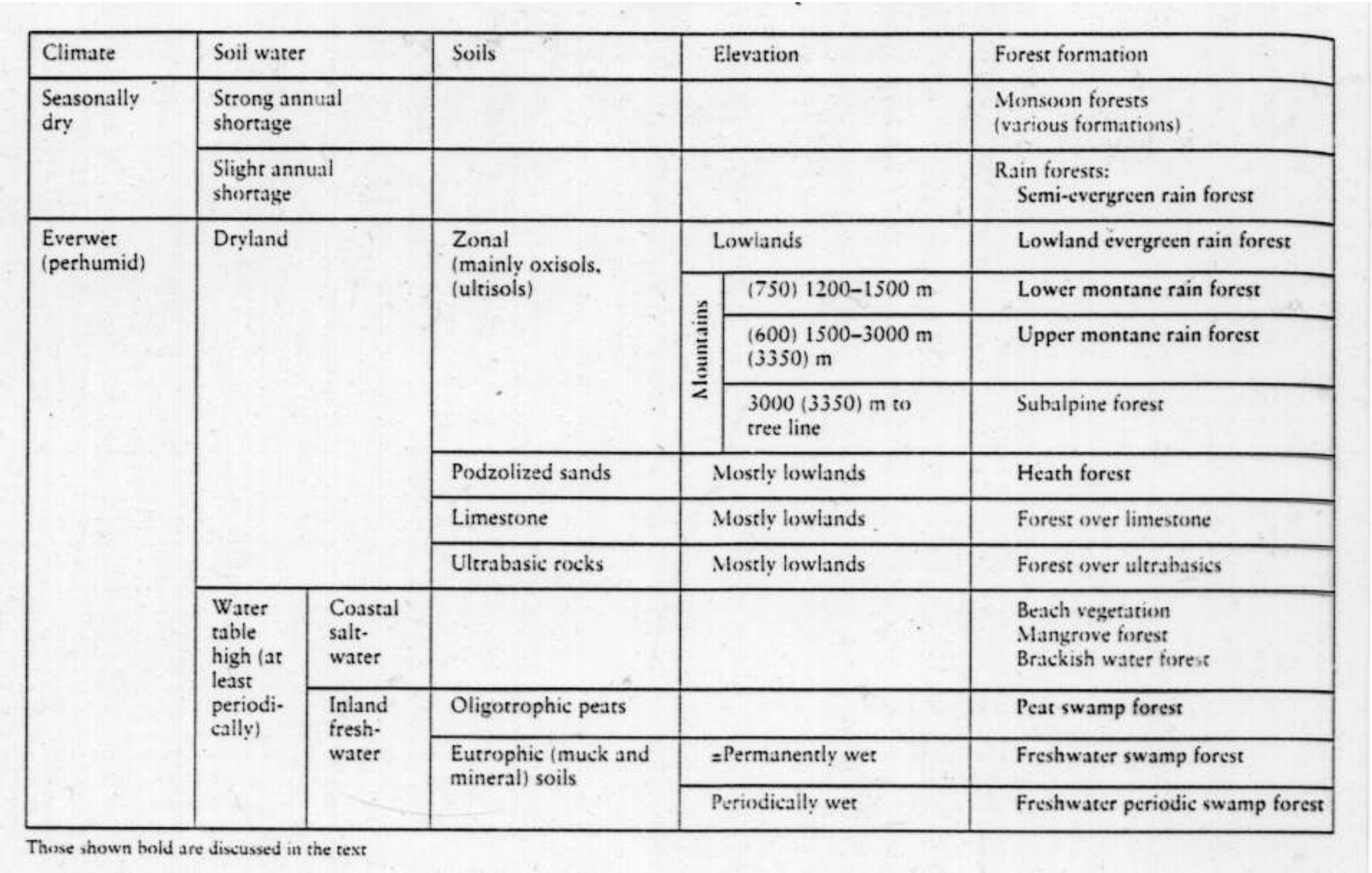
Tropical forest types

Principal rain forest areas: reconstruction of original extent

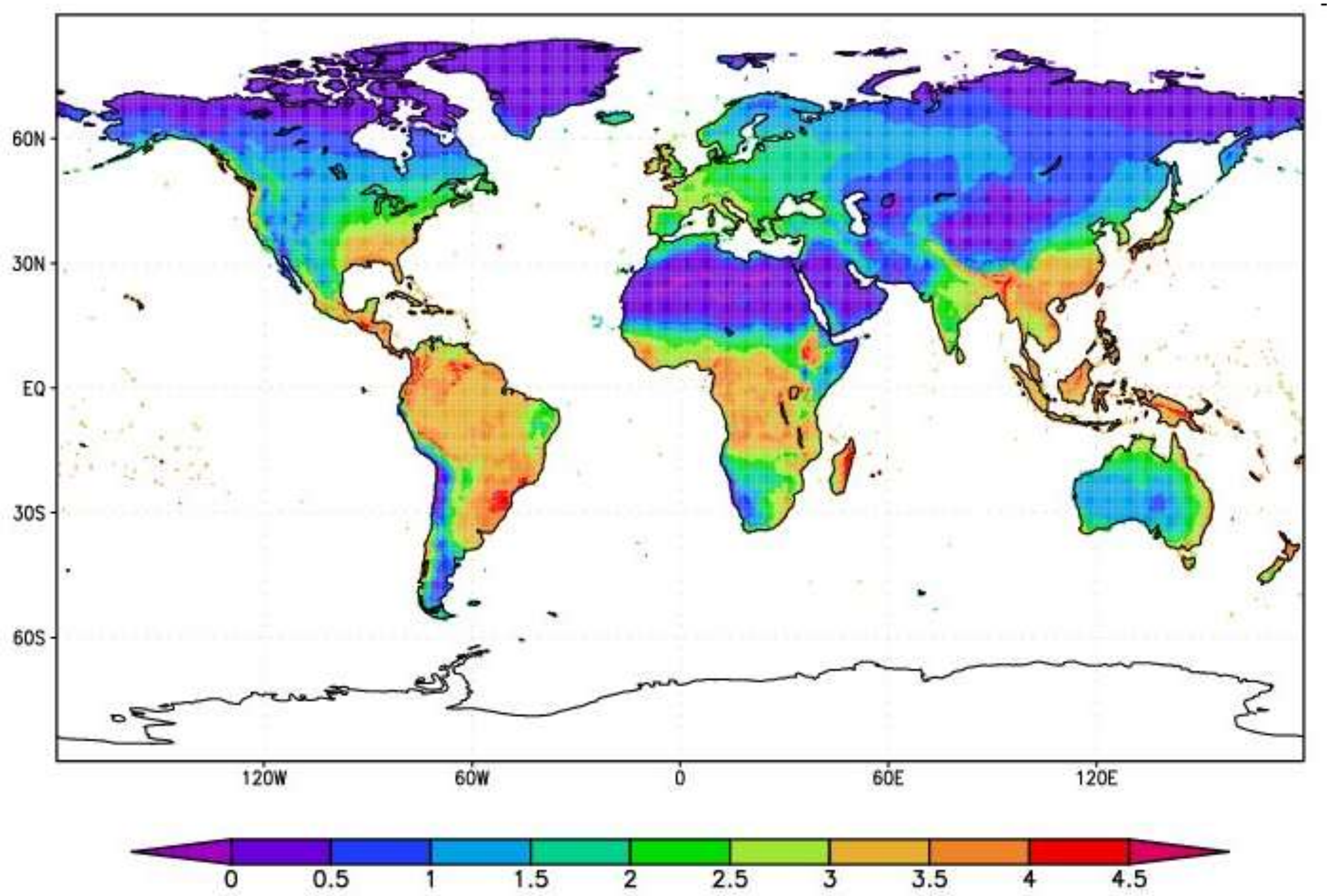
Moist forest types: determined by water regime, soils and temperature



Climate	Soil water		Soils	Elevation		Forest formation
Seasonally dry	Strong annual shortage					Monsoon forests (various formations)
	Slight annual shortage					Rain forests: **Semi-evergreen rain forest**
Everwet (perhumid)	Dryland		Zonal (mainly oxisols, (ultisols)	Lowlands		**Lowland evergreen rain forest**
				Mountains	(750) 1200–1500 m	**Lower montane rain forest**
					(600) 1500–3000 m (3350) m	**Upper montane rain forest**
					3000 (3350) m to tree line	Subalpine forest
			Podzolized sands	Mostly lowlands		**Heath forest**
			Limestone	Mostly lowlands		Forest over limestone
			Ultrabasic rocks	Mostly lowlands		Forest over ultrabasics
	Water table high (at least periodically)	Coastal salt-water				Beach vegetation Mangrove forest Brackish water forest
		Inland fresh-water	Oligotrophic peats			**Peat swamp forest**
			Eutrophic (muck and mineral) soils	±Permanently wet		**Freshwater swamp forest**
				Periodically wet		**Freshwater periodic swamp forest**

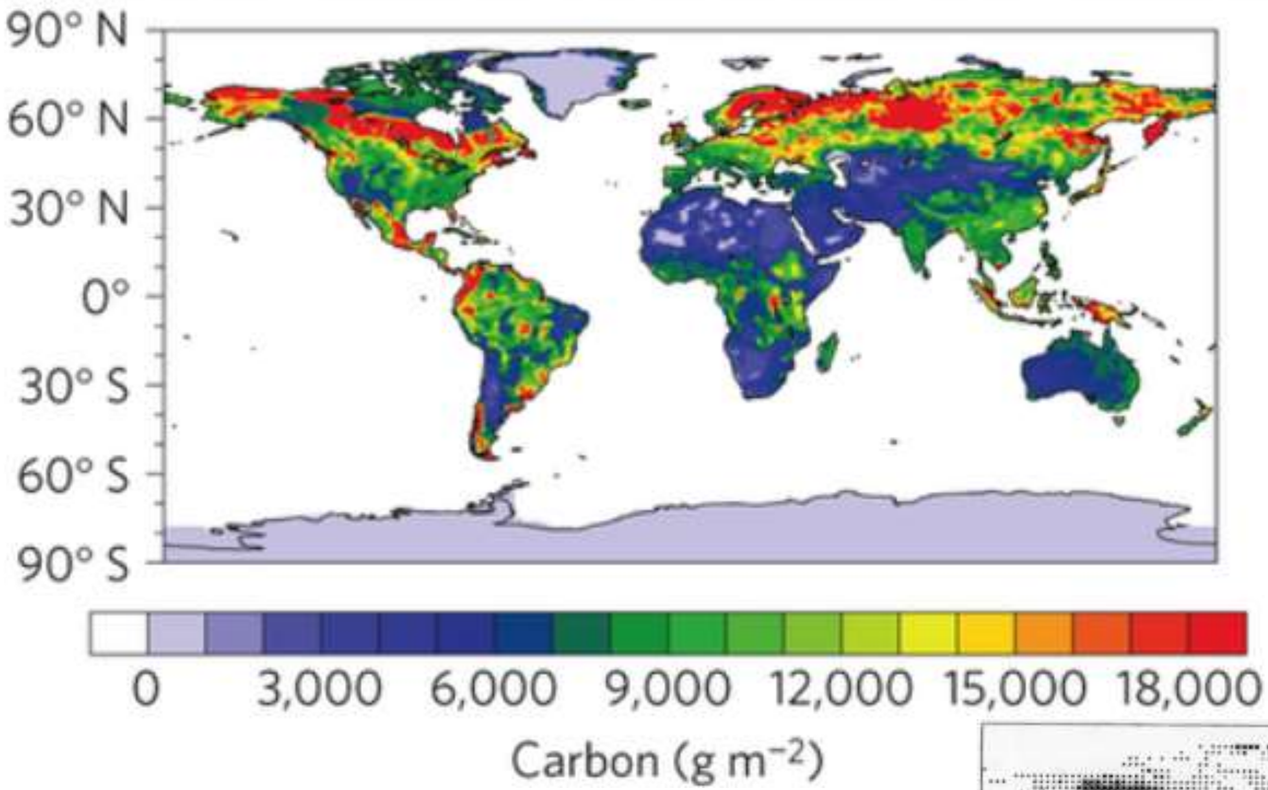
Those shown bold are discussed in the text

Annual litter decomposition rates



The litter decomposition rate scaled to unity when the mean annual temperature is zero and the precipitation does not limit the decomposition.

Plant soil C and litter pools distribution



Wieder et al. Nature Climate Change 3, 909–912 (2013)

Fig. 32.5. The litter pools shown on the map were calculated for woody and herbaceous material separately and then joined together to generate the map. High litter pool sizes are either due to high production of litter, or low depletion rates, or large share of slower decomposing wood on total litter production. The total amount of the global litter pool as presented by this map amounts to 168×10^{9} t dry matter.

Tropical decomposition: plant matter disappears in <1 year

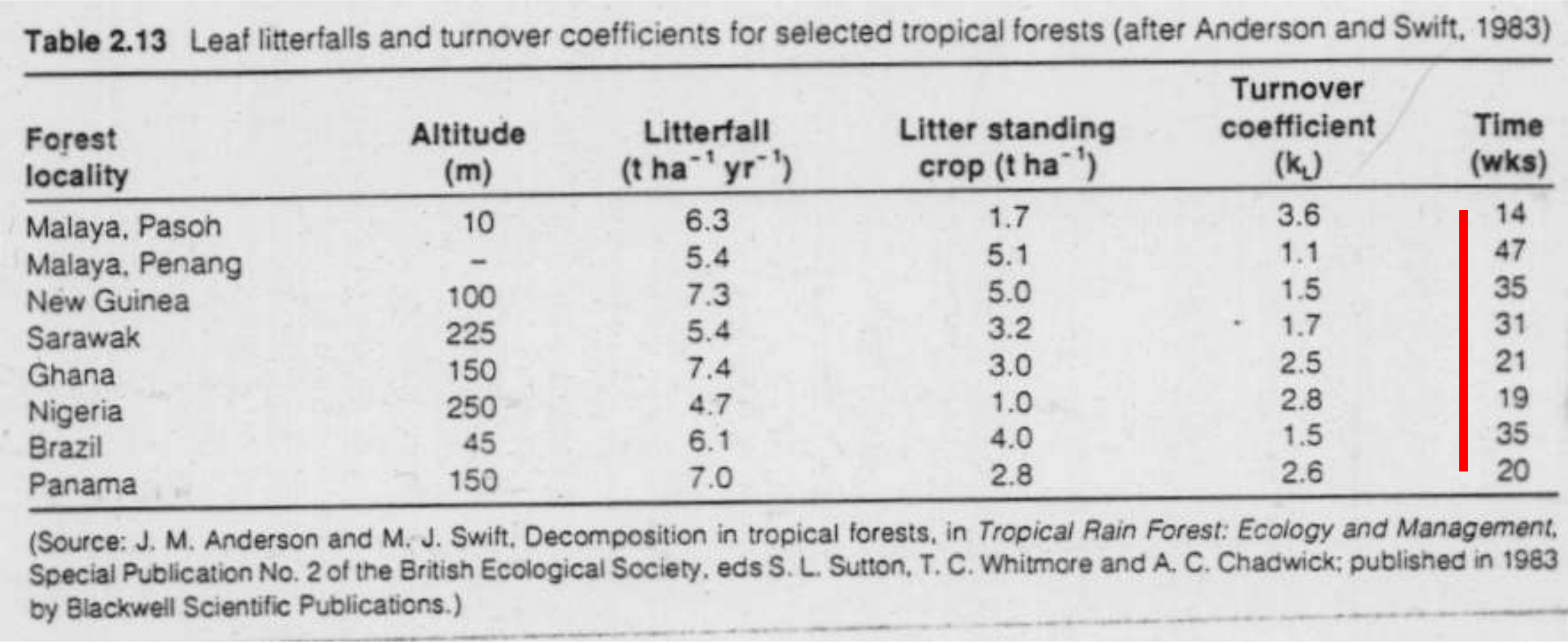


Table 2.13 Leaf litterfalls and turnover coefficients for selected tropical forests (after Anderson and Swift, 1983)

Forest locality	Altitude (m)	Litterfall (t ha^{-1} yr^{-1})	Litter standing crop (t ha^{-1})	Turnover coefficient (k_L)	Time (wks)
Malaya, Pasoh	10	6.3	1.7	3.6	14
Malaya, Penang	–	5.4	5.1	1.1	47
New Guinea	100	7.3	5.0	1.5	35
Sarawak	225	5.4	3.2	1.7	31
Ghana	150	7.4	3.0	2.5	21
Nigeria	250	4.7	1.0	2.8	19
Brazil	45	6.1	4.0	1.5	35
Panama	150	7.0	2.8	2.6	20

(Source: J. M. Anderson and M. J. Swift, Decomposition in tropical forests, in *Tropical Rain Forest: Ecology and Management*, Special Publication No. 2 of the British Ecological Society, eds S. L. Sutton, T. C. Whitmore and A. C. Chadwick; published in 1983 by Blackwell Scientific Publications.)

Tropical forests: nutrients are in live biomass, not litter

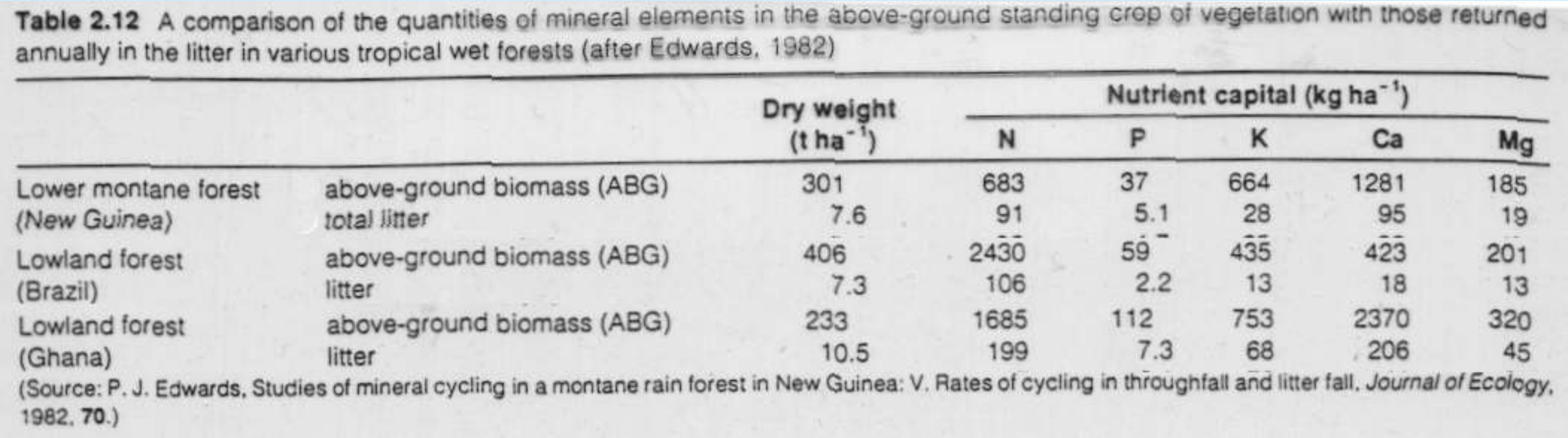


Table 2.12 A comparison of the quantities of mineral elements in the above-ground standing crop of vegetation with those returned annually in the litter in various tropical wet forests (after Edwards, 1982)

		Dry weight ($t\ ha^{-1}$)	Nutrient capital ($kg\ ha^{-1}$)				
			N	P	K	Ca	Mg
Lower montane forest	above-ground biomass (ABG)	301	683	37	664	1281	185
(New Guinea)	total litter	7.6	91	5.1	28	95	19
Lowland forest	above-ground biomass (ABG)	406	2430	59	435	423	201
(Brazil)	litter	7.3	106	2.2	13	18	13
Lowland forest	above-ground biomass (ABG)	233	1685	112	753	2370	320
(Ghana)	litter	10.5	199	7.3	68	206	45

(Source: P. J. Edwards, Studies of mineral cycling in a montane rain forest in New Guinea: V. Rates of cycling in throughfall and litter fall, *Journal of Ecology*, 1982, **70**.)

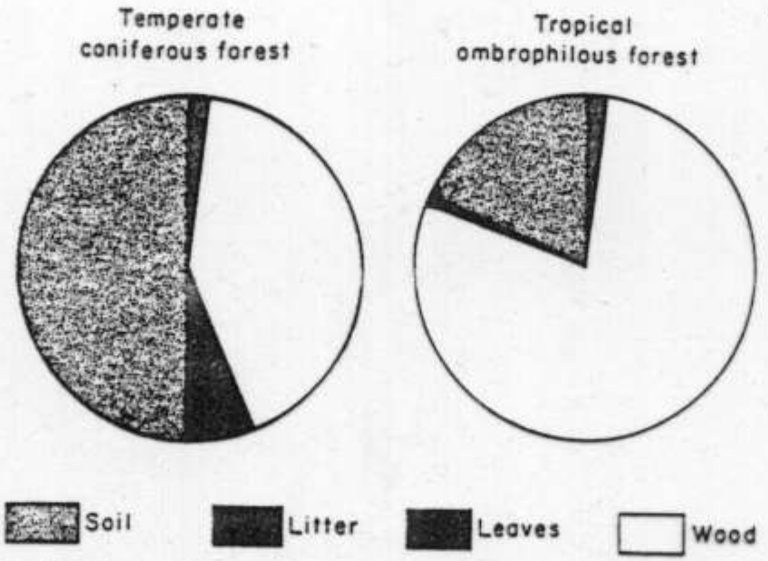


Figure 6.10 Distribution of organic carbon in the abiotic portion (soil litter) and biomass (wood, leaves) of tropical ombrophilous forest and temperate coniferous forest (After Kira and Shidei, 1967; Longman and Jenik, 1974). *Reproduced by permission of Longman Group Ltd*

Decomposition rate:

-- maximum at medium rainfall

-- increasing with temperature

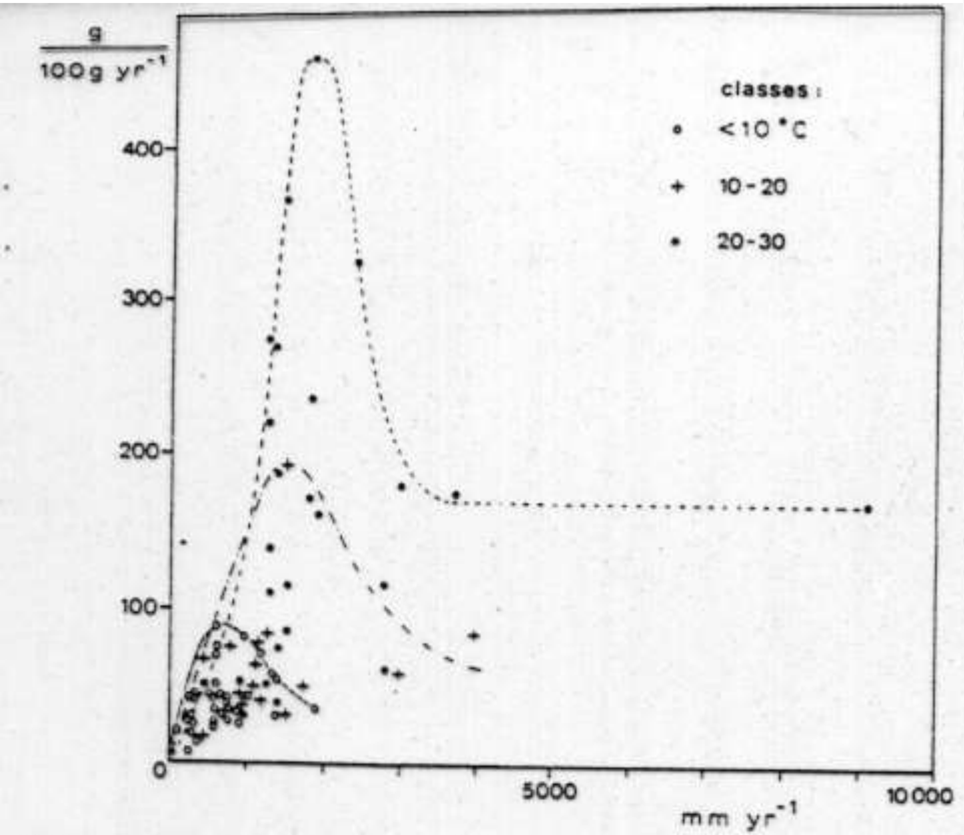


Fig. 32.1. Depletion rates of herbaceous litter separated in temperature blocks. The maxima of the three "Nyquist" lines shift with increasing temperature range to higher values of precipitation.

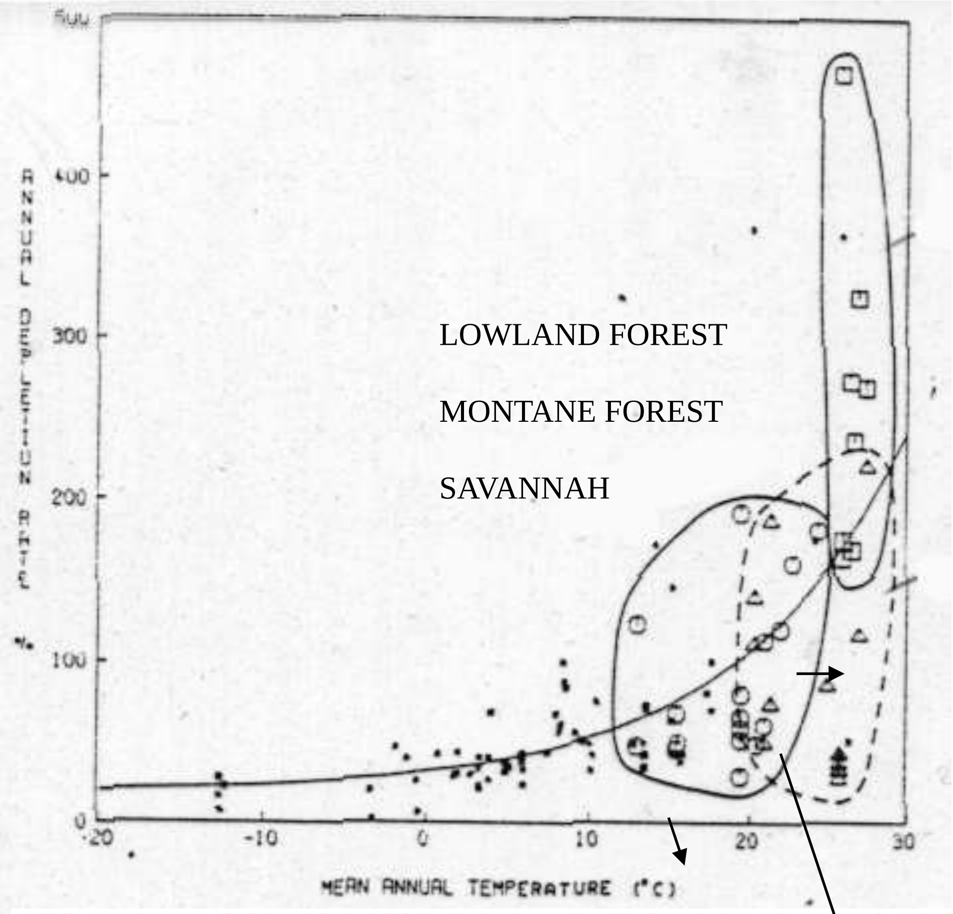
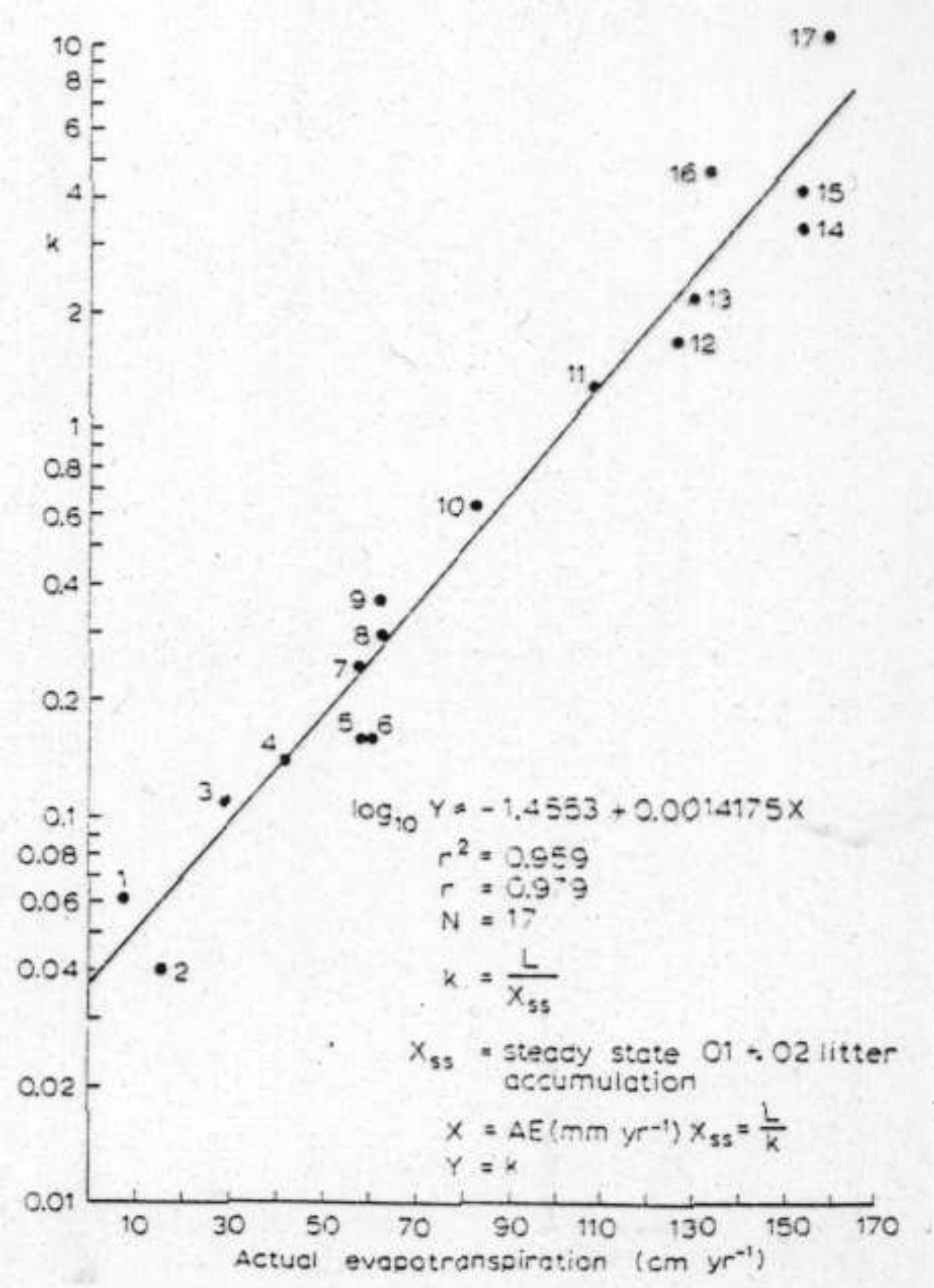


Fig. 32.2. Influence of mean annual temperature (T) on depletion rates of fresh herbaceous litter (D_H). The rates are in % of the reported litter pool per year. The regression curve is calculated from the running means of 5°C classes by Marquardt's least-squares method. Values higher than 100% indicate depletion times shorter than 1 year. Squares: tropical rain-forest data; triangles: tropical savanna data; circles: tropical mountain forest data; stars: data from other regions.



