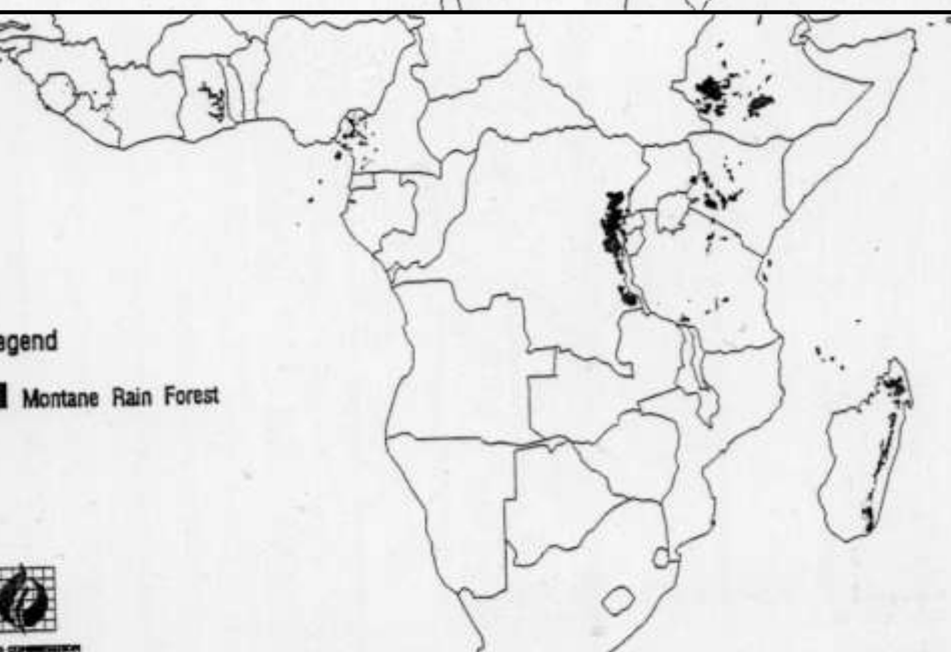
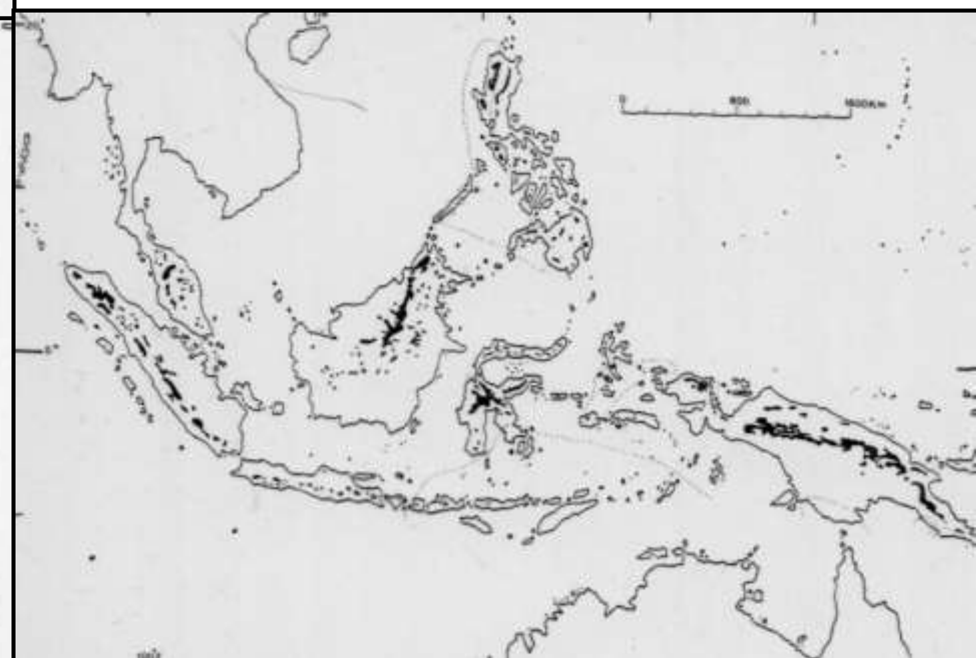
Altitudinal gradients

Montane forests in the tropics





Temperature at the forest limit in altitude in tropical, subtropical and temperate mountains

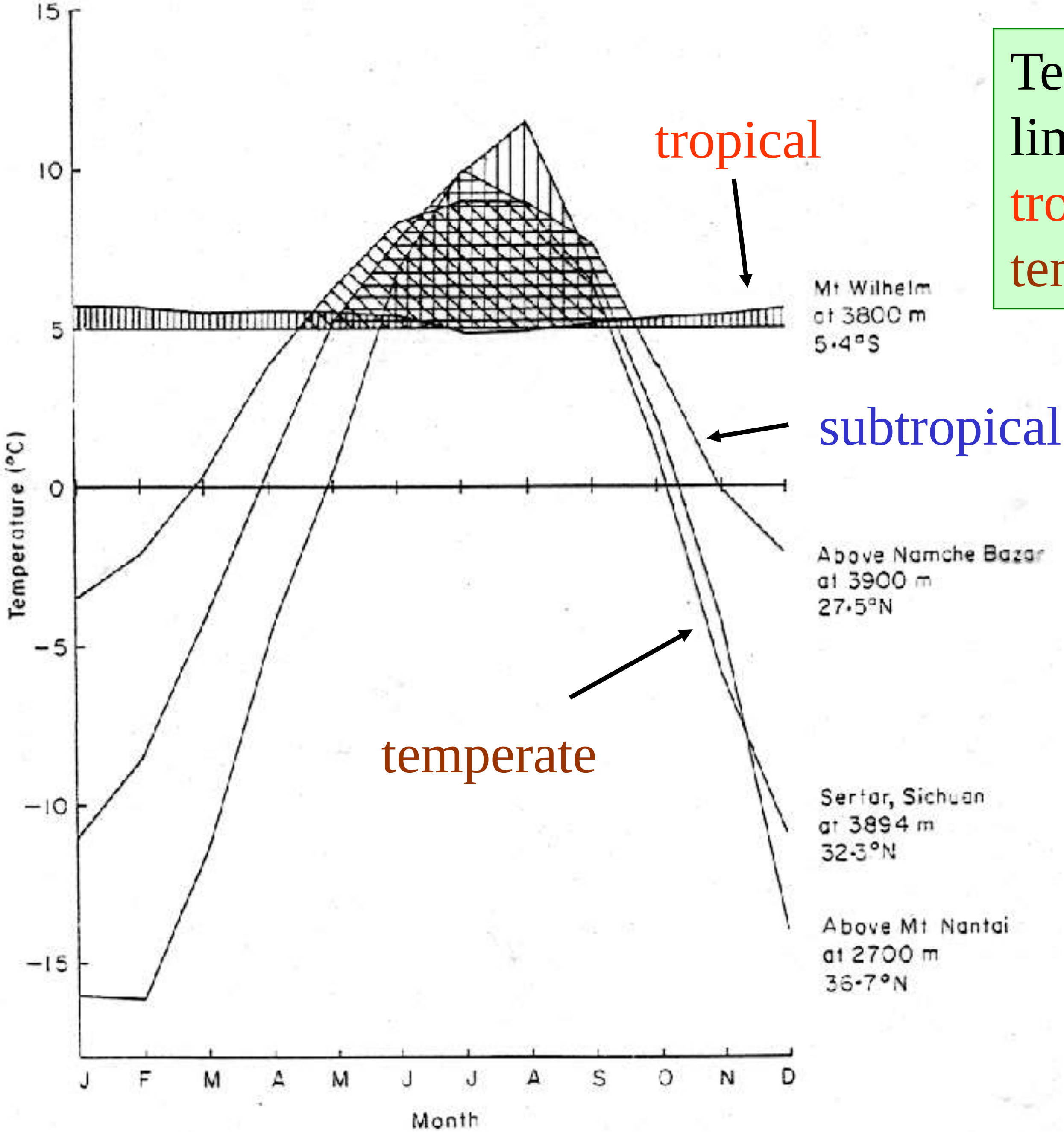
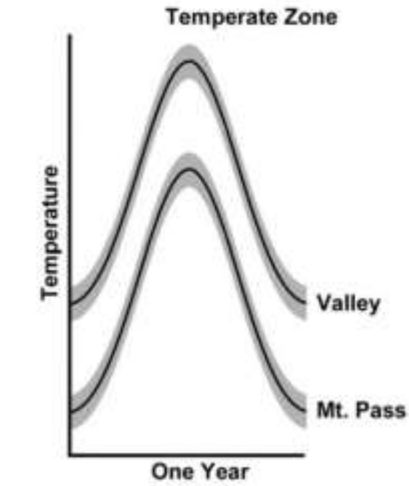
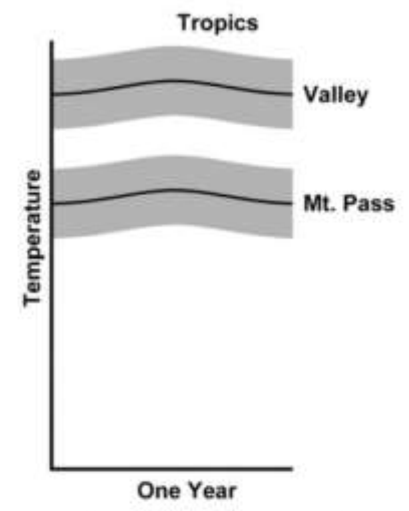
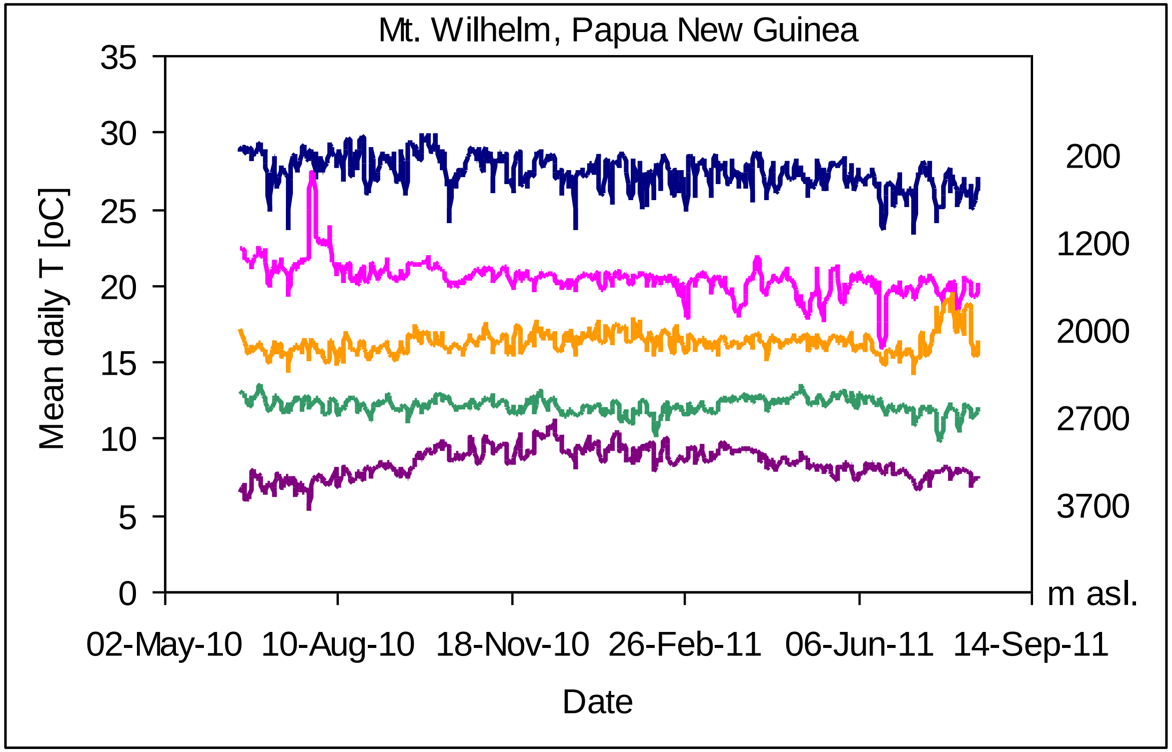


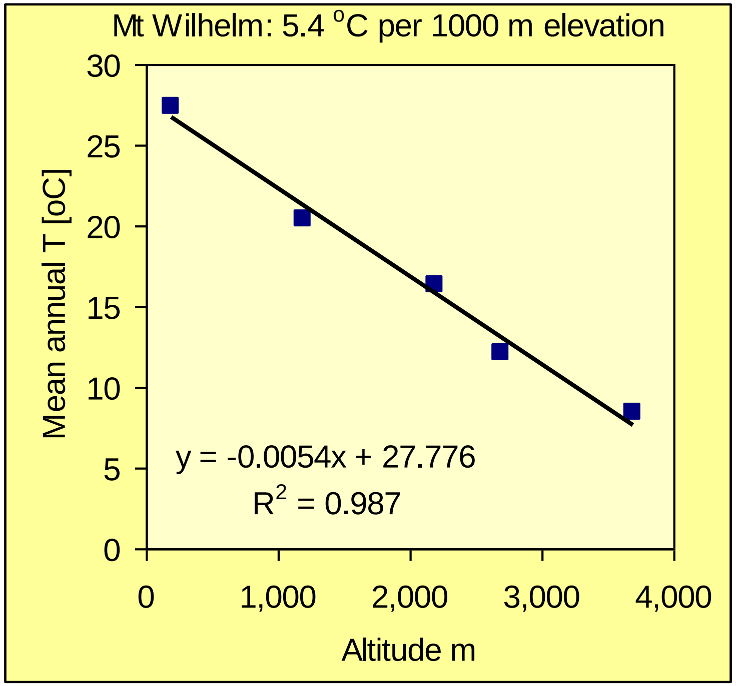
FIG. 3. Annual course of mean monthly temperature at the forest limit in East and South Asian mountains. Hatched areas denote the temperature sum (above 5 °C) for each temperature curve.





Decrease in temperature with altitude: 5-6°C per 1000 m





Annual range of monthly mean temperature: an altitudinal gradient

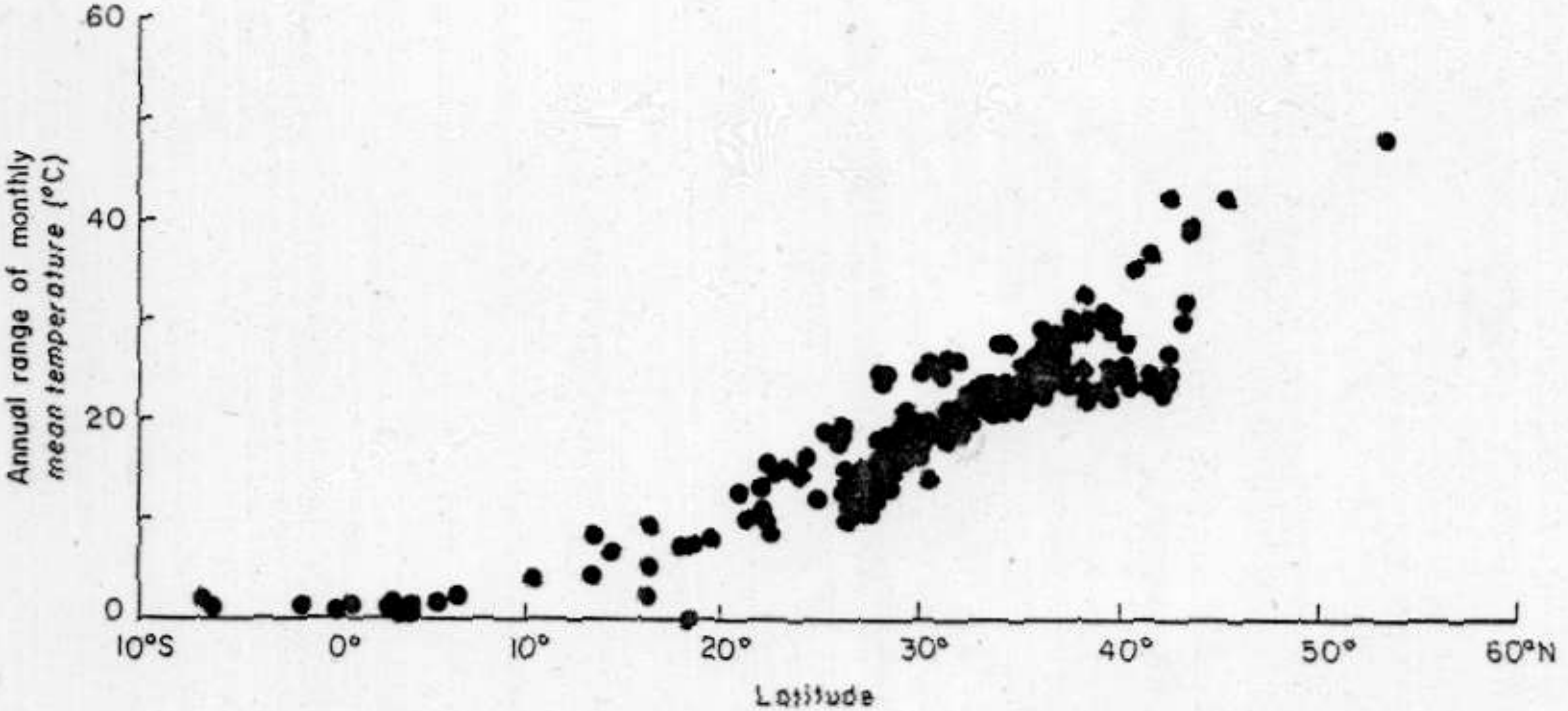
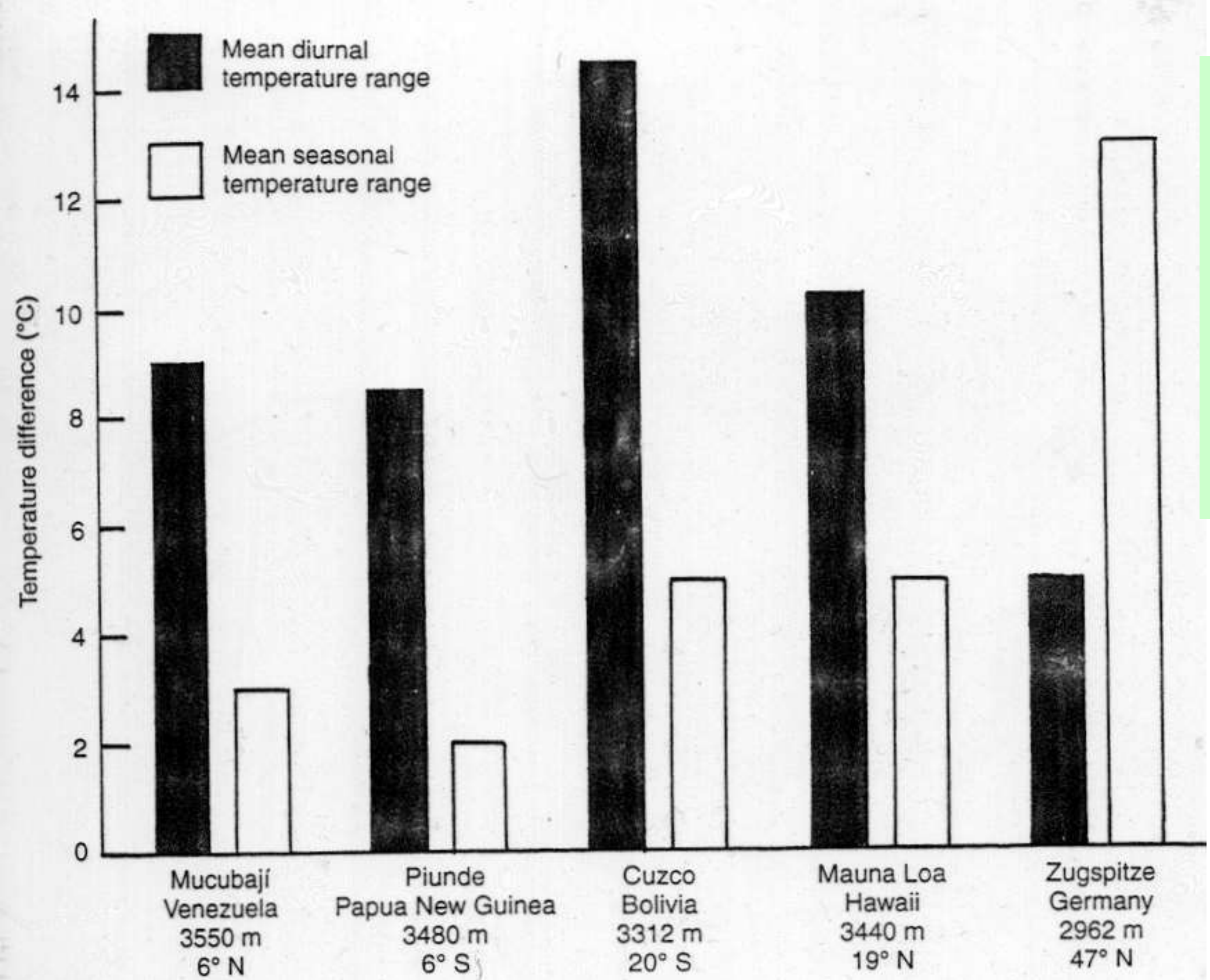


FIG. 7. Latitudinal pattern in annual temperature range in South and East Asia, based on data from 226 stations.

