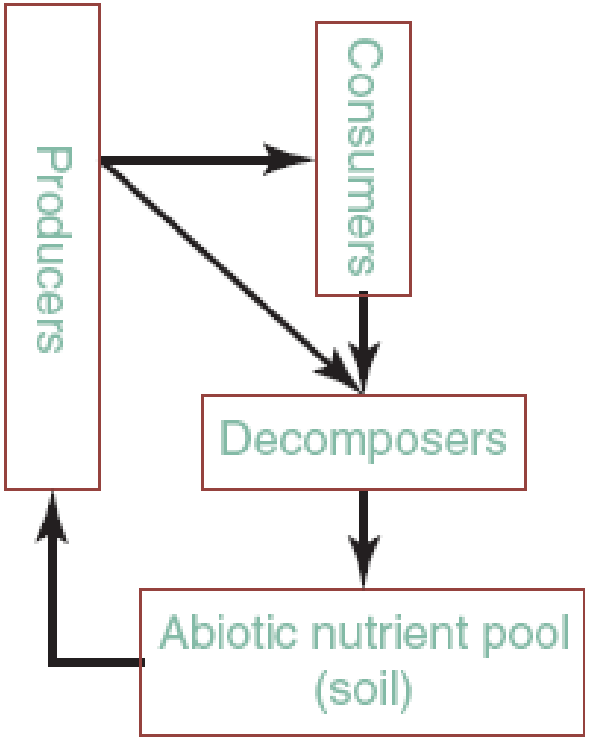
Nutrient Cycling & Tropical Soils

Overview of key aspects of cycling process

Explore bottom-up and top-down factors that affect nutrient flux in the tropics

Nutrient Cycling and the Soil Community

Decomposition involves organisms that return minerals to the abiotic pool, where they are taken up by plants



Material basis for nature comprises key elements essential to life, which are shared through *biogeochemical cycling.*

Atoms present in waste and dead tissues must be reacquired, recycled back to living tissue

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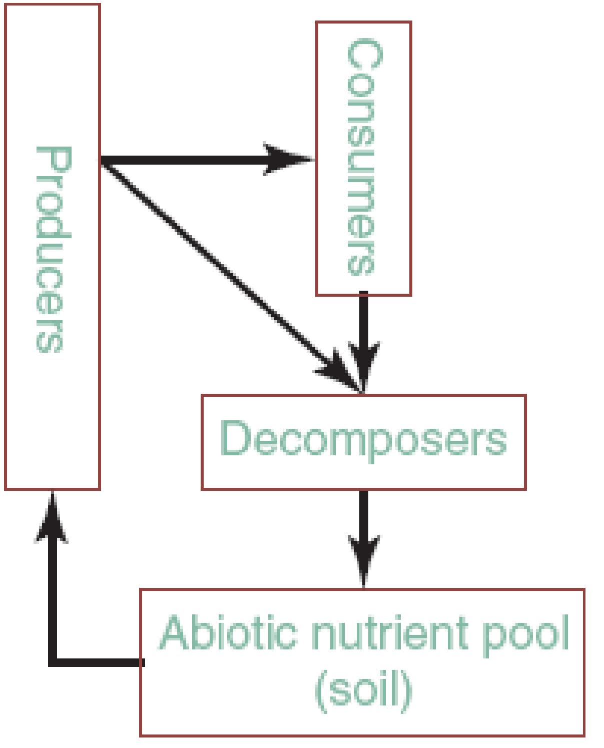

Units of energy fixed during *net primary productivity* (NPP) – the amount of carbon fixed in excess of metabolic needs of plants – moves by one of two ways:

- Being consumed as part of living tissue, where it moves through the food web
- Remains in the leaf until it drops and becomes available to the soil community

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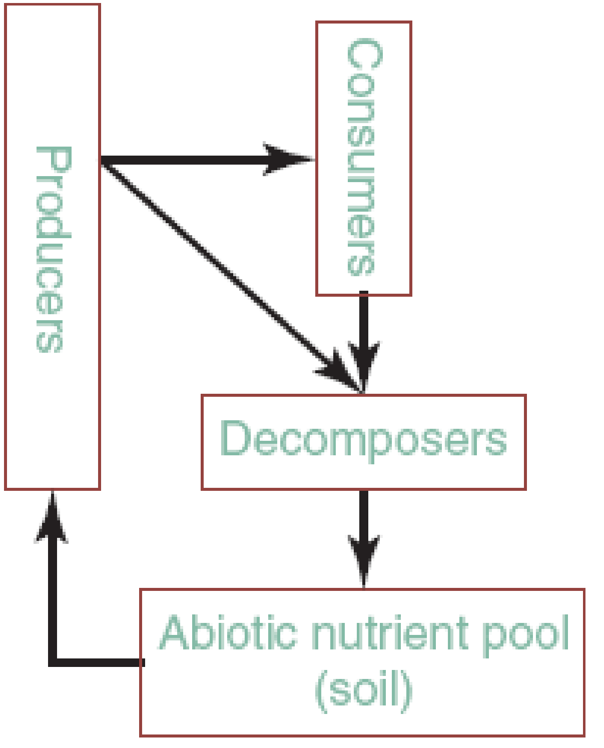


Fungi liberate atoms back to the soil. Multiple fungal species (mycorrhizae) are essential in aiding uptake of atoms by plants

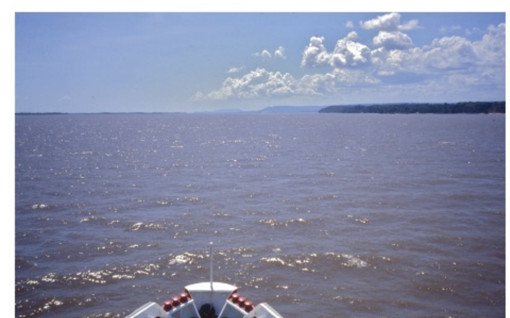
In humification, humus particles, which are negatively charged, retain mineral nutrients like potassium (K^+) and calcium (Ca^{2+})

Nutrient Cycling and the Soil Community

The movement of minerals is strongly influenced by temperature and rainfall

Heat stimulates evaporation, which brings up water and minerals from the soil, cools plants and returns moisture to the atmosphere in a pumping process called *transpiration*

Transpiration is the release of moisture from leaf tissues.
50% of precipitation falling on Amazon basin is directly recycled via transpiration from vegetation.



Factors affecting nutrient cycling

Components of nutrient cycling:

- Size of nutrient pools, distributed across biomass, litter and soil
    - Phosphorous pools are small – limiting factor in plant productivity?
    - Nitrogen is abundant – much is fixed by microbial organisms
- Flux of nutrients, reflected in rates of litter-fall, decomposition, plant uptake
- Flux of nutrients (denitrification, leaching, loss due to herbivore movements)
- Environmental variables, temperature and precipitation

Factors affecting nutrient cycling

Leaching

Most severe in areas subject to heavy downpours; essential minerals and chemicals are washed from leaves

Waxy coatings of tropical leaves and drip-tips speed water runoff and help leaves retain nutrient and moisture

Tropical soils are rich in clay, acidic, low in phosphorous, and with high precipitation, are subject to accelerated leaching

Age affects soil mineral content -- older soils are more leached than younger soils

Factors affecting nutrient cycling

Termites (insect order Isoptera)

Highly abundant pantropical social insects, essential for biogeochemical cycling

2650 known species, most of which are tropical, evolved their social structure independently of other social insect groups (e.g., hymenoptera)