Decomposition rate:

synthesis of temperature and rainfall:

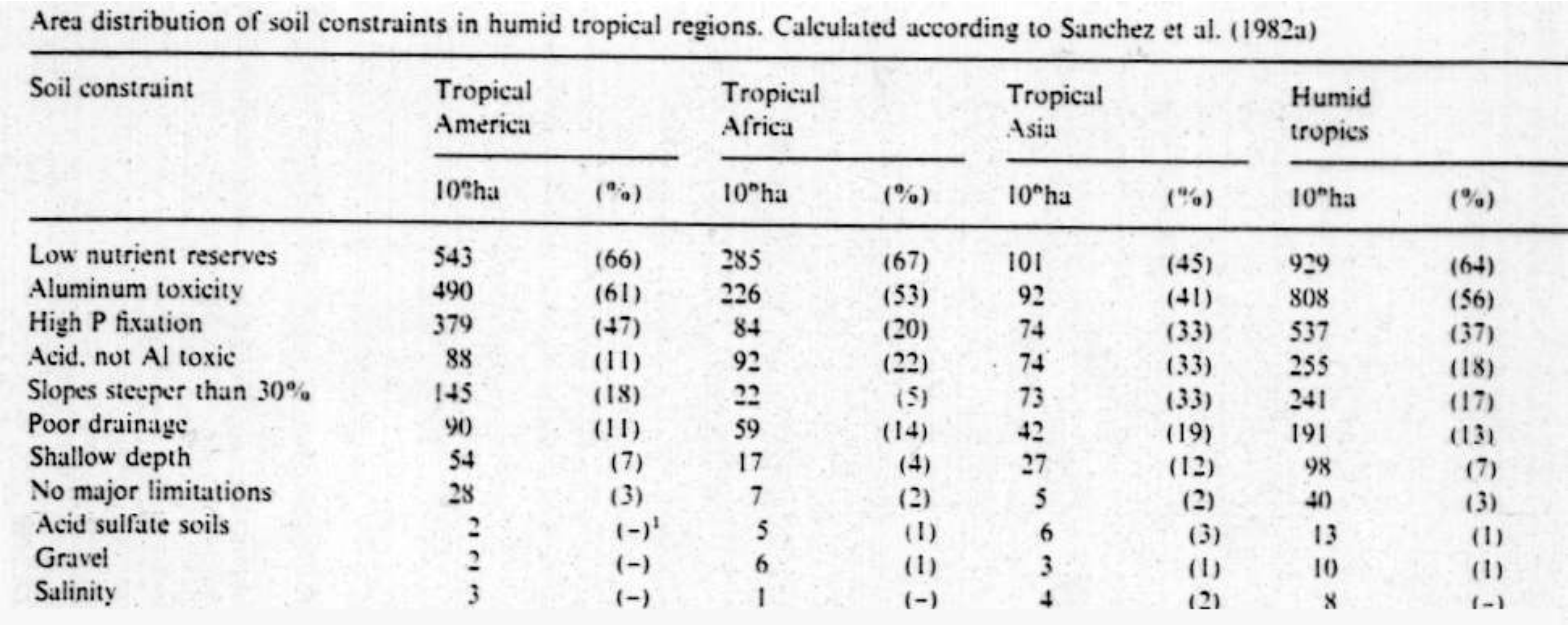
predicted by
actual evapotranspiration

Fig. 31.2. Relationship between decomposition and actual evapotranspiration for seventeen sites (after Meentmeyer, 1985). Sites *10* to *17* are tropical forest. The rate of decomposition is expressed as the Litter Turnover Coefficient K where $K = L/X_{ss}$ (L = Annual Litter Fall and X_{ss} = mean annual accumulation of 01 and 02 litter); the independent variable is Actual Evapotranspiration (AET). The relationship between k (y) and AET (X) is given by $\log_{10} Y = 1.45 + 0.0014X$ ($r = 0.98$, $n = 17$).

Tropical soils

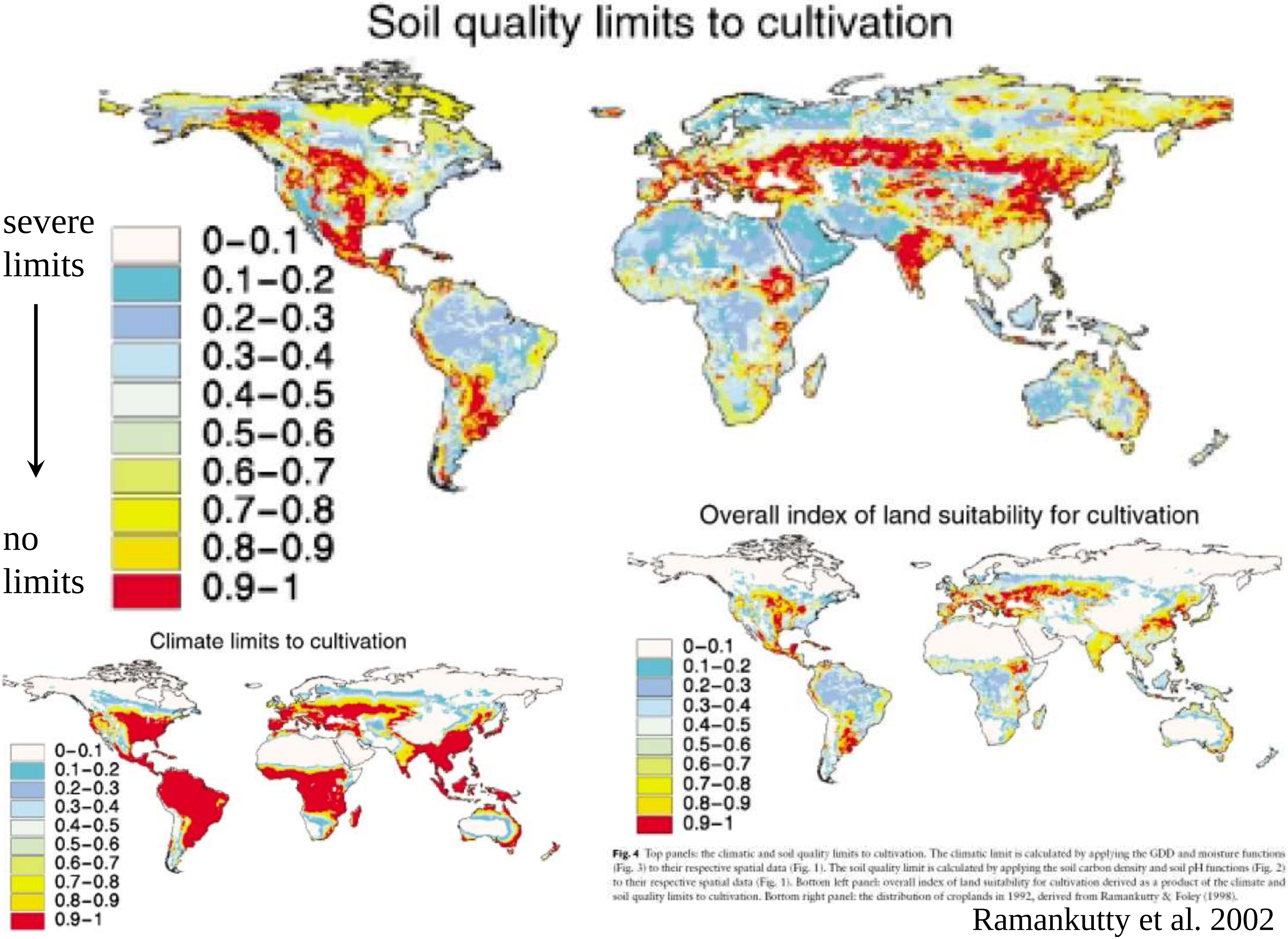
Main soil constraints on plant productivity in the tropics

Low nutrient reserves >50% of area
Aluminium toxicity >50% of area
No major limitations < 10% of area



Area distribution of soil constraints in humid tropical regions. Calculated according to Sanchez et al. (1982a)

Soil constraint	Tropical America		Tropical Africa		Tropical Asia		Humid tropics	
	10^6ha	(%)	10^6ha	(%)	10^6ha	(%)	10^6ha	(%)
Low nutrient reserves	543	(66)	285	(67)	101	(45)	929	(64)
Aluminum toxicity	490	(61)	226	(53)	92	(41)	808	(56)
High P fixation	379	(47)	84	(20)	74	(33)	537	(37)
Acid, not Al toxic	88	(11)	92	(22)	74	(33)	255	(18)
Slopes steeper than 30%	145	(18)	22	(5)	73	(33)	241	(17)
Poor drainage	90	(11)	59	(14)	42	(19)	191	(13)
Shallow depth	54	(7)	17	(4)	27	(12)	98	(7)
No major limitations	28	(3)	7	(2)	5	(2)	40	(3)
Acid sulfate soils	2	(–)[1]	5	(1)	6	(3)	13	(1)
Gravel	2	(–)	6	(1)	3	(1)	10	(1)
Salinity	3	(–)	1	(–)	4	(2)	8	(–)



severe limits

↓

no limits

Fig. 4 Top panels: the climatic and soil quality limits to cultivation. The climatic limit is calculated by applying the GDD and moisture functions (Fig. 3) to their respective spatial data (Fig. 1). The soil quality limit is calculated by applying the soil carbon density and soil pH functions (Fig. 2) to their respective spatial data (Fig. 1). Bottom left panel: overall index of land suitability for cultivation derived as a product of the climate and soil quality limits to cultivation. Bottom right panel: the distribution of croplands in 1992, derived from Ramankutty & Foley (1998).

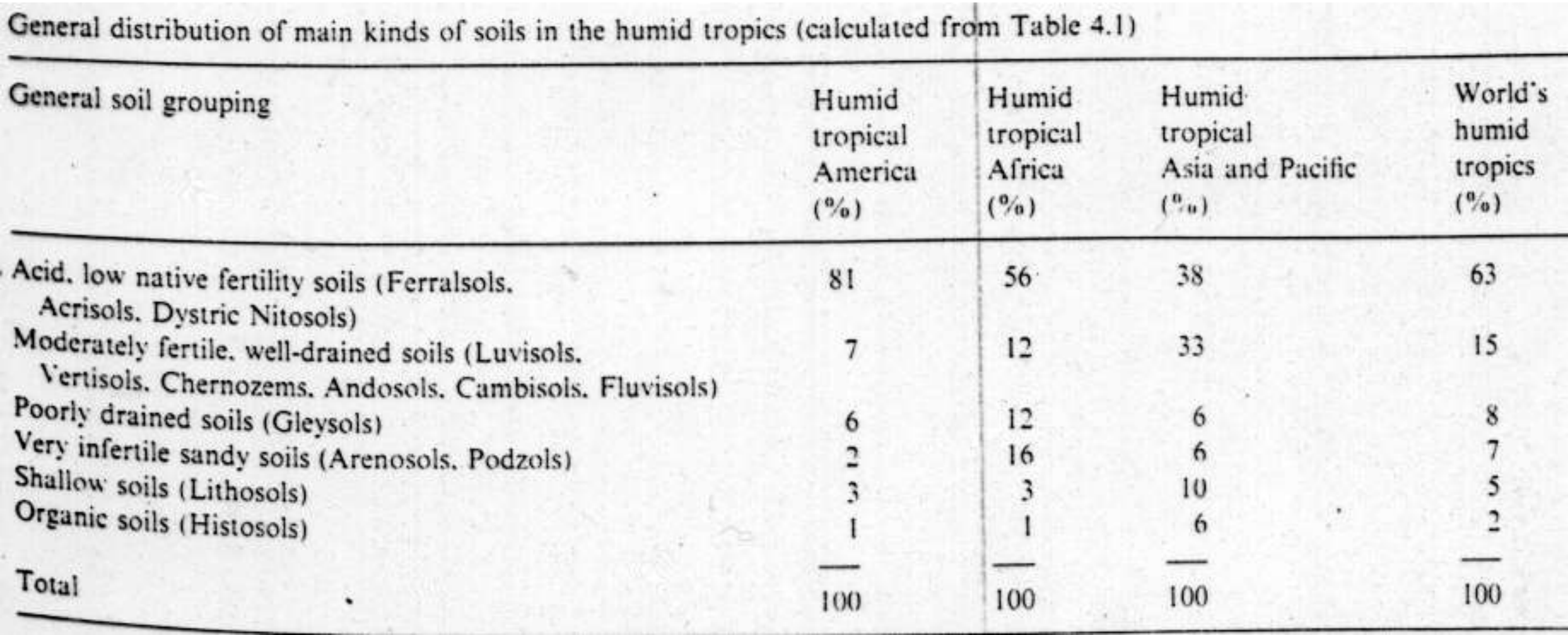
Ramankutty et al. 2002

Red soils of humid tropics (oxisols, ultisols):

- high acidity
- aluminium toxicity

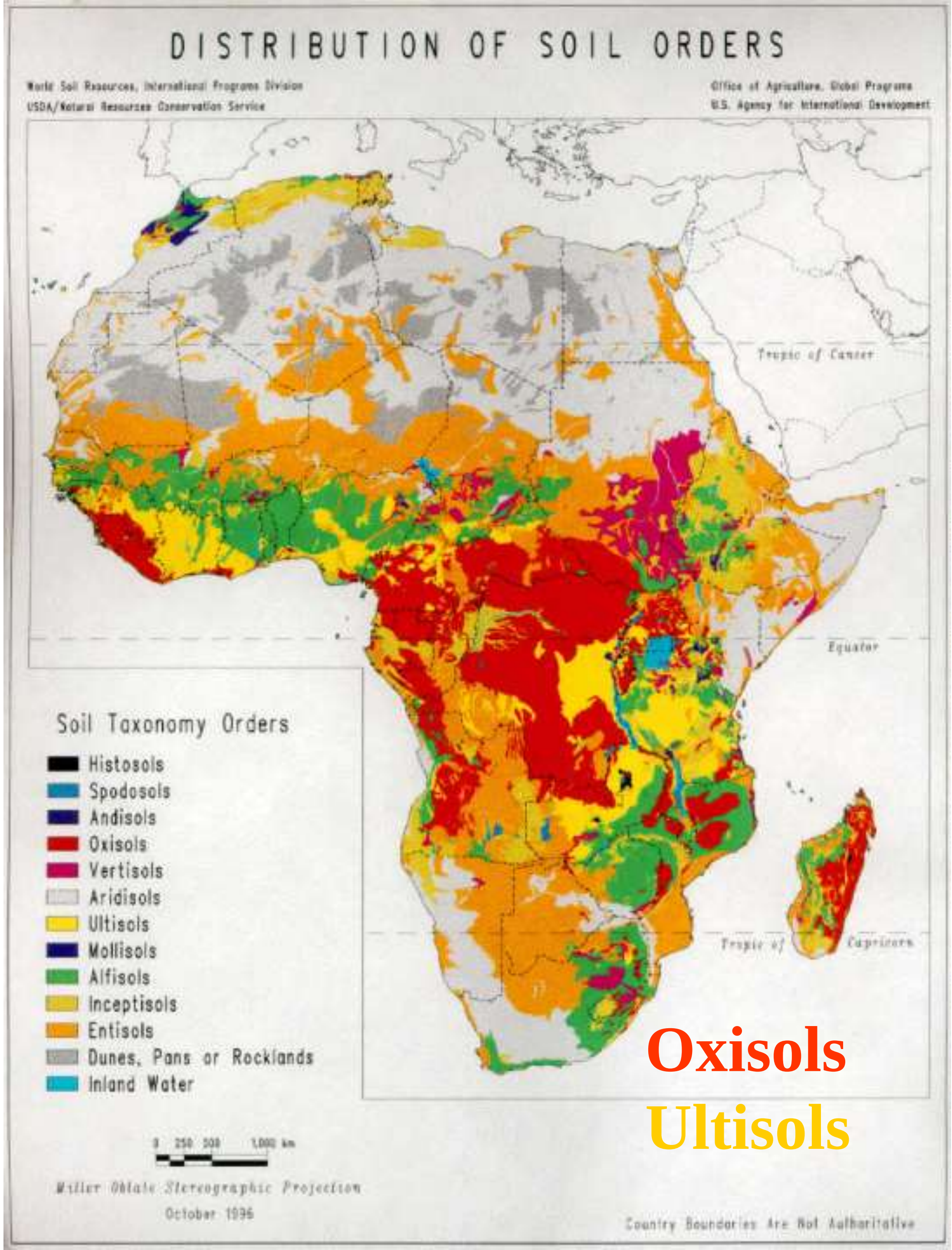
deficiency of P, K, Ca, Mg

- low cation exchange capacity = high leaching
- high organic content



General distribution of main kinds of soils in the humid tropics (calculated from Table 4.1)

General soil grouping	Humid tropical America (%)	Humid tropical Africa (%)	Humid tropical Asia and Pacific (%)	World's humid tropics (%)
Acid, low native fertility soils (Ferralsols, Acrisols, Dystric Nitosols)	81	56	38	63
Moderately fertile, well-drained soils (Luvisols, Vertisols, Chernozems, Andosols, Cambisols, Fluvisols)	7	12	33	15
Poorly drained soils (Gleysols)	6	12	6	8
Very infertile sandy soils (Arenosols, Podzols)	2	16	6	7
Shallow soils (Lithosols)	3	3	10	5
Organic soils (Histosols)	1	1	6	2
Total	100	100	100	100



Oxisols

Ultisols

OXISOL

Madagascar Jan. 2002

K, Ca in biomass, N, P in soil

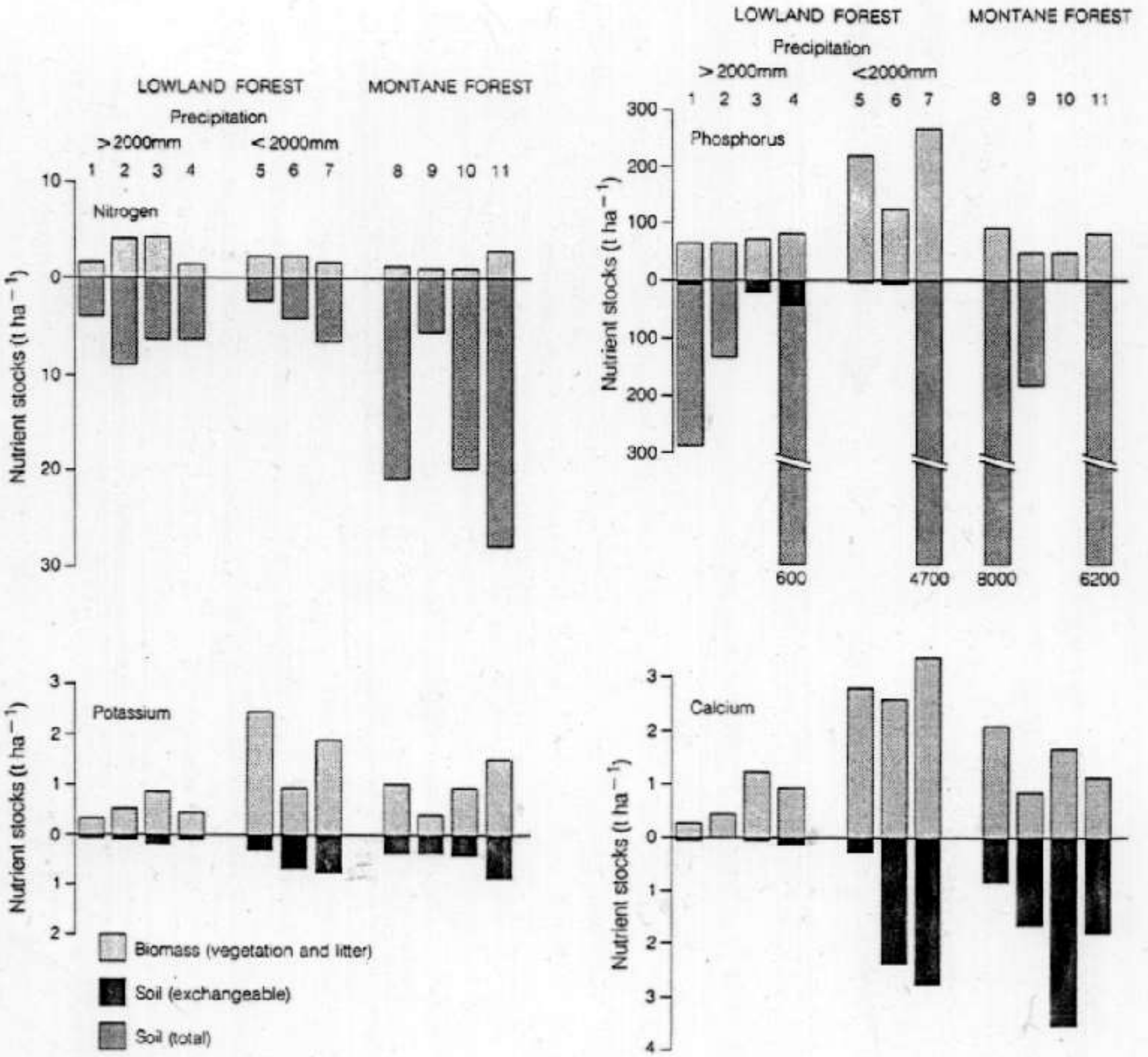


Figure 2.46 Nutrient stocks in living biomass and litter and in soils of tropical forests. The locations of the lowland forest sites are (1) and (7) Venezuela; (2) and (3) Brazil; (4) Ivory Coast; (5) Thailand; (6) Ghana. The montane forest sites are located in (8) Costa Rica; (9) Colombia; (10) New Guinea; (11) Venezuela. (After Jordan, 1985.) (Redrawn with permission from C. F. Jordan, *Nutrient Cycling in Tropical Forest Ecosystems*; published by John Wiley and Sons, 1985.)

Slash-and-burn agriculture: the effect on soil nutrients

Concentration of nitrates and potassium leached in soil water

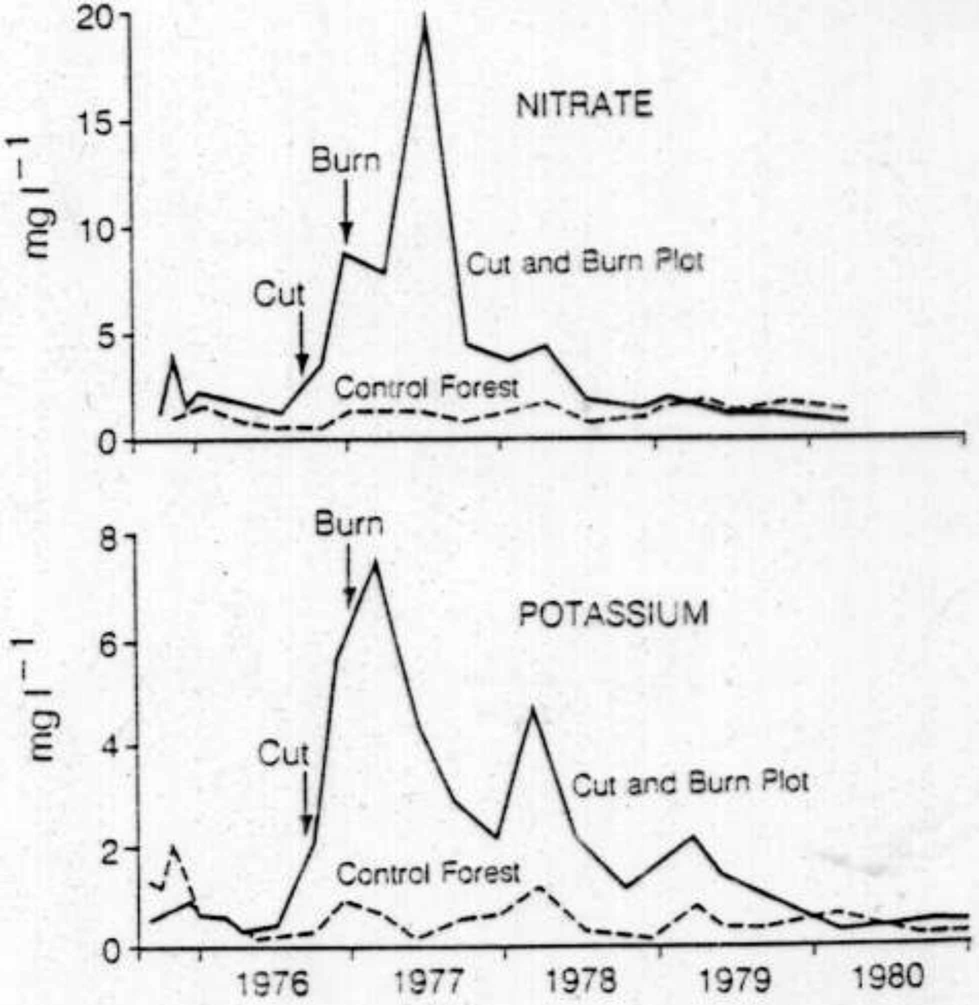
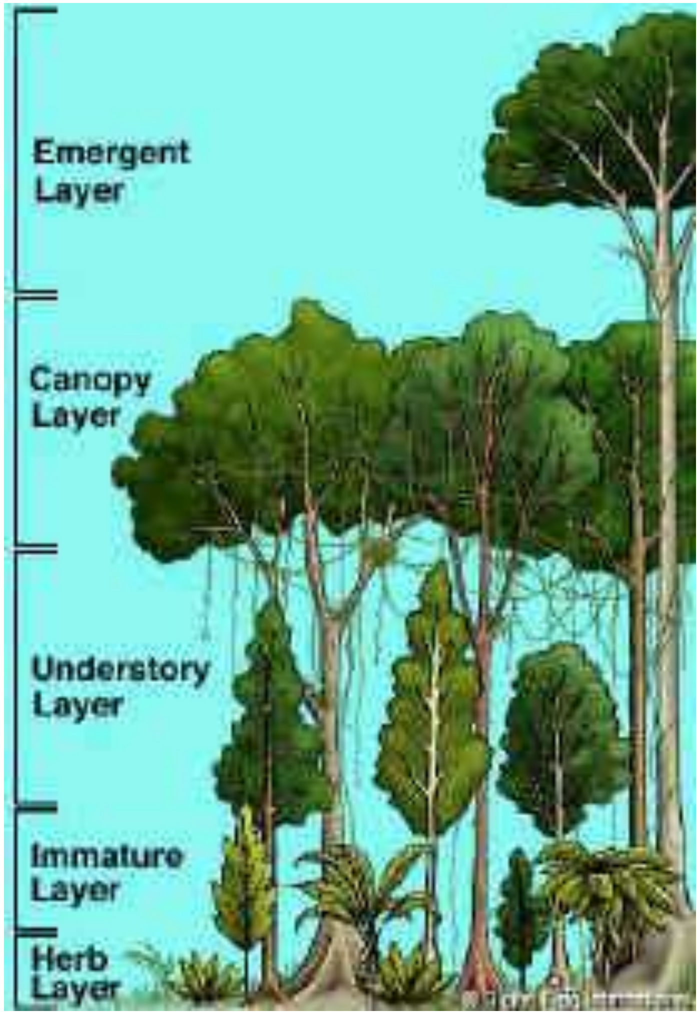


Figure 2.48 Concentrations of NO_3-nitrogen and potassium in soil water collected at 40 cm depth over a five-year period in forest and cut-and-burn plots in lowland rain forest in Venezuela. (After Uhl and Jordan, 1984.) (Reprinted with permission from C. Uhl and C. F. Jordan, Succession and nutrient dynamics following forest cutting and burning in Amazonia. *Ecology*, 1984, **65**, 1485.)