Diurnal and annual temperature range in high mountains



tropical - temperate

Altitude of treeline and snowline at different latitudes

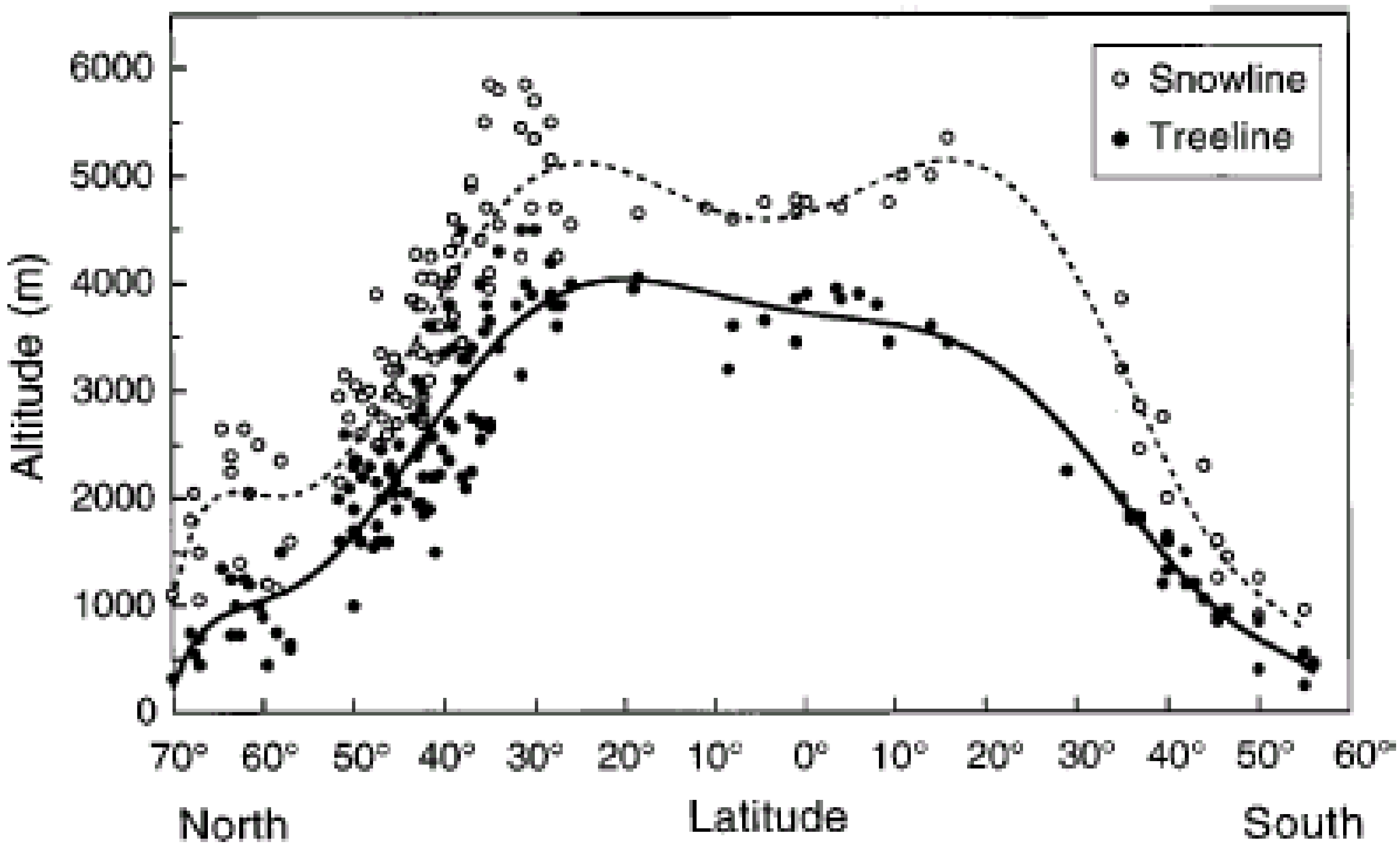


Fig. 1 The latitudinal position of treeline and snowline taken from a worldwide survey by Hermes (1955), supplemented by data from various other sources

Korner 1998. Oecologia 115:445

Altitudes and tree species at the forest limit in humid Asian mts.

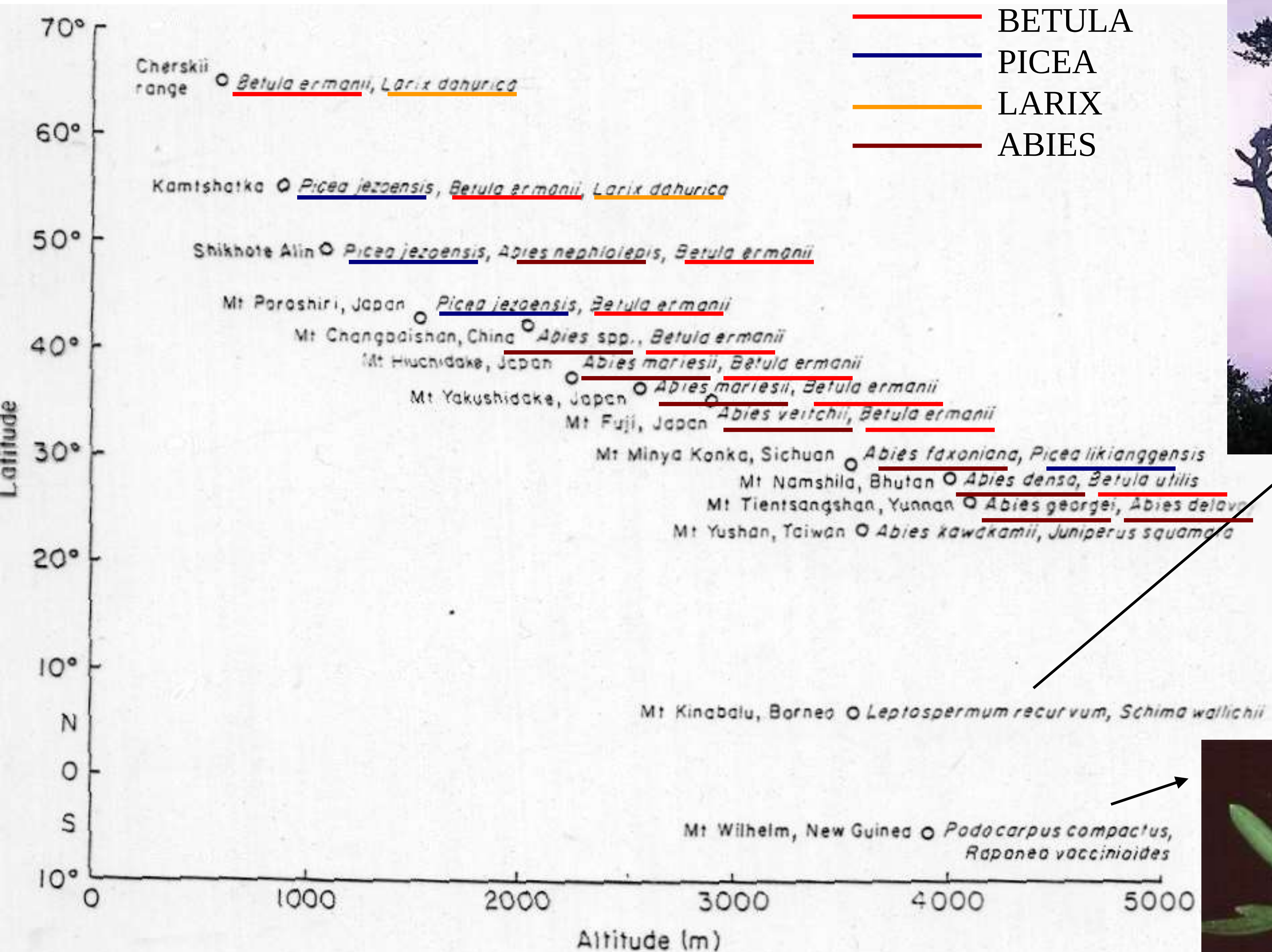
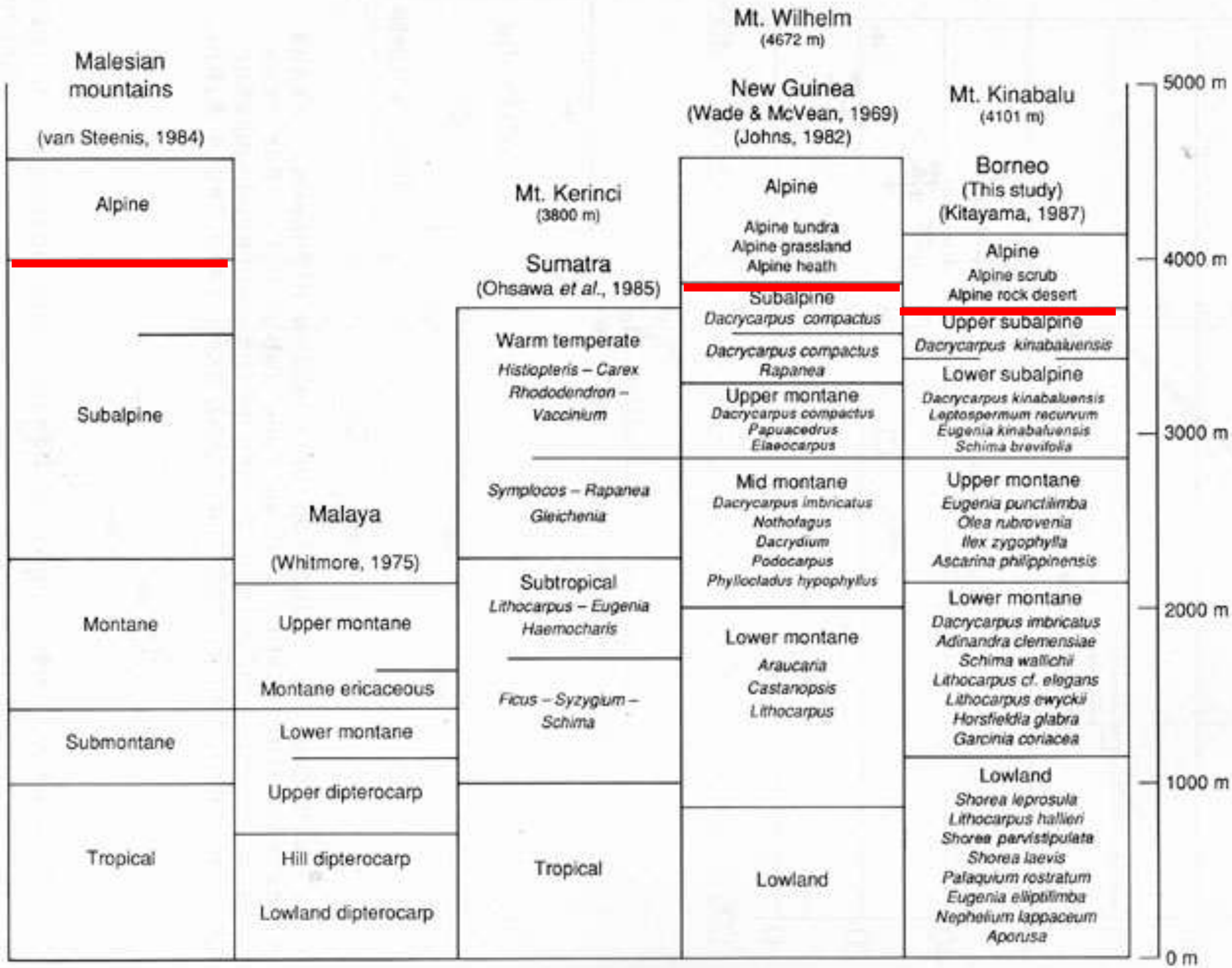


FIG. 1. Altitudes and tree species at the forest limit in humid Asian mountains.



Forest altitudinal zonation in Malesia

Altitudinal zonation on some tropical mountains

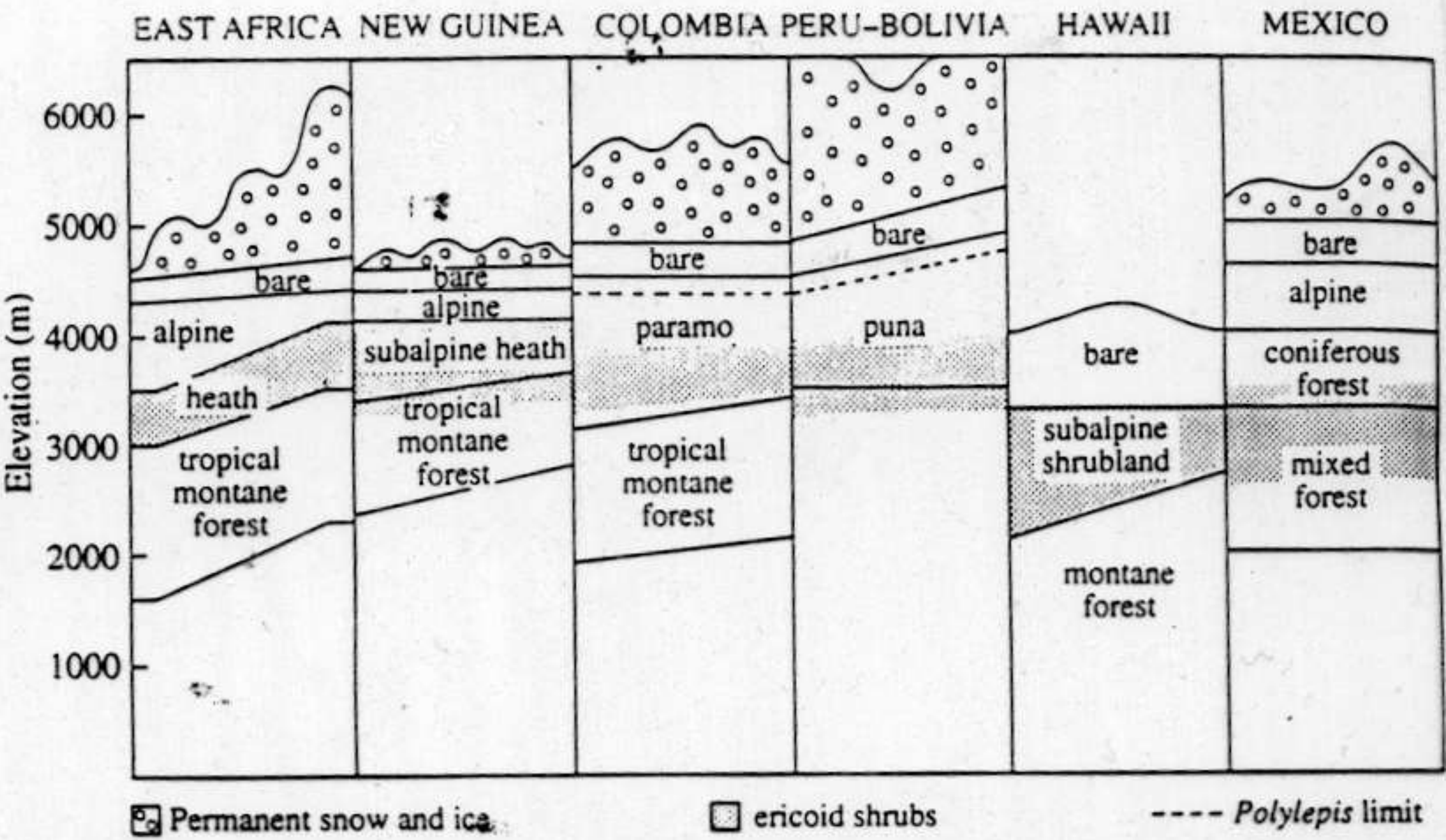


Figure 1.1. A diagrammatic summary of vegetation distribution on some New and Old World mountains. (Adapted from Troll 1968, Figure 16.)

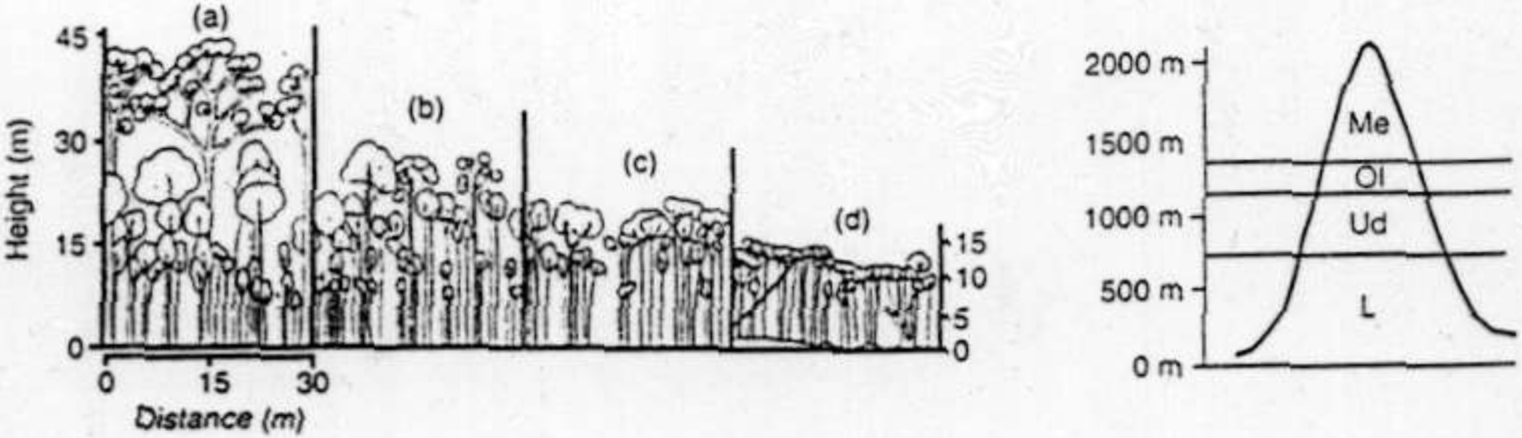


Figure 2.32 Altitudinal forest formation series in Malay Peninsula: (a) lowland evergreen rain forest, 150 m asl; (b) lower montane rain forest 'upper dipterocarp', 780 m; (c) lower montane rain forest, 'oak–laurel' 1500 m asl; (d) upper montane rain forest, 'montane ericaceous'. (From Robbins and Wyatt-Smith, 1964;

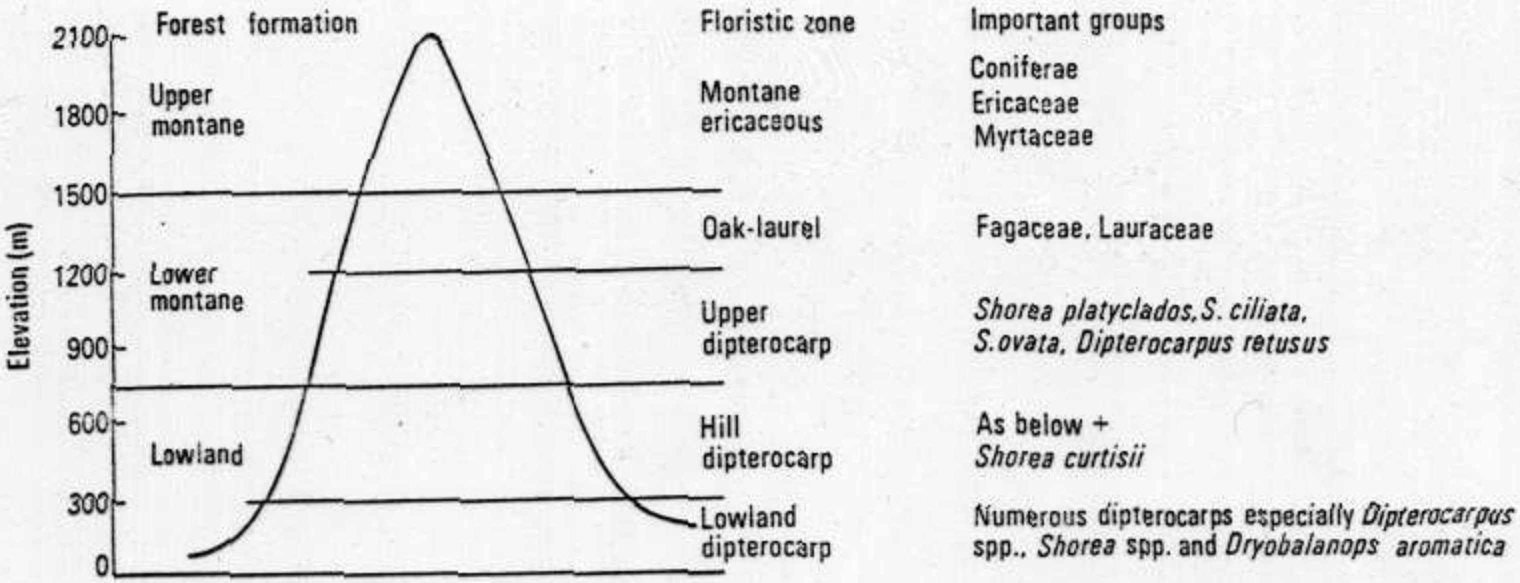
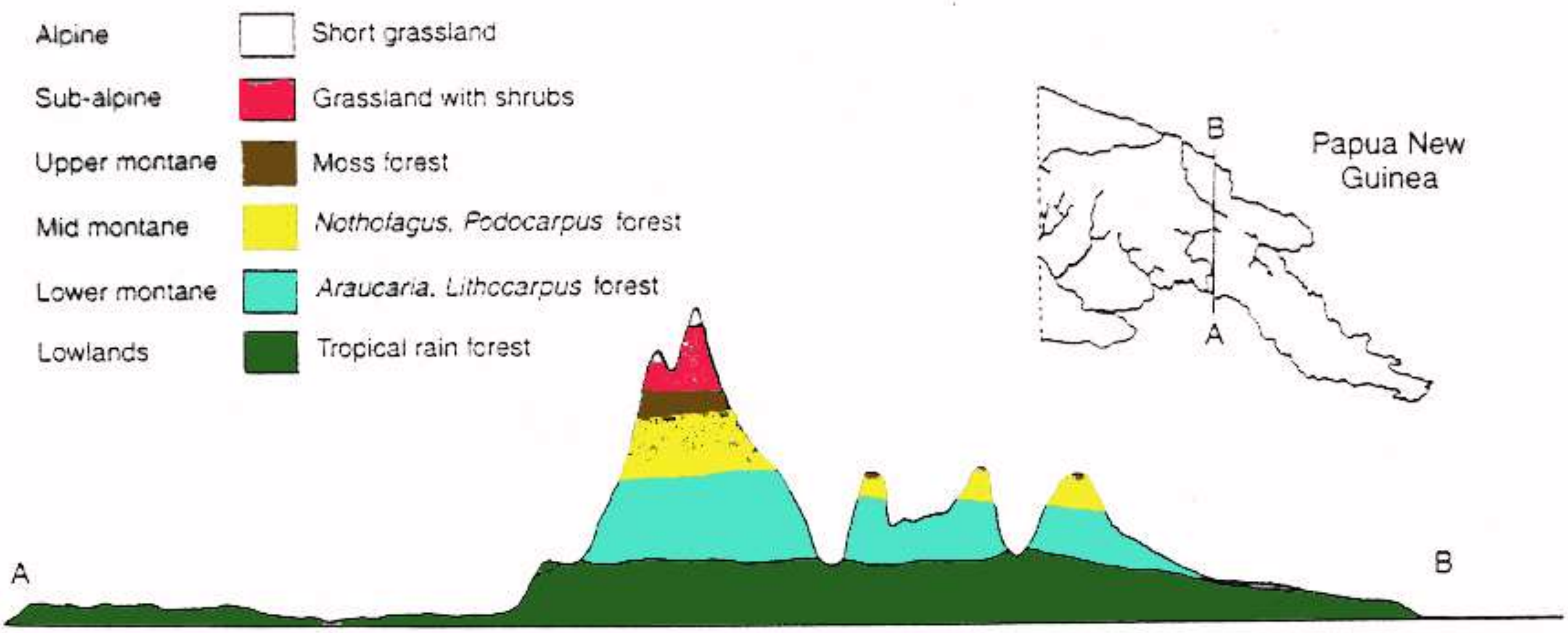


Fig. 2.7. Forest zones on the main mountains of Malaya. (Whitmore 1984*a*, fig. 18.1.)

