b; Glauner, 2000/2002).

#### 1.4 Large- and Medium-scale Dynamic Changes of MDF at Large and Medium Spatial Scales

Plate tectonics, geomorphological changes and climatic fluctuations during the Tertiary and Quaternary have affected the floral, faunal and vegetational evolution of the rainforests. Tree pollen spectra of the equatorial TRF zone show evidence of climate-related changes of the vegetation (Livingstone and Hammen, 1978; Flenley, 1979, 1988, 1992; Newsome and Flenley, 1988; Heaney, 1991; Taylor, 1992). Today, the SEA–Pacific archipelago is important for both its remarkably rich biodiversity and globally significant roles in atmospheric and oceanic circulation. Despite the fundamental importance of environmental history for management of diversity and conservation strategies today, there is little primary evidence concerning the nature of vegetation in north equatorial SEA during the Last Glacial Period (LGP). As a result, even the general distribution of vegetation during the Last Glacial Maximum



**Fig. 1.15.** Structure and depth of the root systems in relation to tree species and soil. Surface feeder roots often form dense litter/root mats (lithosol, histosol, shallow to giant podzol, and transition to arenosol or humult ultisol). The big, deep reaching tap root is of *Agathis borneensis* Warb., which on giant podzol may reach deeper than 5 m. Strong tap and sinker roots occur in all sufficiently friable soils especially in more sandy humult ultisol or ferralsol/acrisol, and less on udult ultisol clay and gleysol. Dense feeder roots develop also at greater depth if stimulated by water and nutrients. Sinker and feeder roots also develop along structural clefts in blocky clay soil, pass through soft parts of the Bh in podzols and penetrate in rock cracks deeply into the substrate. Wide-spreading lateral roots stabilise the tree by pulling against swaying wind forces, especially effectively if joined to buttresses (e.g. *Shorea albida*) and grafted to roots of other trees. Variation between and within species and between sites is great. Compiled from profile descriptions, windthrows and observations along road cuts by the author.

(LGM) is still debated. Wurster *et al.* (2010), using the stable carbon isotope composition of ancient cave guano profiles, found that there was a substantial forest contraction during the period of the LGP on both Peninsular Malesia and Palawan, while the rain-forest area was maintained in northern Borneo. These results directly support hypotheses that Borneo provided “refugia” and provide evidence that environmental barriers may have obstructed genetic mixing of flora and fauna at gamma-diversity level between Borneo and Sumatra. Moreover, it sheds some light on possible early dispersal of plant species by humans.

A general picture emerges of fairly rapid changes of vegetation associated with increasing or decreasing temperature and, independently, precipitation, and of altitudinal and lateral shifting, shrinking and

expansion of the areas inhabited by the TRF and its subdivisions. Tectonic movements, erosion and sedimentation have created a typical diverse and heterogeneous array of site and soil conditions that continue to evolve – accordingly the forest vegetation is diverse and dynamic (Section 1.5). The TRF has survived very drastic climatic and dramatic geomorphological and tectonic changes effectively by evasion (shifting site location), adaptation and autogeneous restoration after natural disasters. A well recorded disaster is the Krakatoa explosion and submergence in 1883, followed by emergence of several small islands, natural primary succession, diverse and localised disturbances, unpredictable deviations of succession into unpredictably island-specific and spatially heterogeneous floral and faunal biodiversity in the 1990s (personal communications from

German scientists studying this phenomenon). Richards (1996, Chapter 13, p. 341) describes these rather complicated and not uni-directional primary successions after the 1883 catastrophe on the three new small islands in great detail. He presents two diagrams after Whittaker *et al.* (1989) for the three islands, demonstrating this variable course and adds in the caption “On Krakatoa the primary succession has been interrupted only by minor disturbances (landslides, etc). On the other islands the development of vegetation has been interrupted since 1931 by damage due to the new eruptions of Anak Krakatoa.” If the general stochasticity of seed invasion (microorganisms) is considered together with the stochasticity of different kinds of changes, fluctuations, disturbances and perturbations, and the intrinsic principles of stochastic mathematics, indeterminism and uncertainty in the universe from nuclear level upward, a bewildering diversity of possibilities results. Obviously, the TRF has survived all these environmental oscillations and geomorphological changes fairly well, being given sufficient time to repair, recover and restore. It was affected by interferences from light perturbation to heavy disturbance by hunters and gatherers from 400,000 BC and very early shifting cultivators from 40,000 BC to the end of the LGP. These human interferences are documented by archaeological evidence, for example by the excavations in and around Niah Cave in the Niah National Forest in Sarawak (Stimpson, 2012), but not by any differences in taxonomic or physiognomic structure of the present pristine, primary forest on the site. I had assumed simply from the geological tectonic history of the Sunda region that at least some of the Bornean lowland MDF rainforests may have remained stable during the Pleistocene/Holocene epochs, unmolested by man and nature over a hundred million years until fairly recently, and that some lowland areas carry truly pristine virgin MDF. I assumed that their dynamics of faunal and structural composition fluctuated only at the spatial and temporal scales of the regeneration cycle of the TRF. But the results of archaeological research indicate

that there was much more dynamics at large spatial scale and also more impact by early man than I had previously assumed, for parts of northern Borneo. For example, the TRF of the Kayan Mentara Nature Reserve, Kalimantan, generally appraised as virgin or pristine forest, was the habitat of the tribal Ngorek people more than 400 years ago, as shown by huge scattered burial jars (urns) (Sim *et al.*, 2004). The extensive black earth and charcoal in the Amazon and Congo basins also point to very early massive tool- and fire-supported disturbance of the TRF by man. Figure 1.13 gives a generalised schematic illustration of the distribution of broad forest types in relation to landform created by tectonic uplifting or subsidence in Sarawak. The relationship between structurally distinct upland forest types in the Amazonian rainforest is very similar, except for the absence of large tracts of oligotrophic peat swamp forests, and the presence of high-altitude plateaux (Tepui) at its northern fringe, Conan Doyle’s “lost world”.

Pollen spectra of various deltaic peat swamp forests in Sarawak (Anderson and Müller, 1975) showed rather similar primary-successional changes of floristic structure that correspond to the sequence of the phasic communities on the present peat swamp surface. However, this view has been questioned recently by Yamada (1995; Section 6.5). In contrast, exploratory pollen analysis of kerapah peatbogs on terraces of Holocene (Dalam Forest Reserve near Miri) and Pleistocene (Gunung Mulu National Park) origin and on a Tertiary high plateau (Merurong Plateau at 730–1125 m a.s.l.) showed no regular pattern, but there were differences between the locations and erratic changes of species composition in the profile, including disappearance and reappearance of species that are difficult to explain. The indication is that the present pattern of species distribution and the presence or absence of regeneration are poor indicators of the direction of stand dynamics. So many site and chance factors interact in the kerangas/kerapah forests in such a diverse manner that no consistent picture of species distribution, association and succession manifests itself in the pollen diagrams and in the living vegetation (Bruenig, 1966, 1974;

Proctor *et al.*, 1983a; Newbery and Proctor, 1984; Newbery, 1991). In the peatswamp forests and some kerapah types, the long-term dominance of one actively peat-forming, competitive tree species over large tracts may create natural monocultures that maintain themselves over many thousands of years. The single-species dominance of the very site-tolerant and aggressively competitive *S. albida* Sym. in the peatswamp forests in Sarawak is the best-documented example (Anderson, 1961a). Gap formation caused by lightning and windthrow and large-scale catastrophic collapse caused by an insect pest (so-called ulat bulu, hairy caterpillar) are very common (Figs 1.3 and 1.4; Section 6.7).

Fire is, in contrast to previous views, being recognised as an ecological factor in primeval rainforests (Goldammer and Seibert, 1989). On the easily drying Bornean kerangas and Amazonian caatinga soils, episodic droughts make the forest susceptible to spontaneous or human-induced fires. Examples are the fires in Sabah and Sarawak around 1880–1890, 1930–1933, 1958, 1983 and 1991. Vegetation recovers rapidly after an initial fire by coppicing and seed germination. Nutrient losses cease within a year or two, as the studies in San Carlos (Jordan, 1989) and Kalimantan (Riswan and Kartanawata, 1991) showed. Repeated fires consume the SOM and eventually reduce the ecosystem to a temporarily arrested state of degradation such as the white-sand savannah described from Surinam (Heyligers, 1963), the Bana in Amazonia, or the various types of Padang in Malesia (e.g. Bako National Park; Bruenig, 1961a, 1965b). Equally fire-prone is limestone vegetation, such as the sclerophyll, xeromorph woods on Gunung Api (Fire Mountain) in Mulu National Park, Sarawak (Bruenig, 1966). Rainforest on deep clay soils, slopes and valley bottoms, and riverine freshwater swamp and alluvial fringe forests do not dry out easily. If fires occur, they are usually light and quickly followed by regrowth of the original type of forest. Shifts of climate towards greater aridity or stronger irregularity may cause fire risk where the forest is opened and fragmented by expanding customary high-impact selective logging, timber mining, shifting cultivation and agriculture. Since the 1940s

to 1960s, there has been an increase in the severity and frequency of drought events and the number of associated damaging fires in the rainforests of Ghana (Orgle *et al.*, 1994). Another complex of factors possibly affecting variation and change are natural and anthropogenic atmospheric pollutants and nutrients, which enter the ecosystem in the form of trace gases, aerosols and solid substances, affecting the productivity and health of the rainforest ecosystem.

As a result of the natural life cycle of trees and the various perturbations and disturbances, the taxonomic structure of the rainforest is not static but variable at small to medium spatial and temporal scale; catastrophic collapse may be caused by the synergistic interaction of several internal and exogenous perturbing factors; species spectra, species richness and diversity are not constant but change in response to short- to long-term disturbances; locally, plant and animal species may become extinct, as indicated for trees in kerangas pollen profiles, but may reappear; constant changes of the floristic and spatial structure of the ecosystem seem to improve its resilience, adaptability and flexibility, while simple natural “monocultural” forests are more vulnerable to persistent damage. Knowledge of the history of changes helps to understand the present capacity for change. The comparison of the present vegetation with pollen profiles in kerangas peats and peatswamp forests have proved to be useful indicators of the forest dynamics (Anderson, 1961a; Wood, 1965; Bruenig, 1966; Müller, 1972; Anderson and Müller, 1975). Alan (*S. albida*) may invade into peatswamp forest phasic community PC1 and ramin mixed peatswamp forest, and initiate succession to PC2, 3 (Alan Consociations) and PC4 (Padang forest and woodland). Kerangas forest species may successfully invade MDF, survive and initiate raw humus formation and greying of surface soil, in extreme cases even pan formation. The raw humus-forming *Casuarina nobilis* Whitm., trial planted in 1939–1940 on a patch of sandy clay-loam ultisol/acrisol in 6th Mile Forest Reserve near Kuching, had produced several centimetres of raw humus and caused considerable bleaching of the surface soil to 5–10 cm depth by 1954–1955.

In Sampadi Forest Reserve a single large *C. nobilis* was found in MDF in kerangas RP 12 (Fig. 1.9). Possibly a surviving gap coloniser, the tree had similarly accumulated a wide disc of thick raw humus-root mat and initiated topsoil greying (Bruenig, 1966, 1974, pp. 20 and 65). On the plateau of the present Bako National Park, MDF was cleared in the mid-19th century by the local communities to grow the tannin-rich gambir, *Uncaria gambir* Roxb., for the production of catechu, cutch and betel leaves (Burkill, 1935, vol. II, pp. 2198–2204). The sandy clay-loam ultisol/acrisol degraded quickly, cultivation was abandoned and a secondary medium-deep humic podzol under a typical tall kerangas forest had developed by 1955. By this time, MDF species began to invade but did not look very healthy (kerangas forest RP 17; Bruenig, 1966, 1974). The examples show the risk to sustainability if the natural dynamics of the forest and the species–site interactions are not well considered. Newbery and Proctor (1984) hypothesise that the highly dynamic nature of the rainforest makes it likely that soil properties change in the course of gap formation and regeneration. Revitalisation of the soil biology, mineralisation of moder and formation of mull during the natural-regeneration gap-phase is well documented in beech and spruce forests in north-west Germany. It would seem plausible to assume that similar effects happen in TRF, particularly in large gaps into which pioneer (early secondary forest) species invade. The general features in TRF of long-term patch patterned soil and vegetation dynamics, originating in the initial micro-heterogeneity of soil and terrain conditions and modulated by gap formations of variable kinds at different spatial scales and temporal frequencies, are very similar to those described in semi-deciduous tropical forests (Taylor *et al.*, 1995) and basically similar to the processes well known and traditionally used in forestry practice of naturalistic silviculture in mixed temperate forests.

GCC, as warned by climatologists and forestry scientists in Germany since the 1970s, has as its most threatening component the increase of severity and frequency of seasonal and episodic events of extreme weather. Thereby, GCC will fuel the dynamics of

forest ecosystem processes, not to the benefit of foresters and society, as we can already witness in some parts of the world. The increased frequency and severity of episodic events of extreme droughts, storms, floods and heat will affect the rainforest ecosystem's health and capacity to repair damage.

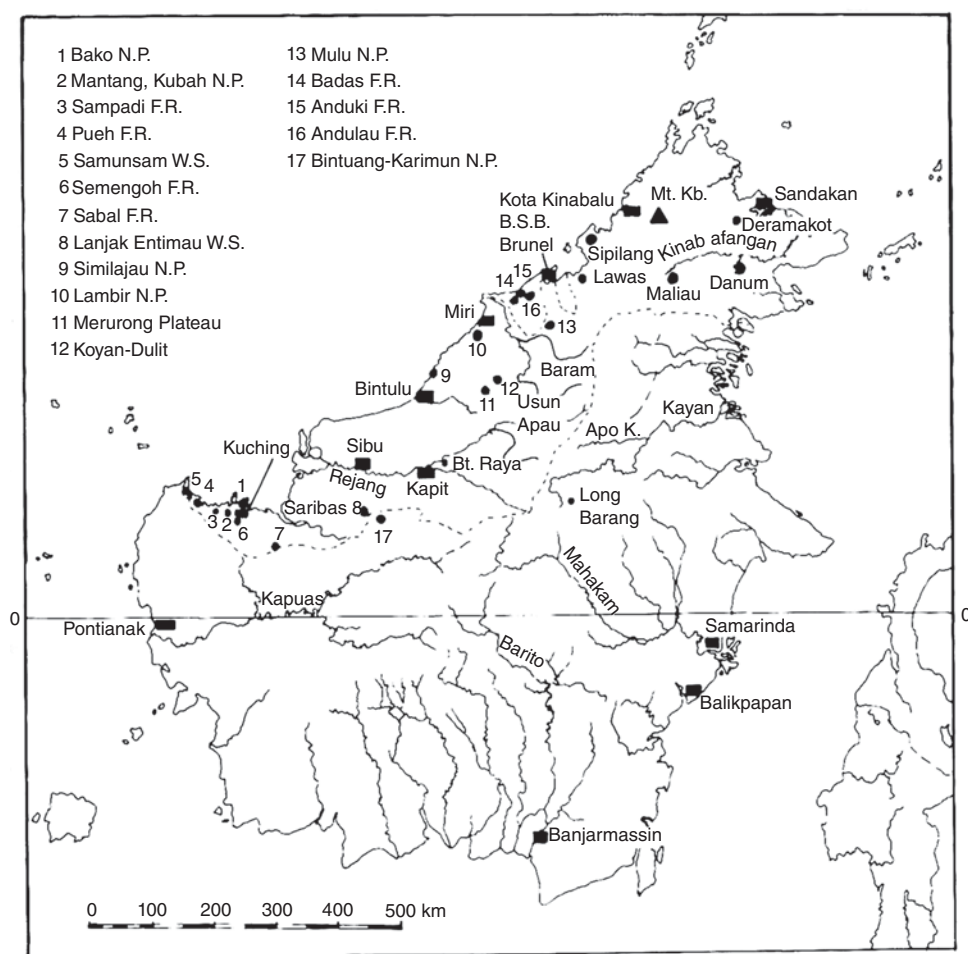
## 1.5 Rooting Sphere

The impertinent classical myth of the habitually shallow-rootedness of TRFs has been finally discredited and is now safely dead. It is now generally accepted that tropical trees develop their root systems opportunistically as soil and parent material permit to maximise supplies needed for growth, to minimise risks of damage during drought and generally to reduce risks of damage and deficiencies. Similar to temperate forest trees, the root systems of tropical trees may be shallow or deep, spreading or compact, or a combination of shallow surface roots, medium-deep spreading roots and deep tap roots, or sinker roots from wide-spreading horizontal roots, depending on the needs arising during their specific life cycle as short-lived pioneer species in gaps or successional communities, or long-lived A-storey species, or D/B-storey species in TRF. The main, but not exclusive (Fig. 1.14), habitat (rhizosphere) of the roots of trees and other plants is the soil including the litter layer (pedosphere) and decaying trees. Arboreal epiphytes and habitually soil-rooting epiphytes, such as strangler figs, have roots in the canopy. Some tree species may develop epibiotic roots from the trunk or root upward from the soil to supplement deficiencies in the edaphic water and nutrient supply. In rainforest, as in temperate forest, roots penetrate into the rotting heart of live or dead standing trees, into the decomposing heart and inner bark of fallen tree trunks, or grow downward or upward among lichens and mosses on bark surfaces to scavenge nutrients and water. If there is opportunity, roots penetrate deep along clefts of otherwise impenetrable clayey subsoil or parent material to supplement supplies. Road cuts are ideal observation sites. The intrinsic tendency to develop deep-reaching tap roots

can be observed in any germinating seed and healthy seedling of tree species which habitually form the A-layer of the canopy of pristine rainforest.

As in temperate tree species, the architectural structure of the root systems of TRF trees differ between species, but also necessarily vary within a species according to rootability and attractiveness of the soil. Light conditions are also important. A light-demanding A-storey species will form a more spreading and shallower root system if growing in the shade of the D-storey of a closed natural forest than in the open sun on excavated soil at the logging roadside or in

timber-mined areas. The variety of shape and depth of rooting systems is consequently as great as the variety of crown forms (Fig. 1.15). Soedjito (1988) describes the root system of 40 saplings (diameter 3.0–4.5 cm, height not reported but probably 3.5–6 m) of 40 species in lower montane MDF near Long Barang, East Kalimantan (Fig. 1.16). The root systems are medium-deep and wide-spreading (e.g. *Macaranga* spp., *Ficus tamarans*, all secondary-forest species) or a combination of shallow surface roots, intense medium-deep rooting and deep-reaching tap roots (*S. parvifolia*, *Agathis dammara*, *Baccaurea macrocarpa*, *Nauclea subdeta*). The tap root depths



**Fig. 1.16.** Locations in Sarawak, Sabah, Brunei Darussalam and Kalimantan that are mentioned in the text. Sabal is Sabal Forest Reserve containing the >600 ha RP 146, which has the highest species richness per hectare recorded in Borneo (Droste, 1995).

of the saplings vary from 35 cm (C–D-layer subcanopy species) to 55–60 cm (*Shorea* and *Agathis*, A-layer species). For saplings of this size and growing in shade, this cannot be considered shallow-rooted.

In the rainforest soils of the CERP-MAB Ecosystem Study Project in Bawangling the carbon content, base saturation and c.e.c. are relatively high in the Ah horizon (the top soil horizon) and decline markedly with soil depth but, depending on soil types, carbon contents and mineral nutrients, can still be high below 2 m (Kehlenbeck, 1993, pp. 84–103). This would be an incentive for roots to penetrate into these soil layers. Rooting in 17 profiles of 13 major soil types was observed right to the bottom of the 1.5–2 m deep pits. Deep fresh road cuts outside the research area showed roots penetrating as deep as 10 m in friable, porous soils in dipterocarp-bearing forest and lower montane oak–conifer forest. In Sarawak, over 200 soil profiles in the 57 kerangas research plots showed a close correlation of rooting depth with soil texture and drainage. Rooting depth ranged from 25 cm in shallow humus podzol and gleysol to over 5 m in deep humus podzol (DHP) (Bruenig, 1966, 1974, pp. 75–76, Table 6; [Fig. 1.15](#); [Table 1.5](#)). In the sandy soils of kerangas tree

roots are more strongly concentrated in the Ah and Ae horizons (Ae is the eluvial part of humid top A horizon of the soil between the organic-matter accumulating Ah and the eluvial, leached mineral B horizon) than in sandy humult ultisol soils of the MDF. Few roots penetrate into the Band C horizons of kerangas soils except in DHP and sandy RYP (red-yellow podzolic, or humult ultisol/acrisol) soils. Strongly tap-rooted species, such as *A. borneensis* Warb., reach as deep as 3–5 m into the B and, more rarely, into the C or D horizon. These roots are probably important generally for nutrient catching, but especially for the water supply during episodic droughts. On the same site, the stilt-rooted, extremely sclerophyllous and xeromorph *C. nobilis* Whitm., in mixture with the microphyllous *A. borneensis*, has a much shallower but wide-spreading root system. In MDF, roots penetrate even deeper and can still be observed at 7–10 m depth in road cuts. Rainforest trees, as trees in other climates, grow their roots where they find the conditions to do so. Wherever the soil and the weathering parent material are physically penetrable and chemically and hydrologically attractive, roots will grow. Germinating seedlings rapidly develop a vigorous tap root with a brush-like collar of

**Table 1.5.** Water availability, wilting point and rooting depth in different soil types have been estimated for typical soil texture and soil organic matter content. Transpiration rates accord with those in Section 1.7, and decline with gradual drying of soils. Water stress is assumed to begin when the soil water potential can no longer be overcome to extract sufficient amounts of water to maintain leaf activity and temperature adequately. The estimated length of rainless periods required to create water stress in natural site-adapted 101 is a useful guide for matching of tree species, stand structure, silvicultural system and site conditions in mixed dipterocarp forest (MDF) on humult and udult ultisol/acrisol, in kerangas forest (KF) on shallow, medium and deep humus podzol and in kerapah forest (KrF) on stagnic gleysol overlain by a thin peat layer. Values are recalculations of Tables 3 and 4, Bruenig (1971a), with new data on the structure and depth of the root systems (for rooting depth see [Fig. 1.15](#), for forest structure see [Fig. 1.11](#)).

Forest	Soil	Field capacity (%)	Wilting point (%)	Rooting depth		Plant available water		Sum (mm)	Dry days to persist water stress
				A (cm)	B/C (cm)	In soil (cm)	Biomass (cm)		
MDF	Humult ultisol/acrisol, sandy loam	24	6	50	600	63	2	650	>100
MDF	Udult ultisol/ferralsol clay	46	26	30	400	40	2.5	425	>70
KF	DHP sand/gravel	20	1	30	300	20	2.5	225	50
KF	MHP sand/gravel	24	2	25	120	15	2	170	33
KF	MHP sand/sandstone	26	2	20	60	10	1	110	25
KF	SHP sand/sandstone	26	2	15	30	5	0.5	55	15
KrF	PGL gleyic clay	32	20	20	60	7	0.7	77	20

nutrient-feeding roots in the F-layer and SOM-rich surface soil layer. These 10–30 cm long tap roots often die during prolonged periods of water saturation and regrow when the water level subsides.

Thick and dense root mats, intricately mixed with decaying litter and raw humus, can be found on almost any soil type. In MDF on ultisol/acrisol they are small, patchy and usually confined to the base of large decaying trees. They cover the surface in extremely oligotrophic peat swamps and on humic podzols, on lithosols, on limestone karst or quartzitic sandstone, and also on some very dense or rocky oxisol/ferralsol soils. Nutrients in the dead organic matter are efficiently recycled and losses to the hydrosphere are very small (Jordan *et al.*, 1980; Jordan, 1985). Within the root mat and the Ah horizon of kerangas soils, Schmidt-Lorenz and von Buch found abundant ectomycorrhiza, leguminous and non-leguminous (*Podocarpus* spp., *Falcatifolium* spp.) nodules and animal faecal pellets (reported in Bruenig, 1966). The proportion of root biomass in the total living tree biomass generally seems to increase with decreasing fertility/productivity of the soil in TRF (Klinge, cited in Kurz, 1983). The same is well documented for forests in Germany (e.g. Vavoulidou-Theodorou and Babel, 1987). In TRF the root biomass as a proportion of total biomass is about 10–15% on heavy clayey soils well supplied with water, and 15–20% on average loamy-clay oxisols and clay-loam ultisols. It increases with increasing sandiness and unfavourability of soil conditions and reaches 50–60% on very adverse sites such as the bana in San Carlos de Rio Negro. A possible explanation is that the roots function as a reservoir of nutrients and water (Klinge cited in Kurz, 1983). The heavy weight of the intricately bonded fine-root mineral soil/SOM complex, together with a low height/diameter ratio, makes the trees wind resistant.