Main features of tropical forests



Structural features of lowland rainforests estimated for trees with DBH > 10 cm

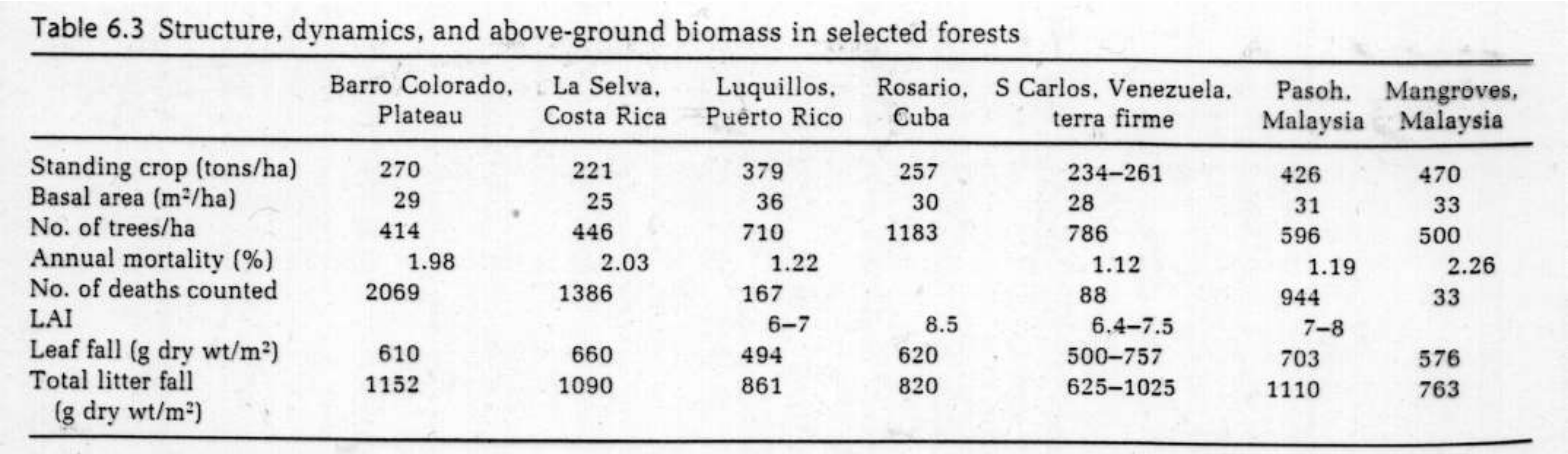


Table 6.3 Structure, dynamics, and above-ground biomass in selected forests

	Barro Colorado, Plateau	La Selva, Costa Rica	Luquillos, Puerto Rico	Rosario, Cuba	S Carlos, Venezuela, terra firme	Pasoh, Malaysia	Mangroves, Malaysia
Standing crop (tons/ha)	270	221	379	257	234–261	426	470
Basal area (m^2/ha)	29	25	36	30	28	31	33
No. of trees/ha	414	446	710	1183	786	596	500
Annual mortality (%)	1.98	2.03	1.22		1.12	1.19	2.26
No. of deaths counted	2069	1386	167		88	944	33
LAI			6–7	8.5	6.4–7.5	7–8	
Leaf fall (g dry wt/m^2)	610	660	494	620	500–757	703	576
Total litter fall (g dry wt/m^2)	1152	1090	861	820	625–1025	1110	763

Standing biomass	221 - 470 t/ha
Basal area	25 - 36 m2/ha
No. of trees	414 - 1183 per ha
Annual mortality	1.1 - 2.3%
LAI	6 - 8.5
Leaf fall	4.94 - 7.6 t/ha
Total litter fall	6.3 - 11.5 t/ha

Leaf area index
(by remote sensing)

Buermann et al. 2008, J. Biogeography 35, 1160–1176

Measuring forest structure

Emergent trees

Drip apex of the leaves

Epiphylls

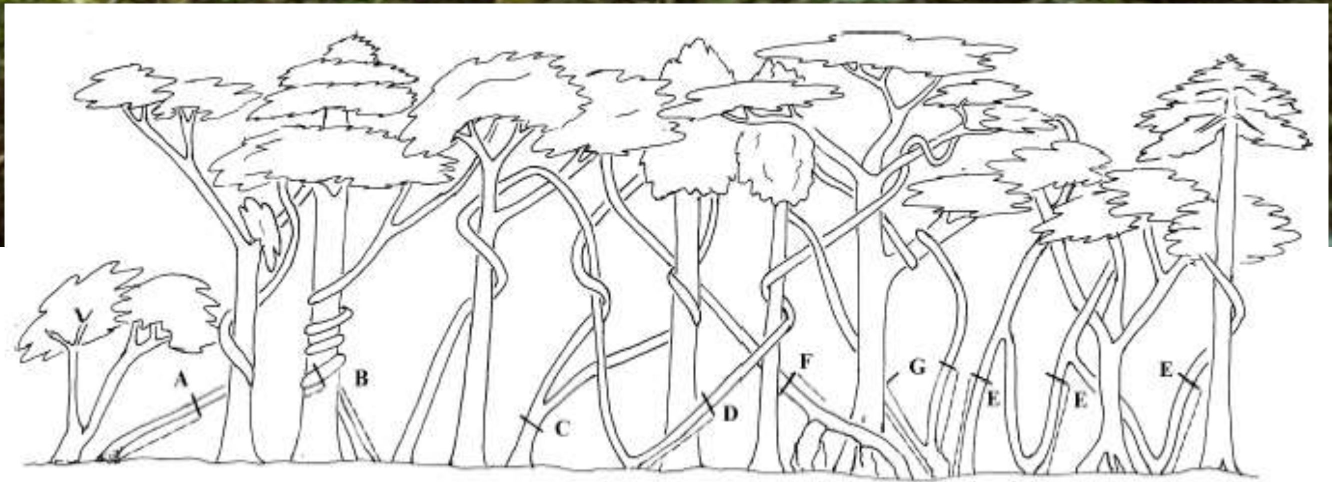
buttresses

support roots

stilt roots
Pandanus

aerial roots

lianas



climbers

Trunk epiphyte Epipremnum. Queensland. Len Webb photo

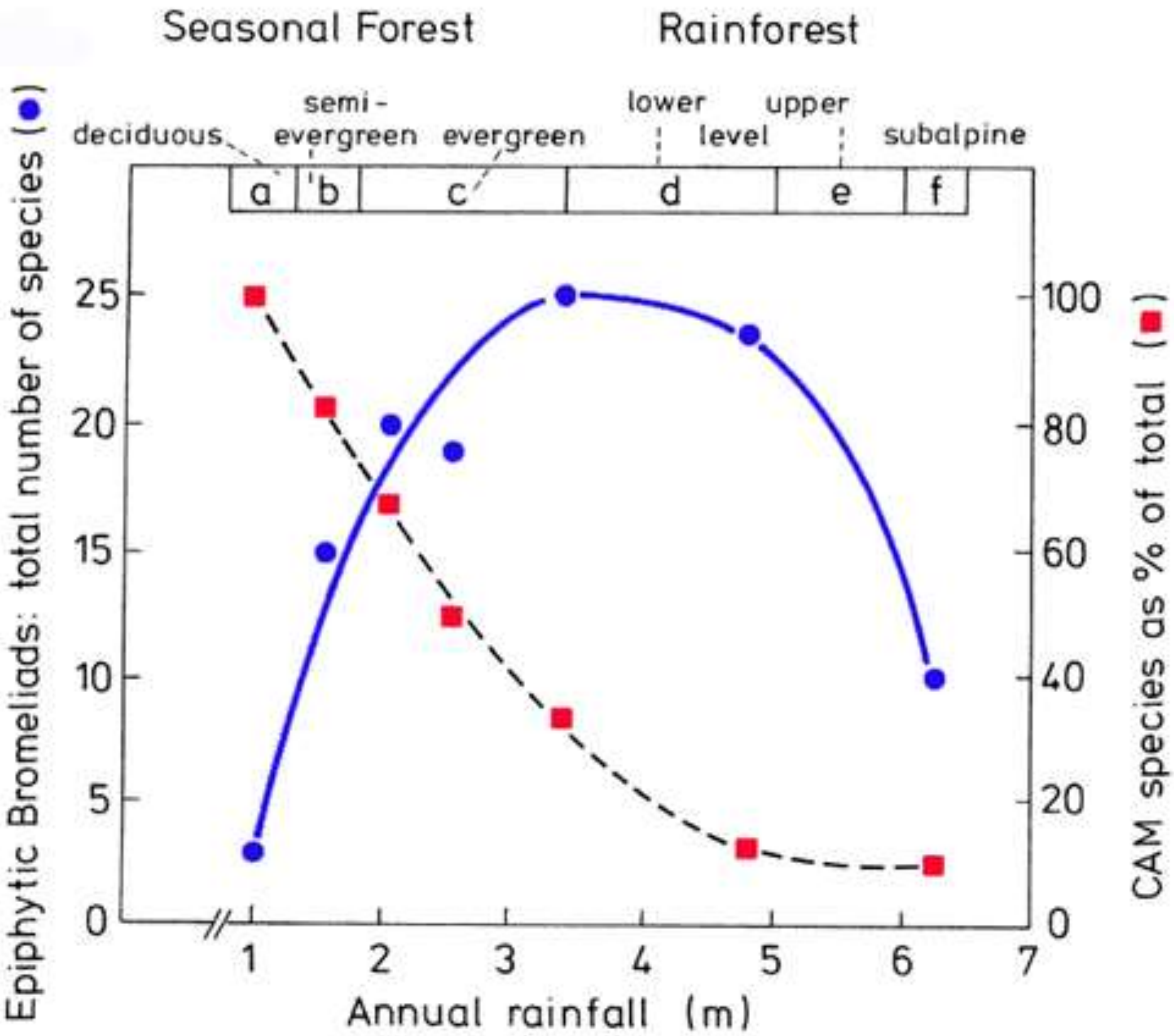
epiphytes

SE Asia: Asplenium ferns

Neotropics: bromelias

[**Vriesea** Aechmea,, Bilbergia, Guzmania]

Forest seasonality, epiphytic bromeliad diversity and % of CAM species in Trinidad

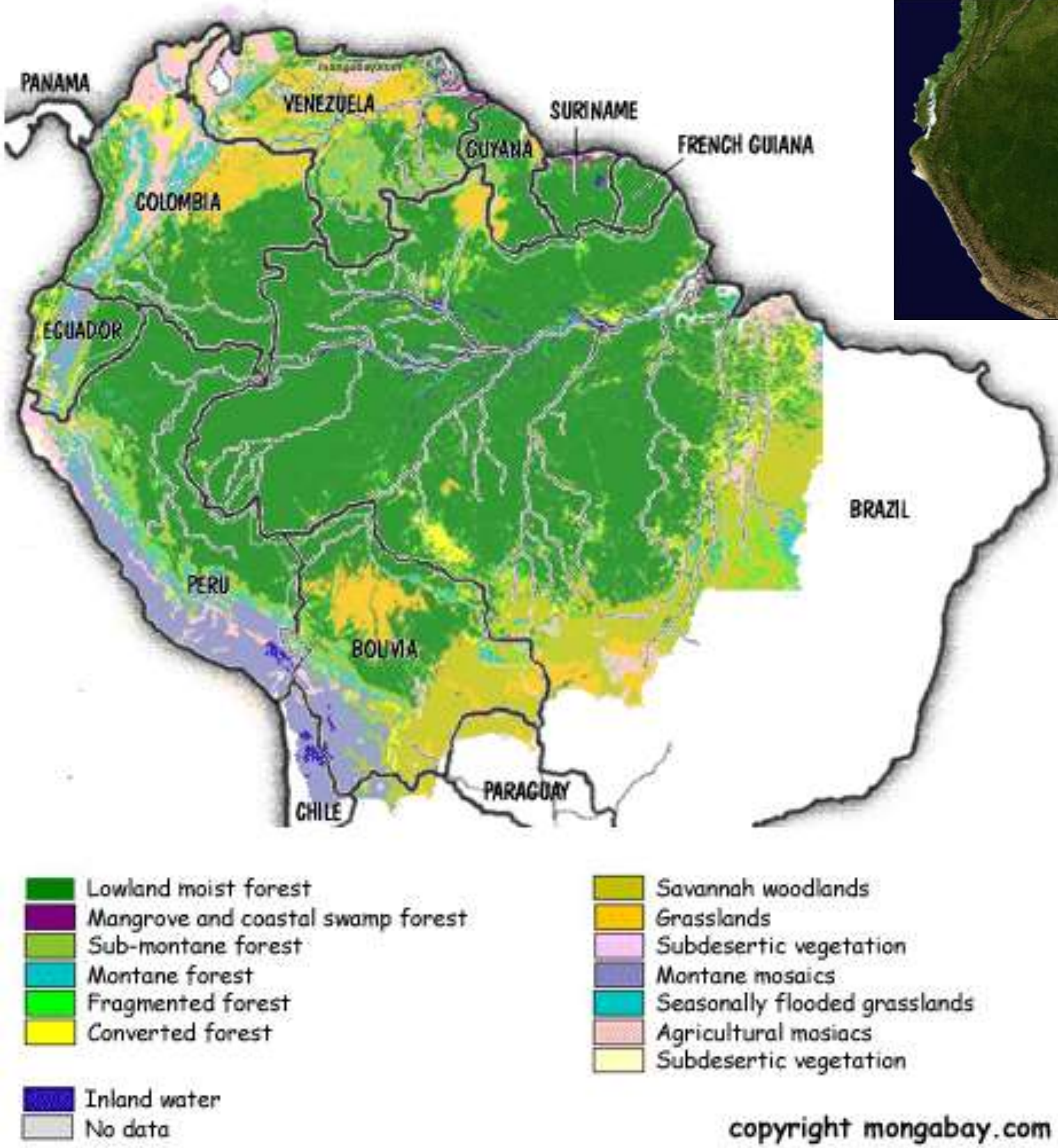


Smith 1989

epiphytes

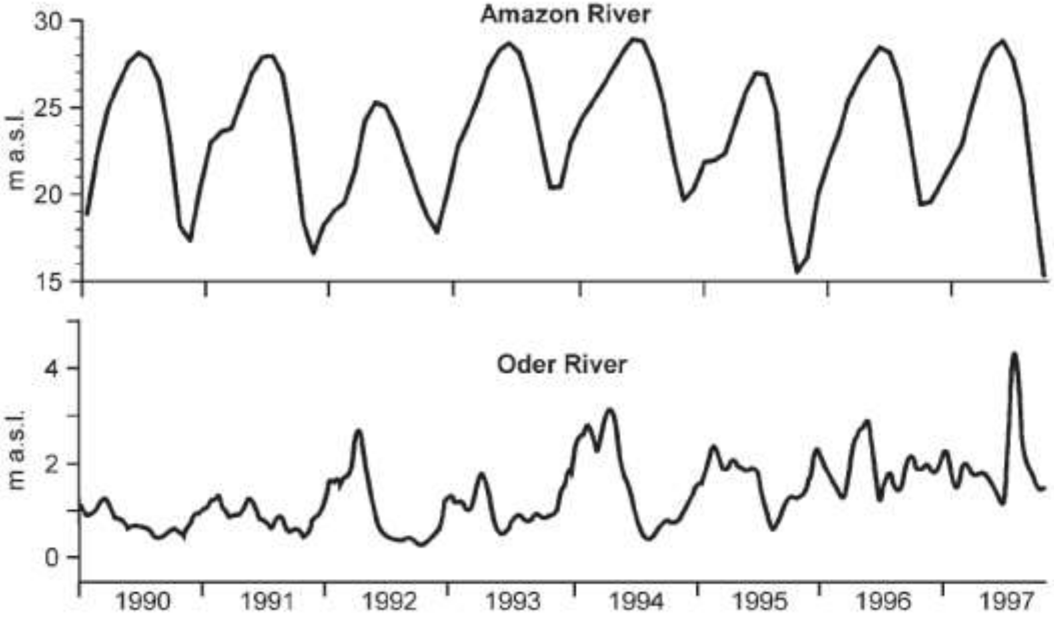
epiphytic moss carpets

Forest distribution in Amazonia

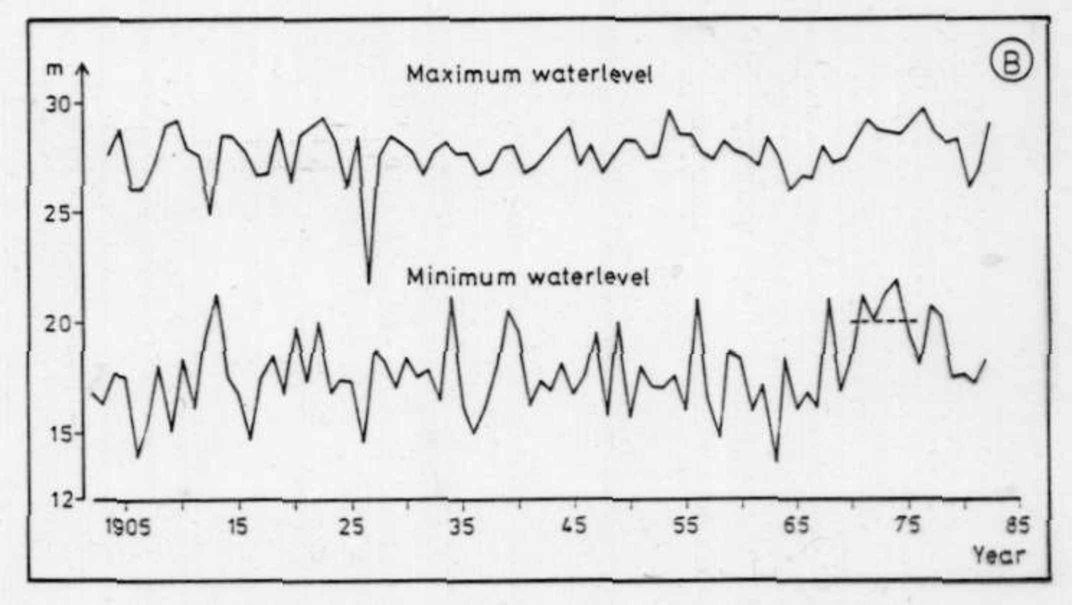


Amazon river system drawn over Europe

Seasonal fluctuation of water level in Amazon and Rhine rivers



Annual fluctuation of water level in Amazon river



Low inclination of Amazon river

+

water level fluctuation

+

flat landscape

=

large inundated areas of varzea forests

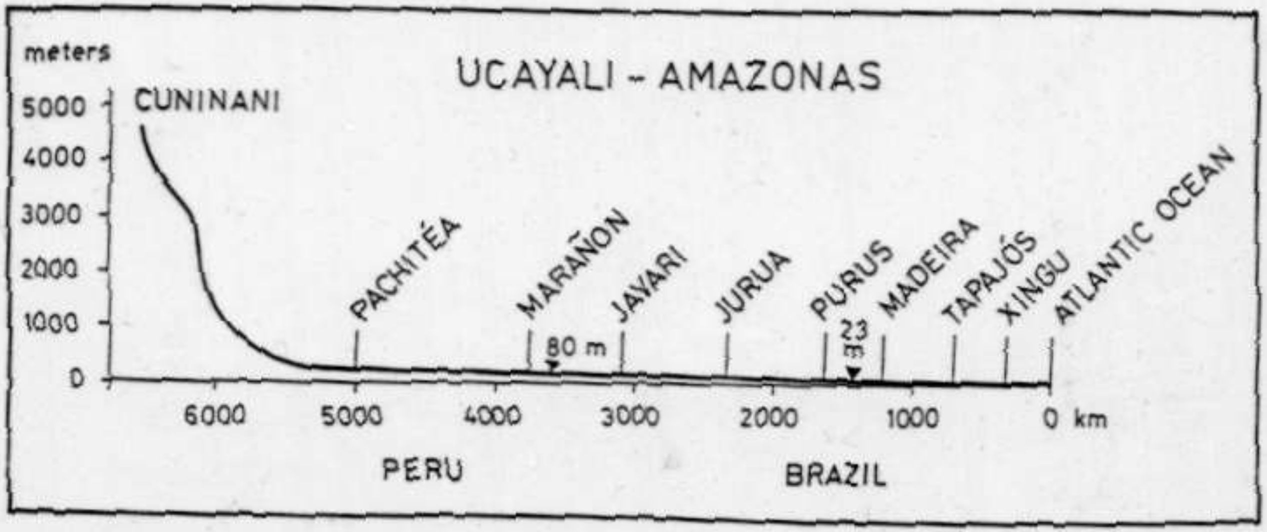
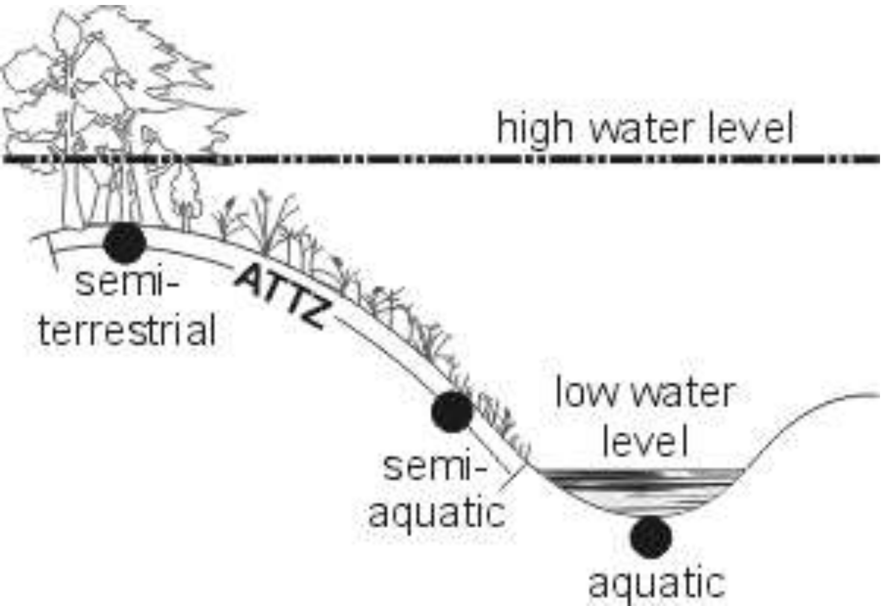


Figure 1. Watertable for the main body of the Amazon river. The low inclination reflects the low altitudes of the Amazon basin (After Soares, 1959).

Varzea: periodically inundated forests of white water Amazon

High water: 6-8 months



Varzea - floating and truly aquatic macrophytes are species rich. 'Floating meadows' are often 10-100s ha in extent, dominated by *Paspalum repens* and *Echinochloa polystachya*. Free-floating aquatic plants form floating mats of *Eichhornia*, *Pistia*, *Limnobium*, *Salvinia*, *Azolla*, *Lemna* etc.

Paspalum repens

Ceratopteris floating fern

Pisces Conservation Ltd. www

Varzea - everything floats, even cattle

White and black waters

The confluence of white water Amazon and black water Rio Negro

White-water sediments originate in the Andes and carry heavy sediment loads (pH=7)

Black-water rivers receive drainage from bleached sands of the central lowlands – low nutrients and stained black (pH=4)

Igapo - periodically inundated forests in black water river systems (Rio Negro)

Black waters are stained by humic acids and tannins, low in nutrients. Forest dominated by palms and legumes.

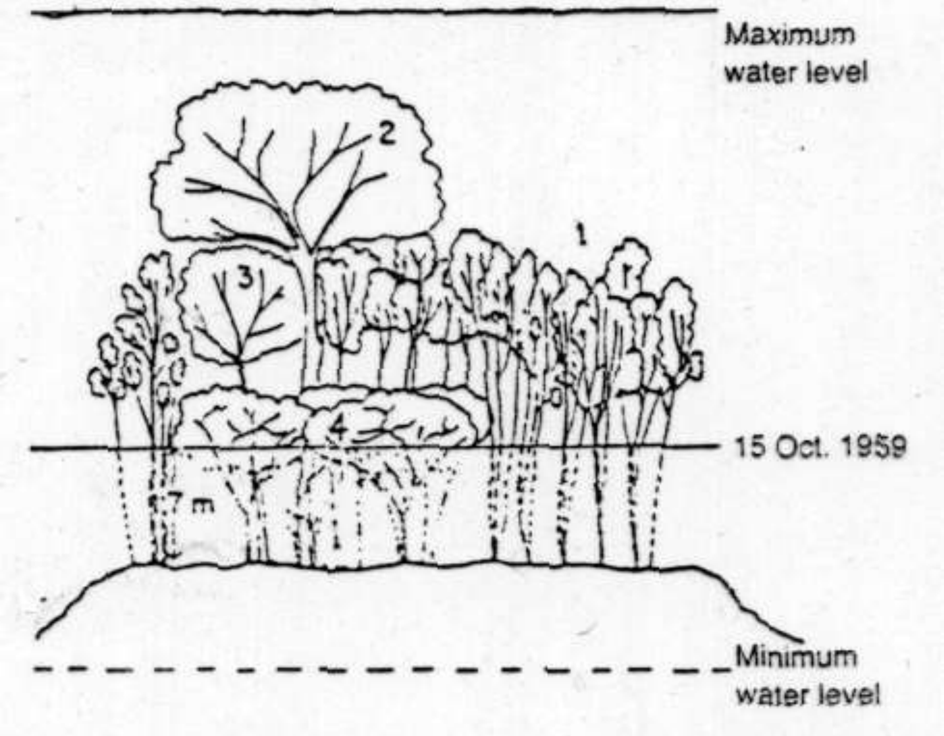
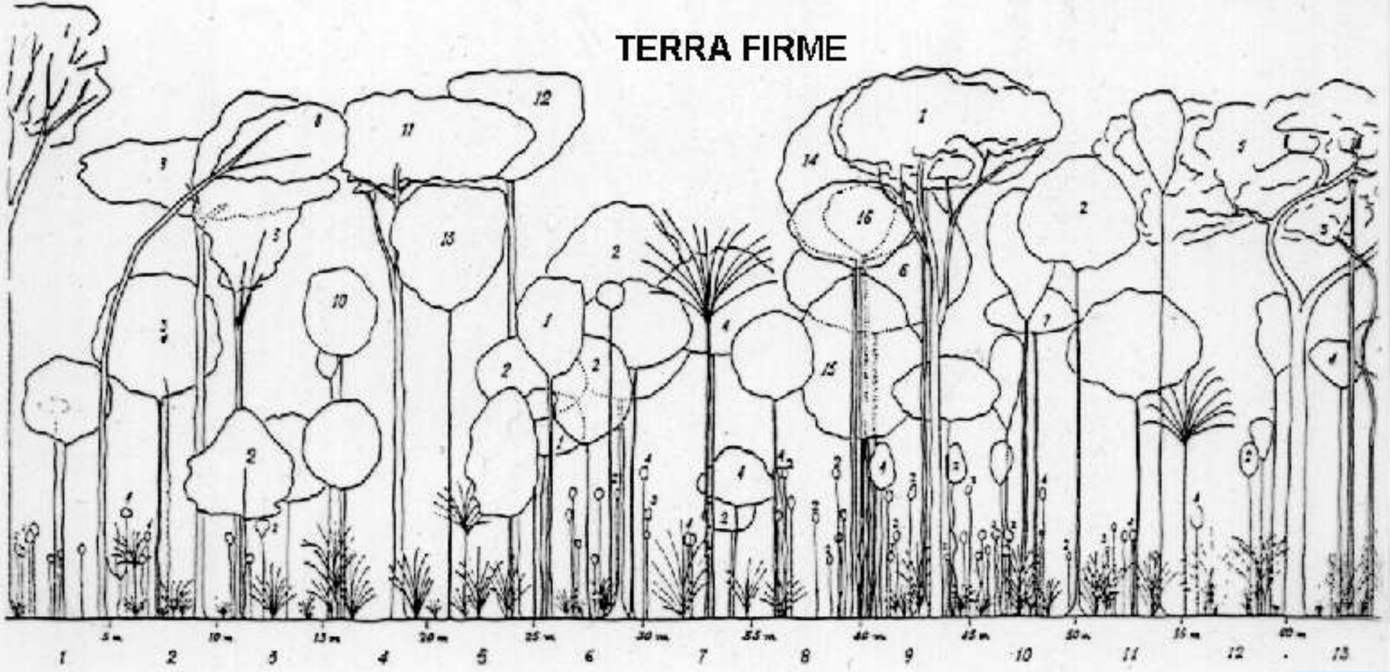
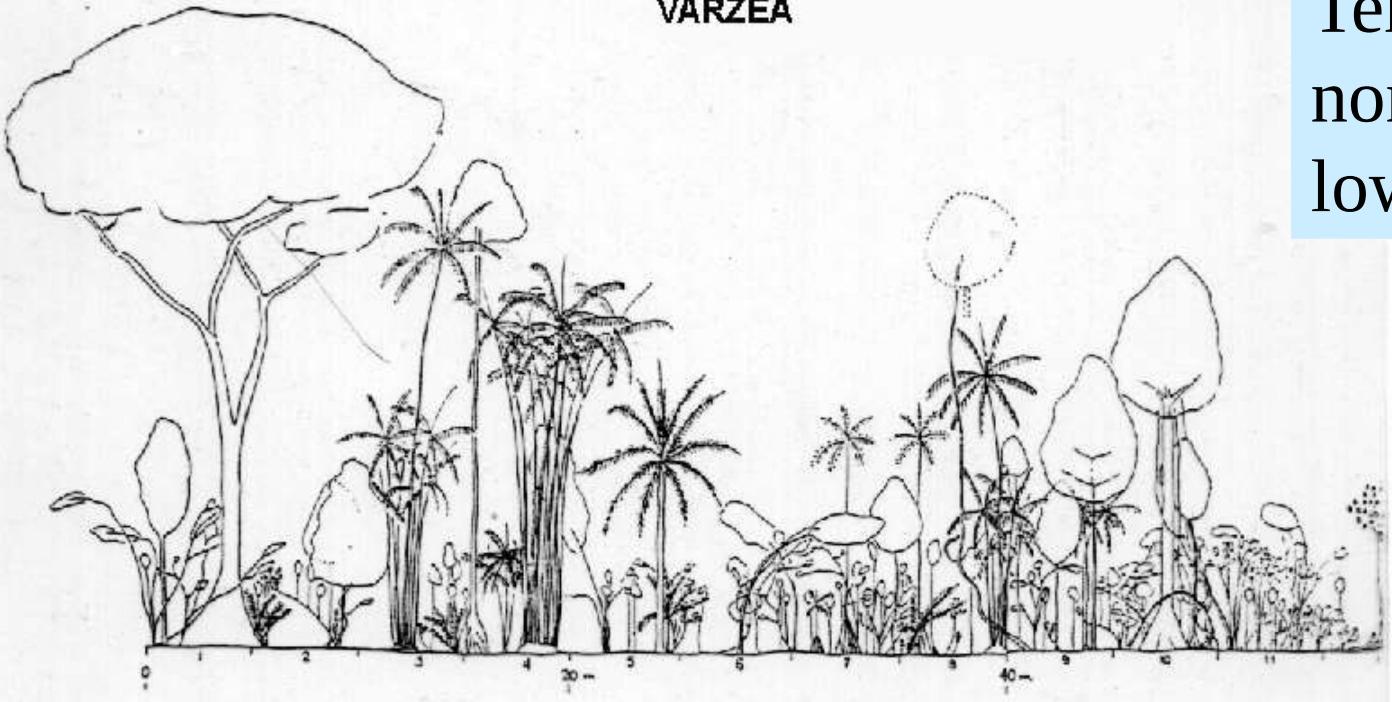


Fig. 14.5 Profile diagram of igapó on Rio Negro near Manaus. After Takeuchi (1962). Key: 1 *Eugenia inundata*, 2 *Campsiandra latifolia*, 3 *Symmeria paniculata*, 4 *Coccoloba* sp.