Malay Peninsula

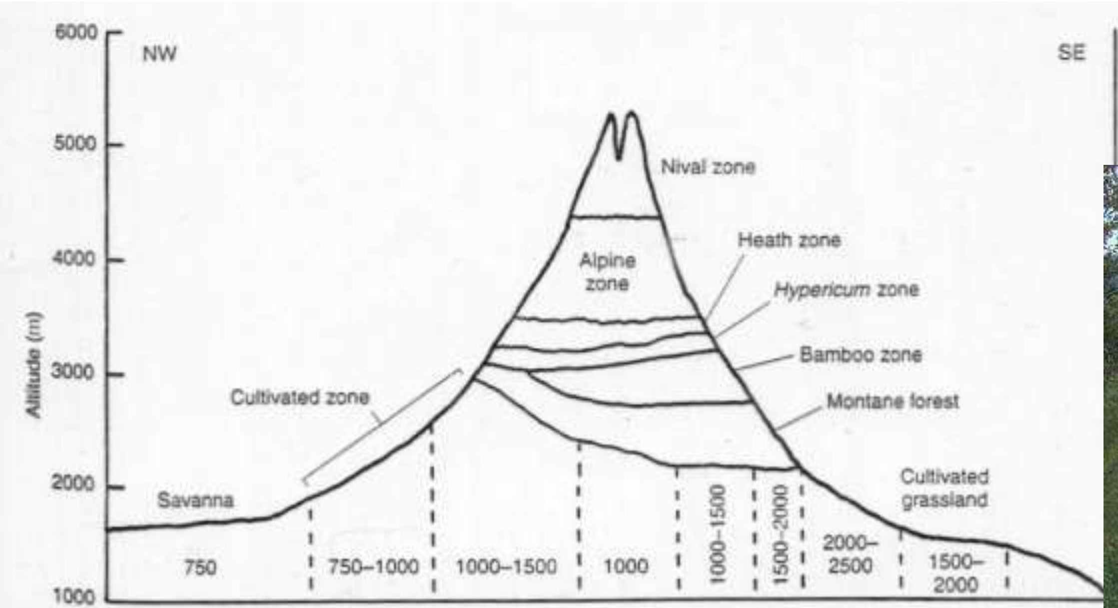
Altitudinal zonation in New Guinea

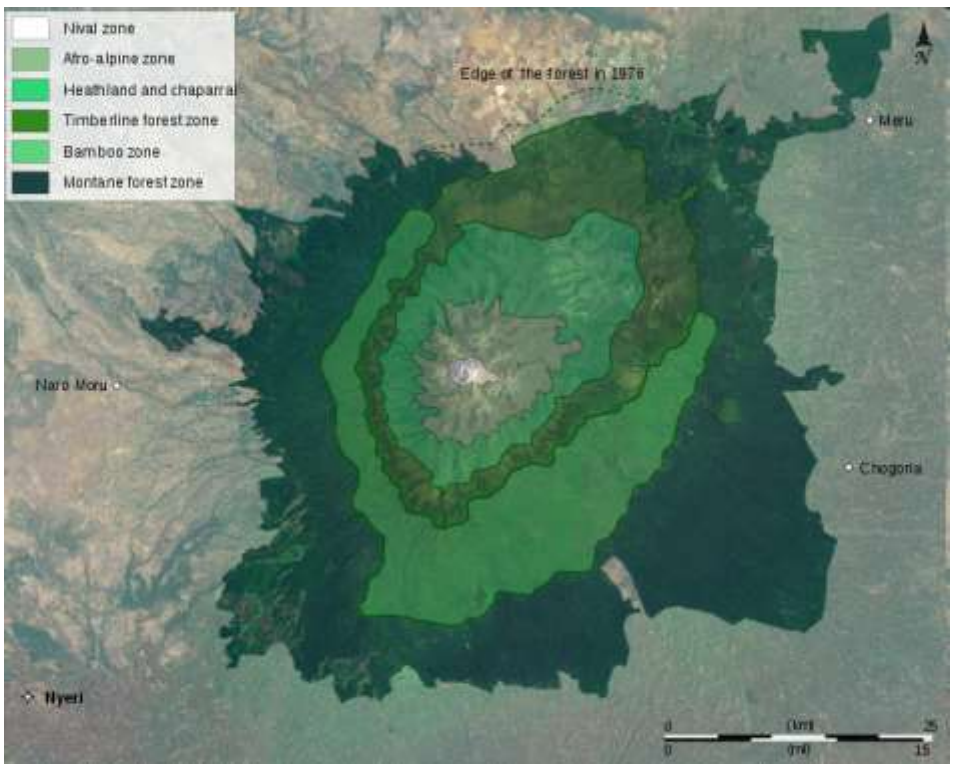


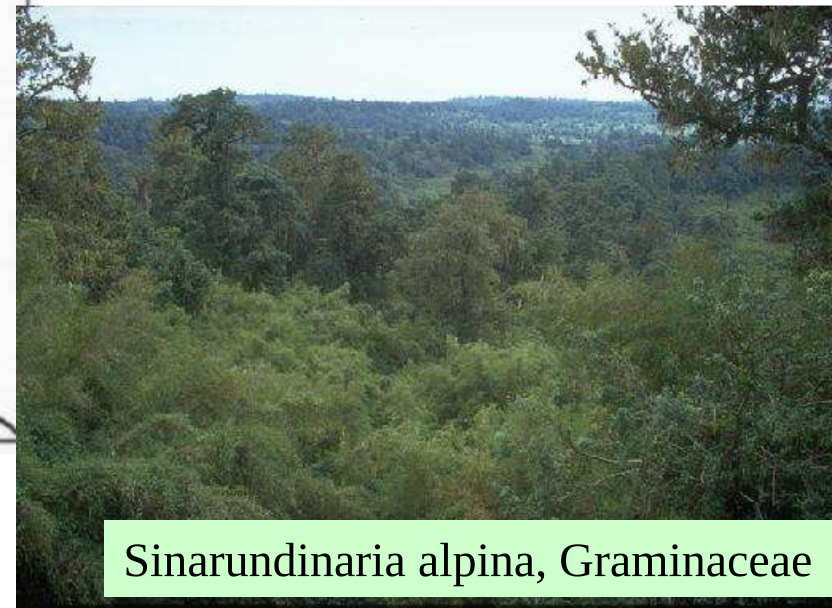
Mt. Wilhem, New Guinea

forest limit at 3,600 m asl

Mt. Kenya

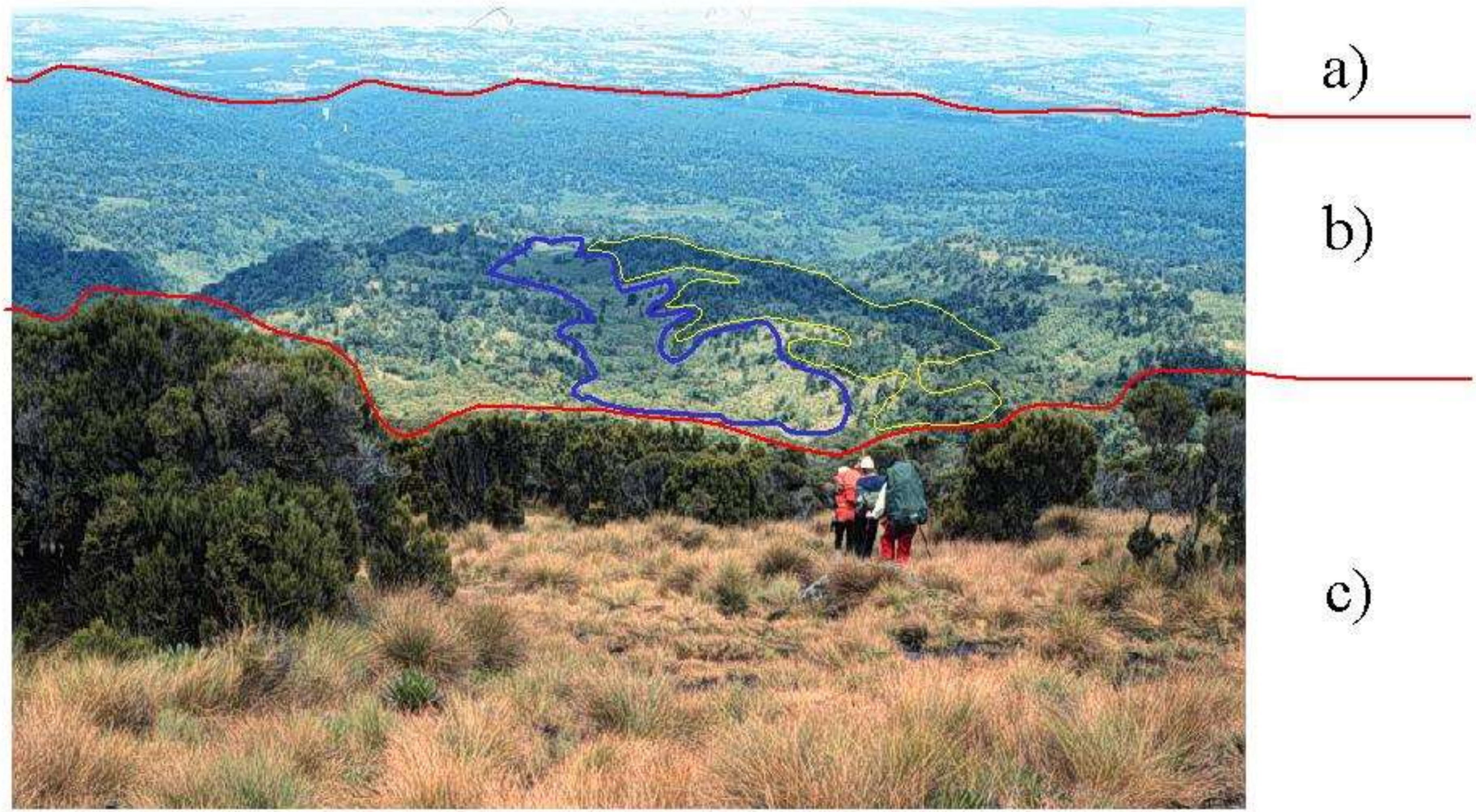






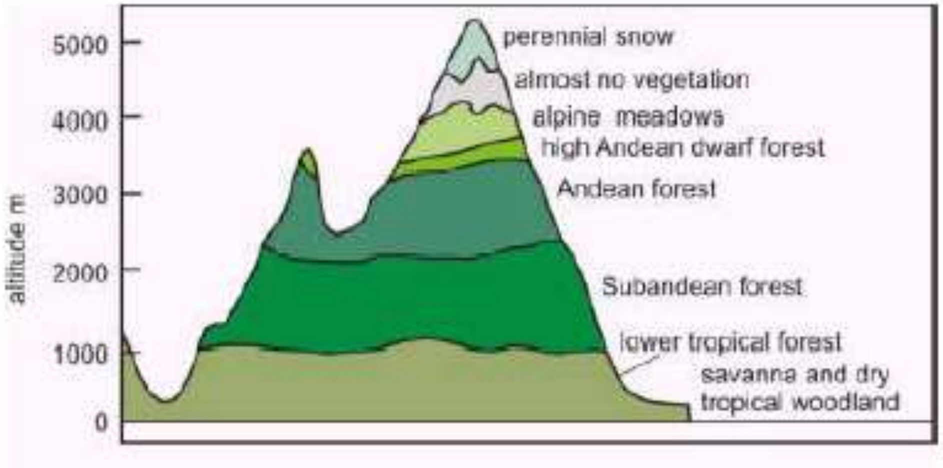
Sinarundinaria alpina, Graminaceae

Mt. Kenya



a) tree and shrub savannah area, up to 2.200 m;
b) mixed forest belt up to 3300m : the blue line represents a Bamboo dominant area, the yellow line defines a Hagenya-Hypericum zone;
c) alpine zone: composed mainly of Ericaceae and grass thickets.

Tropical alpine grasslands: Paramo



- wettest northern high-Andean vegetation called “paramo” (containing thick-stemmed grasses)

- southern high Andes is drier and contains grass-dominated vegetation called “puna”

Tropical alpine grasslands: Puna

Alpine tropical plants: meristems isolated against cold by rosettes, hairs, dry leaves...

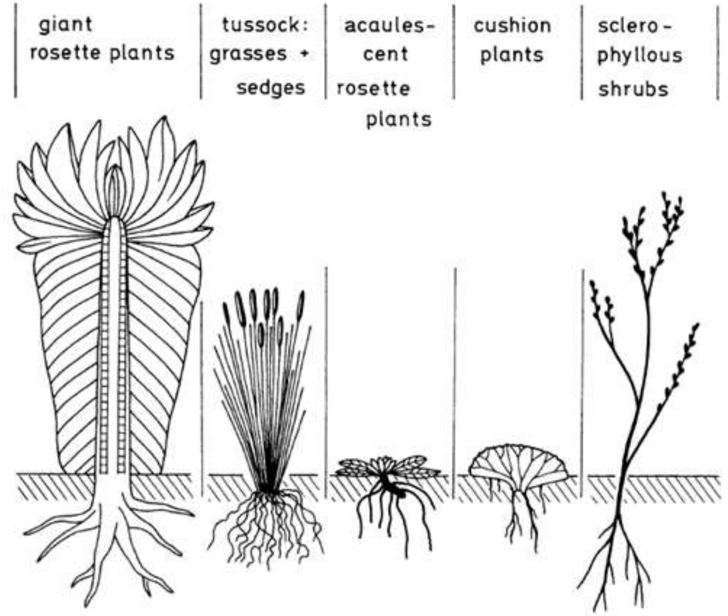


Fig. 12.4 The five major life forms of Afro-alpine vegetation (Hedberg 1964b)

Lobelia telekii (Africa)

Senecio (Africa)

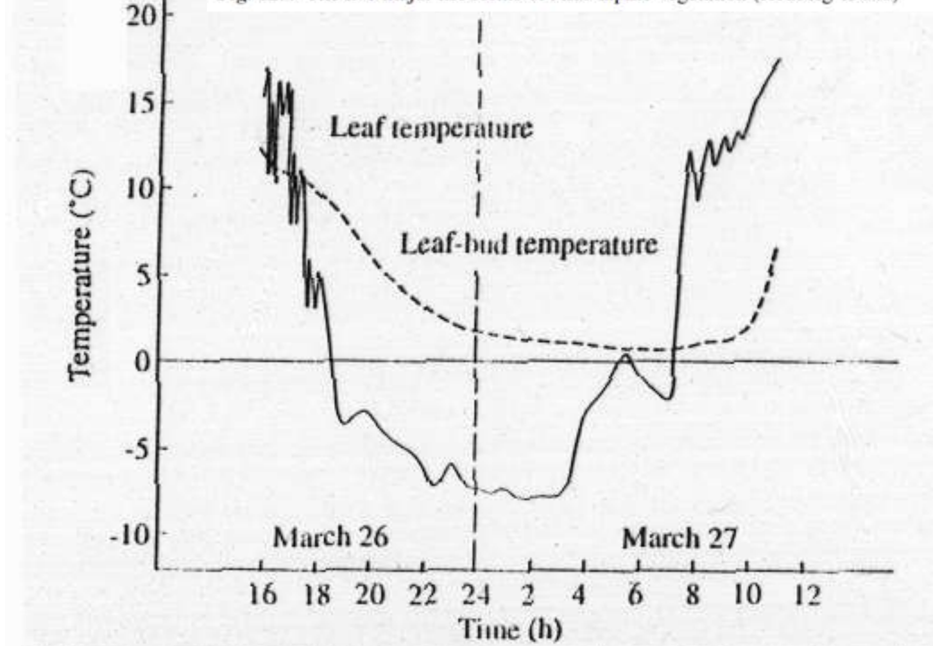
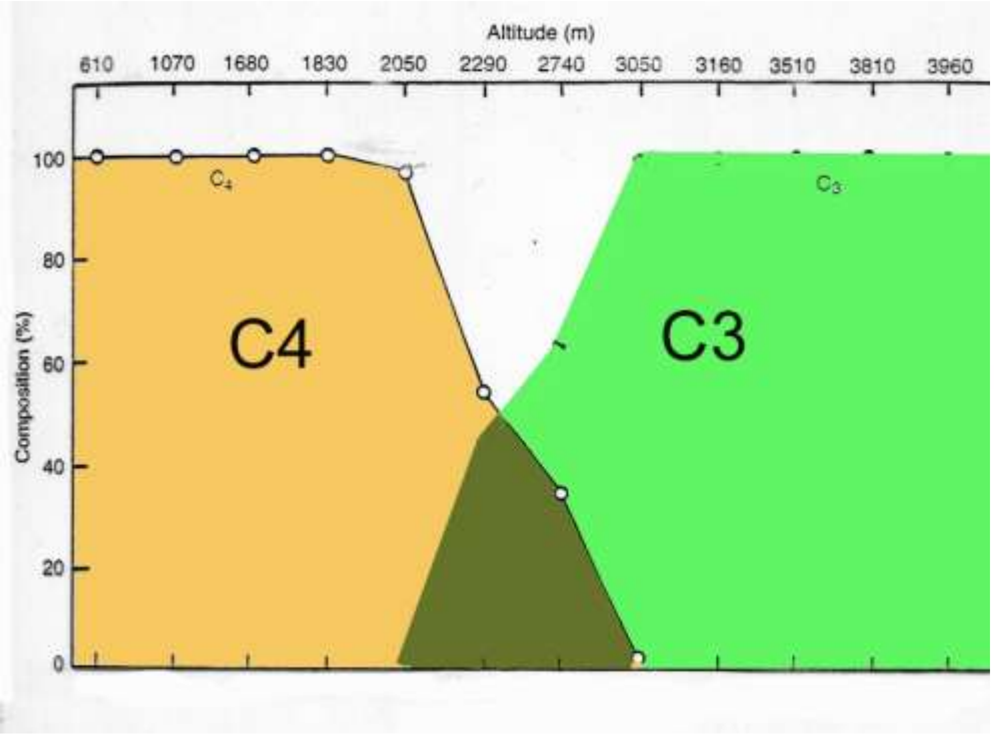
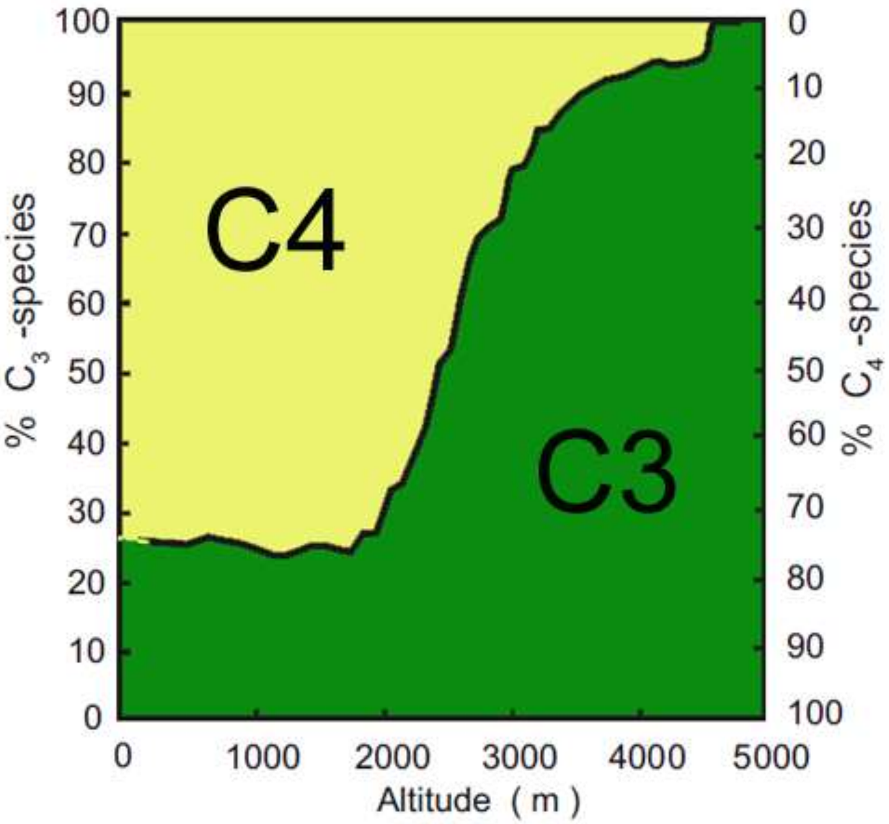


Figure 5.1. *Senecio keniensis* (Mount Kenya, 4150 m elevation): comparison of the temperature course of an adult (outer) rosette leaf with that measured inside the cone-shaped leaf bud. Reference air temperatures are shown in the top panel (from Beck *et al.* 1982).

