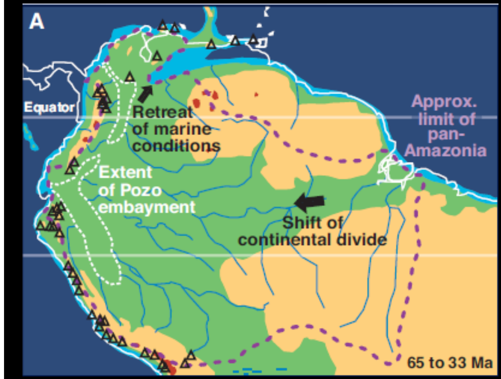
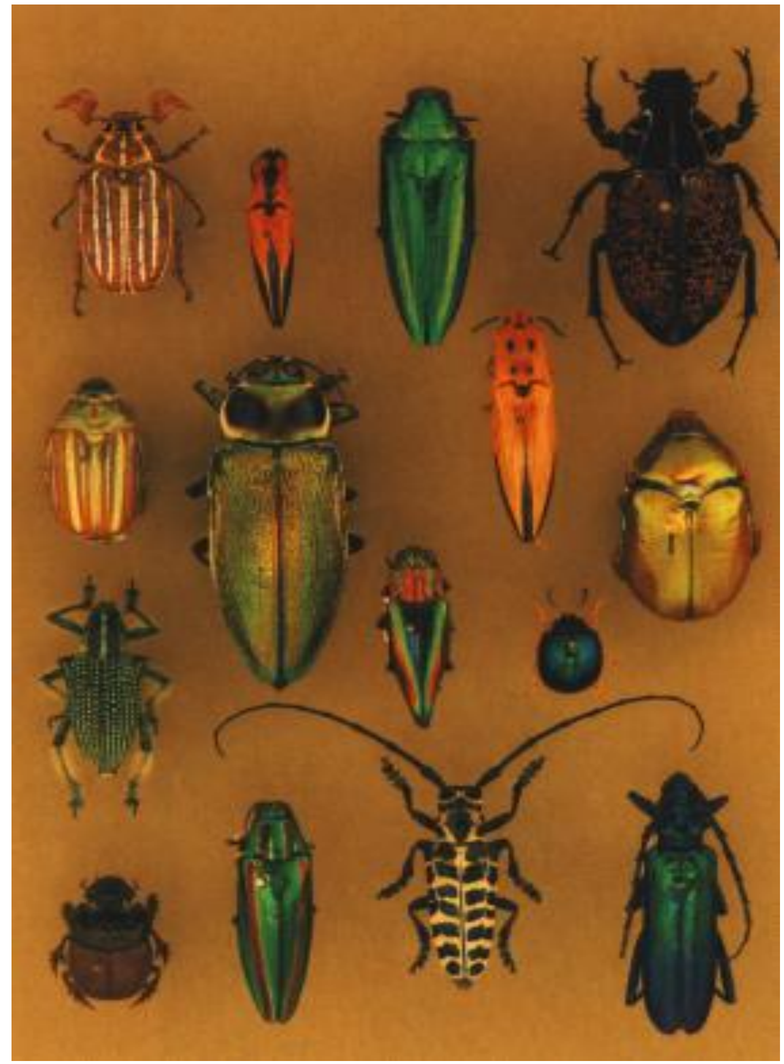
THE AMAZON:

An Ecologist's Introduction

1. Amazon across Time
2. Current Amazon: Ecosystems, Climate and Soils
3. Structure and Dynamics of the Amazon
4. Amazon Diversity
5. Thoughts about a Changing Amazon

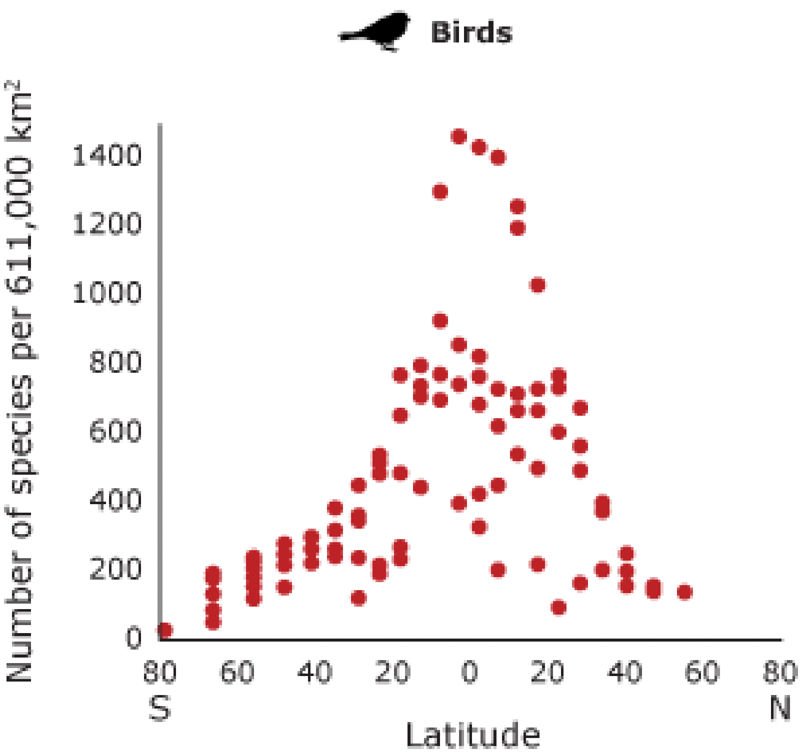


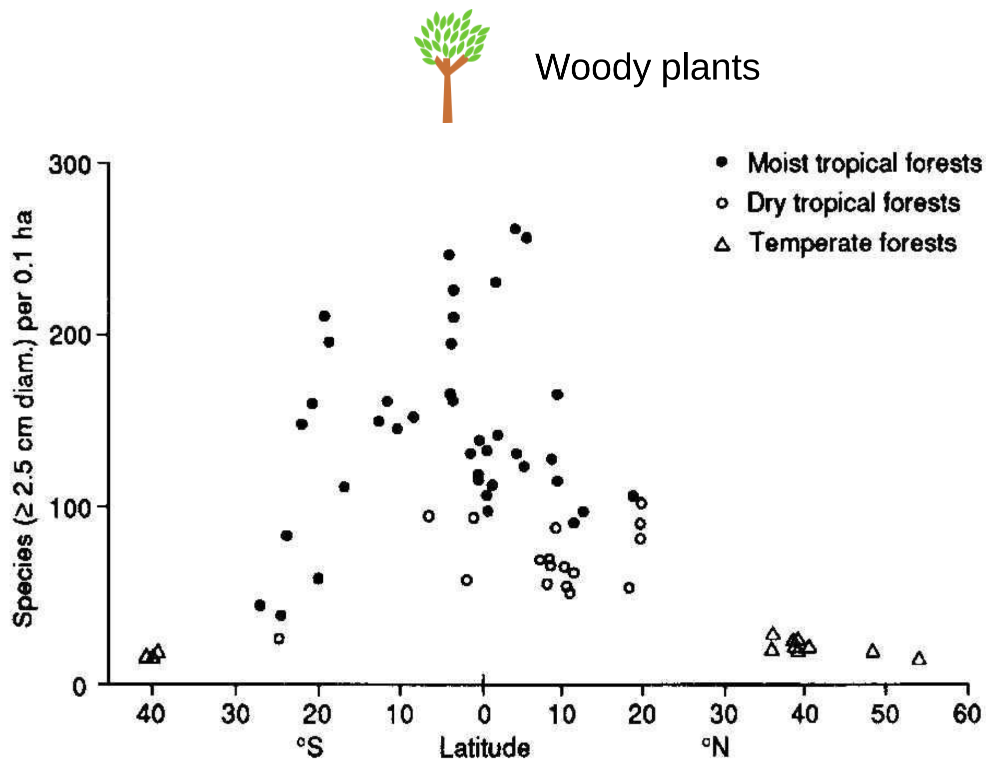
Amazon: "the most species-rich terrestrial ecosystem in the world"



Terry Erwin

Latitudinal diversity gradients: more species in the tropics

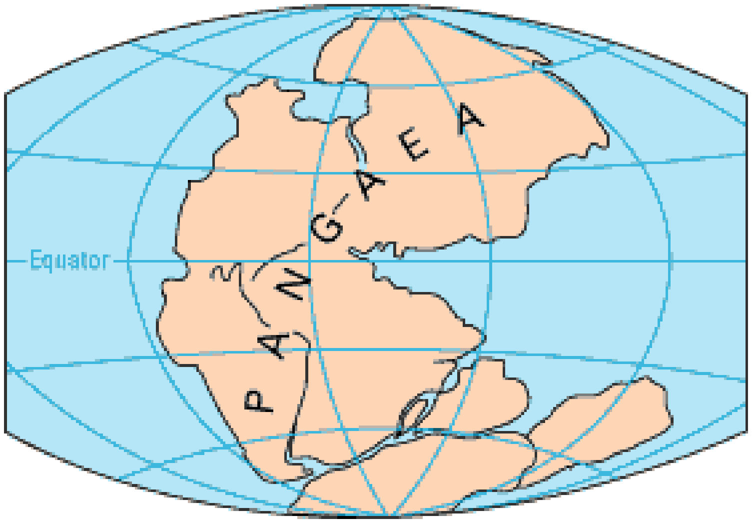




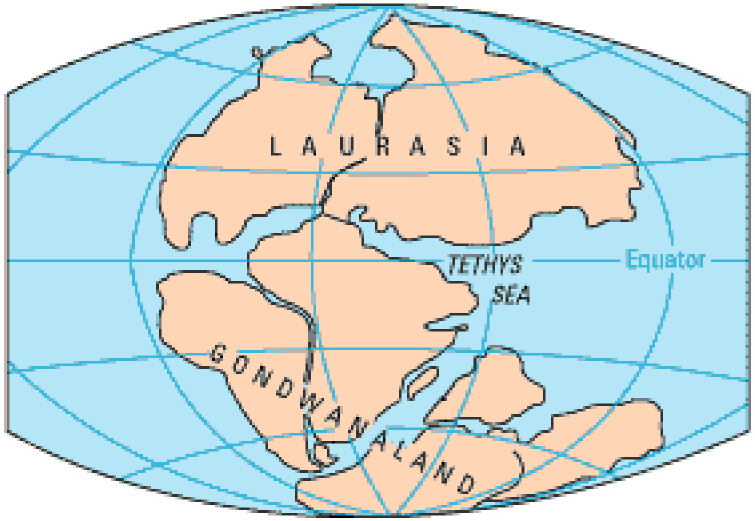
Gaston (2000)

Gentry (1988)

Present diversity in the Amazon reflects the dynamic geologic history of South America



PERMIAN
225 million years ago



TRIASSIC
200 million years ago

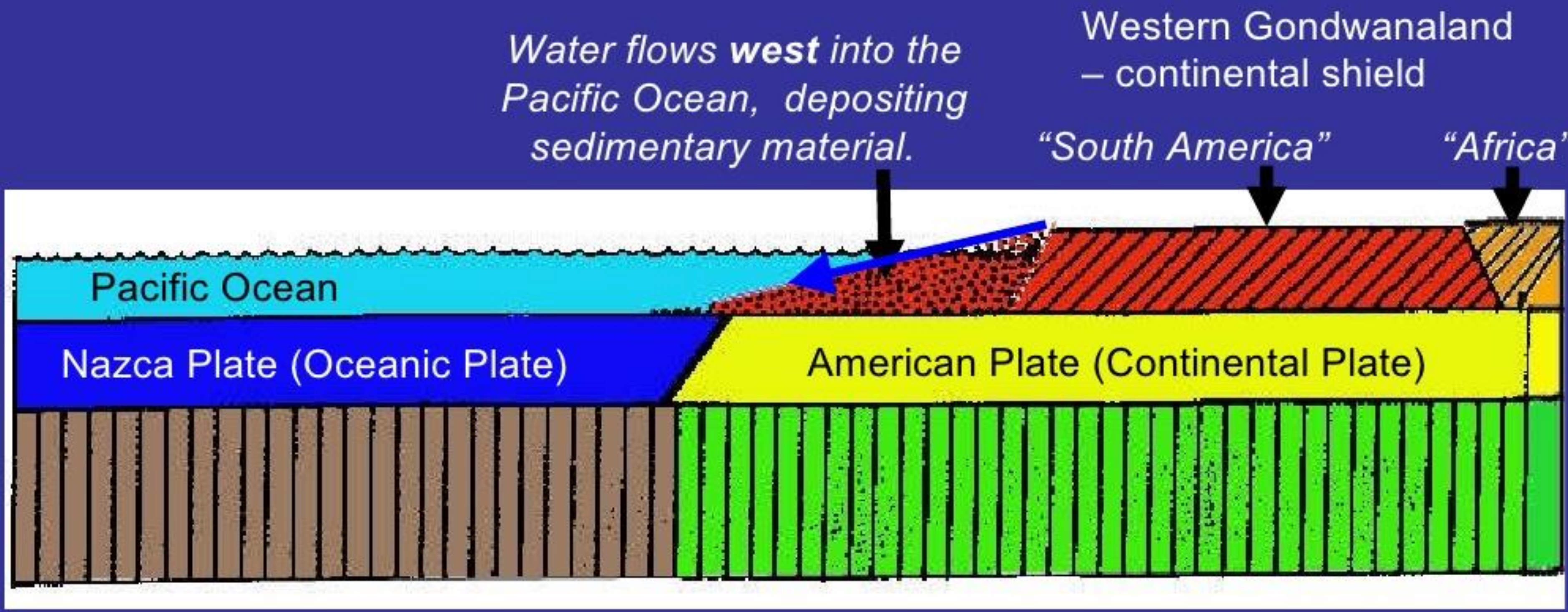
Paleozoic (570-225 MYA): Amazon a giant gulf opening westward to Pacific. Sediments from this gulf are today's soils

Carboniferous (345-280 MYA): seas recede

Mesozoic (225-65 MYA): land was dry with rivers flowing to Pacific

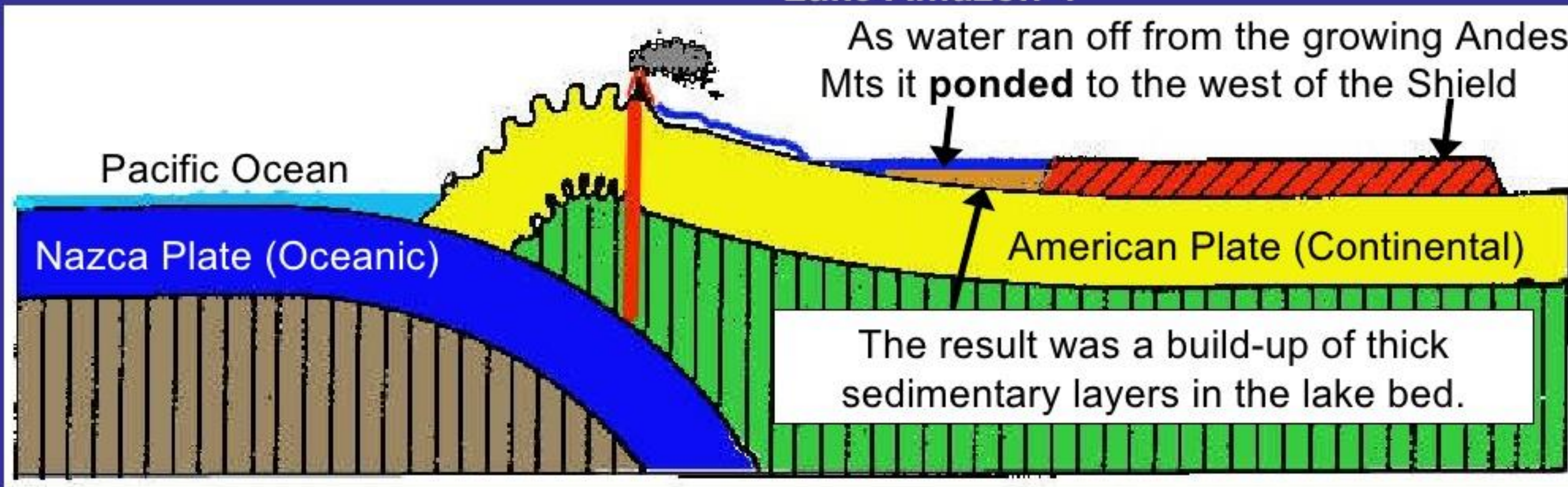
Stage One: "PRE-ANDEAN STAGE" – approx 200 million years ago

(Jurassic)

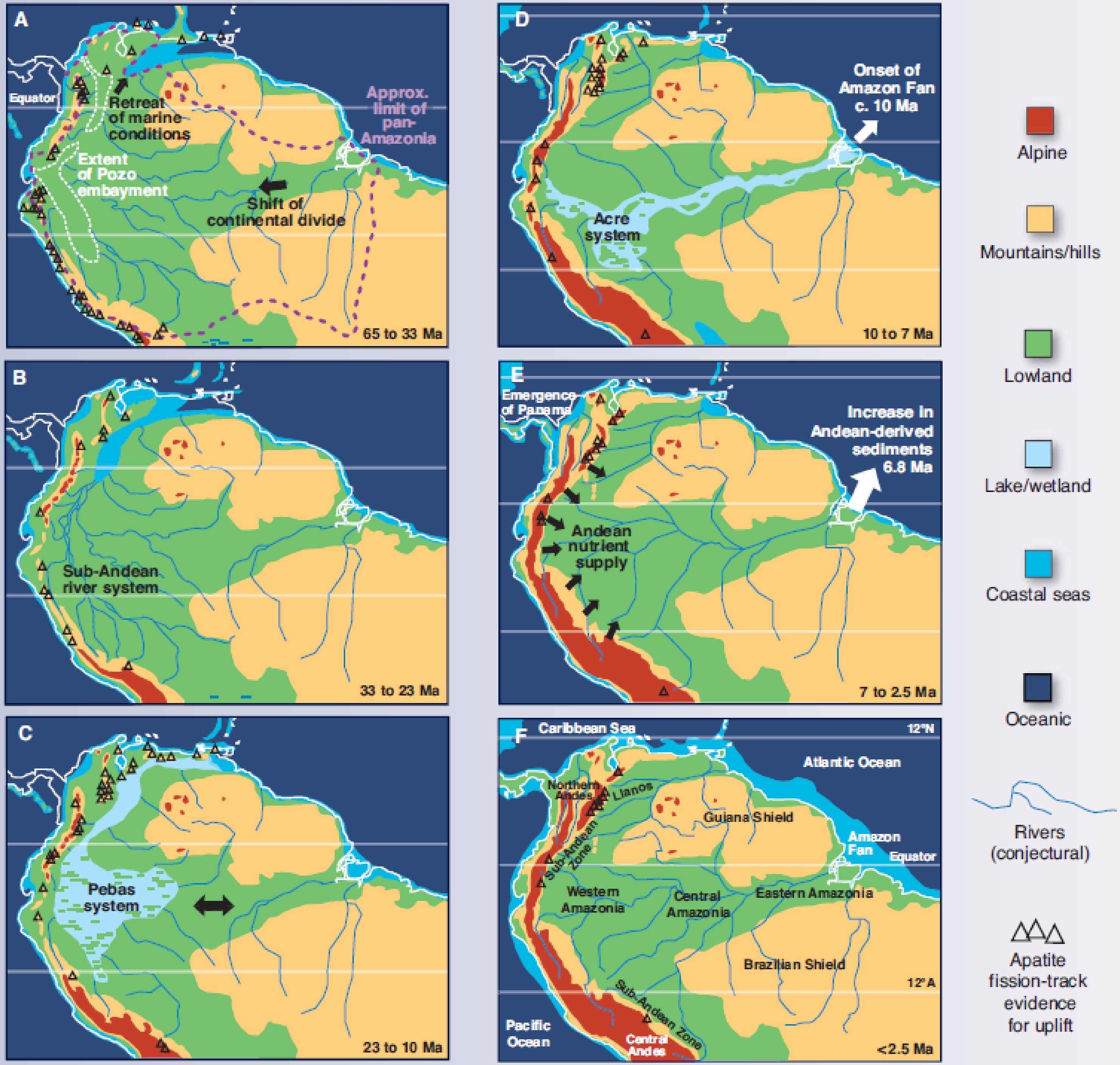


This was before the Andes Mountains were formed by subduction, folding and volcanism. There was no Amazon Basin at this stage.