TERRA FIRME



VARZEA



Terra firme forest: non-inundated lowlands

Cerrado: shrubland in dry areas

Brasil:

Cerrado

Caatinga:

dry forest/shrubland on sandy soils

Brasil:

Dry season (7-8 months)

Cerrado zonation on a moisture gradient

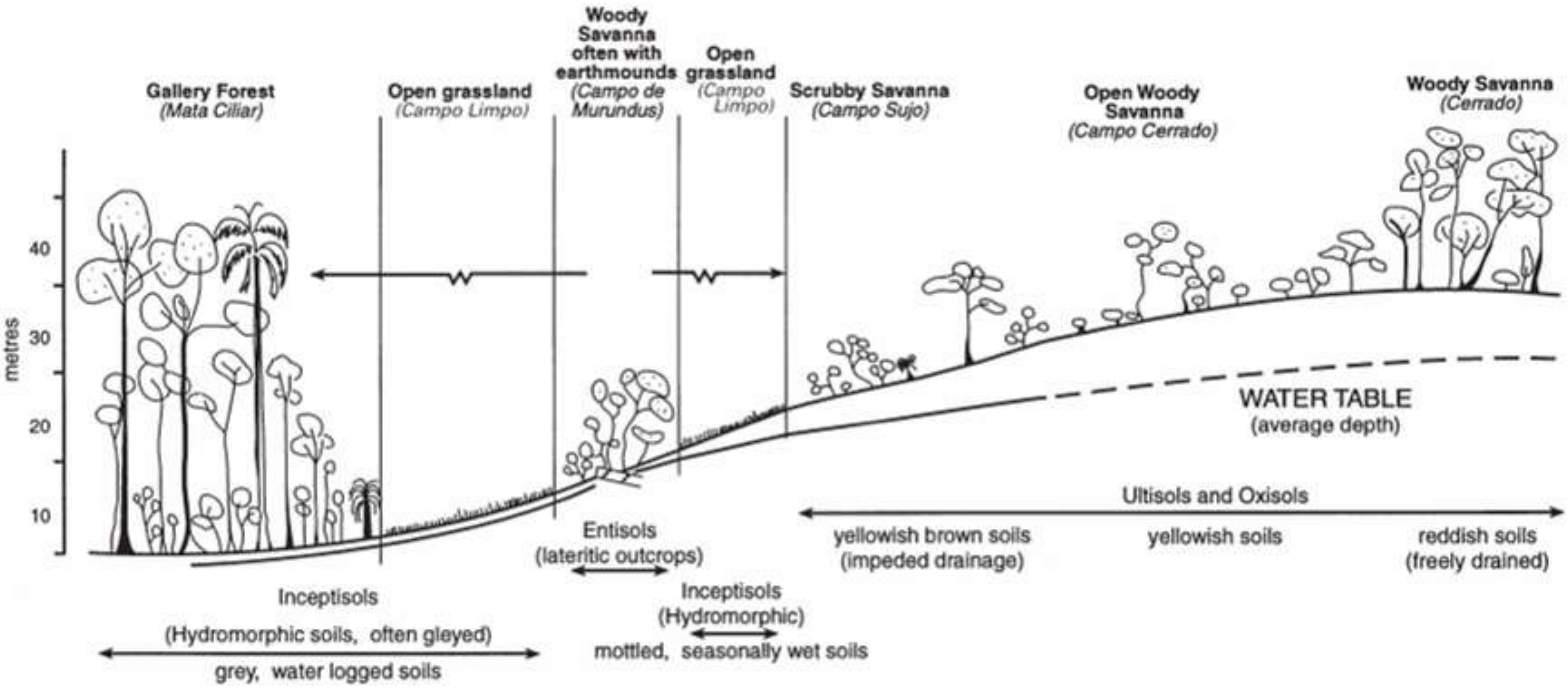
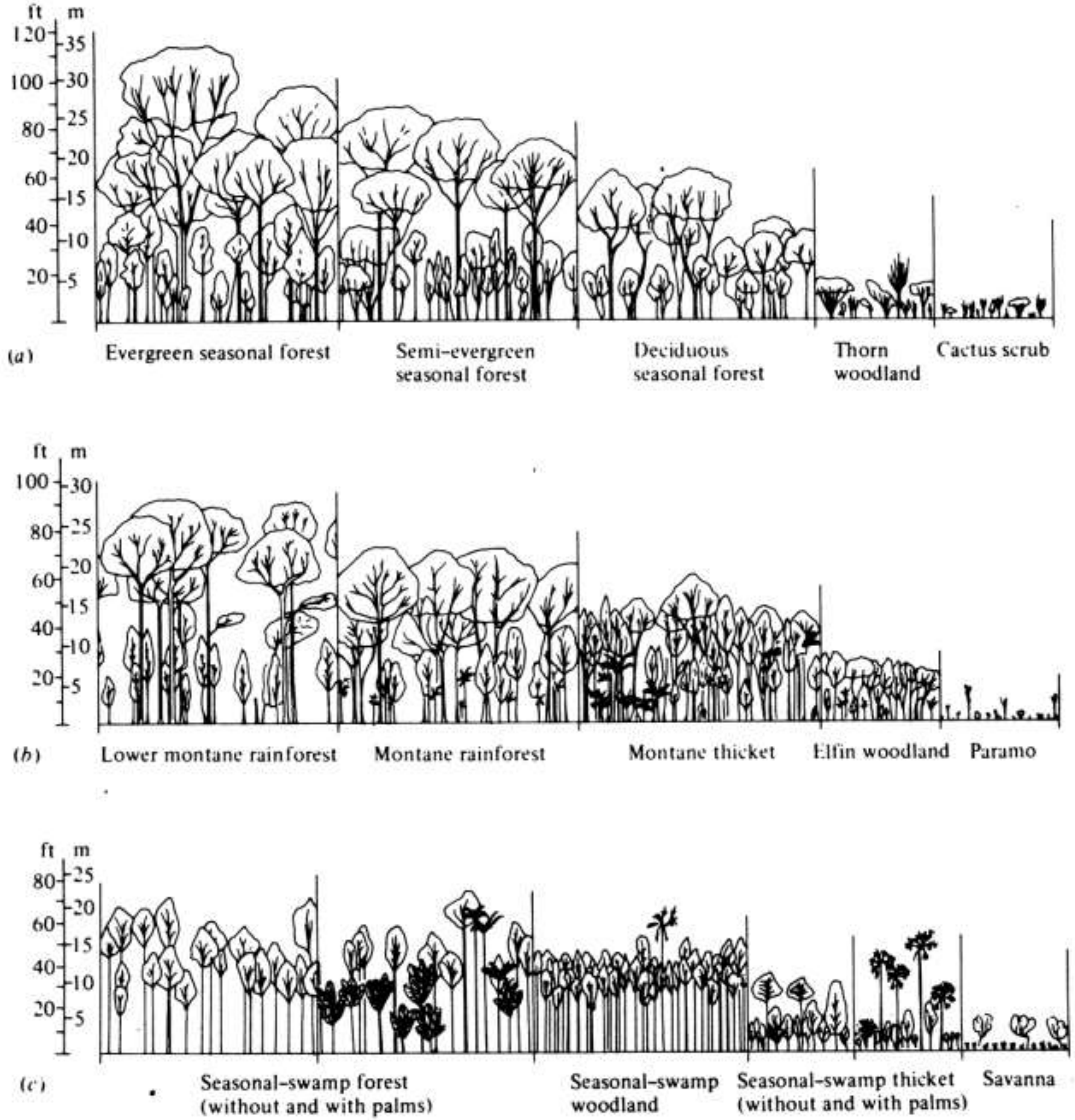
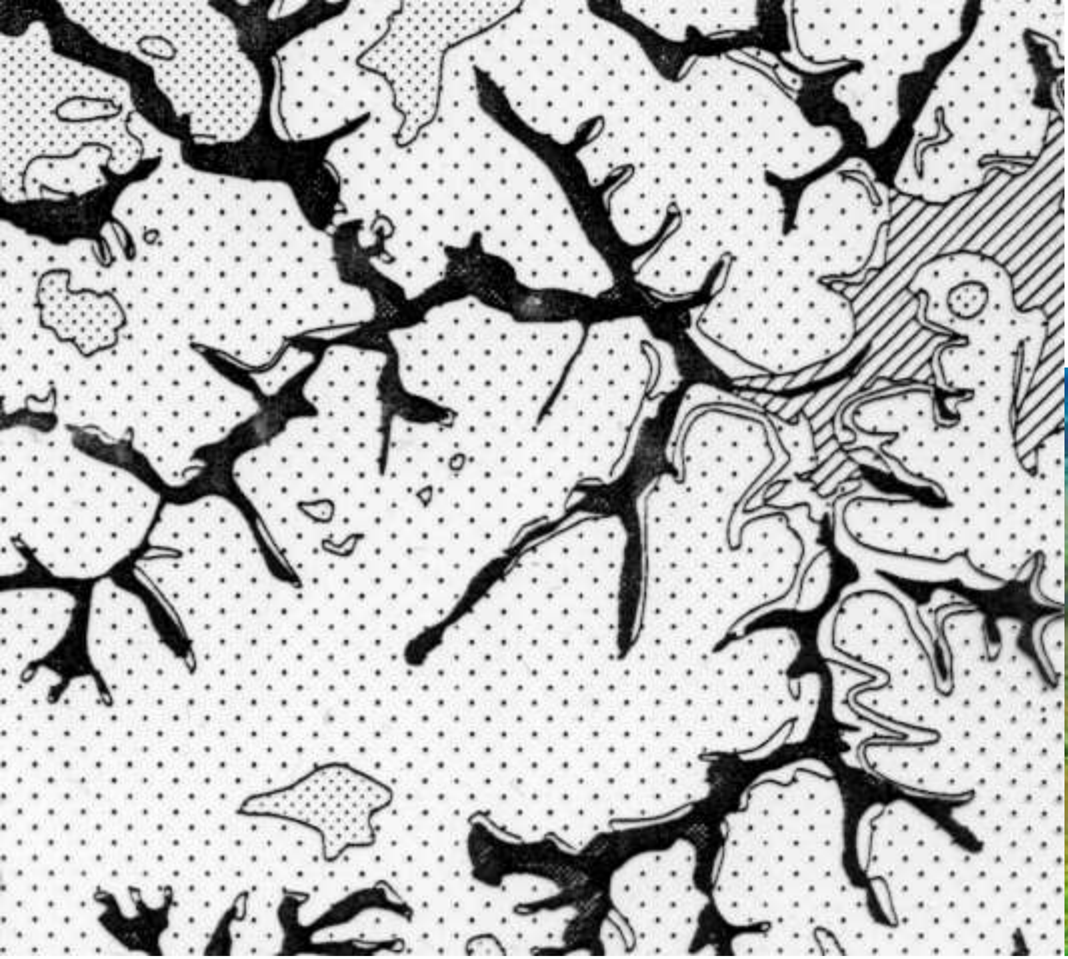


Fig. 5. The influence of topography and drainage on the forms of *cerrado*. The heights refer to the vegetation and not to the schematic relief (after Furley, 1996).

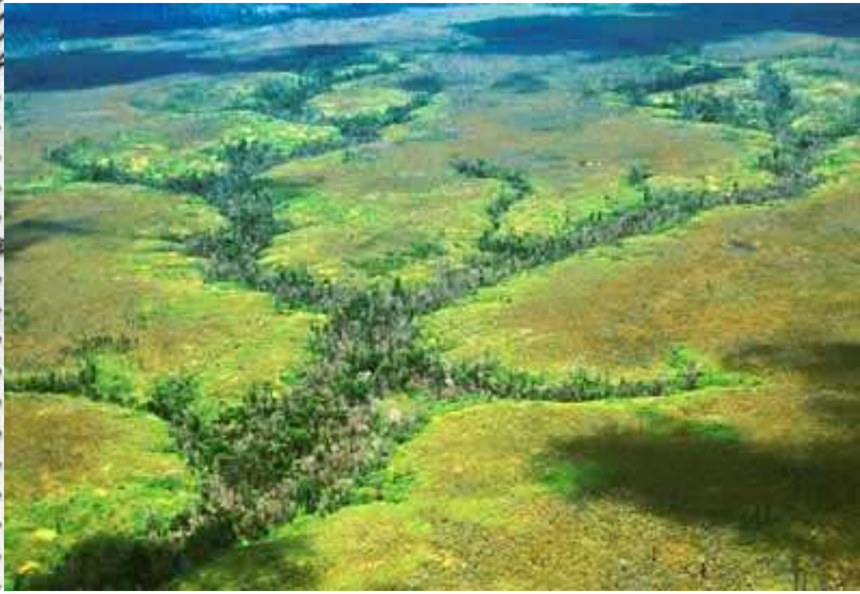
Three (Neotropical) rainfall gradients



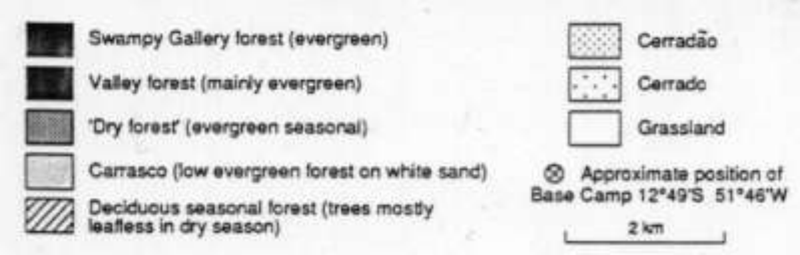
Gallery forest



Gallery forest surrounded by cerrado in Brasil



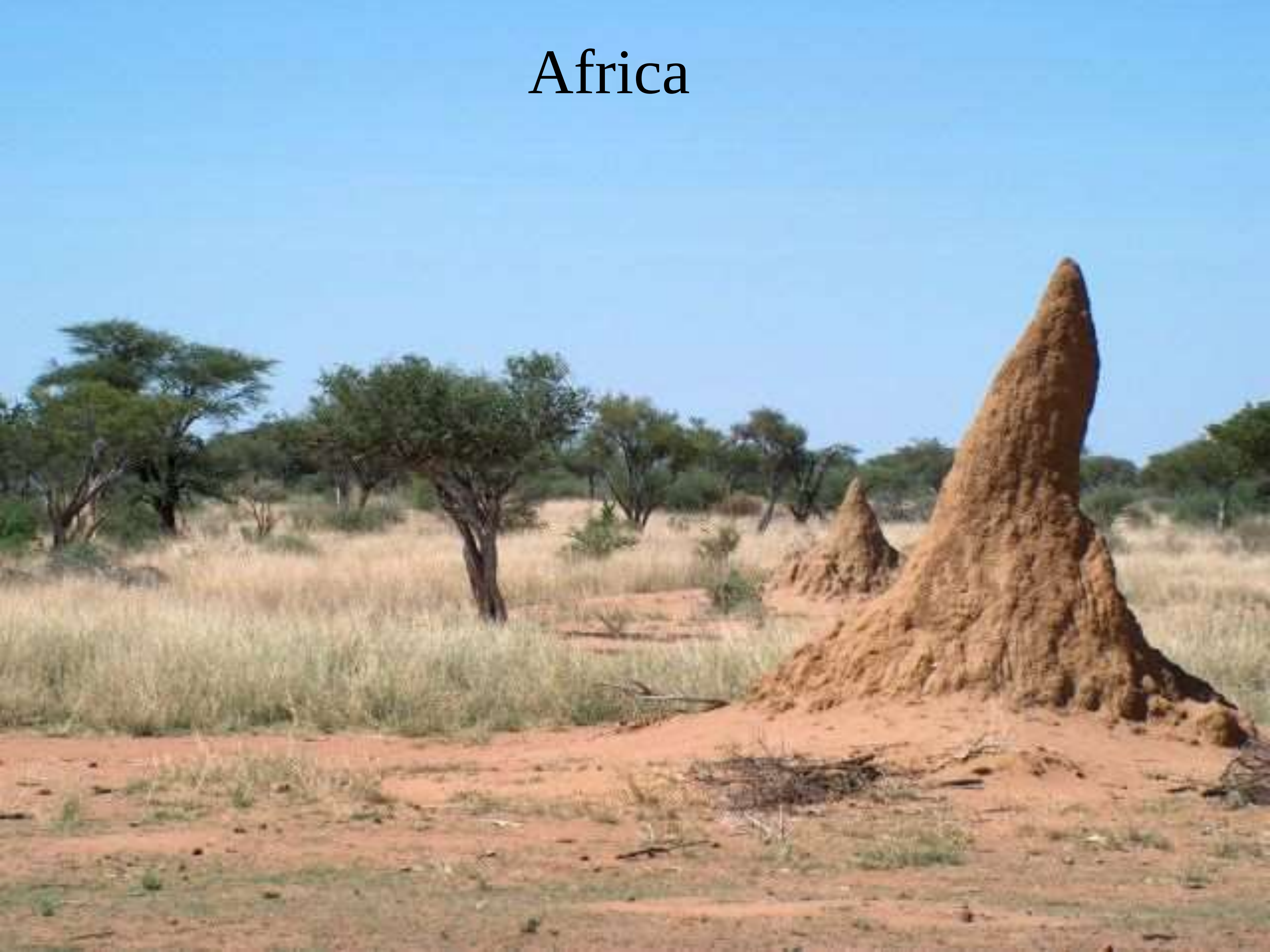
SE Asia gallery forest



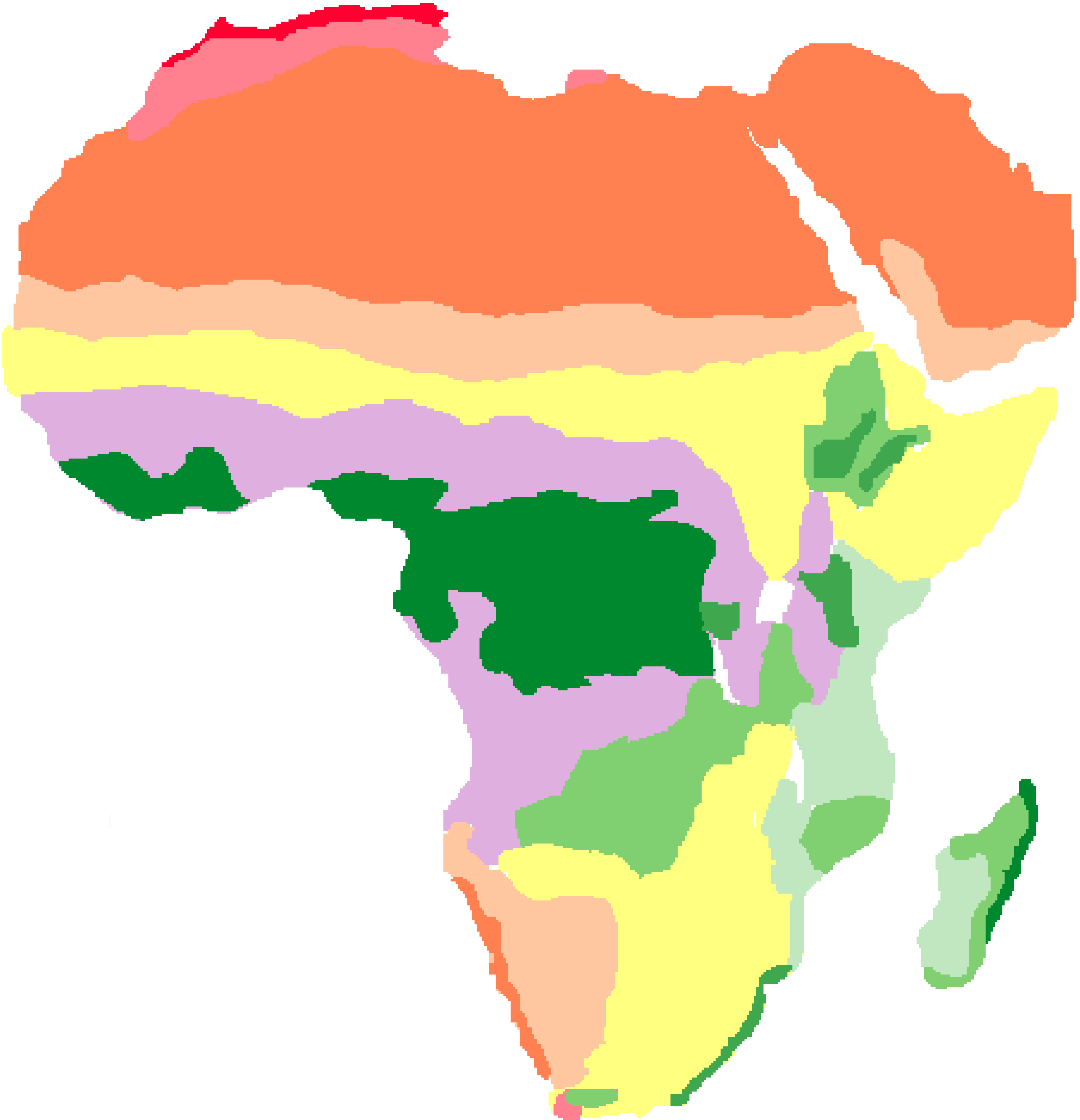
Monodominant forests: on extremely nutrient-poor white sands (e.g., Guyana)

Mora excelsa, the forest dominant:

Africa



Present Potential Vegetation



grassland
savanna

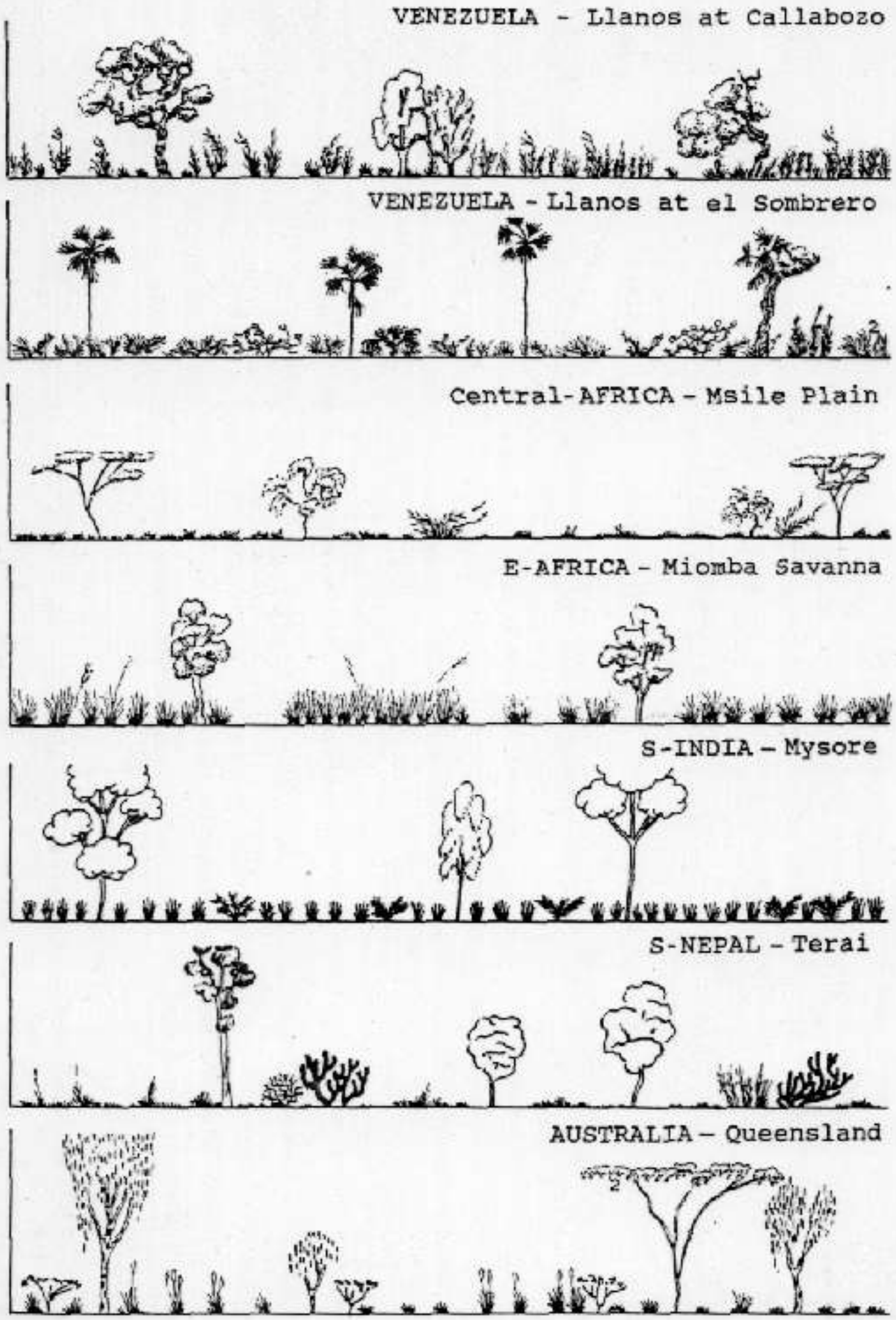
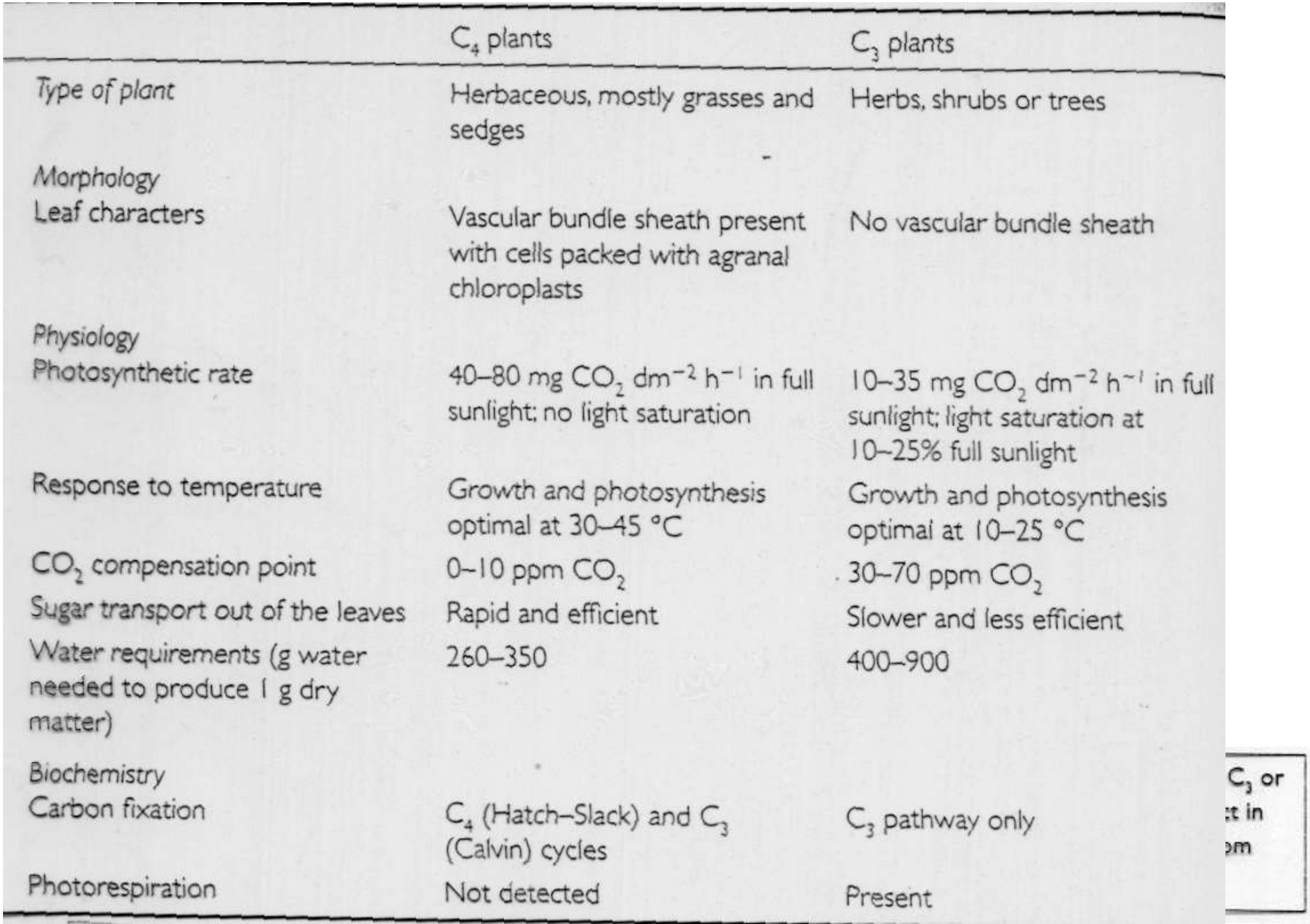


