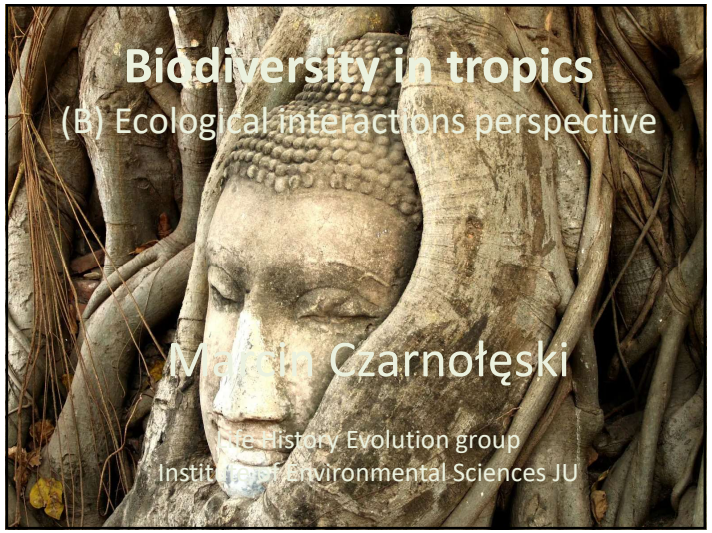
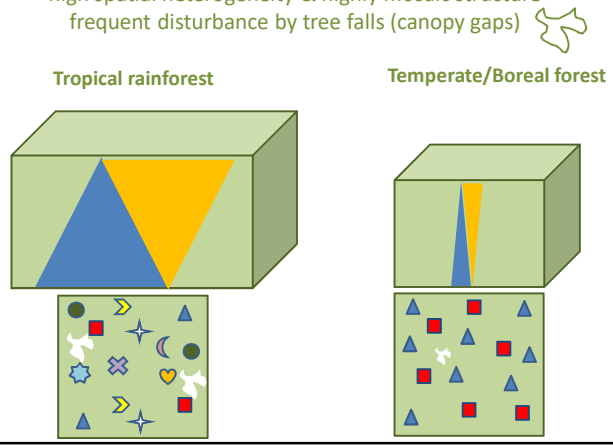


Tropical rainforest

enormous living space volume produced by plants

high spatial heterogeneity & highly mosaic structure

frequent disturbance by tree falls (canopy gaps)



Tropical forests are the largest, most three-dimensional and oldest forest habitats on the planet.

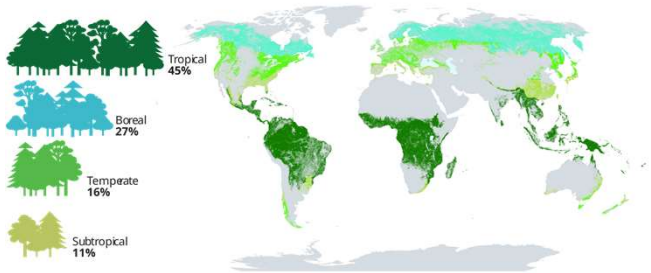
45% of the land

Up to 100 metres above ground

100 million years of continuous history

The highest energy fluxes and matter rotation

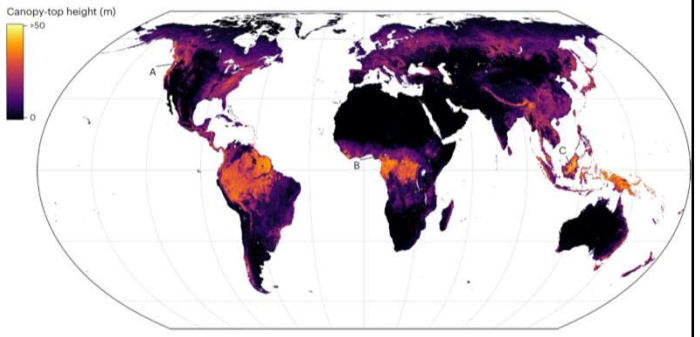
against all presentation rules, a fullstop is here



Global Forest Resources Assessment 2020 – Key findings. Rome: FAO (2020)

Tropical rainforest

extremely highly emergent trees

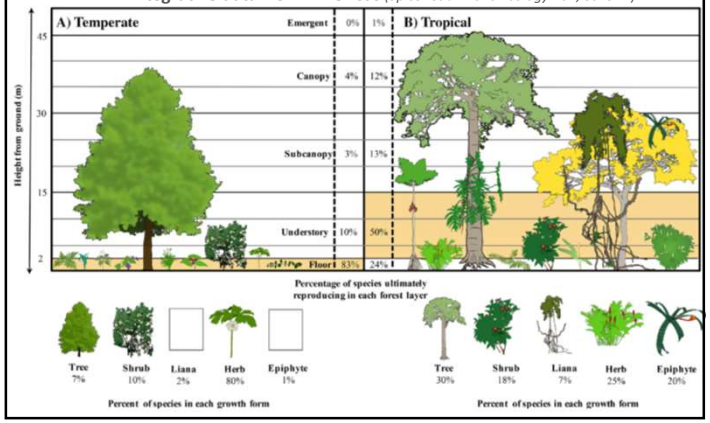


Lang et al. 2023 Nature Ecology & Evolution 7, 1778-1789

Tropical rainforest

trees, lianas, epiphytes & most plants reproduce high above ground

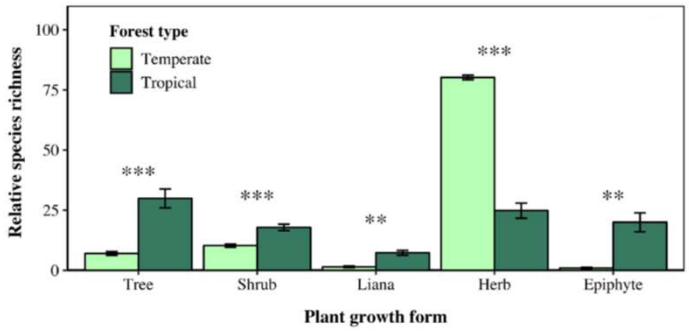
Integrative data from Americas *(Spicer et al. 2020 Ecology 101, e02974)*