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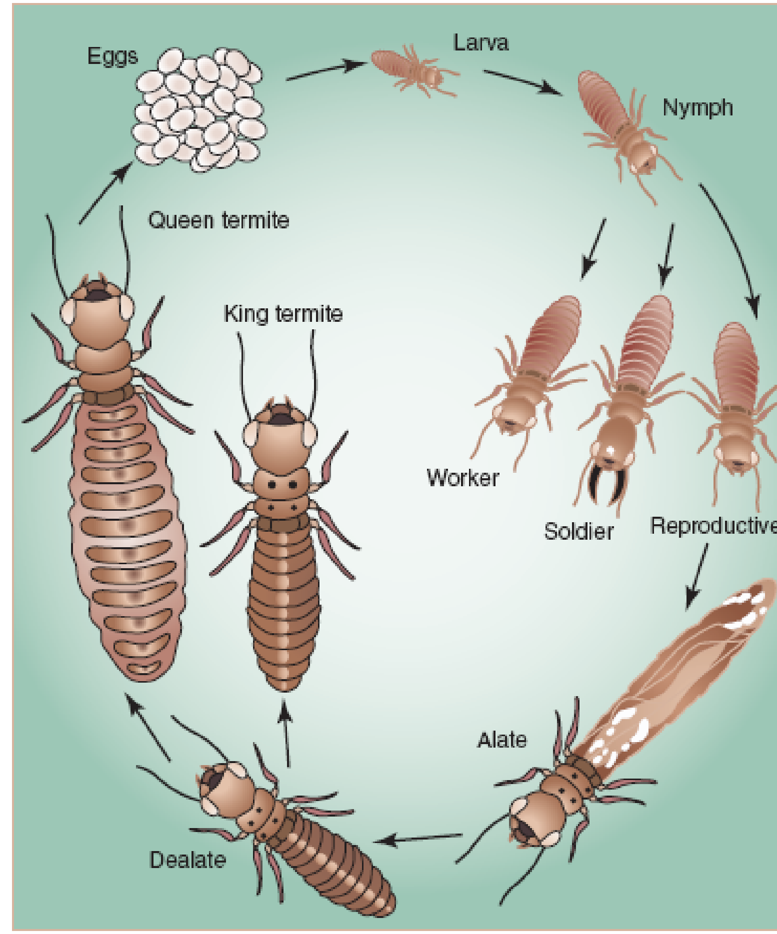


Factors affecting nutrient cycling

Termites (insect order Isoptera)

Basketball-sized or larger nests are attached to tree trunks and branches, with termite-constructed tunnels for workers to travel to and from the colony

Mounds form habitat for nesting birds like Trogons

Factors affecting nutrient cycling

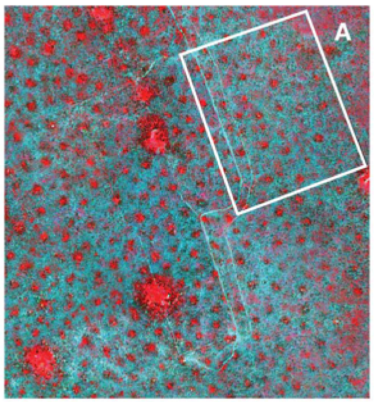
Termites (insect order Isoptera)

Preyed upon by anteaters in the Neotropics, pangolins in Africa and Asia, and utilized by chimpanzees (termite fishing behavior)

Conical termite mounds in southern Brazilian dry forest

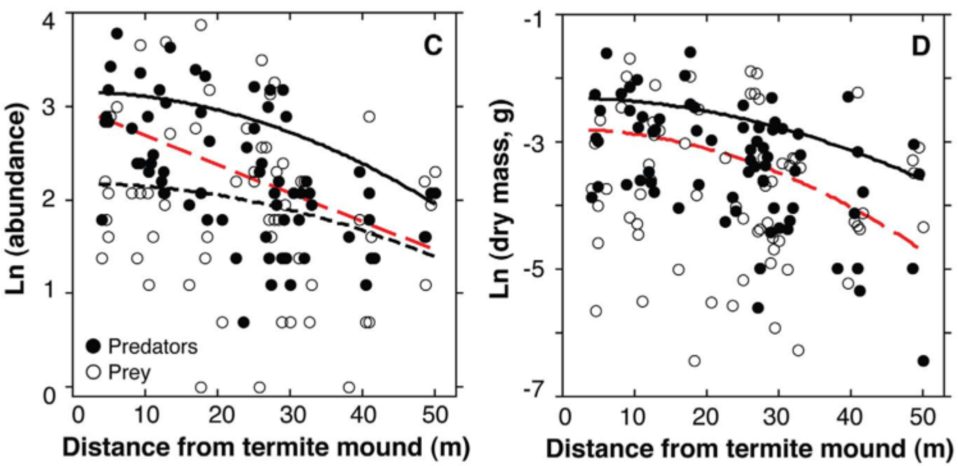
Factors affecting nutrient cycling

Termites (insect order Isoptera)



Termites are decomposers of forest floor litter (in Amazonia, feed on 20-50% of fallen leaves)

- Nests are patches of high nutrient concentrations; once abandoned, sites are ideal for many tree species
- Soil-feeding termites release N and P, aerate soil and increase exchangeable cations (Ca2+ and K+) supporting soil fertility



Termite mounds create evenly spaced areas of high productivity

Patches support higher abundance and biomass of arthropods

Pringle et al. 2010, PLoS One

Factors affecting nutrient cycling

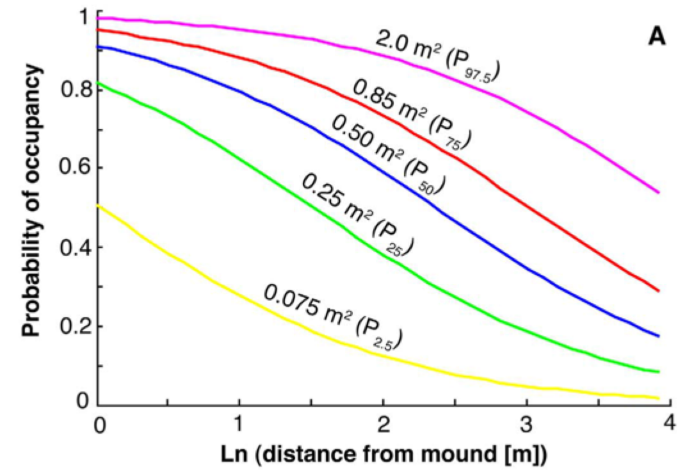
Termites (insect order Isoptera)

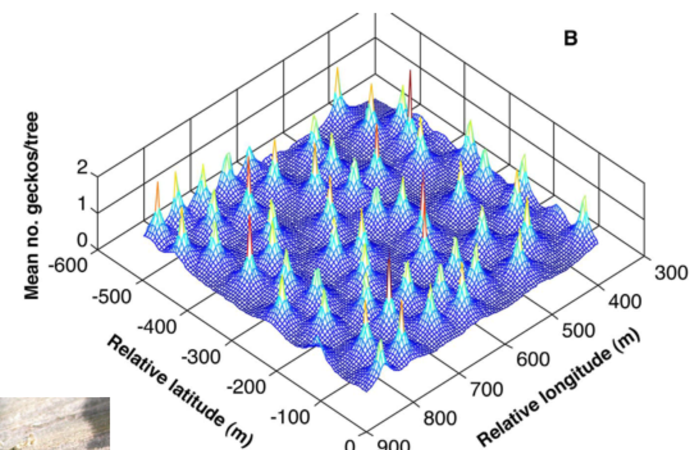
Probability of occurrence in geckos is higher closer to termite mounds

Trees near mounds are larger, have greater foliar N content and growth rates

Termites indirectly influence gecko distribution by increasing local densities of arthropod prey near mounds

Termite activity increases mean tree size and, indirectly, occupancy of those trees by animals like geckos