Fig. 7.2. Physiognomy of savannas with examples from all over the world. Transects of Vareschi (1980, with kind permission of R. Ulmer)

Typical savanna trees:

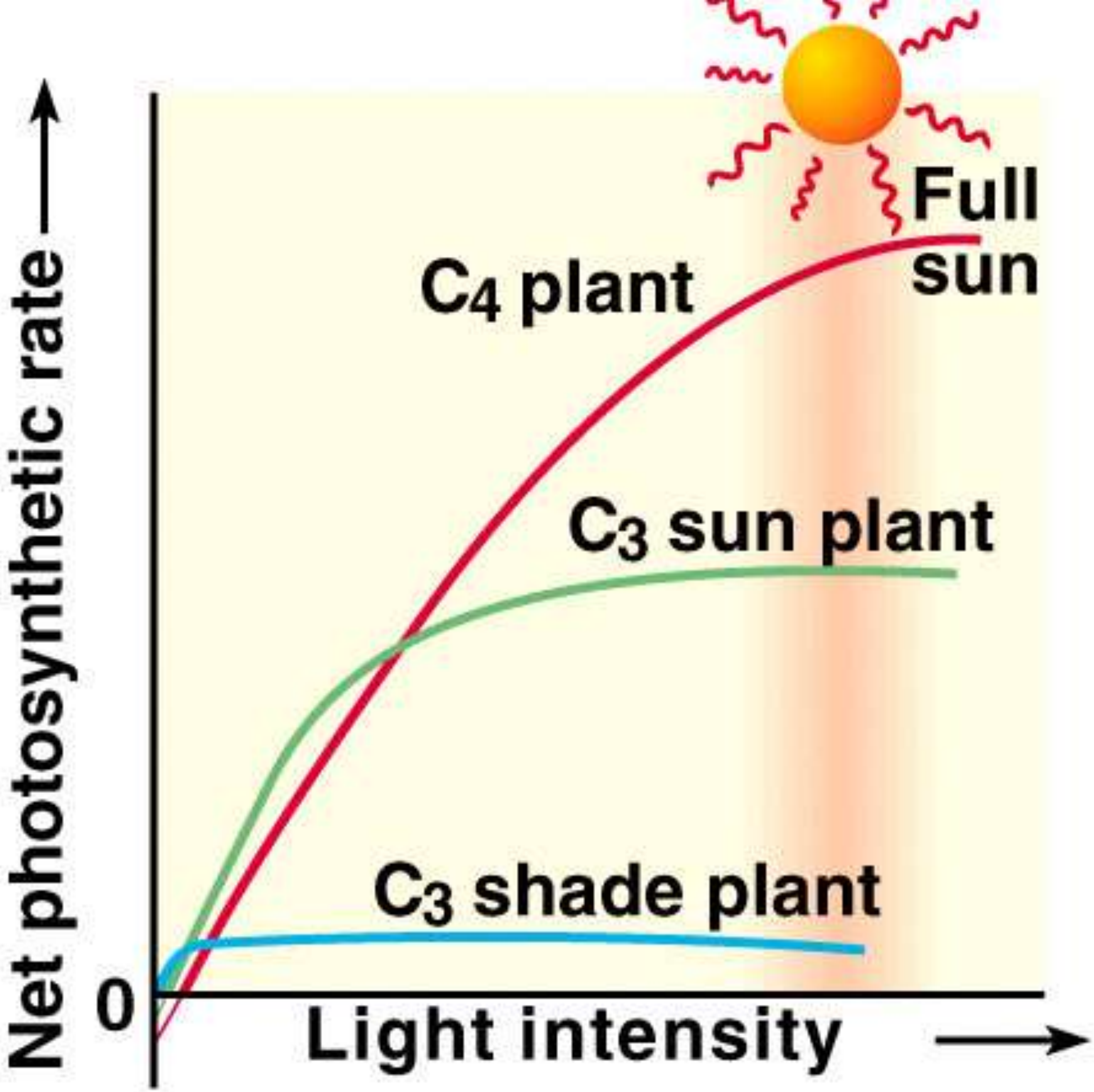
Africa:
Adansonia, Terminalia, Acacia
America:
Vochysia, Caesalpinia
Australia:
Acacia, Melaleuca, Terminalia

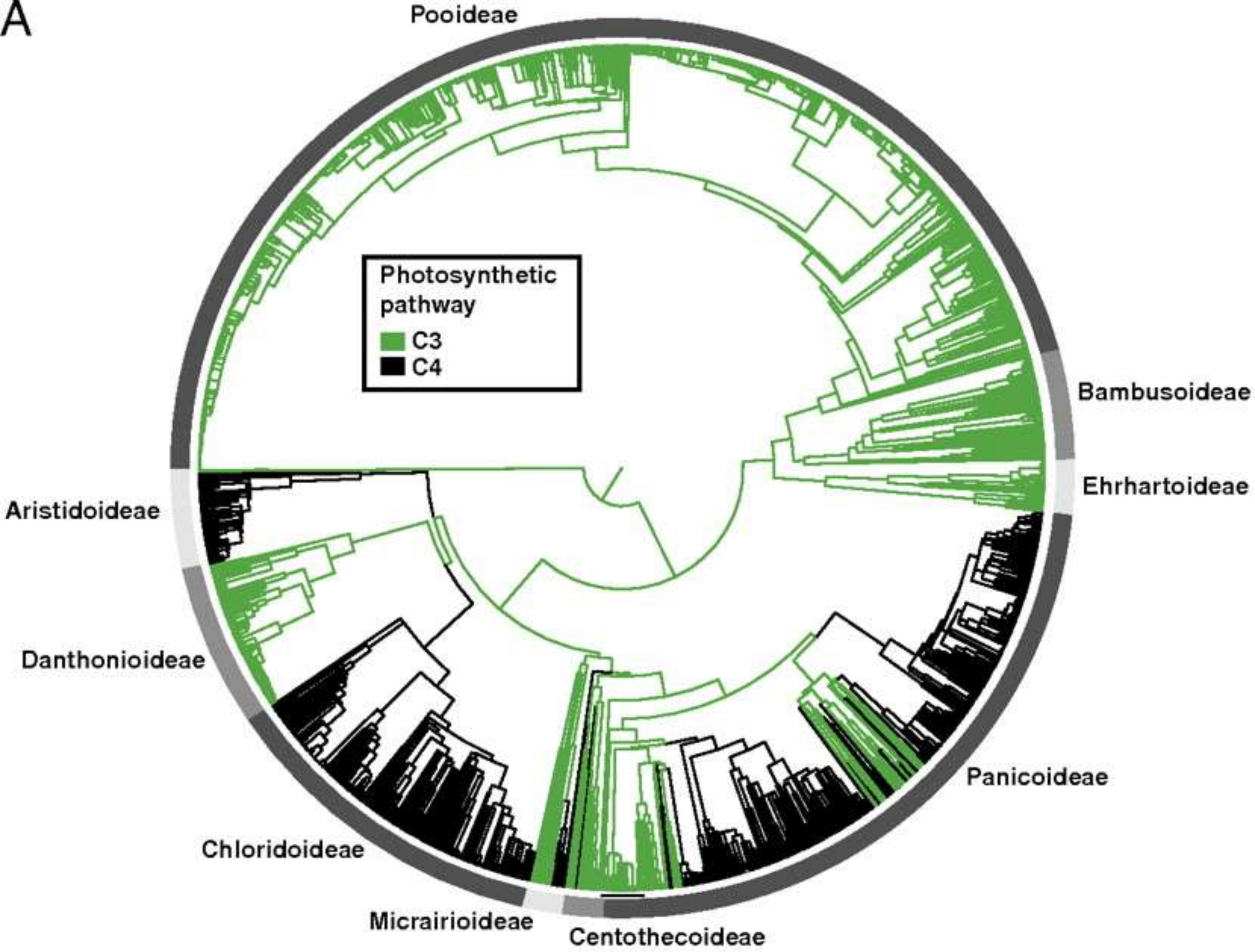
C4 plants: higher photosynthetic rate, more efficient water use, but higher optimum temperature than C3 plants



	C_4 plants	C_3 plants
Type of plant	Herbaceous, mostly grasses and sedges	Herbs, shrubs or trees
Morphology		
Leaf characters	Vascular bundle sheath present with cells packed with agranal chloroplasts	No vascular bundle sheath
Physiology		
Photosynthetic rate	40–80 mg CO_2 dm^{-2} h^{-1} in full sunlight; no light saturation	10–35 mg CO_2 dm^{-2} h^{-1} in full sunlight; light saturation at 10–25% full sunlight
Response to temperature	Growth and photosynthesis optimal at 30–45 °C	Growth and photosynthesis optimal at 10–25 °C
CO_2 compensation point	0–10 ppm CO_2	30–70 ppm CO_2
Sugar transport out of the leaves	Rapid and efficient	Slower and less efficient
Water requirements (g water needed to produce 1 g dry matter)	260–350	400–900
Biochemistry		
Carbon fixation	C_4 (Hatch–Slack) and C_3 (Calvin) cycles	C_3 pathway only
Photorespiration	Not detected	Present

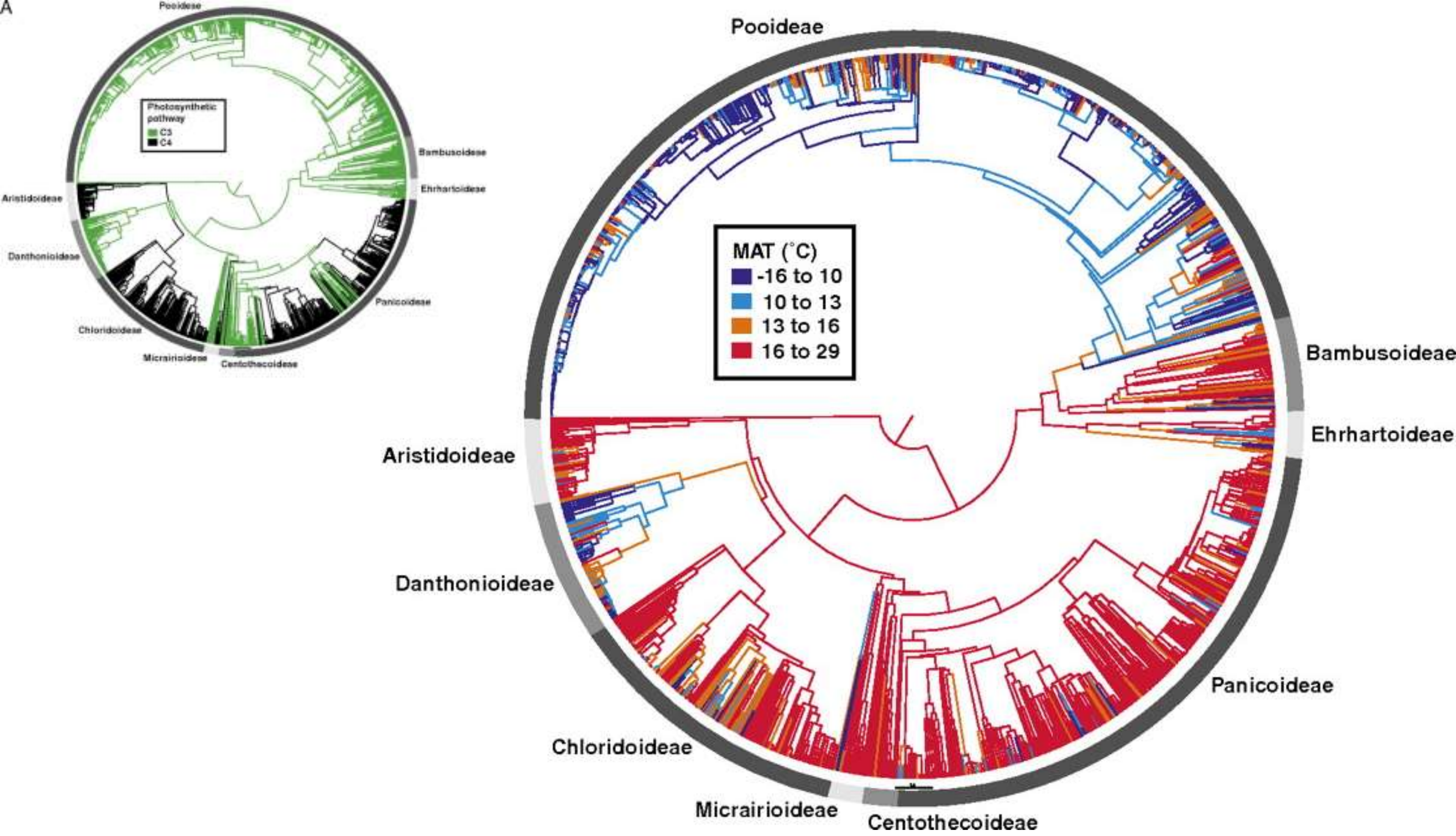
C_3 or
t in
om


Full sun
C_4 plant
C_3 sun plant
C_3 shade plant
Net photosynthetic rate
0
Light intensity



20 origins of C4 photosynthesis and one reversal to C3 photosynthesis in grasses

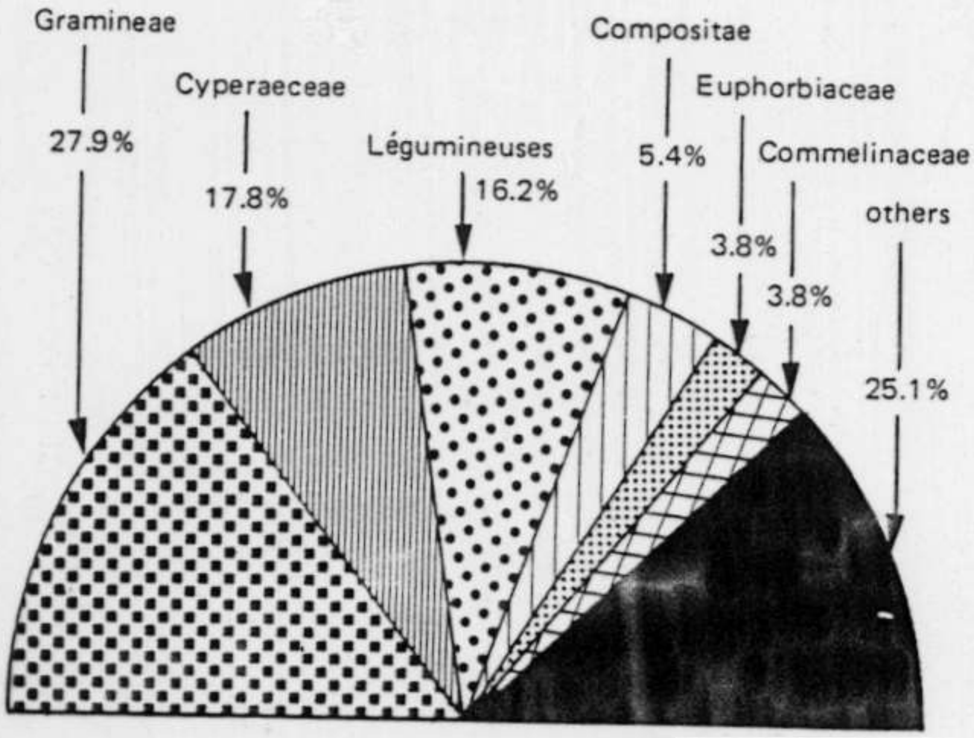
Edwards E J , and Smith S A PNAS 2010;107:2532-2537



mean annual temperature (MAT), using values generated from 1,146,612 geo-referenced herbarium specimens.

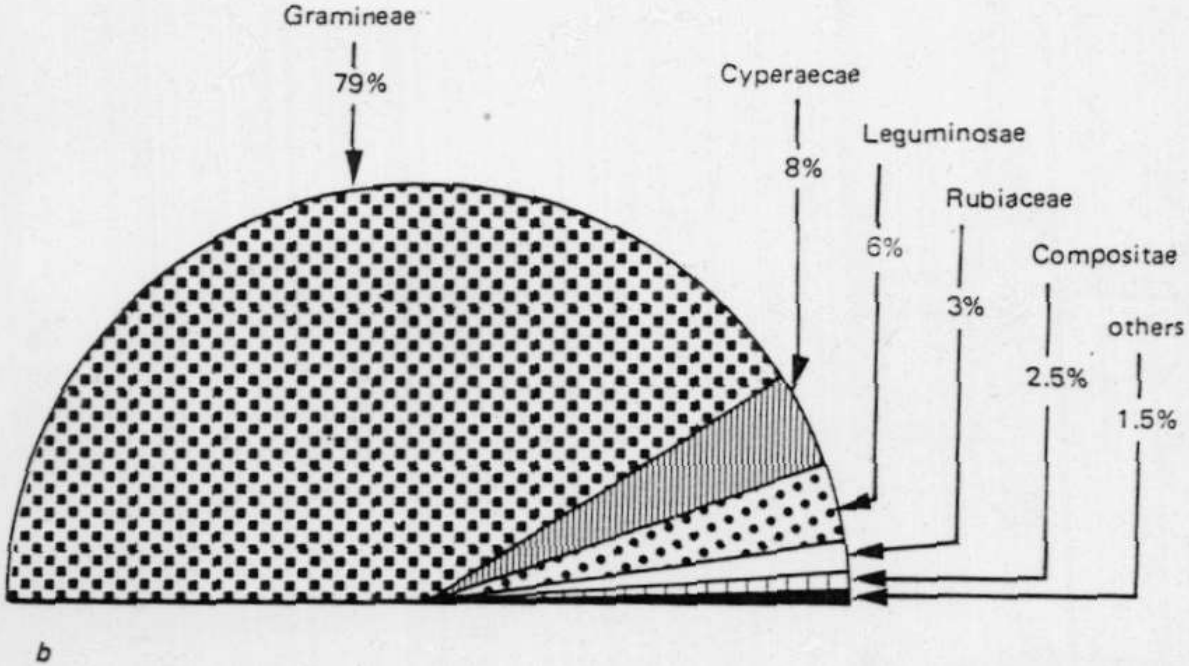
Edwards E J , and Smith S A PNAS 2010;107:2532-2537

Composition of savanna vegetation in Guinea



Species

Biomass



Grassland primary production: limited by rainfall

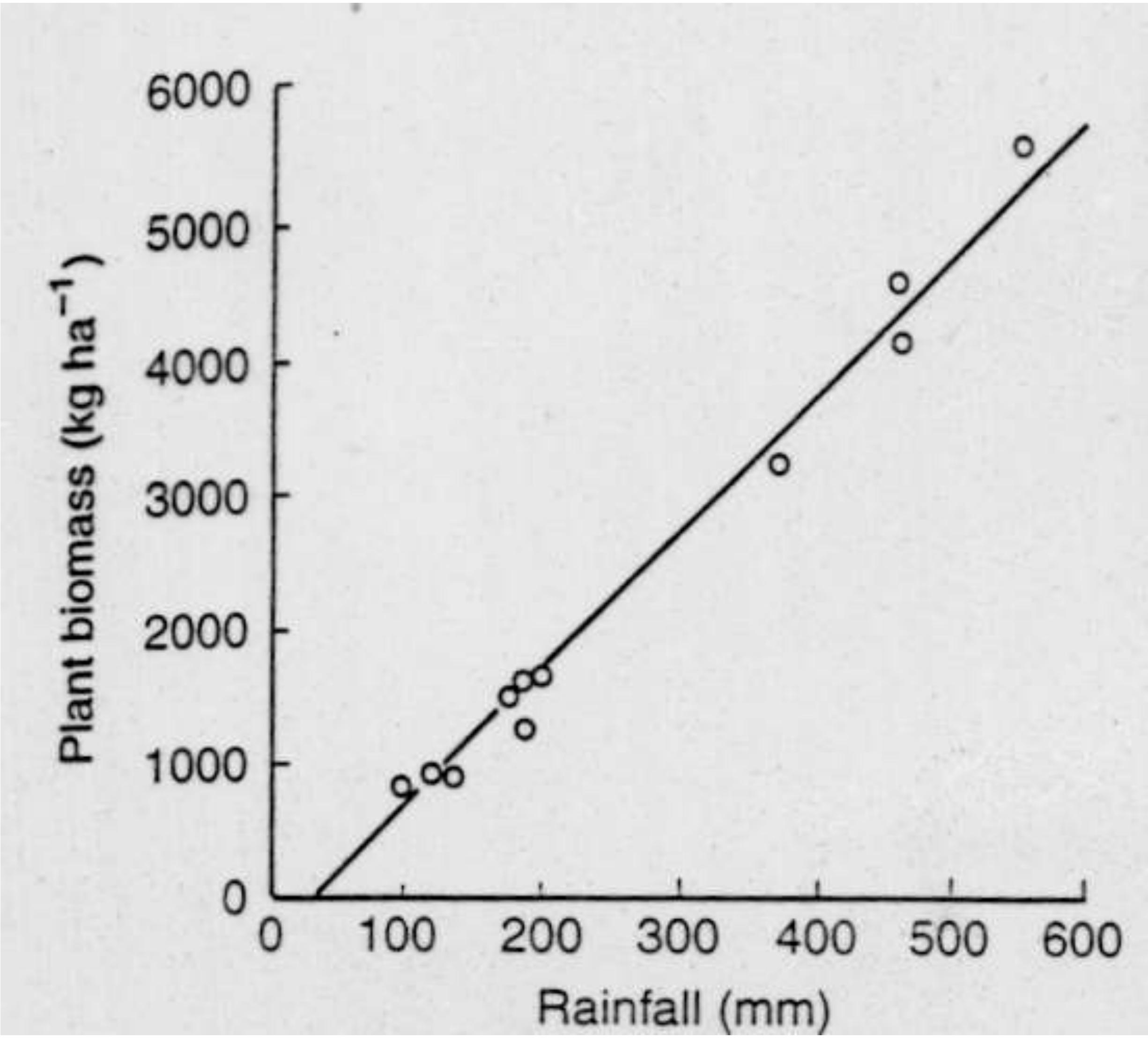


Figure 2.11 Plant biomass (above-ground, dry weight, in kilograms per hectare) in grasslands in Namibia in relation to the annual precipitation (mm) (after Walter 1973 with kind

Anthropic grasslands
C4 grasses (*Imperata*...)

maintained by fire

productive, but
biological desert

Savanna vegetation is shaped by fires

Removal of plant primary production in savanna: fire, grazing ungulates and detritivore

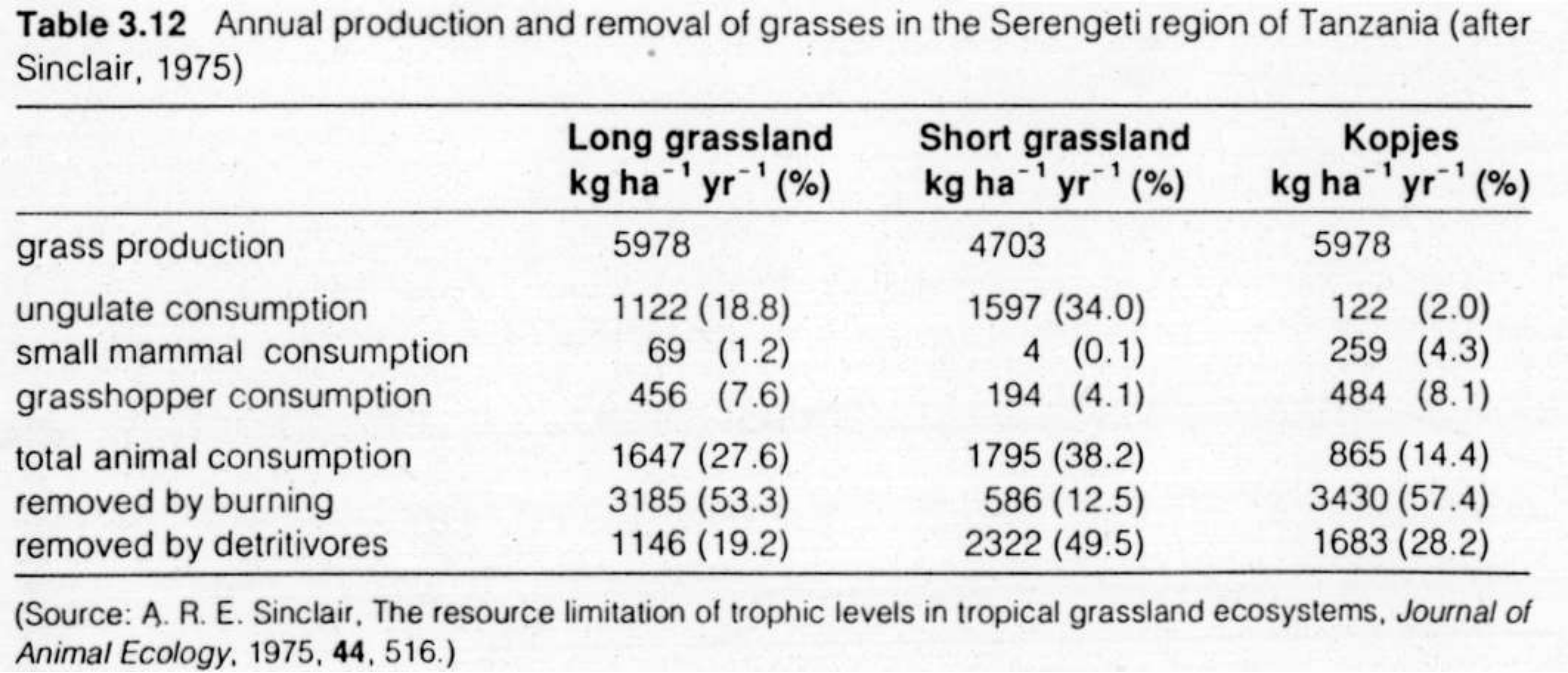


Table 3.12 Annual production and removal of grasses in the Serengeti region of Tanzania (after Sinclair, 1975)

	Long grassland kg ha^{-1} yr^{-1} (%)	**Short grassland kg ha^{-1} yr^{-1} (%)**	**Kopjes kg ha^{-1} yr^{-1} (%)**
grass production	5978	4703	5978
ungulate consumption	1122 (18.8)	1597 (34.0)	122 (2.0)
small mammal consumption	69 (1.2)	4 (0.1)	259 (4.3)
grasshopper consumption	456 (7.6)	194 (4.1)	484 (8.1)
total animal consumption	1647 (27.6)	1795 (38.2)	865 (14.4)
removed by burning	3185 (53.3)	586 (12.5)	3430 (57.4)
removed by detritivores	1146 (19.2)	2322 (49.5)	1683 (28.2)

(Source: A. R. E. Sinclair, The resource limitation of trophic levels in tropical grassland ecosystems, *Journal of Animal Ecology*, 1975, **44**, 516.)