Tropical rainforest

enormous species diversity in each plant growth form,
except for herbs

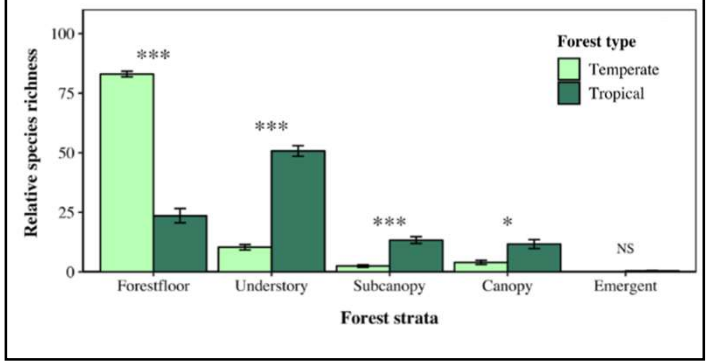
Integrative data from Americas *(Spicer et al. 2020 Ecology 101, e02974)*



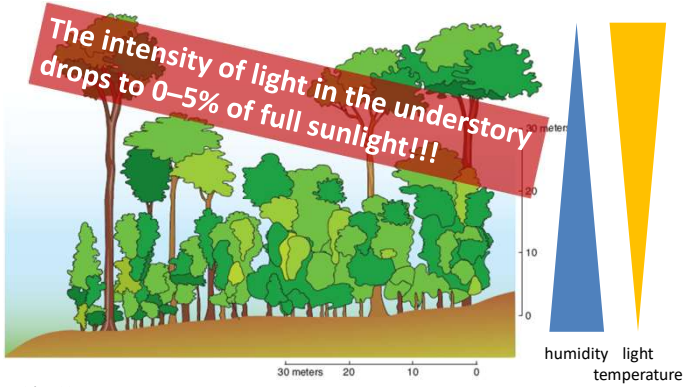
Tropical rainforest

enormous species diversity in all height strata,
except for the forest floor

Integrative data from Americas *(Spicer et al. 2020 Ecology 101, e02974)*



The higher you are above ground, the higher the light levels and temperatures, but the lower the humidity

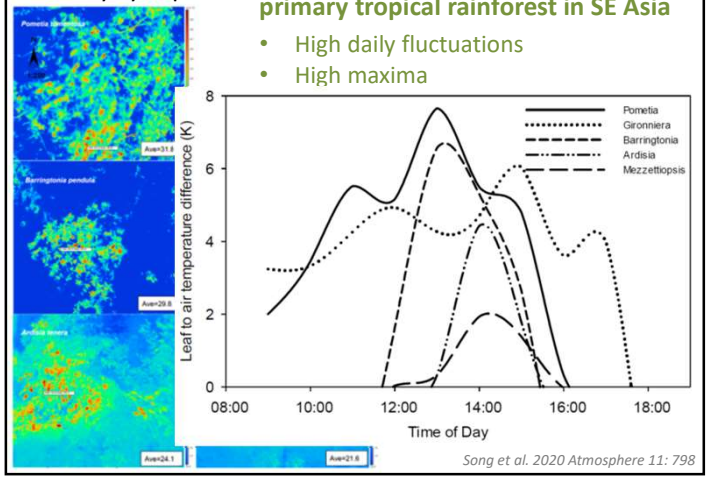


Kricher 2011

heat maps for 5 tree species on a sunny day at 2 pm

Tree canopy temperatures in the primary tropical rainforest in SE Asia

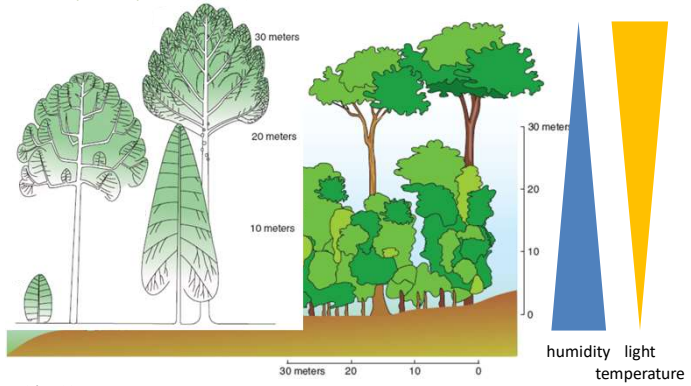
- High daily fluctuations
- High maxima



Song et al. 2020 Atmosphere 11: 798

The higher you are above ground, the higher the light levels and temperatures, but the lower the humidity

Developmental shifts in the crown shape in dipterocarp trees (SE Asia)

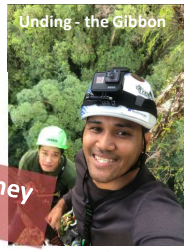


Kricher 2011

The same, but different

Trees have never been higher than they are now in the history of life on Earth

British Gujana



Yellow meranti tree (*Shorea faguetiana*) from Danum Valley - 100.8 metres !!!

Borneo

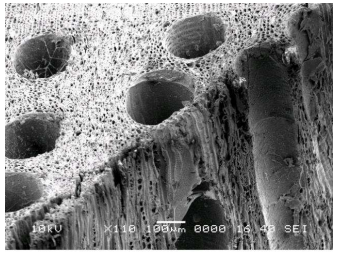
Kricher 2011

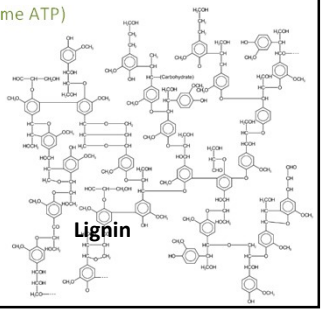
The maximum height of trees is limited by transport capacity of water by wood vessels

Wood vessels (xylem) have reinforced cell walls (**lignin**) – adapted to withstand high pressure during water transport

Water is transported by the action of adhesion, cohesion, and forces resulting from