Stage Two: "ANDES AND AMAZON LAKE STAGE" – approx 180 million years ago (continued) (Jurassic)



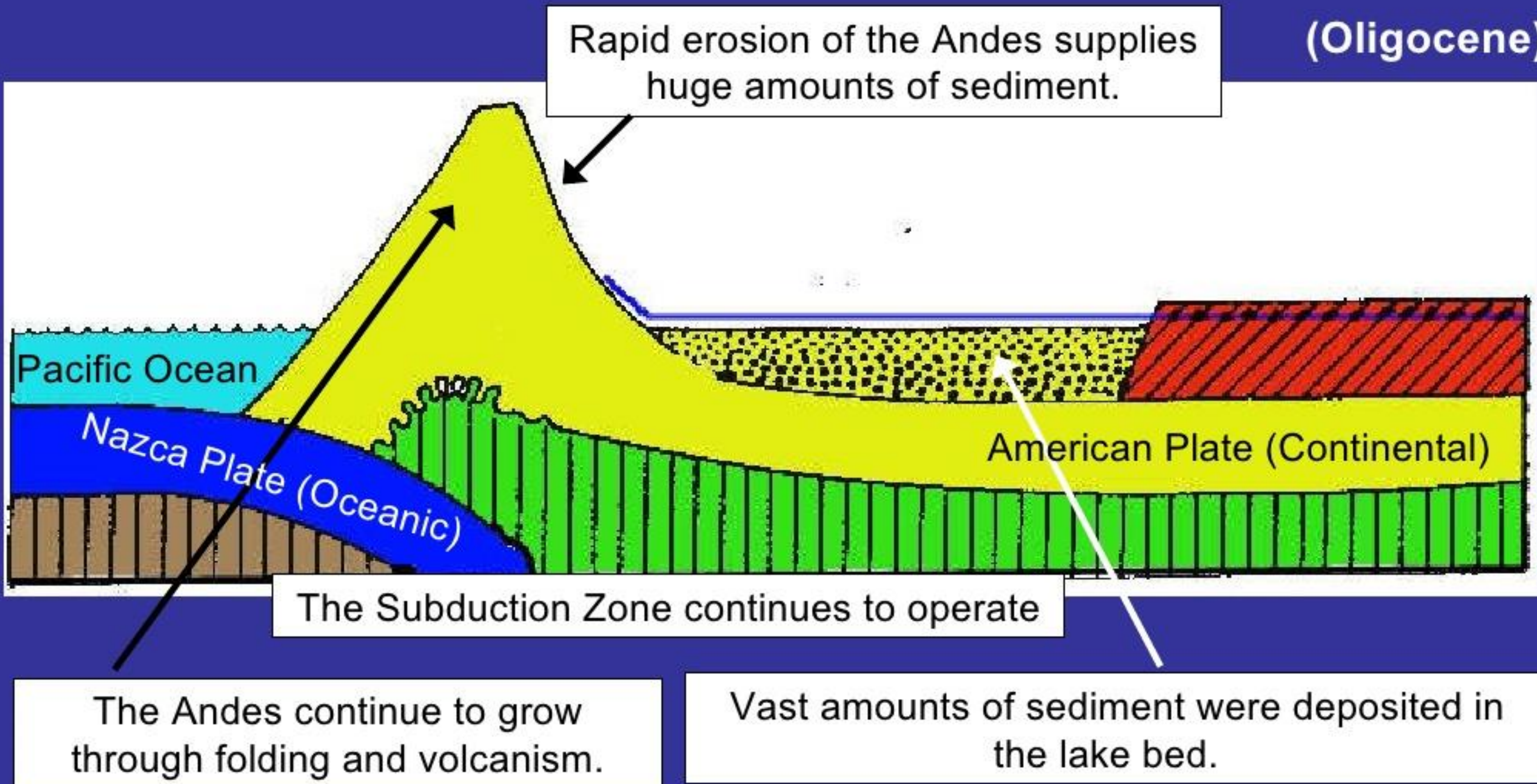
As water flowed eastwards from the Andes it ponded to the west of the Shield. This led to the formation of the Amazon "Lake", trapped between the Andes and the Shield.



Hoorn et al. (2010)

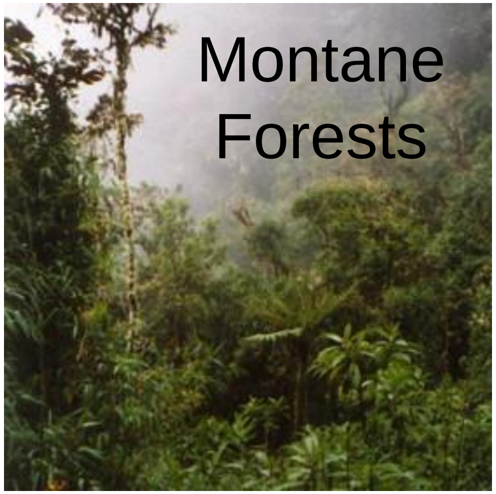
Stage Three: “AMAZON RIVER STAGE” – approx 24 million years ago

(Oligocene)



Ibidos: the point where the Amazon broke through a weakness in the Shield to flow eastwards. Today it is the narrowest and deepest part of the Amazon channel.

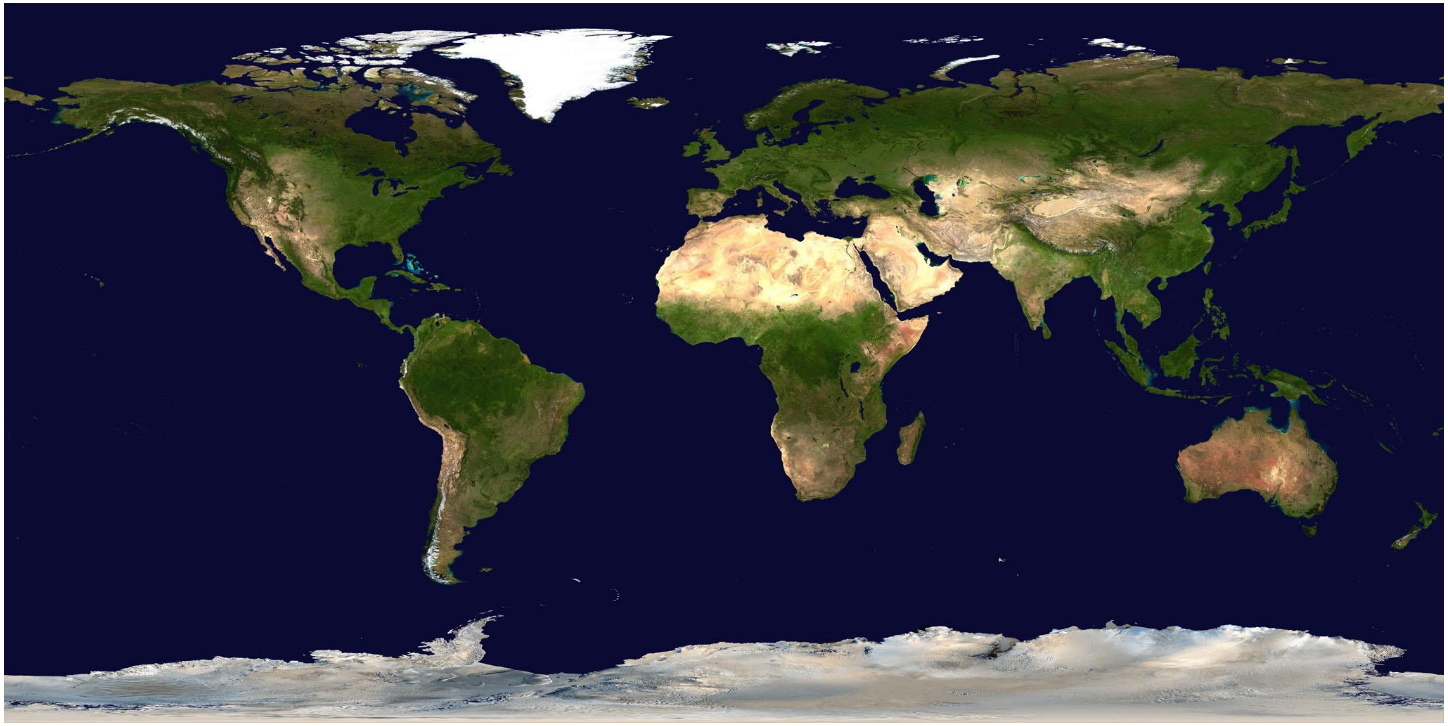
Ecosystems of the Amazon



Flooded forests

Upland forests

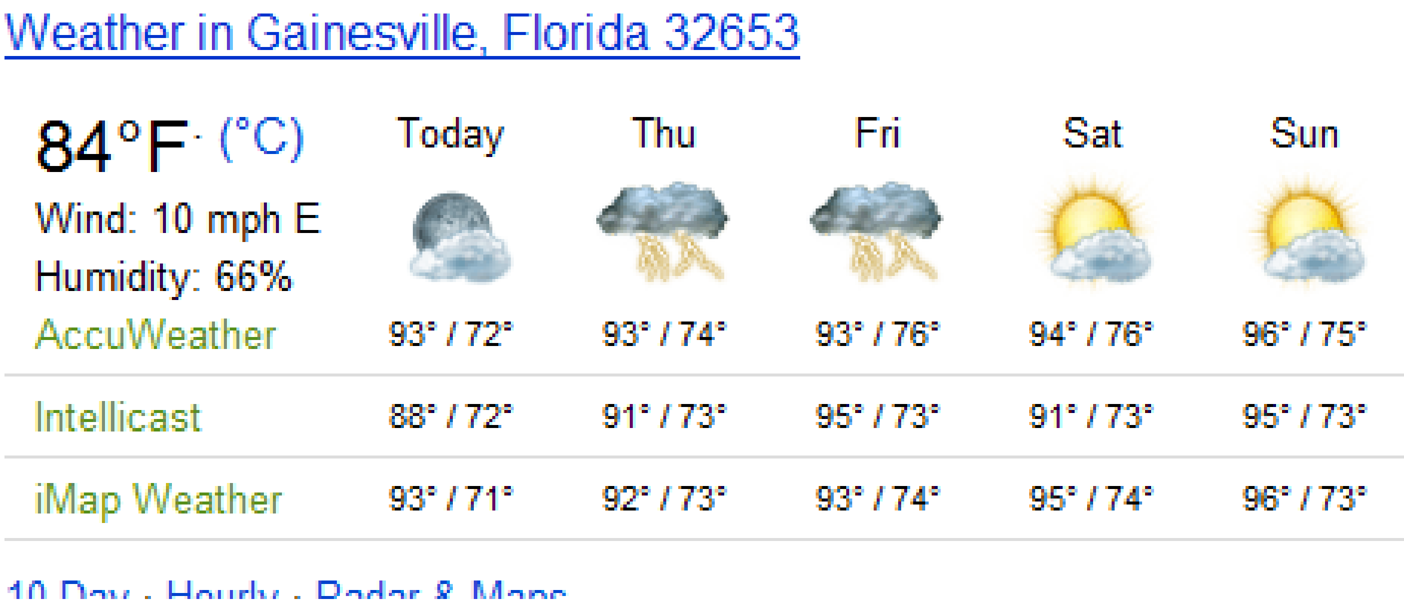
The physical environment drives the distribution of organisms (and these ecosystems) at the global scale…



1. Radiation from the sun (drives the climate system)
2. Chemical environment (salinity, gasses, acidity)
3. Climate (temperature and rainfall)
4. Soil (nutrient supply, medium for growth of organisms)

Weather vs. Climate

Weather: present condition at a site
(and short term variation in these conditions)

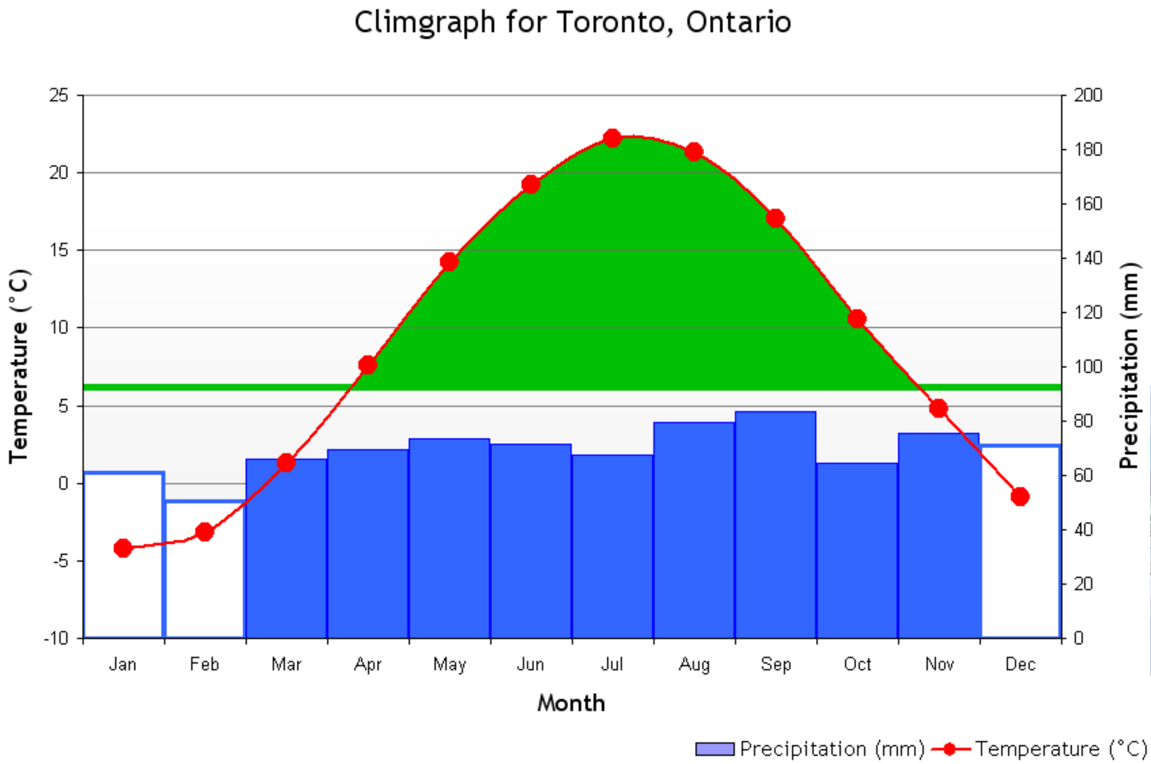


Weather in Gainesville, Florida 32653

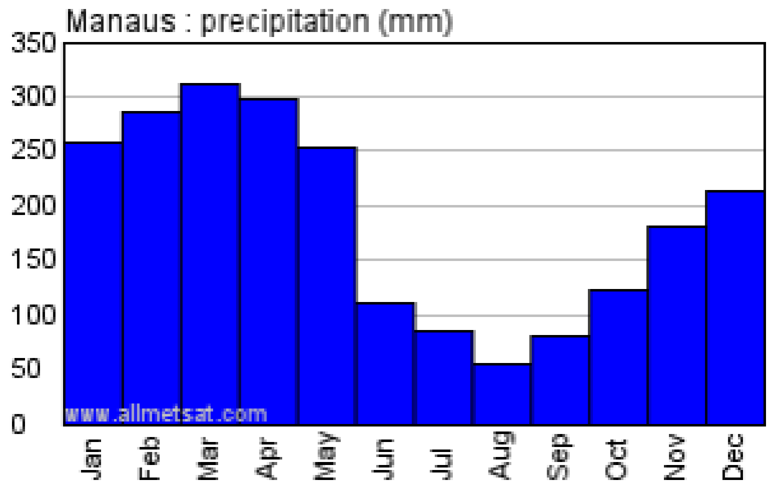
84°F · (°C) Wind: 10 mph E Humidity: 66%	Today	Thu	Fri	Sat	Sun
AccuWeather	93° / 72°	93° / 74°	93° / 76°	94° / 76°	96° / 75°
Intellicast	88° / 72°	91° / 73°	95° / 73°	91° / 73°	95° / 73°
iMap Weather	93° / 71°	92° / 73°	93° / 74°	95° / 74°	96° / 73°

10 Day - Hourly - Radar & Maps

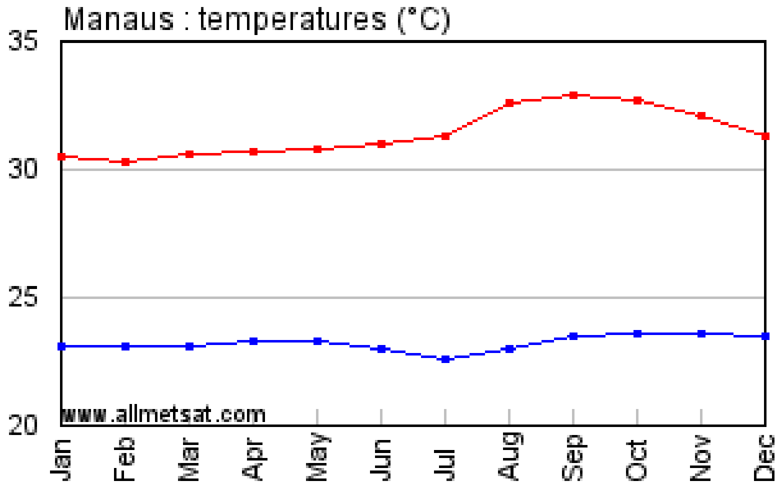
Climate: the average weather condition over longer time scales (e.g., 30 yr avg.)