Nitrogen in savanna:
input through rain and bacterial fixation, loss through fire

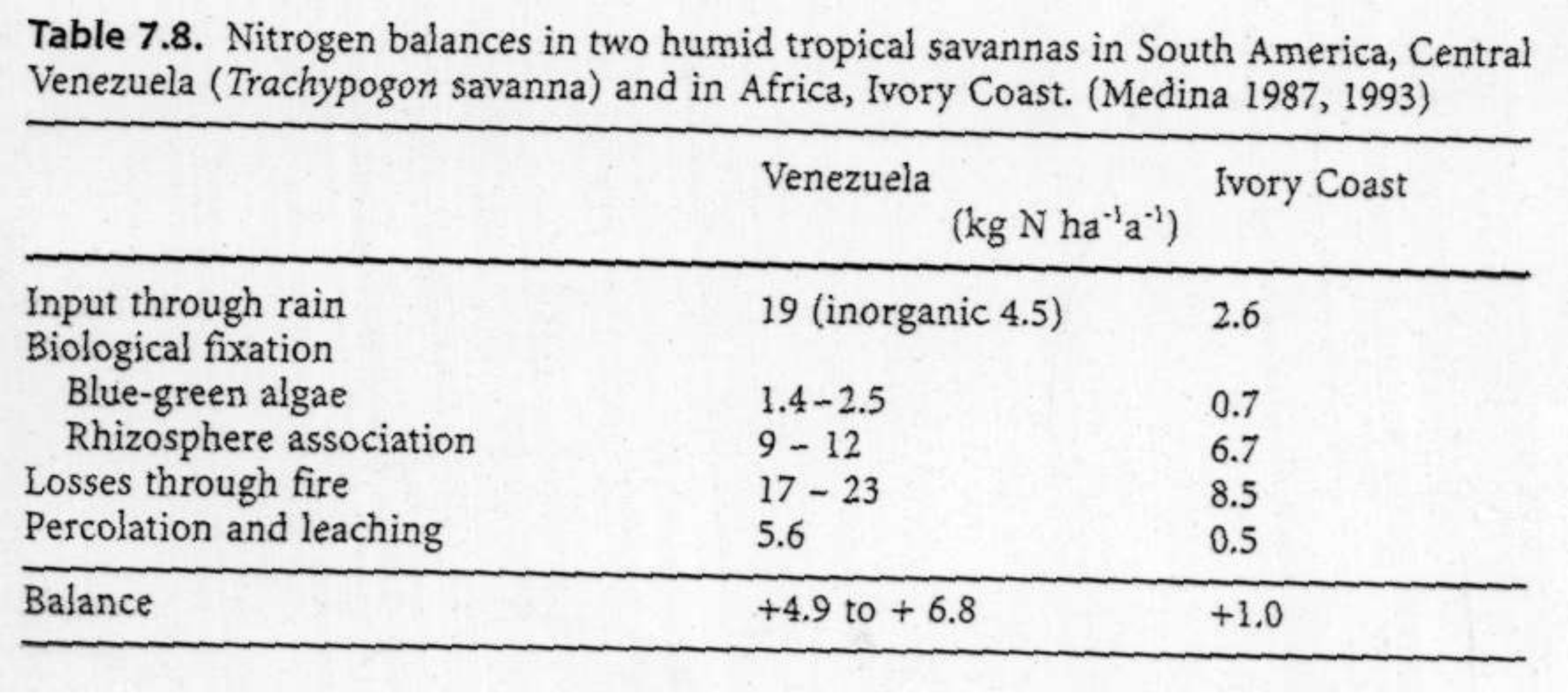
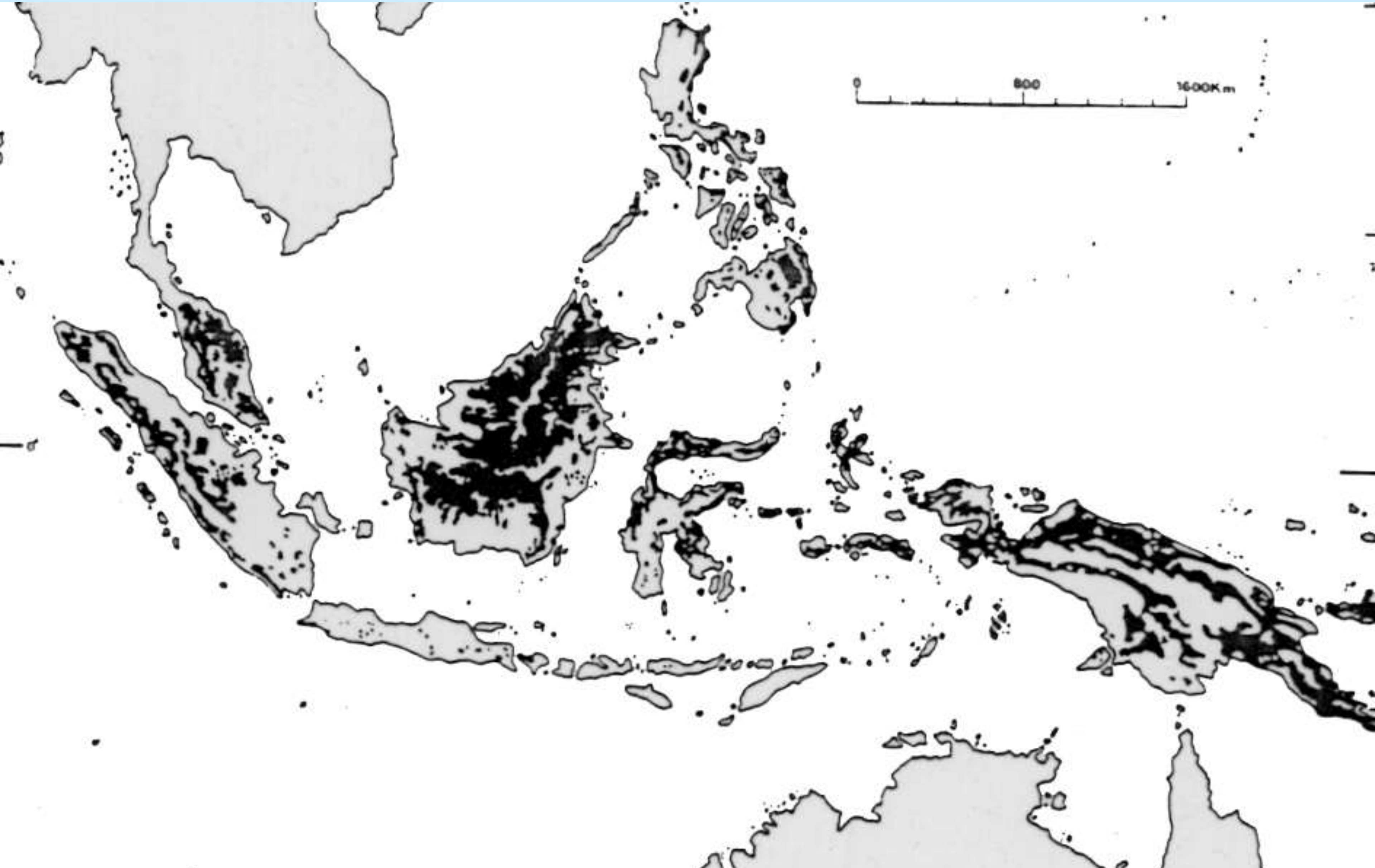


Table 7.8. Nitrogen balances in two humid tropical savannas in South America, Central Venezuela (*Trachypogon* savanna) and in Africa, Ivory Coast. (Medina 1987, 1993)

	Venezuela	Ivory Coast
	(kg N $ha^{-1}a^{-1}$)	
Input through rain	19 (inorganic 4.5)	2.6
Biological fixation		
Blue-green algae	1.4 – 2.5	0.7
Rhizosphere association	9 – 12	6.7
Losses through fire	17 – 23	8.5
Percolation and leaching	5.6	0.5
Balance	+4.9 to + 6.8	+1.0

Forests of South-East Asia and Australia

Lowland forests



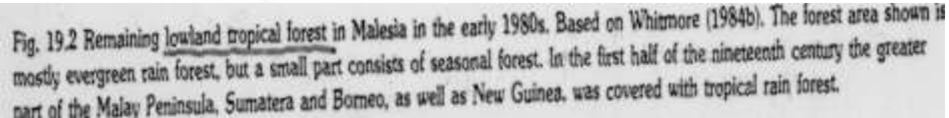
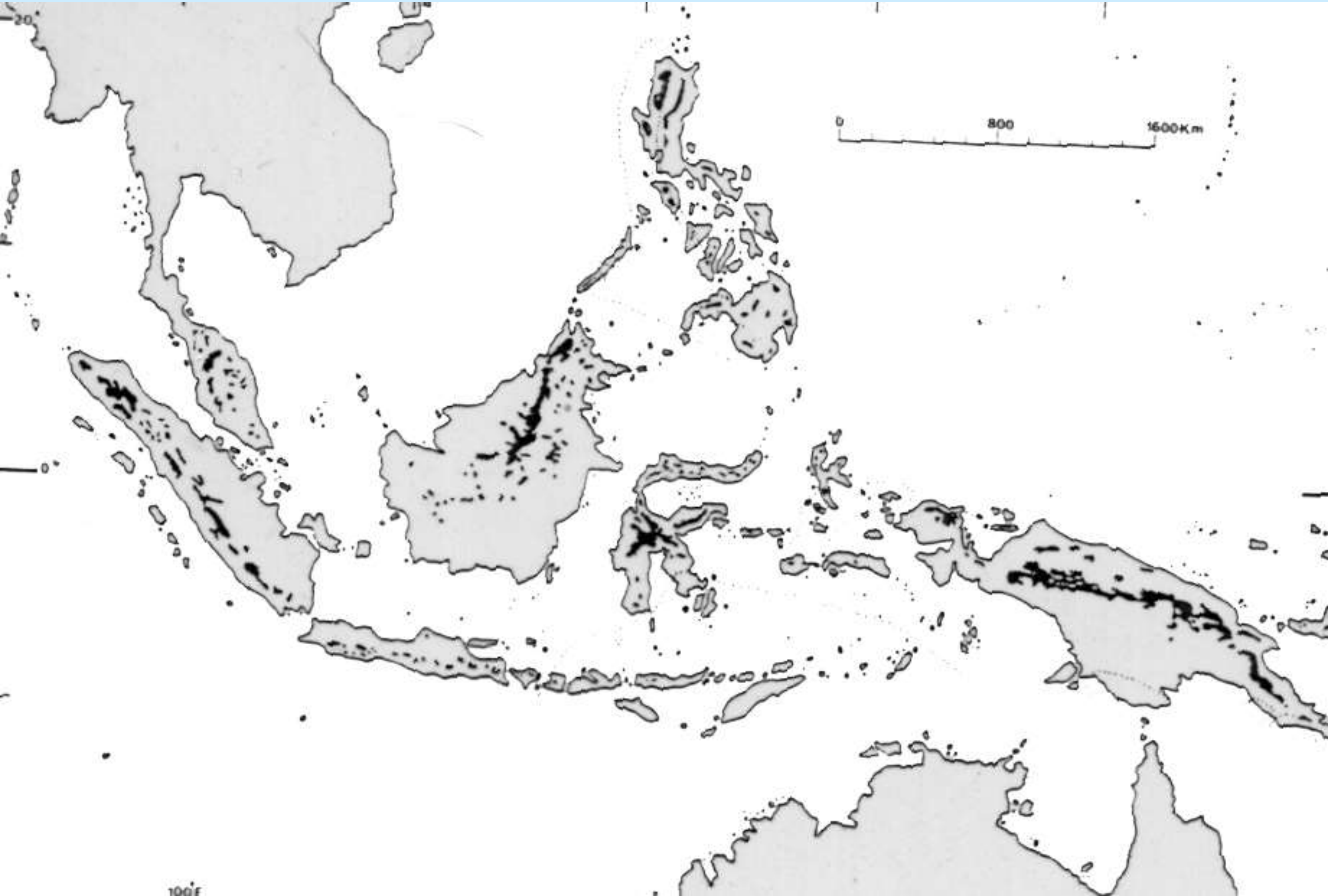


Fig. 19.2 Remaining lowland tropical forest in Malesia in the early 1980s. Based on Whitmore (1984b). The forest area shown is mostly evergreen rain forest, but a small part consists of seasonal forest. In the first half of the nineteenth century the greater part of the Malay Peninsula, Sumatera and Borneo, as well as New Guinea, was covered with tropical rain forest.

Montane forests



Forests on limestone outcrops

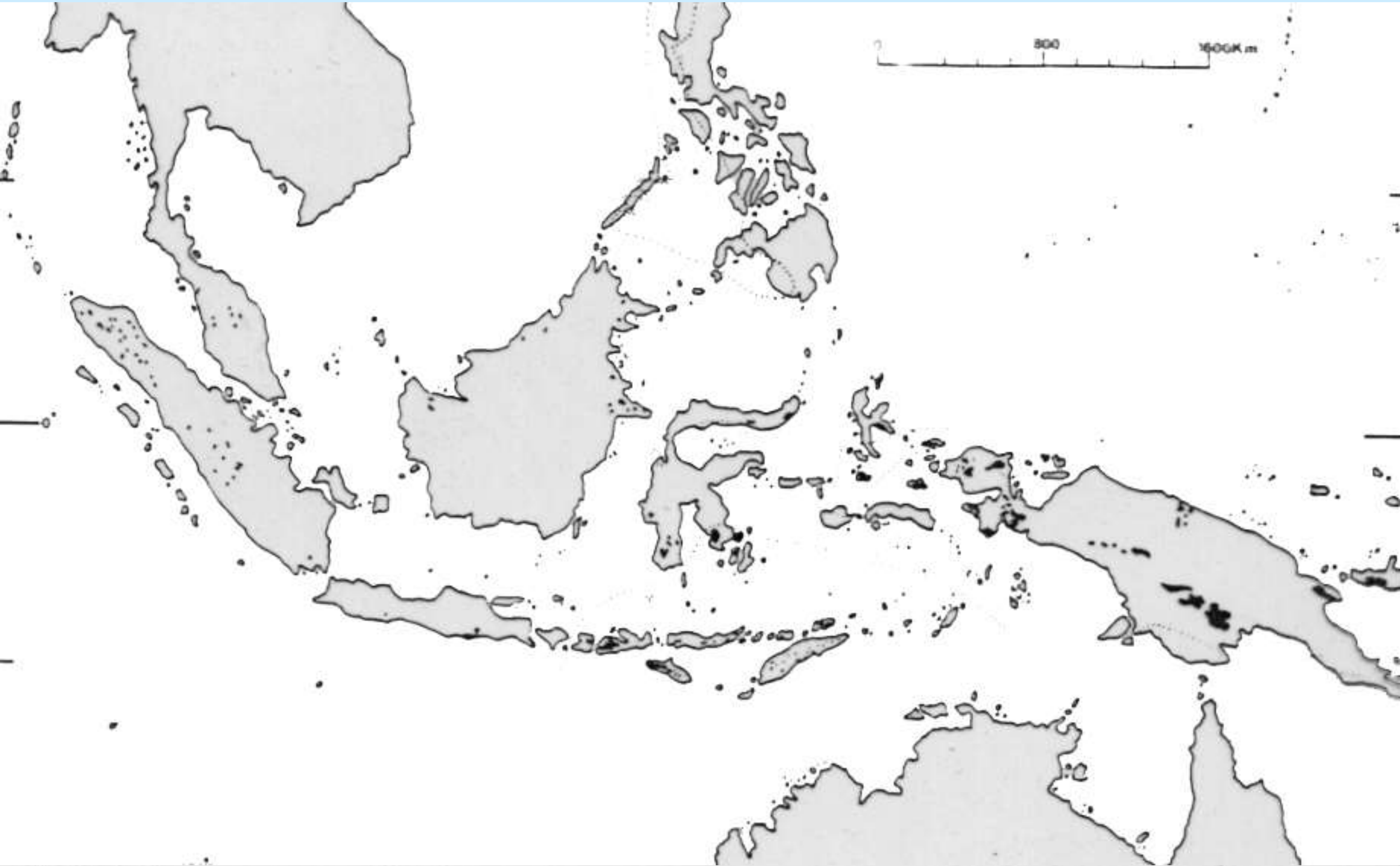


Fig. 10.16. Limestone outcrops which still carry their distinctive forest formation: in many places this has been altered by fire (often started by mineral prospectors). Rain-forest and monsoon-forest limestone are distinguished by the latter being enclosed by dotted lines. (Based on Whitmore, 1984b.)

Peat swamp forests (A) and freshwater swamp forests (B)

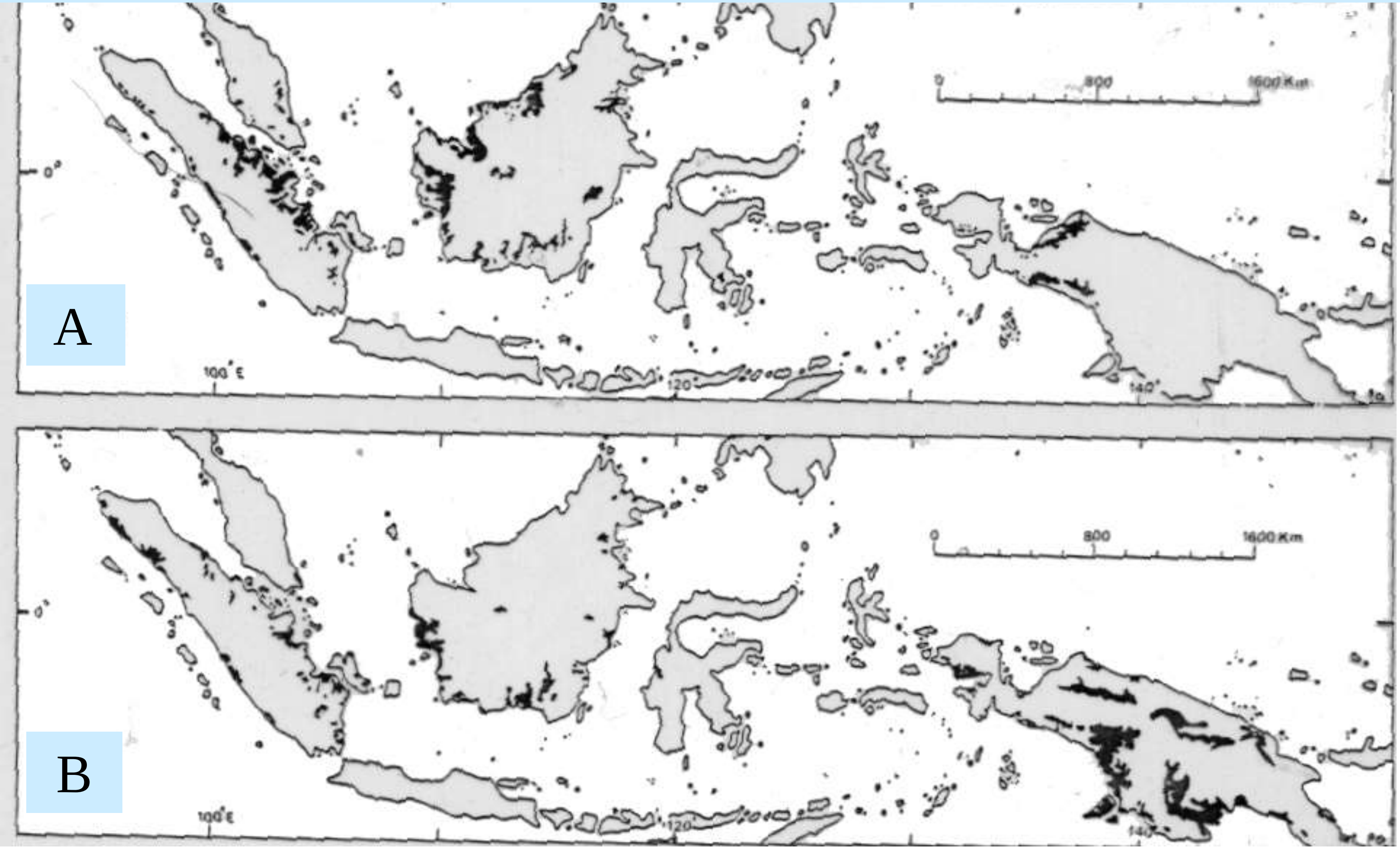
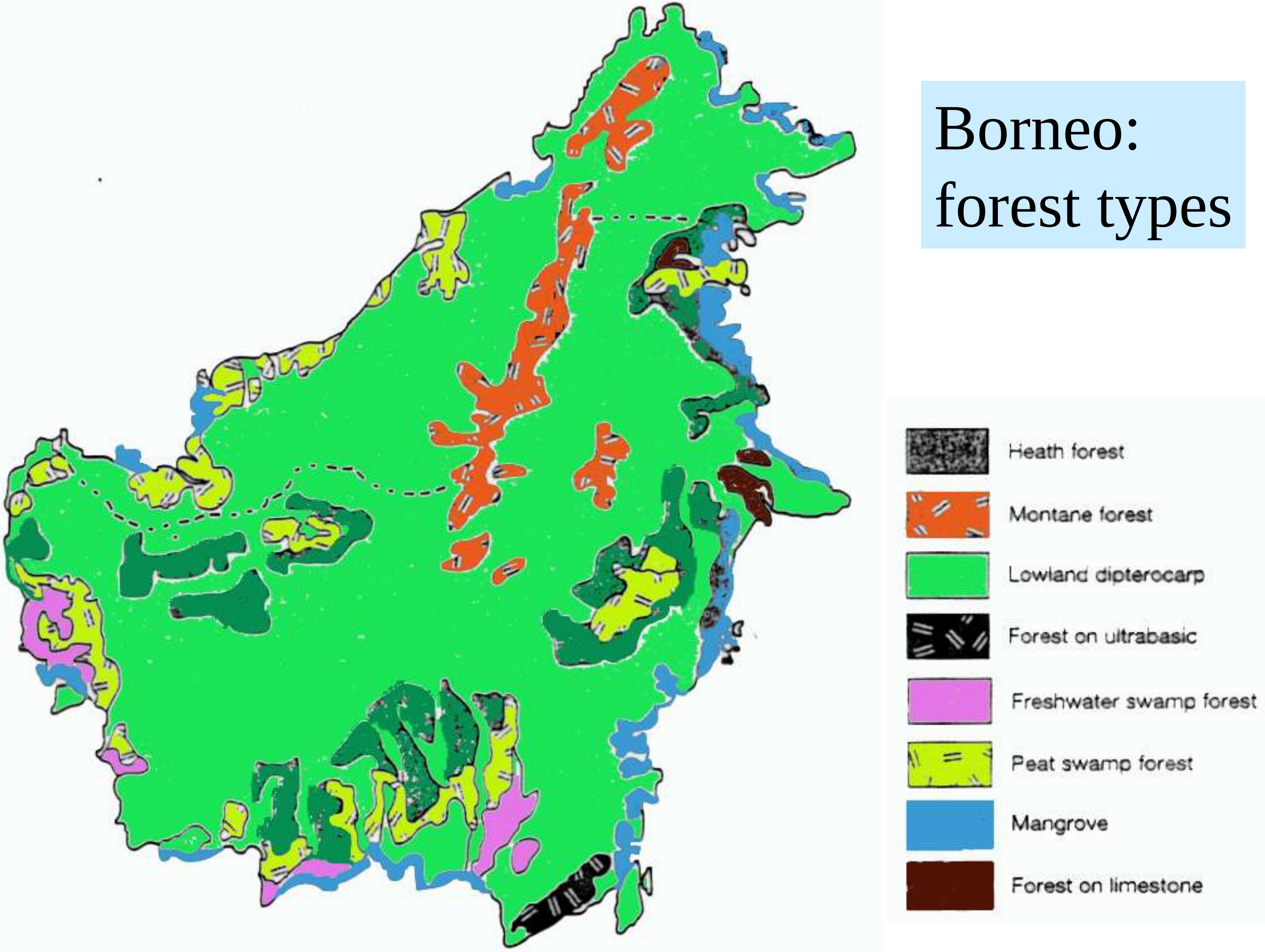


Fig. 10.18. (a) Peat swamp forest. The western stands, in Sumatra, Malaya and Borneo, have long been known but the full extent of those in west New Guinea was only discovered in 1982/83. Shallow peat lands are being developed for agriculture. Deep peat is likely to remain under forest. It is a valuable timber producing resource and has been heavily exploited in west Malesia, especially in Sarawak.

(b) Freshwater swamp forest and seasonal swamp forest formations. The extent in Sumatra, Kalimantan and west New Guinea has recently been accurately surveyed for the first time. Very substantial areas in the west have been converted to agricultural lands, especially wetland rice. Similar changes are planned for New Guinea.

Borneo: forest types



Dipterocarp lowland forests - a SE Asian speciality

Some dipterocarp genera

Cotylelobium

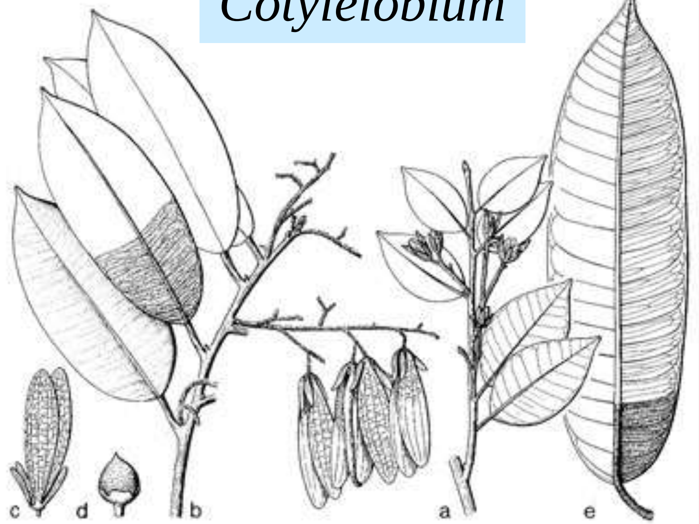


Fig. 40. *Cotylelobium lanceolatum* CRAIB. a. Flowering twig, x2/3. — *C. burckii* (HEIM) HEIM. *b*. Fruiting twig. x2/3, *c*. fruit, *d*. nut, both x2, *e*. leaf from sterile twig, x2/3 (*a* S 28068, *b* S 12995, *c–d* KEP 32615, *e* bb. 15334).

Anisoptera

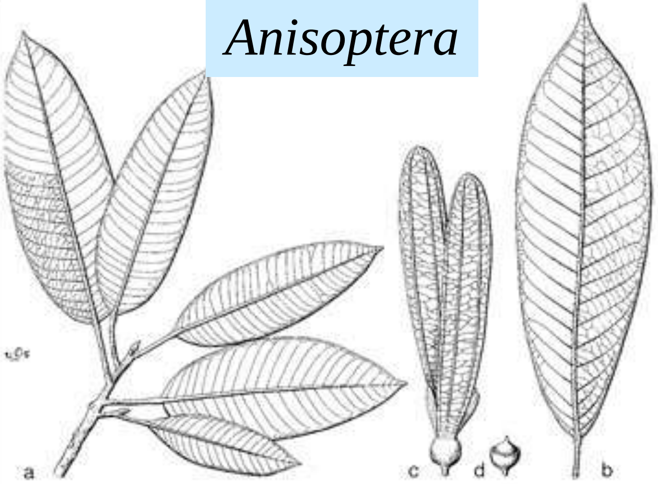


Fig. 30. *Anisoptera grossivenia* SLOOT. *a*. End of twig, *b*. single leaf, *c*. fruit, *d*. nut, all × ½ (*a* S 5819, *b–d* S 6514)

Shorea

Fig. 77. *Shorea falciferoides* FOXW. *a*. Habit, *b*. leaf of seedling 1.2 m high, *c*. fruit, *d*. nut, all × ½ (*a* SAN 37512, S 5718, *c–d* S 2125).

Vatica

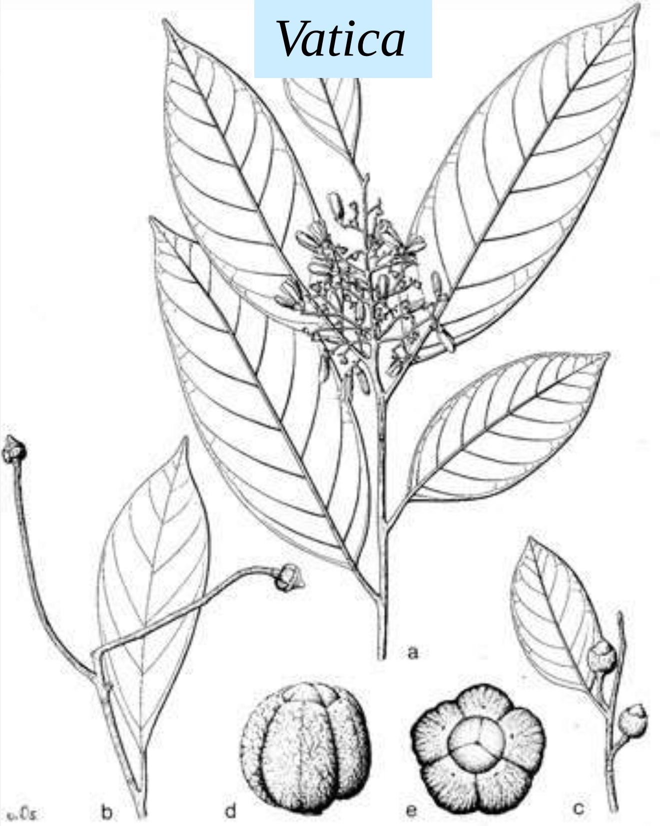


Fig. 41. *Vatica umbonata* (HOOK. *f*.) BURCK. *a*. Habit, x½, *b–c*. young fruits, x½, *d*. ripe fruit, lateral view, *e*. *ditto*, apical view, both nat. size (*a* SAN 68373, flowers from SAN 15367, *b* A 4743, *c* FRI 12496, *d–e* BRUN 933).