C3 replace C4 grasses along an altitudinal gradient



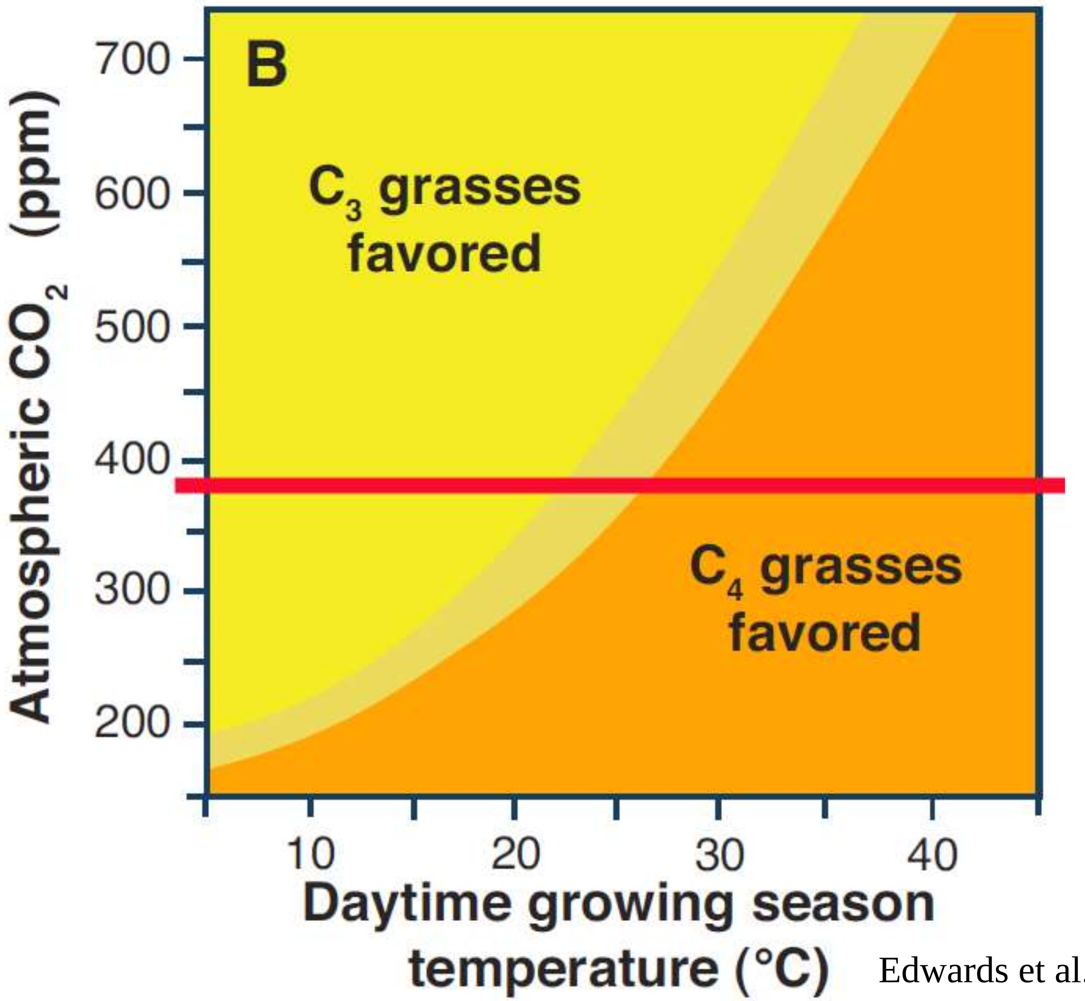
Kenya



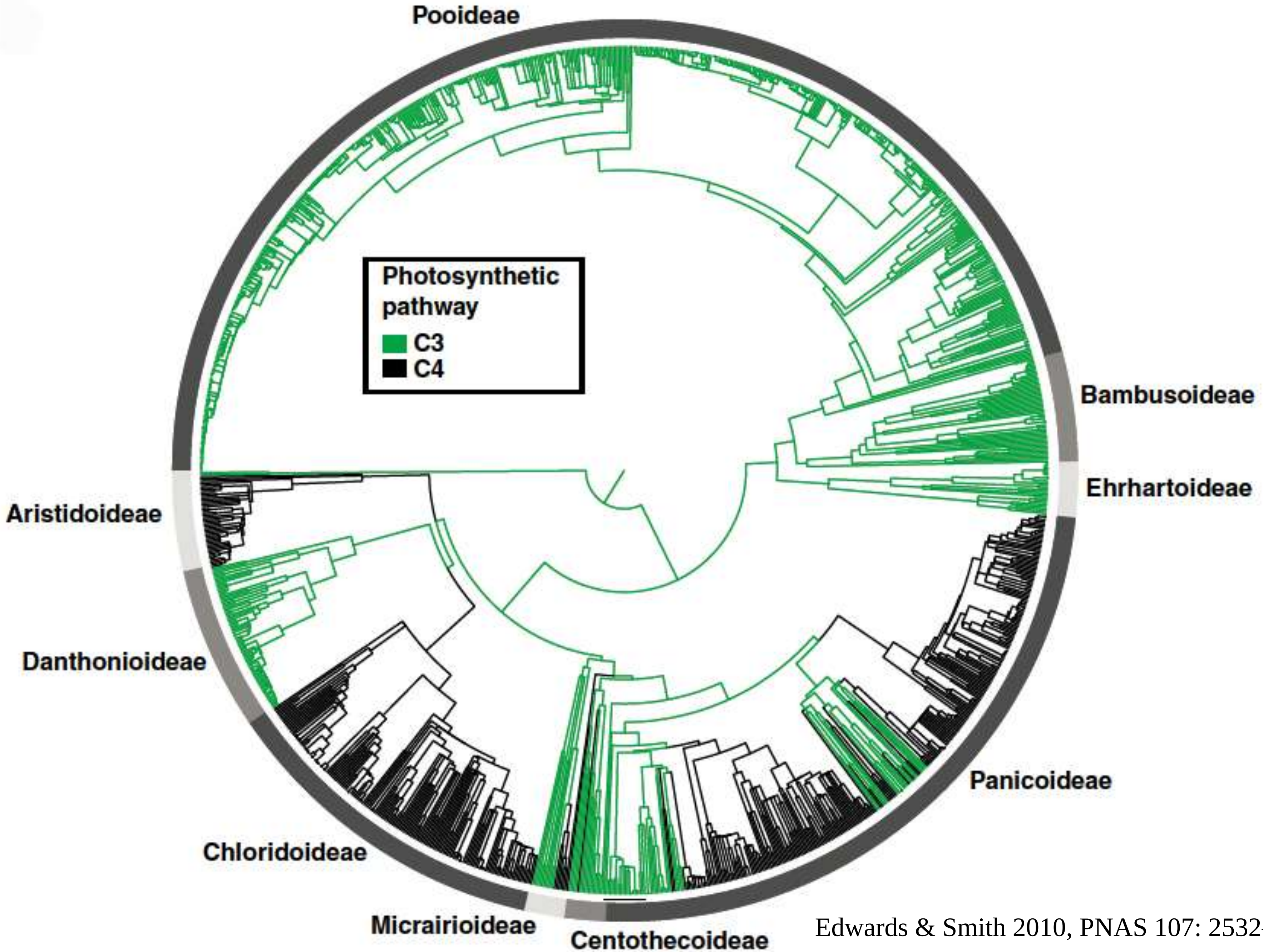
Ecuador [based on 220 species]

Tieszen et al. 1979, Boom et al. 2001

At high temperatures and low CO2, the C3 photosynthetic enzyme rubisco fails to completely distinguish CO2 and O2. This leads to photorespiration, resulting in losses of photosynthetic carbon. C4 photosynthesis suppresses photorespiration by concentrating CO2 internally, but this comes with an energetic cost, which exceeds the photorespiratory costs of C3 photosynthesis at high CO2 and low temperatures.

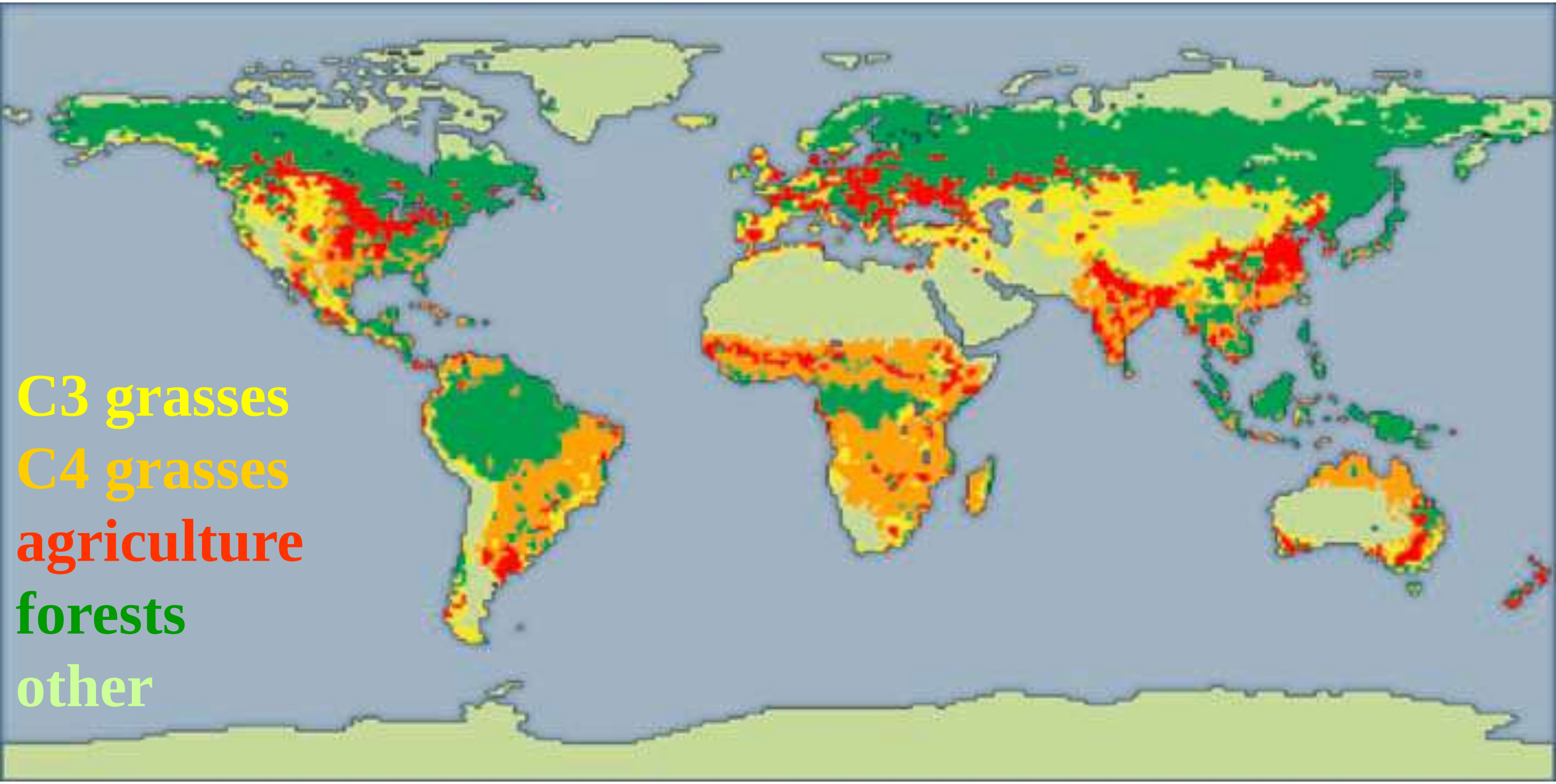


Edwards et al. 2010, Science 328, 587



Edwards & Smith 2010, PNAS 107: 2532–2537

C4 grasses dominate in the tropics



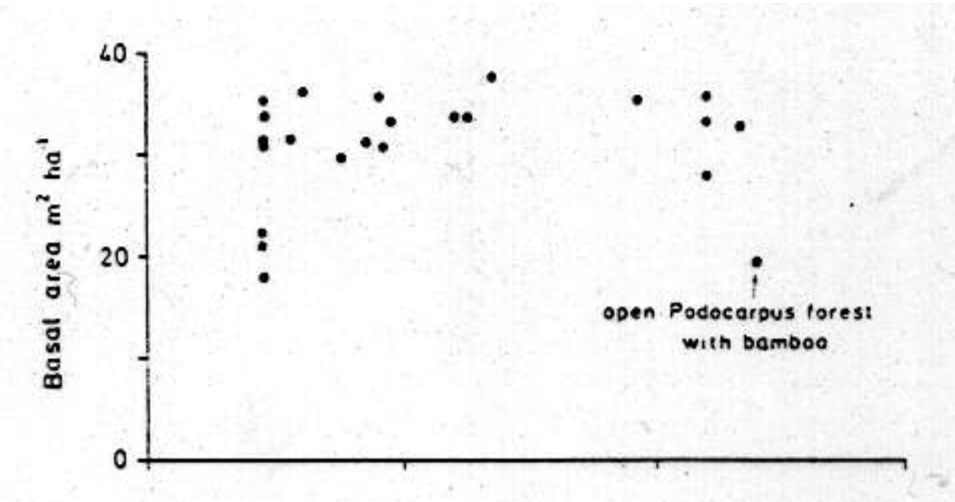
Edwards et al. 2010, Science 328, 587

Montane forests

New Guinea, montane forest at 2,200 m asl

Altitudinal trends - trees >20 cm DBH in Africa

basal area m^2/ha



no. of species /ha

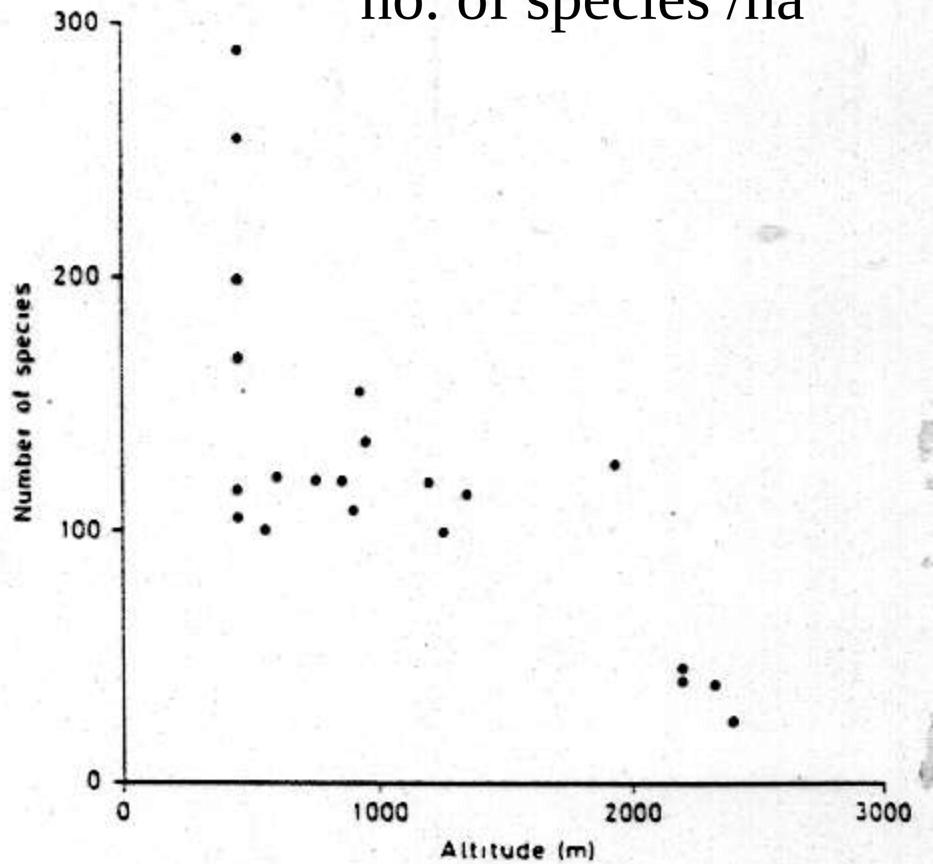


Fig. 8.9. Basal area, tree density and species diversity plotted against altitude for central African forests, mainly in Kivu (Zaïre). Only individuals over 20 cm circumference at a height of 1.5 m above the ground are included. (Constructed from data in Pierlot, 1966.)

Altitudinal trends in the main forest characteristics

Characteristis	Lowland rainforest	Lower montane	Mid montane	Upper montane
Mean height:				
canopy	25–45 m	30–40 m	20–30 m	18–20 m
emergents	60–80 m	70–80 m	to 30 m	to 25 m
Stratification	3–4 layers	Diffuse	Diffuse	1 or 2 layers
Buttress roots	Frequent and large	Common	Rare	Absent
Surface roots	Rare	Rare to common	Common	Abundant
Stilt roots	Rare	Absent to rare	Common to abundant	Absent to rare
Cauliflory	Frequent	Rare	Rare	Absent
Drip tips on leaves	Frequent	Occasional to frequent	Rare	Absent
Lianas	Frequent	Common	Rare	Absent
Lichens, mosses	Rare	Rare	Abundant	Abundant
Tree ferns	Absent	Present	Occasional to common	Abundant
Palms	Abundant	Common	Absent	Absent
Pinnate leaves	**Frequent**	**Rare**		**Very rare**
Leaf size	**Mesophyll**	**Mesophyll**		**Microphyll**

Source: Grubb 1977; Johns 1982; Whitmore 1993.

Elfin forest Costa Rica

Elfin x lowland forests

trees DBH>10cm:	Elfin forest Puerto Rico	Lowland forest Malaysia
No. trees/ha	4000	500
Basal area m^2/ha	44	30
LAI	2.2	7.4
wood support efficiency kg wood/m^2 foliage * m height	1.1 [90 t of wood to support 2 ha leaves 4 m above ground]	0.2 [420 t of wood to support 7.4 ha leaves 30 m above ground]

Biomass and water interception in a mossy elfin forest Tanzania (2140 m asl)

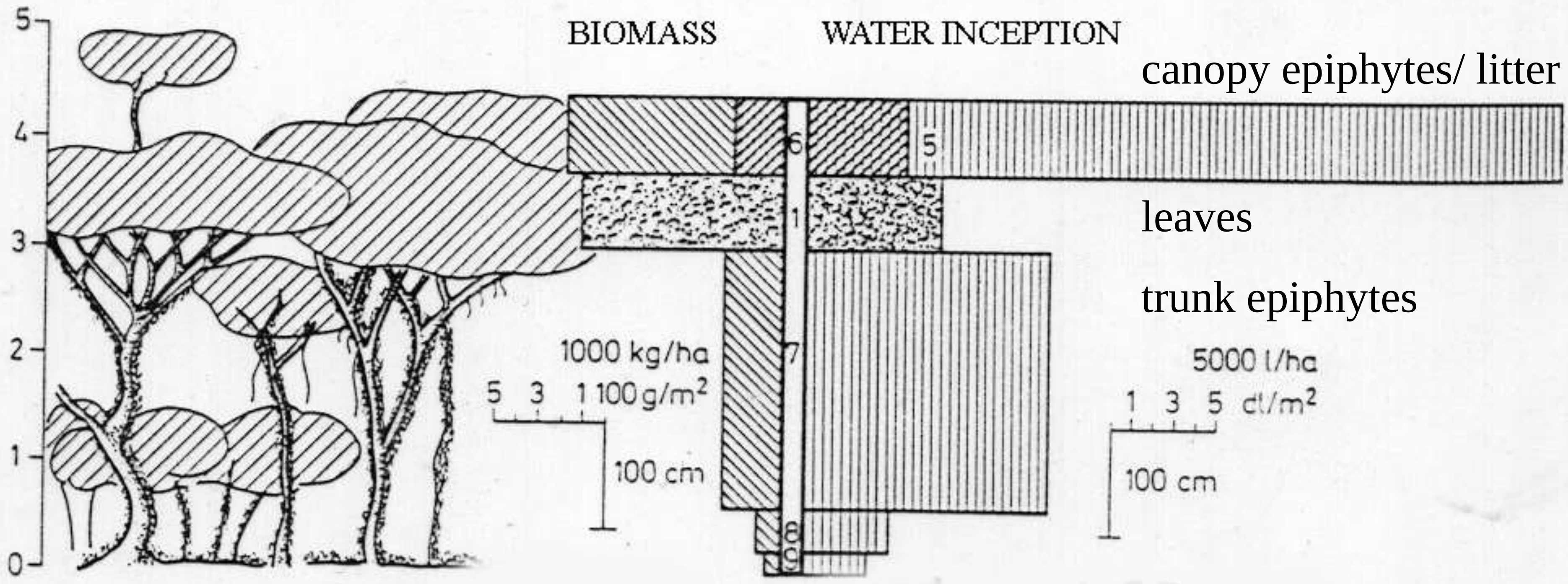


Fig. 16.5. The biomass and water interception of epiphytes and phorophyte leaves in a mossy elfin forest in Tanzania, Uluguru Mts. at 2140 m alt. (after Pócs, 1980). On the left side the dry weight of different layers in 1000 kg ha^{-1}. On the right side the water interception capacity in l ha^{-1} according to the different layers, as: *1*, Leaves of phorophyte trees forming the canopy; *5*, humus and detritus among the canopy epiphytes (the darker part); *6*, canopy microepiphytes including small orchids; *7*, microepiphytes (bryophytes and filmy ferns) on the trunk; *8*, microepiphytes (bryophytes) on the roots; *9*, bryophyte cover on the ground.

Bryophytes along tropical altitudinal gradient

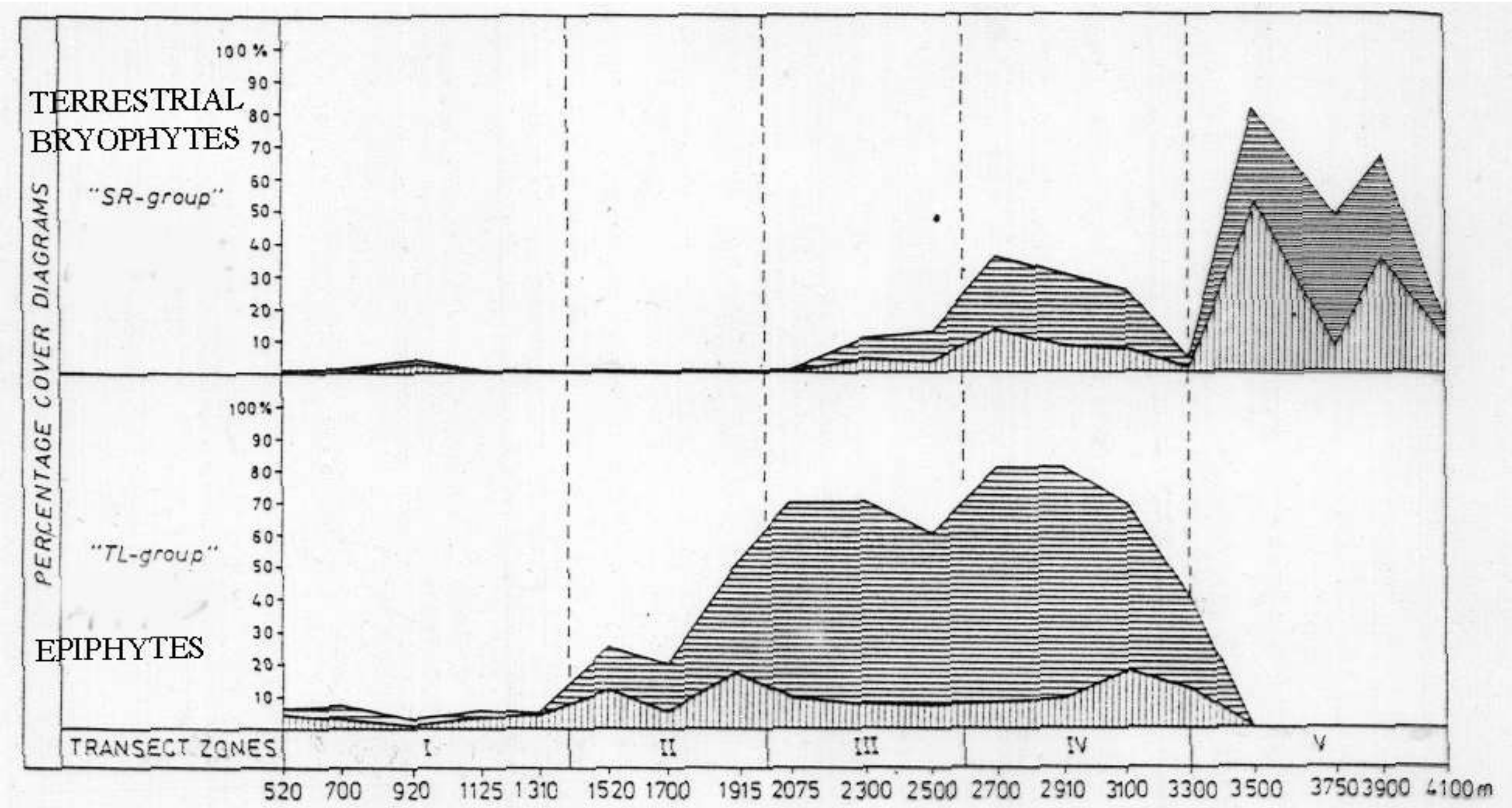
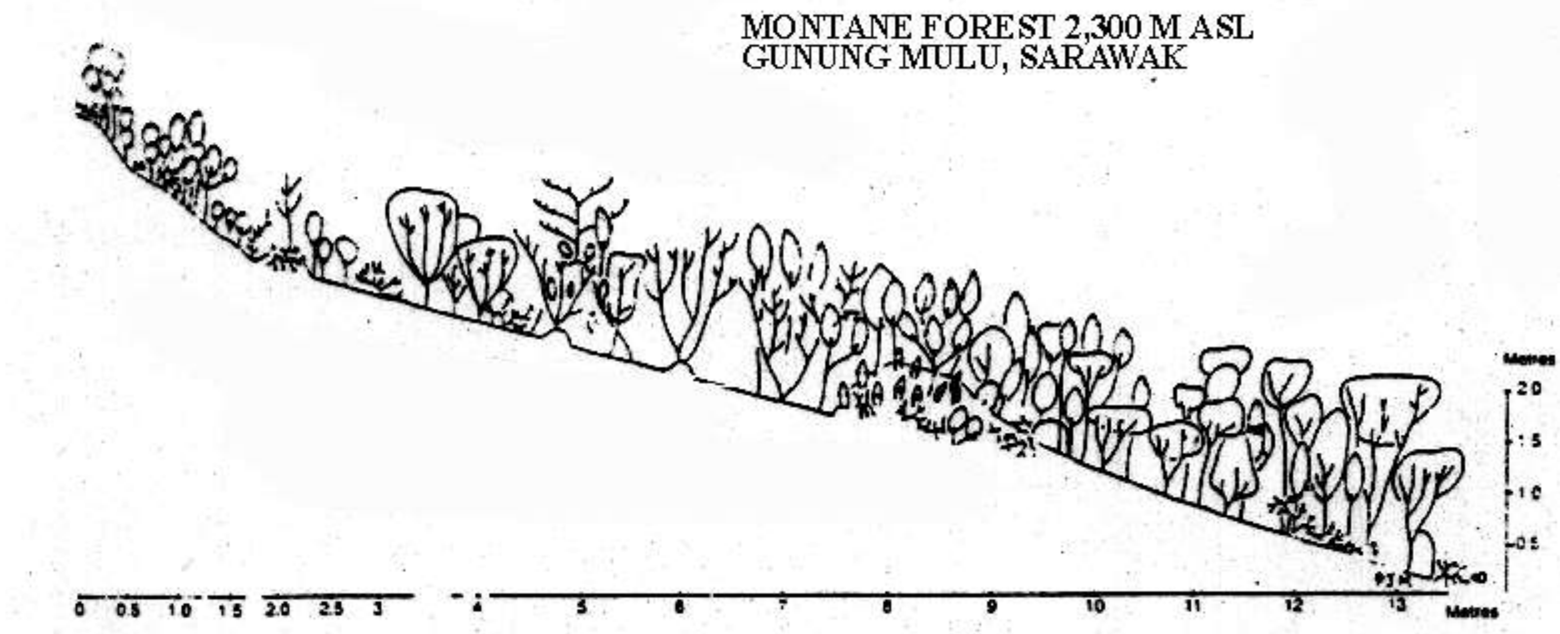
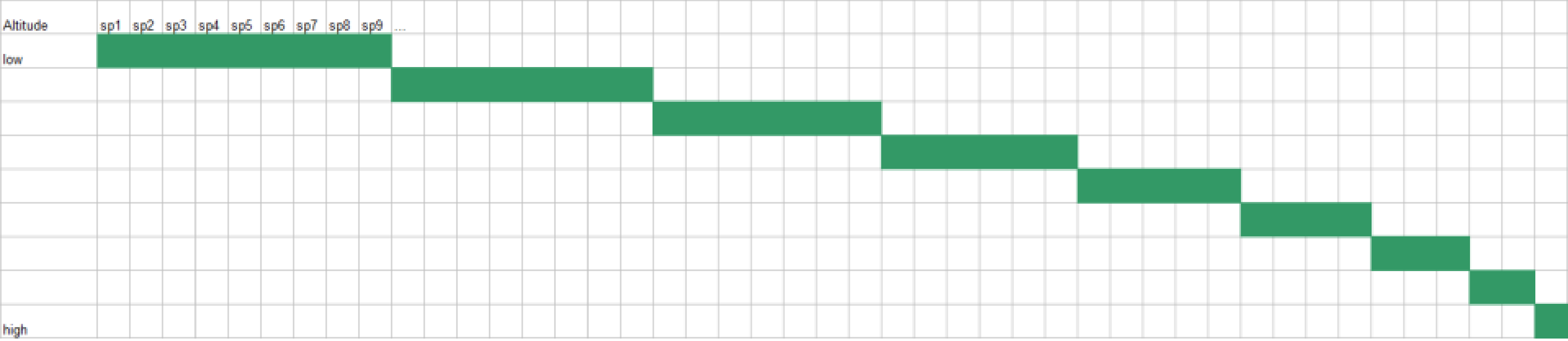
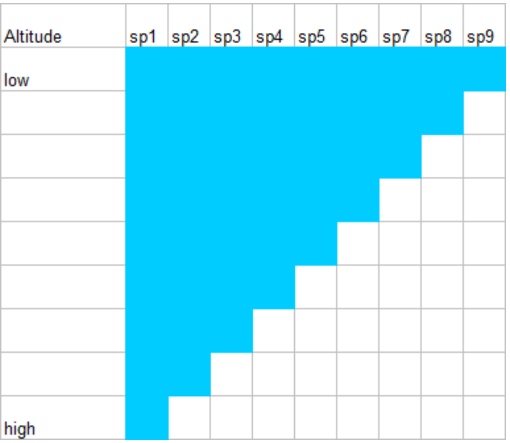