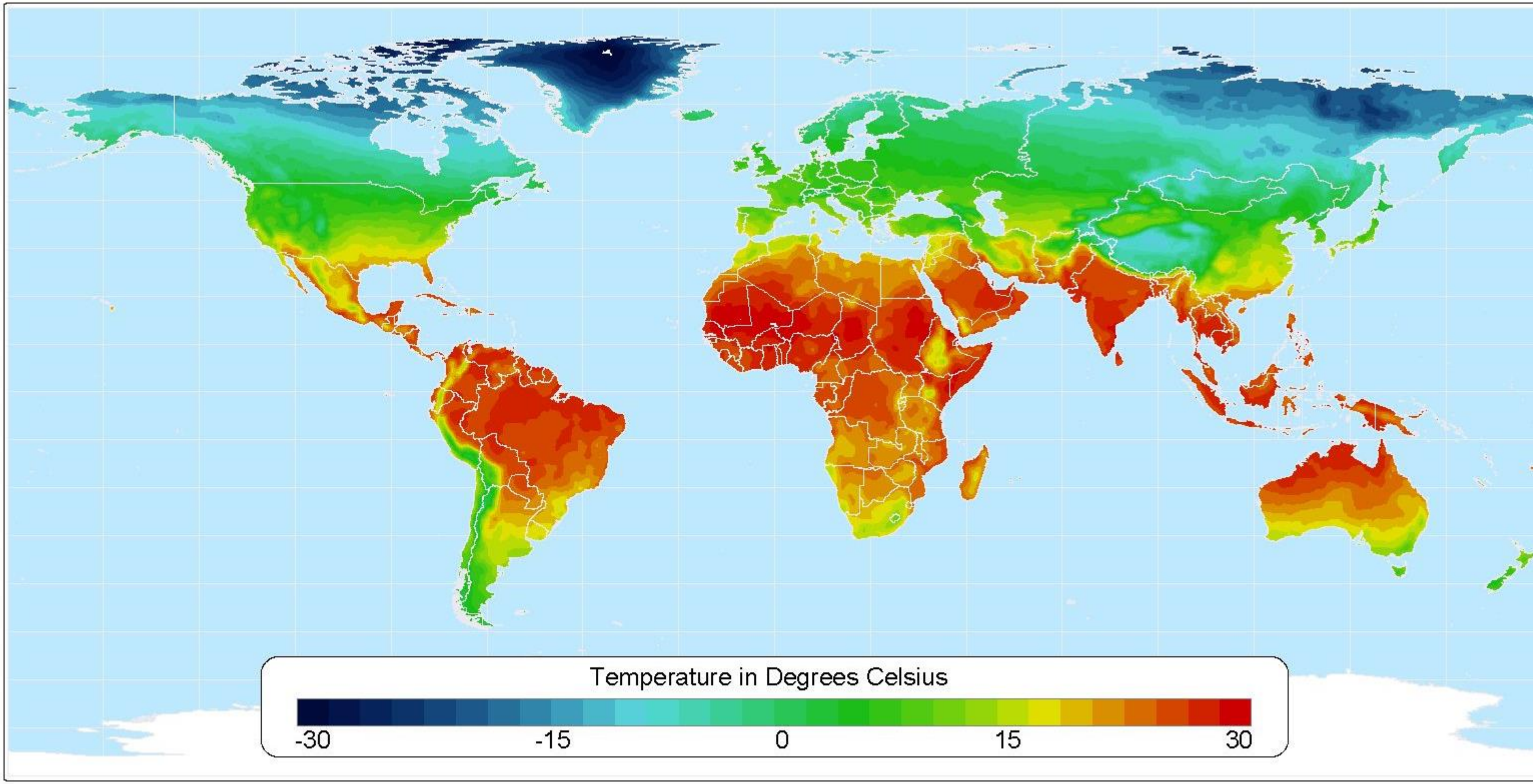
Manaus, Amazonas, Brazil Average Yearly Precipitation



Manaus, Amazonas, Brazil Average Annual Temperatures



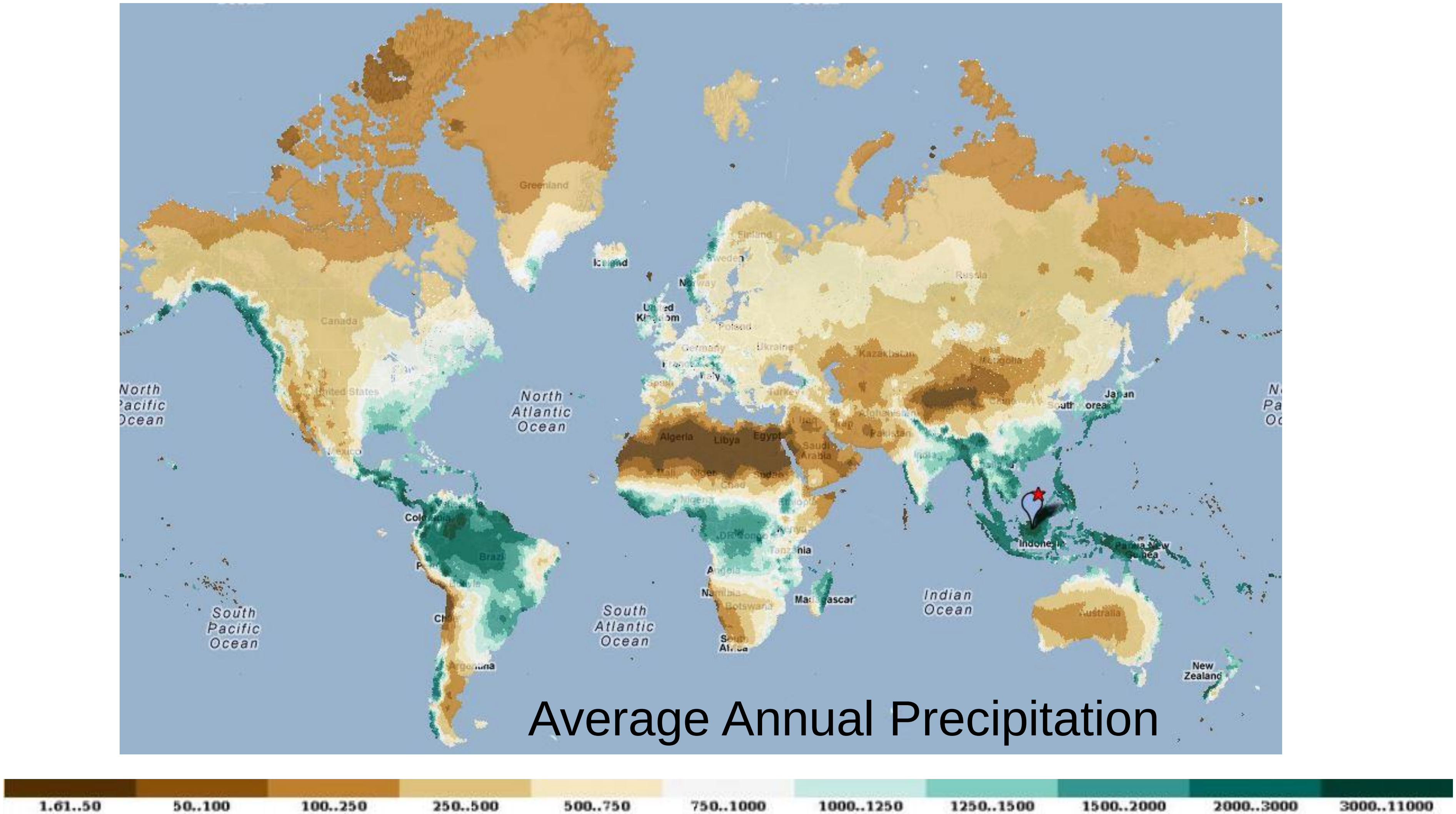
Broad generalization: the tropics experience
1) high & constant average temperature



Data taken from: CRU 0.5 Degree Dataset (New, et al.)

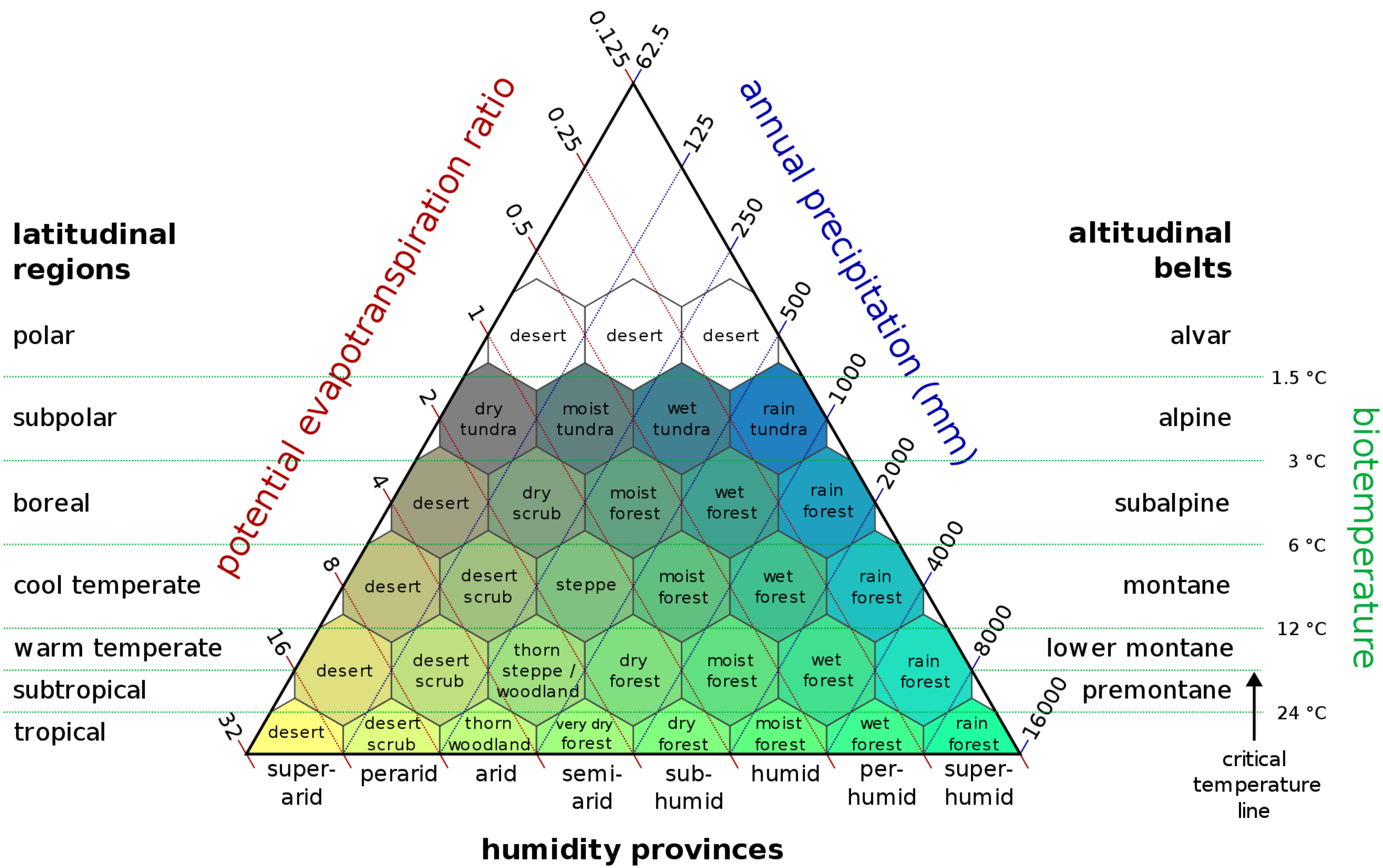
Atlas of the Biosphere
Center for Sustainability and the Global Environment
University of Wisconsin - Madison

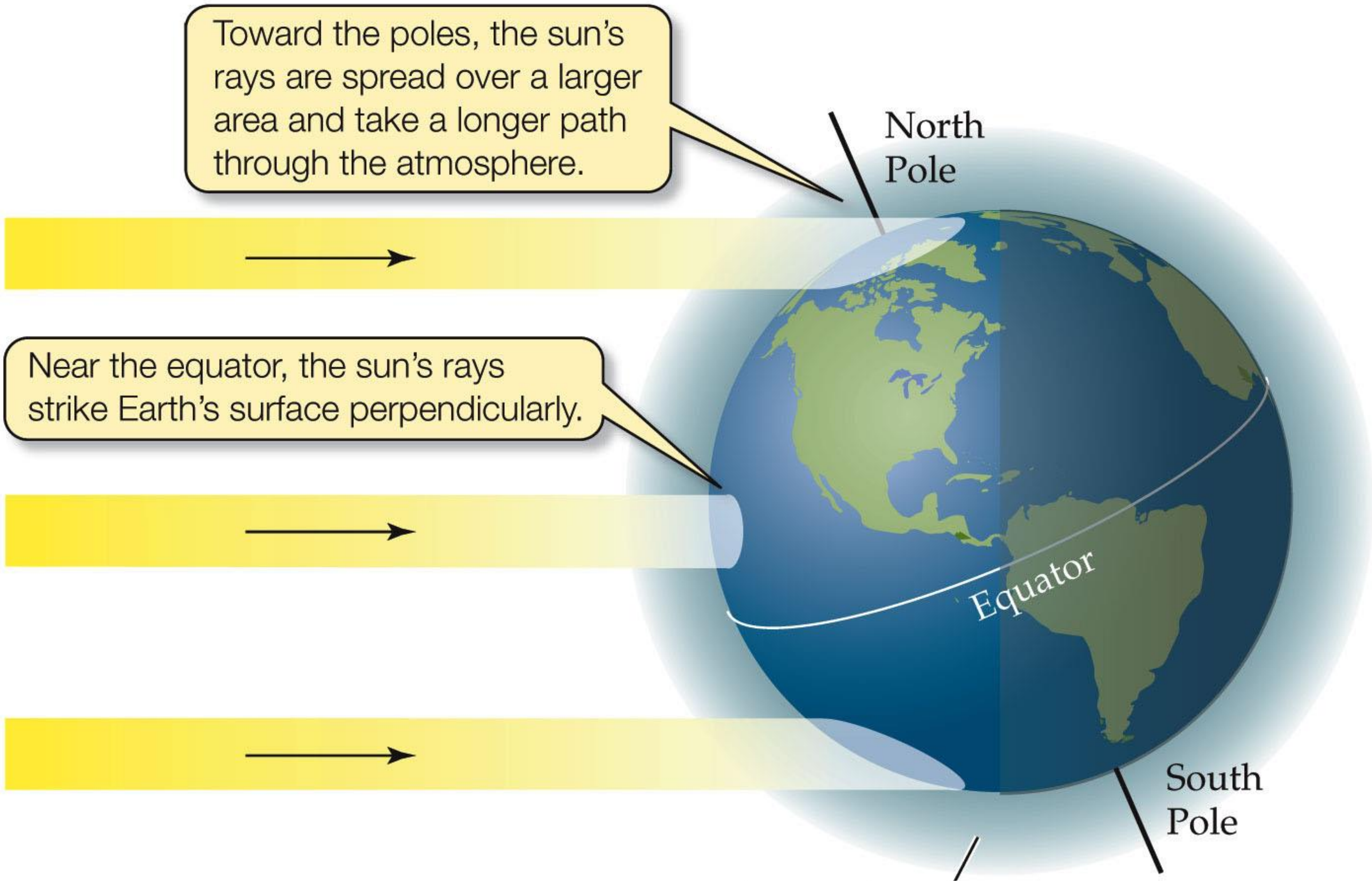
Broad generalization: the tropics experience 2) high (often seasonal) precipitation



http://globe.umbc.edu/documentation-overview/global-variables/average-annual-precipitation/