The dogmatic myths of shallow-rootedness and of lack of litter and humus in TRFs have in the past obscured the view of researchers to recognise the ecological importance of the protective and conserving layers of litter and humus, or litter, moder and raw humus. Equally, the existence and role of diversity of

structure of rooting systems was overlooked far into the 20th century. An adaptable rooting system in TRF, reaching as deep as possible, is essential for nutrient and water preservation and supply, and to provide for emergencies, such as prolonged droughts, episodic events in TRF as in tropical dry and in temperate forests. The myth of litter/humus-void and shallow-rooted TRF has also contributed to the doctrine that almost all nutrients are stored in the above-ground living biomass. But, as Whitmore (1990) points out, in many TRFs most nutrients are fairly evenly divided between above- and below-ground live and dead biomass. This may even apply to extremely oligotrophic conditions, as in kerangas, caatinga and peat swamp forests, if the compartments' root mass and SOM are relatively large and substantial, as they generally are. It is therefore wrong to assume that all fertility rests in the living biomass and in the very top soil horizon (Ah), that it cannot be restored once the phytomass and topsoil have been disturbed, and then to deduce that there is no possibility of sustainable forest management if it involves removal of tree biomass. In reality, not only are the physical, chemical and biological conditions of the humus layer and surface soil amenable and crucial to sustainable forest management, but so are the structure, SOM, nutrients and rootability of the deeper soil layers. Forest management in natural forests therefore should retain the spectrum of natural tree species with site-adapted diverse and adequate rooting systems and litter production. In planted forests, mixing tree species with diverse litter quality and rooting habits should secure full utilisation of the rootable soil volume and adequate SOM quality and quantity.

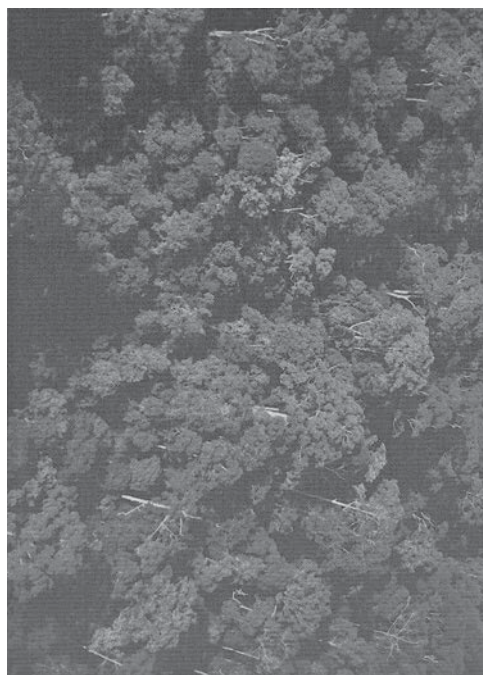
## 1.6 Tree Crowns and Canopy: Physiology/Structure and Functions

Potential sources of stress in TRFs are chronic scarcity of nutrient reserves in the intensely weathered parent material, and diurnally recurrent and unpredictable episodic heat load and water deficiencies in the leaves. The frequency and severity of episodic climatic extremes vary strongly between localities. Their

effects on energy and water balance vary according to soil and site types (Bruenig, 1966, 1971a). If this is so, there should be differences in the physiognomy of the natural forest canopy between sites that could be explained as risk avoidance or risk reduction with respect to nutrient loss and damage from heat, drought or supersaturation. Natural canopy differences of physiognomy between sites are important indicators of the most crucial ecological needs and the most feasible silvicultural strategies of coping with them, especially with climatic and nutrient stress. Foresters should respect this and need sound information from their own discriminating observation and from canopy research (Bruenig, 1970a, 1984c, 1986b, 1991b). The classic, theoretical and experimental work of Denmead (1964), Gates (1965, 1966, 1968), Kung (1961), Lemon *et al.* (1969), Monteith (1963) and Reifsnyder (1967) provided information for interpreting the ecological significance of the differences in rooting, of the physiognomy of the canopy and of the morphology, chemistry and physiology of leaves in zonal TRF and in kerangas in Borneo and in evergreen caatinga in Amazonia (Bruenig 1966, 1969a, 1970a, 1971a, 1976; Bruenig *et al.*, 1978, 1979). These xeromorphic, partly sclerophyll forests growing under ecologically more taxing conditions than the “zonal” forests, are forced to adapt more rigorously to stresses and thus correlations can be more easily observed. Regulatory mechanisms are more obvious and can be studied more easily than in the “zonal” forests. The general conclusions (Bruenig, 1966, 1970a; Bruenig *et al.*, 1979) are that the canopy of the TRF is naturally adapted and can be silviculturally manipulated in a manner that reduces the effects of site-specific stresses and the risks of damage, but at the same time permits the trees to exploit fully the more favourable conditions during average situations. Following public preferences and demands of political correctness, canopy research in TRF has in recent decades favoured the ecologically important animal compartment, biodiversity and neglected ecosystems aspects.

The architectural structure of the crowns and of the canopy of crowns determines aerodynamic roughness of the canopy surface (micro- and macro-structure of

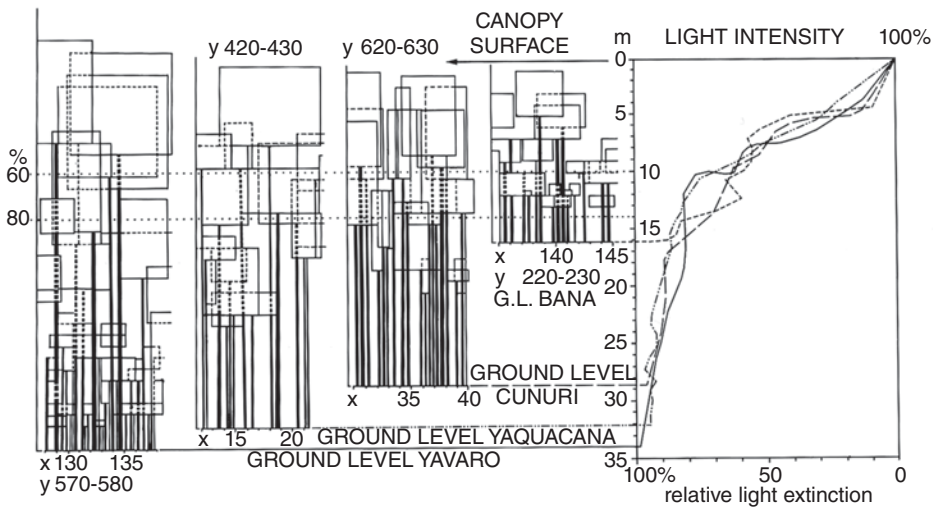
canopy); affects the interception of radiant energy, air moisture and air pollutants; and regulates free and forced convection, wind interception and air turbulence. The aerodynamic roughness and shape of the typically “cauliflower-” or “ravioli-” shaped A-layer crown, the bunched or more diffuse leaf distribution and leaf orientation determine ventilation, energy interception, radiative load distribution, transmission of light to the lower canopy layers and the ground, and up and down transmissions of sensible and non-sensible (latent) heat. In this way, the floristic and structural architecture of the forest, especially of the A- and B-layers, is a decisive contributor to the conditions which determine biodiversity, and close-to-nature silviculture – which provides a complex stand and canopy structure – is the most rational and efficient tool to promote species richness and biodiversity (Fig. 1.17).



**Fig. 1.17.** Canopy of mixed dipterocarp forest in the Mulu area from above. The great richness and diversity of form and species in the canopy enables rapid reaction ('chaotic swinger' type) and reduces the risk of damage from biotic and abiotic factors. Reproduced courtesy of Peter Wee.

But little research has been done on this. The leaf morphology, its more or less xeromorphic or sclerophyllic shape and its chemistry and optics affect energy transmissions and absorptions, and consequently transpiration rates, heat and drought resistance (Fig. 1.11), accessibility of organic matter and nutrients as food to consumers and decomposers, and the humus-forming properties of the litter (Fig. 1.9; Section 1.7). The structural similarity of tree crowns in the A- and B-canopy layers of tall, species-rich complex zonal rainforest, and the whole canopy of the lower, simpler forests on podzols and related unfavourable soils, is paralleled by the similarity of light extinction (Fig. 1.18). The corresponding brightness at ground level of the poorer types of kerangas and caatinga forests explains the relative ease of regeneration by a natural shelterwood system which would not work successfully in the very differently

structured MDF or tierra firme forests. The main problem of regeneration in kerangas and caatinga forests is not light but episodic water supply deficiency, which can cause drought strain and mortality among regenerating trees (Becker and Wong, 1993; Dalling and Tanner, 1995) and in severe cases also among upper-canopy trees (Woods, 1987; Section 1.7). In MDF and related African and Neotropical forests, the light conditions in the D-layer and on the ground are more decisive for success of regeneration than the water supply situation, but episodic severe droughts and even the common sporadic moderate droughts which develop during frequent rainless periods of from 2 weeks to 2 months can affect A-storey seedlings severely, and become causal factors for failure of natural regeneration, particularly on soils with unfavourable water balances and dynamics (Bruenig, 1971a).



**Fig. 1.18.** Stand profile along a gradient of declining quality for plant and microbial life and growth of chemical, physical and hydrological soil conditions as shown in Fig. 1.11, top. The 'structural tree species' of the A-layer and the upper part of the B-layer monopolise and regulate the major processes in the forest ecosystem of primary production, evapotranspiration and energy partitioning. Up to 80% of the incoming direct and diffuse light is intercepted in the canopy of the structural tree species (above the approximate 80% levels). The stand profiles are computer prints from field data of the International Amazon Ecosystem Study at San Carlos de Rio Negro. The crown rectangles represent measured or visually estimated crown length and average diameter. Extinction curves from Heuvelink (1978). Yavaro, *Eperua purpurea* Benth.; yaquacana, *E. leucantha* Benth.; cunuri, *Micandra sprucei* Benth., which are characteristic species differentiating and dominating the respective forest type (association group according to Bruenig et al., 1978).

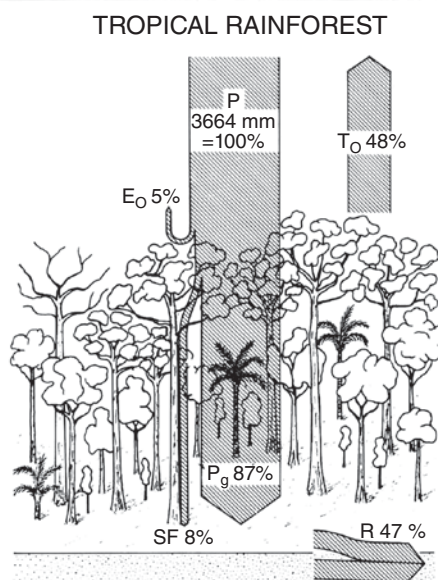
### 1.7 Hydrology, Nutrients and Pollutants

Forests affect atmospheric and edaphic moisture and the hydrological conditions of the site by the stature (height), structure (roughness) and leaf physiognomy of the canopy, the structure of the root system, and the physiological features of the absorption, utilisation and output of water by the trees. The observed changes of canopy and roots along ecoclines (Figs 1.11 and 1.15) suggest that the natural primeval rainforest is structurally adapted to the climatic, edaphic and atmospheric conditions of the site, especially to episodically occurring extreme events. Figure 1.11 illustrates the general trend of change along the two catenas MDF – kerangas forest (KF) and kerangas–kerapah forest (KrF). This catena is structurally analogous to the Amazonian catena mixed upland forest (TF)–caatinga forest (CF)–Bana woodland (Bruenig *et al.*, 1979); the corresponding ecocline lowland-montane, oxisol-podzol in Bawangling, Hainan (Bruenig, 1986a; Bruenig *et al.*, 1986c); and the peat-swamp forest sequence of the phasic communities PC 1–6 according to Anderson (1961a). With increasing adversity of site, especially high risk of alternating drought and water saturation, the aerodynamic roughness of the canopy decreases, while sclerophylly and xeromorphy increase. In kerangas and caatinga forests, crowns are smaller and the leaves more sclerophyllous, coriaceous and smaller than in sclerophyll/mesophyll MDF and TF.

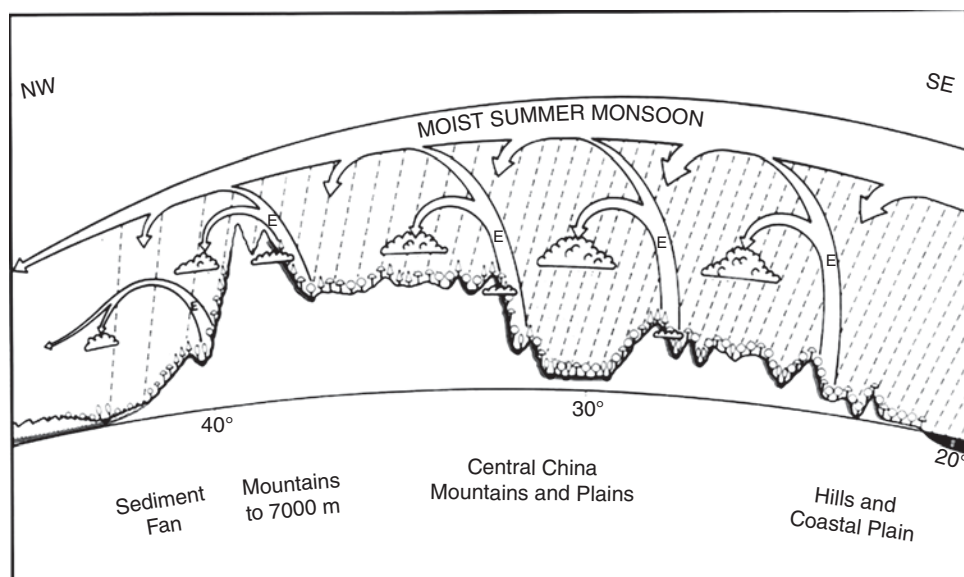
However, as adaptation to site can be achieved by different combinations of the various adaptive features, variability and overlap are wide (Bruenig, 1970a). Classification of forest and woodland vegetation in the MDF–KF and TF–CF complexes by leaf size spectra alone is not generally feasible (Newbery, 1991) in spite of obvious and visible physiognomic trends (Huang and Bruenig, 1987). This diversity of adaptive features offers a range of opportunities for designing site-specifically adapted canopies with certain microclimatic and physio-ecological characteristics for sustainable naturalistic silvicultural management in artificially established (planted or otherwise)

forests, and for water catchment management (Bruenig and Sander, 1983).

The soil in TRFs has a typically high infiltrability. The humus-rich, porous soil surface absorbs rainfall very rapidly. Overland water flow occurs only during extremely heavy and intense downpours or after the soil has been saturated, but then it can be substantial and cause erosion and flash-floods. Heuvelink (1978; Figs 1.19 and 1.20) in San Carlos, and Sinun *et al.* (1992) in Danum Valley showed that, for an annual non-seasonal rainfall of 3600 mm (= 100%), about 12–17% was interception



**Fig. 1.19.** The water balance in the zonal lowland rainforest on oxisol in the MAB International Amazon Ecosystem Study, San Carlos de Rio Negro, Venezuela. Rates of input, throughput, output and runoff of water are high. The high transpiration rate reflects high rates of net radiation, canopy roughness, the 'giant wick' nature of the emergent (A-layer) and codominant (B-layer) crowns, and high water-holding capacity of the soil. Interception and evapotranspiration are lower in the low-stature, simple sclerophyllous and xeromorphic caatinga and kerangas on shallow soils with low water-holding capacity;  $ET_o$  may be as low as 30% at the right hand of the catena in Figs 1.11 and 1.18.  $P$ , precipitation;  $P_g$ , precipitation reaching the ground;  $E_o$ , evaporation from surface;  $T_o$ , transpiration from plant surface;  $SF$ , stemflow;  $R$ , runoff. From Heuvelink (1978).



**Fig. 1.20.** Macroclimatic hydrological cycle South China Sea–Hainan–Mongolia. The basic feature of the “atmosphere–forest–atmosphere” hydrological cycle at macro-scale during the south-west monsoon: sea–atmosphere–rain on seasonal TRF (Hainan)–atmosphere–rain on Deciduous Tropical/Subtropical/Temperate Forest (Chinese mainland) – Semidesert Scrub and montane forest types (Inner Mongolia) – Desert (Inner Mongolia and Mongolia). The return of humidity by evapotranspiration from the pristine forest canopy is maximised so that deforestation or conversion will weaken the cycle. Some of the possible effects on TRF of unpredictable oscillations of climate and GCC and episodic extreme climatic events also appear to weaken the cycle and have generally undesirable ecological consequences along the whole catena, especially at its southern and northern ends (from Bruenig, 1973a, Chapter 1).

loss, 80% direct throughfall, 2–8% stem-flow and 2–3% direct overland flow. Of the 82–88% precipitation reaching the ground, about 97% infiltrated into the soil. Infiltration measurements in very deep, porous, humic soils in the CERP-Tropical Forest Ecosystem Study at Bawangling, Hainan, showed that even a very heavy typhoon downpour will be absorbed instantaneously, until the soil becomes saturated, when overland flow occurs (unpublished research data of the Institute of Forest Hydrology, Hann-Münden, 1990, and final project report to the Ministry of Research and Technology, Bonn, 1991). Destruction of soil structure and loss of porosity at the soil surface reduce the rate of water infiltration and increase the rate of water which runs off as overland water flow. This happens on skidtrails and logging roads on part of the area; careless heavy logging (timber mining) and deforestation extend this to the whole area.

In addition to mechanical damage to the soil on skidtrails and roads, the exposure of the soil surface to the free-falling raindrops clogs the surface pores of the soils. Consequently, the rainwater cannot infiltrate and runs off as surface flow, causing erosion and further clogging of soil pores.

Bruijnzeel (1987) calculated broad global figures for the case of lowland TRFs, which never experience soil moisture shortages (as determined by the water balance method). He calculated an average annual evapotranspiration rate of  $1460 \text{ mm} \pm 27\%$  (SE), a canopy interception capacity of  $14 \text{ mm} \pm 2\%$ , which I consider to be on the low side, and an average of 1–2% of the precipitation as stemflow after the interception capacity has been saturated. This is within the range of values reported by Heuvelink from measurements in the International Amazon Ecosystem Study at San Carlos de Rio Negro. He calculated the annual rate of evaporation

from the ground in the zonal TRF (tierra firme forest) as 183 mm, the evapotranspiration from the canopy as 1759 mm and the runoff as 1722 mm (Fig. 1.20). New data have since generally confirmed, not changed but sometimes refined, the previous knowledge.

Effective protection of the soil against loss of porosity and thereby infiltrability is essential to get as much as possible of the canopy throughfall and stemflow into the soil, and reduce the surface runoff which could cause surface erosion and valley flooding. The target is set for harvesting and silviculture: to maintain a protective, complex, vertically closed canopy with rich and ample leafage, and, as we have concluded in Section 1.3, ample litter fall to protect the soil surface, create ample SOM and maintain healthy soil biology. Containing and possibly reducing water runoff on the soil surface (overland flow) and thereby soil surface erosion require, besides porous, litter-protected soils and favourable terrain, above all an aerodynamically rough forest canopy with site-compatibly high leaf-area index and high interception capacity of leaf and bark surfaces. This offers large surfaces which permit high rates of interception, retention, evaporation and, after uptake by the tree, capacity for high rates of transpiration, high rates of potential and actual evapotranspiration. Mature TRF on average sites meets these conditions and has consequently lower surface-water runoff rates, but only to the limit of saturating the tree plant (leaves and bark) surfaces. This saturation may, in mature zonal TRF, happen between 7 and 14 mm rainfall, depending on stand physiognomy and tree surface area and condition. Beyond this saturation rate the trees and forests do not restrain surface water runoff (overland flow).

Curiosity made me record 2007 and continue until today, the rainfall amount, for each rainfall event separately, in my garden on Bukit Kajang (ca 100 m a.s.l.), 25 km southwest of Kuala Lumpur. The data confirmed my gardener's suspicion, that the bukit (hill) area is one of the distinctly and consistently drier patches in the meso-climatically heterogeneous TRF landscape. The average annual rainfall in the surrounding state of Selangor area is reported as 2600–3000 mm.

In 6 years, I measured frequently monthly deficits of 20–30% and annual deficits of the same order. In 2011, I measured a total rainfall of 1924 mm of which 1307 mm fell in rains >7 mm. My low estimate of interception in pristine MDF is 7–10%, in kerangas and caatinga 3–6%. Most of the intercepted rain will evaporate back into the atmosphere in 54 rainfall events. At least  $54 \times 7 = 378$  mm (25%) would have been intercepted in a pristine MDF, 929 mm (75%) would reach the soil surface. Of this, a small proportion would evaporate directly from the soil, about 1–2% in TRF, the rest runoff on the surface or infiltrate, depending on conditions. The infiltrated proportion would either be taken up by tree roots and returned to the hydrological cycle, or runoff as subsurface flow. The surface and subsurface flows could potentially cause soil surface erosion and subsurface erosion and leaching, depending on terrain and soil conditions. High-intensity rainfalls account for much of the surface soil erosion. In 2010 (annual precipitation (P) 2053 mm) six rainfall events were between 50 and 100 mm, 1 above 100 mm; in 2011 (annual P 1924 mm) the figures were 5 and 1, respectively; in 2012 (a P 2478 mm) 15 and 1, respectively. All these high-intensity rainfall events did not last more than 1–2 hours. All a pristine TRF or well-structured CNF forest can achieve is to scatter the throughfall and reduce the kinetic energy when it hits the soil surface. The 206 rainfall events with less than 7 mm P would be totally intercepted by the canopy and directly re-evaporate from the vegetation surface; the amounts reaching the soil surface in canopy gaps would be minimal.

These simple data may not measure up to conventional meteorological standards, but they show well enough the proportions of rainfall of varying amounts from 1 mm to 180 mm recorded events, falling in several minutes to about 12 hours, with maximum intensity of 60 mm in 30 minutes. The intense throughfall, much of it as enlarged drops from leafage and branches, some as stem flow, hits the soil with high kinetic energy and causes erosion, even below a litter layer. It is well known to foresters and hydrologists that even pristine TRF has no

chance of stopping surface soil erosion completely. Manipulation of the TRF canopy by customary selective logging (timber mining), or the conversion to plantation forest, will unavoidably increase the rate of throughfall – already high in heavy rains >50 mm/h in natural TRF – and reduce the kinetic energy of drops falling on the soil surface little, if at all, but may increase it at canopy heights >8–10 m, and thereby increase surface runoff and surface erosion compared to pristine or CNF-managed TRF on the same site. However, it reduces soil surface porosity substantially, thereby increasing soil erosion and surface water runoff. However, the myths that the balanced, closed TRF ecosystem has no or negligible soil erosion, and that tree planting stops erosion, are still alive in public and commonly traded as politically correct and effective currency in the media. One recently published example is: “trees serve... to provide watershed protection, to stop erosion...” (Gardiner, 2009). The reality is that trees and forests cannot stop erosion: they reduce it in pristine forests and may reduce it in well-managed production forests. The foremost requirements in sustainable forest management (SFM) in TRF are to abstain from overlogging; to contain damage to soil and drainage by skidding, skidtrails and roads; and to stop timber mining. Trees and forests can even increase soil erosion. Examples: the A-storey giant in pristine TRF with no B/C/D vegetation underneath, has a barren crown-size disc of rain-washed soil-and-roots. Another case: ecologically ill-designed, even-aged, uniform plantations have a closed canopy with 8–20 m empty space beneath, enough height for the canopy-intercepted and down-dripping large drops to achieve maximum speed again before hitting and splashing the soil surface with larger kinetic energy. Such plantations do not reduce erosion, but accelerate it.