Fig. 16.4. Bryophyte cover values in relation to altitude in the Sierra Nevada de Santa Marta, Colombia (after Van Reenen and Gradstein, 1983). Zone I: lowland rain forest; zone II: submontane rain forest; zone III: lower montane rain forest; zone IV: upper montane rain forest (condensation zone); zone V: paramo. TL group: epiphytes; SR group: terrestric and saxicolous species. Vertical lines: mosses; horizontal lines: liverworts.

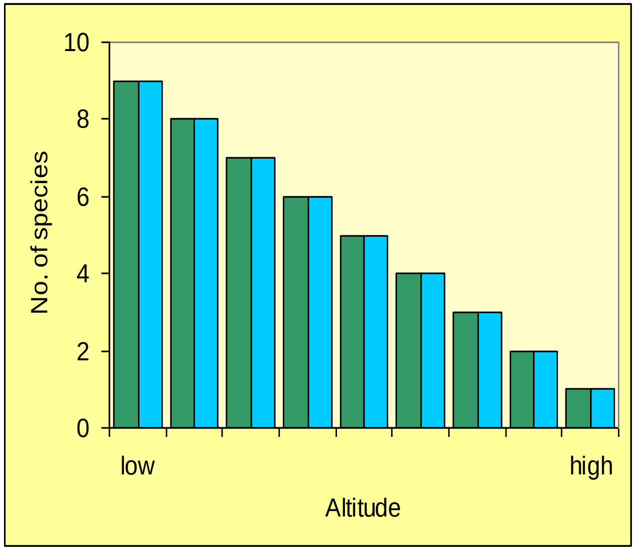

MONTANE FOREST 2,300 M ASL
GUNUNG MULU, SARAWAK
Metres
2.0
1.5
1.0
0.5
0 0.5 1.0 1.5 2.0 2.5 3 4 5 6 7 8 9 10 11 12 13
Metres

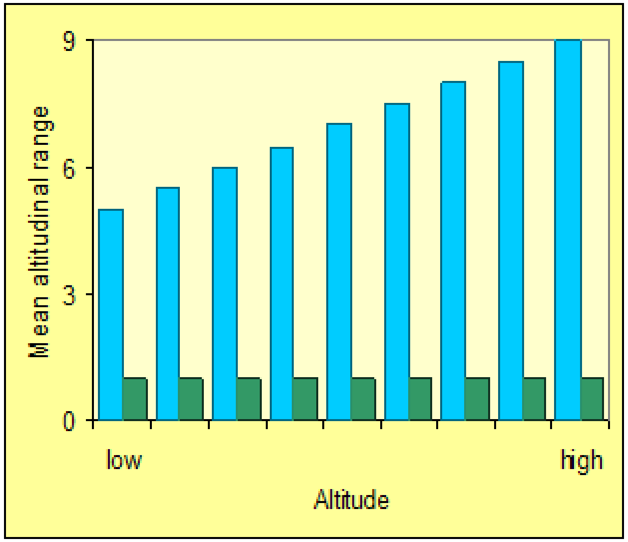


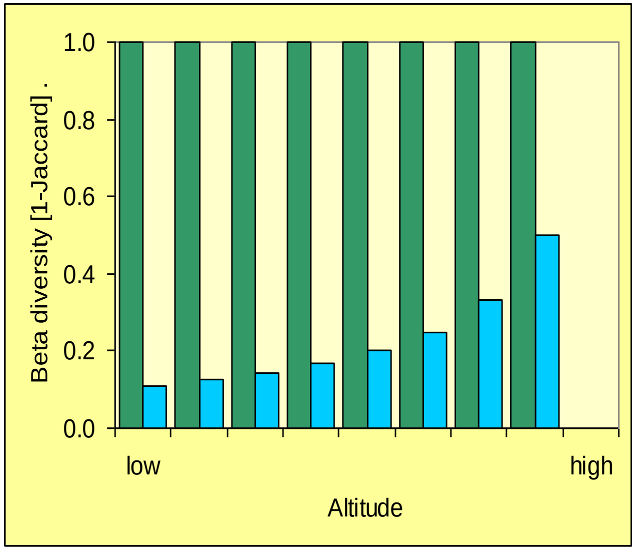


Two modes of altitudinal species turnover: with complete nestedness and zero nestedness

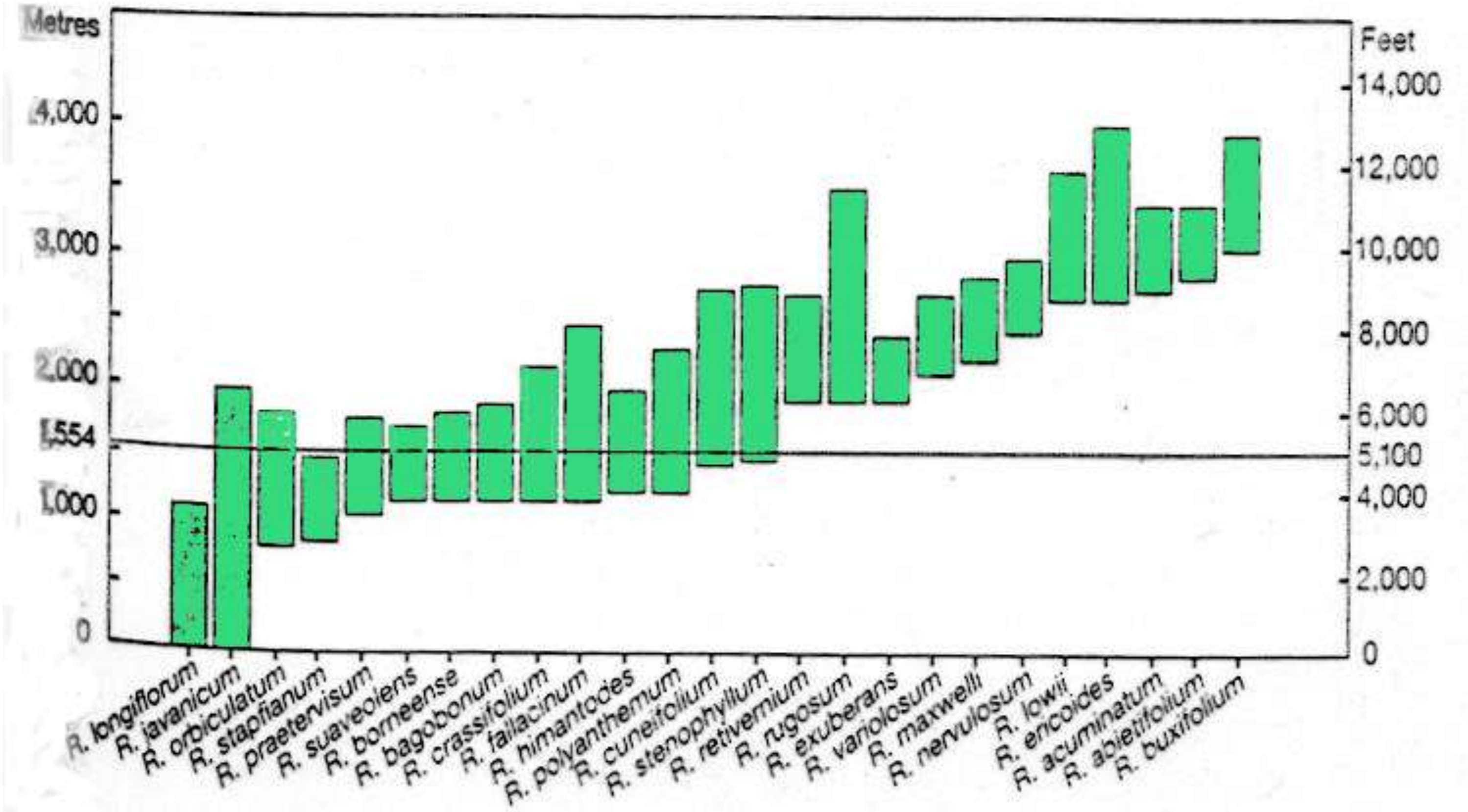
Identical altitudinal trends in species richness mean different trends in mean altitudinal range of species and beta diversity between adjacent altitudes







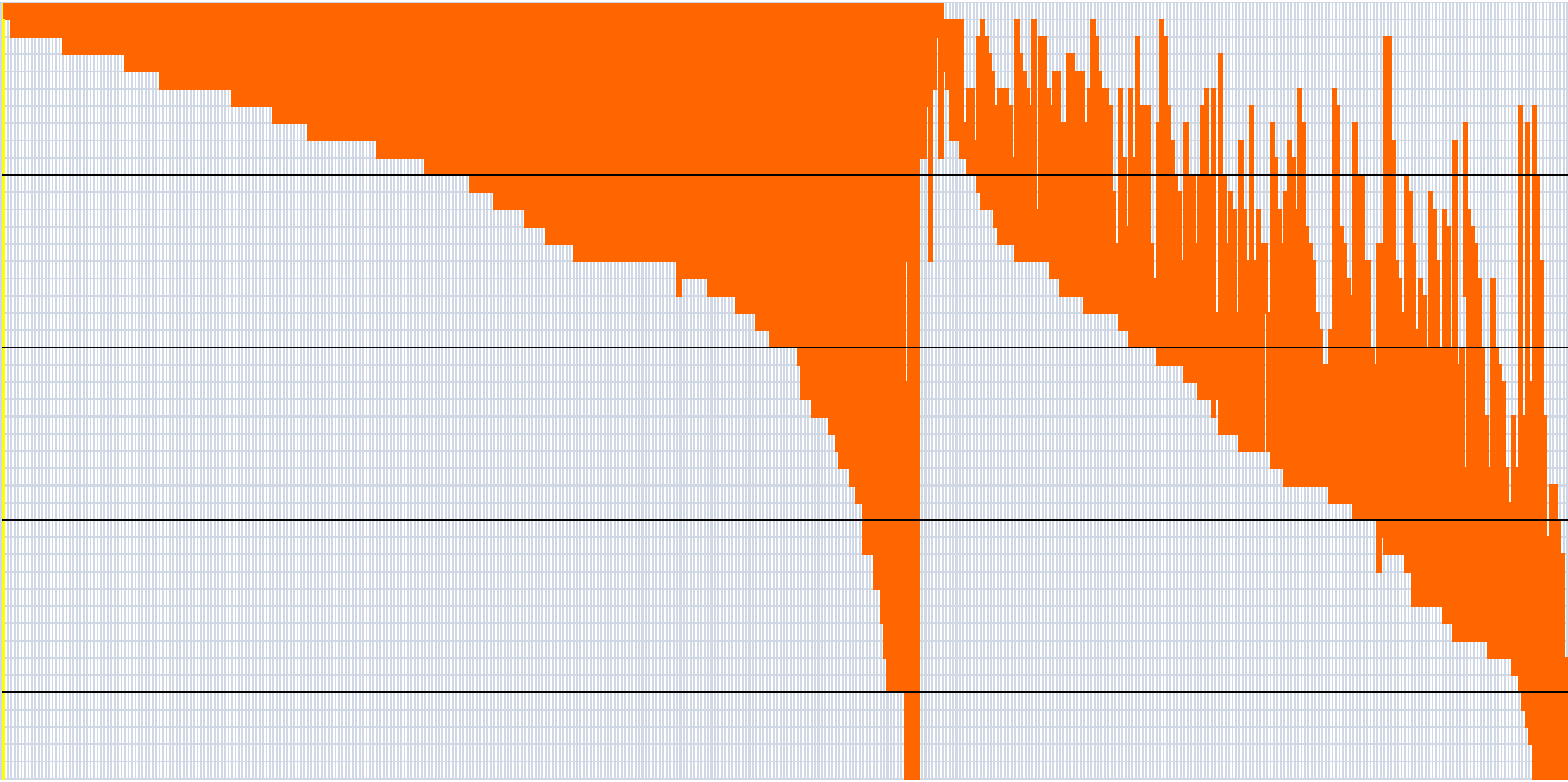
Species turnover along altitudinal gradients:
Rhododendron spp. on Mt. Kinabalu



Rhododendrones: 900 spp. worldwide, 300 spp. in SE Asia, 50 spp. in Borneo, 25 spp. on Mt. Kinabalu, incl. 5 endemic spp.

Altitudinal distribution of 454 bird species in Papua New Guinea

0 m asl.



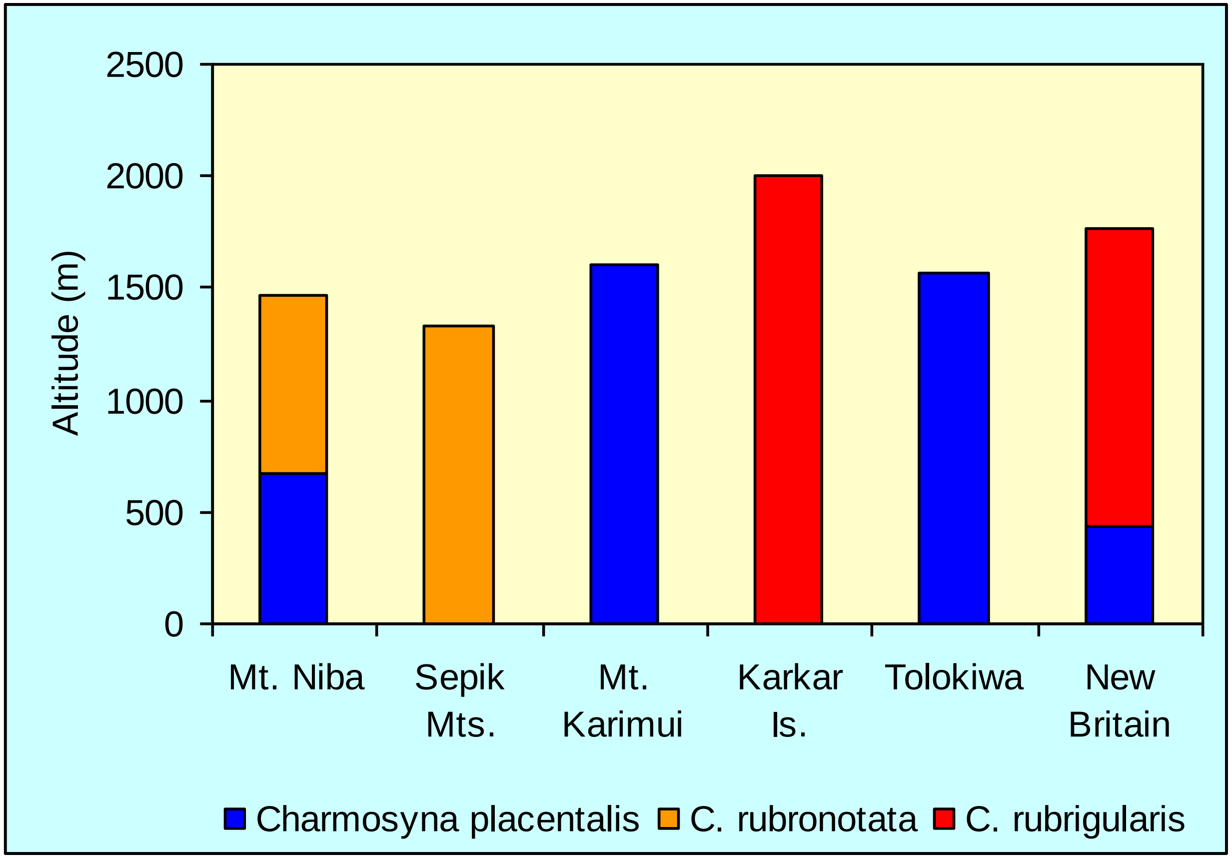
4500 m asl.

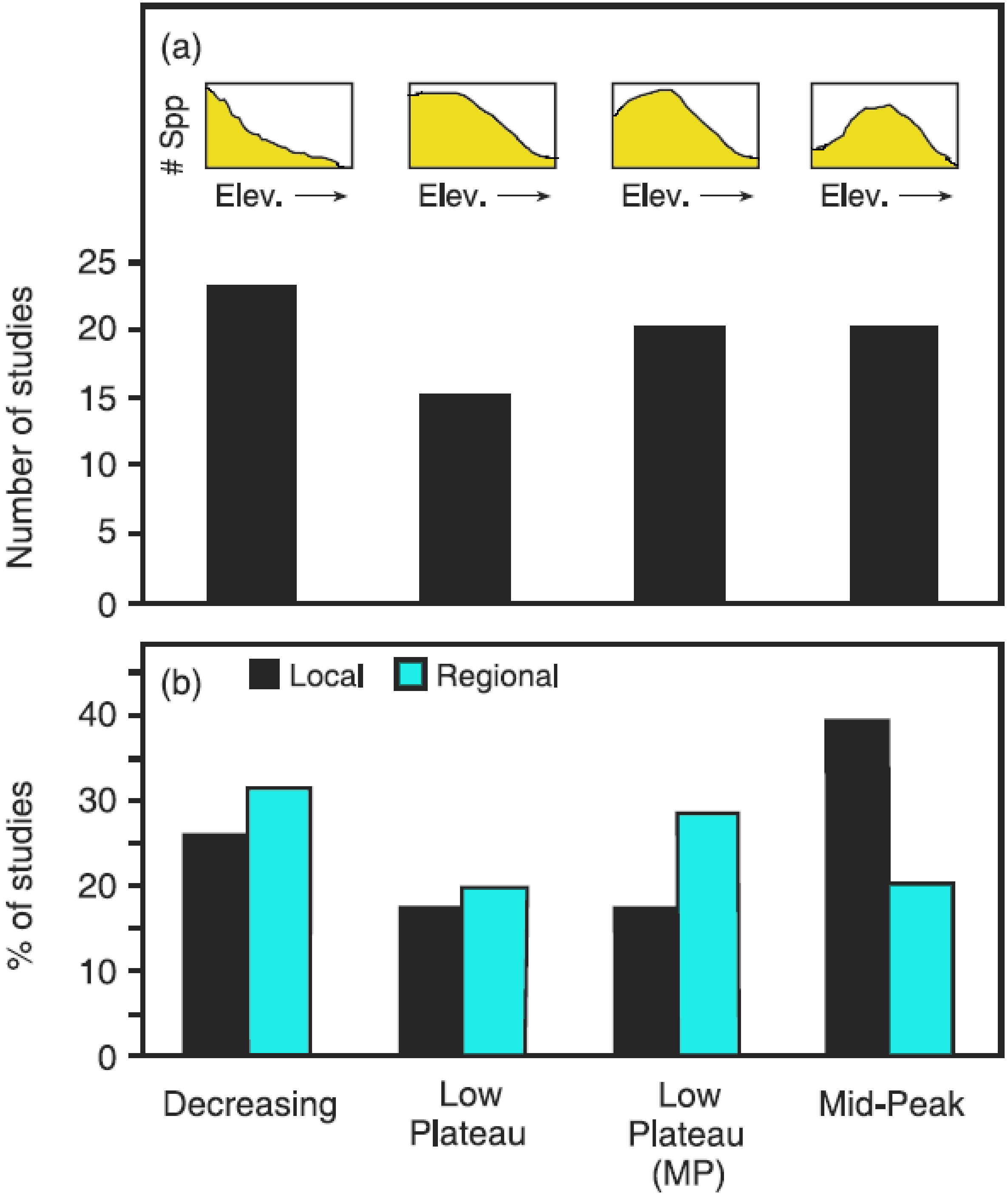
each row is 100 m elevation belt, each column a bird species

K. Tvardikova, unpubl. data

Checkerboard distribution along an altitudinal gradient

Altitudinal segregation of competing parrots in New Guinea:





Global elevation patterns of bird diversity

decreasing diversity

low-elevation plateaus

low-elevation plateaus with mid-peaks

unimodal midelevational peaks

McCain, Global Ecology and Biogeography, (2009) 18, 346–360

Species richness along altitudinal gradients:

• monotonous decrease from the lowland maximum

OR

• peak at mid-elevations?