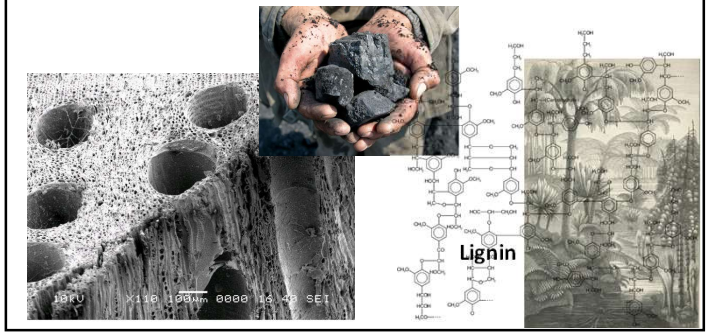
- root pressure (has to consume ATP)
- leaf transpiration (does not need to consume ATP)





Lignin – an adaptation to terrestrial life

- An organic polimer, evolved in vascular plants during the Carboniferous period
- „Hardening material" for plant water transport systems, which is also difficult to decompose but fungi and bacteria can do it – recall, my lecture on fungi gardens of *Atta* ants
- Initially, lignin „surprised" organisms feeding on plant material, which also provided herbivore resistance
- Deposits of Carboniferous plant remains became carbonised (coal) without access to oxygen
- Burning coal is „finishing" decomposition, resulting in the massive CO_2 emmission



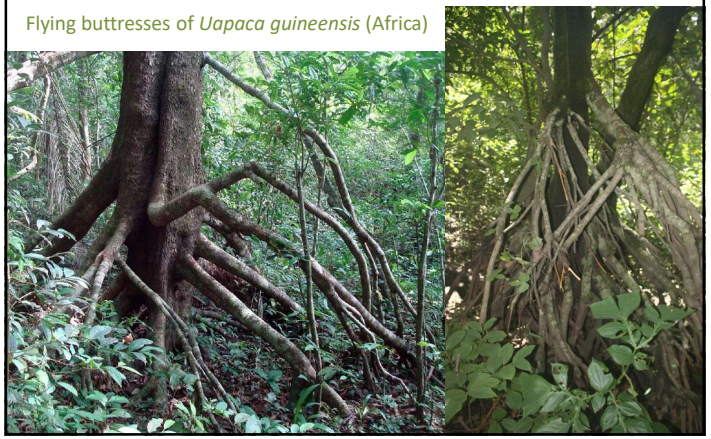
Competition for light & shallow decomposition layer in soil

promotes high trees with buttressed or surface roots

Flying buttresses, prop/stilt roots

help in swamps or to maintain upward position after disturbance

Flying buttresses of *Uapaca guineensis* (Africa)



Flying buttresses, prop/stilt roots

help in swamps or to maintain upward position after disturbance

mangroves

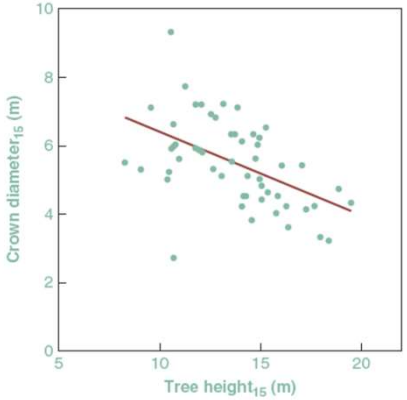
Flying buttresses, prop/stilt roots

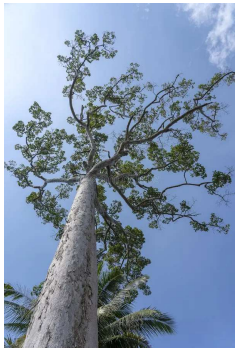
help in swamps or to maintain upward position after disturbance

„Walking palm" *Socratea exorrhiza* in South America

Nonintuitive pattern

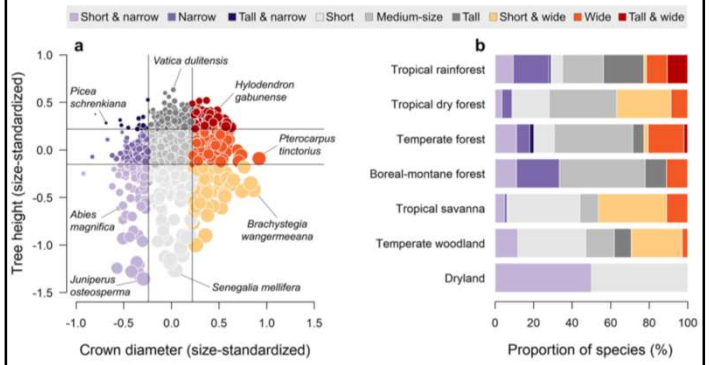
the higher the tree, the narrower its crown (why?)





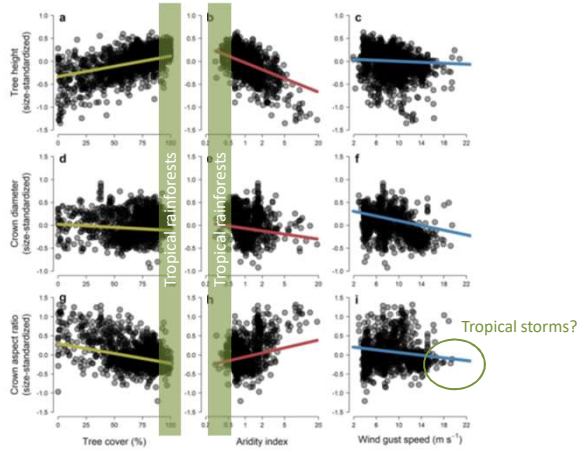
Kricher 2011

Global spectrum of tree crown architecture



Jucker et al. 2025 Nature Communications 16:4876

Global spectrum of tree crown architecture

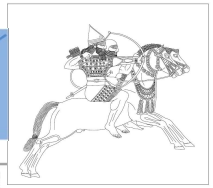


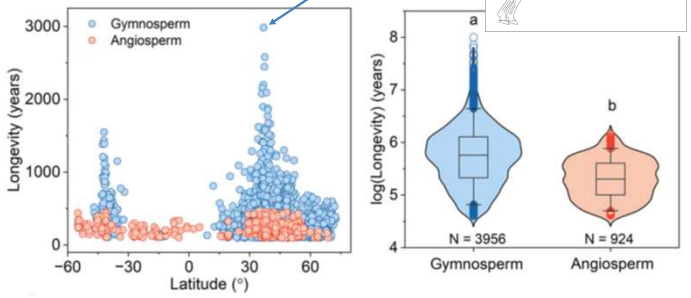
Jucker et al. 2025 Nature Communications 16:4876

Are the tropical rainforest giants long-lived?