The conclusion from 60 years of research by many ecologists, foresters and meteorologists, recorded in Sections 1.1, 1.2 and here in 1.7, and my own observations and measurements in practice and research, is that the TRF climate is neither uniformly tepid and humid in space and time, but

variable and oscillating in the short-term, fluctuating in the long term and changing in human terms. It is generally and at any time harsh and not always charitable to trees and forests. Nor does the pristine TRF offer harmony and balance, and full protection of the soil against leaching and erosion, but its great environmental function is to maximise actual evapotranspiration ( $ET_0$ ) and thereby maximise the local and regional hydrological cycle. Hence, tactical and strategic planning of silvicultural multifunctional management, forest protection, conservation and preservation strategies must first of all consider the interactions and interdependencies between climate (existing and predicted), the forest canopy physiognomy, stand structure and tree forms, if risk reduction and sustainability are to be realised.

One of the key tactical factors related to canopy physiognomy to consider when thinning and harvesting, and in strategic planning of forest canopy development, is the potential annual evapotranspiration ( $ET_0$ ) rate to be expected from the manipulated canopy in comparison to pristine rainforest, and in relation to the mean annual precipitation and its variance and extremes. The standard yardstick for estimating  $ET_0$  is the pan A evaporation. Under the climatic conditions of Kuching (Fig. 1.16) are class A pan evaporation of 1970 mm, the values of regression over sunshine hours 1740–2016 mm, the Penman equation 1800 mm or, amended by Monteith to account for canopy roughness, about 2000 mm. The calculation by the Holdridge formula, using forest stature and a supposed layering into seven (MDF) to four (simple KF) storeys (and assuming unlimited water supply, which, by ignoring the common occurrence of dry and droughty periods, is somewhat unrealistic and pushes the  $ET_0$  values upward), produced similar values for the potential evapotranspiration in West Sarawak (see Fig. 6.8):

1. Mixed dipterocarp forest (height >45 m, complex): 1700–2000 mm
2. Kerangas forest (height >40 m, complex): 1520 mm (height 35 m, moderately complex): 1000–1500 mm; (height <28 m, simple, smooth): 800–900 mm

3. Kerapah (height <25 m, simple, smooth): 740 mm
4. Mixed ramin peat swamp forests (MPSF) (PCI): 1800 mm
5. *S. albida* peat swamp forests
  - Alan (PC2): 1600 mm
  - Alan bunga (PC3): 1400 mm
  - closed Padang Alan (PC4): 1000 mm
6. Mixed Padang and open Padang (PC5 and 6): 800 mm and less.

Similar values would be obtained by the same calculation approach for the catena Tierra firme – between biome – High caatinga – Low caatinga – Closed Bana – Open Bana in the ecosystem research area at San Carlos de Rio Negro, Amazonia.

During the kerangas pilot study in Sarawak, a simple tentative model was constructed to simulate soil-water depletion during dry periods in MDF and KF research plots on deep, medium and shallow soils. The state variables were plant-available water in the biomass and soil (difference between field capacity and wilting point in the actually rooted soil space, Table 1.5) and moisture vapour saturation deficit. The rate variables were transpiration rates and increasing soil water suction tension or decreasing soil water potential. Differences of stomatal reaction between fast-closing mesophyll MDF tree species and slow-closing drought-accustomed, strongly sclerophyll tree species of the KF were considered by different rates of transpiration reduction as water potential in the soil decreased. Rainfall amounts and distribution were taken from real meteorological observation data. The results showed that wilting points were reached in kerangas forest after drought periods of 20–50 days. The MDF required periods in the order of 100 days to exhaust the plant-available water of the soil and the biomass. A test calculation of the course of water depletion in kerangas forest RP 15 (KF) and RP 16 (MDF) in Bako National Park used real daily rainfall and other weather data during the 4-month period March–June 1965 (monthly rainfall P = 361, 239, 101 and 145 mm, respectively). A period of low rainfall began on 9 April and lasted to 20 June. This period created dry

conditions hardly evident in the monthly rainfall figures (in brackets above). Kerangas RP 16 is a marginal MDF on medium-deep humus podzol, 70-cm rooting depth, very close to the plot on sandy ultisol described by Ashton and Hall (1992). RP 15 is a typical KF on a medium humus podzol, but with shallower rooting (40 cm). The unexpected result was that the MDF in RP 16 exhausted the plant-available water within 46 days in spite of five intermittent rainfall events. The nearby KF in RP 15 approached exhaustion at one time after 70 days (18 intermittent rainfall events), but then heavy rain on 20 June and 22 June saturated the soil again. Obviously, the water requirements of the complex, aerodynamically rough and tall MDF could not be supplied, and the type of canopy could not be supported by the moisture capacity of the soil. The explanation for the edaphically aberrant existence of MDF on a KF soil was that additional water, and probably nutrients, were supplied by surface and subsurface water flow from the plateau and escarpment further up-slope (Bruenig, 1971a).

An open, bunched architecture of the crown, such as in rainforest trees and temperate oaks and pines, improves ventilation and facilitates air exchange even during almost calm, bright weather, by active free and forced convective air exchange. Rapid removal of the atmospheric boundary layer is facilitated by small, longish and more-or-less upright leaves. These features have a dual function. They reduce heat stress on bright days during drought and during noon peaks of radiative heat load and water saturation pressure deficits, but they also permit very high rates of transpiration if water is freely available. The high transpiration potential of drought-resistant sclerophyllous evergreens, which naturally occur on nutrient-poor, droughty sites, is well known. Examples in temperate and tropical forests are species of pine and eucalypt. These species transpire luxuriantly if water supply is ample, but survive without damage if there is shortage. High rates of transpiration help with the uptake of nutrients on the nutrient-poor sites on which most species of

pinus and eucalypts, as well as Bornean kerangas and Amazonian caatinga trees, naturally occur.

In conclusion, the leaves, tree crowns and the canopy of the TRF are so designed that very high transpiration and photosynthesis rates can be achieved under favourable conditions, but at the same time short-and long-lasting periods of water deficiency can be endured during bright, hot weather. The root system is accordingly designed to obtain nutrients and water efficiently to support the high rates of net primary production and minimise nutrient losses during wet and moist periods and to exploit plant-available water at the greatest possible soil depth during prolonged dry periods to maintain production and prevent drought damage. Recent research results support our earlier suggestion from Sarawak (Bruenig, 1966, 1971a) that deep rooting in TRF is an important asset during drought. Drought stress on trees can induce their roots to increase exudation of carbon compounds. This process provides additional food for microorganisms and may be of considerable ecological significance, possibly affecting the mycorrhizal association "as a fundamental regulator in plant water relations" (Killham, 1994). Especially important is their role during prolonged periods of drought to maintain water supply from deeper soil layers. According to Shuttleworth and Nobre *et al.* (1992), citing recent research by Hodnett *et al.* (1992), Amazonian forests seem capable of accessing soil water to considerable depth, certainly to a depth of 4 m and quite possibly to depths of 6–8 m, and possibly more if the soil porosity permits. They conclude that this would be an important asset during drought.

It is difficult to assess the effects of plant-available mineral macronutrients in the mineral soil, in the SOM and in the decaying dead organic matter on the distribution and performance of rainforest tree species. Many factors interact, the risk of determining pseudo-correlations is high, and the autecology and physiology of the rainforest species and genotypes are little known. Nutrient contents in fine (mainly leaves, twigs, fine roots) and coarse (trunks, branches, roots)

litter vary between species and individuals, the rates of litter production vary with time and mortality occurs patchily. Consequently nutrient availability would be heterogeneous over an area and variable over time. Simple relationships may be established for some parameters under otherwise relatively uniform conditions (Baillie *et al.*, 1987), but not if conditions are more heterogeneous (Ashton and Hall, 1992). Vitousek (1984) considered phosphorus to be the most important limiting nutrient element in most rainforest. Hogberg and Alexander (1995) state that, while N-fixing nodule-forming tree species (NOD) should, in theory, be limited by phosphorus, non-nodulated tree species could be limited by either N or P. They quote Gartlan *et al.* (1986) and Newbery *et al.* (1988) that in the rainforest at Korup, N:P ratios were high in all three symbiotic groups (ECM, VAM and NOD + VAM), which supports the idea of P being the limiting element there. The authors have previously speculated that in Korup:

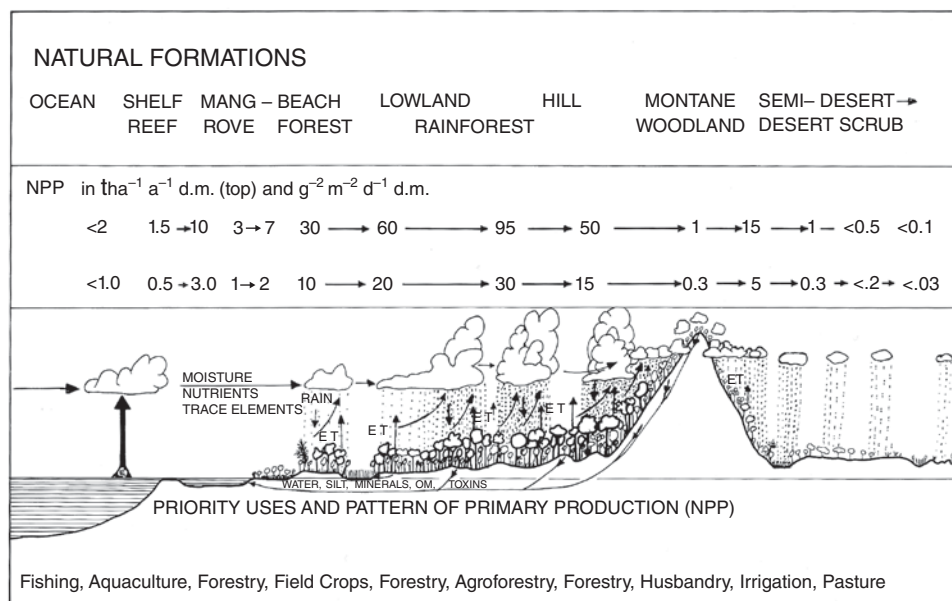
ectomycorrhizas (ECM) might offer advantages over vascular mycorrhizas (VAM) in the utilisation of organic N, but all the new data, the higher foliar % P, the lower N:P ratio and the similar 815N values, argue against that hypothesis and for the notion that ectomycorrhizas are more important in P nutrition in that forest.

In the data on species composition in KF in Borneo and caatinga forest in Amazonia, there is no indication that NOD legumes had any particular advantages in nutrient supply. The mechanisms, dynamics and ecological significance of the nutrient deposits in the roots, stems and branches are as yet little understood, but need to be considered in nutrient cycling models (Noij *et al.*, 1993). Burslem *et al.* (1995), in a pilot experiment with seedlings of rainforest tree species, confirmed the existence of a wide variation of responses to fertiliser applications between species. Phosphorus, taken up in excess of immediate requirements, was transferred to the long-living stems rather than to short-lived leaves. Rainforest trees habitually, like all leaf-shedding perennial plants, retrieve essential nutrients

from the leaves before abscission. Both processes would support the hypothesis that trees are capable of building up an internal slow-release stock of nutrients. In contrast, moisture can be stored in the living biomass to meet the needs of only a few days. The storage in the soil may supply the demand of weeks to months (Table 1.5). When the store in the phytomass and soil is exhausted, critical strain develops (Bruenig, 1966, 1971a). Riswan (1991) analysed the contents of six mineral nutrients in living sclerophyll leaves of kerangas trees. He found that P, K and Ca were higher than in MDF, and N, Mg and Na lower. There was considerable seasonal fluctuation and variation between trees and species. In kerangas, caatinga and peat swamp forests, it seems the hydrological conditions and SOM are more distinct and probably more critical, but certainly less open to manipulation by the vegetation or by management, than the nutrient conditions in the mineral soil.

The deeply weathered parent materials of rainforest soils have few mineral nutrient reserves. Replenishment of nutrients has to

come from the very variable particulate and gaseous contents of nutrients in the atmosphere that enter the forest ecosystem (Fig. 1.21). Episodic or seasonal events, such as large fires, desert and oceanic storms, or eruption of volcanoes, change the atmospheric chemistry and thereby the nutrient and trace-element input into the rainforest. Data on nutrient inputs (Hilton, 1985) suggest that the rate of deposition of macronutrients and trace elements can be substantial and balance losses from natural leaching to which the primeval rainforest has adapted. Wet and dry deposition may restore losses from selective felling within adequately long felling cycles, except perhaps for phosphorus. However, there may be depletion in the course of several felling cycles unless high levels of phytomass stocking are maintained to store and cycle nutrients. Heavy rates of erosion and leaching as a result of selective logging, especially on steep slopes and with heavy machinery, and short felling cycles will very probably cause serious nutrient and microbiological depletion in the soil. Areas with naturally poor soils, high relief



**Fig. 1.21.** Generalised trend of net primary productivity (NPP) and climatic functions in the natural zonal lowland and montane vegetation. Nutrients and trace elements originate from the sea, volcanic eruptions, fires and desert storms and anthropogenic air-polluting sources.

energy and intensive rainfall, such as Borneo, are particularly prone to depletion and lasting degradation. The relative poorness of soil nutrient availability and low nutrient status of the litter reported in MDF, KF and Alluvial forest in Gunung Mulu National Park in comparison with other regions (Anderson *et al.*, 1983) indicates a problem that urgently requires in-depth field and laboratory studies, while forestry practice, in the meantime, has to adopt a precautionary approach. The problem is seriously increased by conventional selective logging. The large amounts of dead biomass that are left behind (Section 2.8; Figs 2.3, 2.4, 2.15) release large amounts of humic acids, polyphenols and tannins for at least 20 years (Section 1.3, decay rate), which leach the soil and pollute the water bodies, causing a multiple and heavy loss to the ecosystem.

The results of a large and long-term (1990–2004 and continuing) ecosystem study into the biochemistry of the forests of two different catchment areas with different soils and forest types in Germany are fully relevant to pristine TRF and SFM in tropical rainforests. Together with the well-known Hubbard Brook study in the USA, it is the most comprehensive problem-orientated research project on the subject of intake, turnover and output of chemicals, including carbon and nitrogen, and toxic pollutants. In the interim report, Matzner (2004) (editor of 50 contributors to 25 subject titles) describes the results of the analyses and the monitoring of intakes, adsorption, absorption, assimilation and dissimilation of chemicals in the vegetation and soil. The effects of GCC and of pollutants on the ecosystem and its compartments are assessed. Man-caused pollutants in air and water can be controlled by political action, as Germany has demonstrated, except for those from volcanic activity, but GCC only as far its cause is anthropogenic. The report points at the huge uncertainties which exist with respect to biodiversity, particularly in the soil, and the likelihood that episodic climatic extremes, such as drought, will be more critical for forests and biodiversity than the shift in the values of climatic averages. Of course, there are critical feedback loops which eventually

also cause critical stress and disturbances for forests. One is the feedback between warming of the atmosphere – warming of the ocean surface – charging the atmosphere with energy and humidity (violent thunderstorms and cyclones, and typhoons, hurricanes and tropical storms generally). Another is between the shift of temperature – warming of the atmosphere – melting of the permafrost in tundra and taiga – emission of greenhouse gases – warming of the atmosphere. A similar and equally vicious feedback loop is activated by clearfelling and converting peat swamp forests to plantations in Borneo, Sumatra and West Irian. This interrupts the process of paludification, causes subsidence of the peat domes and as in the boreal peats causes emissions of CO<sub>2</sub> and, worse, CH<sub>3</sub> discharge. Carbon sequestering will reverse to carbon, and worse, methane discharge.

With increasing industry and road traffic in all tropical countries, the serious air and water pollution has poisoned soils, soil-water and surface runoff water, and reached the water reservoirs. The poisoned water has percolated to the ground water, and this and the polluted reservoirs are a critical threat to the health of people which is too costly to mitigate appropriately. The soil and water pollution has also reached forest ecosystems and agriculture. All this is known because the air pollution is easily observed while visible, but not publicly or officially recognised because effective counteraction and compliance with health and anti-pollution standards are expensive and contradict vested interests. Germany's environmental policy and the insights offered by research (Matzner, 2004) should inspire and in parts may even be suitable role models to guide actions in policy and SFM in the tropics.

## 1.8 Tree Species Richness and Diversity

The number of tropical plant and animal species is most likely around 3–5 million, but there is considerable uncertainty especially with respect to insects and other

invertebrates (Whitmore and Sayer, 1992, especially pp. 8–9). Existing taxonomic and ecological knowledge of soil-dwelling animal, plant and microbial species in most forests of the world is fragmentary. The easily accessible plants are better known. For example, the regional programme Flora Malesiana can build on the results of more than two centuries of botanical collection and research. It possesses an unequalled network of participants including more than 150 scientists. Started in 1947 by Professor van Steenis, the programme was expected to cover up to 30,000 flowering plant species which were hoped could be documented and revised by the end of the 20th century. The current estimate is 42,000 flowering plant species and completion is expected by 2020 or perhaps 2040 (Roos, 1993). If plants take so much time, the cataloguing of mobile animals and microbial organisms will take centuries more. The basic features of global recording and long-term monitoring of biodiversity are only just emerging (Vernhes and Younes, 1993). Sufficiency and representativeness at local and regional levels (Mawdsley, 1993) are particularly difficult to achieve in the species-rich, heterogeneous, constantly changing, complex and dynamic TRF. The problem of species monitoring for sustainable management is mentioned in Section 10.2.

The following text focuses on aspects of species richness and diversity that are directly relevant to sustainability of management and conservation. A primary assumption is that the most practical and rational strategy is preservation of quality and size of habitat. The habitat quality in a forest is determined by the structure and composition of the A- and B-layers of the canopy (Fig. 1.17). They are the key elements in the viability and functioning of forest ecosystems that determine the microclimate, the qualities and quantities of stocks and flows of matter and energy in the ecosystem. The canopy properties of the A/B/C-layers decide the species richness, composition and structure of the D-layer which in temperate forests is the main source of species richness of the stand. Its state served foresters for centuries in silviculture as an indicator of microclimatic

conditions and of the need for action at the time when plant sociology stood for ecology in forestry curricula. In TRF, the other important font of species richness, the tree crowns in the A/B-layers cannot serve in this way. The structural shape of the canopy is a direct biodiversity indicator in temperate forests, traditionally used as such by foresters. The A-layer trees are the objects of harvesting, and their crowns are the major objects and sensors to guide silvicultural manipulation towards adequate self-regulation, self-sustainability, economic viability and social values. However, the species composition and diversity patterns in the C/D-layers of the TRF serve as indicators in the regeneration phases and generally in conservation planning.

The A- and B-layer tree species are the “structural species on which the interstitial species depend” *sensu* Solbrig (1991a). Manipulation of the A- and B-layers is the most sensitive and effective means to regulate species richness and diversity. The state of the canopy determines the amount, quality and diversity of living space offered by the forest ecosystem above and below the ground surface. Therefore, the floristic and geometric structure of the tree canopy determine the ecological and economic diversity and diversity-related features of the rainforest ecosystem. Hence, this section concentrates almost exclusively on the tree-species component, because trees are the primary structural elements with which foresters manipulate, produce and preserve, and trees are taxonomically and ecologically better known than other biological components of the rainforest.

The long-term evolution of the richness of plant, animal and microbe species in the equatorial rainforest is facilitated by the biological barriers between genetic populations, the multitude of breeding systems, genetic isolation mechanisms, heterogeneity of soil and climate and the dynamics introduced by tectonic movements, sea-level changes and multiscale climatic variation and changes. In the present, diversity is maintained by habitat variation due to crown break, tree mortality, wind-throw, lightning, pests and diseases forming gaps from a few square metres to hundreds of square kilometres (Figs 1.3 and 1.4; Browne, 1949).

Species richness and biodiversity are naturally dynamic and not static. Accordingly, biodiversity must be managed and monitored by procedures that take account of this dynamic nature and the features of the ecosystem of which they form part (Chapters 6 and 10). Tree-species richness, in this book, will be expressed as the number of species in 100 randomly selected trees above a certain stem diameter. This measure has the advantage that it is unaffected by the stature of the trees and the heterogeneity of site and forest. The evenness of mixture within the 100-tree batches will be expressed conveniently by the McIntosh index of diversity (Bruenig, 1973c; Bruenig and Huang, 1989). The values of diversity indices, including the McIntosh index, vary widely between sampling points within a forest community (Bruenig and Schneider, 1992; Prevost and Sabatier, 1993). Differences between natural forest communities (tree-species association groups, forest types) are statistically difficult to prove. However, the indices are useful for broad comparisons between distinct forest communities at medium and large scale of area.

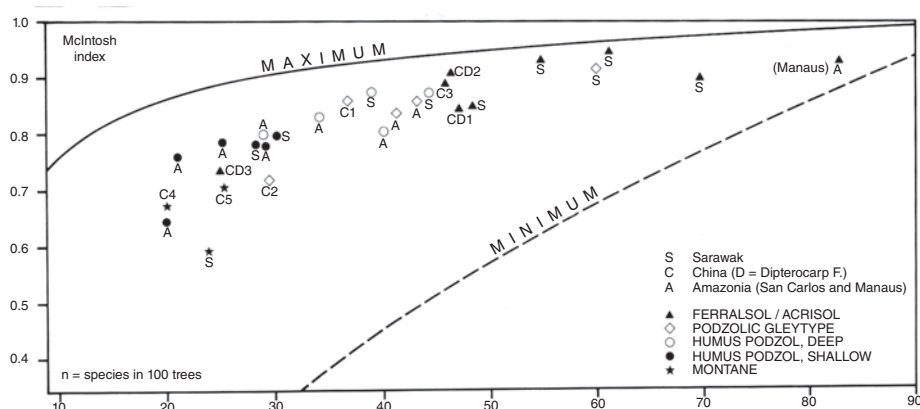
Current species richness in mature, more-or-less untouched (Section 2.1) primeval rainforest is the result of the specific history of the site and is closely related to the present edaphic, climatic and atmospheric conditions. This indicates ecological saturation and sufficiency levels of tree-species richness in relation to the carrying capacities and stress factors of different sites, and could be a guide for target species mixtures in silvicultural management. Saturation and sufficiency levels are still uncertain in the much more intensively researched and managed temperate forests in species-rich North America and Far East, or naturally species-depleted Europe. Global change will very likely complicate the problem by changing stresses and carrying capacity differently on different sites. Tentatively, the actual species richness in mature, untouched primeval forests on a specific site could be taken as an indicator of the upper limit of sufficiency and carrying capacity. The *Dryobalanops beccarii* MDF (Ashton, 1995) in Sabal RP 146 had 241 tree species with

diameters  $\geq 10$  cm ha<sup>-1</sup>, while *A. borneensis* KF and *Casuarina nobilis* KF (Bruenig, 1974) together had only 166 (Table 1.6; Droste, 1995). This indicates the general trend of the ecological gradient correctly, but is too coarse for distinguishing more subtle differences for silvicultural decisions. The area-related data are too strongly affected by forest structure and by the minimum diameter of the chosen sample population. In the *A. borneensis* KF block 84 (50 × 50 m) of RP 146, Sabal, 86 species were enumerated with diameters  $\geq 10$  cm and 260 with diameters 1–9.9 cm on 0.25 ha. These figures are high in comparison with MDF in Mulu and Lambir National Parks. Proctor's 1-ha MDF plot in Mulu National Park (DF in Fig. 1.8) had 223 tree species with diameters  $\geq 10$  cm, and two randomly selected 1-ha MDF plots in Lambir National Park had 160 and 190 tree species with diameters  $\geq 10$  cm and 314 and 344 tree species with diameters 1–9.9 cm ha<sup>-1</sup> (Research Branch, Forest Department Sarawak, Lambir dataset, figures supplied by William Then, 29 May 1995). To avoid the effects of forest stature and tree density, we had chosen to measure tree-species richness among batches of 100 trees with diameters  $\geq 1$ , 10 and 15 cm along ecological site gradients in Borneo, South China and Amazonia, using a randomly selected centre tree and its 99 nearest neighbours. The results (Figs 1.22 and 1.23, Table 1.7) show a close association of species number with soil type and latitude. The number of species declines with soil quality. The maximum is on deep ultisol/acrisol in a tierra firme forest adjacent to the W. Egler Forest Reserve near Manaus (Klinge *et al.*, 1974) and on humult ultisol in transitional MDF in Sarawak (Sabal Forest Reserve, RP 146). Species richness consistently declines through deep, medium and shallow humus podzol and related soils in lowland to minima in montane KrF and KF in Sarawak, Brunei and South China, and in Bana in Amazonia. The rainforest analogues in China have, on soil of equal quality, a consistently lower species richness (Bruenig, 1977b, 1986a; Bruenig *et al.*, 1979, 1989). The forests near San Carlos are slightly less species rich than their analogues on equivalent soils in Sarawak and

**Table 1.6.** Species richness in RP 146, Sabal F.R. (Section 1.8) and growing stock above ground and growth (Section 1.12) in lowland mixed dipterocarp forest (MDF) and kerangas forest (KF). (a) Sabal RP 146. Growing stocks  $\geq 10$  cm diameter in 1963 (primeval, except for native collecting gaharu by felling *Aetoxylon sympetalum* (Steen. and Domke) Airy Shaw) and 1990–1991, probably 12 years after selective logging MDF and creaming part of KF (forest type with *Agathis borneensis* Warb.) The tree trunk volume increment 1978–1990 in MDF is  $10 \text{ m}^3 \text{ ha}^{-1} \text{ a}^{-1}$ . (b) Mulu RP 142 B, MDF, and D, KF. Diameter increment in primeval MDF per diameter class and per crown position and social class, indicating the same trends as shown in Fig. 6.2 by *Shorea* spp. (Section 6.3). Crown scales are defined according to Dawkins (1959, 1963a,b) in Synnott (1979). N, number of stems; G, basal area;  $V_{\text{tw}}$ , volume of thickwood ( $>7\text{cm}$ ) of trees  $\geq 10$  cm diameter;  $PM_{\text{tw}}$ , phytomass of thickwood volume;  $PM_{\text{tot}}$ , total phytomass; Spp., species; st, standing; f, fallen to the ground; d, diameter “breast height”; i, increment. The MDF soil in Sabal RP 146 is sandy-loamy humult ultisol, and in Mulu RP 142 B clayey udult ultisol. The KF soil in Sabal RP 146 is medium-deep to shallow humus podzol with some aquic-spodosols along streams and miniature woodland peat bogs in depressions, and in Mulu RP 142 D medium-deep humus podzol over Pleistocene gravel (Bruenig, 1966, 1974).  $V_{\text{tw}} = 0.5 \text{ (d} \bullet \text{ h)}$ . From Droste (1995, 1996).