Factors causing decreasing species richness with altitude:

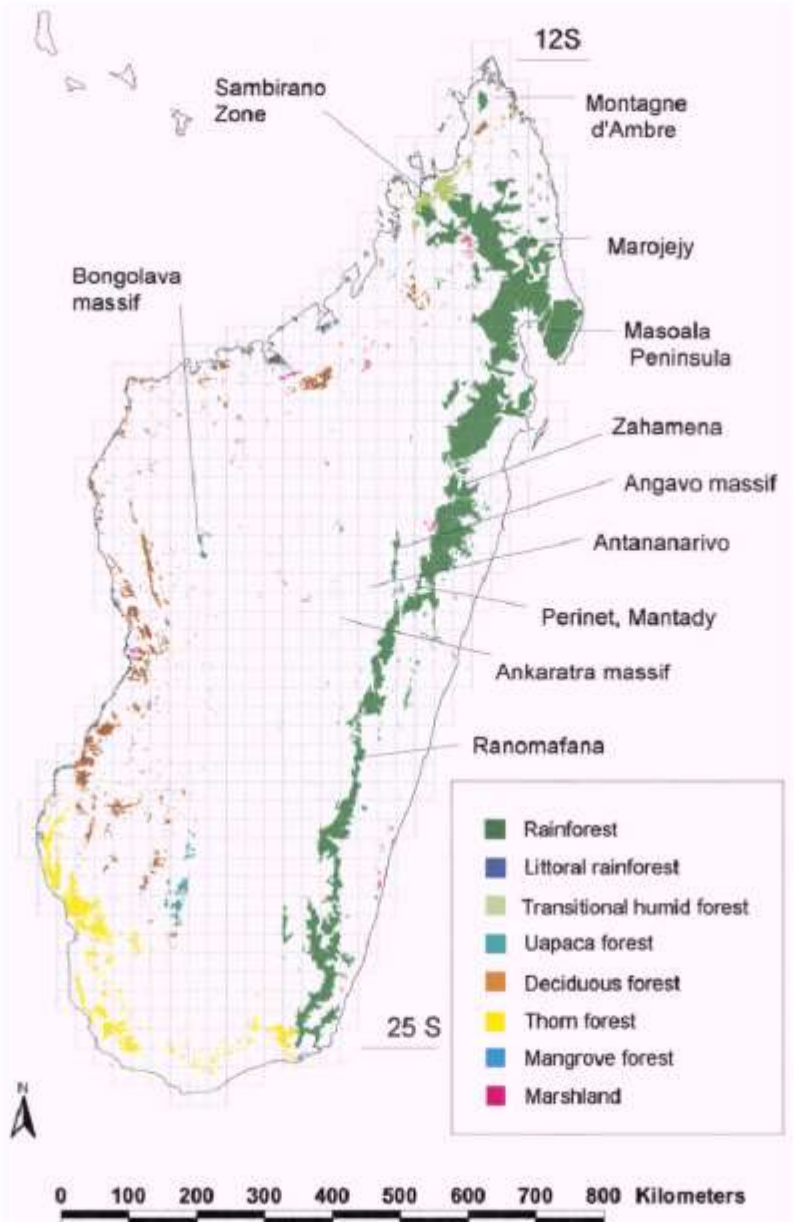
- harsh environmental conditions (temperature)
- diminishing habitat area with altitude

Mid-elevation peak:

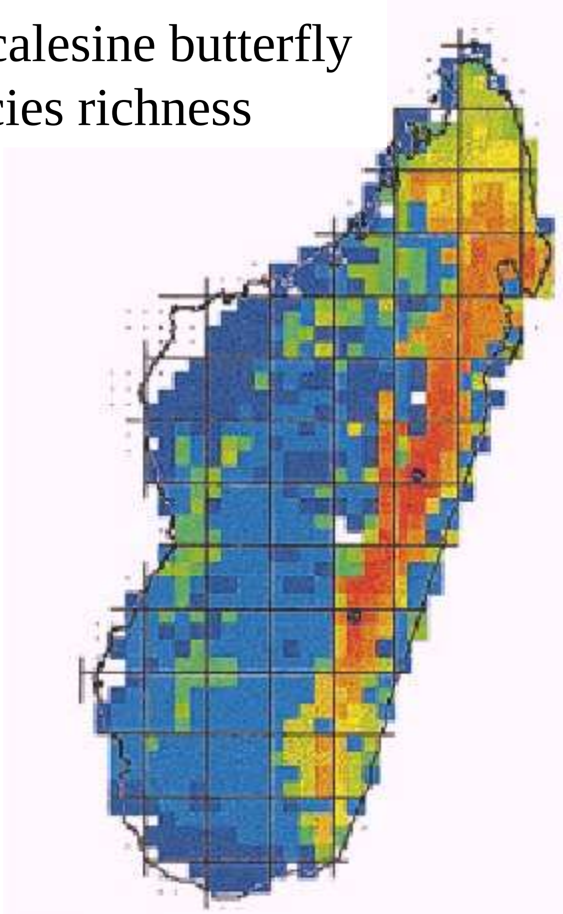
- possibly as a result of geometric constraints:

both lowland and high-montane species can overlap to the mid-elevation

Geometric constraints: Madagascar study of mycalesine butterflies

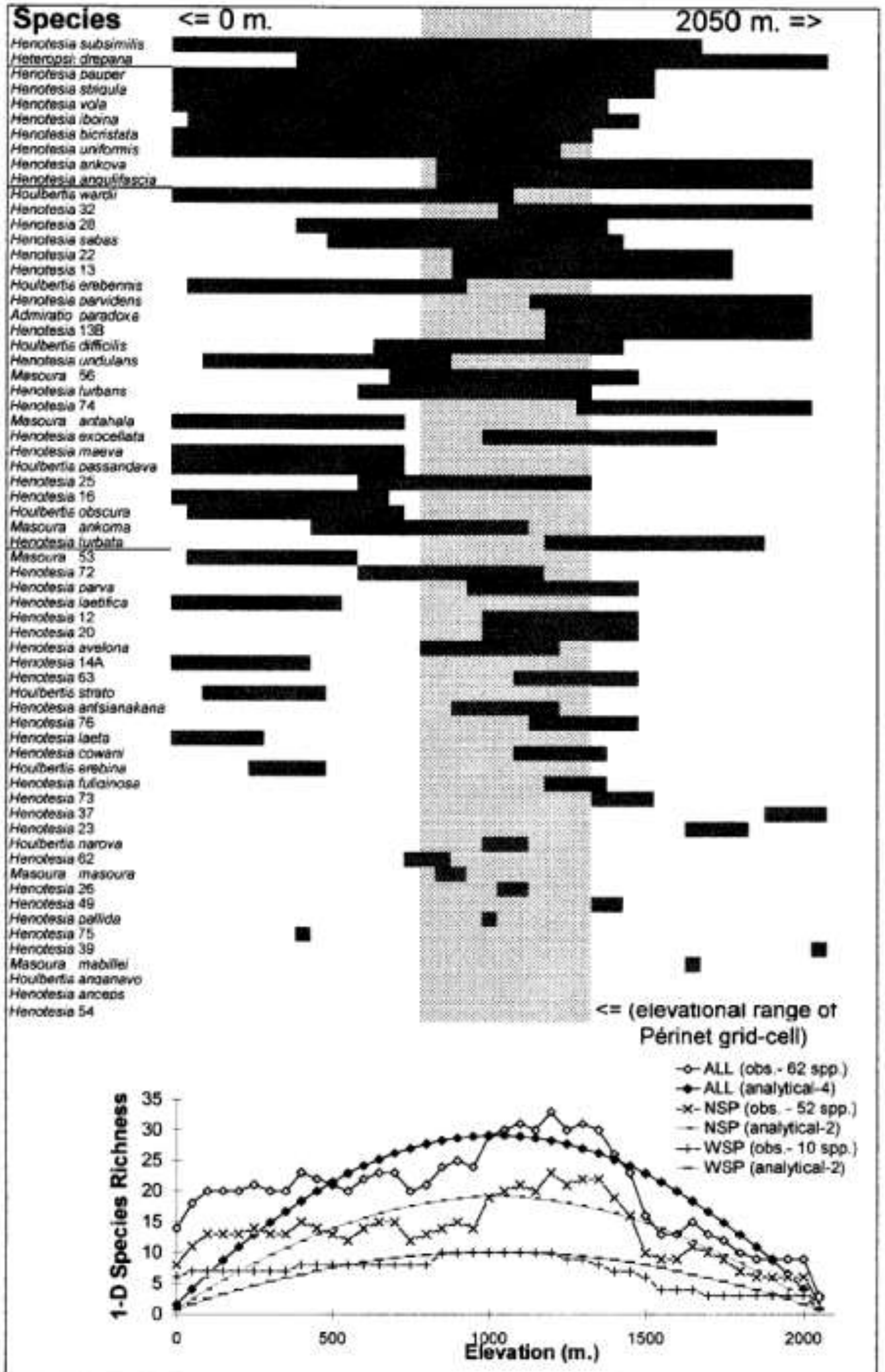


Mycalesine butterfly species richness

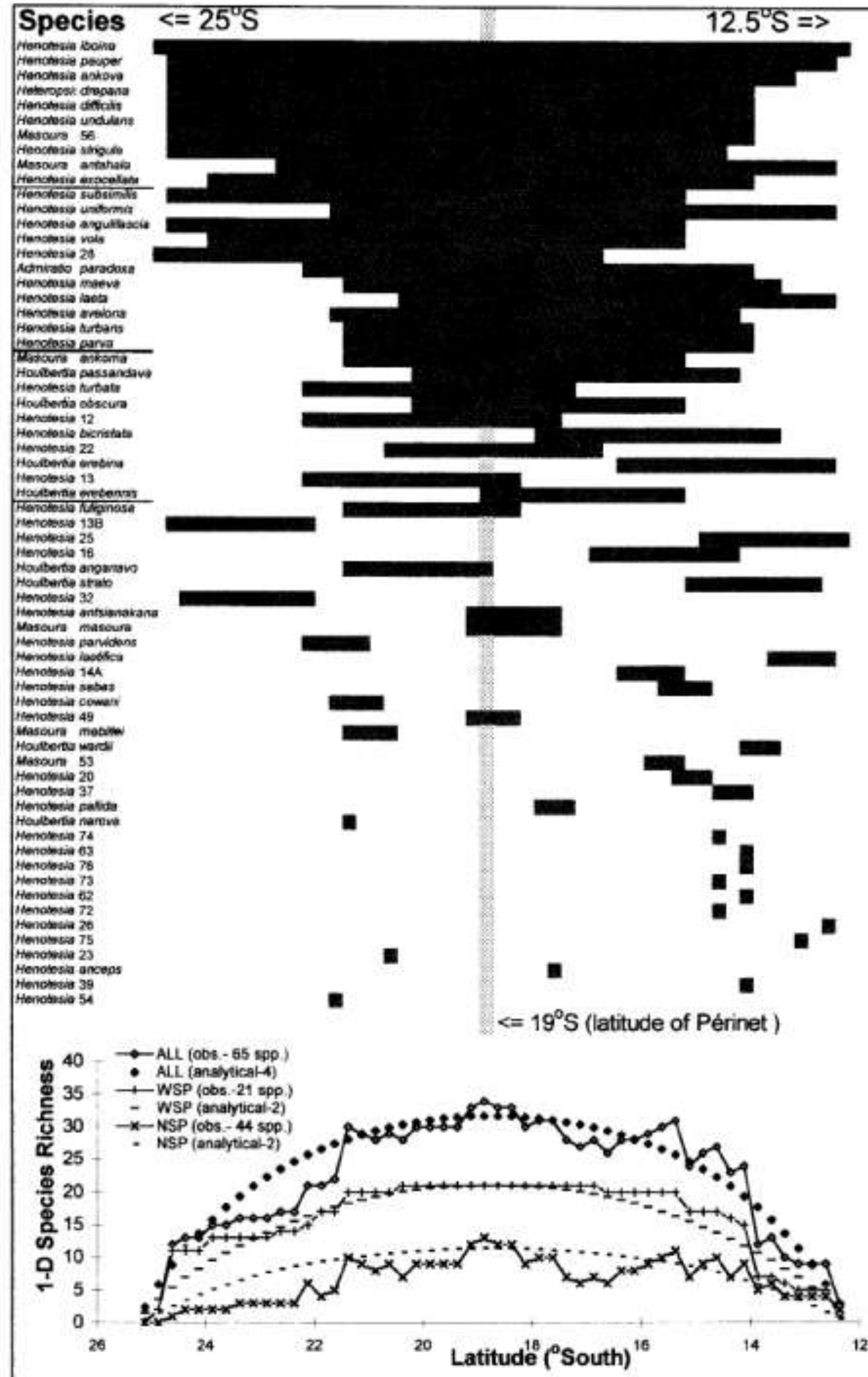


Henotesia fraterna

Lees et al. 1999. Biol. J. Linn. Soc. 67:529

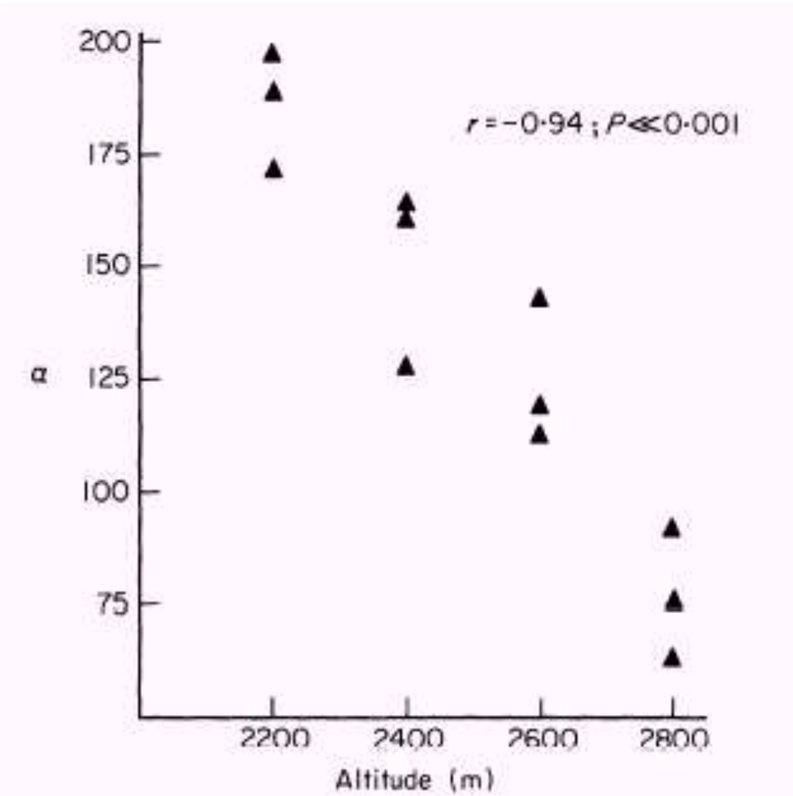


Species
<= 0 m.
2050 m. =>
Henotesia subsimilis
Heteropsis drepana
Henotesia pauper
Henotesia strigula
Henotesia vola
Henotesia iboina
Henotesia bicristata
Henotesia uniformis
Henotesia ankova
Henotesia angulifascia
Houlbertia wardii
Henotesia 32
Henotesia 28
Henotesia sabas
Henotesia 22
Henotesia 13
Houlbertia erebennis
Henotesia parvidens
Admiratio paradoxa
Henotesia 13B
Houlbertia difficilis
Henotesia undulans
Masoura 56
Henotesia turbans
Henotesia 74
Masoura antahala
Henotesia exocellata
Henotesia maeva
Houlbertia passandava
Henotesia 25
Henotesia 16
Houlbertia obscura
Masoura ankoma
Henotesia turbata
Masoura 53
Henotesia 72
Henotesia parva
Henotesia laetifica
Henotesia 12
Henotesia 20
Henotesia avelona
Henotesia 14A
Henotesia 63
Houlbertia strato
Henotesia antsianakana
Henotesia 76
Henotesia laeta
Henotesia cowani
Houlbertia erebina
Henotesia fuliginosa
Henotesia 73
Henotesia 37
Henotesia 23
Houlbertia narova
Henotesia 62
Masoura masoura
Henotesia 26
Henotesia 49
Henotesia pallida
Henotesia 75
Henotesia 39
Masoura mabillei
Houlbertia anganavo
Henotesia anceps
Henotesia 54
<= (elevational range of Périnet grid-cell)
ALL (obs.- 62 spp.)
ALL (analytical-4)
NSP (obs. - 52 spp.)
NSP (analytical-2)
WSP (obs.- 10 spp.)
WSP (analytical-2)
1-D Species Richness
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
Elevation (m.)



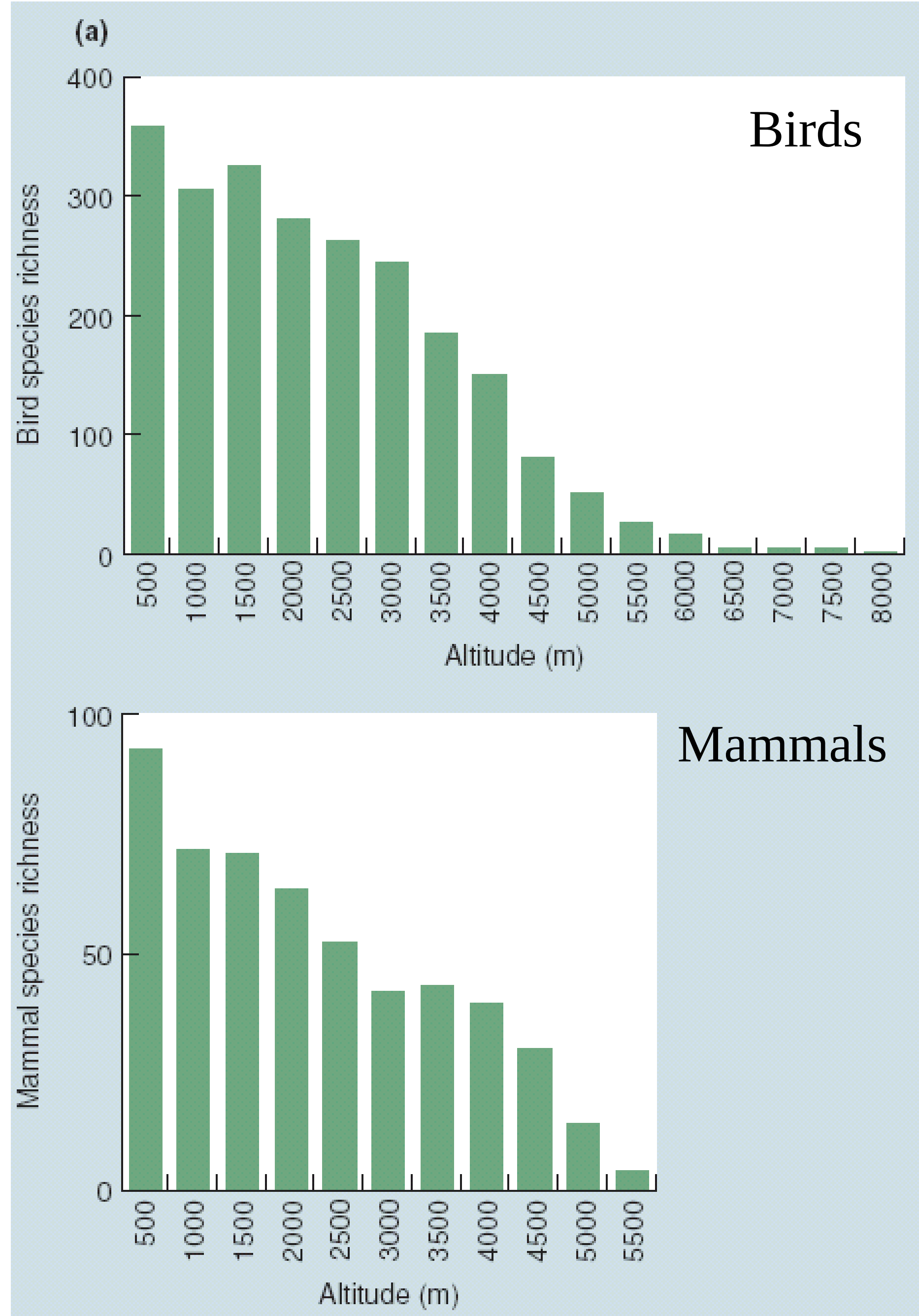
Species
<= 25°S
12.5°S =>
Henotesia iboina
Henotesia pauper
Henotesia ankova
Heteropsis drepana
Henotesia difficilis
Henotesia undulans
Masoura 56
Henotesia strigula
Masoura antahala
Henotesia exocellata
Henotesia subsimilis
Henotesia uniformis
Henotesia angulifascia
Henotesia vola
Henotesia 28
Admiratio paradoxa
Henotesia maeva
Henotesia laeta
Henotesia avelona
Henotesia turbans
Henotesia parva
Masoura ankoma
Houlbertia passandava
Henotesia turbata
Houlbertia obscura
Henotesia 12
Henotesia bicristata
Henotesia 22
Houlbertia erebina
Henotesia 13
Houlbertia erebennis
Henotesia fuliginosa
Henotesia 13B
Henotesia 25
Henotesia 16
Houlbertia anganavo
Houlbertia strato
Henotesia 32
Henotesia antsianakana
Masoura masoura
Henotesia parvidens
Henotesia laetifica
Henotesia 14A
Henotesia sabas
Henotesia cowani
Henotesia 49
Masoura mabillei
Houlbertia wardii
Masoura 53
Henotesia 20
Henotesia 37
Henotesia pallida
Houlbertia narova
Henotesia 74
Henotesia 63
Henotesia 76
Henotesia 73
Henotesia 62
Henotesia 72
Henotesia 26
Henotesia 75
Henotesia 23
Henotesia anceps
Henotesia 39
Henotesia 54
<= 19°S (latitude of Périnet)
ALL (obs.- 65 spp.)
ALL (analytical-4)
WSP (obs.-21 spp.)
WSP (analytical-2)
NSP (obs.- 44 spp.)
NSP (analytical-2)
1-D Species Richness
40
35
30
25
20
15
10
5
0
26
24
22
20
18
16
14
12
Latitude (°South)