No

Did you know?
This tree 'remembers' the Assyrian cavalry, who were the first mounted warriors in history. There were no saddles at that time! Two-horse cavalry units were used, with one worrior controlling the reins of both horses and another worrior using a long-range weapon.



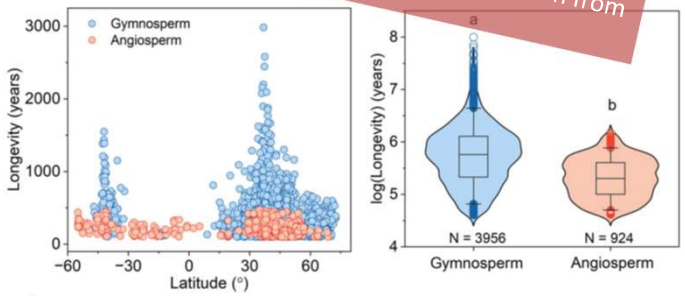


Gao et al. 2025 Comminications Earth & Environment 6:610

Are the tropical rainforest giants long-lived?

No

But why? Let's discuss
Recall principles of life history strategy evolution from my last lecture



Gao et al. 2025 Comminications Earth & Environment 6:610

Tropical rainforest

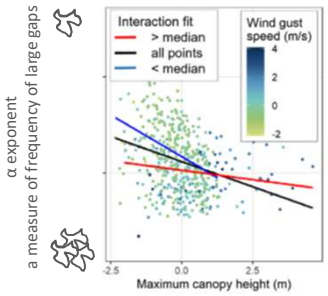
time dynamics that lead to spatial mosaics

- Tropical trees grow fast because they can (environment) and they „choose" to do so – competition for light, fertility advantage of large adult size
- Tall trees with shallow roots more prone to mortality/fall down due to instability
- Life horizon of trees also shortened by torrential tropical storms and intense ecological interactions with organisms (lianas, stranglers, epiphytes, epiphyls, herbivores, fungi, etc.)
- Evolutionary response – reduced selection for prolonged tree lifespans
- Recall my lecture on tropical societies, group cooperation in human ancestors increased security, selecting for prolonged lifespans

Tropical rainforest
time dynamics that lead to spatial mosaics

- Tree falls disturb forest structure, change light conditions (spatial heterogeneity), and … are a mortality source for other trees!
- Gaps are more frequent and larger in tropical rainforest

Data on tropical rainforests in Amazon basin *(Reis et al. 2022 Journal of Ecology 110:2971–2983)*



- Taller trees produce larger gaps when they fall
- Wind and lightning are associated with a high proportion of large gaps

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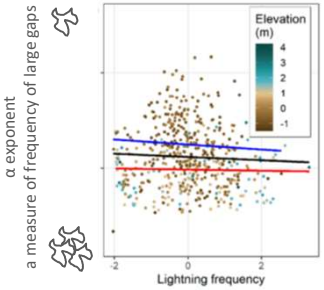

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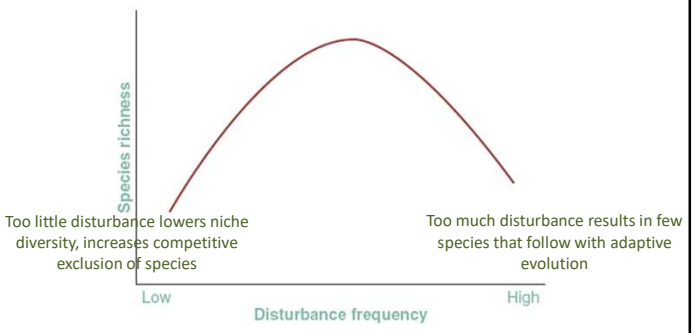
Why tropical rain forests are so rich in plant species with different life stratiegies?

Gradients in light and humidity

Intermediate Disturbance Hypothesis

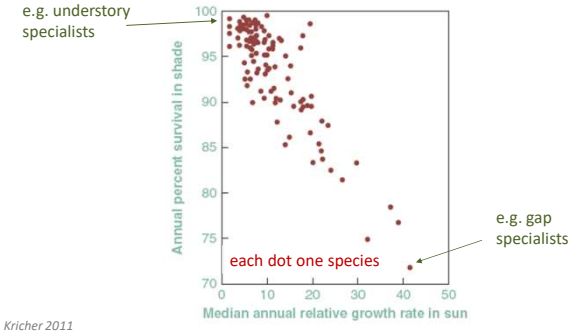


Kricher 2011

Why tropical rain forests are so rich in plant species with different life stratiegies?

Gradients in light and humidity

Physiological trade-offs between shade tolerance and light conversion capacity

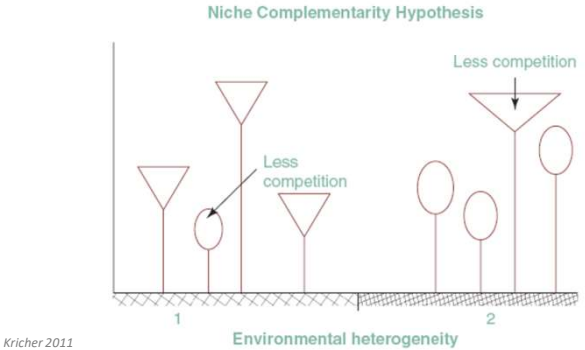


Kricher 2011

Why tropical rain forests are so rich in plant species with different life stratiegies?