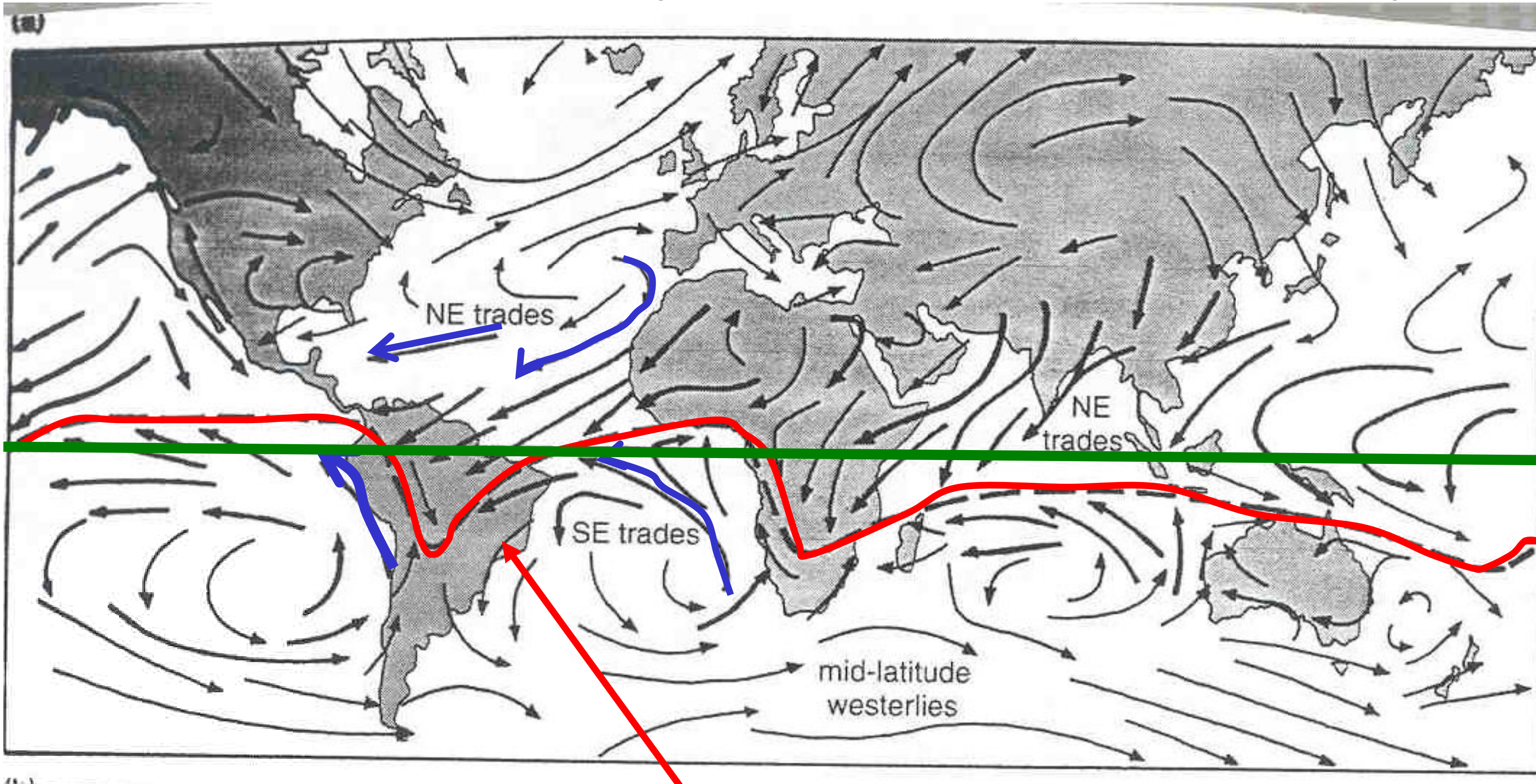
Holdridge's Life Zones: predict terrestrial ecosystem in a region with
(1) precipitation
(2) biotemperature
(3) Ratio of mean potential evapotranspiration to mean annual precipitation





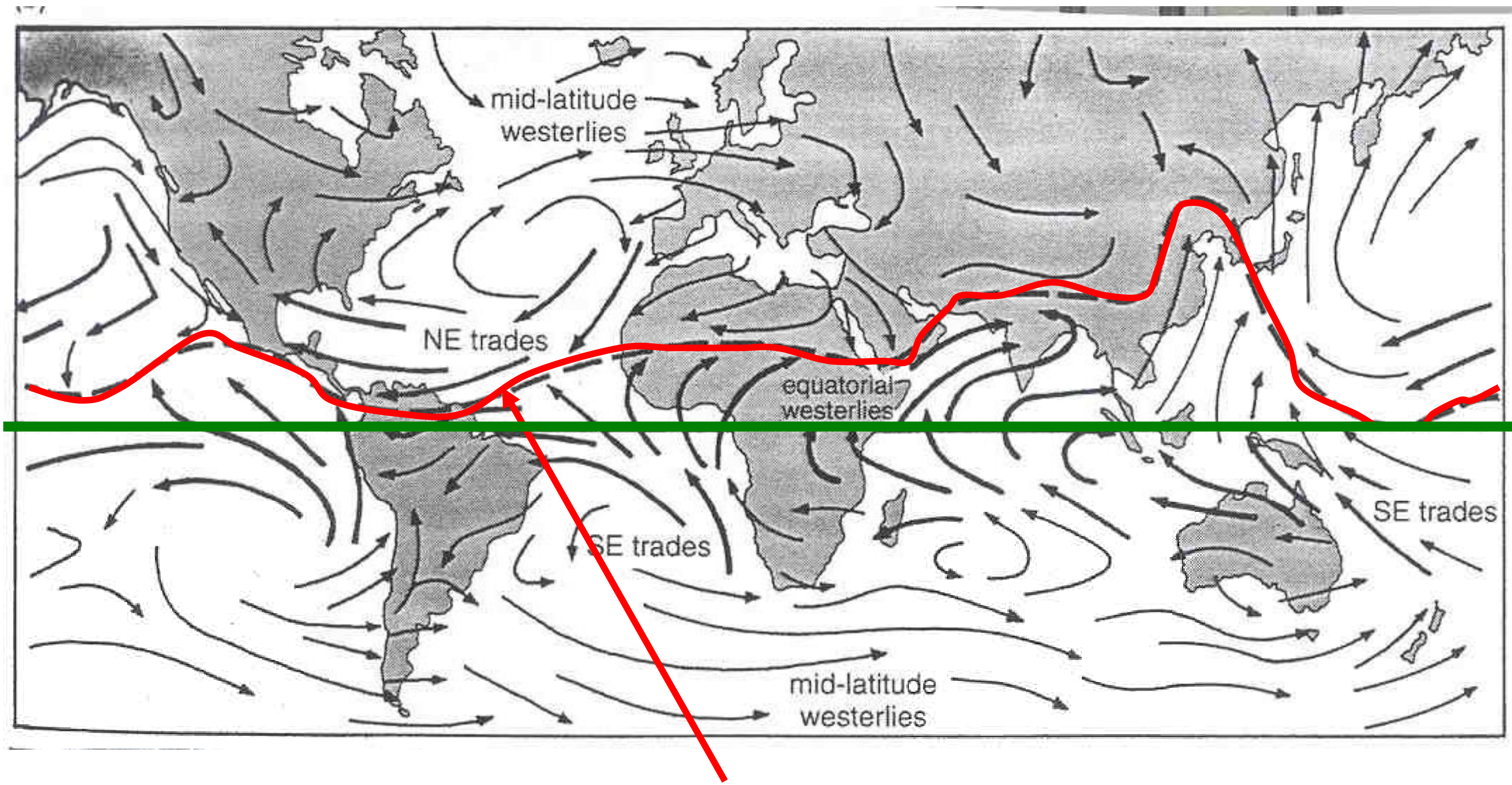
Result: Longer Days, More sunlight

Cells and the Rotation of the Earth (Coriolis Effect) cause deflections of the wind (which influence surface currents)



Inter-Tropical Convergence Zone

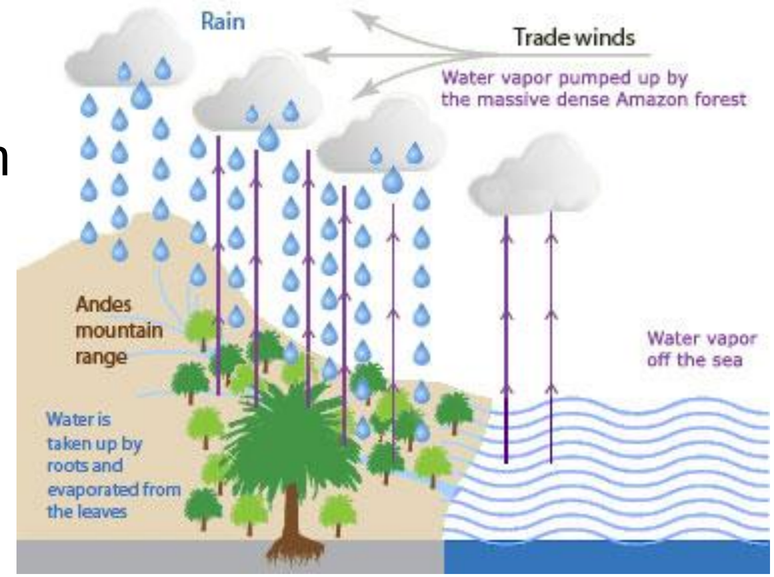
The ITCZ moves with the seasons

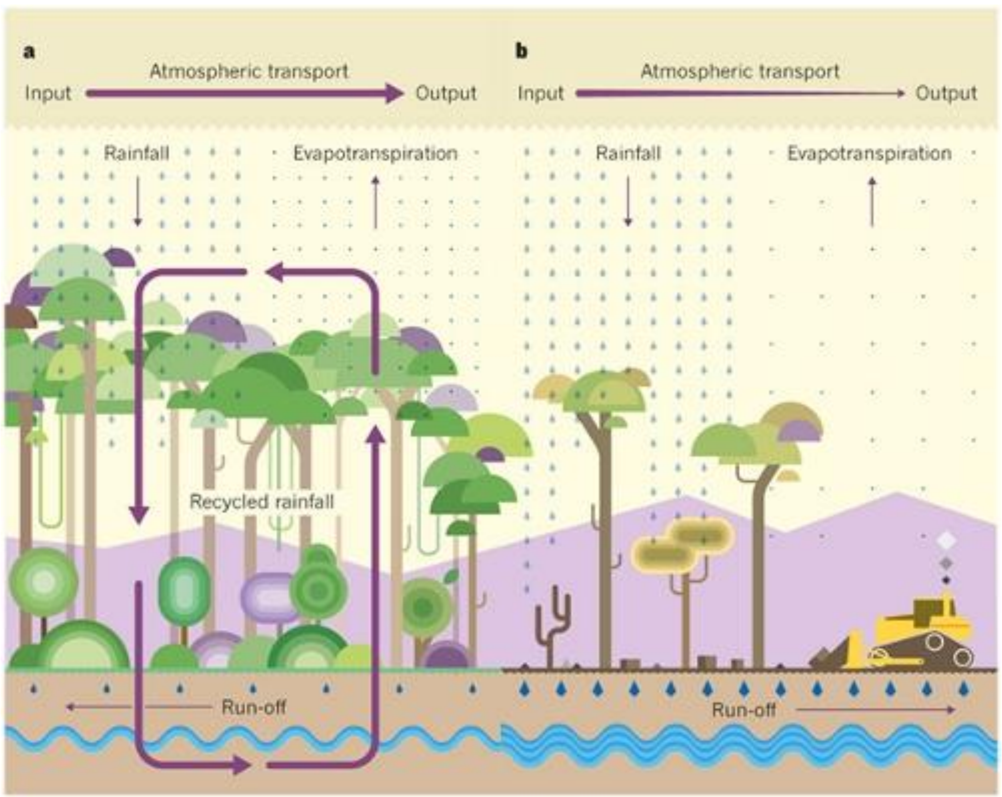


Inter-Tropical Convergence Zone (Global: ITCZ Regional: ITCZ)

Rainfall: Where does it all come from?

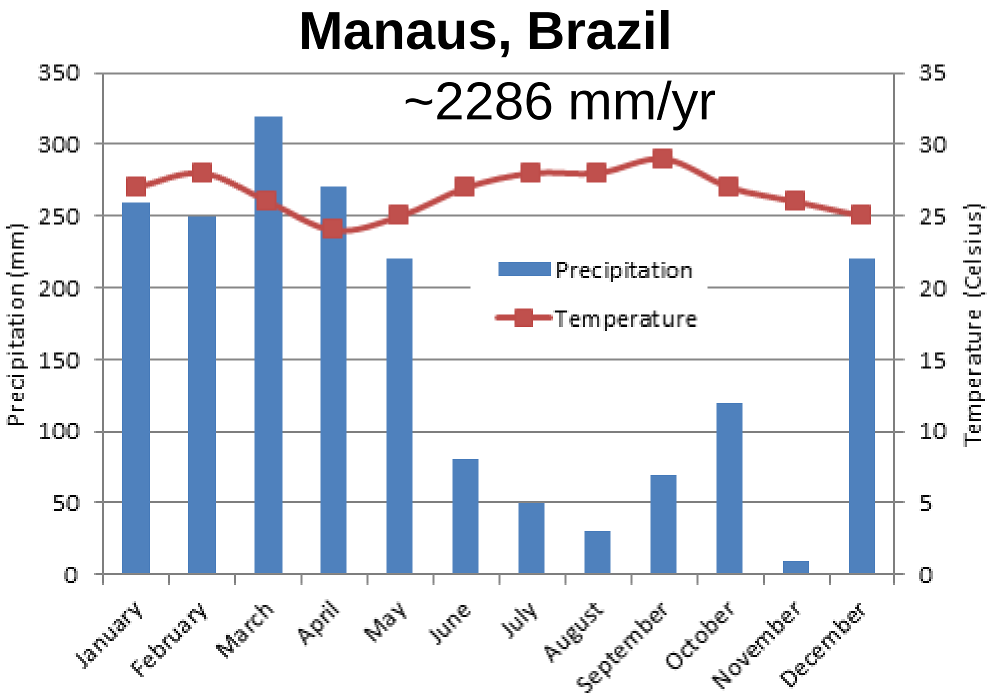
Warm, moist air cools as it rises, condensing water which falls as precipitation

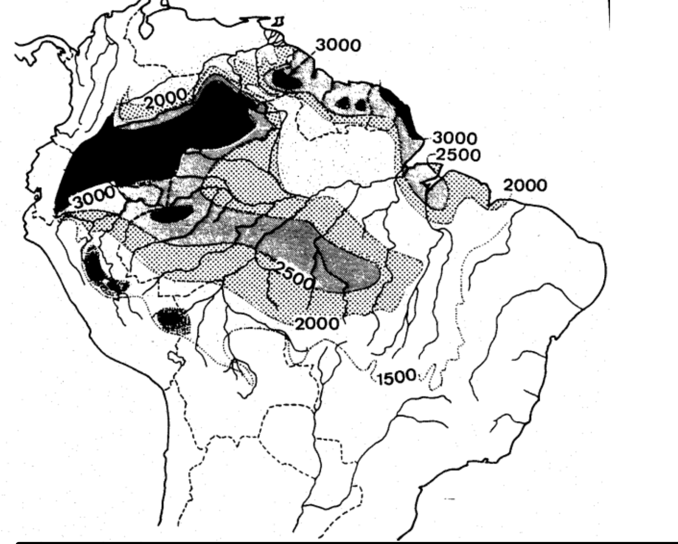




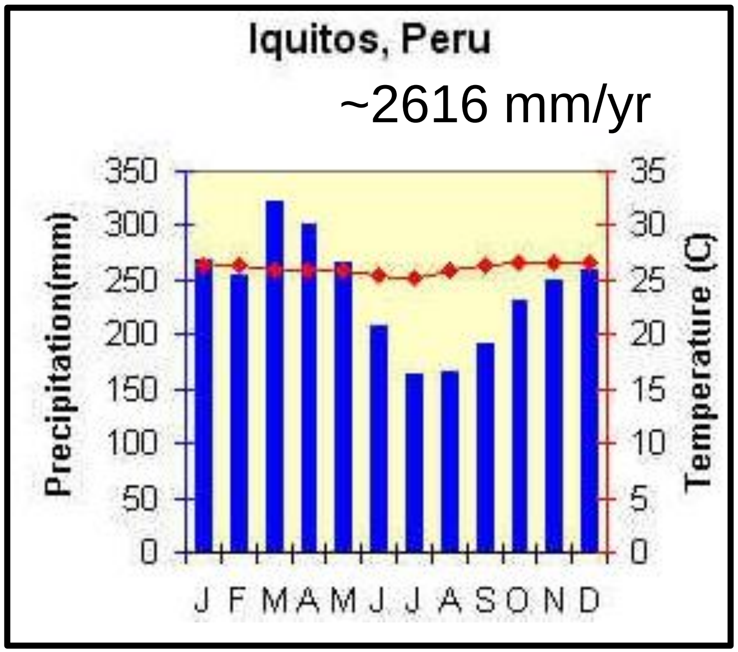
~50% brought into basin by eastern trade winds

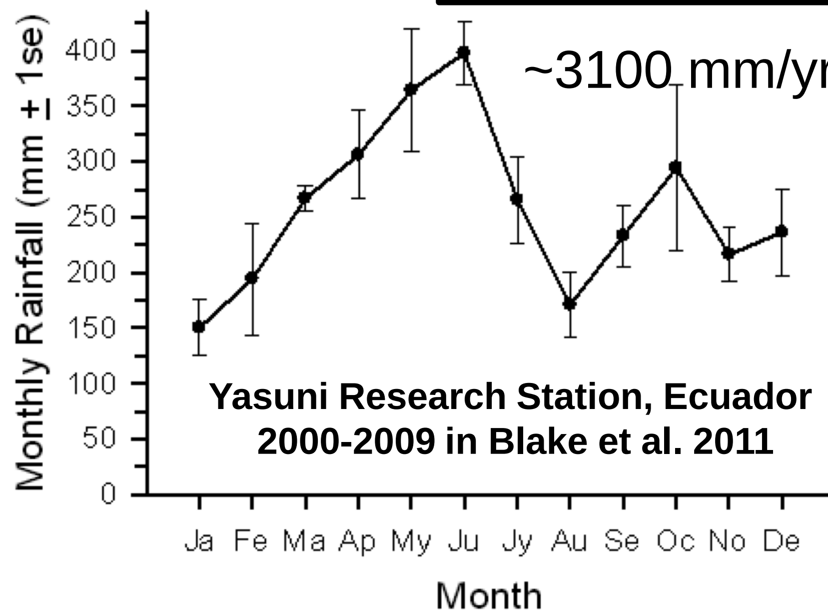
~50% from evapo-transpiration of forests





Manu National Park, Peru
~2000 mm/yr
Oct-April: rainy season
May-Sept: <100mm/month



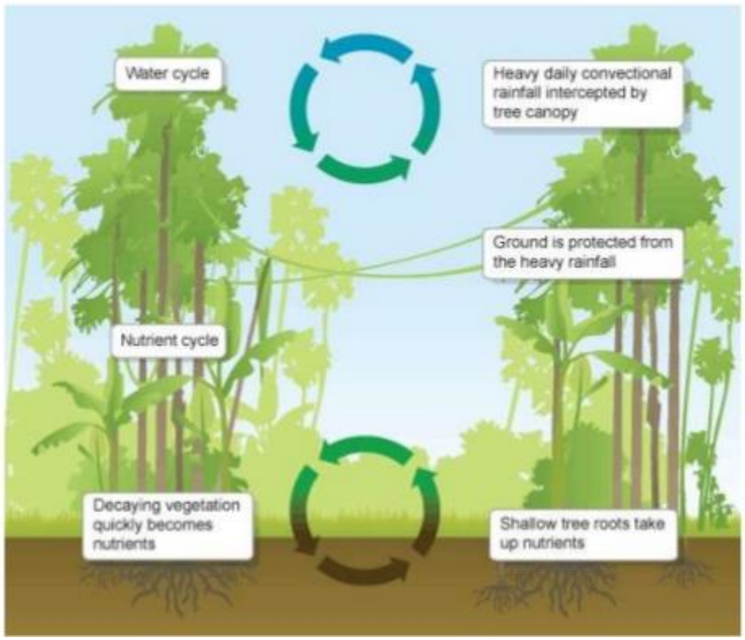


Ecology of Amazon is driven by two major physical factors

#2 Soils (and nutrient cycling)

oxisol

dark earth or terra preta



Like rainfall, there is no "typical" Amazonian soil or pattern of nutrient cycling – both can be highly variable

What Contributes to Variation in Soils?