Himalayas

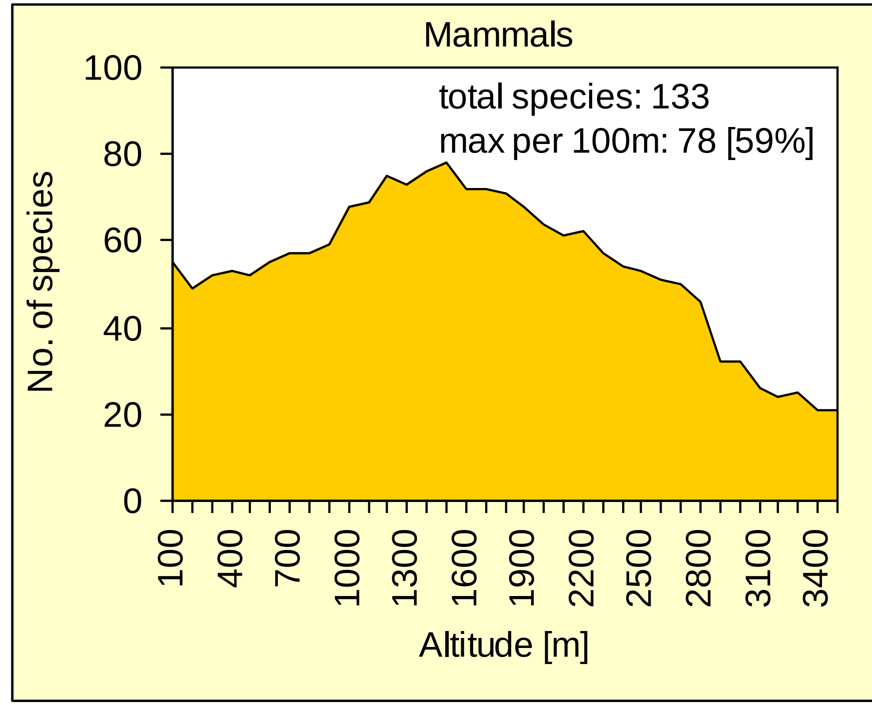


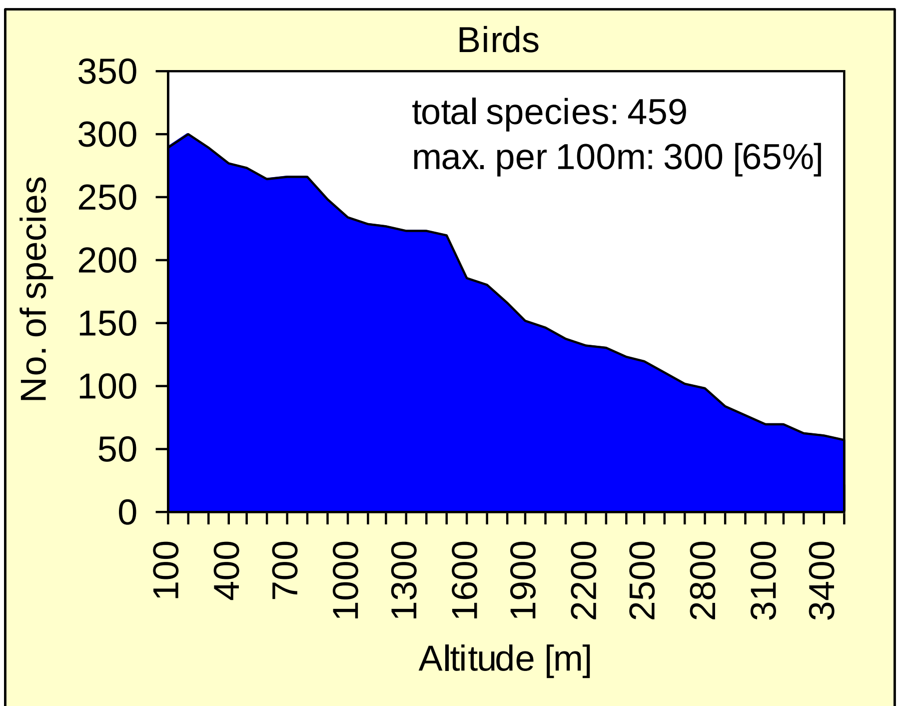
Lepidoptera, Mt Wilhelm, New Guinea

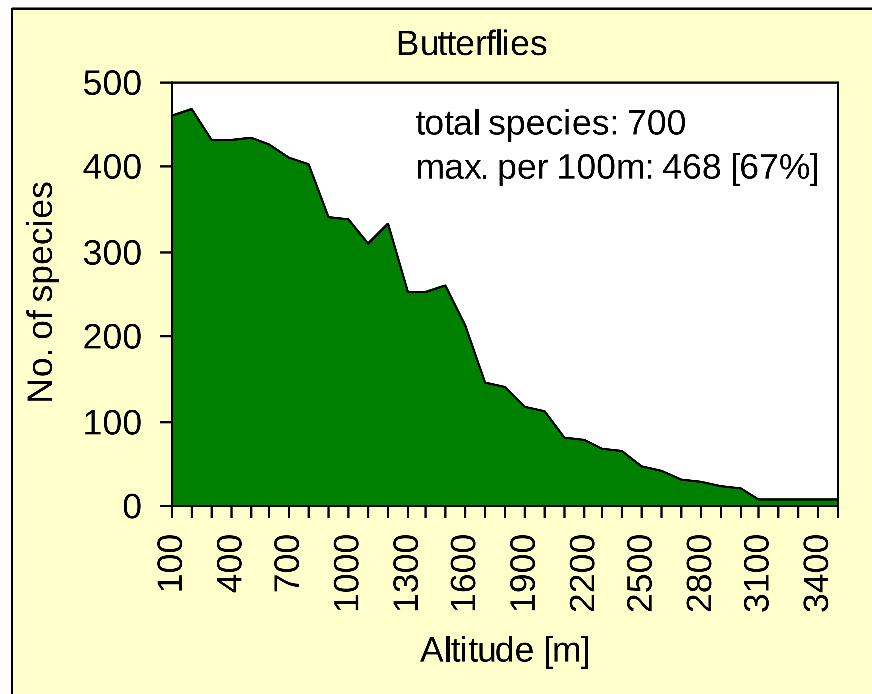
Ants: decreasing abundance and species richness with altitude, practically absent above 1,800 m

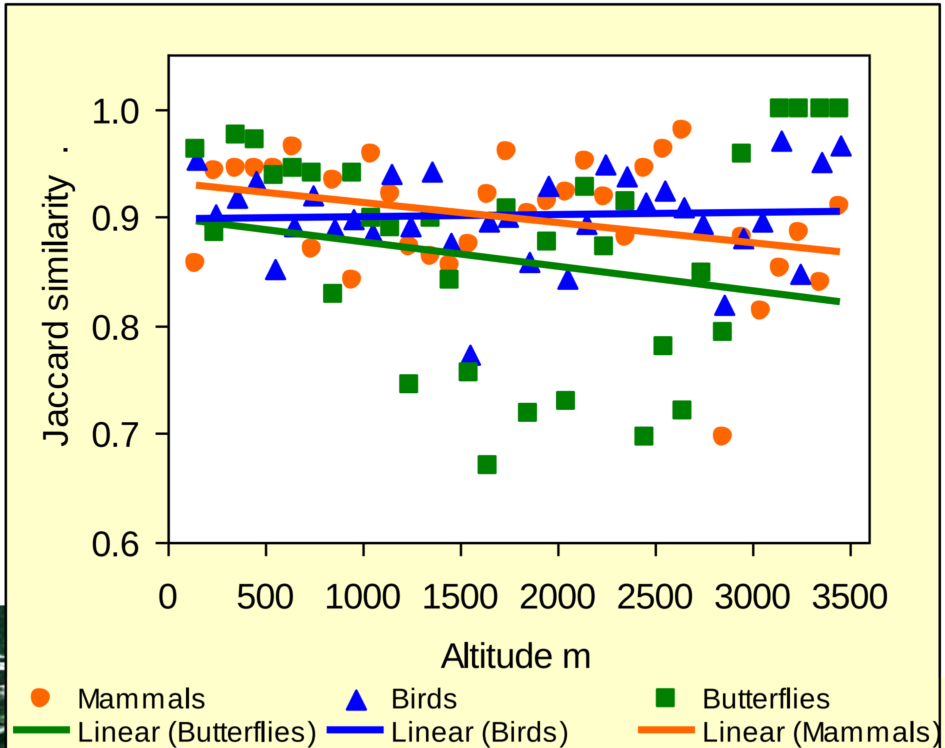


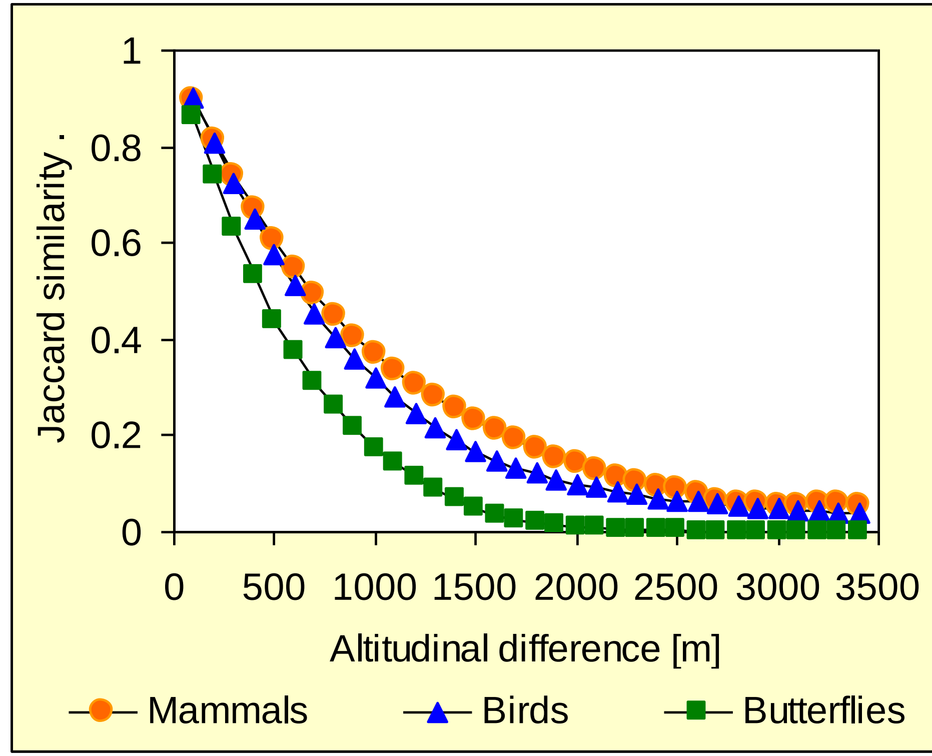
Altitudinal gradients in New Guinea

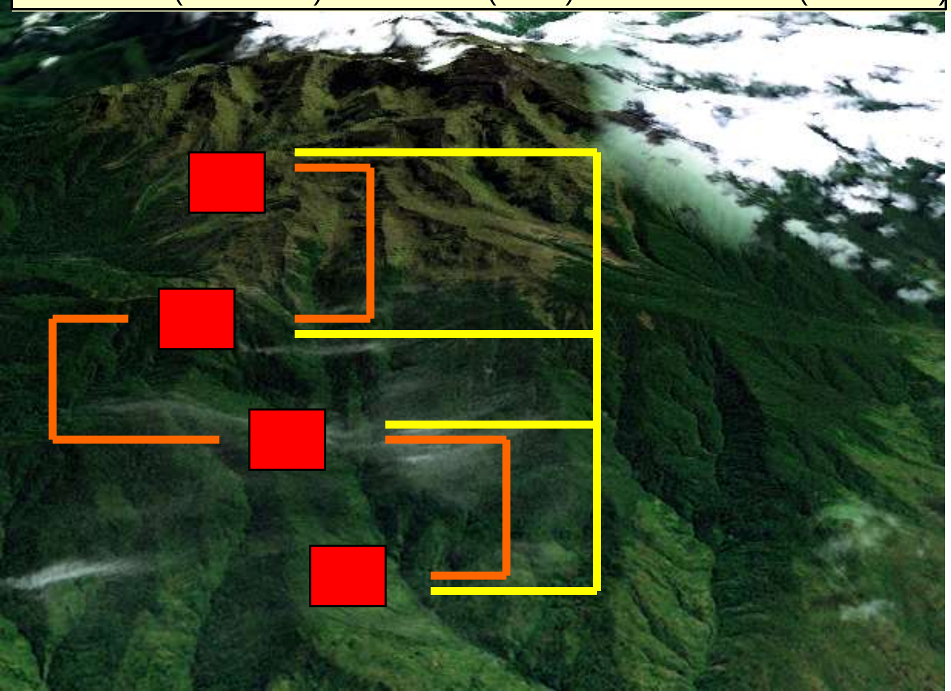












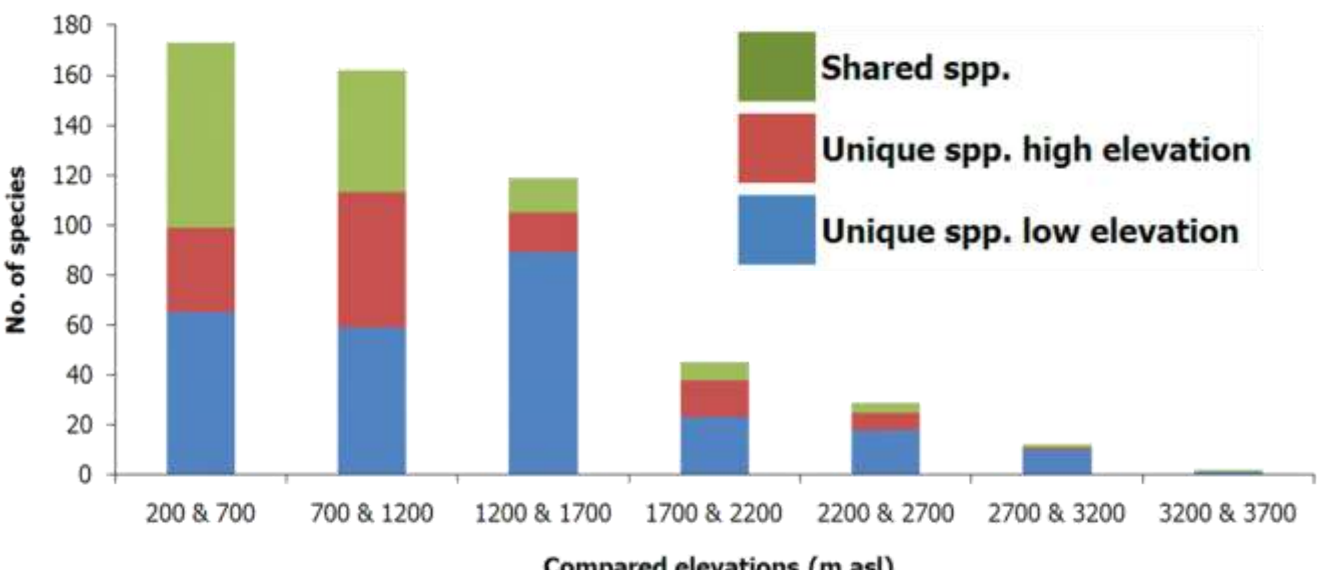
Species turnover:

- between neighbouring 100m altitudinal zones

- with increasing altitudinal distance

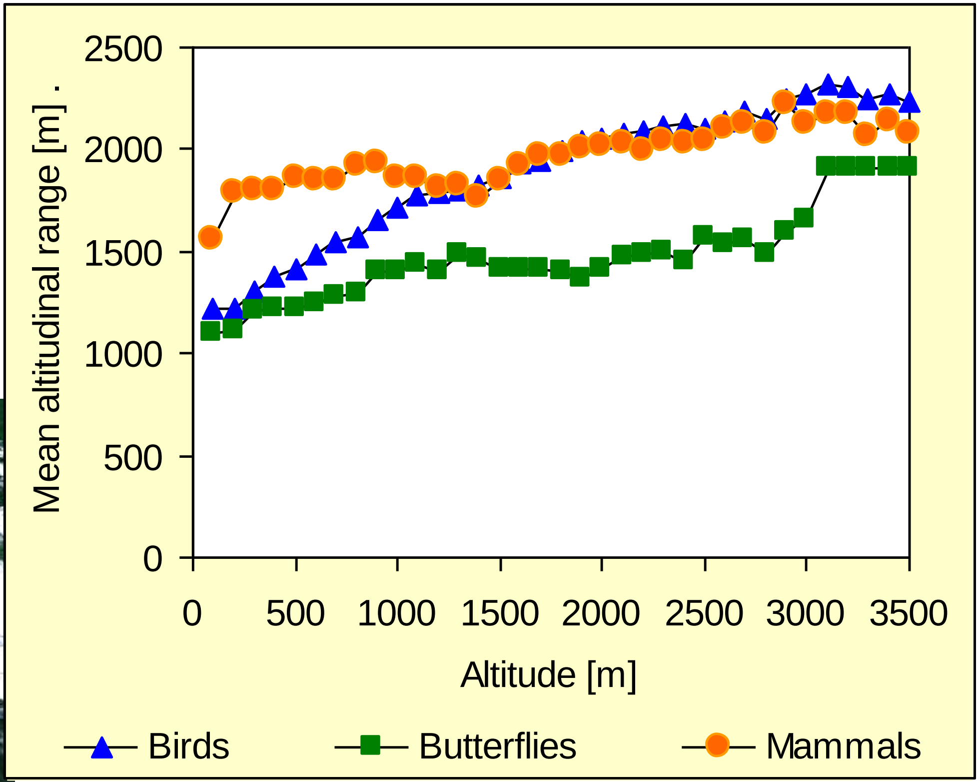
Butterflies along altitudinal transect at Mt Wilhelm:

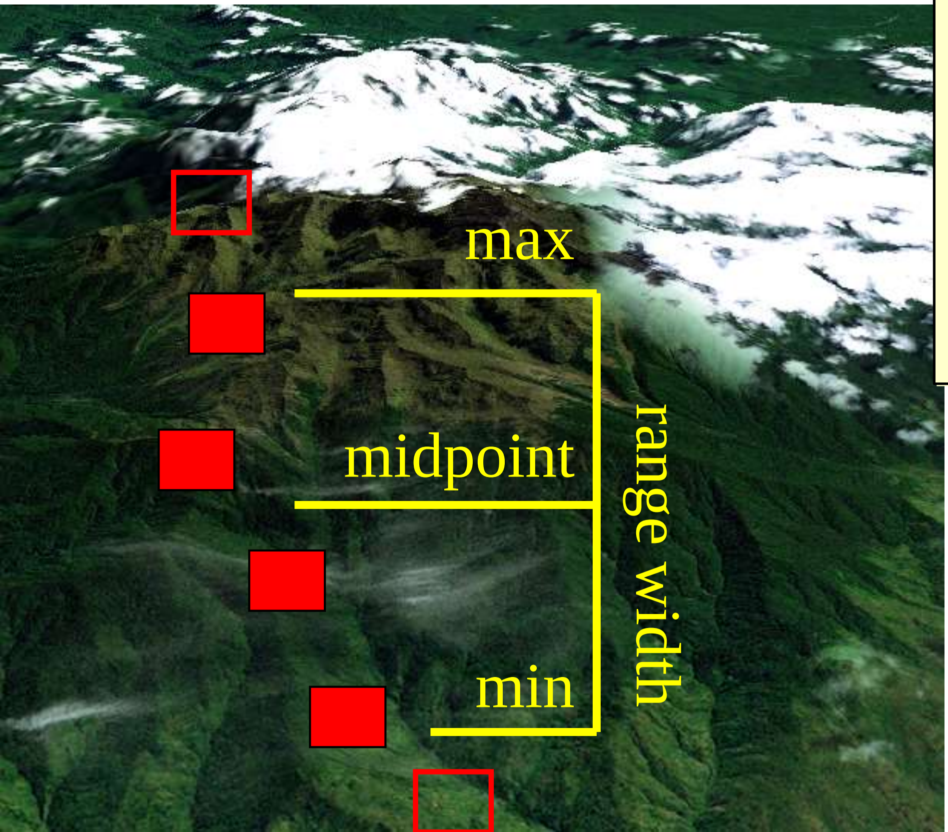
are lowland species just disappearing with altitude, or are only new montane species appearing, or both at the same time?



Legi 2011

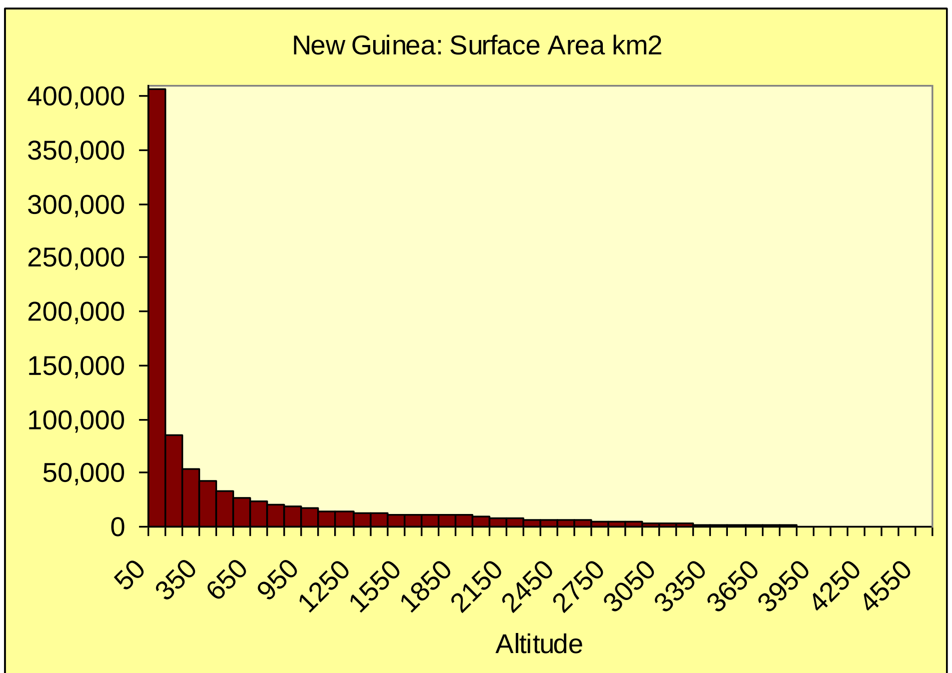
Rapoport's rule:
do montane species have wider altitudinal ranges?