Gradients in light and humidity

A rare species is favoured locally because of reduced competition strength



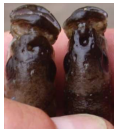
Kricher 2011

In fact, mechanisms of frequency-dependent (apostatic) selection are widerspread in tropics

Explains coexistence of alternative forms/genotypes

Cichlid *Perissodus microlepis*

- Endemic in Tanganyika
- Breeds offspring in the mouth
- Scale eater, a kind of parasite
- Two genetic forms (two alleles in one locus)



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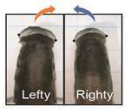
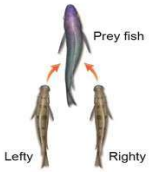
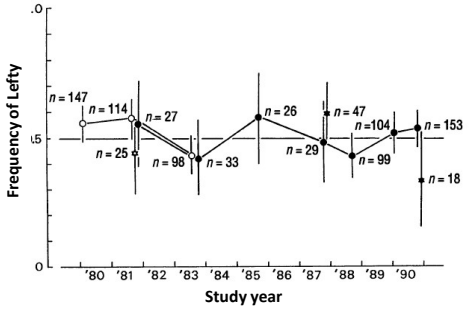




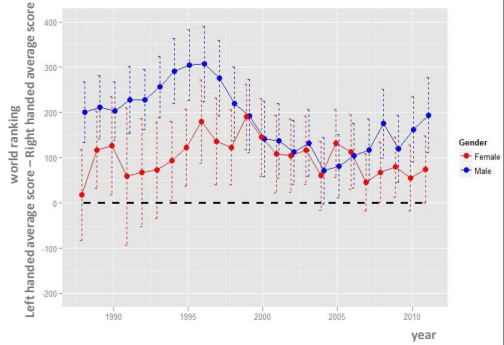


Hori 1993 Science, 260: 216-219
Lee et al. 2010 J. Fish Biology , 76: 1940-1957

In contact sports

Left-handed champions are higher in world rankings, but only because they are „rare and challenging cases" that surprise the right-handed opponents

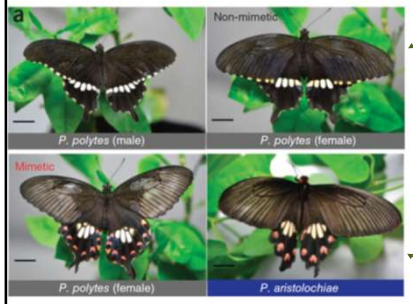
Martina Navratilova



Breznik 2013 J. Sports Science and Medicine, 12: 346-353

Some more examples of frequency-dependent selection that can be discussed on „common grounds”

Batesian mimicry
e.g. edible buttterfly species can evolve to mimic toxic species, but mimics can exist only at low frequencies. The same applies to the evolution of aposematic (warning) colouration in non-toxic animals.



Non-toxic species

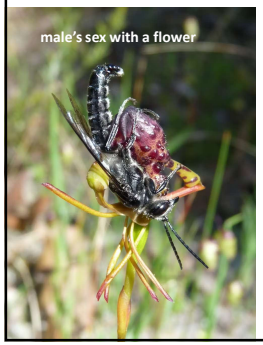
- An example from SE Asia
- Two *Papillio* butterflies, one toxic
- In *P. polytes,* only females show mimicry, but there is mimetic and non-mimetic genetic form
- The two forms coded by one gene

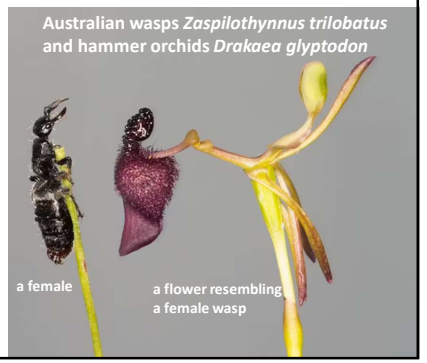
Toxic species

Nishikawa et al. 2015 Nature Genetics 47, 405–409

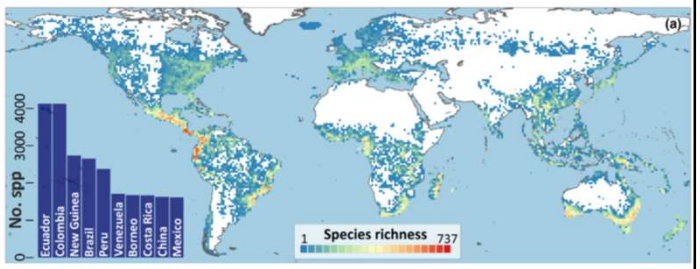
Some more examples of frequency-dependent selection that can be discussed on „common grounds”

Pollination by sexual deception (coevolution, specialization, endemic distribution)
Many orchids are pollinated by insect males, attracted for copulations by flowers resembling insect females (colour, texture, smell). But „plant females” can occur only in low frequencies.





Tropics are hot spots of orchid diversity
Tropical orchids are often epiphytes



Perez-Escobar et al. 2024. New Phytologist 242: 700–716

Why males are easily decepted by „super females”?

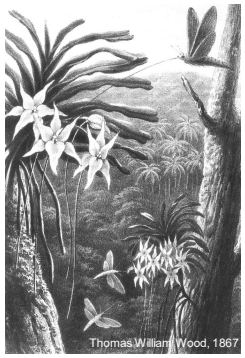
Unequal cost of gamete production in males and females select for

- choosy females (good genes, sexy sons)
- non-choosy males (aggresive competition for matings)

Many classic examples of co-evolution between plants and pollinators

the evolutionary snowball effect, resulting in high diversity

Darwin noticed that the orchid *Angraecum sesquipedale* (so-called Darwin's orchid) from Madagascar has an extraordinary long spur with nectar (35 cm!!!). In his book about orchids (1862), Darwin predicted that the coevolution with pollinators should have created a moth with the adequately long broboscis.