Shorea johorensis

Dipterocarpus applanatus

Dipterocarpoideae - limited to SE Asia and New Guinea

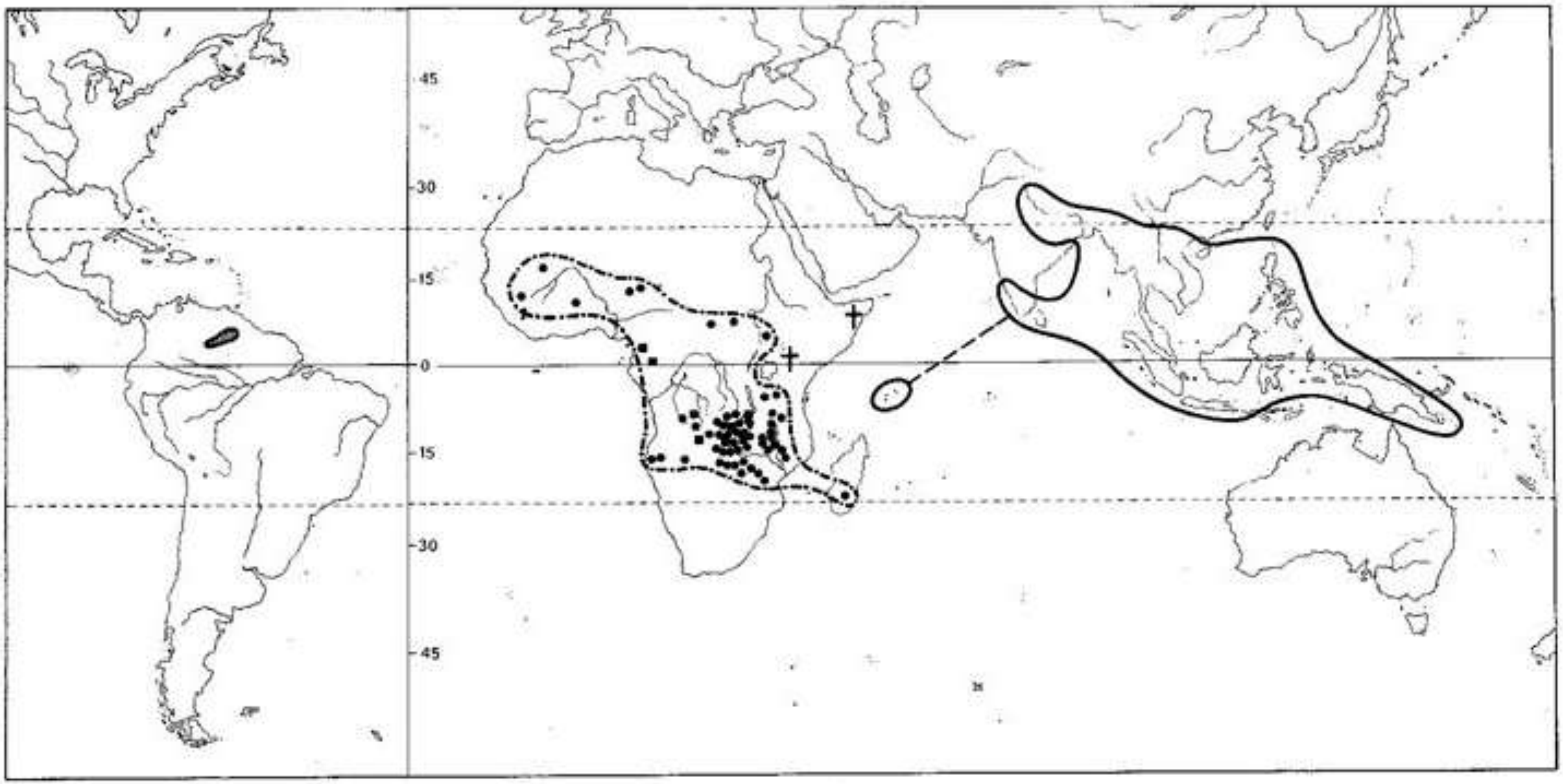
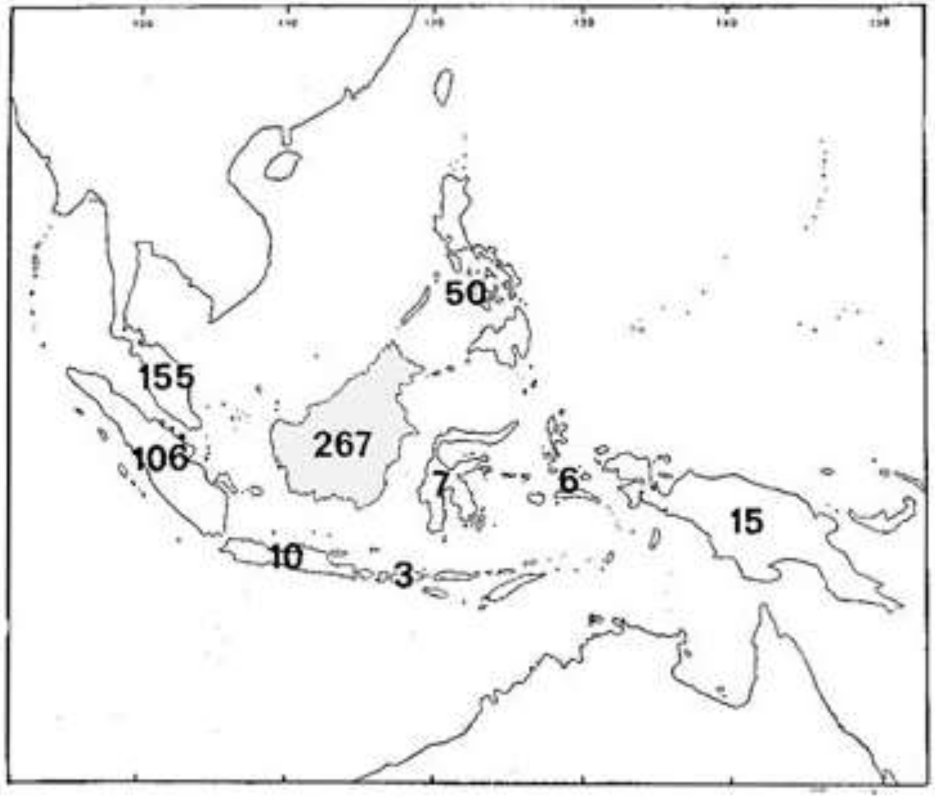


Fig. 2. Range of the *Dipterocarpaceae*: *Dipterocarpoideae* (line and 2 fossil sites in E. Africa), *Monotoideae* (2 genera, Afro-Madagascan, interrupted line, dots *Monotes*, squares *Marquesia*), *Pakaraimoideae* (monotypic genus in northern South America).

Borneo - the center of species richness and endemism of dipterocarps



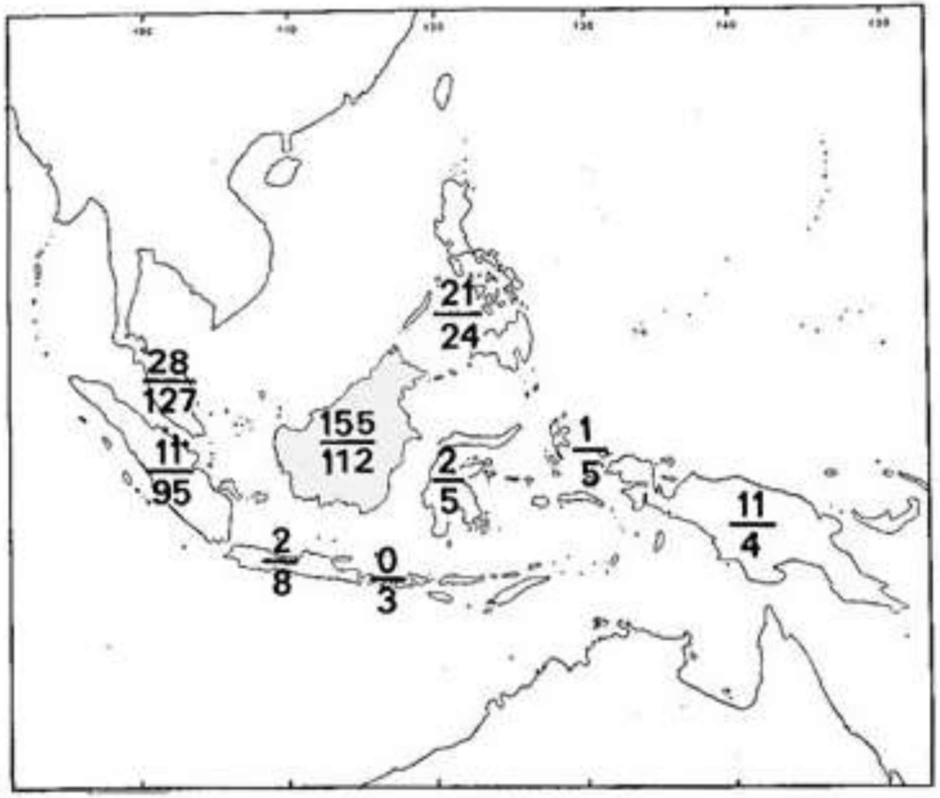
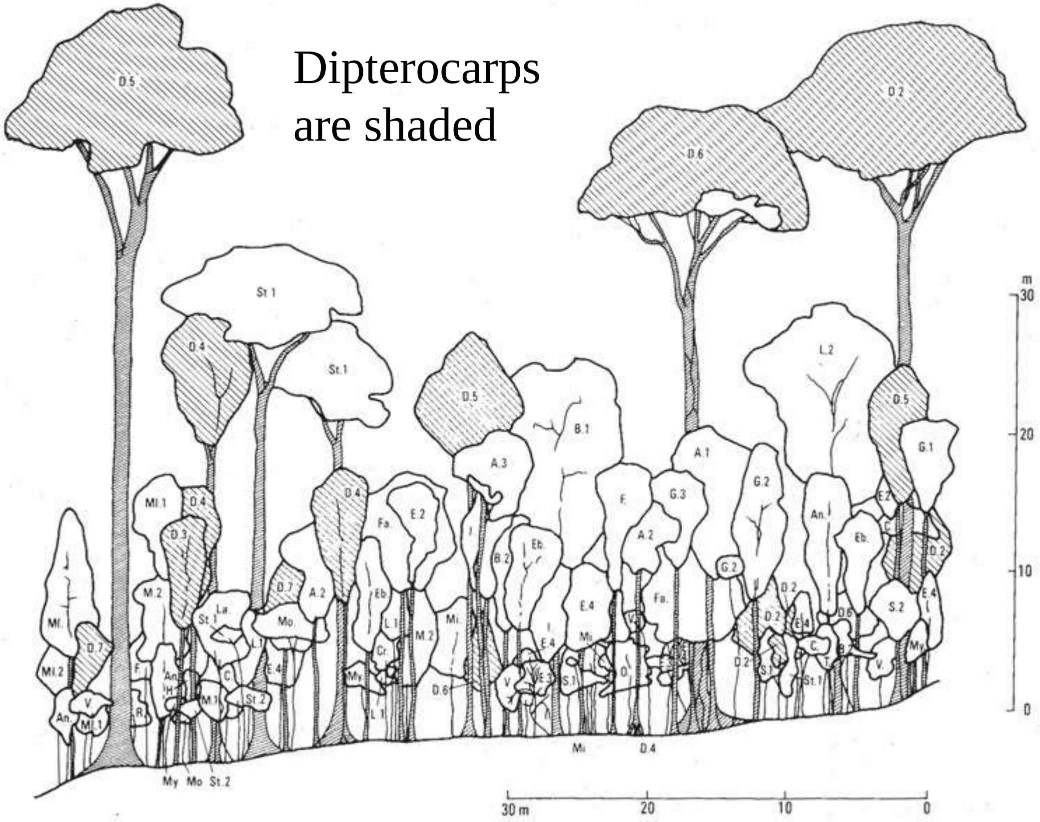


Fig. 3. Density map of *Dipterocarpaceae* in Malesia, total number of species in each island.

Fig. 4. Density map of *Dipterocarpaceae* in Malesia, segregated into endemics (above the hyphen) and non-endemics (below the hyphen).

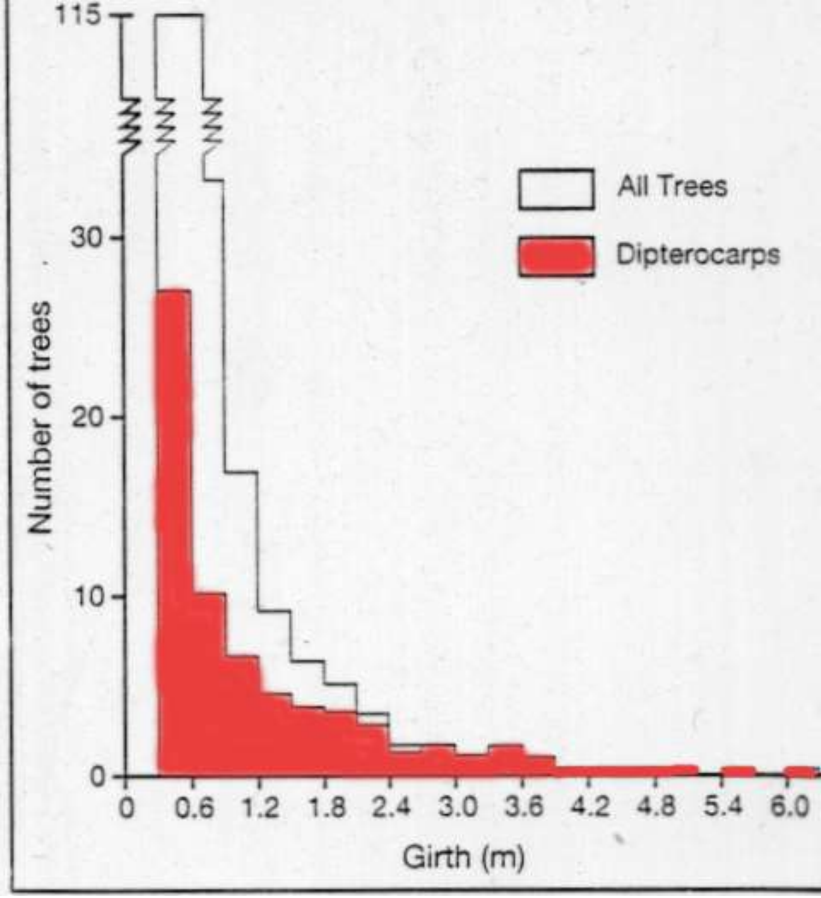
Dipterocarps: the dominant component of lowland forests



Dipterocarps are shaded

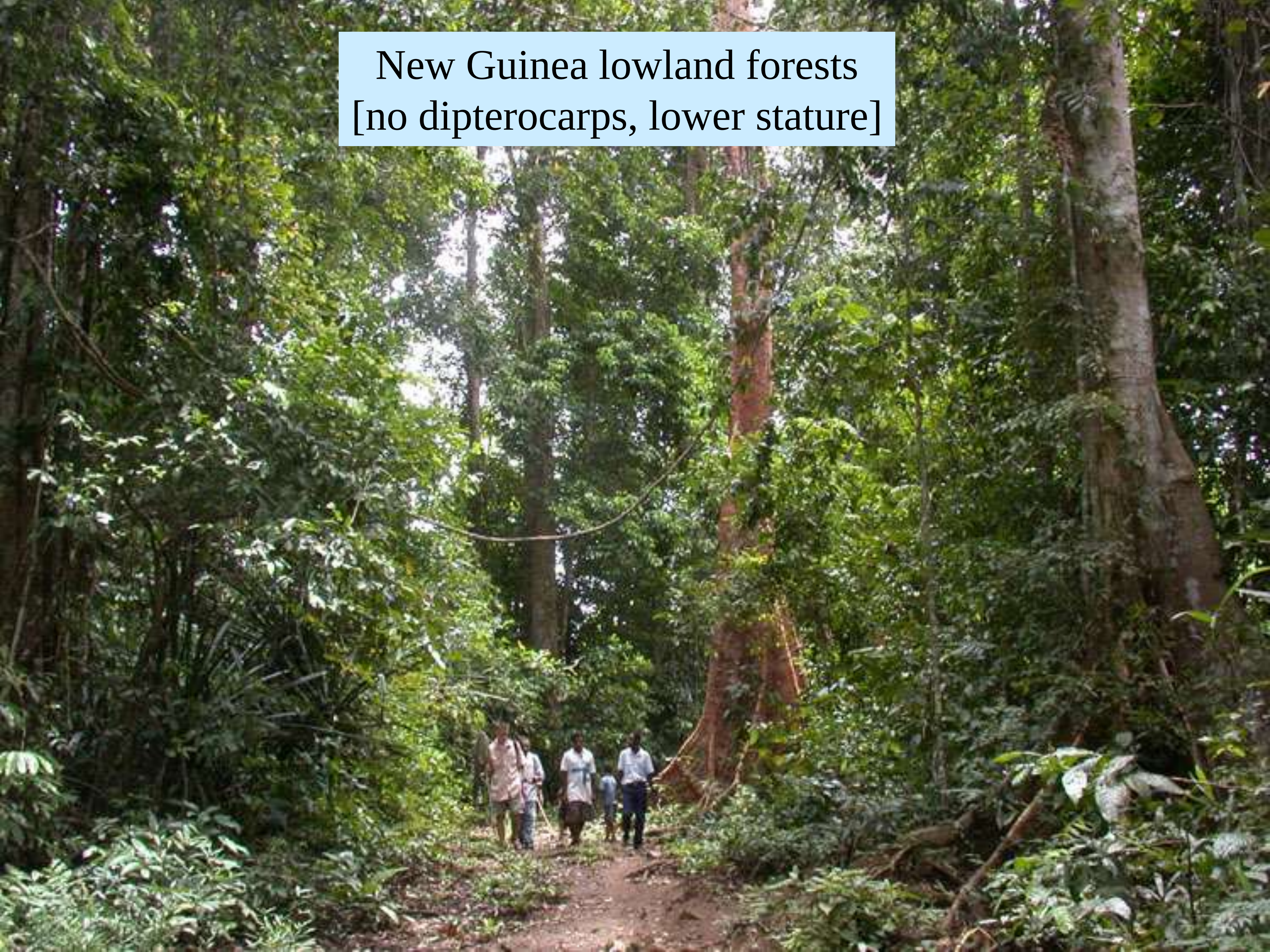
Fig. 2.24. Profile showing mature (ends) and building phases of the lowland evergreen dipterocarp rain forest at Belalong, Brunei. Plot area 60 × 7.5 m, all trees over 4.5 m tall shown. (Ashton 1964 in Whitmore 1984*a*, Fig. 2.1; see latter for species names.)

Dipterocarps shown hatched; note how these still have tall, narrow, youthful monopodial crowns in the building phase, which change to sympodial, broader than deep, and with several large limbs in the mature phase.



Predominance of dipterocarps among the big trees in Sabah lowland rainforest.

Source: Burgess 1961



New Guinea lowland forests [no dipterocarps, lower stature]

Lowland forest New Guinea:

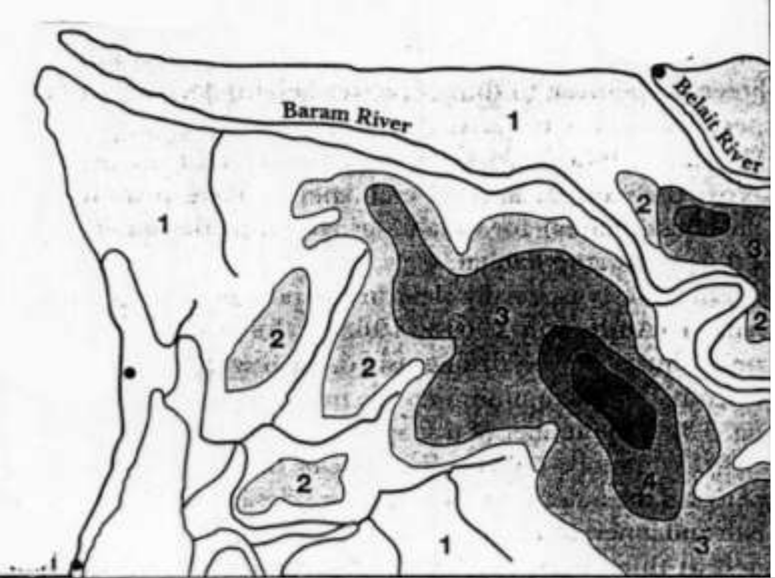
canopy gap

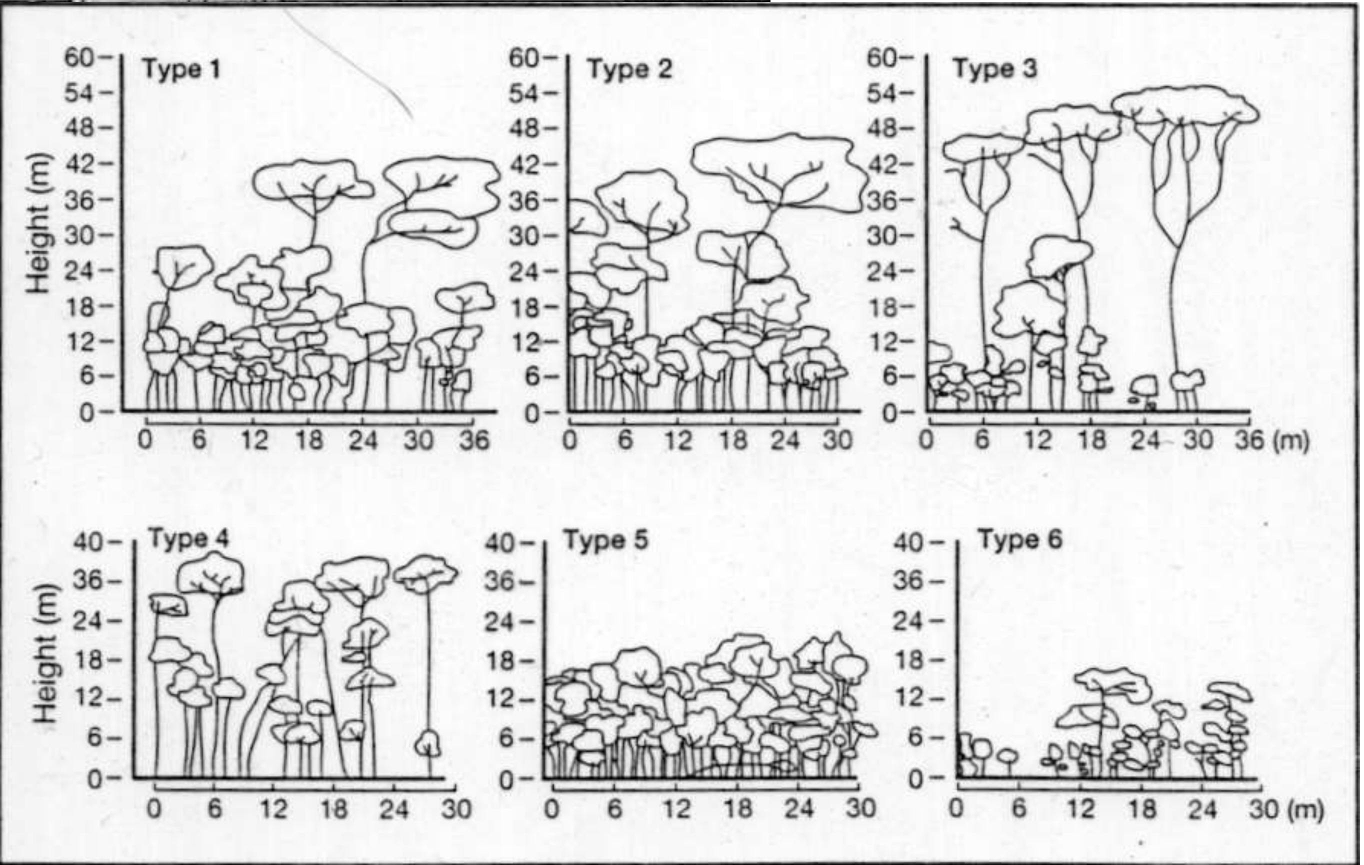
understorey
(with a BF JU student for scale)

Peat forests of Borneo

Peat and heath forests share many species (Borneo 25-70%, including *Shorea albida*, *Casuarina nobilis* etc.) and also conifers (*Agathis*, *Dacrydium*, *Podocarpus*); also supplementary means of obtaining nutrients (myrmecophily: *Hydnophytum*, insectivory: *Nepenthes*, *Drosera*) are common

Zones of the peat swamp forest in Borneo





A tropical peatbog (Kauai, Hawaii Islands)

Heath forest (keranga) in Brunei

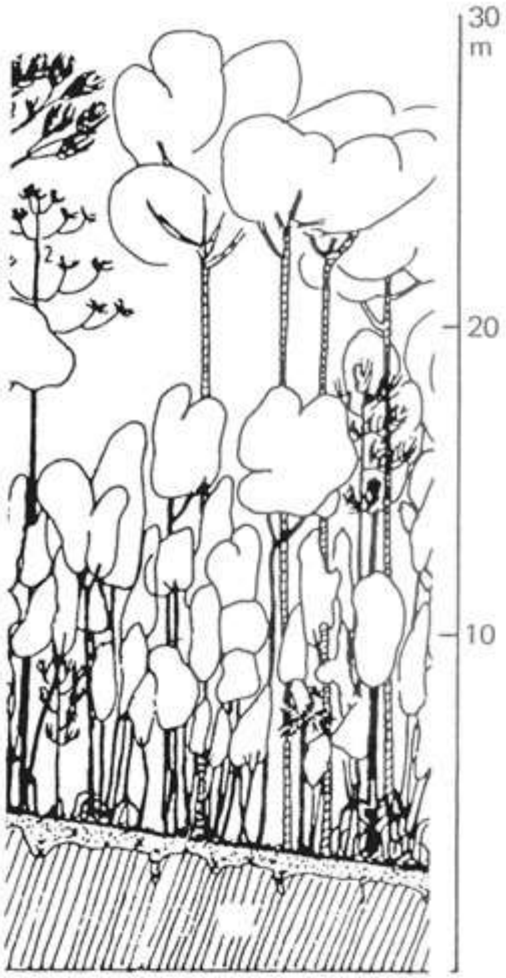
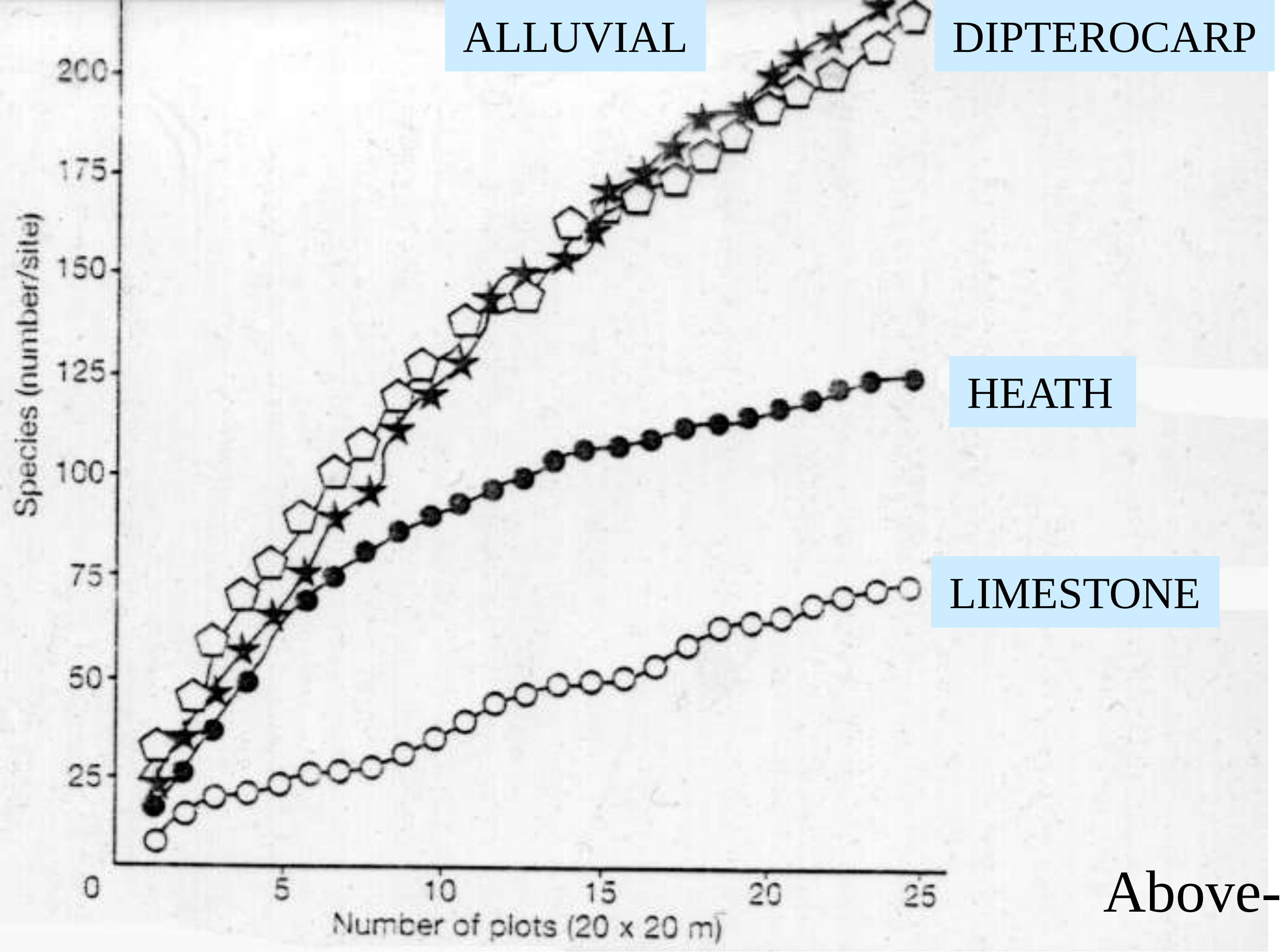


Fig. 15.9 Profile diagram of kerangas forest in Brunei, Borneo. The width is 18 m, the trees reach up to 20 m height (After Brünig in Whitmore 1975, p. 127; also includes a list of species)

Limestone forest

New Guinea

Borneo

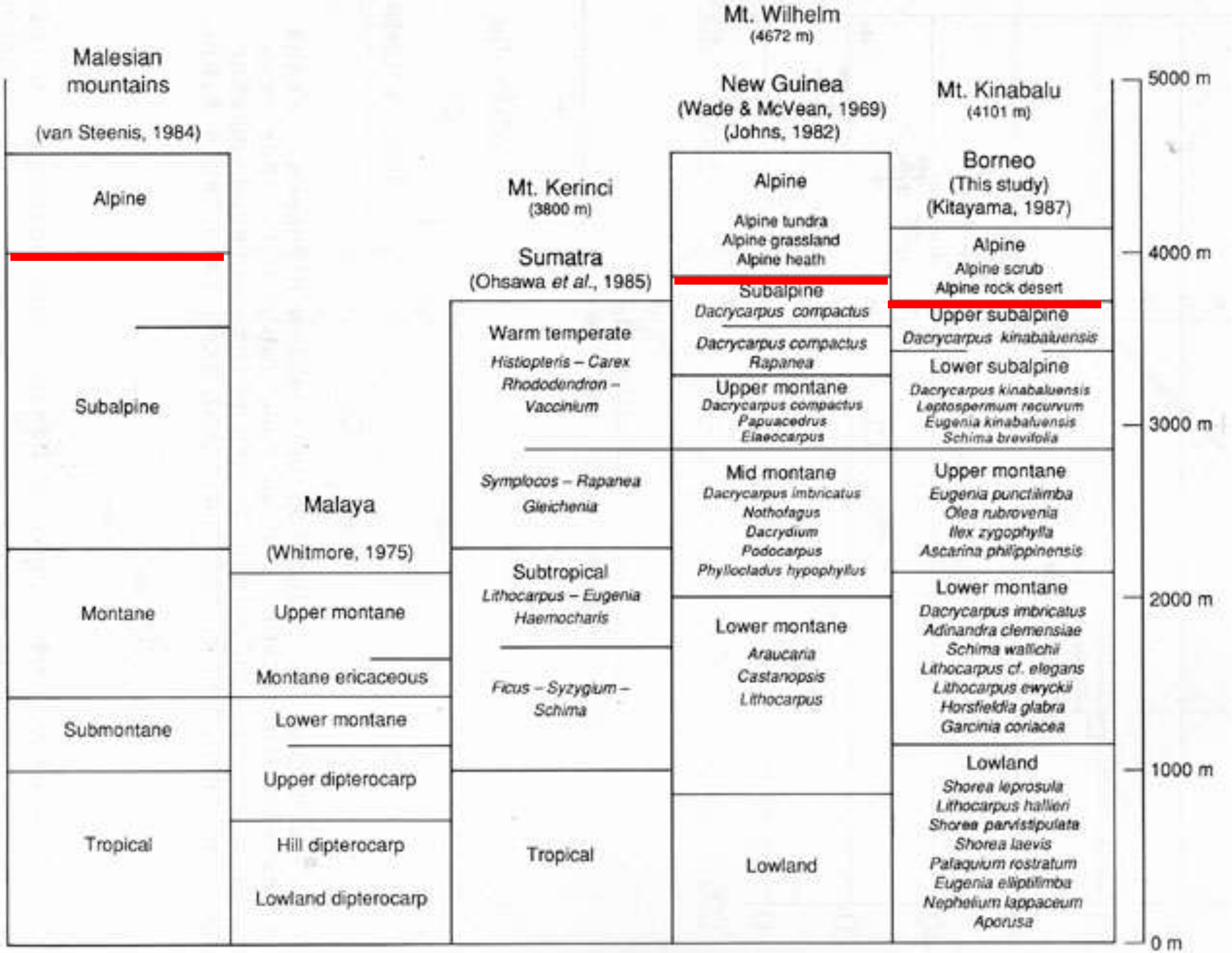


Species richness of different forest types

Above-ground biomass t/ha

Dipterocarp	650
Heat	470
Limestone	380
Alluvial	250

Montane forests



Forest altitudinal zonation in Malesia

New Guinea, montane forest at 2,200 m asl

Mt. Wilhem, New Guinea

timber line at 3,600 m asl

Nypa fruticosa swamp

Monospecific sago swamps

Metroxylon sago - the sago palm

Sago production

today on Sepik river, New Guinea

in 1860 on Ceram Island

(Alfred Russel Wallace, The Malay Archipelago)

Sago: bon apetite!