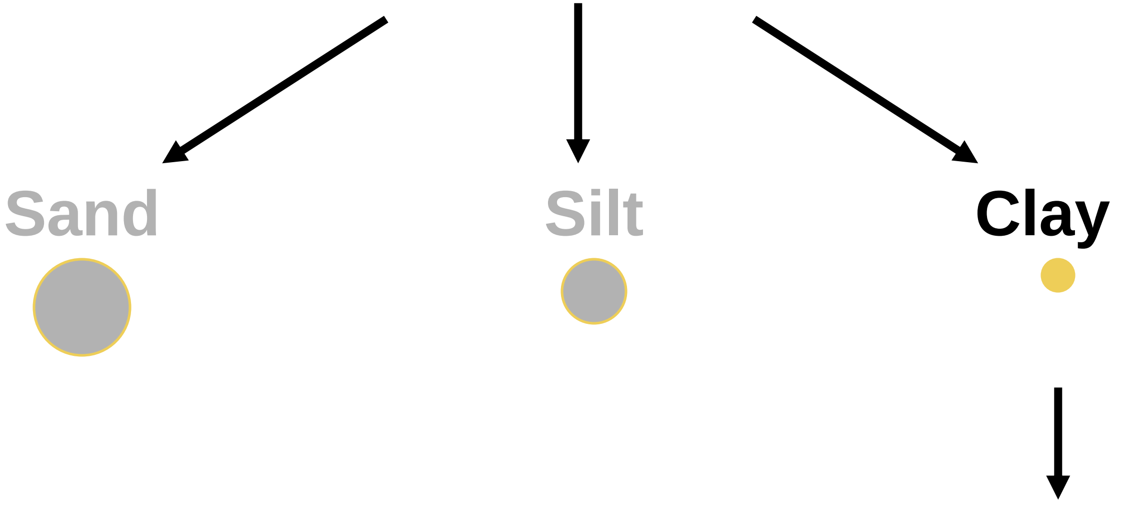
- Climate
- Topography
- Parent Material
- Biota
- Age of Site
- Human Activities

oxisol

dark earth or
terra preta

Important Properties: TEXTURE and CHEMISTRY

Texture: size distribution of <u>mineral particles</u>



1. Largest Ratio of SA:V
2. Attracts + charged Ions
3. Absorb water

Soil Chemistry

Macronutrients: Needed in large amounts

Micronutrients: Needed in trace amounts

TABLE 21.2

Plant Nutrients and Their Principal Functions

Nutrients	Principal functions
Carbon, hydrogen, oxygen	Components of organic molecules
Nitrogen	Component of amino acids, proteins, chlorophyll, nucleic acids
Phosphorus	Component of ATP, NADP, nucleic acids, phospholipids
Potassium	Ionic/osmotic balance, pH regulation, regulation of guard cell turgor
Calcium	Cell wall strengthening and functioning, ionic balance, membrane permeability
Magnesium	Component of chlorophyll, enzyme activation
Sulfur	Component of amino acids, proteins
Iron	Component of proteins (e.g., heme groups), oxidation–reduction reactions
Copper	Component of enzymes
Manganese	Component of enzymes, activation of enzymes
Zinc	Component of enzymes, activation of enzymes, component of ribosomes, maintenance of membrane integrity
Nickel	Component of enzymes
Molybdenum	Component of enzymes
Boron	Cell wall synthesis, membrane function
Chlorine	Photosynthesis (water splitting), ionic and electrochemical balance

Sources: Salisbury and Ross 1992; Marschner 1995.

***ECOLOGY*, Table 21.2**

© 2008 Sinauer Associates, In

Nutrients must be present in simple, water soluble forms for plant roots to take them up

Ca^{2+}
K^{+}
Mg^{2+}

Many of these are positively charged ions…this will be important later!

2) Water Retention Capacity

Determined by type of particles in soil & their distribution throughout the soil

Clay Soils: Hold large volumes of water

Sandy Soils: Drain Well

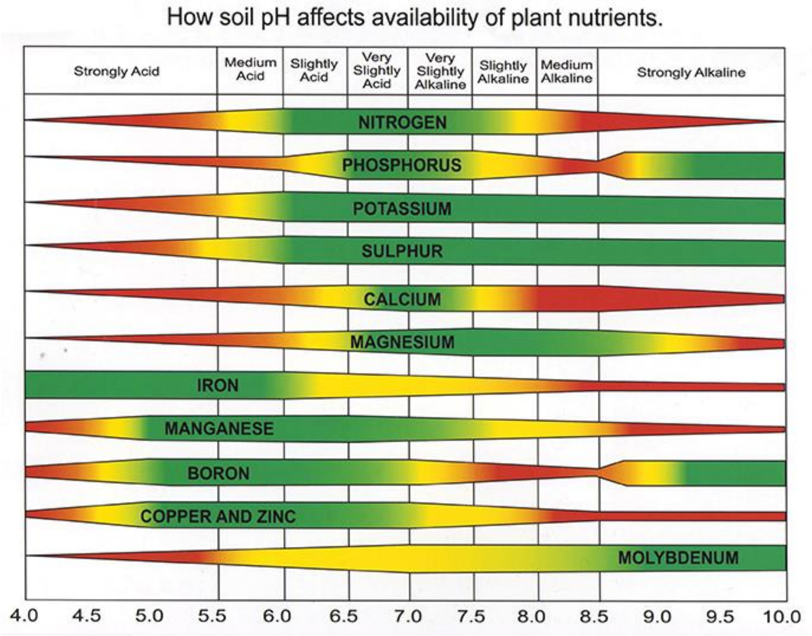
What does this mean for nutrient availability?

3) Soil Chemistry: soil pH strongly influences nutrient availability

↓ pH: large concentration of H^+ (acidic)

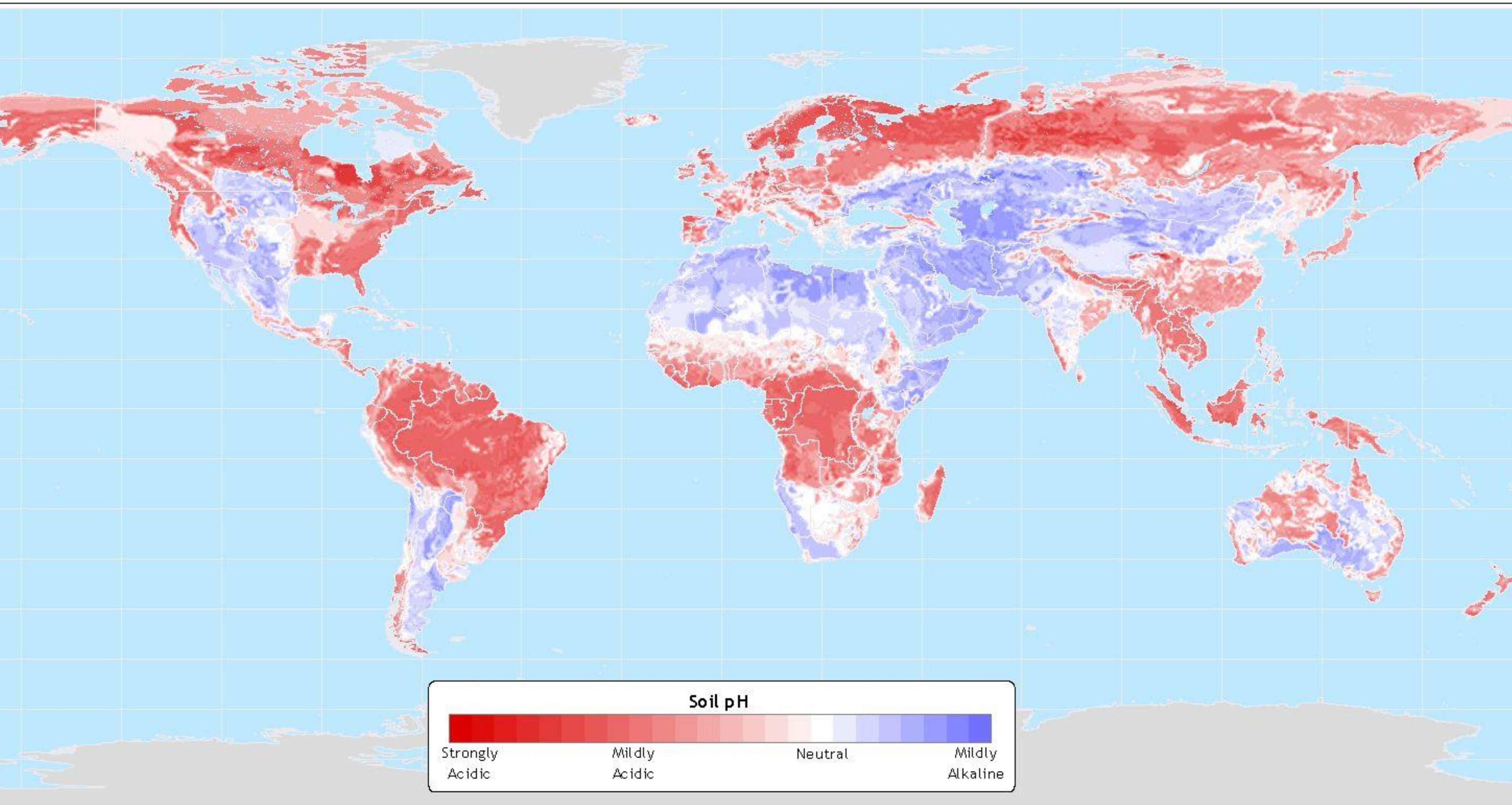
↑ pH: low concentration of H^+ (basic or alkaline)

A little acidity promotes nutrient availability. How?



Below about pH 5.5…nutrients leach out of the soil.

Maximum soil fertility: pH = 6.0-7.2



n from: IGBP-DIS Global Soils Dataset (1998)

Atlas of the Biosphere

Center for Sustainability and the Global Environment
University of Wisconsin - Madison

Like rainfall, there is no "typical" tropical soil…

…although in general they are deeply weathered, highly acidic and highly leaching

50%

Oxisols: most weathered, typical tropical soils, high in iron & aluminum oxides (making them red yellow)

Ultisols: highly leached

Entisols (Alluvial soils): young, recently deposited soils carried by water

Alphisols: least weathered, younger soils, often in montane areas 1500-2000 m

Inceptisols: Derived from volcanic eruptions

Varzea, BR

Arenal, CR

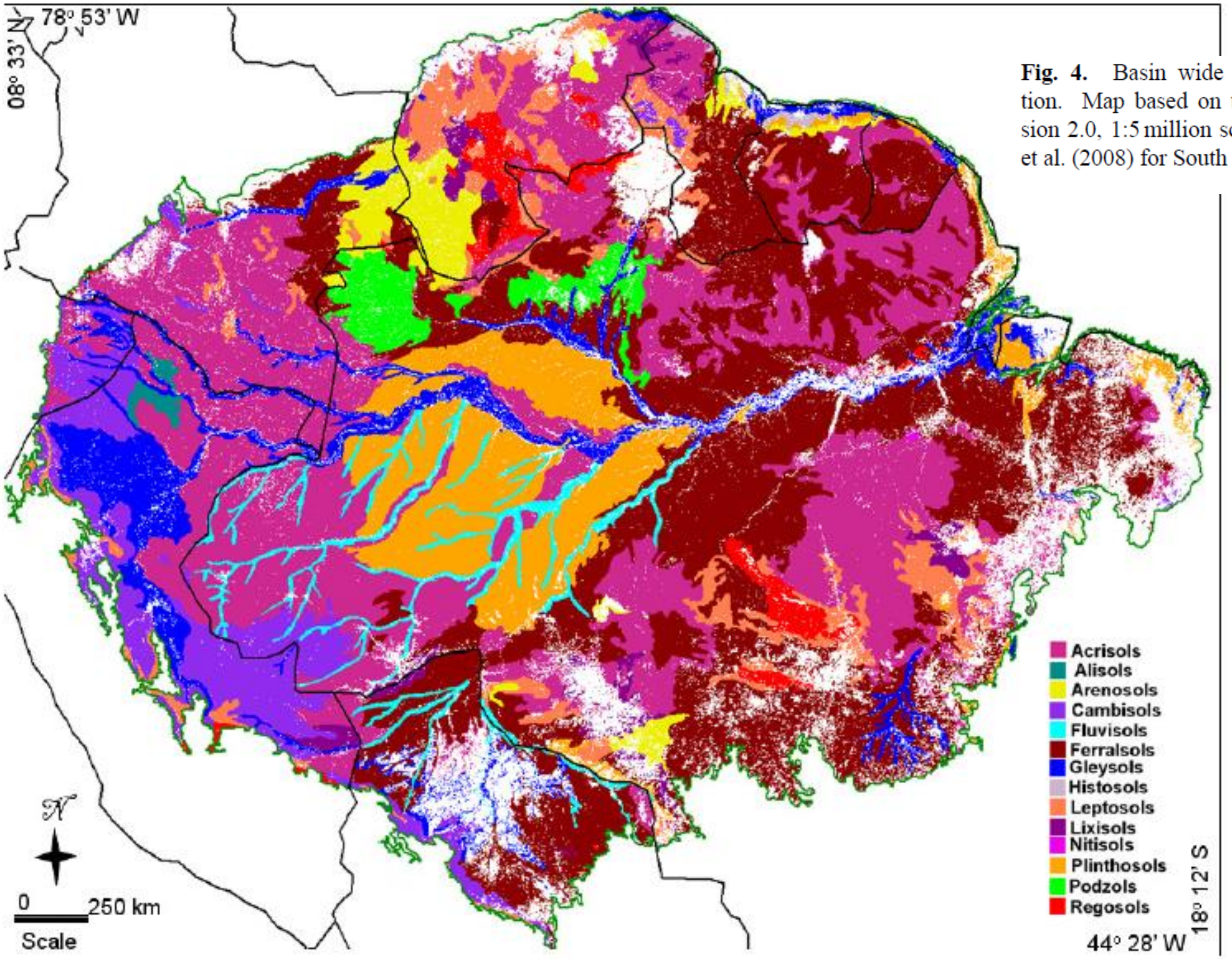


Fig. 4. Basin wide distributions of soils under forest vegetation. Map based on the SOTERLAC–ISRIC soil database (version 2.0, 1:5 million scale) and the vegetation database of Saatchi et al. (2008) for South America.

Biogeosciences, 8, 1415–1440, 2011
www.biogeosciences.net/8/1415/2011/
doi:10.5194/bg-8-1415-2011
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Biogeosciences

Soils of Amazonia with particular reference to the RAINFOR sites

C. A. Quesada[1,2], J. Lloyd[1,3], L. O. Anderson[4], N. M. Fyllas[1], M. Schwarz[5,*], and C. I. Czimczik[5,**]

Variability in soil quality has major ecological impacts

Plant fertility, phenology

Animal abundance, home range sizes,

Human settlement and agriculture

Forest biomass

So if tropical soils are so terrible, where did all this productivity come from?

© copyright by Johnathan Esper

Most of the nutrients in these ecosystems are in the living tree biomass

How do nutrients get back into the soils?