Pringle et al. 2010, PLoS One

Factors affecting nutrient cycling

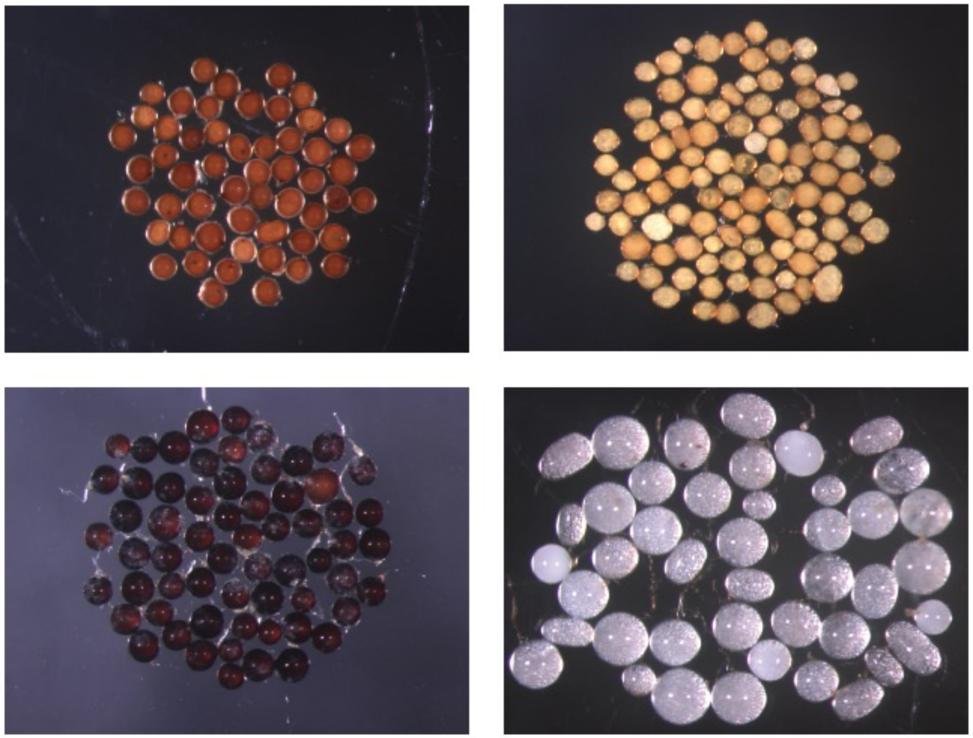
Mycorrhizae & Fungal Endophytes

An intimate mutualistic association exists between tree roots and a diverse group of fungi called mycorrhizae

Mycorrhizae use some of plant's photosynthate as food, but benefit plants by facilitating update of minerals from the forest litter

Very important in nutrient-pool soils

Essential in uptake of Phosphorus (limiting nutrient)



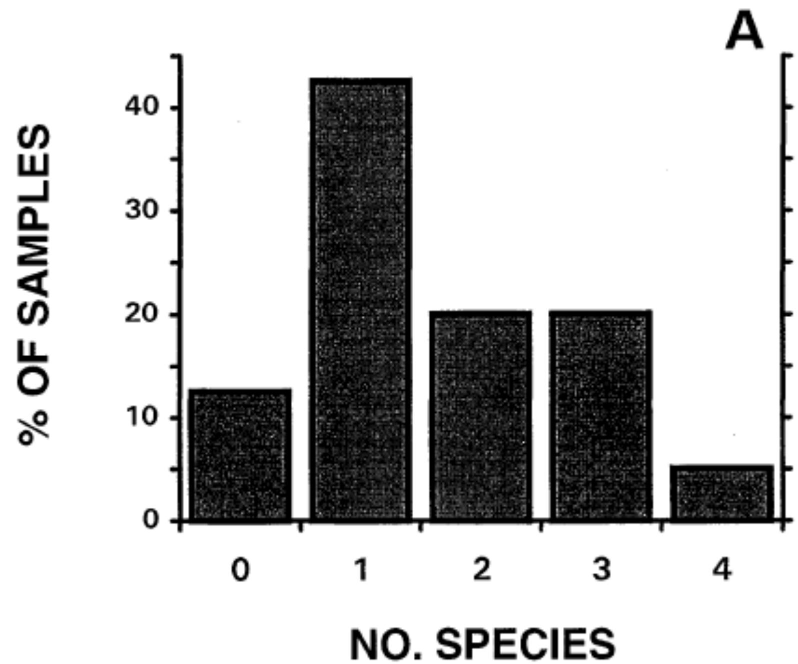
Spores from four species of mycorrhizal fungi (most in phylum Glomeromycota, termed *vesicular-arbuscular mycorrhizae*)

Factors affecting nutrient cycling

Mycorrhizae & Fungal Endophytes

Mycorrhizae may be widely distributed by rodent species (spiny rats, rice rats)

Long-distance dispersal of arbuscular mycorrhizae could be facilitated by mammalian spore transport

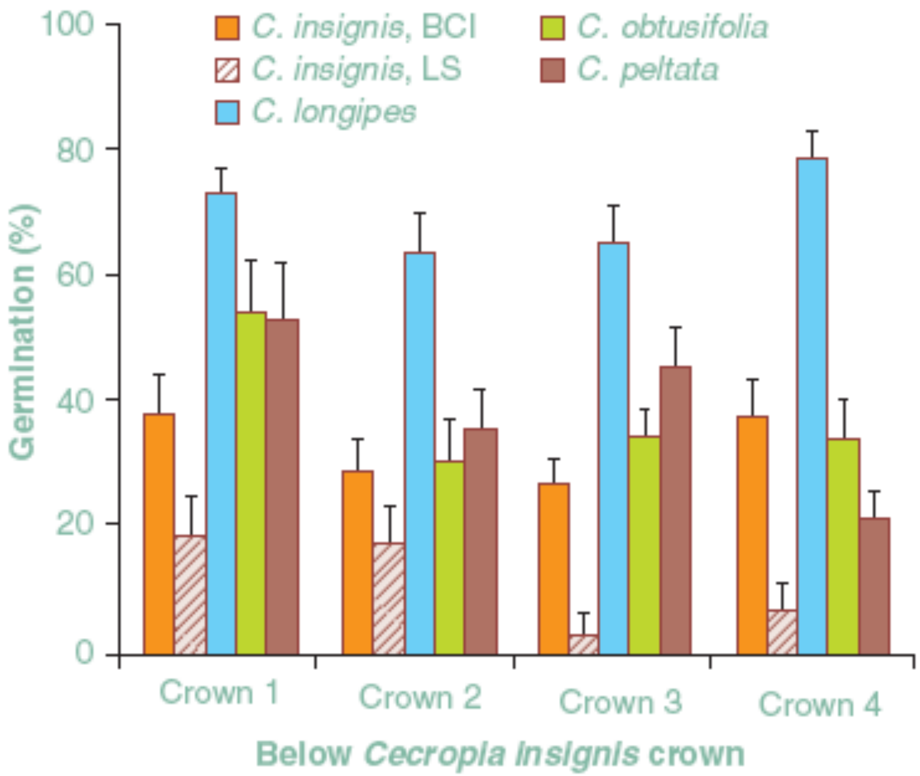


Study in Cocha Cashu, Manu National Park, showed that arbuscular mycorrhizae spores are well represented in feces of spiny rats

Factors affecting nutrient cycling

Mycorrhizae & Fungal Endophytes

Diversity of fungi and negative density dependence in trees



Recall that not all fungi are mutualistic with plants

Janzen-Connell model suggest that seeds dropped near parent trees have reduced fitness (due to predators and pathogens)

Study from BCI found that seeds buried in common gardens below *Cecropia insignis* crowns showed that *C. insignis* (conspecifics) had lowest germination rates