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After Darwin's death, biologists found the predicted species, a hawk moth *Xanthopan morganii*

Many classic examples of co-evolution between plants and pollinators

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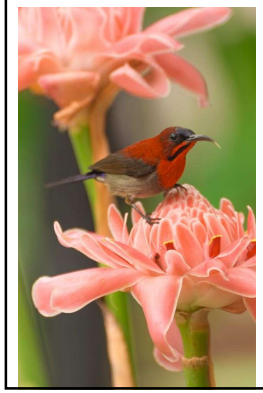
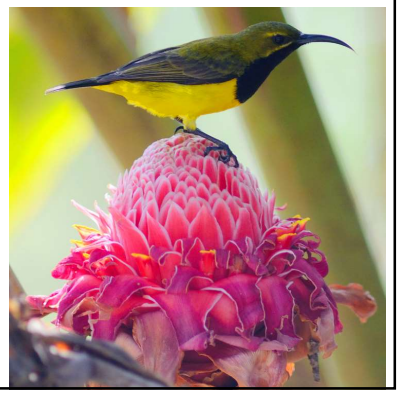
Neotropics: hummingbirds & heliconias

Many classic examples of co-evolution between plants and pollinators

the evolutionary snowball effect, resulting in high diversity

South-East Asia: sunbirds & ginger flowers



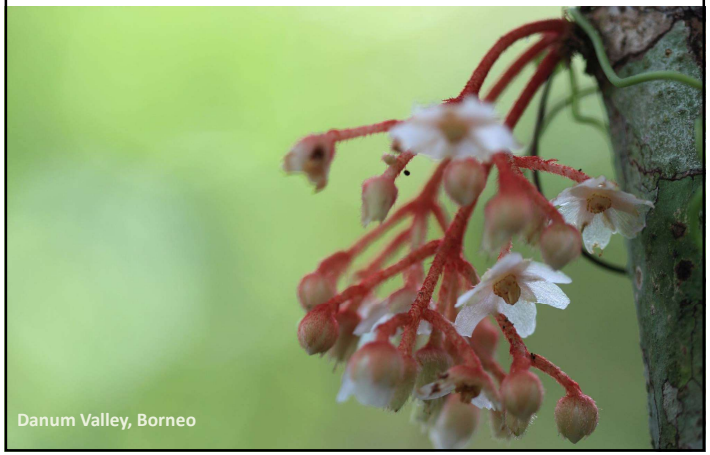


Many classic examples of co-evolution between plants and pollinators
the evolutionary snowball effect, resulting in high diversity

African mountain slopes
sunbirds & lobelias

Cauliflory and Caulicarpy very common in tropics
pollination & seed-dispersal by larger animals predominates

Cauliflory and Caulicarpy very common in tropics



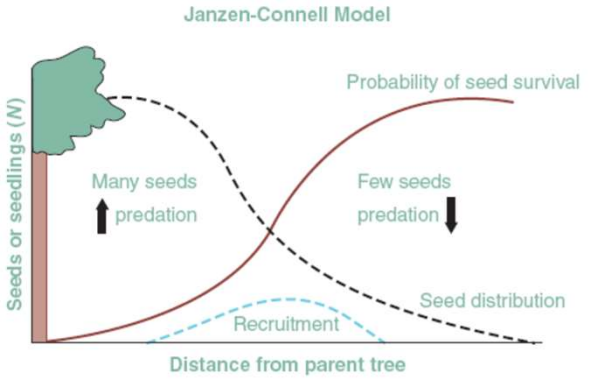
Cauliflory and Caulicarpy very common in tropics

Cauliflory and Caulicarpy very common in tropics

Durian tree (South-East Asia)

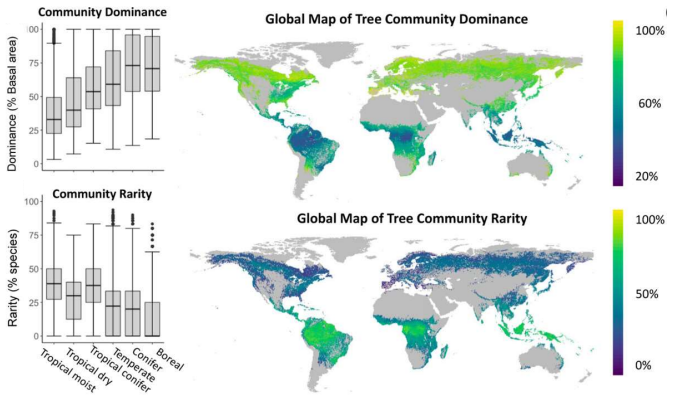
Combined effects of seed dispersal by long-range animals, seed predation, and the presence of tall trees

low population densities but high biodiversity of trees (per area)



Kricher 2011

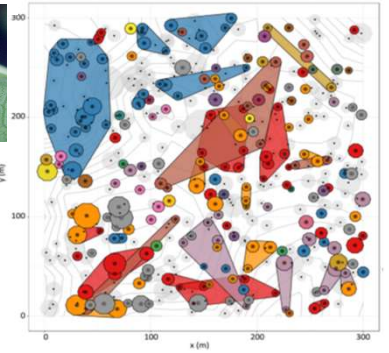
Tropical rainforests are less dominated by single tree species



Hordijk et al. 2024 Global Ecology & Biogeography 33(10):e13889

Aggression behaviours result in the mosaic spatial distribution of tree ants

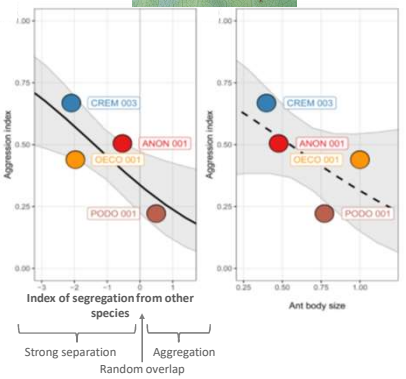
Primary rainforest in Papua Nova Guinea
300 x 300 meter plot: 57 ant species in tree canopies, with highly variable abundance and vertical stratification (Poland has 98 native ant species)



- Species were significantly over-dispersed, with their territory overlap significantly reduced
- Ant community composition was not affected by tree species composition or canopy connectivity
- **Spatial distribution was mainly related aggressive behaviours**