- Rain
- Exposure of new parent material
- River deposits
- Volcanoes
- Outer space
- Nutrient Cycling / Decomposition

Input: leaves, stems, roots, dead animals

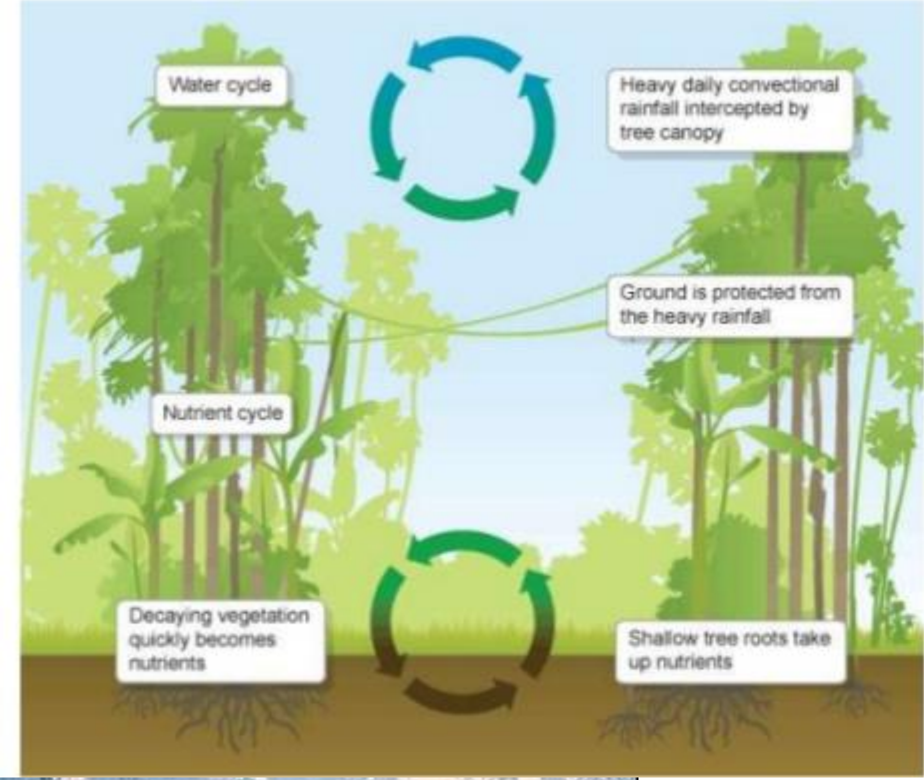
Broken down into progressively smaller fragments

Bacteria / fungi release enzymes that convert organic macromolecules into inorganic nutrients

Small organic compounds and inorganic nutrients are released into solution

When tropical forests are cleared and burned, those nutrients are lost in smoke and ash and soil erosion

Terborgh's "Paradox of Luxuriance"



STRUCTURE & DYNAMICS OF AMAZON FORESTS

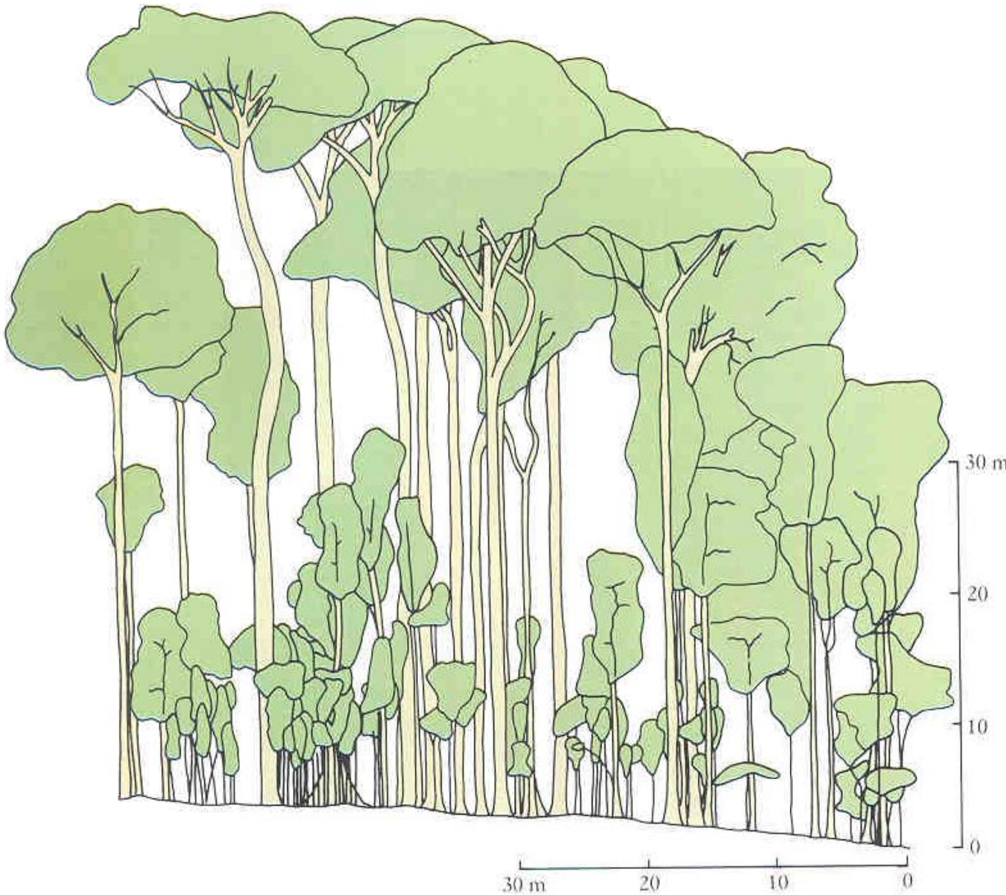
1. Tropical forests are **“stratified”**

Emergent (45 m)

Canopy (25-45 m)

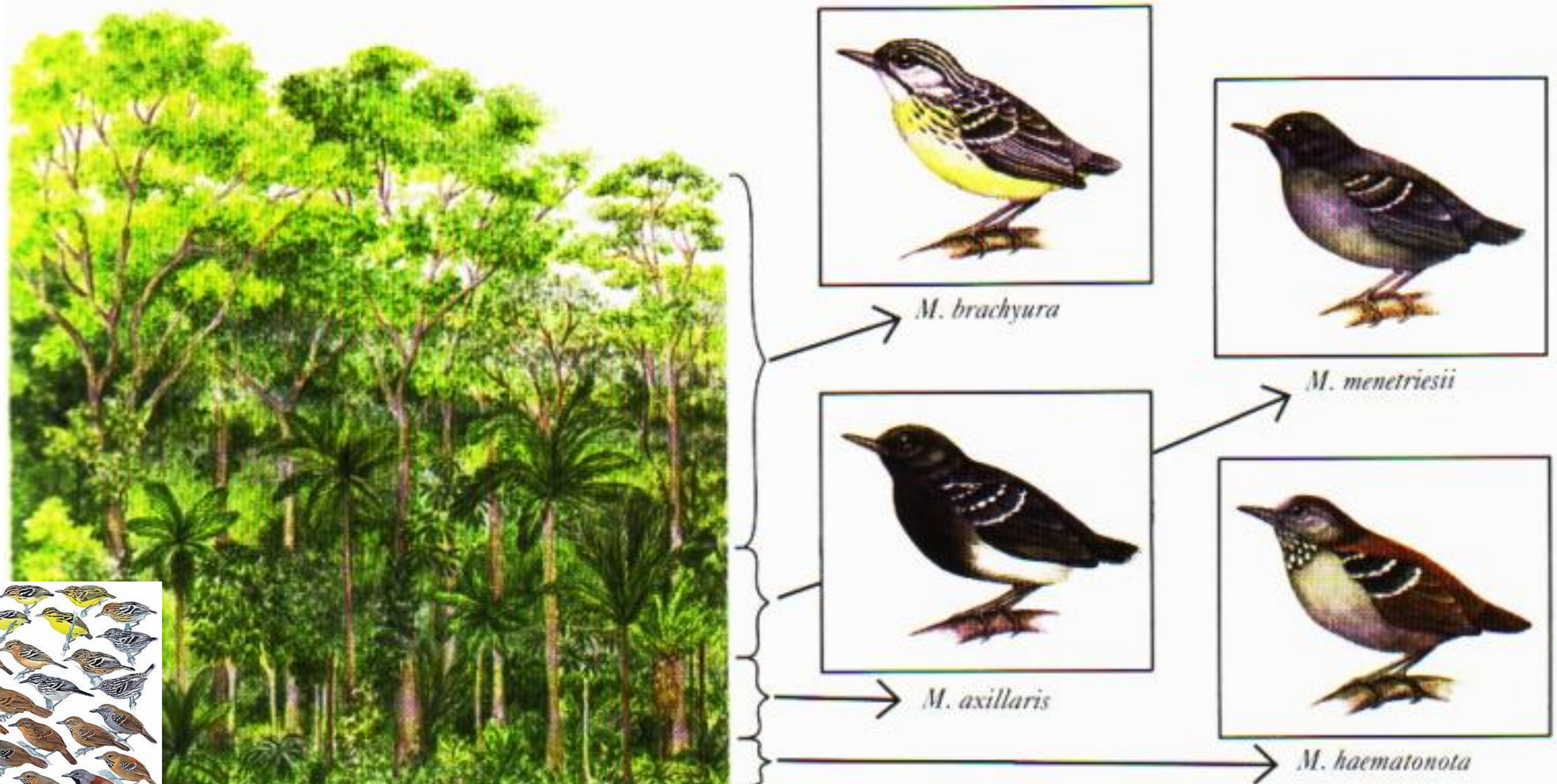
Mid or Subcanopy (5-25 m)

Understory < 5 m (shrubs, herbs, palms)



The profile of a lowland mixed dipterocarp forest in Brunei, Borneo, hints at the presence of distinct strata. Dipterocarps tower above the many lesser trees that occupy the forest understory. "Flying" frogs, lizards, lemurs, and squirrels have evolved sail-like structures that allow them to glide from one lofty crown to another in Southeast Asian forests.

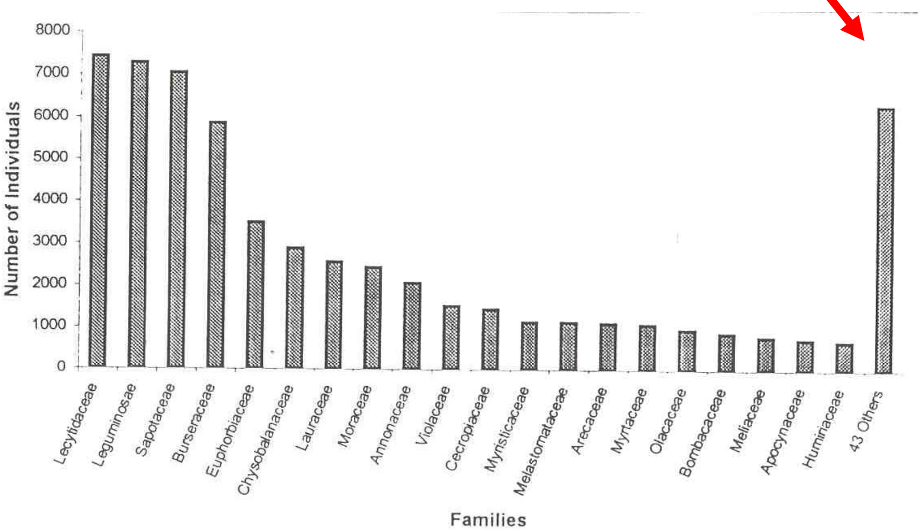
Result of stratification: many different habitats (heterogeneity) and opportunities for "species packing"

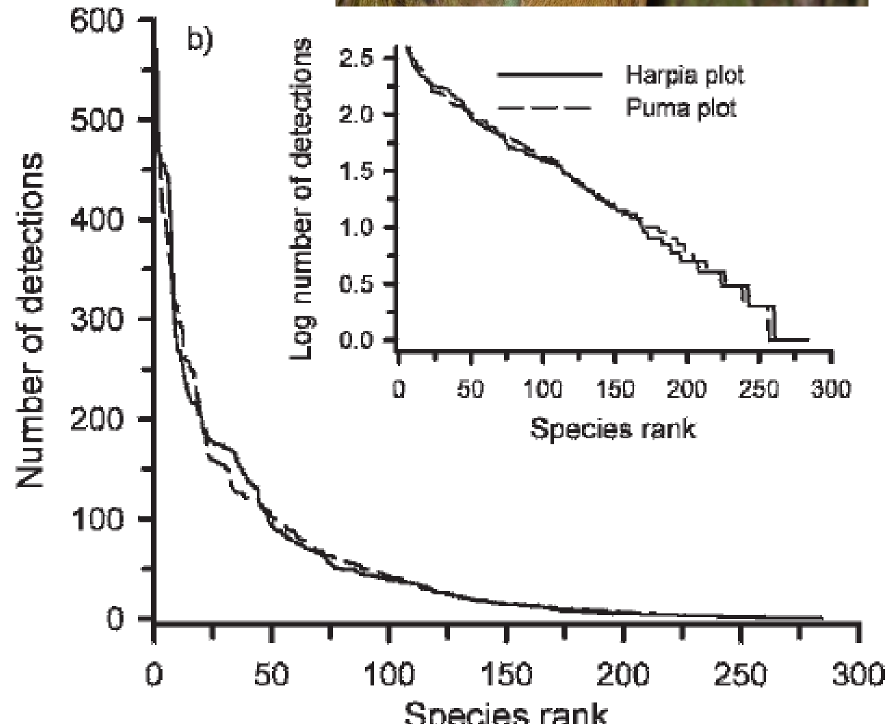


Four species of antwrens (genus *Myrmotherula*) show vertically stacked foraging zones in an Amazonian forest. Such close ecological relationships are an indication of tighter species packing in tropical guilds.

2. Within a location: most species are rare

each of 3 most common = 43 others

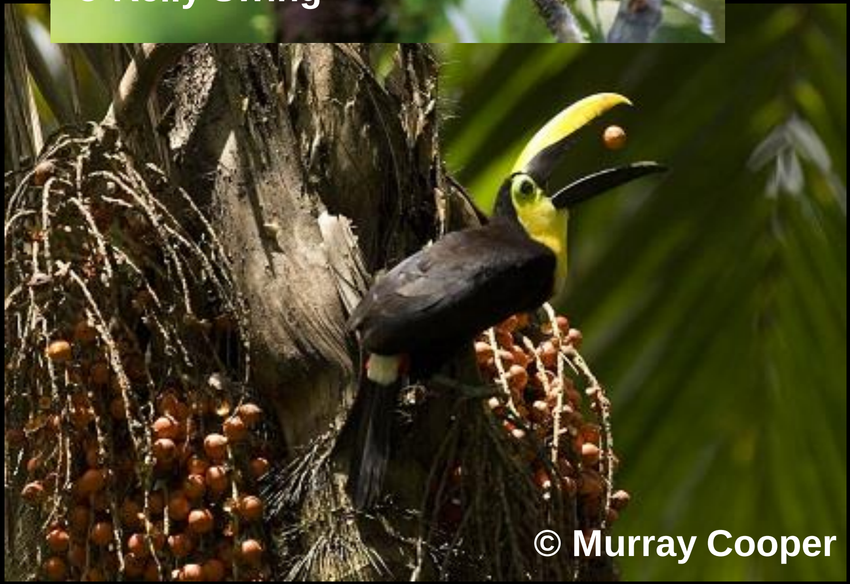




3. Tropical forests are characterized by interactions (e.g., seed dispersal mutualisms)

Vertebrates disperse seeds from 60-90% of plant species in tropical forests

Wide diversity of animals consume fruits and act as seed dispersers

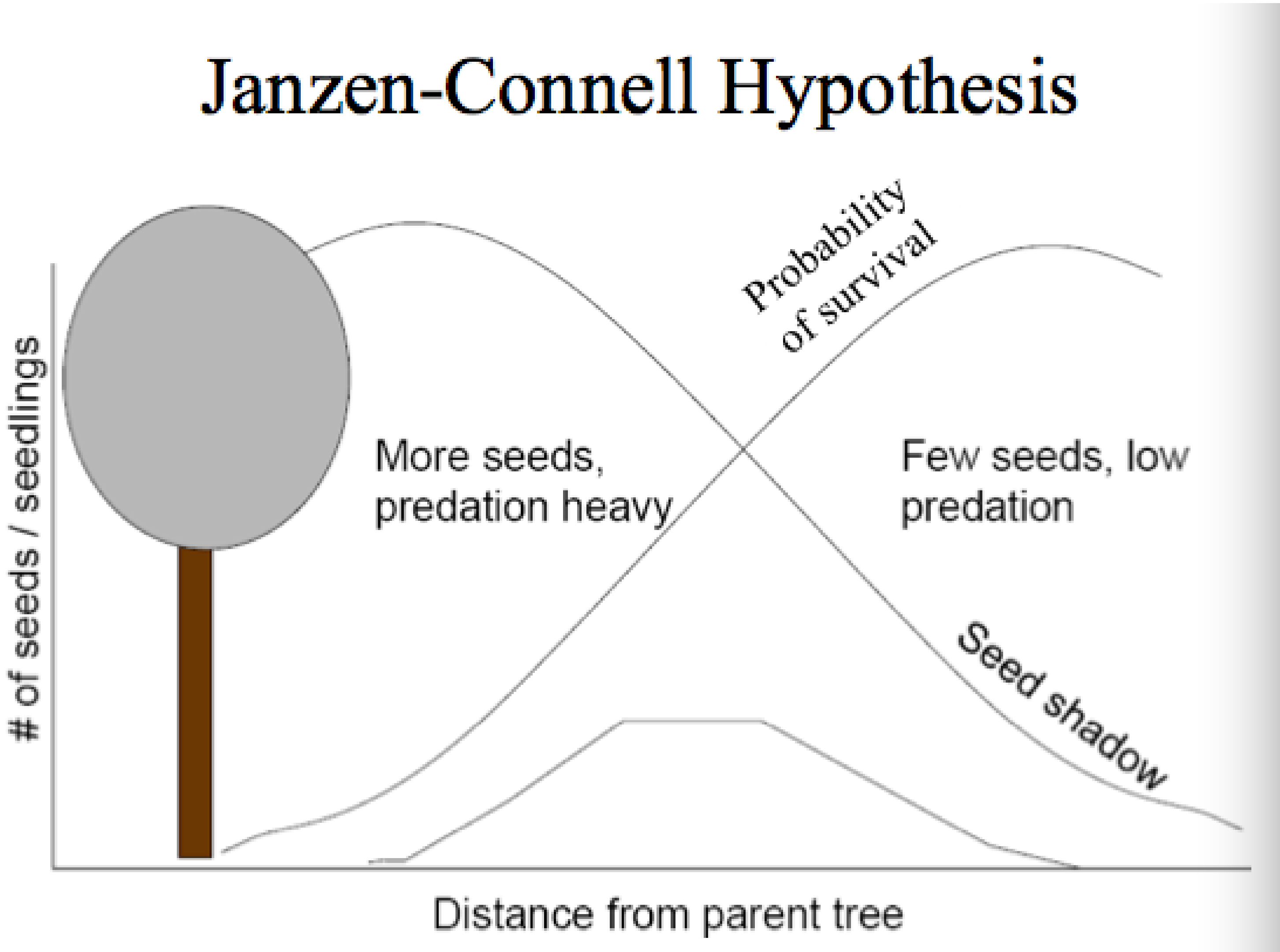


Plants largely depend on animal seed dispersal for recruitment – Why?