Photo G. Weiblen

Sago proteins:
in the form of cerambycid larvae

It is an extraordinary sight to witness a whole tree-trunk converted into food with so little labour and preparation. A good-sized tree will supply a man with food for a whole year. The labour to produce this is very moderate; <u>in ten days a man may produce food for the whole year</u>. The effect of this cheapness of food is decidedly prejudicial, for the inhabitants of the sago countries are never so well off as those where rice is cultivated.

The Malay Archipelago (1869) by Alfred Russell Wallace

Sago & fish subsistence:

a present-day hunter-gatherer societies

Mangrove forests

Mangrove (New Guinea)
in low and high tide

Mangrove species: distinct zonation on the salinity gradient Australia

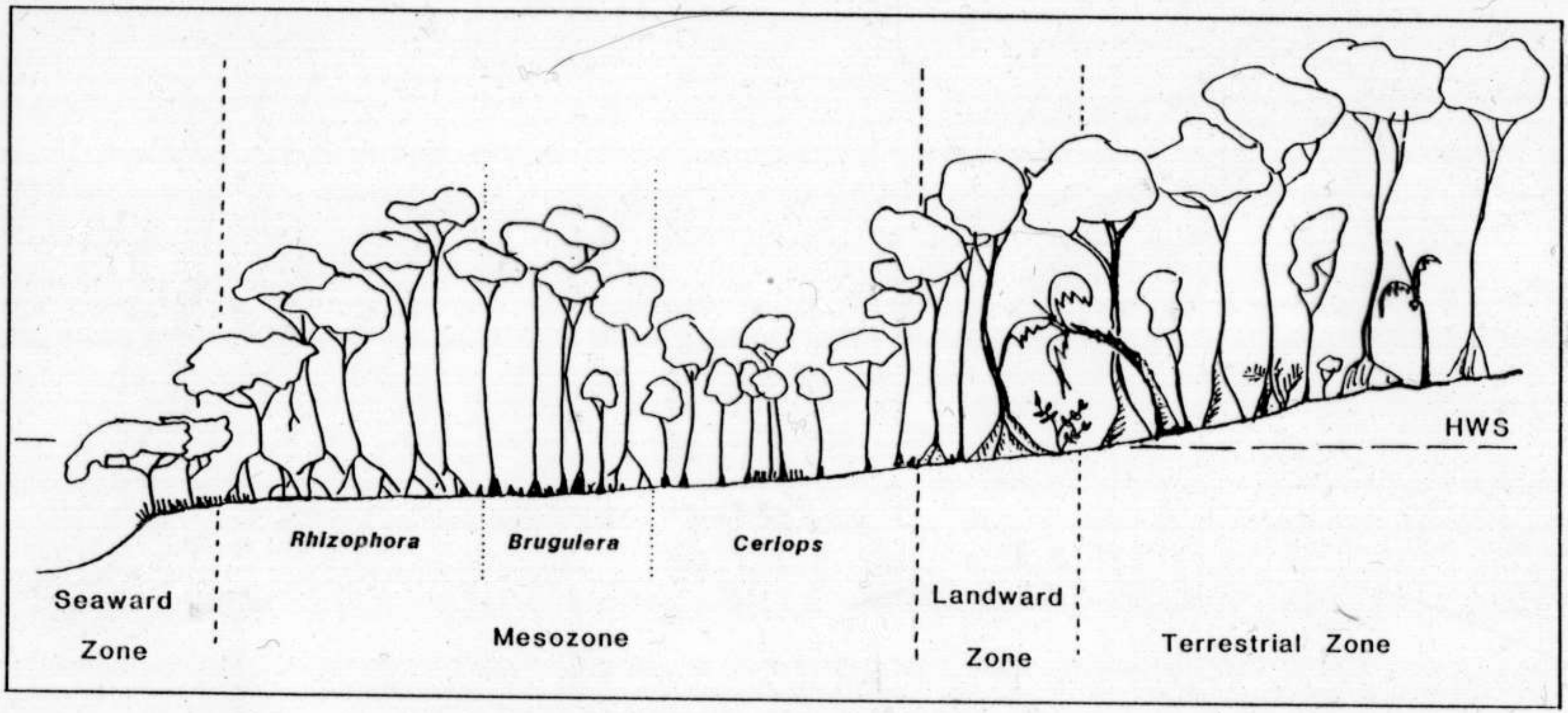


Figure 1.8. Schematic and generalized profile of a tidal flat in northeastern Australia (Queensland) to contrast zonation in a region of high rainfall with the region shown in Figure 1.7. The seaward zone is usually *Avicennia*. The salt flat in Figure 1.7 corresponds to the *Ceriops* zone in Figure 1.8. It is assumed that rainfall is the controlling factor, but site (like distance up river), latitude, tidal range, and substrate affect the zonation. Profiles similar to Figure 1.7 therefore can occur in eastern Australia in drier areas. (Courtesy of N. C. Duke)

Mangrove species: distinct zonation on the salinity gradient Malaysia

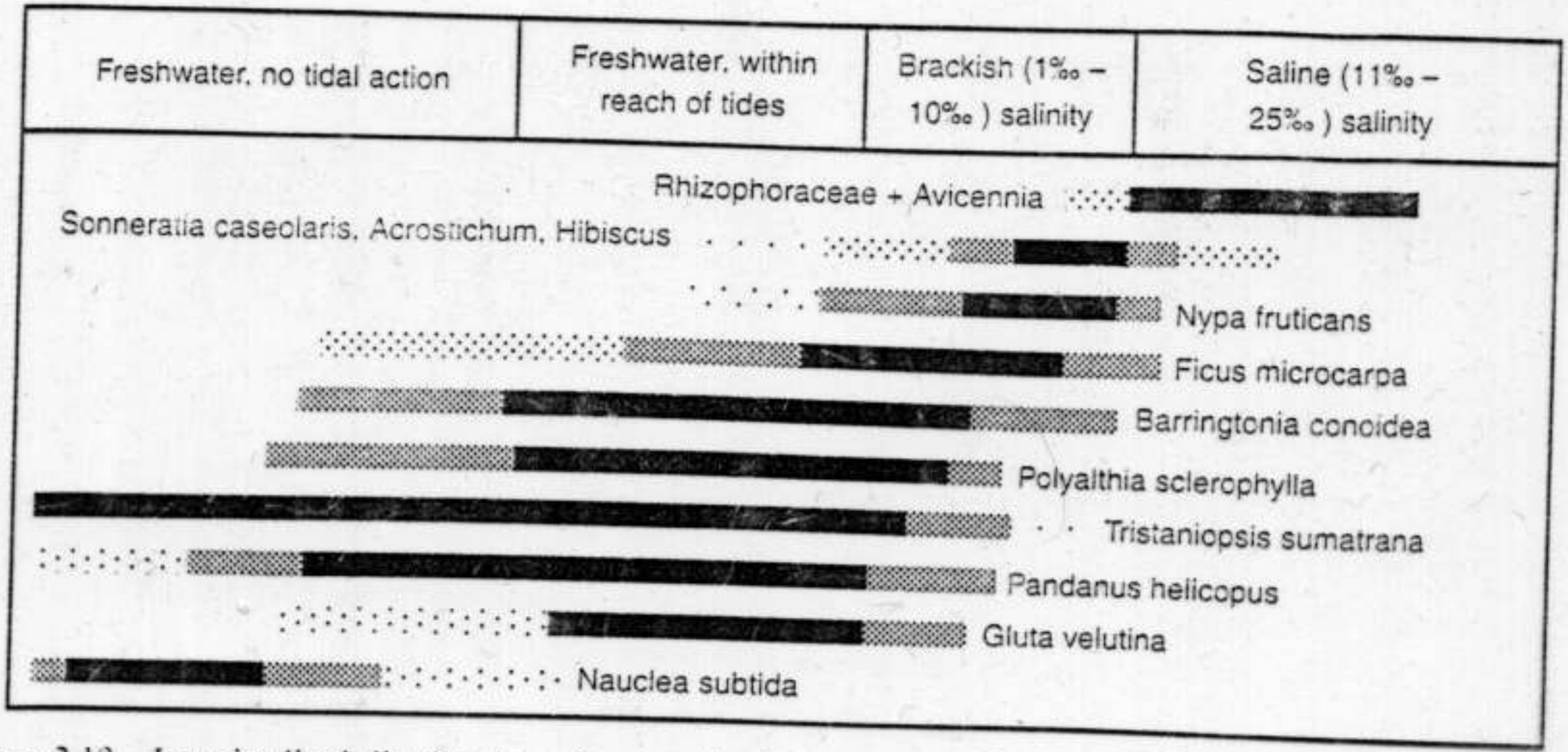


Figure 2.19 Longitudinal distribution of vegetation belts along the Sungei Sedili Besar, southern Peninsular Malaysia. Density of shading indicates frequency of occurrence, highest density suggests continuous occurrence. Transect length 35 km. (Modified from Corner, 1978). Reproduced by permission of Gardens Bulletin Singapore, published by Singapore Botanic Gardens.

Rhizophora

Ceriops

Bruguiera

Avicennia

Mangrove trees: leaves of uniform morphology

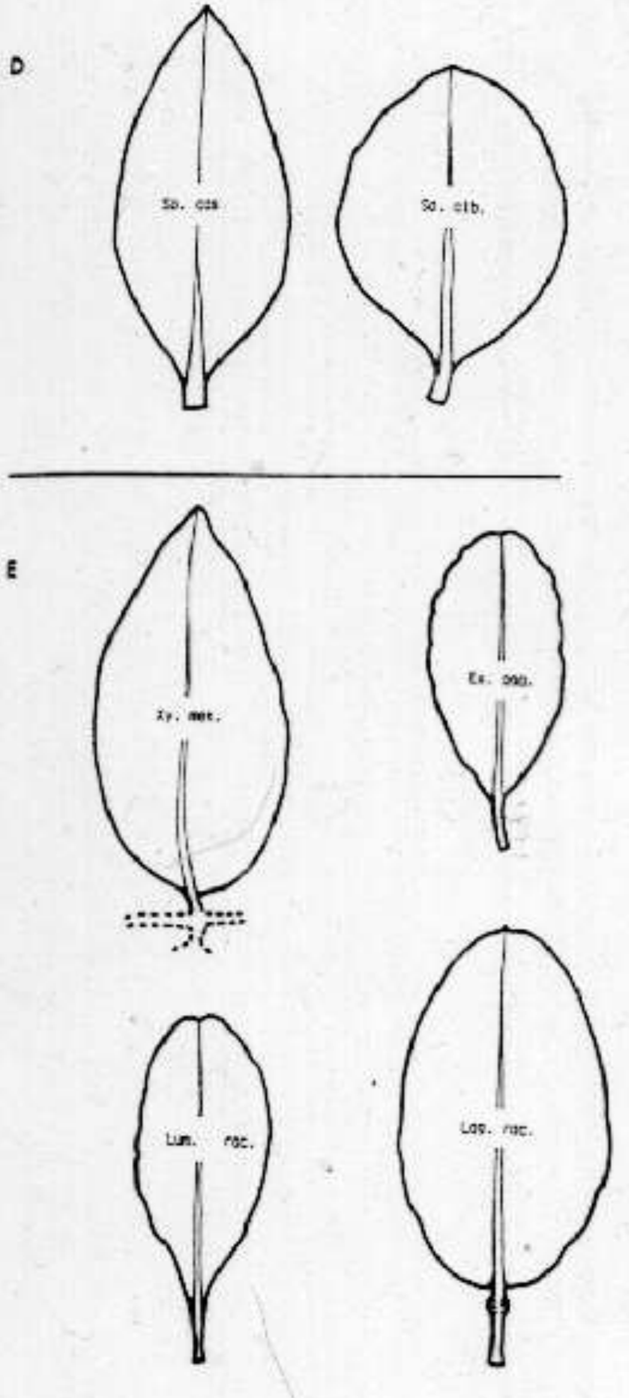
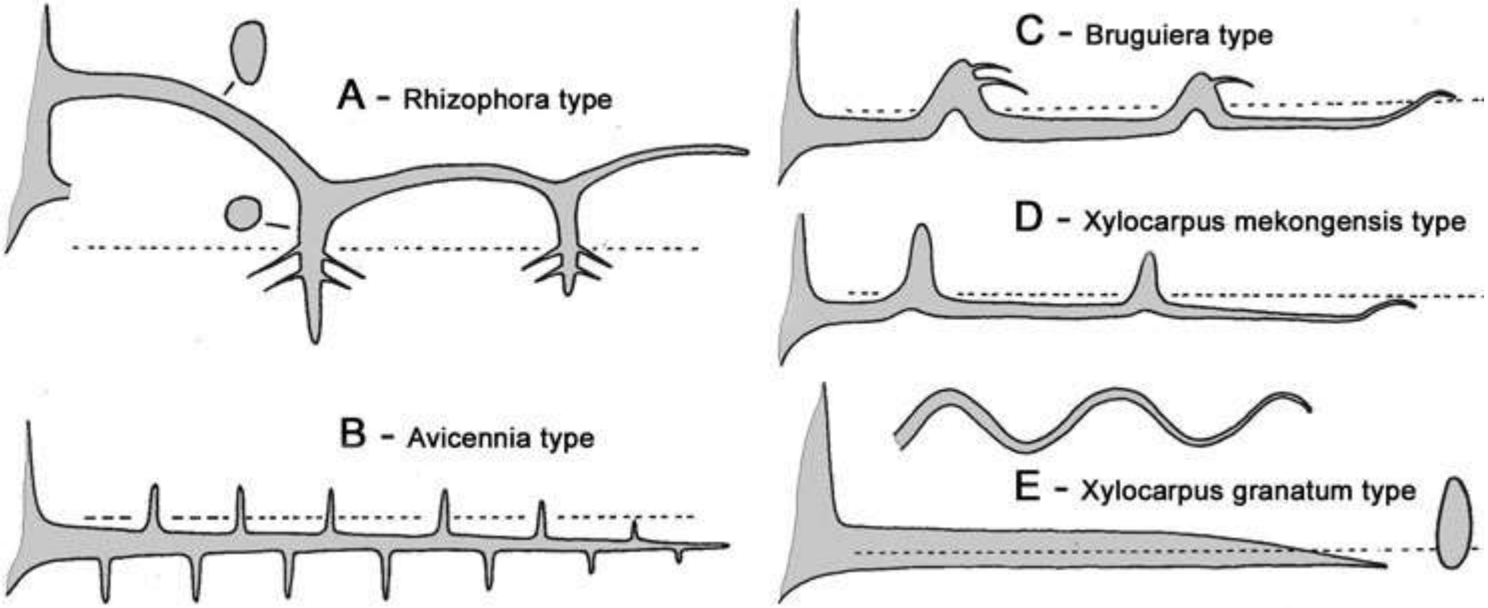


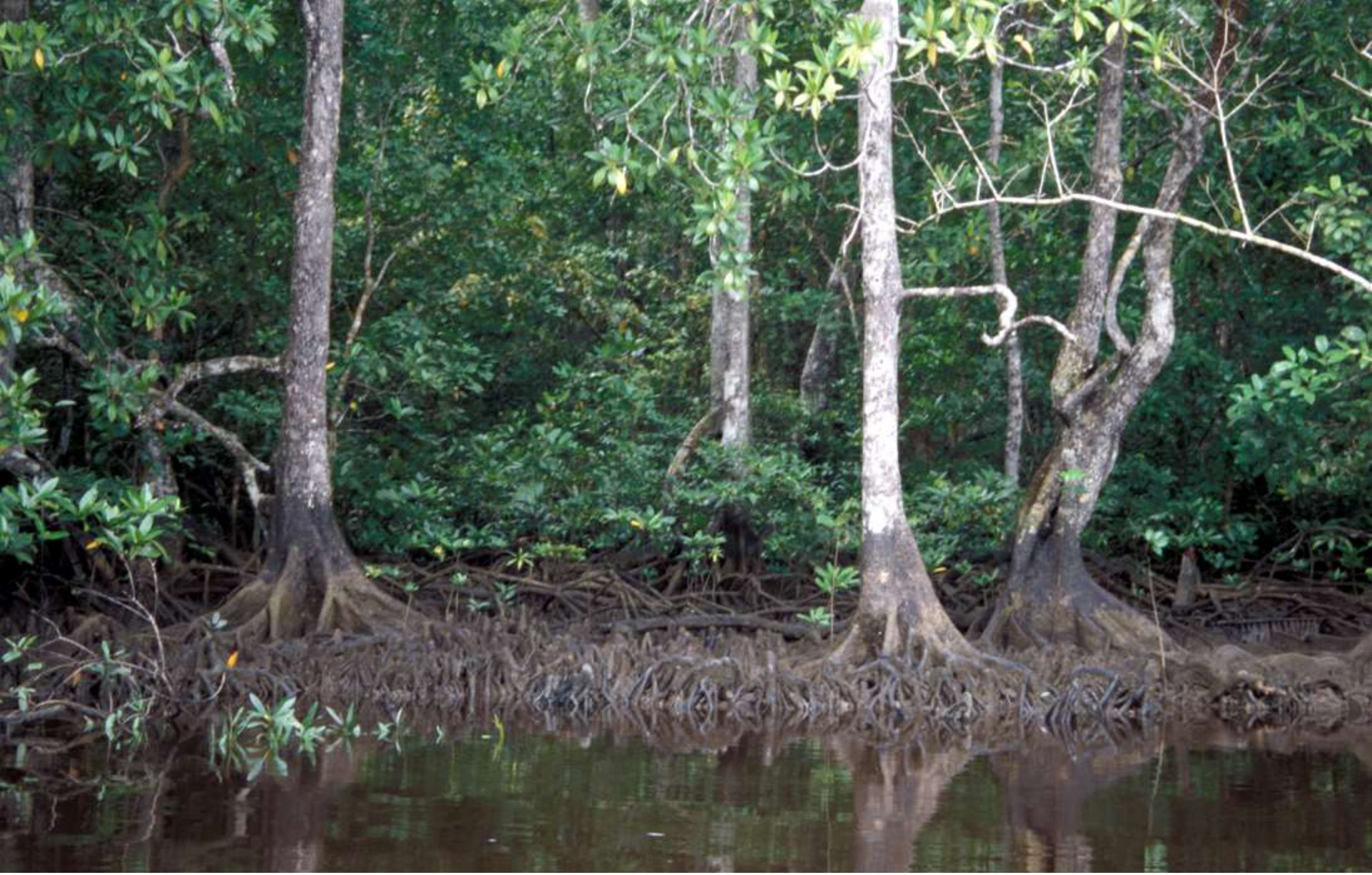
Figure 4.11. Mangrove leaf shape outlines to show uniform size and shape.

(D) *Sonneratia*: left, *S. caseolaris*; right, *S. alba*; (E) above, *Xylocarpus mekongensis* (one leaflet), *Excoecaria agallocha*; below, *Lumnitzera racemosa*, *Laguncularia racemosa*.

Mangrove trees:
aerial roots of great morphological diversity



Avicennia breathing roots

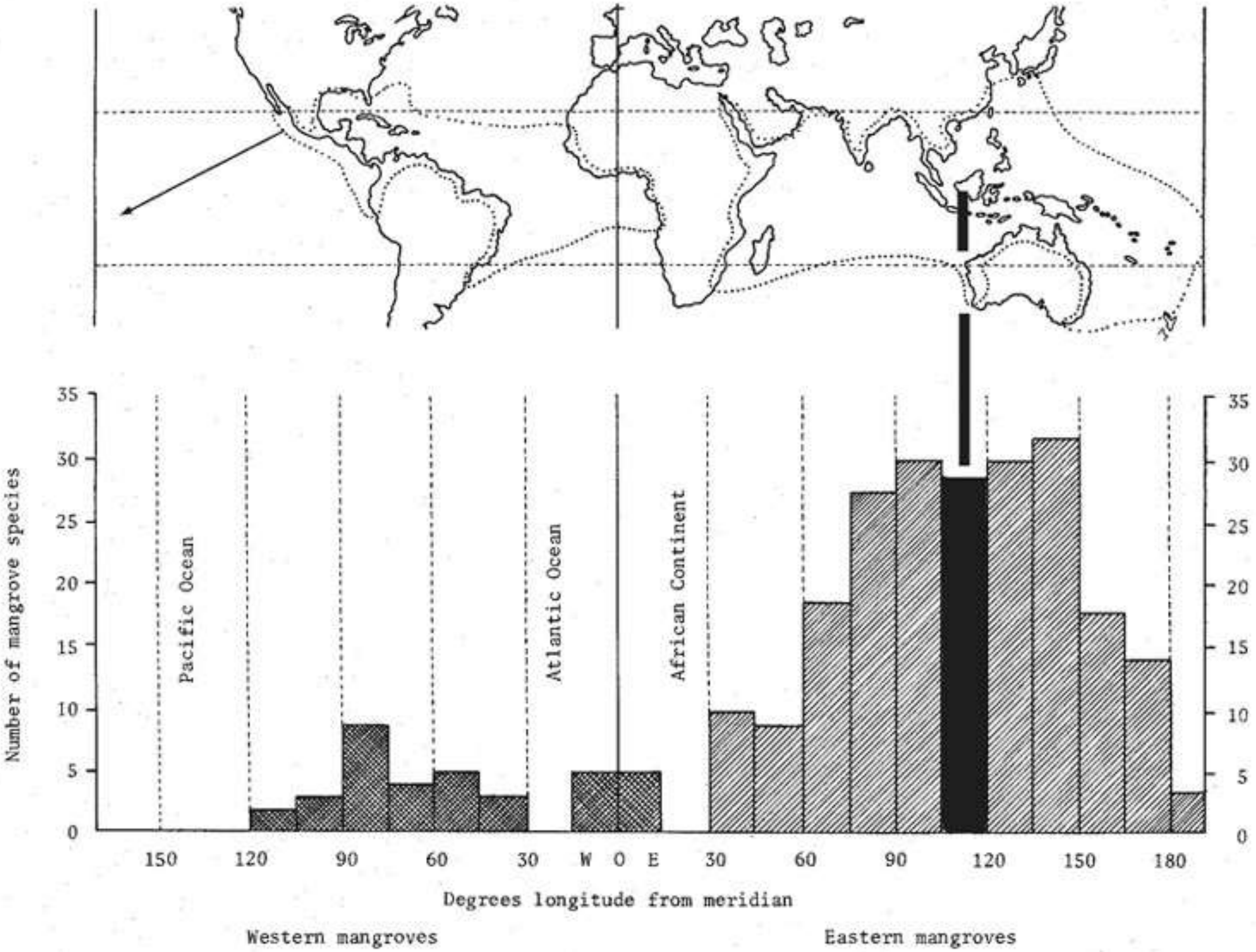


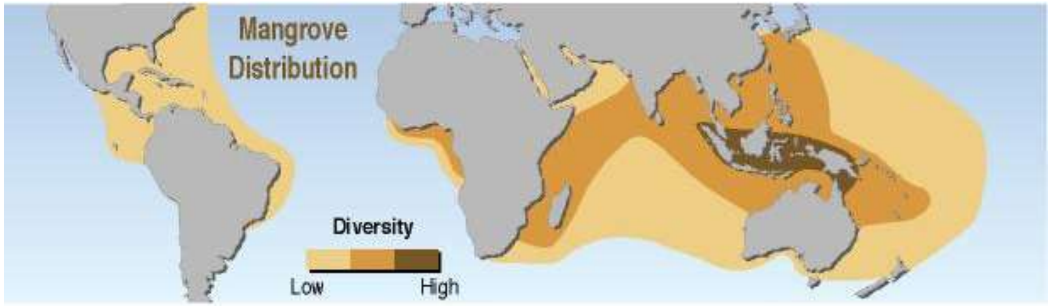
Bruguiera “knee” roots

Rhizophora stilt roots

Lyn Webb photo, Queensland

Species richness of mangroves - the SE Asia peak





Niche occupation patterns in mangrove forests on two continents

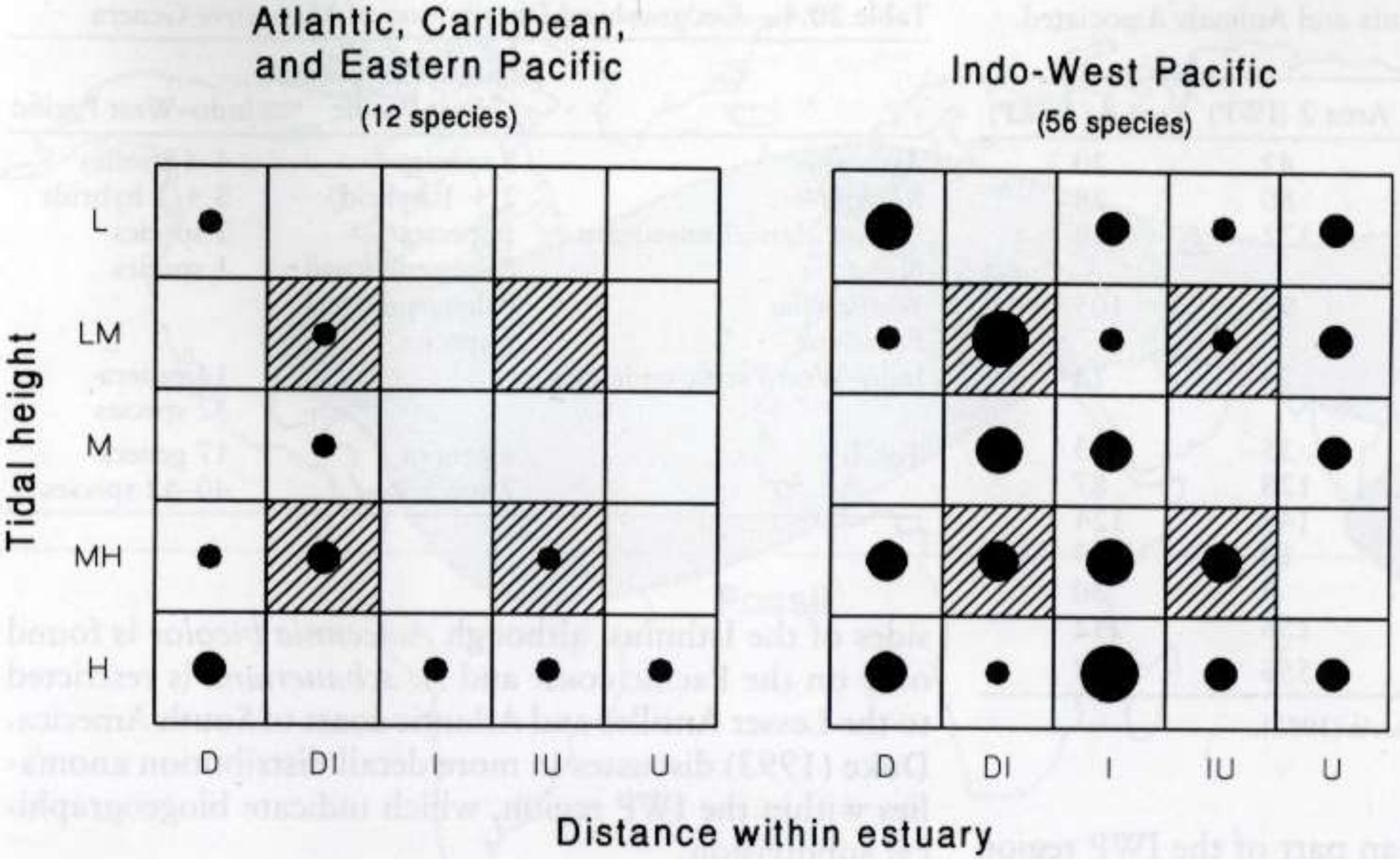


Figure 20.2 Distribution of mangrove taxa among categories of intertidal zone height (L, low; M, mid; H, high) and position within an estuary (D, downstream; I, intermediate; U, upstream) in the ACEP and IWP regions. Numbers of taxa per cell (1–6) are indicated by the sizes of the dots. Generalized taxa distributed in more than one category within each ecological axis are indicated by hatching. (Data from Duke 1993.)