Mottl et al. 2021 OIKOS 130: 1087–1099

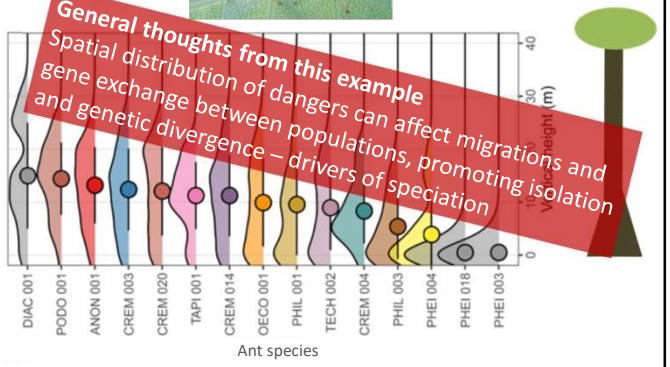
Species that were more aggresive in tests, were also spatially more separated from other species in tree canopies



Mottl et al. 2021 OIKOS 130: 1087–1099

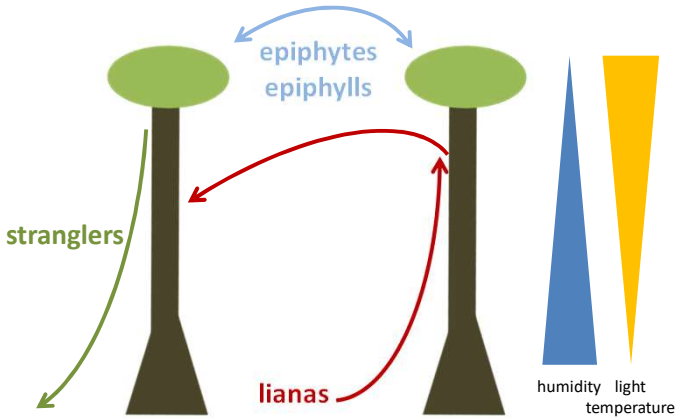
Ant species were also stratified vertically

General thoughts from this example
Spatial distribution of dangers can affect migrations and gene exchange between populations, promoting isolation and genetic divergence – drivers of speciation



Mottl et al. 2021 OIKOS 130: 1087–1099

Competition for light & alternative strategies to „being a decent tree"

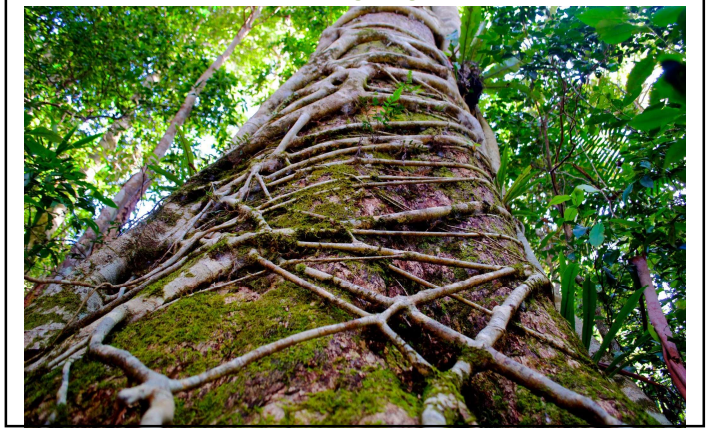


Competition for light & alternative strategies to „being a decent tree"

Lianas

Competition for light & alternative strategies to „being a decent tree"

Strangler fig



Competition for light & alternative strategies to „being a decent tree"

Epiphytes

Orchids (all tropics)

Neotropics

Dry forests: 9-24 species of epiphytes (2% of local flora)

Humid forests: 238-368 species of epiphytes (24% of local flora)

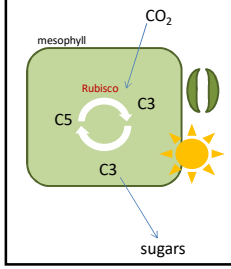
(all tropics)

Bromeliads (Neotropics)

Competition for light & alternative strategies to „being a decent tree"

Crassulacean acid metabolism (CAM photosynthesis) in many epiphytes inhabiting crowns of emergent trees

Photosynthesis C3



Competition for light & alternative strategies to „being a decent tree"

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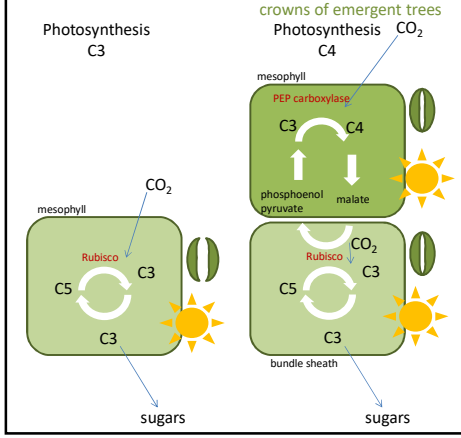
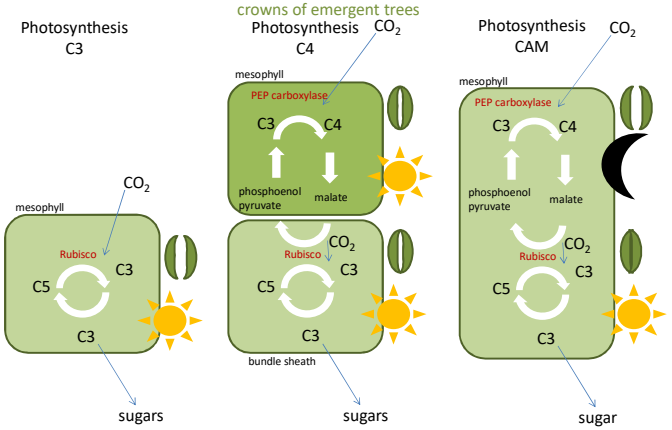
Photosynthesis C3

Photosynthesis C4

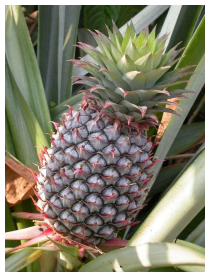


Competition for light & alternative strategies to „being a decent tree”

Crassulacean acid metabolism (CAM photosynthesis) in many epiphytes inhabiting crowns of emergent trees