Seed/seedling recruitment is limited by:

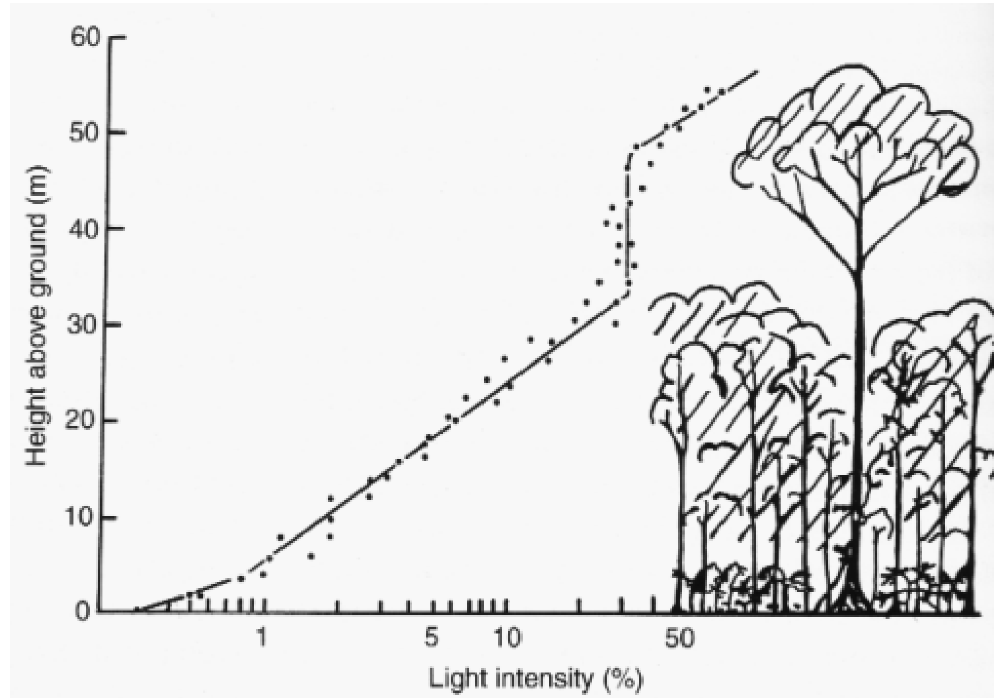
- Light
- Soil nutrients/other microsite conditions
- Predators/pathogens
- Competition

Seed dispersers provide "escape" from distance- and density-dependent mortality



Janzen 1970

Seed dispersers provide opportunity to "colonize" favorable sites for recruitment, such as light gaps



New Gap **Old Gap** **Intermediate Gap**

4. Tropical forests are characterized by high local and regional diversity

© Kelly Swing

Tree Diversity

Location	Tree Species
Appalachians (USA)	~50-60
North America	~620
BCI (15 km^2, Panama)	~365
Yasuni (Ecuador)	~1100/25 ha
Manaus (Brazil)	~1300
Amazonia	6000?

+ high local diversity

Total Floristic Diversity

Location	Species of Vascular Plants
BCI (Pa)	1320 (118 families)
La Selva (CR)	1668 (121 families)
Cocha Cashu (Pe)	1856 (130 families)
Ducke (Br)	>2000 (~135 families)
Amazonia	> 50,000

Epiphytes / Hemiepiphytes

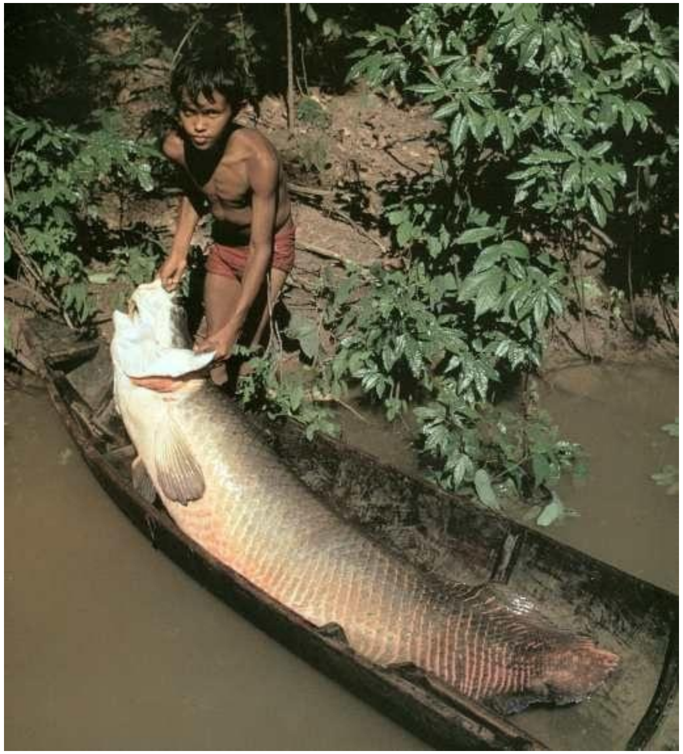
Herbs

Palms

Bird Diversity

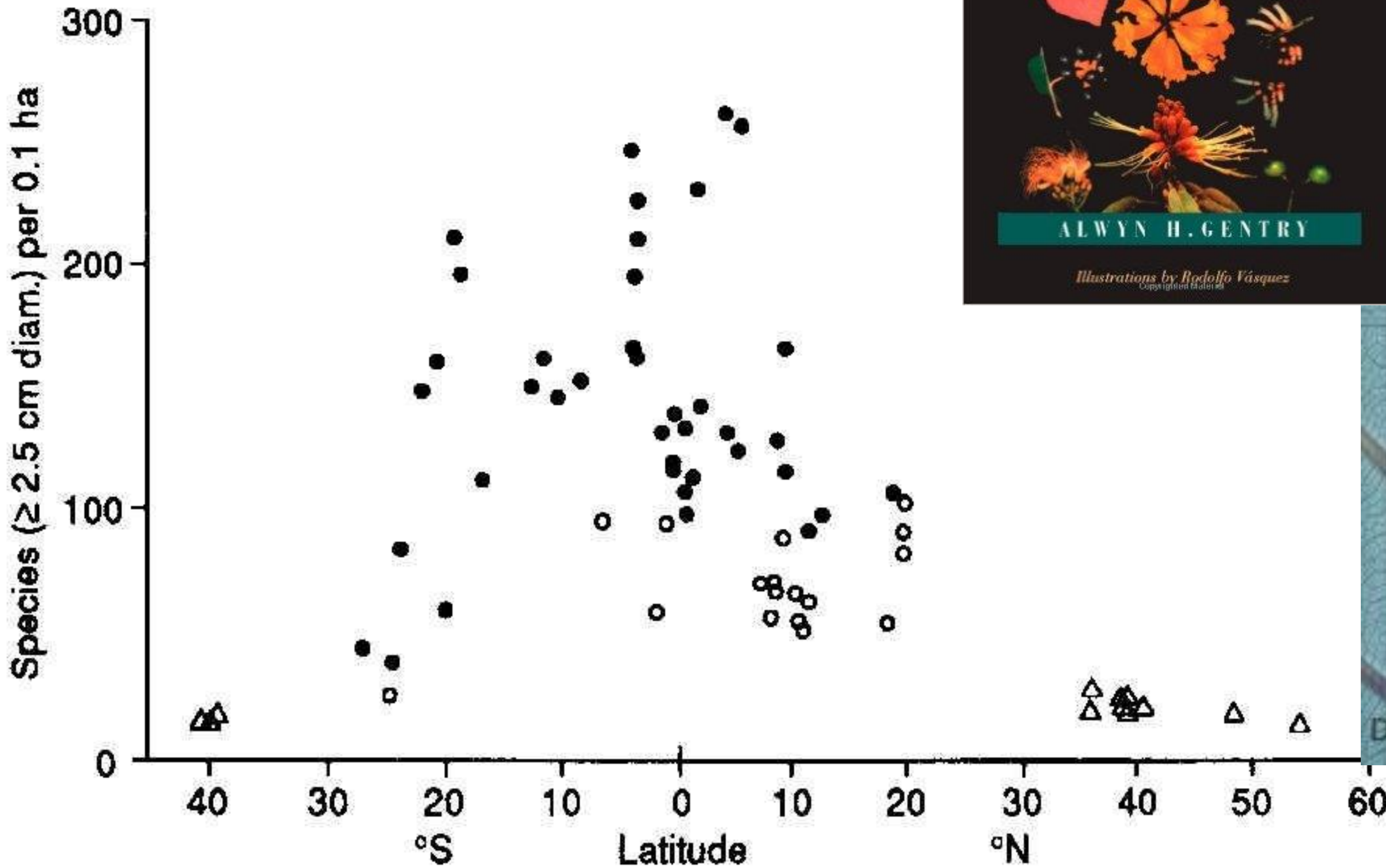
Location	Bird species
N. America	620-700
La Selva Station (CR)	410
Cocha Cashu (Peru)	550
Yasuni (Ecuador)	~600
Colombia	1400-1600
Amazonia	>2000?

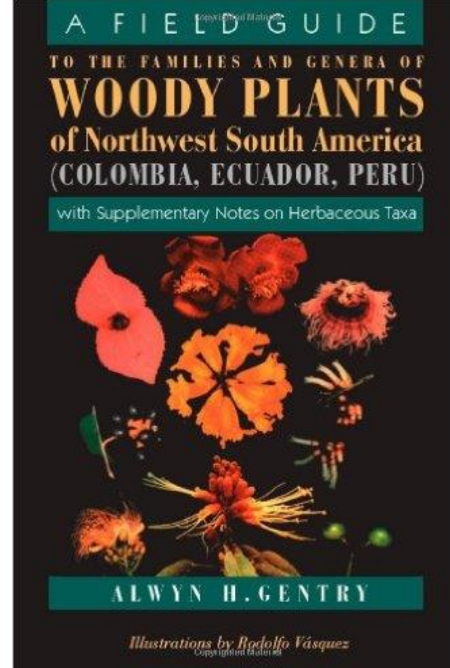
Fish: 1300 described species



Mammals: >500 (~350 in N Am)

Large turnover in species across sites





Gentry (1988)

100,000 insect species/ha in w Amazonia

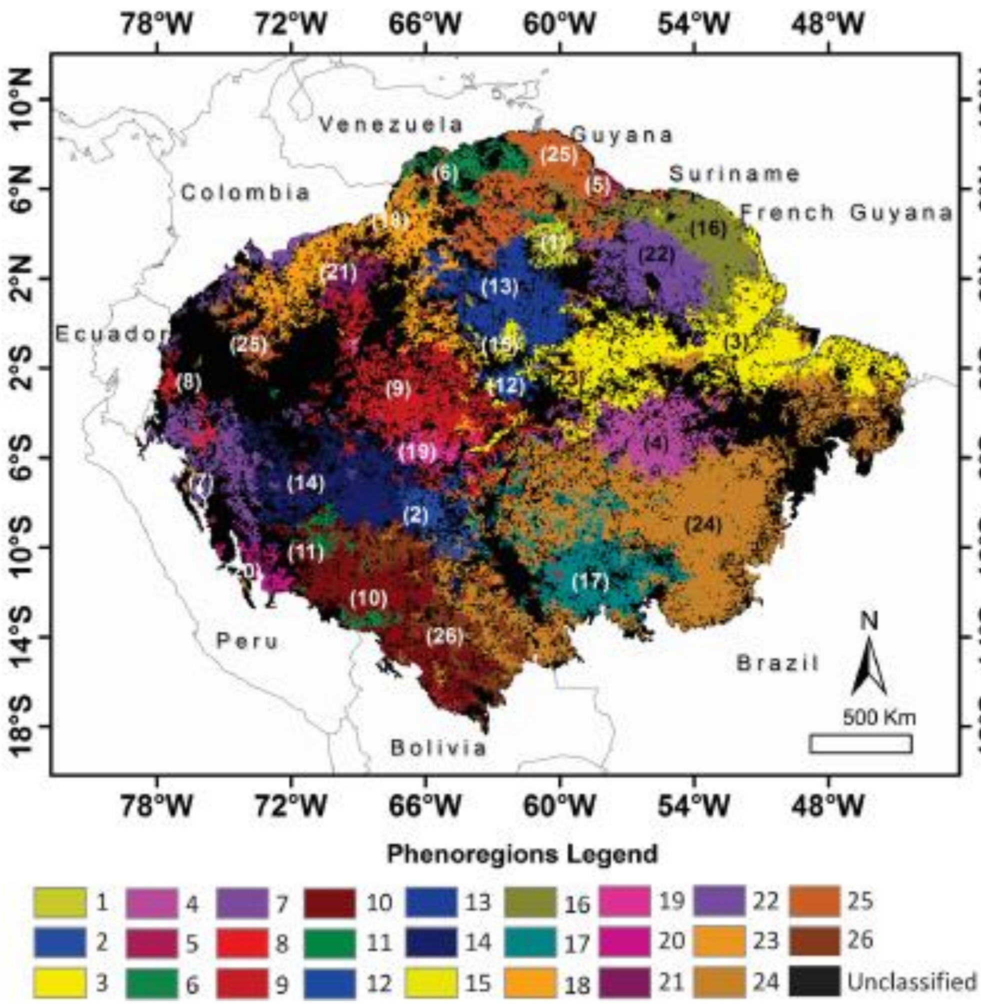
Terry Erwin, Smithsonian Institution

http://zookeys.pensoft.net/articles.php?id=5168

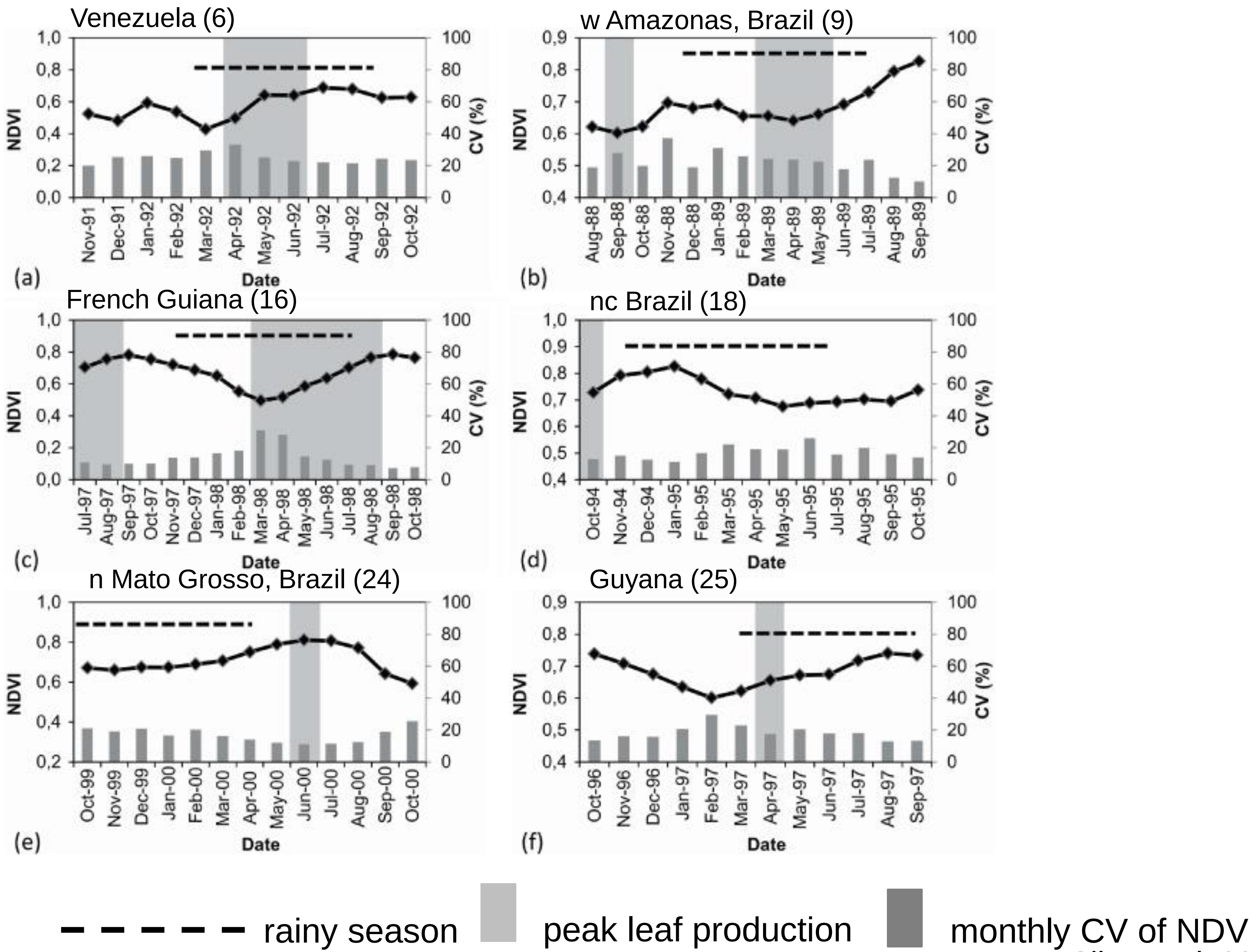
How many are host-specific?
How many tree species are there?

Species turnover is not surprising.