	MDF – <i>Dryobalanops beccarii</i>				KF – <i>Agathis borneensis</i> (and) <i>Casuarina nobilis</i>			
	1963 (primeval)		1990–91 (post-logging)		1963 (primeval)		1990–91 (creamed)	
<i>Living PM</i>								
$N(\text{ha}^{-1})$	642		693		850		891	
$G(\text{m}^2 \text{ ha}^{-1})$	29.2		26.6		31.7		32.3	
$V_{\text{tw}}(\text{m}^3 \text{ ha}^{-1})$	410.3		359.3		425.1		427.8	
$PM_{\text{tw}}(\text{t ha}^{-1})$	246.2		215.6		255.1		256.7	
$PM_{\text{to}}(\text{t ha}^{-1})$	451.3		395.2		467.6		470.6	
Spp. ( $\text{ha}^{-1}$ )	–		241		–		166	
Spp. (100 $N^{-1}$ )	69		70		53		55	
<i>Dead woody PM</i>								
$N_{\text{st}}(\text{ha}^{-1})$	–		37		–		63	
$V_{\text{st}}(\text{m}^3 \text{ ha}^{-1})$	–		15.0		–		34.3	
$PM_{\text{tw}}(\text{t ha}^{-1})$	–		9.0		–		20.6	
$PM_{\text{to}}(\text{t ha}^{-1})$	–		16.5		–		37.7	
$V_{\text{f}}(\text{m}^3 \text{ ha}^{-1})$	–		167.5		–		67.9	
$PM_{\text{f}}(\text{t ha}^{-1})$	–		100.5		–		40.7	
Stem diameter class in cm (d)								
d-increment in mm per d-class in cm	10–20	20–30	30–40	40–50	50–60	60–70	70–80	>80
<i>B. MDF id</i> (mm $\text{a}^{-1}$ )	1.0	1.6	1.7	3.2	3.1	1.9	3.4	1.5
Stem diameter class in cm (d)								
<i>N</i> (observed)	433	131	76	39	19	17	13	18
<i>D. KF</i>								18
<i>id</i> (mm $\text{a}^{-1}$ )	1.1	1.6	2.0	2.5	3.2	3.5	4.7	3.7
<i>N</i> (observed)	300	93	43	16	13	8	4	16
Crown position class								
Canopy layer	5		4		3		2	
Social position	D		C		C/B		A/B	
	Suppressed		Suppressed		Oppressed		Dominant-codominant	
							A	
							Emergent	
<i>B. MDF</i>								
d-increment in mm								
<i>id</i> (mm $\text{a}^{-1}$ )	1.0		1.3		2.2		2.5 (max. 6.9)	
<i>N</i> (observed)	170		122		103		29	
<i>D. KF</i>								
<i>id</i> (mm $\text{a}^{-1}$ )	0.7		1.1		1.6		3.1	
<i>N</i> (observed)	111		146		161		61	
							13	





**Fig. 1.23.** Mean species richness and mean evenness of mixture or diversity among batches of randomly selected trees and their 99 nearest neighbours in predominantly evergreen lowland and montane forests on a variety of different soil types in rainforest types in Sarawak and Brunei (S), Hainan (C), Guangdong (CH) and Amazonia (A). Species richness is closely related to soil type, and diversity (Fig. 1.21) is more variable and less closely related to soil type-vegetation unit and the canopy roughness and disturbance regime. The series in the monsoonal climate of Hainan and Guangdong is shifted to the left in the coordinate matrix where soils are more unfavourable (hydrologically!) in the equatorial forests. From Bruenig and Huang (1989).

264, 235, 261, 76, G (stand basal area,  $\text{m}^2 \text{ha}^{-1}$ ) = 29.1  $\text{m}^2$ ; Lagong: 253, G = 41.1  $\text{m}^2$ ; Menyala: 232, G = 31.8  $\text{m}^2$ ). There was no clear distinction between hill and lowland forest. Ordination by the detrended correspondence analysis DECORANA, as would be expected, showed distinct floristic differences between the hill forest at Lagong and the two lowland forests at Menyala and Pasoh. Within the lowlands, Menyala differed somewhat from Pasoh, but the floristic variation between the four plots at Pasoh was as great as the difference between Menyala and Pasoh (Manokaran and Lafrankie, 1991, Fig. 5).

Newbery and Lingenfelder (2009) state that “tropical rain forests are highly dynamic and responsive ecosystems. Their physical structure and processes may remain relatively stable over time, but species composition is thought to fluctuate constantly around a quasi-equilibrium or change slowly”. This is certainly true and accords with the results of research by Anderson, Muller and Bruenig in peatswamps and kerangas forest in the 1950s and my later research in Malaysia, Amazonia and China. The generally accepted conclusion is that the tree-species composition fluctuates over time, but also that the frequencies and densities of the

spectra (tree species diversity) of composing individual species follow patterns which are spatially heterogeneous and change with time. Consequently, tree species composition and diversity are not stable, but variable. Their usefulness as indicators under the criteria “biodiversity” is therefore limited and any recorded changes must be judged with discrimination against the background of natural dynamics. Any presently existing TRF vegetation in a distinct area exhibits a consistent variation related to site condition, which might suggest uniformity and stability, until the area and the sample are sufficiently enlarged and observations cover sufficiently long periods in terms of natural species, vegetation and ecosystem dynamics. Only then it is possible to identify and prove the interactive effects of intrinsic and extrinsic conditions and possibly causal factors other than direct effects related to soil and physiography.

Generally, within a small area of a few hundred  $\text{km}^2$ , any actual or construed catena of physical soil conditions will represent a gradient of aeration, moisture conditions, nutrient status and humus quality. There will be a correlated gradient of size, shape and complexity of rooting, and consequently

**Table 1.7.** Mean number of tree species and evenness of mixture (diversity) in randomly (105 points) or systematically (diagonals, 37 points) selected sample batches of 100 individual trees above 1.5 and 13 cm diameter at breast height in 10 ha Amazonian evergreen caatinga in the International Amazon Ecosystem Study MAB pilot project near San Carlos de Rio Negro. The forest types are groupings of tree species association groups classified by a nearest-neighbour monothetic divisive programme FANTASMB. The species richness (spp./100N) and the evenness of tree-species mixture (diversity index for 100 trees according to McIntosh, see Figs 1.21 and 1.22) are closely related to soil type, landform and intensity of gap formation. The roughness of the canopy surface, expressed in terms of aerodynamic roughness by the dimensionless estimator  $z_0$ , is also closely associated with the soil type, landform, frequency and kind of disturbance (all forms of mortality), and consequently with species richness. Yevaro, *Eperua purpurea*; cunuri, *Micrandra spruce yaguacana*, *E. leucantha*; tamacuari, *Caraipa densiflora*. Piapoco, media luna, concha amarillo are not reliably identified. The collection of ca 800 fertile reference specimens were lost in the herbarium in Caracas. From Bruenig *et al.* (1978, 1979); Bruenig and Schneider (1992).

Forest type	Tree-species association group	SAG	Number of species per 100 trees				Mixture evenness		
			10 ha area, over diameters d = 1, 5, 13 cm			>13 cm	10 ha area >13 cm	Two diagonals >13 cm	Canopy roughness 10 ha are $z_0$
			>1 cm	>5 cm	>13 cm				
Complex transitional caatinga	Yevaro-hina	I	43	46	49	46	0.88	0.89	200–350
Complex caatinga	Yevaro-cunuri	H	41	41	38	n.d.	0.82	n.d.	100–250
	Yevaro-yaguacana	K	40	51	26	27	0.70	0.66	100–200
Simple caatinga	Yevaro-cunuri	J	29	30	21	21	0.61	0.76	100–200
	Cunuri-yucito	L	34	25	22	22	0.59	0.77	80–150
	Piapoco	M	n.d.	21	17	15	0.55	0.59	50–100
	Cunuri-yucito								
Ecotone caatinga → alluvial	Cunuri-piapoco	N	29	31	25	23	0.69	0.67	80–150
	Yaguacana-tamacuari	O	n.d.	19	14	16	0.55	0.64	80–200
Ecotone caatinga → Bana	Yucito-media luna Cunuri	P	n.d.	24	18	19	0.63	0.67	80–200
Bana	Yucito-concha amarilla	Q	n.d.	21	15	19	0.73	0.4–0.6	100–200
Mean		I–H–Q	36	35	28	26	–	–	–
Number of points			13	46	52	37	105	37	–

a change of tree species composition, richness and diversity consistent with the soil conditions. This trend is analogous to that linked with catenas of physiographic change, and is not confined to the tropics. Data from West Malesia confirm the existence of correlation between species richness and site conditions, irrespective of the kind of specific floristic composition, while the actual causal site factors remain obscure. The very similar tree-species richness in natural forest on equivalent site types in Borneo (Sarawak and Brunei) and Amazonia (San Carlos), and the constancy of the diversity of mixture in mature natural primeval rainforests, while species may change, suggest that these features may have some relevance for the ability of the forest ecosystem to sustain itself under stress by a structure-related elasticity to avoid damage. The information on trends of species richness in pristine forests could be used tentatively as an indicator for designing site-specific sustainable silvicultural systems for natural forest management (Chapter 6) and for restoration/rehabilitation (Chapter 7) or afforestation (Chapter 8). Generally the available information is sufficiently indicative and concrete for decisions on practical activities and to guide long-term strategic planning of silvicultural management and conservation programmes, and forest protection and preservation purposes. However, more concrete and reliable data are needed for defining the indicative threshold of the critical lower limits of tree species richness and diversity for SFM and CNF. This information would help GCC sceptics to overcome their rejections, and calm ideologists. The need is for simple, straightforward, practical and easy to use, reliably science-based guidelines on optimum and minimum species richness and diversity in tropical forests. Such guidelines must be compatible with the reality of the rainforest ecology and forestry. It does not appear that this need will be supplied in the near future. Existing guidelines are more a hindrance and wasted cost than help in the quest for sustainability. But even the long-term prospects are slim. Broad intuition based on sound experience in CNF silviculture will continue for a long time to provide a more

reliable and practical guidance than formal indicators and threshold values. There is no convincing theory or practical evidence to support the claim for mandatory application of such criteria and indicators in forestry in an environment in which the only constant is constant change. An example is the well-known individual, specific and provenance differences of responses to drought of Douglas fir and Norway spruce, in pure stands and mixtures, in Germany. Consequently development of each species in mixtures of the same planting stock on edaphically dry or moist micro-sites during and after drought differs. This indicates a problem of predicting biodiversity and growth responses in TRF after prolonged drought or prolonged water saturation. Species composition and biodiversity in the TRF may also be more dynamic even at relatively short temporal scale than often assumed. The academic community has to date been unable to supply scientifically sound evidence of the role and importance of biodiversity for the ecological functions and processes of forest ecosystems. Therefore, we are unsure what biodiversity means in terms of ecological ecosystem sustainability. All this indicates that it is unlikely that the present, most unsatisfactory situation will soon change for the better. Present theories and conclusions about the role of species richness and diversity – as of genetic variation and diversity – are unconvincing, and of little help to practical forest management, conservation and preservation.

Dynamic tree responses were put into a habitat (ridge-to-valley topography and soil type) catena pattern and ecosystem context. A worrying conclusion from the results is that the most probable nature and long-term direction of GCC will result in lower growth and stature of trees, lower biomass productivity, biomass production and on-site storage of organic matter in TRF in Borneo, and most probably in the whole affected TRF biome. This conclusion increases doubt about the feasibility and effectiveness of current policies and programmes aiming at mitigating GCC by storing carbon in TRF and the world's forests generally. Suspicion cannot be avoided that these lobby- and

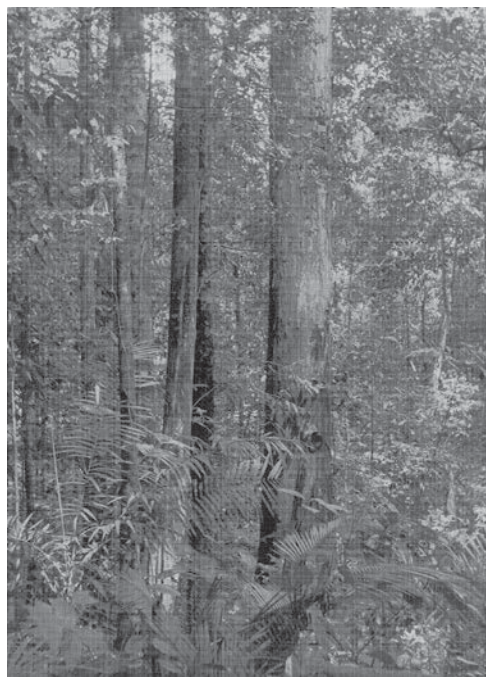
vested-interest driven policies and programmes primarily serve as opportunities for benefitting financially from carbon emission credit trading and REDD+ incentives, while CO<sub>2</sub> emissions by the fossil fuel-using industries and consumers can stay at high levels, or even rise, and comply with conservation principles, criteria and agreed indicators (Lingenfelder and Newbery, 2009; Newbery *et al.*, 2011; von Storch and Krauß, 2013).

### 1.9 Floristic Changes and Distribution Patterns

Silvicultural systems cannot be well designed and their results cannot be judged if the ecological significance of natural floristic patterns and changes are not understood. Consequently, so-called plant sociology, as a precursor of forest ecology, has been a hot

subject in the forestry curriculum at German universities since the early 20th century. The analysis of tree distribution patterns at a small spatial scale in Sarawak (Newbery *et al.*, 1986) and Liberia (Poker, 1992) has indicated that tree-species associations are probably ephemeral and shifting. The statistical probabilities that a number of co-occurring tree species form a persistent and recurrent association from seedling to over-mature stage in the form of a calculable and predictable “eco-unit” (Oldeman, 1989, 1990) are very slim.

Application of divisive association analyses to the data in the Sabal (Weiske, 1982) and San Carlos (Bruenig *et al.*, 1978) research areas produced, at a relatively high level of division, a close association between species ranges and landform-soil units (LSU). The same held true for tree-species



**Fig. 1.24.** Taxonomic and structural stand diversity: *Dryobalanops beccarii*-meranti-keruing MDF on sandy-clayey loam humult ultisol on low hilly terrain, Selang F.R., Mattang, new Kubah N.P., Sarawak.



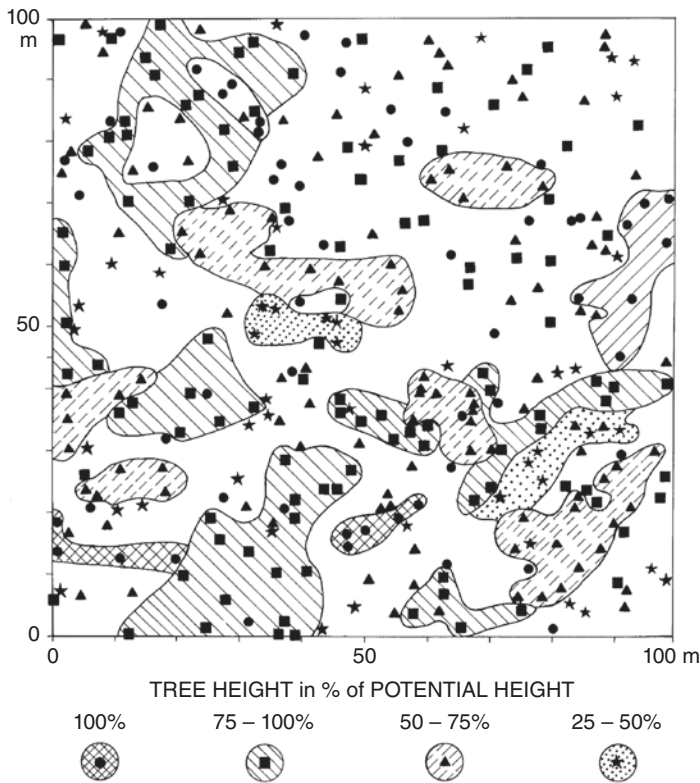
**Fig. 1.25.** Well-illuminated interior of a simple kerangas forest on medium to shallow podzol, coastal terrace in Dalam F.R., near Miri, Sarawak. A/B-layer species regenerate well in contrast to MDF (Fig. 1.23), but invading MDF species cannot survive and die as seedlings or saplings.

association groups and the regularly zoned LSU in San Carlos (Bruenig *et al.*, 1979) but not in the edaphically and topographically more irregularly heterogeneous Sabal area (Weiske, 1982). In Menyala Forest Reserve, Peninsular Malesia, the tree-species composition over 34 years in a 2-ha ecological research plot is unpredictable. In 1947 and 1981 (the latter date appears in parentheses in the following text) the plot had 244 (244) species among 538 (484) trees with diameters  $\geq 10$  cm ha<sup>-1</sup>; 48 of the 244 species with diameters  $\geq 10$  cm recorded in 1947 were not found in 1981, while 48 new species were added; six species invaded after 1947 and disappeared again before 1981. The lowest recorded level of species richness was in 1971 with 229 species, 6% below the level in 1947 and 1981. Of all species, 95% are primary forest species, 5% are secondary forest species; 24 species with 100 (82) trees are potential emergent-layer species, more than half of these being dipterocarps (Manokaran and Kochummen, 1987).

Newbery *et al.* (1986) analysed patterns in the 20-ha RP 146 in Sabal Forest Reserve, Sarawak. The soil and site mosaic is small scale and heterogeneous, and accordingly so is the pattern of the lowland mixed dipterocarp–kerangas forest tree species mosaic. The 64 most abundant species, representing 13,154 trees, were selected from the 16,063 enumerated trees with diameters  $\geq 10$  cm (diameter at breast height). All 64 species had individuals in the upper canopy; 30 of the 64 species showed pattern in the form of clumps. The most frequent scales of clump size were between 35 and 55 m across, or 0.01–0.3 ha. These 30 patterned species were the less abundant species in the plot, had a greater proportion of smaller (10–20 cm diameter) trees and a lower ratio of upper to lower canopy trees than species without pattern. The scale of pattern matched the common size of gaps (Bruenig, 1973b; Bruenig *et al.*, 1978, 1979; Fig. 1.3). It is hypothesised that patterned species are light-demanding and grow from seeds in or near gaps, whereas non-patterned species are shade tolerant and persist and grow relatively well in the shade below

the closed canopy. A preliminary comparison of the tree-species lists in 1963 and 1990 produced no evidence of species loss, but some additions occurred through ingrowth, such as the extremely rare *Falcatifolium angustum* de Laub which previously was considered to be extremely endemic and restricted to two sites near Bintulu.

The existence of persistent associations between species within tree groups or mosaic units of the same age was tested with data from 20 1-ha long-term silvicultural research plots in Liberia, West Africa, and six paired 0.5-ha plots in the Philippines (Poker, 1992). The hypothesis was that the trees form a mosaic of phasic eco-units (see Ashton and Bruenig, 1975; Whitmore, 1975a) ranging in size from 0.01 ha (single tree crown size) to about 0.3 ha (five to seven tree group size); such units would be persistent and could be defined quantitatively. In Liberia, all trees were classified into four height classes (25–50, 50–75, 75–100, 100%) relative to the maximum attainable by the species on that site. The mosaic was computed for each 1-ha plot by classifying the species as emergent (A-layer), intermediate (B-layer) or sub-canopy (C-layer) species. The potential maximum height of each species was determined from the literature (Vorhoeve, 1965) and the recorded maximum height in or around the 1-ha research plots. Finally, each tree was classified according to its height in one of the four height classes, and digitised. The height class distribution map is reproduced for one plot in Fig. 1.26. The distributions in all plots show the existence of some phasic units or equal height class clumps in a matrix of random scatter, despite the very small size (1 ha) of the individual plots. Periodic remeasurements indicated that the mosaic units in the lower height percentage classes rapidly change and shift with time. Some members retain their growth rate, others accelerate growth and yet others reduce it. Eventually new ephemeral associative mosaic groups are formed. A similar study of mosaic structure was made in smaller sample plots (50 × 100 m) in MDF in the Philippines. Two enumerations of diameter and height, 6 years apart, showed



**Fig. 1.26.** Example of the small-scale mosaic structure of the trees in a tropical semi-evergreen rainforest in Grebo National Forest, Liberia. The mosaic units comprise trees that have reached 25–50, 50–75, 75–100 or 100% of their specific maximum height which they could reach on that particular site. The mosaic units are apparently not composed of trees of equal age and relative vigour, and change and shift rapidly with time (Poker, 1992, 1995) (compare Fig. 6.5); they also do not represent guild associations as described by Taylor *et al.* (1995).

a slight change of pattern, possibly indicating that mosaic structure may shift noticeably within such a short period of time. This constant oscillation and change between states of order (structurally complex mature phases) and disorder (structurally simpler, more chaotic decay and regeneration phases) in a small-scale, shifting mosaic pattern on a very heterogeneous soil and often also heterogeneous micro-relief (LSUs) may facilitate the co-existence of many tree species (structural elements of biodiversity). Kohyama (1993) linked such dynamics to one-sided competition related to cumulative basal area of the light-depriving larger trees around a subject tree, irrespective of species and assuming constant rates

of gap formation and of mortality with stand age. This model accords too little with reality because it does not account for the irregularity of the distribution of events over space and time that affect the patterns of growth and mortality. The strong random element of distribution and dynamics at the spatial scale of gaps (0.1–0.3 ha) forces silvicultural research and monitoring to use plot sizes of at least 10 ha.

At a medium scale spatial distribution pattern (a few hectares to many square kilometres) there is generally a close association between the distribution of tree species and the pattern of clearly separated LSU (Anderson, 1961a, 1983; Ashton, 1964; Bruenig, 1966; Bruenig *et al.*, 1978; Newbery and

Proctor, 1984; Huang and Bruenig, 1987; Droste, 1996). This simple association becomes obscured if the LSU form a mosaic of small scale patches, such as in RP 146 (Weiske, 1982). The overlay of variation due to stand dynamics and site heterogeneity obscures either pattern (Weiske, 1982; Newbery *et al.*, 1986). Pattern at large scale may become obscured if species are replaced by vicariants (Bruenig, 1966, 1974; Ashton, 1988b). A tree species may characterise a forest type on an LSU in one area and be absent in the same LSU in another region. The peculiarly disjunct and irregular LSU coverage by *S. albida*, *Dryobalanops fusca* and *A. borneensis* in Sarawak is an example (Bruenig, 1974, pp. 150–154). Ashton gives examples of vicariousness at a wider scale of spatial separation. The arboretum in Semengoh Forest Reserve and the ecosystem research area in Pasoh (1000 km apart) have some of the most abundant dipterocarp species in common, but *S. acuminata* Dyer and *S. parvifolia* Dyer are vicariants. Others such as *S. dasyphylla* Foxw. and *S. parvifolia* change their rank order. We believe this is due to edaphic differences between the two sites, because the most abundant species are remarkably constant on the same soil in different localities in northwest Borneo (Ashton, 1988b, p. 364).