Famous CAM plants



Ananas (South Am)

Welwitschia mirabilis – **gymnosperms**!!
„living fossil” from Namib Desert (Africa)

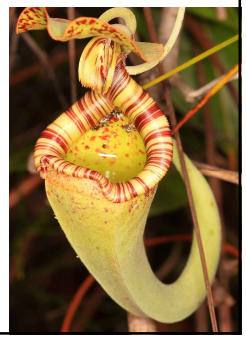
Agave

Cactuses, Central/North America

Competition for light & alternative strategies to „being a decent tree”

Heterotrophic plants

Pitcher plants: carnivorous plants forming pitfall traps from leaves, belong to *Nepenthaceae* (South-East Asia) and *Sarraceniaceae* (Neotropics) families. Borneo – the biodiversity & endemism hotspot of *Nepenthes* (often climbers)



Competition for light & alternative strategies to „being a decent tree”

Heterotrophic plants

Hemiparasites (partially autotrophic): sandal-wood trees (*Santalum*, mainly South-East Asia)

Competition for light & alternative strategies to „being a decent tree”

Heterotrophic plants

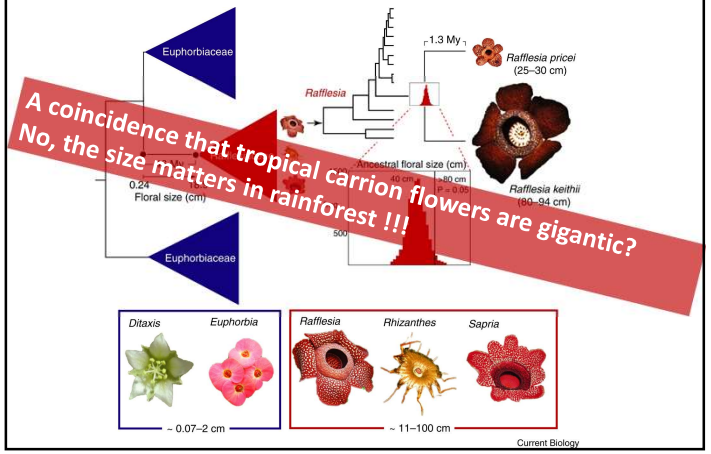
Holoparasites (full parasites): South-East Asian rafflesias are (sic!!!)

endophytes of lianas

gigantic carrion flowers mimic rotting flesh (odor, colour, texture, size)

Rafflesiaceae's flowers: extreme size and dramatic interspecific differences (11-100 cm)

Genus *Rafflesia*: recent (last million years) and extremely rapid evolution of flower size



Mimicking rotting flesh attracts pollinators (common in *Araceae*)

necrophagous insects: females seeking dead bodies for egg-laying and males seeking mates near dead bodies

Evolution of carrion flowers: selective conditions

1) scattered distribution of plant species
- high biodiversity in tropics means scattered distributions
- specializations (forest gaps, parasitism) means scattered distributions

2) scattered plants can be limited by pollination (distance)

3) many necrophagous insects evolved to fly long distances to look for dead bodies of large animals as food and egg-laying sites

4) insects selected to avoid breeding on fake dead bodies, so plants with carrion flowers selected to be deceptive: odor, size, shape, texture, colour

5) frequency-dependent selection
- if there are more carrion flowers, there is more pressure on insects to detect fake flowers, which selects against carrion flowers
- 'over-careful' insects also ignore some real dead bodies, so insects do not evolve to be over-restricted

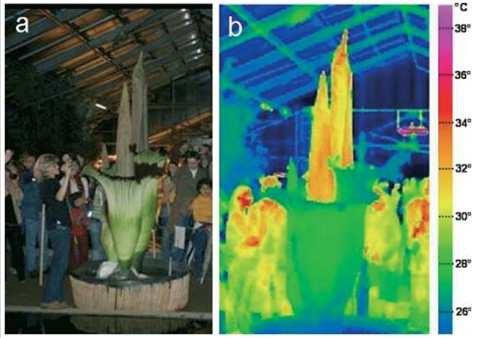
Size matters

Large flowers help to imitate dead bodies and strengthen odor that needs to travel long distances to attract long-distance dispersing insects

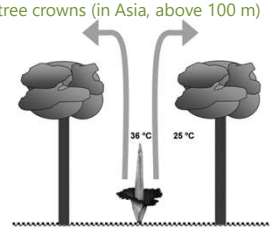
Insects selected to avoid breeding on fake dead bodies, so plants with carrion flowers selected to be deceptive: odor, size, shape, texture, colour,
Production of heat and CO_2 that mimicks decomposing dead body!!!

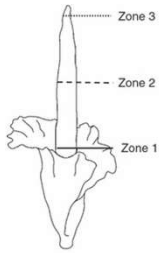
Thermogenesis in Titan arum: an extreme example

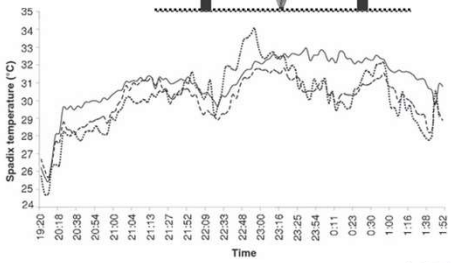
Amorphophallus titanum



Heating at night creates convective currents that help to send odor long distances, above tree crowns (in Asia, above 100 m)







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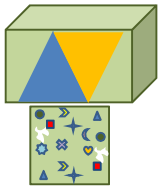

Take home thoughts

- Tropical rainforest produces enormous living space
- The space is highly three dimensional and heterogenous, and is exposed to intense disturbances (tree falls)
- High heterogeneity leads to high evolutionary divergence

- The evolutionary divergence involves
  - ✓ coevolution that results in intimate endemic relationships
  - ✓ frequency-dependent selection that preserves alternative life strategies
- High biodiversity results in long distances between individuals/populations of the same species
  - ✓ this requires specialized travel mechanisms for getting resources
  - ✓ this exposes to mosaics of ecological interactions (e.g., riks of mortality)
- The alternative to long travel is short travel, resulting in isolation, evolutionary divergence and endemism