Factors affecting nutrient cycling

Mycorrhizae & Fungal Endophytes

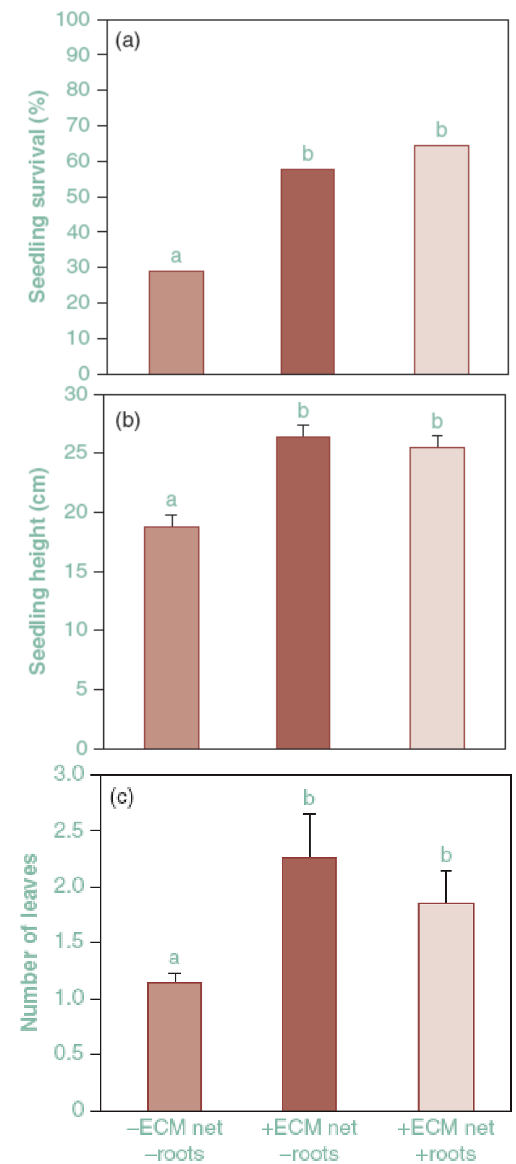
Another study from Guyana challenged the Janzen-Connell hypothesis

Survival (a), height (b) and number of leaves across treatments where ectomycorrhizal fungi (ECM) were restricted

Seedlings with access to ectomycorrhizae did well; those seedlings without access fared poorly

Because of ECM, there was a positive density dependence relationship associated with proximity to mature trees

Thus, the benefit of growing near conspecifics is to use host-specific microbes…But at the same time, this risks increased predation and disease, as predicted by Janzen-Connell hypothesis

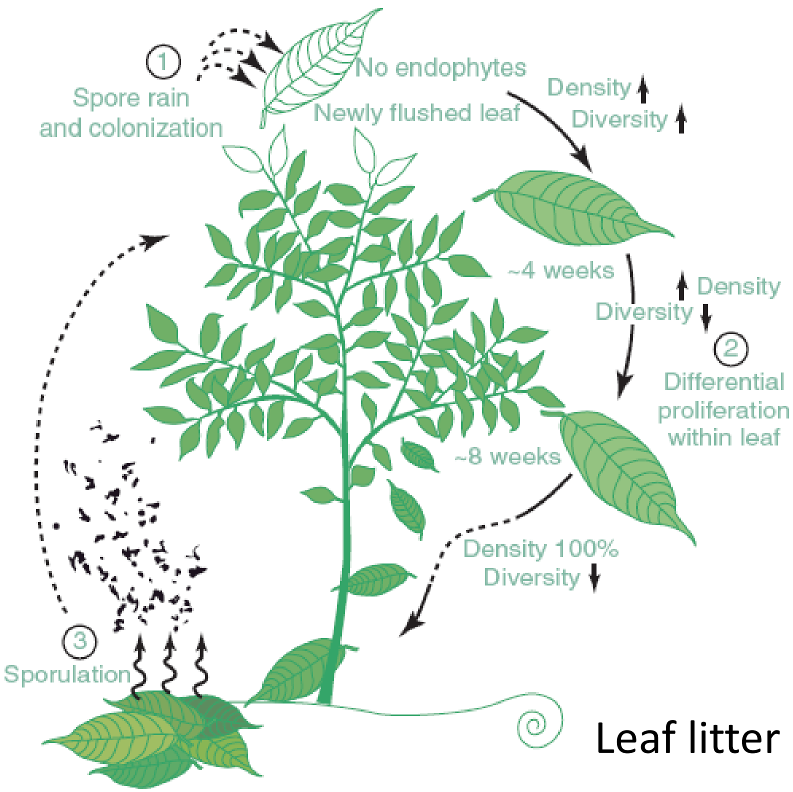


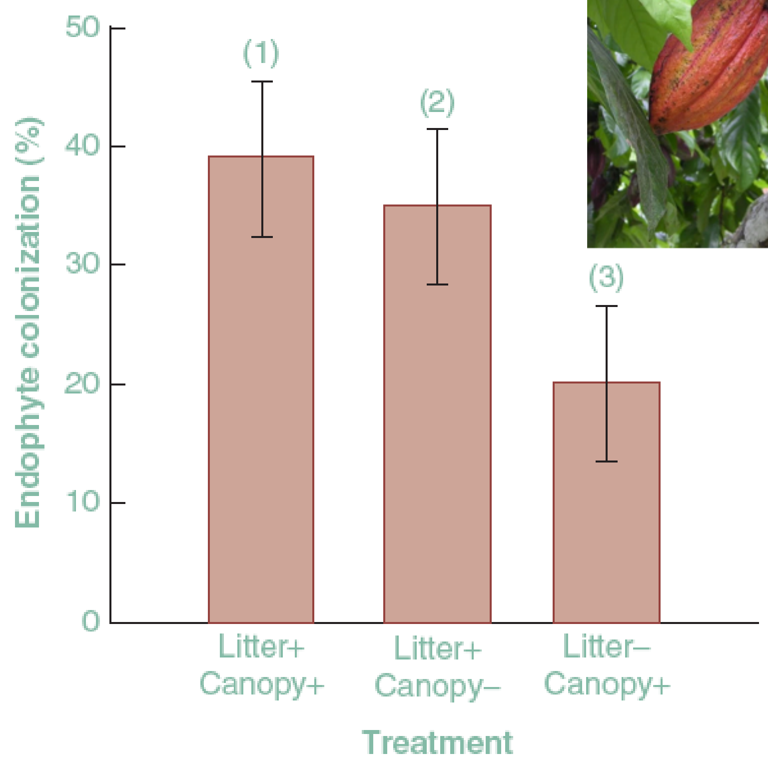
Factors affecting nutrient cycling

Mycorrhizae & Fungal Endophytes

The role of leaf endophytes fungi found with in photosynthetic tissues of leaves

Presence of foliar endophytes on cacao plants enhanced defense against pathogens.



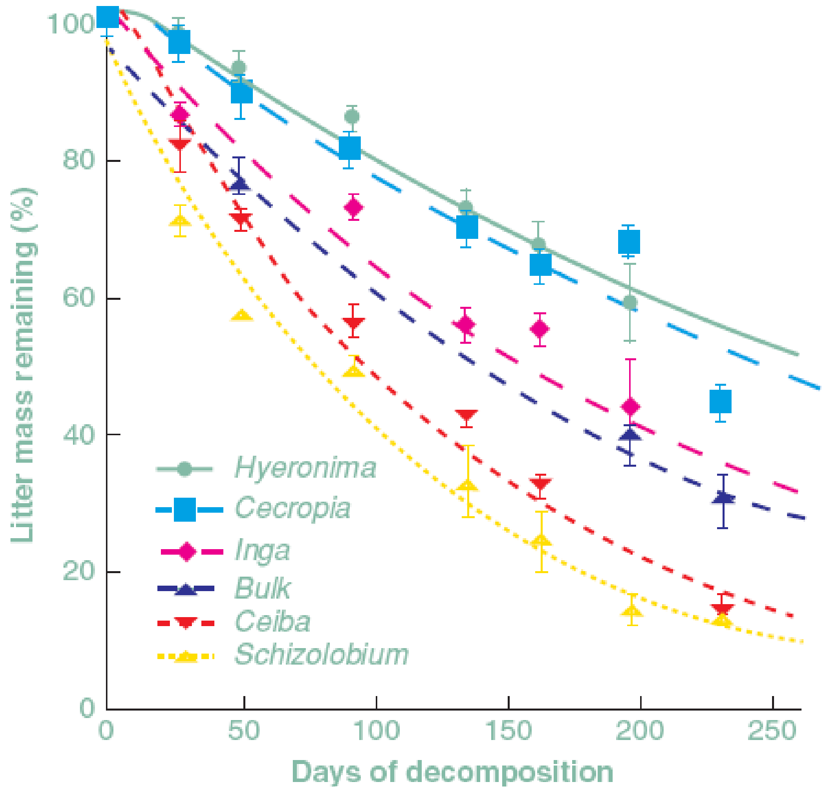


Leaf litter is a more important source of foliar endophytic fungi

Rapid recycling

Key variables like phosphorus level and amount of precipitation and temperature affect decomposition rates

Species-specific characteristics of leaves and the quality of the leaf litter can determine how quickly leaves are decomposed.