The abundant and very site-tolerant *S. albida* in KF, KrF and peatswamp forest is not very constant, nor are other abundant, site-tolerant or intolerant kerangas tree species, such as *A. borneensis* and *G. bancanus* (Miq.) Kurz. (Newbery, 1991). Species distributions are determined by such a multitude of physiological and ecological factors, history and chance that generalisations and predictions about probable site requirements, species occurrence and compatibility for purposes of conservation and silvicultural management are hazardous.

The problem is even more difficult for rare species. In 1959, the conifer genus *Falcatifolium* de Laub. species *F. angustum* de Laub. was first collected on a kerangas ridgecrest in Niah Jelalong Protected Forest (P.P.) north of the Merurong Plateau. The new species was thought to be extremely rare, site-intolerant and strictly endemic. In the same

year, it was recorded 80 km further west from kerangas terraces in the Binio basin near Bintulu; some years later 420 km further west on Gunung Santubong in western Sarawak; and in 1990 in Sabal RP 146 on medium-deep humus podzol near a stream. Rare and very rare tree species may be either restricted to very rare sites, or have a wide site tolerance but are scattered at very low frequencies (distances between mature trees 200–330 m (10 ha) for rare and >330 m for very rare species). Inventory of these species for the purposes of conservation is extremely difficult and expensive. A low-intensity sampling with 0.1–1 ha sample plots has little chance of yielding useful statistics on rare and very rare species. Sampling of occurrence and association of common, characteristic tree species by low-intensity survey poses the same problems. Newbery (1991) re-evaluated 38 small (0.1 ha) kerangas plots, which had been distributed subjectively after air-photo interpretation and ground check to obtain first data on the floristic and biomass structure of kerangas forest types on different sites, supplemented by visual interpretation along reconnaissance lines and tracks, to obtain data for a preliminary classification of the kerangas forests in Sarawak and Brunei. The data set was 21,727 trees with diameters  $\geq 2.5$  cm which contained 637 taxa.

Various analyses produced no evidence of consistent differences in species associations and physiognomic-structural features between plots and regions, in spite of their visually obvious existence in the field. This is no surprise if the effects of the pronounced micro-site heterogeneity, even in lowland MDF, and of the pronounced stochastic element of environmental and ecosystem interactive processes, including growth processes in the widest sense of the word, are considered. Tree species inventories at regional scale must combine a few large core plots (i.e. 20–50 ha in MDF, 10–20 ha in KF and peatswamp forest) with many small plots in the order of 0.1–1 ha, and linking survey lines. The small plots and linear links cover the regional variation of sites and random species associations; the large plots cover a great proportion of the regional tree flora, including some of the

rare species, and can be used to monitor dynamics and study structural variation in relation to regional position and within plot micro-site variation. The recording of very rare species will require additional site-focused, subjective reconnaissance.

### 1.10 Pristine and Manipulated Forest, and Animal Life

Browne (1949) reported the most drastic recorded change of rainforest canopy over large tracts of land due to natural causes. A devastating tropical cyclone had felled probably more than 1000 km<sup>2</sup> of mostly meranti keruing type of MDF in Kelantan in 1883. In 1949, this “disaster tantamount to clear-felling has resulted either in a complete victory or in utter failure (in about equal proportions) of a new dipterocarp stand”, that is, an MDF. Some previously abundant species, such as the heavy-wooded *Neobalanocarpus heimii* (King) Ashton, had become rare. Browne did not comment on animal life, but the results of the Danum and Deramakot studies suggest that it would have been back to “normal”. Browne suggested that the ability for self-sustainability had not been lost and restoration of the canopy was well under way in the “new dipterocarp stand” 70 years after the disaster. The fauna and soils biology (which may have benefitted from the disaster), as research in Demarakt F.R. has demonstrated, is likely to follow, if not to spearhead natural restoration. The recovery of the canopy by the MDF high forest species also meant that the animals, including pollinators and seed distributors, could be assumed to be in the process of recovery.

Little is yet known of the pollination systems of individual tree species but it appears so far that exclusive specialisation, such as in figs, is rare. Pollination by animals would benefit from habitat diversity and animal species richness if there are several pollinators for one species and the various pollinators have different habitat requirements. A recent study of the pollinators of a widespread climbing rattan palm

species in Sabah, *Calamus subinermis* Bl., listed insect visitors from at least 21 genera during 48 h of the pollen-release period. Microlepidoptera seemed to be the main pollinators (Lee *et al.*, 1993). An effect of the foraging range of pollinators on genetic evolution of species richness in outbreeding species was suggested by Appanah (1987). He argued that the short-ranging, rapidly propagating species of thrips, which are the favoured pollinators of dipterocarp species, may have been a factor in the evolution of the species richness in the family.

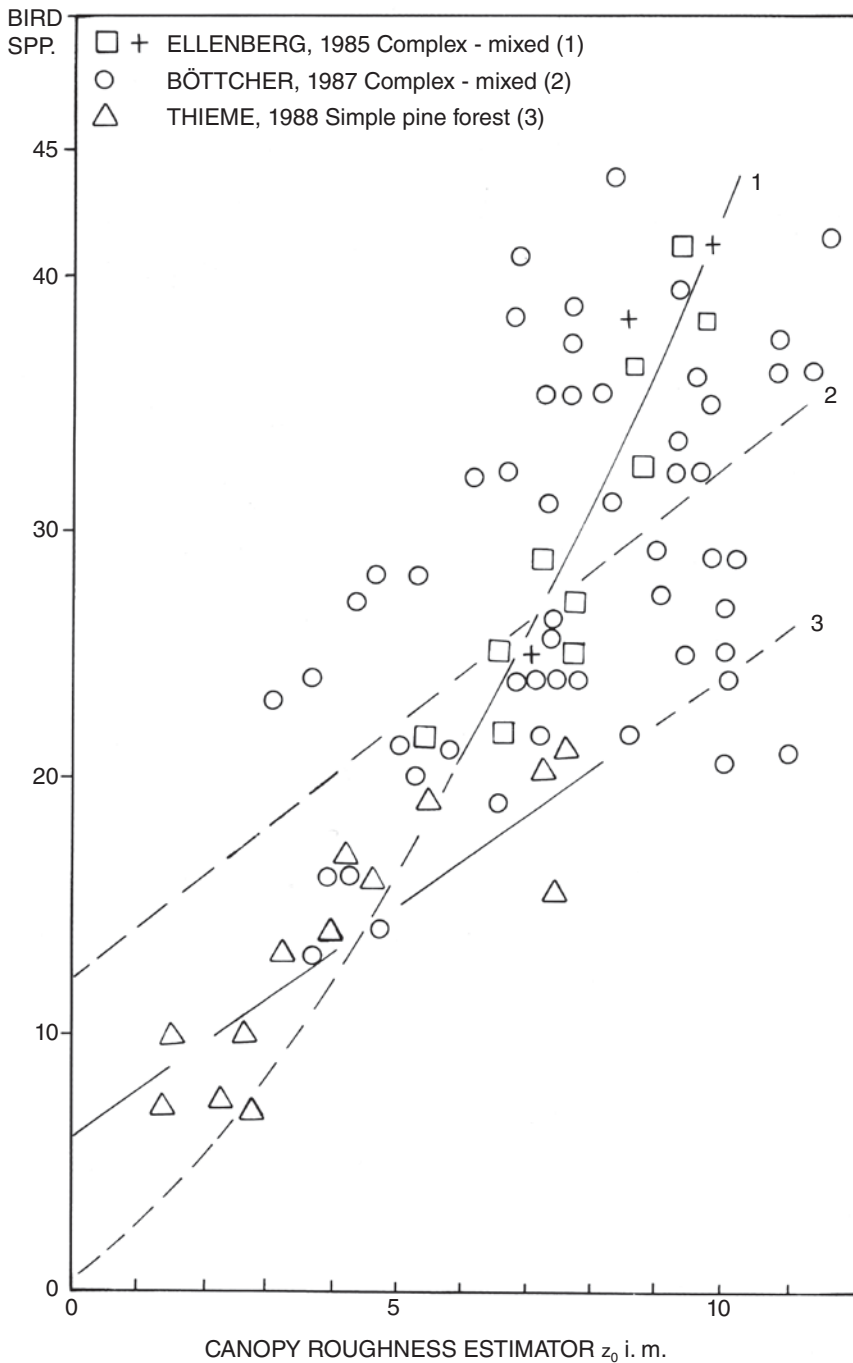
Apart from pollinators and seed distributors, forest self-sustainability also depends on the herbivorous consumers and detritus decomposers in the canopy, on the soil surface and in the rooting sphere of the soil. Frass and decay of leaves affect the rates of photosynthesis and respiration. Net primary production may increase or decrease depending on whether herbivores eat young and productive or old and consumptive leaves. Herbivory pathways were studied for five species of trees in the subtropical rainforest of New South Wales, Australia: 21% of the leafage of the crowns of the five species was consumed annually by herbivores. This amount is very high and, if the five species are considered representative, would indicate the great importance of canopy herbivory in this forest (Lowman, 1992). Values for TRF in the literature are generally much lower and range between 2 and 10% but may reach 100%, for example the mysterious ulat bulu epidemic in the uniform, single-species *S. albidia* forest, PC3, in Sarawak peat swamp forests (Anderson, 1961b). Large spatial and temporal variation is probable, but not yet well documented. Proctor *et al.* (1983b) estimated eaten leaf area of fallen leaves in four forest types in Mulu. They stratified the frass in “20%-area removed” classes and counted leaf frequencies in each class of fallen leaves. The results showed relatively uniform values in the four forest types (Proctor *et al.*, 1983b, Table 8). The frequency distribution indicates an overall reduction of leaf area by frass of 7–8%. There is a weak ranking Alluvial > KF > MDF > Limestone forest. Herbivory in the generally animal-poor KF

would have been expected to be substantially less than in MDF because of the microclimatic and productivity limitations on microbial and animal life. However, the concentrated food source in the simple, species-poor KF probably favours contagious pest expansion.

The more complex, vertically more integrated structure of an aerodynamically rough canopy is a more diverse habitat and can harbour more species of animals and plants than a smooth, simple canopy. A greater number of tree and other plant species in a rough canopy would also support more species, and a larger number of animals, pollinators, decomposers, pests and predators. The traditional concept of permanent forest (Dauerwald) uses this linkage to maintain high levels of biodiversity and self-sustainability. The main criteria of self-sustainability in forestry practice are the balance between litter production, decomposition and humus formation, and the effectiveness of biological regulation and pest control. Integrating key indicators are the humus type, reflecting the state of soil biology and ecology, the non-tree and tree ground flora and the diversity of mammals, birds and insects (Möller, 1922, 1929). Also possibly important, but largely unknown in their role as indicators, are epiphytes and dead organic matter in the canopy (including humus) (Paoletti *et al.*, 1991) which provide habitat for animals. There are no quantitative studies on the complex relationships between the floristic and spatial structure of the canopy and animal life, nor is there much information on the interaction between orderly, careful harvesting and diversity in the rainforest (Kitayama, 2013). Understanding this relationship better is an important prerequisite for designing and integrating sustainable harvesting, silvicultural management and conservation (including refuge habitats) in forests, and for designing integrated landuse pattern in landscapes. The results of the trapping in the four forest types in Gunung Mulu National Park (Proctor *et al.*, 1983b) and results of comparing the fauna in successional stages of the restoration sequence of ecosystems on barren coastal lands in the CERP ecosystem study

(Bruenig *et al.*, 1986b) suggest that interaction between successional stage and faunal richness and diversity exists, tempered by the effect of the sub-formation community and site type. The close relationship between forest structure, particularly to the leafage pattern in the D/A-storeys, more than to the tree species mixture, and birdlife in temperate and tropical natural and managed forests, is well known and documented (Bruenig, 1971c; Kikkawa, 1982; Kitayama, 2013). There is also evidence of ecological association between avian variables such as bird abundance, bird species richness and diversity, and various measures of vegetation structure including plant species composition and life form, vertical and horizontal stratification, canopy roughness, and patchiness (Kikkawa, 1982; Böttcher, 1987; Thieme, 1988; Ellenberg, 1985; MacKinnon and Freeman, 1993; Fig. 1.27). “The main group of phytophagous birds and animals live in the top of the canopy, the other zones contain fewer primary consumers. Studies in greater detail have led to the discovery of considerable subtlety in niche differentiation” (Whitmore, 1975a, p. 38). Canopy roughness and complexity could be indicators of this subtlety. Self-sustainability and sustainable forest management and conservation, to a large measure, depend on the preservation of this subtlety. Carefully adapted harvesting and appropriate silviculture can maintain or even increase the floristic and geometric structural diversity needed for the niche differentiation that may be essential for adequately functioning biological self-regulation and regeneration.

A most intriguing and novel use of the correlation between canopy physiognomy (physical structure) and habitat preferences of an animal has been made by Stimpson (2012), postulating that wing morphology (wing shape, loading and aspect of the wings in flight), the techniques of echolocating by signals and the methods of catching prey all are designed to make optimal use of the hunting habitat of a bat species and are an indicator of its habitat (open air, open or dense canopy) and adapted flying mode when hunting in these different



**Fig. 1.27.** The number of birds counted in censuses in broadleaf, mixed broadleaf-conifer and conifer forest stands in relation to the aerodynamic roughness  $z_0$  of the canopy, estimated from canopy stature (tree height). All three regression lines are statistically highly significant. (From Böttcher, 1987 (47 diverse stands, size range 6.3–25 ha); Ellenberg, 1985 (15 diverse stands sampled by 25 1-ha plots); and Thieme, 1988 (17 uniform stands of Scots pine, size range 13–18 h.)

and specific habitats. Therefore, wing morphology and echo locating system give an indication of the physical structure of the hunting habitat of a bat species. He determined the species identity of bat bones which had been recovered in 22 dated assemblages during archaeological excavations in the Great Niah Cave, Niah National Park, Sarawak. The morphology of the distal articulation of the humerus (outer bone of the wing) of seven families and nine genera of bats could be identified, and the specific identity of five species could be determined. The 22 assemblages formed a time series spanning the period 48,000–350 a BC, incorporating samples from the warm interglacial interval (26,000–18,000 a BC) and the LGM (23,000–19,000 a BC). The bones of bat taxa that are adapted to forage in the cluttered environment of a closed TRF canopy (named “Strategy I” bats) were used as proxy evidence for the presence of closed, complex forest canopy existing in the vicinity (<30 km radius from roost) of the Great Cave. Strategy I bats are principally small (*Hipposideros* spp.) and have a distinct wing morphology which makes them agile, nimble flyers. Strategy I bat bones were identified in all examined 22 assemblages of the time series. Statistical testing indicated no evidence of differences in the absolute frequency of distal humeri of Strategy I bats in the samples from the Pleistocene (48,000–11,800 a BC) and Holocene (11,800–350 a BC). No significant linear trend was found in the time series to suggest an increase in numbers of the bones of Strategy I bat taxa with the onset of the Holocene. These findings suggest a close association between habitat (cave as roosting site and closed canopy as hunting ground) and that closed-canopy forest habitats have been a persistent component in the landscape around the Great Cave of Niah since 48,000 a BC, when man appeared. But there seems to be some still unexplained contradiction between these findings, concluding that TRF in Borneo persisted as a refugium throughout the Quaternary, or alternatively, that there was a wider regional persistence of TRF, and a palynological pollen record of the site which suggest periods of more open

vegetation. The close association between animals and intact TRF, as demonstrated in this study, is now in Niah as almost everywhere in the biome, seriously threatened by large-scale habitat destruction. In 1972, closed-canopy lowland MDF covered two-thirds of the 1300 km<sup>2</sup> Niah river catchment; the rest was modified by customary shifting (swidden) agriculture along the rivers. The former Rajah’s ban on commercial plantations was still showing an effect here at Niah, and equally in the whole state. By 2002, MDF covered only 27% of the land after logging (timber mining) and subsequent conversion to oil palm (*Elaeis guineensis*) plantations. In this context, the 31,400 ha MDF in Niah National Park are a valuable vestigial remnant of habitats that were present in the local landscape for at least 48,000 years. However, it is debatable how “ecologically representative” this eventually unavoidably isolated remnant forest will be considered in future. Already now, the changes in the structure of the landscape around the Gunong Subis are assumed to have had a negative impact on the abundance and diversity of insects, and records show severe and rapid decline of the populations of cave swiftlets and insectivorous bats of the Great Cave populations (extracted by the author from the abstracts and text of Stimpson, 2012). A census of the orang hutan population, counting nests in canopies of different logging-disturbance status and position to water and mineral sources on aerial photographs, showed the high level of adaptability of this assumedly pristine-forest-only animal (Kitayama, 2013, pp. 113–128). This ability of animals to adapt to man, provided they are not an easy prey of ruthless hunting (as were the large and slow wisent in Europe and the bison in America) or total habitat destruction. The forest-living fox and the small roe deer in Europe have infiltrated suburban residential areas, and foresters’ flower and vegetable gardens and backyards, in the search for food or shelter. Some formerly extremely shy virgin-forest birds, like the blackbird in Europe, have become completely domesticated garden pests. This inherent ability of most animal species to adapt to humans,

their activities and habitats is well known to tree fellers and foresters in Germany, but not always acknowledged by conservation fanatics. The provision of sufficient species-specific ground for roaming and seasonal migration is essential in TRF, if necessary by corridors – which unfortunately the animals quite often quit in favour of more attractive cultivated land – and by the maintenance of the unique structure of the TRF in Totally Protected Areas (TPA) and by CNF silviculture and Low-Impact Logging (LIL or RIL) in management and conservation.

### 1.11 Small-scale Dynamics, Regeneration, Sub-Formations and Early Growth

The floristic, faunal and spatial structures of the TRF are extremely heterogeneous, variable and constantly changing. Gap formation is equally heterogeneously distributed over time and space, depending on site, canopy structure and fluctuations of the causal factors (Bruenig, 1966, 1973b; Bruenig *et al.*, 1979; Hall, 1994). The composition, distribution and successional development of tree-species associations are determined by many interacting biotic and abiotic factors of site, internal gap-mosaic dynamics and external disturbances (Section 1.6). Flowering, fruiting, seed viability and dispersal are affected largely by climatic and faunal factors. The coincidence of favourable or unfavourable conditions of weather, pollination, pests and diseases during flowering and fruiting influences the amount and quality of seeds. Weather, soil conditions, transmissibility of light for crowns and canopy, and predators determine the subsequent chances of germination, establishment and growth of the seedlings. Microhabitat conditions and their haphazard changes determine the chances of survival and growth of the saplings. The rate of mortality from seeds to over-mature tree proceeds theoretically by a negative exponential curve of population decline (Sheil *et al.*, 1995). In reality, mortality occurs in unpredictable leaps and bounds related to accidental combinations of mostly non-linear relationships of causal

factors which affect different species differently. The negative exponential selection-forest tree frequency curve and stand-table projection are, therefore, idealistic generalisations, and little more than a theoretical background concept in a silviculture management system (SMS). Reality requires more sophisticated models (Bruenig *et al.*, 1991). Summary reviews of the ecological aspects of fruiting, seed dispersal, gap formation, establishment and growth of trees in the rainforest are given by Whitmore (1975a, 1990) and Longman and Jenik (1987). The periodic fluctuations of abundance of seedling regeneration in closed TRFs are rather similar to conditions in temperate broadleaf forests, but the spatial heterogeneity of conditions within a forest stand is much greater in the species-richer rainforest. Flowering, fruiting, success of establishment and subsequent growth are even more unpredictable than in temperate forests. The high rate of light extinction throughout the year in the evergreen mesophyll canopy (Fig. 1.18) makes seedling establishment, survival and growth more hazardous than in seasonally deciduous forests. Consequently, regeneration requires either natural gap formation or fairly drastic opening of the A- and B-layers of the canopy to provide more light, and also more nutrient for rapid growth and more water to survive erratic drought. Conditions are fundamentally different in sclerophyll/microphyll forests where the illumination at ground level is several times stronger than in the “zonal” rainforest (Figs 1.18 and 1.25).

In zonal, and particularly in edaphic forest formations (Table 1.2), in ecotones and in successional forest, the absence or presence of seedlings of the canopy species, or the presence of invading species, are not absolutely reliable indicators of the dynamic trends in the community. Well-documented cases are the initial misinterpretations of observed absences of regeneration of *S. albigata* in Alan bunga PC3 and the presence of *G. bancanus* in the understorey of Alan PC2 (Section 6.7) in peat swamp forests, and of the presence of invading MDF species in KF (Anderson, 1961a, 1964, 1983; Wood, 1965; Bruenig, 1966). It is safer and more in

accord with the natural dynamics to work with trees in the “great period” of growth (ca 40–80 cm trunk diameter) in SMS, and leave seedling regeneration to nature (Sections 3.5 and 6.4).

The significance for predictably successful regeneration of the relative roles of seed abundance, and of limitations on success during germination and seedling establishment in natural and manipulated tree communities, has vexed silviculturists and forest farmers in Europe at least since the early days of planned use of natural and planted forests possibly more than a millennium ago. During the development of the Malesian Uniform System, its essential component, the enumeration of regeneration before the decision to go ahead, was hotly debated among foresters and in *The Malayan Forester*. The main issues were its ecological sense, silvicultural usefulness and management relevance. The Milli-Acre Regeneration Sampling or Milli-Acre Linear Regeneration Sampling, in short the Milli-Acre Survey (Wyatt-Smith, 1995) question remained open in spite of much research and discussion in the 1950s and 1960s. All three issues remained elusive. The question of the relative significance of seed abundance and seedling-to-sapling establishment continued to vex foresters and to elude the anxious silviculturists and forest planners in TRF for the rest of the 20th century. This is not surprising. The development of seedlings and saplings in the D-layer is chaotic in the MDF type of forest, as Jutta Poker (Poker, 1989, 1992, 1995) could prove by applying methods of system analysis, modelling and simulation to extensive data sets from West Africa and the tropical Asia-Pacific Region (APR).

Specifically, problem- and hypothesis-orientated research by sampling produced some indirect evidence by comparing seed or seedling spatial distributions and species richness with those of surrounding adults. The results of regeneration research in a long-term study in a Panamanian rainforest supported in the 1980s and 1990s the allocation of a pivotal role to seed limitation (Dalling *et al.* 1998, 2002; Hubbell *et al.* 1999), a conclusion which was not reached

in later studies by others in species-rich MDF in Borneo (Webb and Peart, 2001). Direct evidence may be generated by an experimental approach as applied by Norghauer and Newbery (2011) in a pristine African rainforest in Korup National Park, Cameroon. Propagules of two A-storey trees species were added to the natural seed fall from masting at eight different application levels to 63 gap-understorey subplots in a 82.5-ha research plot. The purpose was to test directly the strength of each of the two limitations to the success of natural regeneration by seed: seed and establishment (germination/development of seedling) limitation. The tested species were the ecto-mycorrhizal A-storey Caesalpiniaceae tree species *Microberlinia bisulcata* A. Chev. and *Tetraberlinia bifoliolata* (Harms) Haumann which masted in 2007. A third Caesalpiniaceae tree species, *Tetraberlinia korupensis* Wieringa had not masted and was excluded. The three tree species represented together 48% of G (basal area) >50 cm d, and 87% >100 cm d. The course of seedling establishment was monitored for 6 weeks. Seed rain into the plots was recorded and enumerated. Seedling recruitment was higher in seed-addition quadrats than in control quadrats, which according to the authors indicates seed limitation existing in both species. Addition of seeds to a rich seed-fall from a mast would therefore produce more seedlings. However, fitting the Beverton–Holt model indicated that establishment limitation was consistently 2–4 times stronger than seed limitation for *Microberlinia*, whereas seed limitation greatly exceeded establishment limitation for *Tetraberlinia*. Strong density dependence was operating in the short seed-to-seedling transition for *M. bisulcata*, whereas it was almost negligible for *T. bifoliolata*. Although early post-dispersal mortality was very high for both species (80%), they may achieve local co-dominance as a result of differing strengths of seed limitation versus establishment limitation. Assessing the importance of seed limitation for tree populations requires knowledge of the species-specific seed rain feature, as well as reliable information on establishment and recruitment

functions. The outcome of early establishment processes also needs to be seen in the context of later stages of tree dynamics (adapted from authors' abstract). The authors conclude:

our study demonstrated that natural enemies through their interaction with type of forest canopy cover (gaps versus understorey) could play a fundamental role in the early post-dispersal dynamics of the two dominant Korup species. They can do this by modulating the relative effects of survival and growth across varying levels of canopy cover to generate both potentially equalising forces: in the form of satiation of small mammals in gaps by a more light-demanding species, such as [*M. bisulcata*], and apparent competition between species in the understorey; and by stabilising forces: in the form of differential species-specific mortality from enemy guilds and compensatory attacks, and density-dependent insect herbivory in gaps (on the more light demanding [*M. bisulcata*] in gaps). The relative strengths of these forces, however, likely change when considered over longer time scales, and so too, might their net effect upon forest structure and species composition. In either context, this suite of important enemy-mediated processes can help determine and shape the seedling abundance and distribution of coexisting tree species after masting events in this primary tropical rain forest

(Adapted from Norgbauer and Newbery, 2011, p. 465)

This sounds very complicated and esoteric, but accords with my own practical experience in temperate and tropical forests. I agree with the authors that “Environmental stochasticity in the form of coloured noise may therefore be causing a major part of the variation in rainforest dynamics and explain its complexity”, and conclude that the best chances of reducing risk of failure and increasing the chance of success in such situations of complexity and uncertainty would be to mimic nature by some form of CNF, and not by aiming at maximising approaches to gain profit.