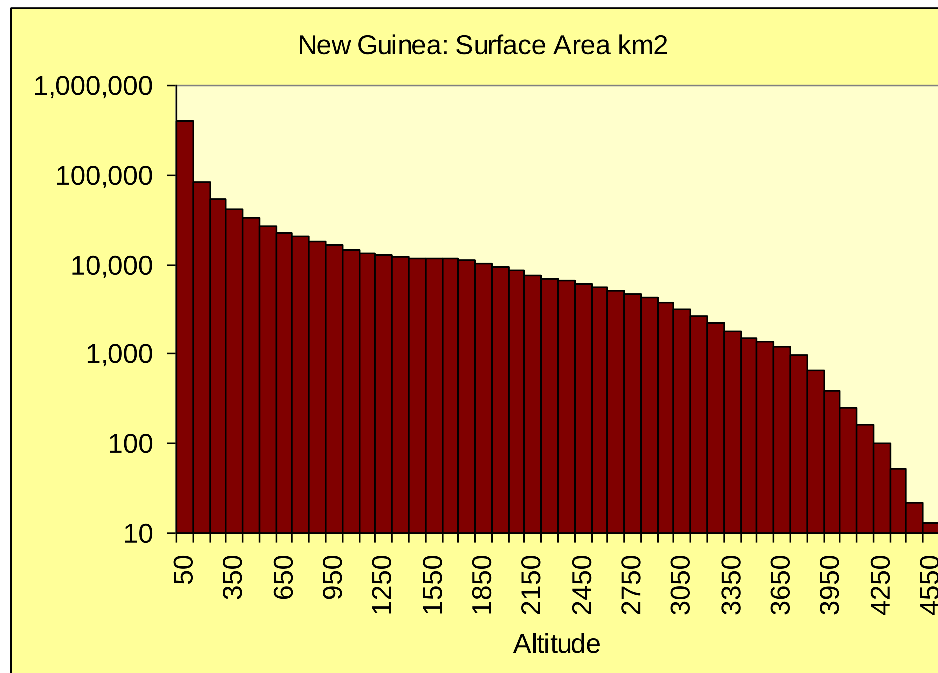


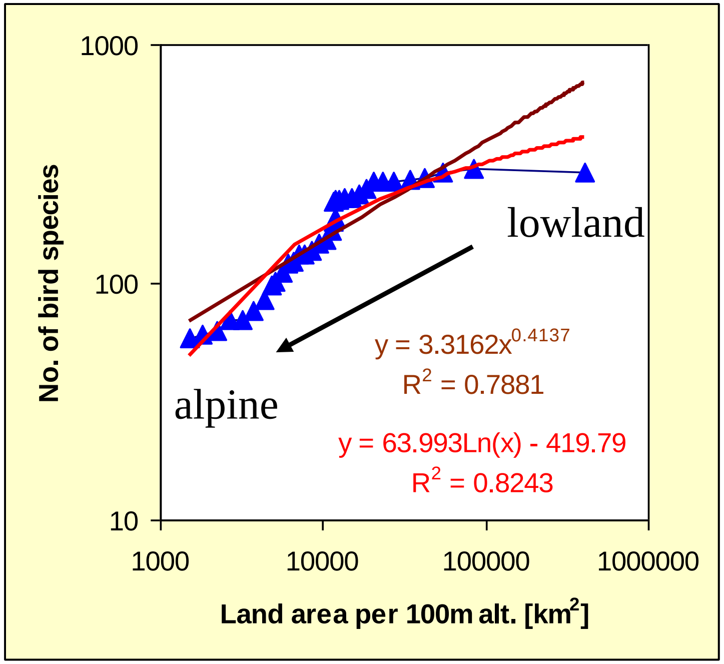


Land area decreases enormously with altitude:

we need to consider species-area effect in all altitudinal patterns

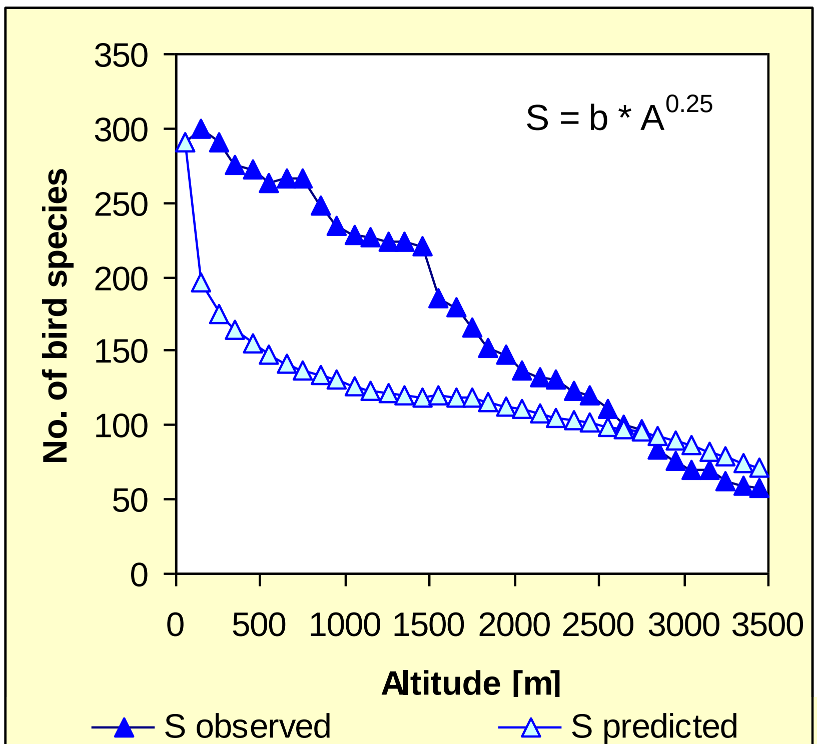


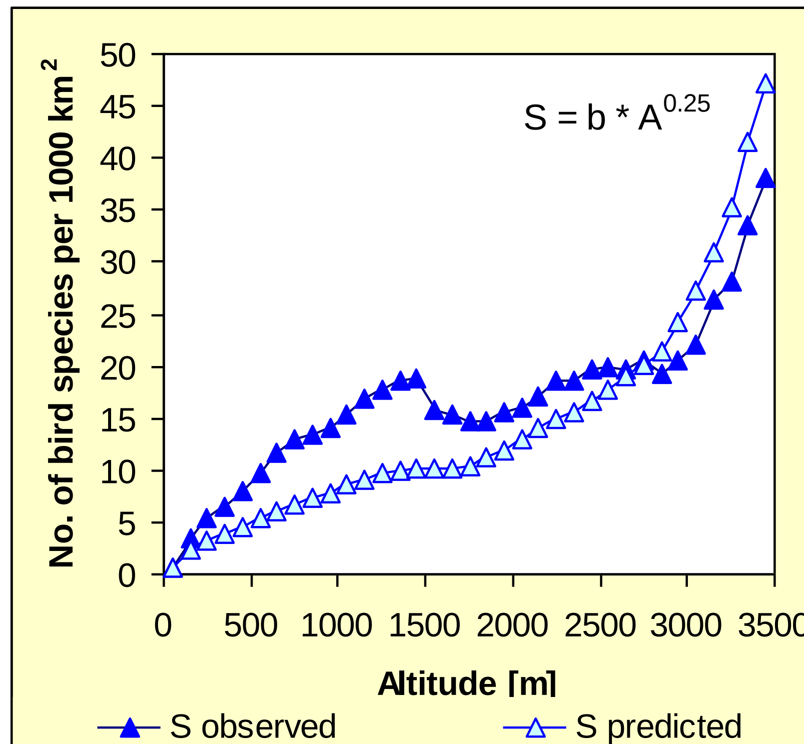


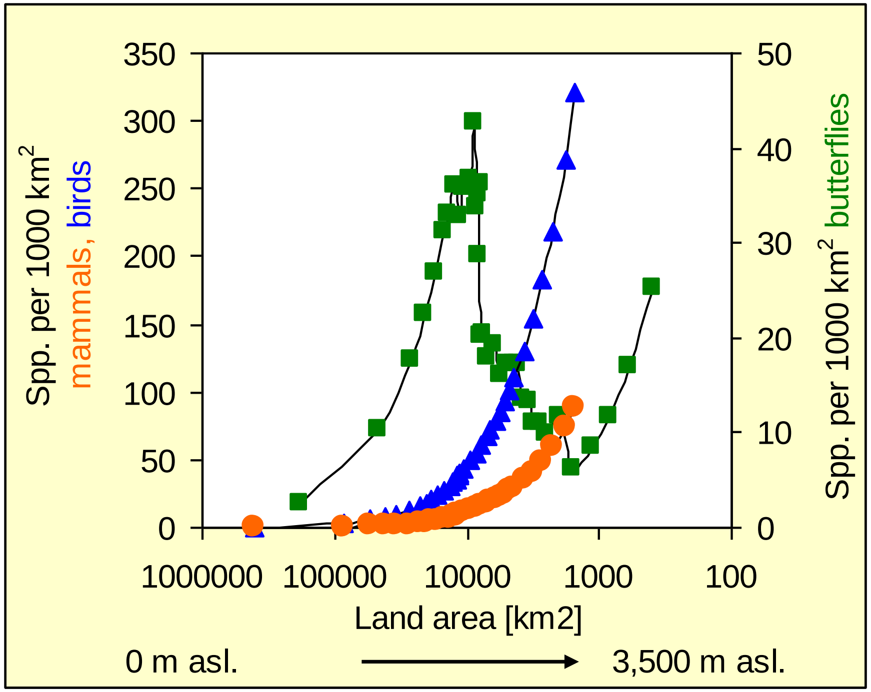


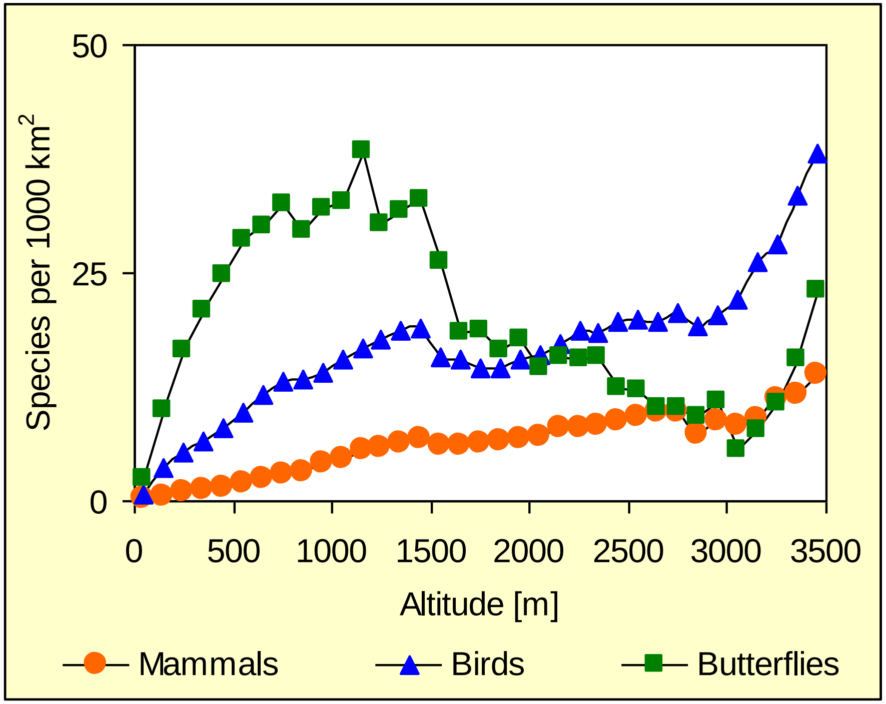
Species-area curves [power and logarithmic] fitted in altitudinal richness gradient: area alone predicts a strong diversity trend

Species-area curve $S=b*A^z$ with z=0.25 and b estimated from lowland data used to predict altitudinal trends in species richness and density in birds







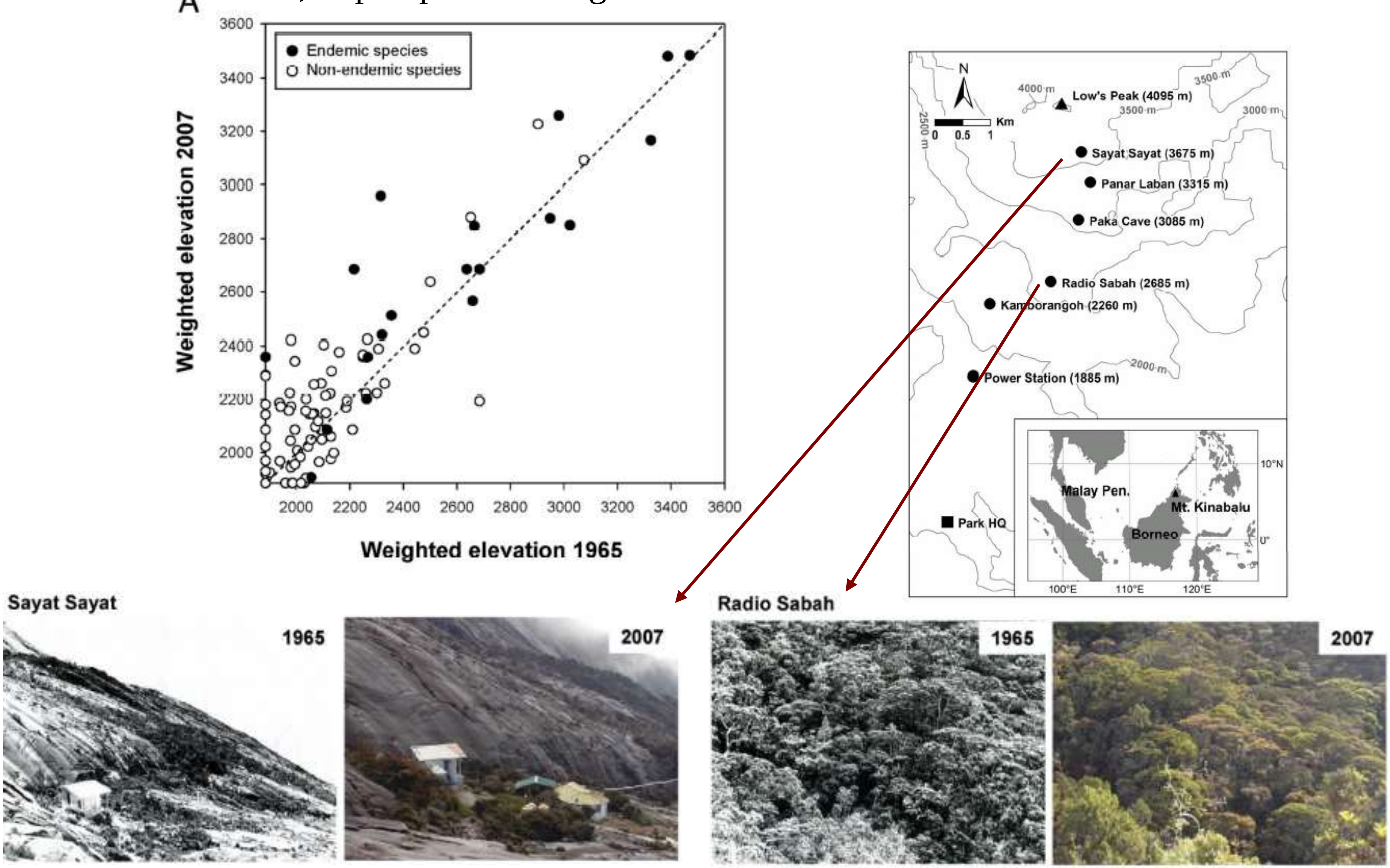


Species density:

typically [but not always] increases with altitude, as expected from a power species area relationship

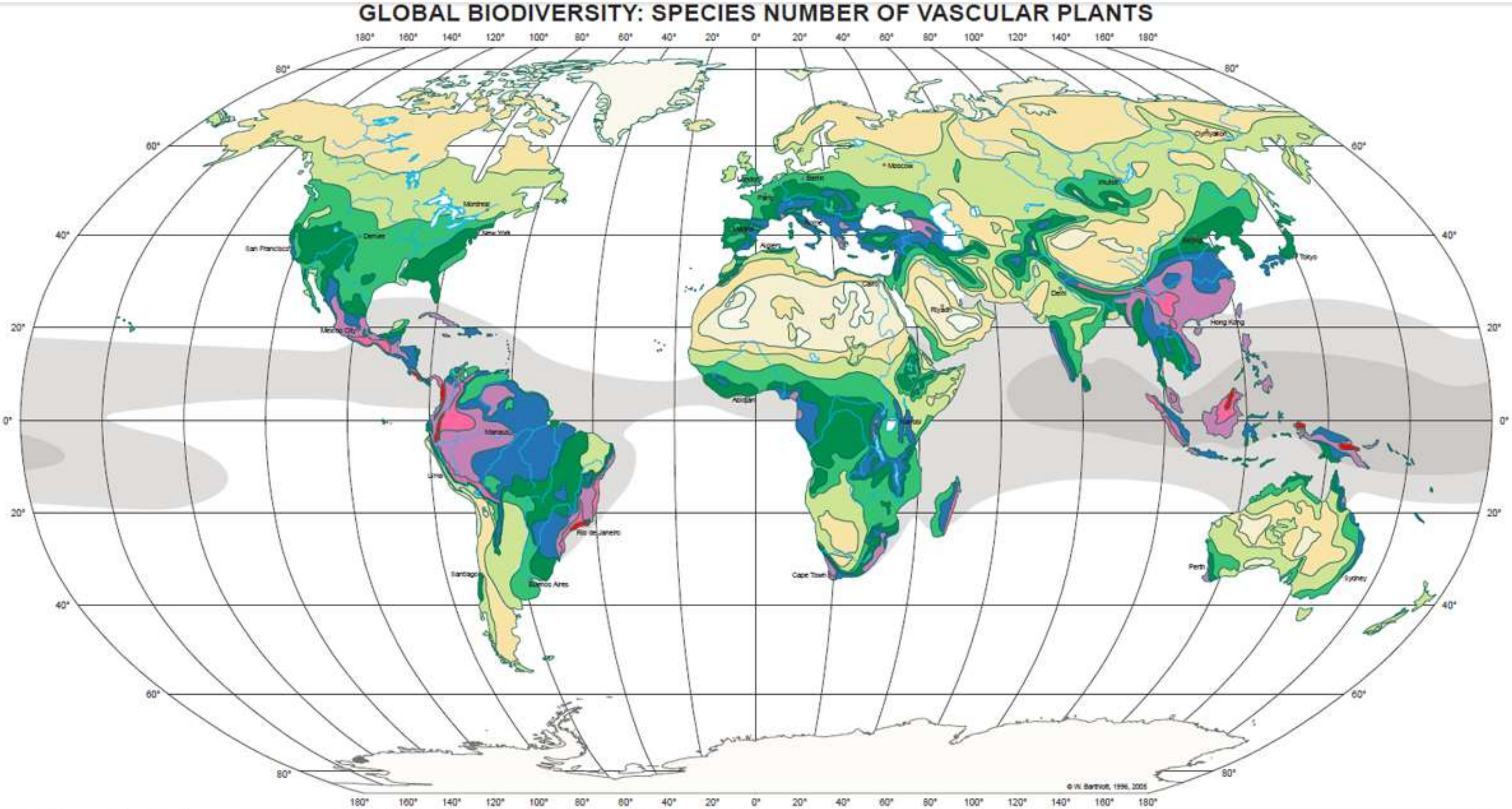
Climate change: species climbing up montane slopes

Mt. Kinabalu, Lepidoptera: average increase in altitude 67 m from 1965 to 2007



Chen et al., PNAS 106:1479, 2009

Altitudinal gradient: the mother of all environmental gradients



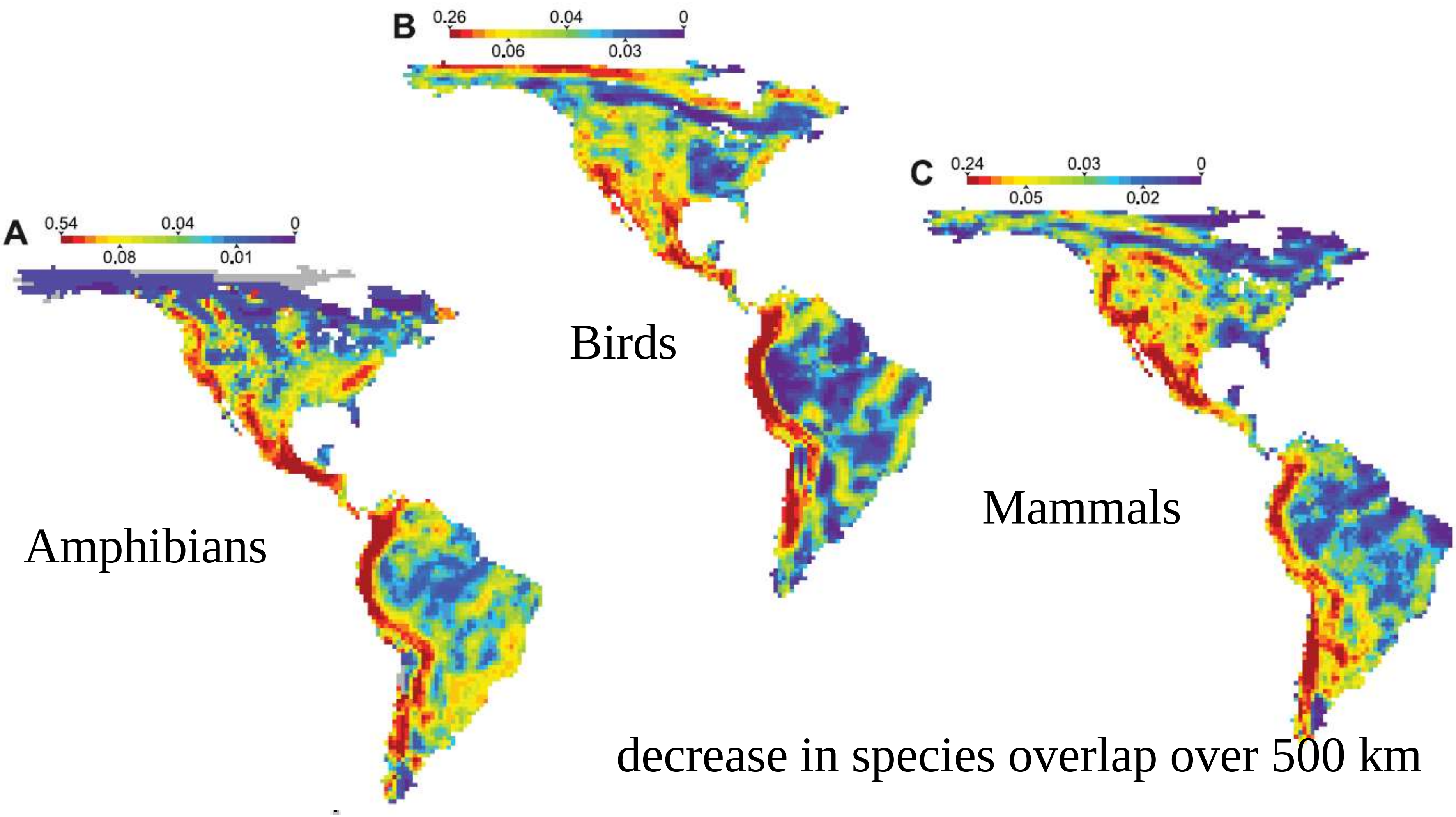
Diversity Zones (DZ): Number of species per 10 000 km^2

DZ 1 (<100)
DZ 2 (100 - 200)
DZ 3 (200 - 500)
DZ 4 (500 - 1000)
DZ 5 (1000 - 1500)
DZ 6 (1500 - 2000)
DZ 7 (2000 - 3000)
DZ 8 (3000 - 3500)
DZ 9 (4000 - 5000)
DZ 10 (>5000)

sea surface temperature
> 27°C
> 29°C

W. Barthlott, G. Kier, H. Kreft, W. Küper, D. Rafiqpoor & J. Mutke 2005

Altitudinal gradient: the mother of all environmental gradients



decrease in species overlap over 500 km

$$\beta_{\text{sim}} = \frac{\min(b,c)}{a + \min(b,c)},$$

Figure 1. Beta-Diversity of Amphibians, Birds, and Mammals Mapped Continuously across the Continental Western Hemisphere
Beta-diversity ($\beta_{sim\text{-}d}$) values for each taxon are divided into 20 quantiles, represented by warm (higher $\beta_{sim\text{-}d}$) to cool (lower $\beta_{sim\text{-}d}$) colors.

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Putting Beta-Diversity on the Map: Broad-Scale Congruence and Coincidence in the Extremes

Meghan W. McKnight[1*], Peter S. White[2], Robert I. McDonald[3], John F. Lamoreux[4,5], Wes Sechrest[6], Robert S. Ridgely[7], Simon N. Stuart[8]