Different tree genera have different rates of decomposition

Rain Forest Soil Types & Nutrient Cycling

Oligotrophic soils

Eutrophic soils

Edaphic characteristics vary regionally due to several variables:

Climate, vegetation, topographic position, soil age

Many soils can be characterized as: Ultisols, Oxisols and Alfisols

Ultisols are well-weathered (minerals have been leached)

Oxisols are also well-weathered, old acidic soils, found on well-drained soils of humid regions – occur on old geological formations such as the Guianan Shield

High in iron content, reddish color

Alfisols are closer to neutral pH

Red Oxisols soils common in the tropics

Nitrogen fixation in the tropics

Symbiotic and *free-living* nitrogen fixation are recognized

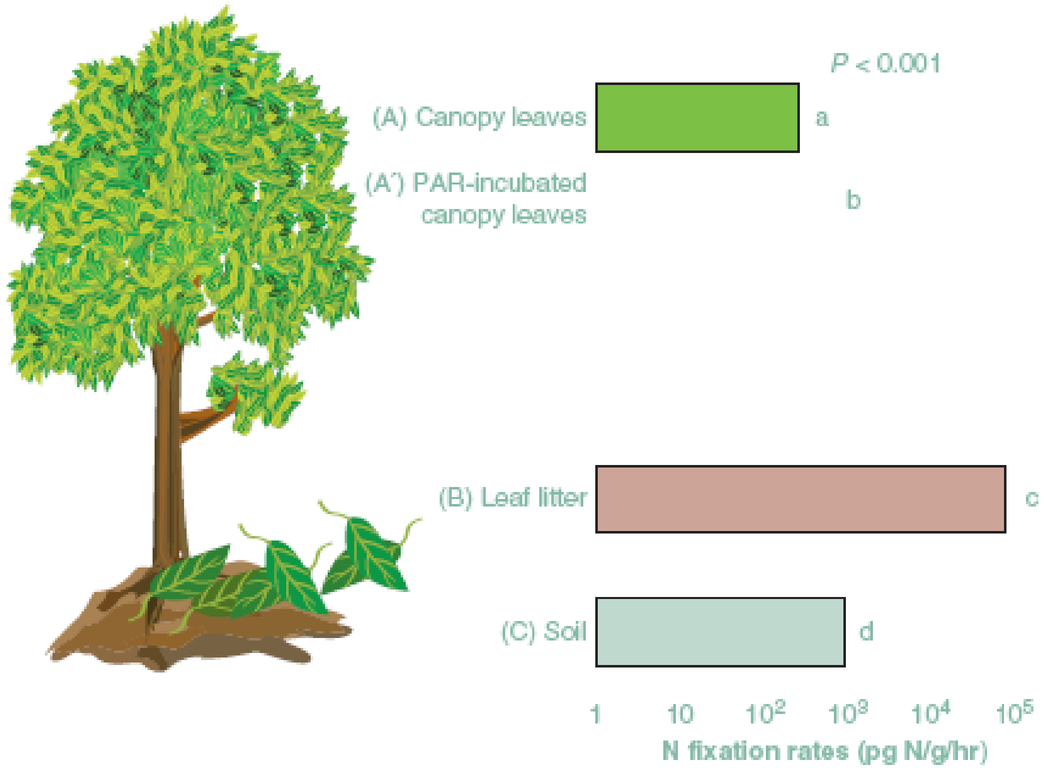
- Symbiotic is closely associated with legumes (Fabaceae – a huge family found across the tropics)
- Free-living occurs in soil with bacteria, associated with epiphyllic microbes, lichens

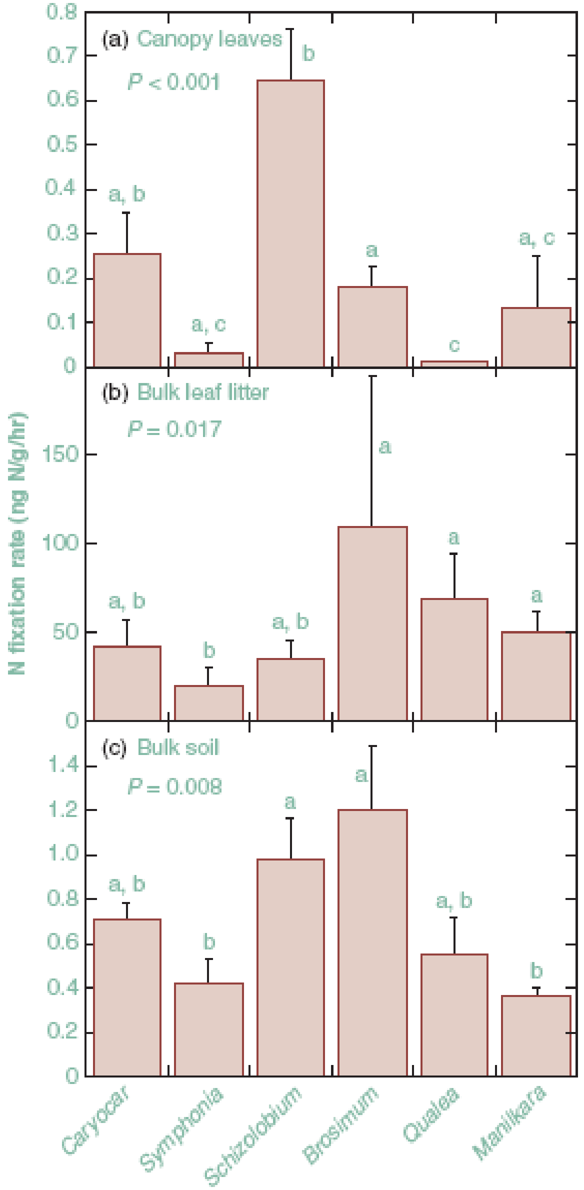
Nodules on roots have symbiotic bacteria that facilitate uptake of N. Bacteria are supplied with energy from the plant (obligate mutualistic association).

Epiphylls are common on forest understory leaves

Nitrogen fixation in the tropics

Rates of free-living nitrogen fixation differ among tree species and at different heights above the forest floor





Comparisons of free-living N fixation rates across six tree genera show significant differences not only across species but along the vertical forest profile

Leaf Economics Spectrum & Leaf Decomposition

Large size and diversity of shapes in tropical leaves – evolution of leaf characteristics involves trade-offs

Leaves may grow quickly, devoting most energy to photosynthesis, to be dropped and replaced; Or, slow-growing leaves can acquire chemical and structural protection, with longer duration on the plant.