The following scheme gives a simplified overview of common situations in primeval/pristine or slightly disturbed TRF in SEA/Asia-Pacific Region (APR), especially in

Borneo (compare profiles in Figs 1.11, 6.6 and 6.7) at the state of knowledge in the mid-1990s.

1. Complex, mesic “zonal” rainforest on “zonal” soil, regeneration patchy and fluctuating according to the seedfall, pest-and disease-cycle fluctuations and the weather conditions (mortality due to drought), but on average and over larger areas, adequate (e.g. majority of lowland MDF types, such as the mosaic-patterned “Red meranti keruing” and “Balau” types in Pasoh described by Manokaran *et al.*, 1991). The stocking of A-layer species in the intermediate size classes (C- and B-layers) depends on the local disturbance regime (gap formation). The sub-canopy layers B and C and the ground vegetation D play an important role as matrix through which the light-demanding A-layer species struggle to the top when gaps are formed naturally or by harvesting or silviculture. This reduces the tendency to overcrowding especially after mast years. This filtering effect of the understorey matrix is an essential feature of natural regeneration mechanisms in primeval and in managed forests in the species-rich and diverse zonal forest formations such as the Malesian MDF.

According to Newbery and Lingenfelder (2009):

Drought perturbation driven by the El Nino Southern Oscillation (ENSO) is a principal stochastic variable determining the dynamics of lowland rainforest in SEA. Mortality, recruitment and stem growth rates at Danum in Sabah (Malaysian Borneo) were recorded in two 4-ha plots (trees  $\geq 10$  cm gbh) for two periods, 1986–1996 and 1996–2001. Mortality and growth were also recorded in a sample of subplots for small trees (10 to 50 cm gbh) in two sub-periods, 1996–1999 and 1999–2001. Dynamics variables were employed to build indices of drought response for each of the 34 most abundant plot-level species (22 at the subplot level), these being interval-weighted percentage changes between periods and sub-periods. A significant yet complex effect of the strong 1997/1998 drought at the forest community level was shown by randomisation procedures followed by multiple hypothesis testing. Despite a general resistance of

the forest to drought, large and significant differences in short-term responses were apparent for several species. Using a diagrammatic form of stability analysis, different species showed immediate or lagged effects, high or low degrees of resilience or even oscillatory dynamics. In the context of the local topographic gradient, species' responses define the newly termed perturbation response niche. The largest responses, particularly for recruitment and growth, were among the small trees, many of which are members of understorey taxa. The results bring with them a novel approach to understanding community dynamics: the kaleidoscopic complexity of idiosyncratic responses to stochastic perturbations suggests that plurality, rather than neutrality, of responses may be essential to understanding these tropical forests.

(Newbery and Lingenfelder, 2009, p. 147)

The conclusions fit better to observations and empirical experience in forestry practice. The basis to the various responses lies with the mechanisms of tree-soil water relations which are physiologically predictable: the timing and intensity of the next drought is not. To date, environmental and tree response and stochasticity (Poker, 1989, 1992, 1995; Lingenfelder and Newbery, 2009; Newbery *et al.*, 2011; Newbery and Stoll, 2013) has been insufficiently incorporated into models of tropical forest dynamics, a step that might considerably improve the reality of theories about these globally important ecosystems.

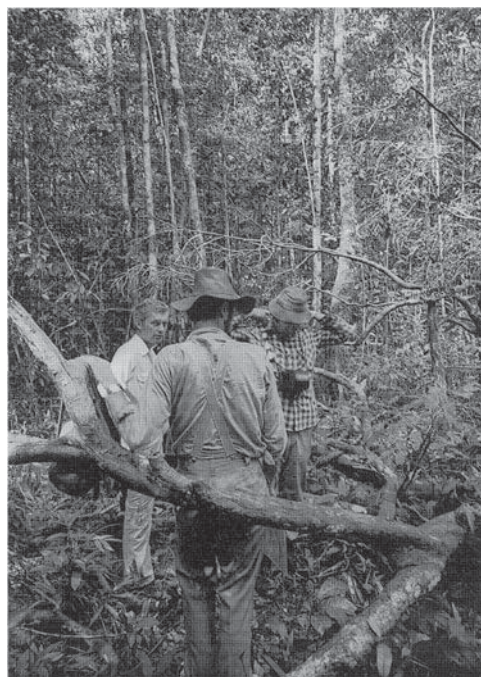
2. The same forest formation, but consistently (except immediately after seed years) deficient in regeneration, intermediate size classes of A-layer species poorer than in (1), sometimes completely lacking (e.g. Hill mixed dipterocarp *S. curtisii* forest in West Malesia, also most African rainforest types in a state of successional development).

3. Moderately complex, less mesic and more sclerophyll forests with more-or-less pronounced dominance of one or several A/B-layer species, seedling regeneration mostly sparse, but present as scattered singles or in patches, intermediate size classes patchy but adequate (e.g. complex tall kerangas with *A. borneensis*, *S. albida*, *D. beccarii*, *D. fusca* complex, tall caatinga

with *Eperua purpurea* Benth. (Figs 1.28 and 1.29), Yevaro mixed ramin-bearing peat swamp forest, PCI), regeneration, survival and growth of seedlings and saplings regulated by the dense C/D-layer matrix, and by occasional drought conditions.

4. As in (3) but more sclerophyll/xeromorph, intermediate (younger) size classes of the dominant species distinctly deficient or completely absent (e.g. tall and dense kerangas–kerapah ecotone with gregarious *S. albida* or *D. rappa* Becc.), differentiation of regeneration in the well-illuminated B-, C- and D-layers is strongly affected by drought-related mortality.

5. Simple, xeric, sclerophyll forest with smooth canopy and good illumination to the ground (Figs 1.18 and 1.25), ample regeneration of the species of the A/B-layer (e.g. kerangas forest *C. nobilis*, *Dacrydium pectinatum* de Laub., caatinga with *Micranda sprucei*), regeneration primarily controlled by hydrological conditions.



**Fig. 1.28.** Impact area of the crown of a large wind-felled *Eperua purpurea* in high caatinga forest (Fig. 1.18, Yevaro-Yaquacana forest ecotone). MAB International Amazon Ecosystem Study, San Carlos de Rio Negro, Venezuela.



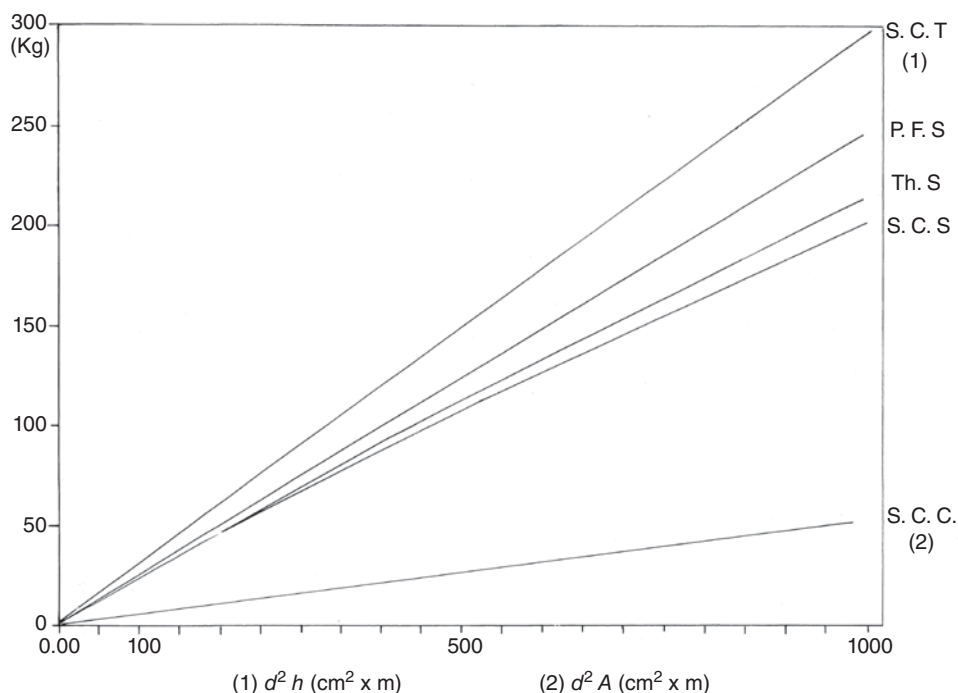
**Fig. 1.29.** Canopy gap caused by the fall of the tree in Fig. 1.28. The crowns of the edge trees close the gap within 10–15 years from the sides (A/B-layer trees), while the regeneration in the C/D-layer rushes upward.

**6.** Single-species dominant forest, regeneration of seedling and sapling size rare or absent, only sporadically and ephemerally dense after mass fruiting, inadequate intermediate size classes, densely closed, uniform main canopy of uncertain age structure and not even-aged (e.g. peat swamp forests with *S. albidia*, FT36, PC2 and FT37, PC3, occasionally vicarious species, not occurring in Amazonia or Africa). The regeneration mechanisms in these forests are still a complete mystery. Tracts defoliated by ulat bulu, or that are clearfelled, do not seem to regenerate.

### 1.12 Forest Biomass, Stocks and Accretion

The primeval rainforest has been successful in coping with the variable natural environment over millions of years on a wide

variety of soils and sites. The amount, structure and physiognomy and dynamics of the primeval forest biomass should be expected to accord with the requirements of self-sustainability. Therefore, the primeval rainforest can provide baseline information for developing rational strategies of forest management and conservation, but data are scarce (Whitmore, 1975a, 1990, 1991). Data on amounts and structure of forest biomass in small plots can only be meaningfully generalised if the position of the sample in relation to the pattern of spatial and temporal variance of the surrounding forest is known (Bruenig, 1973d; Kurz, 1983). Few cases fulfill this condition. Most biomass data are from small plots on some insufficiently defined sites that were selected subjectively from an area of diverse, heterogeneous TRF with some purpose in view. In Sarawak, the 57 single plots in the kerangas study 1955–1963 and one plot in Alan bunga PC3 were subjectively selected in mature and intact patches to assess the tree biomass above ground in a simple management-orientated manner to get data to support the refusal of an application from Japan for chipwood supply from Sarawak (Bruenig, 1966, 1974). The International Amazon Ecosystem Study at San Carlos was the first to assess biomass in TRF in a manner that integrated biomass assessment with large-area structural analysis in a range of sites along an ecological gradient with ten different forest types (species association groups (SAG) H–Q in Bruenig *et al.*, 1979). H. Klinge harvested 1543 trees and their fresh- and dry-weight biomass was determined. Various biomass regressions were developed and applied to the population of 13,920 trees in the 10-ha research area (Kurz, 1983), which were enumerated according to the harmonised MAB-IUFRO methodologies (Bruenig and Synnott in Bruenig, 1977b; Synnott, 1979). The regressions of the dry-weight of the tree trunk and for branch weight are reproduced in Fig. 1.30. Trunk and branch weight add to total biomass, but separate regressions were necessary because the best fits were obtained with different independent variables ( $d^2h$  for trunk weight;  $d^2A$  for branch weight, where  $A$  is crown diameter



**Fig. 1.30.** Linear regression of tree biomass over structural tree parameters  $d$  (diameter of stem),  $h$  (total height of tree) and  $A$  (sectional crown area) (from Kurz, 1983). SCT: San Carlos total wood biomass above ground; PFS: Pasoh forest, MDF, stemwood (Kira, 1978) (1); Th.S.: Thailand semi-evergreen, stemwood (Ogawa *et al.*, 1965) (1); SCS: San Carlos caatinga and bana, stemwood (1); SCC: San Carlos caatinga and bana, crownwood (2).

$\times$  crown length). Stratification by forest type did not improve the fit. The regressions were then used to compute the standing above-ground dry weights and leaf areas of the 13,920 trees in the 10-ha research plot. Biovolume ( $BV = L \ 0.5 \ g. \ h$ ) was calculated, stratified by canopy layer. Biovolume is quick and easy to calculate from enumeration data and is a useful indicator of biomass, if the differences in timber specific gravities between forest types are considered. The results for the various forest types (association groups) are shown in Table 1.8. The amounts of biomass in the diameter classes 1–5 cm and 5–13 cm (C- and D-canopy layers) are inversely correlated ( $R^2 = 0.94$ ) with the biomass densities in the 15–20 and  $\geq 30$  cm diameter classes. This makes it possible to simplify biomass assessment considerably by subsampling procedures. Leaf area index and leaf weight are

correlated with the independent variables  $d^2h$  ( $R^2 = 0.756$ ) and  $d^2A$  ( $R^2 = 0.746$ ). The tree height  $h$  and the crown sectional area  $A$  in turn are positively correlated with the aerodynamic roughness. These relationships can be used for pre-stratification and assessment on aerial photographs of biomass stocking and of changes over time.

The biomass assessment approach of Klinge *et al.* (1974), Klinge and Herrera (1978), Kurz (1983), and the work of Ogawa *et al.* (1965) and Kato *et al.* (1978) have produced regression equations which make destructive complete biomass harvesting in TRF unnecessary. Total biomass and the proportions of the various components, including roots if the soil type is known, can be estimated from parameters that are relatively easy to enumerate. The total-tree biovolume  $\geq 1$  cm diameter was accordingly calculated from the enumeration data of

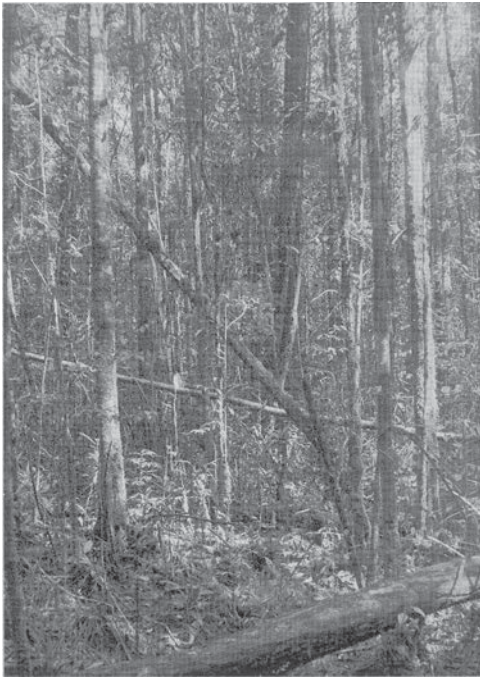
**Table 1.8.** Basal area (G), above-ground oven-dry tree biomass of stem, crown and twig wood (SCT), leaf area index (LAI) and leaf area per biomass unit in the ten tree-species association groups (SAG, landform-soil type-plant sociological (trees and ground vegetation) units) in the International Amazon Ecosystem MAB-Pilot project near San Carlos de Rio Negro, Amazonia, Venezuela. (From Kurz, 1983, table 541–2; dead-wood distribution data previously published only as map in Bruenig *et al.*, 1978, 1979.)

Forest types and species association group (SAG)						
Forest type	SAG	G (m <sup>2</sup> ha <sup>-1</sup> )	SCT (t ha <sup>-1</sup> )	LAI (m <sup>2</sup> m <sup>-2</sup> )	LAI/SCT (m <sup>2</sup> kg <sup>-1</sup> )	Deadwood >10 cm (t ha <sup>-1</sup> )
Complex transitional caatinga, yevaro SAG	I	41.2	330	3.7	0.11	35.0(10.6%)
Yevaro–cunuri SAG	H	38.5	270	3.6	0.13	
Complex cunuri caatinga (2 SAG)	J	37.5	236	3.7	0.16	26.0(10.5%)
	K	39.1	259	3.5	0.13	
Simple cunuri–yucito caatinga (3 SAG)	L	35.9	208	3.7	0.18	
	M	37.5	233	3.6	0.16	28.2(10.1%)
	N	40.9	278	3.8	0.14	
Wet caatinga → alluvial	O	36.9	232	3.3	0.14	33.7(14.5%)
Ecotone caatinga → Bana	P	33.8	136	3.1	0.22	31.7(23.3%)
Bana (open woodland)	Q	16.8	57.7	1.4	0.24	6.6(11.4%)

nine of the 57 kerangas plots, and measured in one clearfelled plot in *S. albida* peat-swamp forest, PC3. All plots were fully stocked patches in mature-phase stands representing the maximum biomass-carrying capacity of their respective sites. Biovolume was converted to dry-weight by specific gravity values obtained from weighing wood samples (*S. albida*, *D. fusca*, *A. borneensis*) and from the literature. The total tree dry-matter above ground of trees ≥1cm diameter varied widely between forest types. The lowest value was in a kerapah (Fig. 1.31) forest with 215 m<sup>3</sup> wood volume ≥5 cm and 246 t total plant dry-weight above ground per hectare (basal area G 27.3 m<sup>2</sup> ha<sup>-1</sup> and top height 30 m). A biovolume of 1279 m<sup>3</sup> ha<sup>-1</sup> was enumerated in MDF on deep rich basaltic soil (SPI0, *h* 62 m, rough canopy, G 55.5 m<sup>2</sup> ha<sup>-1</sup>). A biovolume of 1269 m<sup>3</sup> ha<sup>-1</sup> was determined by complete harvesting in *S. albida* peatswamp forest PC2/3 (*h* 42 m, moderately rough to moderately smooth canopy, G 38.2 m<sup>2</sup> ha<sup>-1</sup>) and 1381 m<sup>3</sup> ha<sup>-1</sup> estimated from tree enumeration in *S. albida* kerangas/peatswamp ecotone (Fig. 1.32) on ground water humus podzol (*h* 41 m, closed dense canopy, G 67.7 m<sup>2</sup> ha<sup>-1</sup>). The mean



**Fig. 1.31.** Ecotone between lowland *Shorea albida*-bearing kerangas on podzol (Fig. 2.9) and kerapah on peat. High mortality, dead-wood stocks and species diversity. Pueh F.R., Sarawak.



**Fig. 1.32.** Ecotone, edaphically similar to that in Fig. 1.30, between *Agathis*-bearing kerangas and *Shorea albida*-bearing kerapah on the Merurong plateau, 750 m a.s.l. Mortality and dead wood stock, and tree-species diversity are higher in the ecotone than in the adjoining forest types.

biovolume of the 53 kerangas and kerapah survey plots, all in mature, closed forest patches, was  $590 \text{ m}^3 \text{ ha}^{-1}$  (mean top  $h$  38.5 m, mean  $G$   $36.5 \text{ m}^2 \text{ ha}^{-1}$ ). The actual biovolume and biomass stocking over larger tracts in these forests are lower as a result of young gaps (1–5 year old gaps average 0.5–2% of area) and low biomass density in the subsequent building phases. The variation of basal area of the various statistical tree populations in the 20-ha RP 146, Sabal Forest Reserve (data of 1963, mean  $G$   $32.5 \text{ m}^2 \text{ ha}^{-1} \geq 10 \text{ cm}$ , mean top  $h$  38.5 m) suggests that the mature-plot values had to be reduced by approximately 25–30% to arrive at an estimate of the most probable mean value for large tracts of natural primeval forest (Bruenig, 1966, 1973d, 1974).

The biovolume and biomass of dead wood (coarse litter including standing dead trees and stumps) were assessed in San Carlos de Rio Negro in 1975 (Bruenig *et al.*, 1979)

and in the Sabal RP 146 in 1988–1990. The proportion of dead wood is consistently, and with little variation between forest types and regions, about 9–15% of the total above-ground live and dead tree biomass, or 10–17% of the live tree biomass. The data for San Carlos are shown in Table 1.8. The dead tree biomass  $\geq 10 \text{ cm}$  diameter was enumerated, mapped and assessed in the newly enumerated 16-ha of the Sabal RP 146. The standing dead trees on the 7-ha MDF, selectively logged in 1978, amounted in 1990–1991 to  $15.0 \text{ m}^3 \text{ ha}^{-1}$  biovolume and  $16.5 \text{ t ha}^{-1}$  total dry-weight woody phytomass. Fallen tree trunks and branches were  $167 \text{ m}^3 \text{ ha}^{-1}$  and  $63 \text{ t ha}^{-1}$  (Table 1.6). The total dead-wood biomass  $\geq 10 \text{ cm}$  diameter was  $117.0 \text{ t ha}^{-1}$ , amounting to 22.9% of the total living and dead tree biomass above ground of trees  $\geq 10 \text{ cm}$  diameter of  $512.2 \text{ t ha}^{-1}$ , or 29.6% in comparison to the biomass of living trees of  $395.2 \text{ t ha}^{-1}$  (Bruenig and Droste, 1995; Tables 2.2 and 6.2). In the KF, creamed mainly for *A. borneensis* in the *A. borneensis*-type, the standing ( $37.7 \text{ t ha}^{-1}$ ) and fallen ( $40.7 \text{ t ha}^{-1}$ ) dead woody phytomass totalled  $78.4 \text{ t ha}^{-1}$ , or 14.3% of the total phytomass and 16.6% of the living phytomass (Table 1.6). Klinge *et al.* (1974) reported a dead-wood dry weight biomass of  $25.8 \text{ t ha}^{-1}$  from a 0.2-ha plot in tierra firme forest adjacent to the W. Egler Forest Reserve near Manaus (forest stand MA in Fig. 1.23). This amounted to only 4.4–5.7% of the 450–500  $\text{t ha}^{-1}$  total dry tree biomass. They also reported a dry weight of  $250 \text{ t ha}^{-1}$  ( $25 \text{ kg m}^2$ ) of SOM which gave a total of  $750 \text{ t ha}^{-1}$  dry weight of living and dead phytomass. Yoneda and Tamin (1990) assessed the states and flows of the standing dead-wood matter of trees  $>10 \text{ cm}$  and fallen wood  $>10 \text{ cm}$  in two 1-ha plots in upper-lowland dipterocarp forest in West Sumatra. The enumeration was repeated six times over 5 years. The living standing tree above-ground biomass over bark  $\geq 10 \text{ cm}$  in one plot was  $519 \text{ m}^3$  and  $408 \text{ t ha}^{-1}$ . The dead-wood biomass  $\geq 10 \text{ cm}$  diameter in the same plot was  $116 \text{ m}^3$  or  $39 \text{ t ha}^{-1}$ , equalling 22% of the volume and 9.5% of the weight of living standing biomass  $\geq 10 \text{ cm}$  diameter, or 18% and 9% respectively of the total living

and dead standing tree biomass of 635 m<sup>3</sup> and 447 t ha<sup>-1</sup>. The conversion factors for volume to phytomass used by Yoneda and Tamin obviously differ from those used by us, but the values are within the range of data from RP 146, Sabal, Sarawak (Table 1.6).