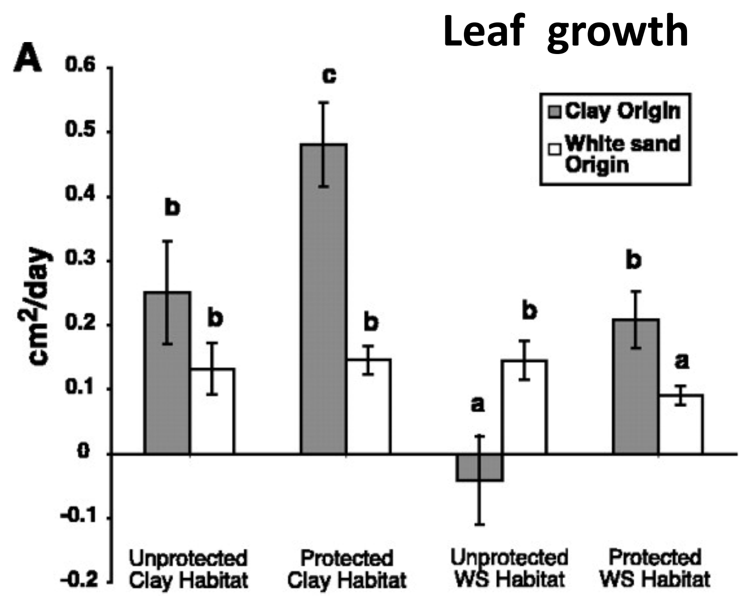
Decomposition rate of leaves correlates with specific leaf area (SLA), leaf nitrogen (N), phosphorus (P) and potassium (K)

Thin leaves have high nutrient contents and decompose easily
Thick leaves have more investment in defensive compounds (slow decomposition)

The Guianan Shield & White-sand Forest

Recall: White sand forest - a unique nutrient poor soil habitat that occurs in patches throughout the Amazon basin

White sand forest near Iquitos, Peru



Leaves on plants growing on white sandy soils tend to concentrate defense compounds that discourage herbivory (with resulting trade-offs in leaf growth)

Speciation on white sands may have resulted from strong selection for defense compounds

White-sand Forest and Blackwater rivers

White sandy soils are usually drained by *Blackwater* rivers (water appears tea-like, dark and clear, colored by tannins)

Blackwater river distribution

Confluence of the Rio Negro and the Amazon River near Manaus, Brazil:

The clear, dark Rio Negro (blackwater), a major tributary draining the white-sand soils of the ancient Guiana shield meets the muddy whitewater Amazon, rich in nutrients and sediments draining from the younger Andes

Collpas: Why eat dirt?

Many animal species ingest soil – *geophagy.* Typically involves soils high in clay content

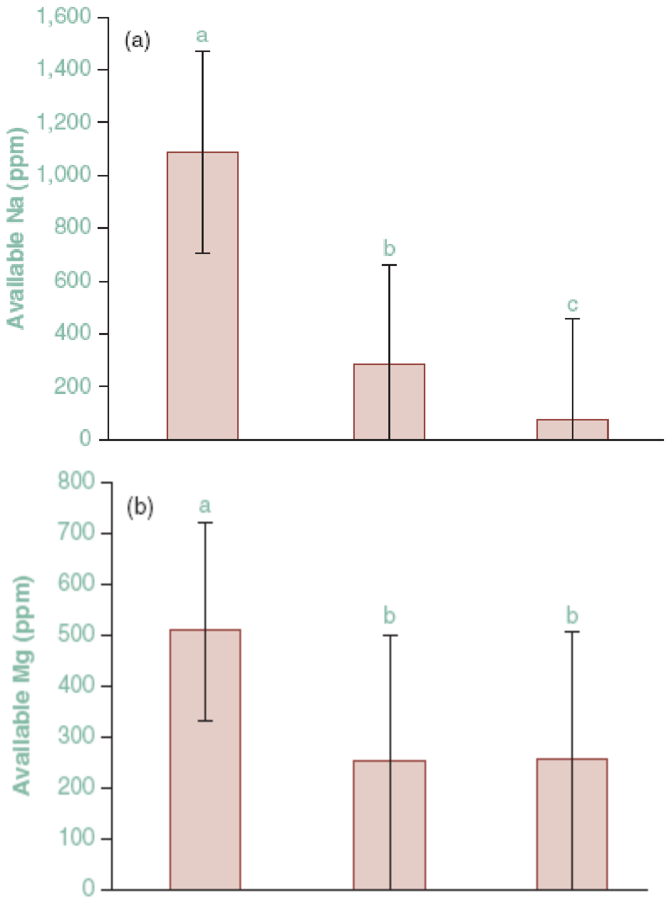
Clay has a negative charge, which can bind to potential toxins like alkaloids and phenolics

Parrots (Psittacidae) are known to attend clay licks

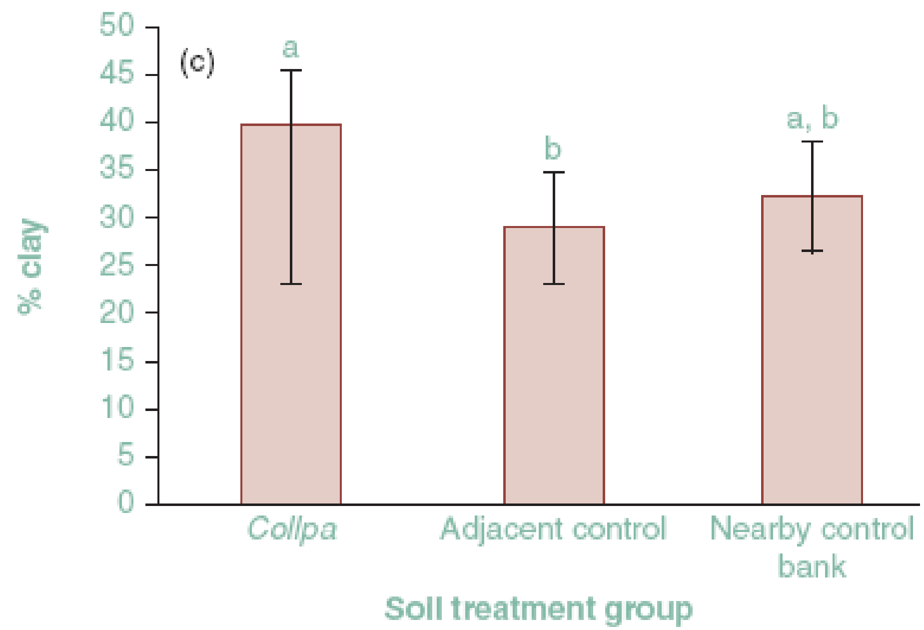
At one 500-m long clay lick, 1700 parrots of 17 species visited daily

Collpas: Why eat dirt?

Clay licks have sodium concentrations that are 6 times those available in natural foods for parrots



Soils compared from *Collpas*, unused areas of the same riverbank and unused areas of a different riverbank showed that only sodium and magnesium occurred at higher levels in clay licks vs controls.

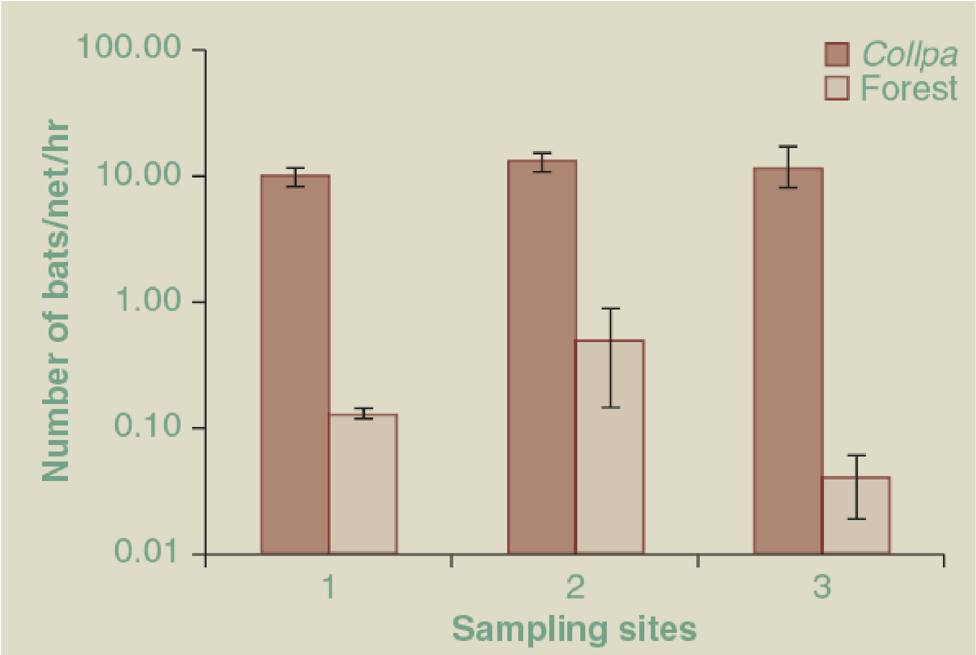


Brightsmith et al. 2008, Powell et al. 2009*, Biotropica*

Collpas: Why eat dirt?