Since the early 2000s, there has been a flurry of research on biomass stocks in TRF, but the estimated values do not deviate significantly from those known already and published during the UNESCO-MAB programme and the SCOPE-Carbon project. Methods of biomass, carbon stocks and turnover were refined in connection with the carbon sequestering incentive schemes and the role TRF had been assigned for the mitigation of GCC. Refinement has reached a point where the question arises: how much refinement and apparent precision do we want and need for the overdue political decisions and actions? This is the same situation and question put by foresters and forest owners in the field of satellite-based remote sensing: how much refinement, how much image quality do we need for monitoring, checking and decision making in forest management and policy? In addition, there is increasing interest in whether and how GCC or any extreme climatic oscillation changes phytomass production and decomposition rate in the TRF. Most publications on the subject re-digest existing publications, some are purely speculative assumptions to support external, non-forestry and non-environmental financial interests, and very few contain new and substantial scientific information of relevance to the real problems. A selection of these has been reviewed in this book.

The structure and amount of the phytomass of the trees in the rainforest have manifold functions. The phytomass provides a multipurpose protective semi-transparent and interceptive filter, is the exchange interface between atmosphere and the soil, functions as a medium- to long-term store of nutrients and supplies organic matter to the soil. Modification and manipulation of structure and amount of tree phytomass by harvest and silviculture will affect these functions. It is the science-based art of the forester to find the range within which the

phytomass can be manipulated safely without unacceptable risks (Section 6.2). The phytomass is a constantly flowing slow-release (wood) and instant (leaves, exudates) source of organic matter which mulches the soil at ecosystem scale, which in itself is constantly changing in an unpredictable manner due to internal indeterminism (Heisenberg Principle; Spemann, 1935), exogenous stochastic events, which, superimposing on more regular cycles such as ENSO and Indian Ocean Mode, in the forest ecosystems cause risk and uncertainties.

### 1.13 Forest Growth, Productivity and Production, Above-Ground and Soil Organic Matter (SOM)

Productivity of the ecosystem in this context is the rate of annual net primary productivity (NPP), which is the apparent gross photosynthesis (GPP) minus respiration from leaves, branches, stem and roots of a tree or a tree community. The NPP is allocated to various parts of the tree, metamorphosed and stored or used as a source of energy for maintenance and growth. Phytomass is constantly converted to litter and exudate and released in and above the soil. The biological net primary productivity and production (BNP, annual rate or sum over a period) supply the material for primary economic productivity (the process and rate) and production (the product and yield) of commercial products. How much of this is actually merchantable and extractable will be determined by the current economic and political environment and the safe range of phytomass manipulation (Section 1.12). For timber, the rate of effective PEP of the potential varies from 80% (full utilisation in RIL) to 20–40% (selective logging), to less than 5% in native customary collecting of speciality timber for sale or own use. Growth in this context is the change over time of tree height, stem diameter, stem form and of roots and consequently of biovolume and biomass, and of PEP.

Conventional timber-orientated inventories of forest growing stock and studies of

growth and yield give little useful information to assess the potential or actual BNP or PEP. First, information on site (soil, hydrology, biology, atmospheric, physical and chemical conditions, climate), vegetation and tree growing stock is usually inadequate. There are rarely data to relate site conditions to tree performance. Increment and yield are usually expressed in units of some arbitrarily defined merchantable volume content and based on the means of tree populations which are neither representative nor relevant to the problems in forestry practice. Yield tables are based on unrealistic assumptions of uniformity, stability and equilibrium of the forest and its natural and economic environment. Often simplistic linear regressions of growth that do not accord with the range of complexity and variability of reality (see also Kimmins, 1988) are used. The merchantable volumes change if standards of grading and utilisation change in accordance with law enforcement and market conditions (Vanclay, 1991c; AIFM, 1993). An early step towards improvement of PEP assessment was the variable timber volume table for *S. albidia* by Haller (1969). The PEP estimates of merchantable timber volume were flexible according to different grading standards and timber defects. Essential improvements for estimating the growth of trees and stands were the various types of model simulation for TRF tree and stand growth, and merchantable yield (Bossel, 1989; Vanclay, 1989, 1991a, b, c, 1994; Korsgaard, 1992; Ong and Kleine, 1995) as tools for long-term planning of integrated sustainable management and conservation. However, these sophisticated tools were rarely applied in the differently orientated practices of state forestry and private logging companies. This has only changed marginally at the beginning of the 21st century. Only some of the bigger, environmentally and socially responsible timber companies and state forest services seem to be sufficiently concerned and financially or politically strong enough to use these tools and to test possible strategies of approaching sustainability in the TRF (for examples, see Chapter 5).

The conventional yield tables, based on simple or multiple linear regression, and

stand-table projection models, still prevail, but cannot cope satisfactorily with the heterogeneity of sites and forests, the variability of growth dynamics of trees in complex mixed forest stands and the effects of variable utilisation standards. Therefore, they are of limited value for productivity assessment even of single species, and even less so of mixed forest stands. Trees in the aseasonal evergreen TRF exhibit marked rhythms of stem growth (diameter or basal area growth) that vary widely between trees of the same species within a community, between different radii within one stem, and between species, in a manner that is difficult to explain. Superimposed are the effects due to variation of flowering and fruiting, leaf fall and flushing, climatic events, damage, mortality and gap formation (Bruenig, 1971c; Wrobel, 1977). To overcome the information gap, a workshop on age and growth rate determination for tropical trees recommended solving the problem by means of an international network of study plots with harmonised recording of ecological and growth data (Bormann and Berlyn, 1981) but the problem still exists in 2013. Roxburgh (Grove, 1997) would not have been surprised and might possibly even have been amused by the similarities to his problem of raising interest in acting against deforestation-related climate change (desiccation) 300 years later.

The root compartment within the soil probably consumes a large proportion of GPP and NPP. It is possible that the total amount of root litter and exudates may produce equal or even more organic matter for SOM formation than the leaf fall, if data from temperate forests can be used as an indication (Fahey and Hughes, 1994). The tropical database is especially small and improvements are expensive and difficult (Kurz and Kimmins, 1987). Kimmins (1988) recommends, for PEP assessments, a combination of the traditional linear-regression analysis of increment and yield ("historical bioassay") with analyses based on growth, increment and yield processes ("ecophysiological approach") in an ecosystem simulation procedure. His "hybrid" forest production simulation model FORCYTE-11 provides

such a modelling framework. The model includes factors that are of particular relevance to growth and yield assessment in TRFs such as nutrient and moisture inputs and fluxes, litter fall, decomposition, soil compaction, erosion and harvesting. The same principal process-based approach is adopted by Bossel (Bossel and Bruenig, 1992, Chapter 5). The unexplained and unpredictable variation of BNP and PEP of stands and trees above ground, and the lack of simple linear relationships between growth and growth factors, are the enigma of forestry growth and yield research and management planning. It is largely solved in temperate forests, but progress is slow in TRF research and practice.

After World War II, global and regional assessments of forest resource production potentials became fashionable. Climatic parameters such as rainfall, rainfall distribution, moisture, temperature and net solar radiation were used as independent variables to estimate potential gross and net phyto-mass production (Paterson, 1956; Weck, 1960, 1970). Since the 1960s, data processing has improved and more field data have become available for modelling NPP (Munn, 1981, 1984; Lieth, 1984). The review of gross and net primary production in UNESCO (Golley, 1978, Chapter 10) quoted theoretically derived rates of gross primary productivity (GPP) in rainforests between 56 and 89  $\text{t ha}^{-1} \text{a}^{-1}$  on a wide range of soils (Bruenig, 1966) and between 82 and 95  $\text{t ha}^{-1} \text{a}^{-1}$  on very good sites (Weck, 1960; Fig. 1.21). Measured values were 53  $\text{t ha}^{-1}$  (Müller and Nielson, 1965) from a plot in seasonal evergreen, assumedly pristine but probably very old secondary forest in Côte d'Ivoire, with high respiration; 119  $\text{t ha}^{-1} \text{a}^{-1}$  (Odum and Pigeon, 1970) from lower montane forest at El Verde, Puerto Rico; and 144  $\text{t ha}^{-1} \text{a}^{-1}$  (Kira *et al.*, 1967) from dipterocarp-bearing seasonal lowland moist evergreen forest at Khao Yong, Thailand. The amounts and variation of light and dark respiration in leaves and of respiration in the other parts of the plant are still factors of great uncertainty. In MDF in Pasoh, Malaysia, Whitmore (1990) added an estimated 50.5  $\text{t ha}^{-1} \text{a}^{-1}$  respiration to an NPP of 29.7  $\text{t ha}^{-1} \text{a}^{-1}$  which gave 80.2  $\text{t GPP}$  and came

very close to the classic estimate of Weck (1960). Whitmore's NPP estimate for Pasoh consisted of measured, estimated or guessed values for tree biomass increment (7.1  $\text{t}$ ), fine and coarse above-ground litter and root mortality (10.3, 3.7, 4.0  $\text{t}$ , respectively) and grazing (insects measured 0.3  $\text{t}$ , mammals and birds – guessed – 4.4  $\text{t}$ ).

Golley in UNESCO (1978, pp. 241–242, Table 3) gave five NPP values from TRF: Yangambi, Zaire 32  $\text{t ha}^{-1} \text{a}^{-1}$ ; Khao Yong, Thailand 29  $\text{t ha}^{-1} \text{a}^{-1}$ ; Pasoh, Malaysia 22  $\text{t ha}^{-1} \text{a}^{-1}$ ; El Verde, Puerto Rico 16  $\text{t ha}^{-1} \text{a}^{-1}$ ; and Côte d'Ivoire 13  $\text{t ha}^{-1} \text{a}^{-1}$ . Whitmore's value for Pasoh, 29.7  $\text{t ha}^{-1} \text{a}^{-1}$  NPP (Whitmore, 1990, Fig. 9.7 and Table 9.8) was higher than the 22  $\text{t}$  given by Golley (1978, citing Bullock's publication in Gist, 1973). Three different methods used in Pasoh to estimate GPP gave rather similar values (summation 80.2  $\text{t}$ , canopy photosynthesis 87  $\text{t}$  and  $\text{CO}_2$  flux 89  $\text{t}$ ; again corroborating Weck). The  $\text{CO}_2$  flux method gave an NPP value of 49  $\text{t ha}^{-1} \text{a}^{-1}$ , much higher than any of the other values. Measured coarse litter (branches and trunks or stems  $\geq 1 \text{ cm}$ ) fall per hectare between May 1991 and February 1973 (1 year 9 months) was 10.8  $\text{t}$ , with a wide variation between subplots of 3.7, 12.4, 10.1, 3.5 and 24.3. This added to the existing litter stock of 52.6  $\text{t}$ . Golley (UNESCO, 1978, Table 4) listed the leaf litter and total litter fall in 48 tropical forests; 12 of these are rainforests with a mean leaf litter fall of 5.1  $\text{t ha}^{-1} \text{a}^{-1}$ . Whitmore (1990) recorded 10.3  $\text{t ha}^{-1} \text{a}^{-1}$  leaf litter and 3.7  $\text{t ha}^{-1} \text{a}^{-1}$  coarse litter fall in a 0.8-ha plot in Pasoh. Coarse litter fall is naturally erratic and more variable in space and time than fine litter fall. The long-term value for coarse litter would probably be somewhat higher than 3.7  $\text{t}$ . Judging from the measured stocks of dead wood and the estimated decay times (Section 1.5) it may even be as high as almost twice the amount actually recorded by Whitmore (1990).

For the purposes of estimating the order of size of sustainable yield, we may tentatively assume that the potential NPP above ground ranges between 20 and 40  $\text{t ha}^{-1} \text{a}^{-1}$  on zonal soils and average lowland sites (Table 1.9; Fig. 1.21). From this about 20%

**Table 1.9.** Tree biomass (dry matter) above ground and annual net primary productivity (NPP) in tonnes in various tropical forest formation classes including the Malesian mixed dipterocarp forests: (a) values apply to the zonal forest formation; (b) values include the whole range of edaphic conditions (Bruenig, 1966, 1977b; Kurz, 1983; Lieth, 1984). Harvestable refers to current market conditions and the proper utilization in an orderly harvesting system (reduced-impact logging, RIL) with extraction by tractors or long-distance cable.

Forest formation class, resp. forest formation	Tree biomass stocking (t ha <sup>-1</sup> )		Total tree biomass on 1.6 × 10 <sup>9</sup> ha (t × 10 <sup>9</sup> )(1990)	Annual NPP (t ha <sup>-1</sup> )	
	Mean	Range		Average	Range
Predominantly evergreen wet (rainforest)	450	(a) 300–800 (b) 50–1500	180	25–30	(a) 20–40 (b) 3–40
Mixed dipterocarp forests:	550	400–1500	–	30–35	20–40
harvestable volume in SMS	50	20–100	–	5–10	2–15
Predominantly rain-green, seasonally moist	300	200–500	160	15–20	10–25
Rain-green, dry, closed	150	50–250	70	7	3–12
Predominantly rain-green, semi-arid, open	30	10–60	~ 10–20	1	0.5–2

has to be deducted for leaf litter and 30% for woody litter. The remaining 50% or 10–20 t tree biomass consists of crownwood (20–25%), bark (10–15%) and trunkwood (60–65%). The merchantable proportion of the trunkwood varies between 40 and 80% depending on site (e.g. hollowness), quality of utilisation (waste) and market conditions. The upper limit of PEP would then lie between a low of 6 t and a high (maximum) of 13 t on average lowland sites in natural rainforest. Natural damage and inefficiencies in management cause losses of about 20–30% in production and 15–25% in harvesting. We then arrive at a realistic estimate of potentially harvestable yield of 3.4–4.1 t ha<sup>-1</sup> a<sup>-1</sup> at a low production level and 6.8–8.3 t ha<sup>-1</sup> a<sup>-1</sup> at a high production level. How much of this can be harvested depends on external forces. Markets determine what species and timber grades are merchantable; political, social and private preferences determine intensities and efficiency of harvesting. Ecological considerations may demand the retention of part of PEP, especially of lesser used species (LUS) and non-commercial species, and of moribund giant trees for litter and seed production and as habitat. This, and the establishment of nature reserves and TPAs, may reduce the yield potential by another 10–30%. The comparatively

higher global net radiation balance and the species dominance pattern in Malesia make it likely that the potential PEP is generally higher than in Africa, possibly even in Borneo, in spite of the nutrient scarcity assumed for Borneo by Anderson *et al.* (1983) (Section 17). Potential PEP is possibly lowest in Amazonia.

These estimates of potential PEP apply to the late building–early mature phase forest on deep-rooted, porous clay-loam or sandy-loamy clay with good crumb structure in the lowlands up to 700–1000 m a.s.l. Forest ecosystems consist of a mosaic of developmental phases from young gaps to overmature patches. One-year-old gaps occupy about 0.2–0.5% of the forest surface, while 1–10-year-old gaps (regeneration below 5 cm diameter and 7 m height) account normally for 1–5% of the area (Bruenig, 1973b; Bruenig *et al.*, 1979; Heuveland and Neumann, 1980). Building and mature phases cover 60–75% but are difficult to distinguish, and overmature patches may cover 20–30% of the area, depending on the past history of disturbances. In the Kelantan storm forest, the pre-storm dominance of *N. heimi* indicated over-maturity over much of the area. The species almost completely disappeared after the storm of 1883. Most of the forest developed into the building phase, but in

parts remained arrested in the early gap phase throughout the 66 years to 1949 (Browne, 1949). Over-mature phases, failure of regeneration and delayed regrowth in the gaps caused by large-scale natural disaster or by selective logging may, in large management units, reduce NPP and PEP by another 15–25% on average. A plausible long-term sustainable-yield estimate for lowland mixed natural forest, such as MDF, would be 2.6–3.6 t ha<sup>-1</sup>a<sup>-1</sup> at a low production level and 5.2–7.2 t ha<sup>-1</sup>a<sup>-1</sup> at a high production level, or roughly between 3 and 5 m<sup>3</sup> ha<sup>-1</sup>a<sup>-1</sup> and between 6.5 and 8.0 m<sup>3</sup> ha<sup>-1</sup>a<sup>-1</sup>, respectively, provided all species are commercial which reach the A- and B-canopy layers (Table 1.10). Of these, perhaps only one-third to one-half are more-or-less constantly merchantable in Malesia, but currently much less than that in Africa and America under prevailing market conditions.

The productive forest in the permanent forest estate (PFE) will include a large proportion of steep terrain or rocky sites, especially in South-east APR, and on disadvantaged soils. Yield assessment for forests on these less productive sites suffers from almost complete lack of data. Long-term ecosystem

studies that include assessment of GPP and NPP do not exist. An exception are the growth data from RP 146, Sabal Forest Reserve, Sarawak, which are supported by comprehensive data sets on site and forest conditions (Table 1.6; Sections 1.8 and 1.12). A preliminary estimate of the mean annual stemwood increment over bark in *D. beccarii* MDF from 1978 (the earliest year of selective logging) to 1990 is 10 m<sup>3</sup> ha<sup>-1</sup>. The potential increment in KF is estimated to range from 5 m<sup>3</sup> ha<sup>-1</sup> (*Casuarina nobilis* KF) to nearly 10 m<sup>3</sup> ha<sup>-1</sup> (*A. borneensis*-type) after proper selection felling (Section 6.3) (Droste, 1995). The large caatinga research plot at San Carlos de Rio Negro had only once been remeasured, in 1979. The annual diameter increments in 1975–1979 in the caatinga forest were very small, 0.9–1 mm in trees ≥30 cm diameter, less than 1 mm in trees 13–30 cm diameter and just above 0.2 mm in trees 1–13 cm diameter. This is only a fraction of average values in zonal forest and points to very low levels of PEP in the caatinga under a moderate disturbance regime with 0.8% mortality, 0.5% first-year gap area, and 2.6% older gaps (Bruenig *et al.*,

**Table 1.10.** A. Mean annual periodic increment of trunk-base diameter, basal area and merchantable volume, 37-year-old *Dryobalanops aromatica* Gaertn. f. from natural regeneration, unthinned and with heavy thinning, FRIM research plots 85 and 86 (Abdul Rahman *et al.*, 1993). B. Annual volume increments of selected elite trees, other dipterocarp and non-dipterocarp trees in logged and thinned (TSI) and logged and untreated stands of natural mixed dipterocarp forest in the Philippines. The annual volume increments are the means and in parentheses the minima and maxima in the range between plots, calculated from 5-year periodic volume increments (Manila, 1989). I, increment of stand per hectare; G, basal area per hectare; V, volume per hectare. See also Fig 6.3, p. 169, in Abdul Rahman *et al.*, 1993.

	Unthinned		Thinned	
Increment parameter	85	86	85	86
<i>A. FRIM RP 85 and 86</i>				
<i>Id</i> (cm)	0.4	0.5	0.6	0.6
<i>IG</i> (m <sup>2</sup> ha <sup>-1</sup> )	0.31	0.28	0.41	0.31
<i>IV</i> (m <sup>3</sup> ha <sup>-1</sup> )	5.4	5.1	7.2	5.5
	Logged, noTSI		Logged and TSI	
<i>B. MDF Philippines</i>				
<i>IV</i> (m <sup>3</sup> ha <sup>-1</sup> )				
Élite dipterocarp trees	1.0 (0.4–1.9)		2.4 (1.1–4.1)	
Other dipterocarp trees	2.5 (1.4–3.6)		4.1 (2.2–5.2)	
Non-dipterocarp trees	3.2 (1.0–4.4)		1.9 (0.3–3.4)	
<i>IV</i> total (range)	6.7 (2.3–9.3)		8.4 (3.6–12.7)	

1979; Heuvelink and Neumann, 1980). There are few tree increment plots in, and growth assessments of, kerangas and peat-swamp forests, and their conventional, simple diameter growth data are not very suitable for assessing NPP and PEP (Section 6.6). Indirect deduction of CPP and NPP by comparing biomass parameters with MDF is not generally possible. Very tall canopies, high leaf area index, very high densities of basal area and biomass stockings are not always useful, reliable indicators of the relative or absolute CPP and NPP. Extremely oligotrophic soils can carry very high biomass stocking provided water supply is adequate (e.g. *A. borneensis* in kerangas on giant podzol (haplic arenosol) or on medium deep podzol over clay-loam, and peat-swamp forest PC2 and 3). NPP and PEP are higher in the less tall mixed peat-swamp forest, PC1, than in the much taller PC2 and PC3 where the phytomass density culminates (Fig. 1.11).

In contrast to peat-swamp forest, in the caatinga and kerangas forests stature and soil types within the forest formation are associated in a manner that appears to relate to productivity. If this is so, relative productivity may be assessed from canopy height. In caatinga and kerangas forests episodic drought strain and frequent alternation between waterlogging and dryness are probably the primary growth-limiting factors, possibly more so than soil nutrients. Bruenig (1974) estimated the BNP for stemwood on the best sites in MDF as  $16 \text{ t ha}^{-1} \text{ a}^{-1}$  (total NPP  $40\text{--}50 \text{ t ha}^{-1} \text{ a}^{-1}$  minus coarse and fine above-ground litter fall of  $16 \text{ t ha}^{-1} \text{ a}^{-1}$  and root litter  $16 \text{ t ha}^{-1} \text{ a}^{-1}$ ) on deep soils well supplied with water, and an evapotranspiration ( $ET_0$ ) of 1800–2000 mm. Assuming tree height and  $ET_0$  to be reasonable indicators of NPP (Bruenig, 1971c, 1974), the tall forests on deep, mainly sandy-silty podzols could produce 20–25 t NPP and 5–8 t stemwood BNP ( $ET_0$  1200 mm). The forests on medium deep soils could produce 3–5 t stemwood BNP ( $ET_0$  900 mm) and the low forests on shallow sandy podzols, bleached clays and lithosols 1–3 t ( $ET_0$  700–800 mm). From the BNP, 30% must be deducted for unavoidable and unpredictable losses, 20% for

harvesting loss and 20–25% for defects, or a total of 70–75%. This would leave about 1.5–2 t for PEP in the tall kerangas types with *A. borneensis*, *S. albida* and *D. fusca* or *D. rappa* and just enough PEP ( $2\text{--}3 \text{ m}^3 \text{ ha}^{-1} \text{ a}^{-1}$ ) to qualify as potentially commercially productive under CNF management in future. Most of the medium and all of the poor kerangas and kerapah forests fall out of the category of commercial timber production forest. The generally 20–30% lower canopy height of the corresponding types of Amazonian caatinga indicates that the NPP is generally lower, perhaps by more than 20–30%. Probably only the Yevaro forest type (Bruenig *et al.*, 1978; Fig. 1.1) could be considered commercially productive and suitable for CNF management.

#### 1.14 The Worrying Global to Local Significance of Uncertainties, Risks and Constant Changes

The worrying effects of GCC on trees and forests are much discussed for temperate forest, but few hard facts are published for TRF. Newbery and Lingenfelder (2009), Lingenfelder and Newbery (2009) and Newbery *et al.* (2011) began research at Danum, Sabah, in 1998 to monitor d-growth as a parameter for assessing the growth of trees and forests in relation to drought. In 22 years, it has produced important data, valuable scientifically and relevant for forestry in TRF. Here it suffices to say that the results confirm our contention since the 1970s that uncertainties and risks in TRF and temperate forestry are great, but still underestimated and not yet properly considered in long-term forestry planning. GCC will probably change that. Newbery and Lingenberger give a clear indication that change is coming, the reaction of different species and individuals vary and prediction at this level of dissolution for management planning has to cope with high levels of uncertainty. Research with beech (*Fagus sylvatica* L.) in Spain supports this finding of a variety of response at provenance levels. Seedlings of 200 provenances had been planted in 65 sample plots throughout the EU. In the sample plot in

Spain, 3930 seedlings from 36 provenances were planted in 1998, and tested after a prolonged drought in May–August 2008 for (a) survival rate, tree height and stem diameter at ground height, (b) hydrological situation in the leaves, (c) gas exchange through the stomata, (d) nitrogen content of leaves and (e) hydrolic potential soil-leaf. The results demonstrated a wide variation of responses to drought and to site (weakly sandy brown forest soils) between provenances, which confirms the well-known genetic plasticity and epigenetic adaptation in *F. sylvatica* that makes assessment of the suitability for a new site or the responses to GCC uncertain until the causal factors and processes of suitability are known (Wülisch, 2012). We must expect to face a similar situation in silviculture in TRF. Alan (*S. albidia* Sym.) with its enormous range of sites from coastal peat swamp, high plateaux, kerangas to transitional MDF and the results of Newbery and Lingenfelder give some indication of the probable magnitude of the problem in TRF.

### 1.15 Forest Diversity and Functions

There seems to have been hardly any suitable research done in TRF on this difficult, but ecologically and silviculturally interesting and politically most important subject. Towards the end of the 20th century, the flurry around biodiversity and, after Rio 92, also around forests, and the link between biodiversity and forest functions and processes became ever noisier in the international and national arenas. Biodiversity, stability and sustainability were functionally linked by pushing lobbyists, scheming politicians and campaigning activists who did not and could not have the facts to justify such noise (for functions see (Glossary, Paragraphs 1 and 6); for more detail on noise see Sections 1.11 and 1.12). The dearth of knowledge of the subject in science is understandable, because research in this field (as defined in the title of this section) is difficult, expensive and long term; the dearth of reliable information, the purposeful

distortion of truth and intentional deception in the public debate is opportunistic and inexcusable. It was a timely decision by scientists to hold a workshop in 2004 to review and assess the state of knowledge and of ongoing research, although understandably forced by circumstances restricted to the temperate and boreal forests. But remember: the tropical forests are subject to the same natural laws as the temperate forests, while the anthropogenic scenarios differ. Therefore, the findings of this workshop are relevant to our problems in the TRF. But, “unfortunately there are few relevant results from explicit experiments on the diversity/functioning/stability relationships. We (the participating scientists) had to turn to ‘experiments’ that nature has provided, i.e. observing the functioning of systems of varying diversity” and “It is just not possible to hold all habitat conditions constant, with only diversity varying, under natural conditions” (Scherer-Lorenzen *et al.*, 2005). If this is true for temperate and boreal systems, it is certainly and even more so an obstacle to research in tropical systems generally, and worse in the TRF ecosystem. The report was published as a book in 2005 (Scherer-Lorenzen *et al.*, 2005) and is the only available comprehensive record of the state of knowledge about the relation between forest diversity and forest functioning (not functions in terms of forestry policy and forest services, but in terms of ecological processes and functions). The following text is a revised and abstracted version of my review of the book in the *International Forestry Review* 7, 1995, pp. 267–269. Peter Mooney, Stanford University, said in the foreword “This volume is an important first step in launching the kinds of experiments and measurements that are needed to bring us much further along in our understanding of the perennial woody systems that cover so much of the surface of the earth”. This refers to experimental research in purpose-designed man-made forest ecosystems. In the 1950s and 1960s, several workshops called for globally linked holistic ecosystem research projects and outlined harmonised methodologies for studies of floristic and physical structure, functions

and processes of natural and semi-natural temperate and tropical forests to be applied in projects of the International Biological Programme (IBP), the UNESCO-Programme "Man and Biosphere" (MAB), the Scientific Committee on Problems of the Environment (SCOPE) and the International Union of Biological Sciences (IUBS) in the International Council of Scientific Unions (ICSU)) with the distant goal of creating a global network. Hypotheses, principles and goals of functional biodiversity research were formulated by a symposium in Weidenberg near Bayreuth in 1992 (Schulze and Mooney, 1993).

Ten years later, a LINECOL (Linking Community and Ecosystem Ecology Programme) workshop was held at Weimar on 13–15 June 2002, to continue and extend the debate. The following is an abstract of my review of the workshop report 1993 in the IFR 1994.

On productivity and growth H. Pretzsch scrutinised evidence of direct effects of diversity on growth, using data from long-term observations, empirical trials and scientific experiments, and concluded that shortfalls of modern growth and yield research, hidden factors and unexpected episodic extremes made confounding of growth, yield and diversity research, predictions and interpretation precarious.

G. Müller-Stark *et al.* defined genetic diversity as genetic variation within and among populations. Assessment of direct interactions and predictions of the long-term performance of a genotype in association with other genotypes and tree species are affected by the great heterogeneity of conditions, the variability of causal factors and episodic events. This would even affect analyses and predictions in short-rotation, highly intensive plantations of cloned elite or genetically manipulated (GM) trees. The reality of uncertainty in ecology and forestry was demonstrated by H.E. Jones *et al.* with the fate of the long-term tree diversity experiment at Gisburn, north-west England. The experiment was destroyed by an unpredicted violent storm 34 years after establishment, and had to be completely re-established. The experimental design, a mosaic mixture pattern of four species in  $3 \times 6$  single-

species units, was reasonable statistically, but difficult to handle and to reconcile with ample, mostly negative management experience with similarly complicated mosaic designs which are difficult to manage.

D.D. Baldocchi dealt with the effects of diversity on evaporation, a subject also of great interest in TRF forestry in view of the expected consequences of further deforestation and GCC for the hydrological cycle. The relevant basics, facts and formulae of micro-meteorology and plant physiology were discussed at leaf, tree and canopy scales and supported with published data from five field sites, but simple, practical conclusions could not be drawn. The exceedingly complex and very variable micro-meteorological interactions between leaf, tree and canopy scale levels affecting the various exchange processes and thereby biodiversity, puzzle silviculturists everywhere. For their decisions, practitioners depend on profound scientific knowledge and long-term practical experience, and, last not least, system-orientated intuition if they want to design and implement adaptive, low-risk and high-performance silvicultural management procedures for biodiversity and with biodiversity. An important compartment in the network of ecosystem processes involved is the SOM and biodiversity in the soil (see Section 1.3, above).

On the subject of tree species diversity, litter and decomposition, S. Hättenschwiler confirmed empirical concepts, scientific knowledge and practical experience, but added the aspect of systemic complexity. The manifold interdependences and linear, non-linear and positive and negative feedback interactions create a complex web of variable factors and processes which defies simple and narrow interpretations, even in temperate forests. Polyphenols are given the prominence they deserve to explain balancing of SOM and nitrogen preservation during decomposition and humus formation, leading to the subjects of two following papers written by S. Hättenschwiler which remind me of the research and lectures of Professor Wittich, Hann. Münden, and Dr Handley, Oxford, on the effects of tree species and species mixture on litter quality,

decomposition rates, SOM and soil dynamics in the 1950s, and which I found highly relevant to TRF and my later research in temperate and tropical forests.

G. Gleixner *et al.* reviewed the effect of biodiversity on carbon storage in soils and turnover rates, and came to the conclusion that direct links between plant diversity and carbon storage might not exist. Indirect influences might work through nutrient and hydrological regimes, within-soil litter and root exudates, food-webs and soil biodiversity. The question, how far biodiversity can directly influence the carbon balance, remains as open as those with respect to other functions and processes in the ecosystem.

M. Mund and E.-D. Schulze asked: how far can silviculture influence the carbon balance? The answer to the question remains vague. In my opinion, this is not surprising. Since Wiedemann a century ago, we know that thinning and most mixing have remarkably little direct effect on total wood production, and have learned more about the roles of risk and uncertainty in forest growth predicting. This vagueness touches a fundamental dilemma of forestry: the complexity, dynamic variability and heterogeneity of reality. Apart from the effects of interaction of plant taxons and site diversity (alpha, beta, gamma), more elusive factors such as interplant and interspecies interactions, damaging animals, pests, diseases and abiotic disturbances and perturbations have over centuries successfully prevented foresters from reaching any narrowly defined silvicultural management goals, more often destroyed their hopes and only occasionally helped them. The resulting high level of uncertainties in silviculture makes interpretations and predictions of the effects of silviculture rather spurious, except in such simple cases as crown releasing of regeneration and residual trees in TRF, and even there, risk and uncertainty are substantial.

On the subject of pests and disturbances, S. Scheu gave a comprehensive account of a quantitative study of the linkages between tree diversity, soil fauna and forest ecosystem processes. This was again a global first in kind and results. It described the relevant, ecologically effective linkages

based on data from the classic ecosystem research projects in Hubbard Ford, Solling and in the Göttingen city forest. Plant diversity matters in general terms for mycorrhiza development, but the key drivers for the structure and functioning of the soil bio-community are the specific features of the above-soil plant community, such as the C/N ratios and tannin contents, affecting the concentration of nitrogen and polyphenols in the soil. Effective feedback processes keep the mutualistic vegetation-soil subsystems in a functional state. The system dynamics of the decomposer food web, bio-cybernetically regulated by processes along “the decomposer: generalist predator: pest: herbivore” interactive chain, forced by perturbations and disturbances, are essential components of ecosystem sustainability. Understanding these phenomena is of great and direct relevance to forest ecosystem management and conservation practice in the TRF, but much further research is needed in temperate and tropical forests before we have a sound foundation on which to build knowledge and understanding to replace subjective experience and intuition.

H. Jacktel *et al.* presented an extensive and carefully chosen meta-analysis of information from literature published between 1966 and 2000 on the effects of tree species diversity on pest and diseases. The results support the assumption, commonly held in traditional forestry practice, that tree species in mixture suffer less damage by pests than tree monocultures, but that there are many exceptions depending on circumstances. Examples of “lucky” and “unlucky” simple monocultures and “lucky” and “unlucky” complex mixtures with respect to damage by pests and diseases and non-biological causes demonstrate the wide range of possibilities and the low level of predictability.

In my lecture in the 1970s on the ecological, economic, social and silvicultural significance of forest structure I analogised between natural and man-made systems by comparing the Soviet Union (uniform, single-function maximising monoculture, industrial tree plantation) and West Germany (diverse, heterogenous, multifunctionally muddling mixed forest) to support my view

that the Soviet Union monoculture was doomed to collapse and the “Cold War” was either hysterics or strategic deception (*sensu* Flyvbjerg, 2011; see Chapter 11). In both uniform and mixed forests, generalist herbivores and newly introduced pathogens may episodically reduce the tree diversity and in mixed forests induce restoration by successional dynamics. Episodically disturbing events of freak herbivore epidemics affecting monocultures at very large spatial scale, and possibly long-term timescale, have been documented in the unique, but now threatened Alan peatswamp forests of Sarawak (Anderson, 1961b; see Figs 1.3 and 1.4 above) and Sumatra. The conclusion is that direct effects of tree diversity are relatively strong and obvious with respect to pests, diseases and soil biology, depending on forest and site conditions and the action of confounding “hidden factors”; responses to climatic factors depend more on the architectural diversity of the tree community than on species richness. Much more focus must be put by scientists and practitioners in forestry on the very complex patterns by which the dynamic processes of forest ecosystems and their environments evolve and operate under the rule of universal laws and principles, creating indeterminism, uncertainty and induction (Spemann, 1935; Heisenberg’s indeterminism).

### 1.16 Some Afterthoughts: How Much Science, How Much Ecological Insight Do We Still Need to Act, and Why is There so Much Talk and Little Action?

There is certainly a critical and inexcusable dearth of knowledge about the structure, processes and functions of the TRF ecosystem and the role of TRF in the global environment and world economy. This is partly due to peculiar, short-sighted, narrow-minded and selfish political preferences in the TRF countries, in cooperating developed countries and in the UN; partly due to instabilities and warfare in some TRF countries; partly due to scientists in the developed countries having other options which are more attractive; and

partly due to scientific education and research in most TRF countries not keeping up with national needs, and general development in science largely being supported only if it suits vested interests. But this dearth of scientific knowledge and action is not the crucial point in the discussion of sustainability in TRF and why it has generally not been achieved. A major obstacle was the opportunistic argument by some scientists and NGOs in the 1980s and 1990s, unsupported by facts, that we cannot manage, conserve and preserve TRF properly and sustainably unless we know much more about its ecology. Therefore, we should stop any logging and management operation and buy no more tropical timber. I argued then and now that we have enough practical and empirical experience and scientific knowledge of the working of the TRF ecosystem to manage and conserve it, but we should stop timber mining, native customary rights (NCR) and state land grabbing immediately. There are well-tried silvicultural, harvesting, planning and monitoring systems.

The crux lies elsewhere, not in ecological science or in the science and art of forestry. It lies in the world of official and grey economics and finance, and in the grey zones of politics. It is here where the doctrines, attitudes and schemes have been converging into convoluted networks of organised crime (UNEP and INTERPOL, 2013) that cause the decline of resource value in the TRF and of quality, and survival value, of air, water and soils, and which are the causal factors for the development of the anthropogenic GCC for TRF. The actual causal factors forcing the decline of the past 50 years are the Manchester Doctrine of *laissez faire*; Adam Smith’s wishful Utopia of the self-regulating free market where money is made at the top, and wealth filters down the social pyramid automatically, still affects neoliberals and neocapitalists in the 21st century. The consequences in the TRF zone are obviously the “green light” to greed, irresponsibility and introverted individualism which make sustainability of TRF management and conservation unachievable. In a world where uninhibited individual fulfilment is a basic right, to

thrive for maximum Net Present Value (NPV; in forests, liquidation of stock) and cash profit (in forestry, the highest net stumpage value) is prudence; its achievement, success. Profit-maximising timber mining, illegal logging, speculative plantation establishment in agriculture for biofuel and food, and in forestry for biofuel and industrial commodity timber for mass production, serves the players on the globalised commodity and financial markets more than sustainable development in the tropical countries, which continue to lose their assets through loopholes into the grey national and international markets.

Examples of early warning by scientists, initial misunderstanding and rejection, followed by awareness of the public, but escapism and delaying action by governments are:

1. Deforestation, GCC and increase of drought and desiccation as a serious threat to social and biocoenotic systems. These were recognised by botanist Roxburgh in India three centuries ago, but nothing was done and even now governments are dragging their feet.
2. The effects on forests of air and water pollution. Forestry scientists warned of these in the 1950s, but only after the public developed the hysterical idea of a general “Waldsterben” (forest dieback) in the 1980s was decisive action taken, at least in Germany.
3. That climate appeared to change and extreme weather events increased. Scientists warned of these in the 1970s; the public may now be aware but is still apathetic, and governments and UN – after initial rejection – are still dragging their feet by agreeing to conventions and commitment, which will hardly be met. The Paris GCC agreement in December 2015 will be no exception.

About the same time in the 1970s, it became politically correct and fashionable in science (and still is) to drivel about a change of paradigms in forestry – mostly re-inventing the wheel or looking through a tunnel. One popular paradigm change of the 1970s was that the age of wood had come to an end and the new era of oil and its derivatives, metals, concrete and synthetics had begun. For-

estry for production was outdated; forestry for the people, meaning only welfare or social functions, was modern. This was in line with the change of paradigms in the world of economy and finance. The hallmark of the new era was the Tertiary Sector, and forestry had to adapt to it. Unperturbed by drivel, a more far-sighted group of forest scientists kept to multifunction social forestry which maintained timber production as ecologically benign, environmentally favourable and socially beneficial as primary function of forestry, followed by welfare or social, and income functions. Eventually, this was also recognised by postmodern foresters, the public and politicians. The interest in the effects of GCC, sustainable timber production and improved timber technology rose. Even the commercial lobby acknowledged the trend, but not to support production forestry and safeguard adequate timber supply, but to safeguard the interests of the fossil fuelling and using industry. It created the paradigm that forests can sequester CO<sub>2</sub> in sufficient amounts to contribute substantially to the efforts to mitigate GCC, and promoted affirmative news in the media, ignoring the sobering facts presented by Baumgartner and Bruenig (1978), Bruenig and Heuvelink (1994) and by the contemporary thawing permafrost taiga and tundra and deforested and drained tropical peatswamps.

The ecological long-term research into tree-growth in MDF in Danum was luckier than that in Gisburn. It was also hit by an unexpected severe disturbance, which did not destroy it but opened disturbing aspects of TRF turning from a sink to a source of CO<sub>2</sub> and possibly CH<sub>4</sub>. Another timely warning to politicians to take effective action against GCC and against speculation with TRF and forest lands is given by Newbery and Lingenfelder (Newbery and Lingenfelder, 2009; Lingenfelder and Newbery, 2009 (both also included in the compilation by Valck, 2009: *Forest Ecology – Recent Advances in Plant Ecology*). The first 22 years (1986–2008) of observation in Danum MDF have produced new knowledge which is relevant to the problems posed by GCC to rainforest management, conservation and policy and to the understanding of responses of

individual trees to oscillations and changes of growth affecting site conditions. The authors monitored tree growth by measuring breast-height girth/diameter of all trees above 10 cm girth, and recorded mortality and mapped the position in two 4-ha plots at Danum, Sabah for two periods, 1986–1996 and 1996–2001 (1986 17,946 trees, 450 confirmed species; 1996 17,265 trees, 466 confirmed species; 2001 16,623 trees, 489 confirmed species; 2011, re-measurement not possible). About 4000 saplings/small trees between 10 cm girth at breast height (bh) (3.18 cm d) and 50 cm g were measured in a sample of sub-plots for the periods 1996–1999 and 1999–2001 (see next paragraph). The association (significance of correlation) between the tree growth/mortality data in TRF in Danum, Sabah, and environmental/drought data was tested by a number of sophisticated analyses, particularly to find proof of correlation with the strong 1997–1998 ENSO-driven drought and its complex effects. The recent results at Danum (Newbery and Lingenfelder, 2009; Newbery *et al.*, 2011; Newbery and Stoll, 2013) support the theorems of indeterminism and uncertainty, which could help to explain the diversity of deflected successions on ultisols and podzols in Bako N.P. (Bruenig 1968 and 1974) and on Krakatau islands on newly exposed magma (Whittaker *et al.*, 1989). Species-specificity and species-plurality of responses are crucial preconditions for the development and maintenance of complexity in tree associations, and generally of structure/functions/processes adaptability and viability in complex dynamic forest ecosystems in environments of stochastic perturbation and disturbance events. Foresters in the temperate forests of Central Europe will agree on the basis of trial and error experience and knowledge from scientific research. Species- and system-specific thresholds of resistance determine the responses to the prolonged extreme stresses caused by the ENSO-related episodic droughts, such as those in 1877–1878.

In 1888, the drought in Sarawak was so severe that the forests on the plateau and the gambir plantations in some of the val-

leys of the Bako peninsula, now Bako National Park, were reported by travellers on ships to have been burning like cinder. The fire created the padang scrub vegetation type which has not returned to forest to this day, and is a unique ecological feature of the park. During the drought in 1958, when I was stationed in Brunei, the coastal kapor paya (*Dryobalanops rappa*) and Alan (*S. albida*) peatswamp forests in Anduki F.R. burned for days and had not recovered when I visited the area a decade later. There were severe droughts again in the region in 1986 and 1997–1998.

If the forest is not completely consumed, the variable individual tree thresholds of resistance due to acquired traits and/or variable micro-site/soil factors affect the recovery of individual trees, and thereby the speed and direction of the recovery of the vegetation. With or without fire, the recovery from drought by intrinsic tree and ecosystem resilience is rarely fast and simple, and may require decades or, as in Bako N.P., centuries. It will most likely be interrupted and deflected by new perturbations and disturbances, such as new droughts, supersaturation, storms, pest and diseases. It may happen that kerangas or caatinga tree species with high tannin contents in their litter cause secondary podsolisation of an ultisol-type soil, as happened in Bako N.P., and deflect succession to a “dis-climax” (Bruenig, 1974). Finally, tectonic events can cause divergent developments of vegetation as has been recorded from the Anak Krakatau islands, and other disturbance events of varying intensity.

Newbery *et al.* (2011), in their long-term project mentioned above, further studied the stem diameter (d) growth of around 3700 understorey trees (12.5 to  $\leq 50$  cm girth (approx. 4–16 cm diameter; my calculation) in two sub-periods between 1986 and 2007, to supplement the study of the larger trees in the  $2 + 2 = 4$ -ha plot in response to the ENSO-related drought event of 1997–1998. Relative growth rates (rgr) of the 48 most abundant species in these smaller size classes were considered individually and as relative changes between periods, and from them a measure of reactivity was derived.

The rgr of one-third of species varied significantly between species; rgr within-species were highly variable. Often species had very variable (pluralistic) response patterns over time. The rgr decreased in the drought period, increased and overcompensated directly afterwards, and later returned to original levels. Drought-related responses proved to be: the mortality rate of the larger population of 19,000 in the B/A-storey of the two 2-ha plots increased by 25%, and of the smaller sapling/pole population of 3700 in the C-storey of the two sub-plots by 6 and 9%. The growth rate of the 19,000 population of larger trees decreased by 38%, but increased at fine scale of small diameter, not basal area or volume at larger scale (size) by 98%. This positive response of the small trees in the understorey and strongly negative response of the B/A-storey trees is very plausible in terms of the difference of microclimatic conditions between the B/A- and D/C-storeys and the difference of amount and spatial pattern in the canopy and the understorey. The positive growth response and low mortality are probably reliance “designs” off-setting the effects of mortality by drought for the ecosystem’s functionality, but not even nearly off-setting the large reduction of its function and capacity as CO<sub>2</sub>-sequestering carbon sink. The forest ecosystem had already displayed moderate resistance, high resilience and stability within about 4 years after the perturbation/disturbance by drought. Oscillatory responses were more pronounced among true D/C-storey saplings/pole species than among small trees of A/B-storey species, suggesting that the former might play a key role in stabilisation and recovery. The authors conclude that environmental stochasticity in the form of so-called coloured noise may therefore be causing a major part of the variation in rainforest dynamics and may explain its complexity. This accords with my experience as forester and researcher of the important ecological role of drought in TRF (Bruenig, 1971a), and my assumption that the stochasticity and complexity of growth of the trees and dynamics of the tree assemblages, and consequently of all depending ecological processes (includ-

ing timber production) in the rainforest and any other forest ecosystem, and the unpredictability of stochastic events of extreme climatic episodes (drought and storm in particular), cause a high level of risk, uncertainty and unpredictability, which the rainforest avoids or survives by the elasticity and resilience which complexity and diversity confer. This is a useful indication for forestry planning with definite consequences for any type of TRF and its management and conservation. The Danum study, running since 1998, was designed to measure d-growth as a parameter for assessing the growth of trees and forests in relation to drought. Other research groups assessed the amounts of tree biomass in forest growing stock and non-wood organic matter above and in the soil; the uptake and fixing of carbon; and the carbon balances, all with a view to understanding the effects of GCC on the forests and – unperturbed by facts – unswervingly on the mitigating effects of forests on GCC. These activities produce scientifically valuable and generally interesting and useful knowledge. This knowledge will contribute to the understanding of structure and processes of the TRF but it will not contribute knowledge with direct relevance for immediate mitigation of GCC. Its effective role is minor (Baumgarten and Bruenig, 1978). More relevant is that the TRF forest vegetation and soils must be protected against the effects of GCC: more frequent and prolonged severe droughts and more severe rain- and thunderstorms, tornados and water saturation, higher temperatures, more kinds and virulent pests and diseases. All these, and with risks and uncertainties growing, will increase as GCC develops. The TRF is a valuable and viable productive and serviceable common natural resource, essential for sustainable development in most countries where it is found. The means to protect it and safeguard its meso- and macro-environmental effects are well known: integrated CNF management and conservation, supplemented by 10–15% TPA in and outside forest management units (FMU) and conversion only in exceptional and well-argued cases. Goals and methods of many GCC-orientated research projects remind me of an analogy

we used in seminars on system analysis and simulation in the 1980s at Hamburg. Calculating and recalculating with more and more refinement and precision the weight, momentum, aerodynamic state and sinking rate of an aircraft with failing engines will not prevent the crash unless it helps the captain to reach the nearest airstrip by gliding (as an airbus successfully did from far away over the Atlantic to Tenerife many years ago) or the causal factor can be identified and neutralised. In the case of GCC the first option does not apply. The second does. We know the anthropogenic causal factors and could neutralise them, but we seem to be too weak to do it against vested political and

commercial interests. What applies to GCC also applies in principle to tropical forest management and conservation, forest protection and ecosystem preservation. The scientific knowledge and ecological insights provide a solid and adequate base for implementing the existing forest policies, stopping further resource degradation and applying CNF silviculture in natural and planted forests. Scientific knowledge and empirical experience is available to ensure SFM, conservation and sustainable integrated regional development, but again as foresters and civic society we seem too weak to do the necessary and act against apathy and vested interests; business goes on as usual.

## Notes

<sup>1</sup> Pembroke, G. Earl of (2012) The Malayan Tapir *Tapirus (Acrocodia) indicus*: once in Borneo, and again in Borneo? A summary of the palaeontology, archaeology and history of the Malayan tapir, with a proposal for reintroduction to Sabah/ Sarawak. Personal communication of typescript, 1 April 2012.

<sup>2</sup> Pembroke, G. Earl of (2012) A flagship enterprise for South-east Asian large mammal conservation. Proposal for planned re-introduction of Malayan Tapir to Sabah and Sarawak. Personal communication of records, 1 April 2012.