Many mammals (monkeys, peccaries, rodents and bats) visit clay licks, too

Bats in the family Phyllostomidae visit clay licks to drink water accumulated in depressions caused by other large animals (all visiting bats were fruit bats)



70% of those captured at *collpas* were pregnant or lactating females (away from *collpas*, females made up 44% of captures)

Fruit is poor in certain essential minerals (sodium and calcium)

Bravo et al. 2008, *Biotropica*

Herbivores & Nutrient Flux

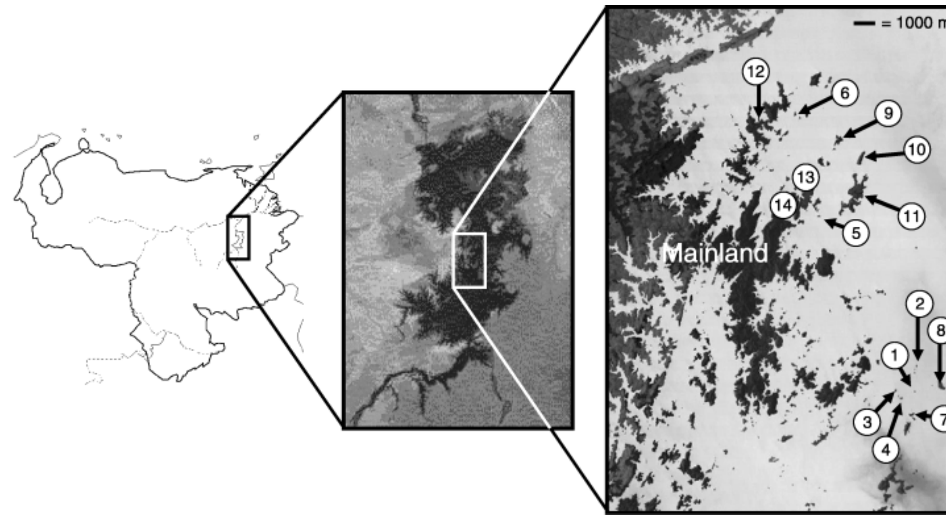
Herbivores can exert strong top-down effects on plant composition and productivity – Case study of the Lago Guri Islands, Venezuela

Lago Guri was formed in 1986 by the creation of a large hydroelectric reservoir in eastern-central Venezuela (near confluence of Caroni and Orinoco Rivers)

Caused inundation of 4300 km2 of hilly terrain, permanently flooding contiguous lowland forest and leaving hilltop islands

This trapped many animals on newly formed islands, including Red howler monkeys, by up to 10 km of open water

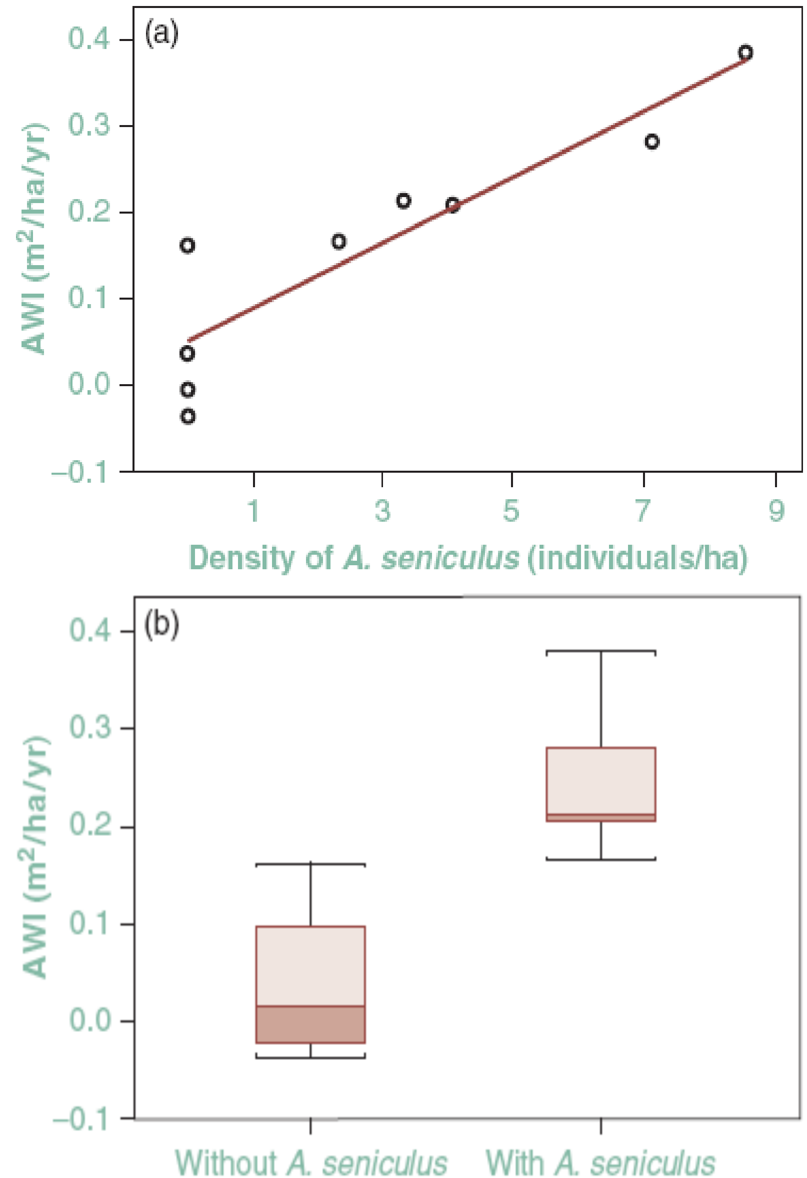
Red howler density has increased up to 30 times that in mainland forest

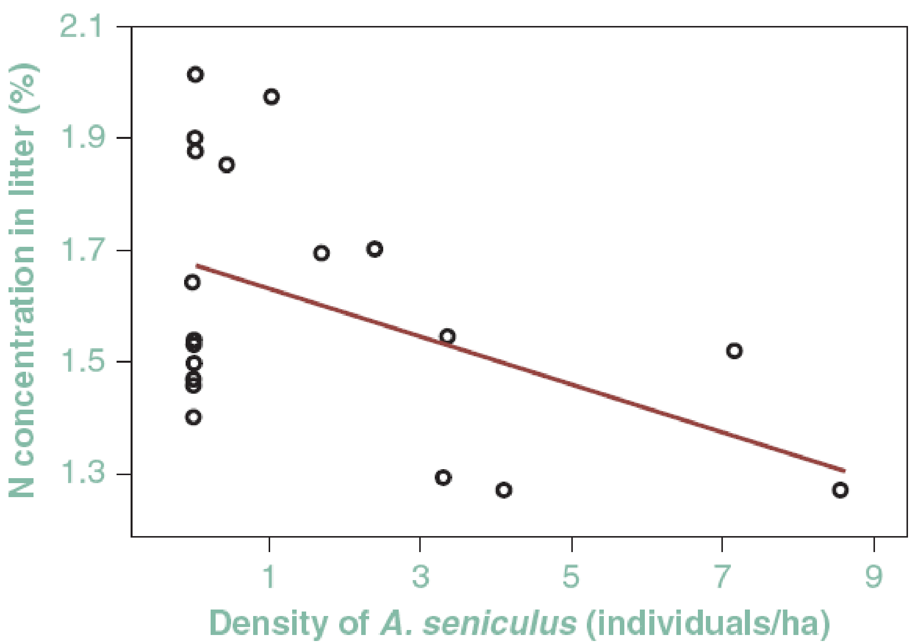


Herbivores & Nutrient Flux

Found striking results across the islands:

- Nitrogen concentration was negatively correlated with monkey density
- Soil C:N ratio increased with monkey density
- Annual woody increment (AWI) increased with monkey density



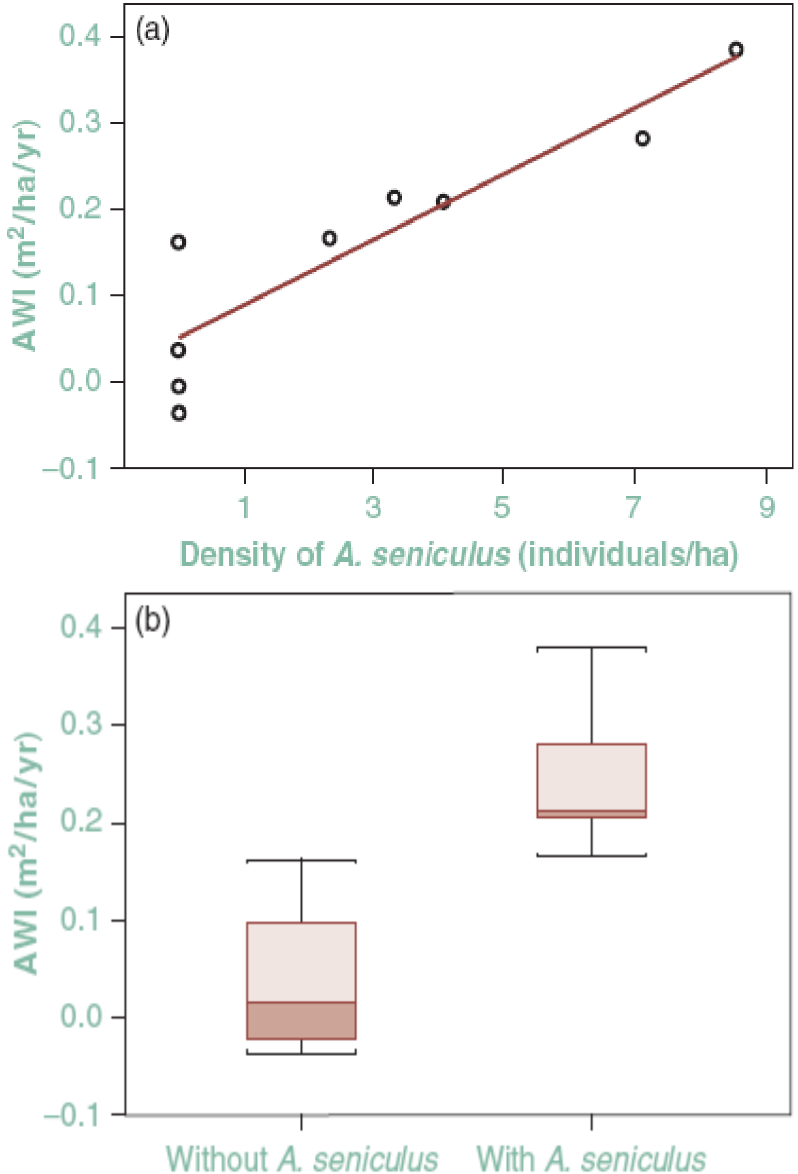


Herbivores & Nutrient Flux

Howler monkeys are highly selective foragers on leaves – islands with howlers had very different tree communities, with high abundances of species that howlers avoid (e.g., *Ocotea glomerata* with high defense compounds)

Greater AWI of islands with monkeys was due to growth of species released from competition from species that monkeys prefer

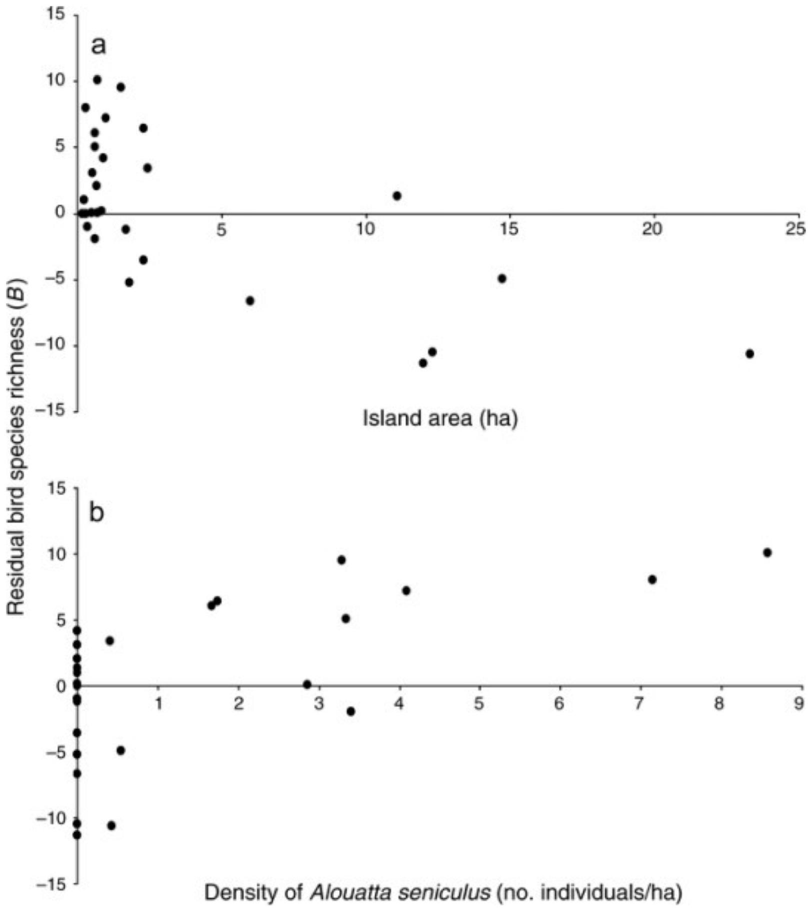
Loss of litter fertility (C:N ratio) probably due to slower rates of litter decomposition of well defended plants

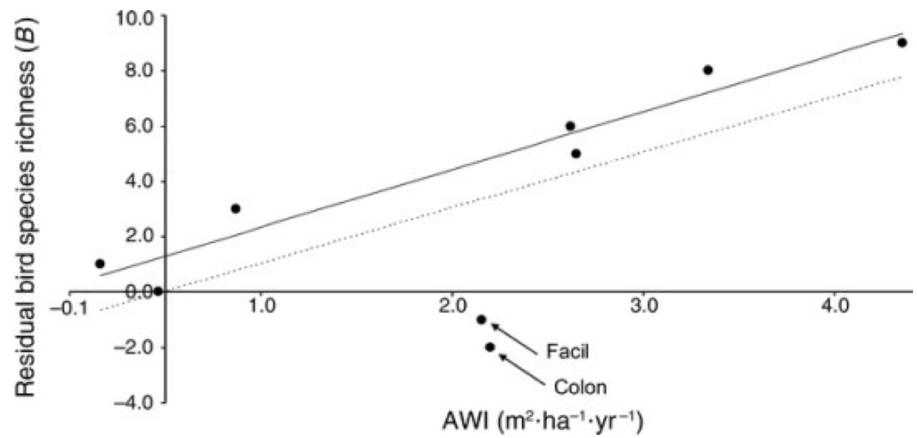


Herbivores & Nutrient Flux

Change in plant species composition on Lago Guri islands occurred in only 17 years

- Indirect effects on other communities (positive effects on bird richness)
- Islands with monkeys are clearly not in equilibrium, as nutrient availability declines





Understory of an herbivore-impacted island compared to normal dry forest

Feeley & Terborgh 2006, *Ecology*