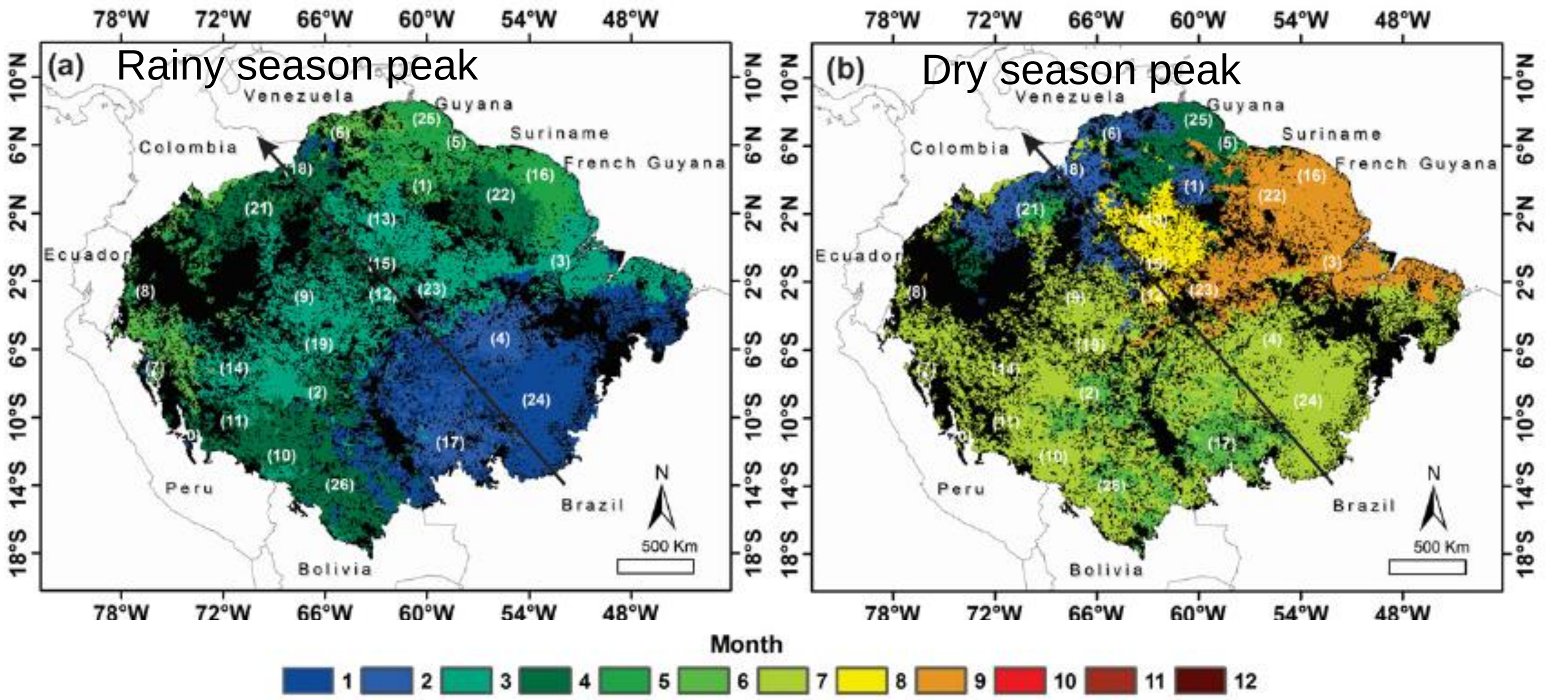
Amazon forest phenology is very heterogeneous and likely a product of varying soils, geomorphology, vegetation, and climate



Silva et al. 2013



Silva et al. 2013


(a) Rainy season peak
(b) Dry season peak
Venezuela
Guyana
Suriname
French Guyana
Colombia
Ecuador
Peru
Brazil
Bolivia
500 Km
Month
1 2 3 4 5 6 7 8 9 10 11 12

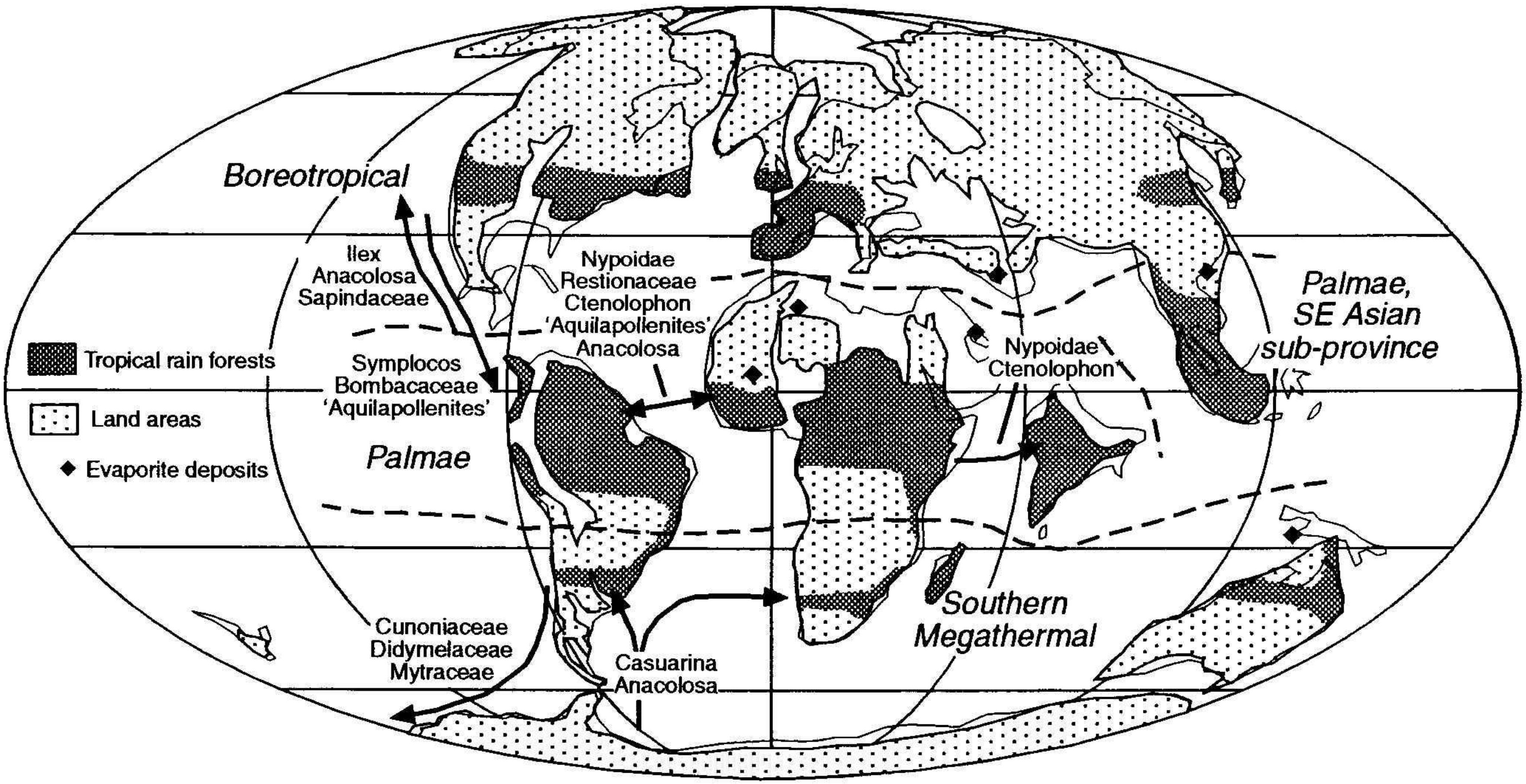
Question: Why is diversity so much higher in the tropics than at higher latitudes?

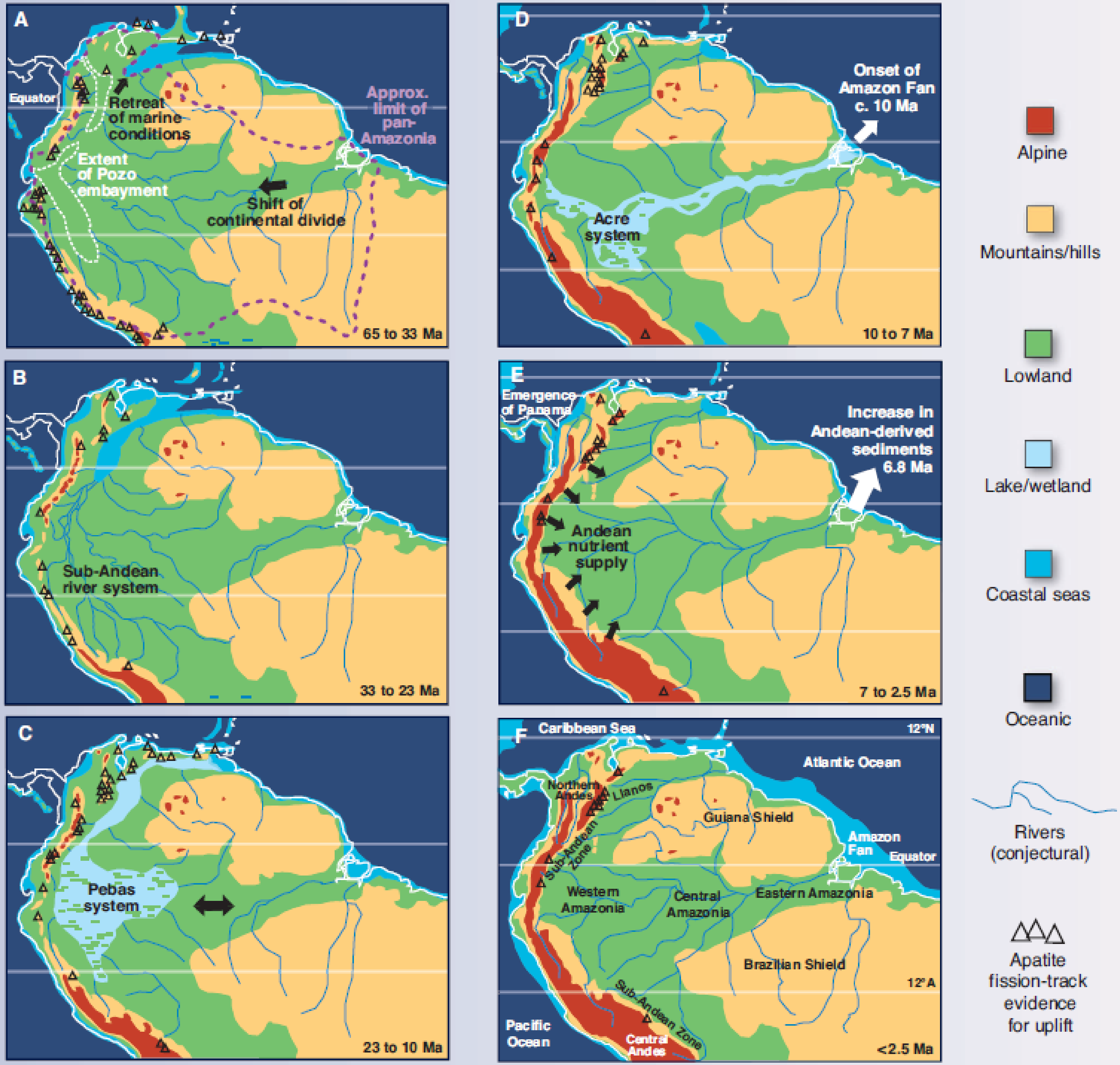
Two part answer:

1) What are the ***origins*** of the diversity?

2) What ***maintains*** this diversity?

Paleocene (65-54 Ma): the first appearance of closed-canopy tropical rain forests in ‘greenhouse’ climate





Hoorn et al. (2010)

4-5 MYA: following connection
There was a Great American Faunal Interchange

Northern
Stopped by Filter
Shrews
Pocket mice
Pocket gophers
Beavers
Pronghorn
Bison

Southern
Crossing Filter
Porcupines
Glyptodonts
Armadillos
Ground Sloths
Opossums

Northern
Crossing Filter
Rabbits
Field mice
Foxes
Bears
Raccoons
Weasels
Cats
Mastodons
Horses
Tapirs
Peccaries
Camels
Deer

Southern
Stopped by Filter
Primates
Octodonts
Spiny rats
Nutrias
Agoutis
Capybaras
Cavies
3-toed sloths
Anteaters
Shrew Opossums

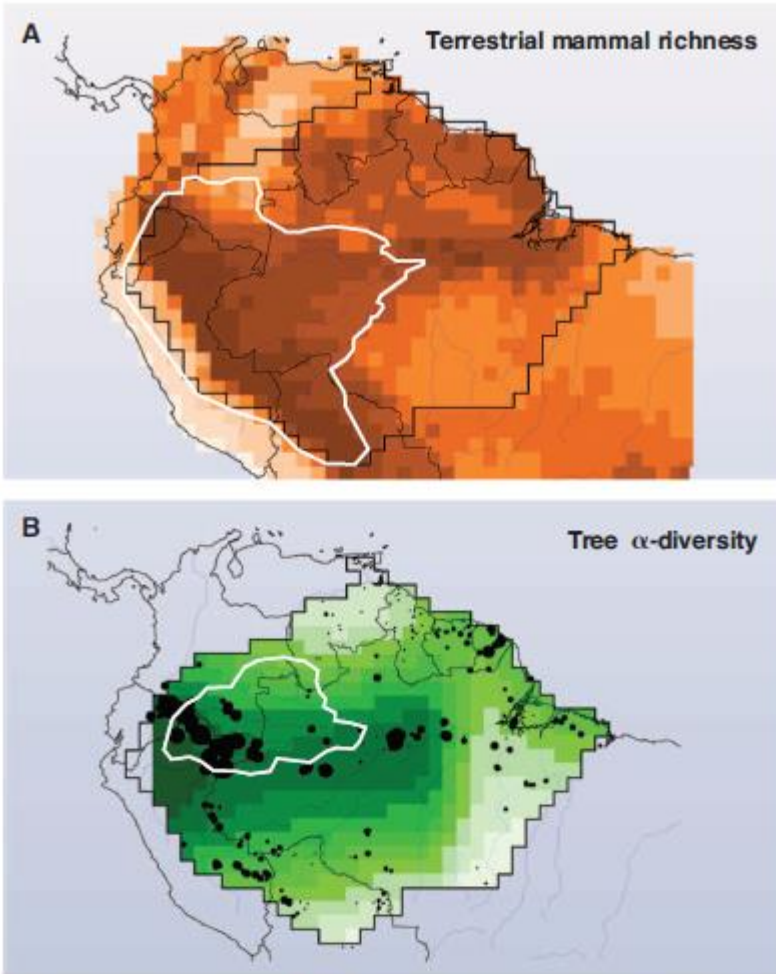


Fig. 3. Present Amazonian diversity patterns. See figs. S6 and S7 for depictions of the close relationship among Amazonian geology, soils, climate, and diversity. (**A**) Terrestrial mammal richness (range: lightest color, 2 to 10 species; darkest, 89 to 109 species) (*69*); white polygon denotes relatively rich soils (fig. S6C). (**B**) Tree α-diversity (*66*). Black dots: local tree α-diversity on 1-ha plots ($n = 752$); Fisher's α ranges from 3.6 to 300; green shades: loess spatial interpolation of 1-ha values (6 to 117); white polygon: area of least severe water shortage (see fig. S6D).

Hypotheses to explain tropical diversity

- Time and Area
- Climate Change
- Climatic Stability
- Spatial Heterogeneity
- Primary Production
- Etc

Factors *maintaining* diversity in tropical ecosystems

The big questions: why are there so many species in tropics? Why don't some drive others to extinction?

1) Niche Differences (Specialization)

Ex. 1: plant-pollinator interactions (for plants and animals)
Ex. 2: plant-herbivore interactions (for animals)
Ex. 3: topography & soils (for plants)

Some hypotheses (continued):

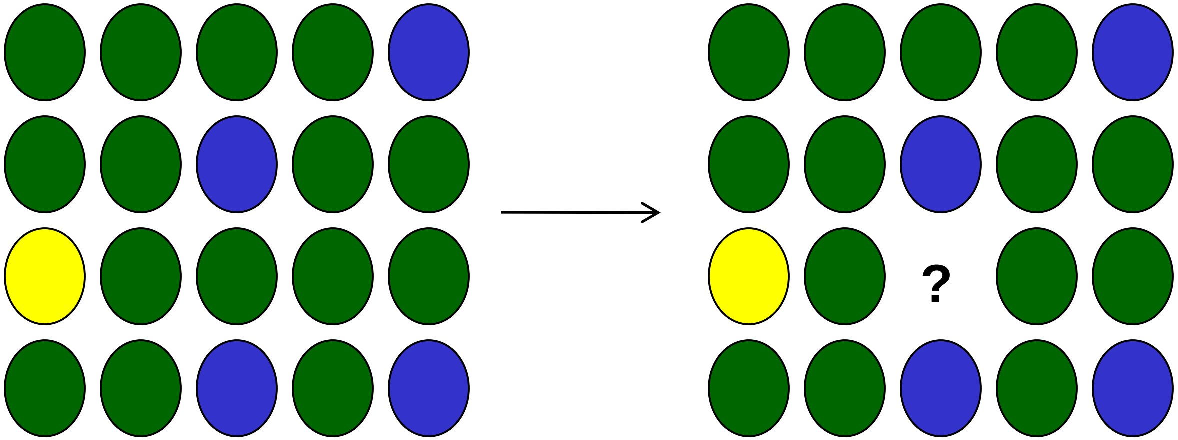
2) Janzen-Connell Effects, aka 'Negative density dependence": preference for competitive dominants by herbivores, pathogens, and predators allows rare species to persist

Some hypotheses (continued):

3) Trade-off between survivorship and growth *(species that are really good dispersers are often very <u>poor</u> competitors)*

Some hypotheses (continued):

4) “Neutral” mechanisms (Stephen Hubbell, 2001): species that replaces drawn at random from local community



Some Thoughts about Change in the Amazon

The Empty Forest

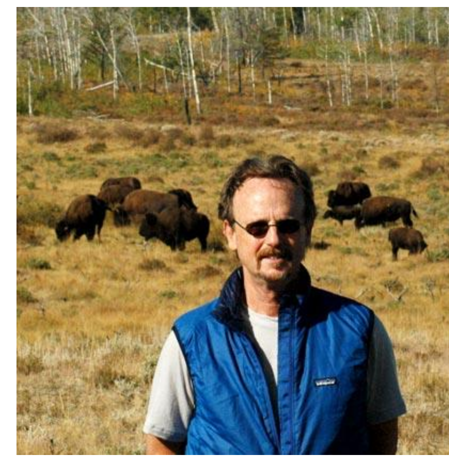
Many large animals are already ecologically extinct in vast areas of neotropical forest where the vegetation still appears intact

Kent H. Redford

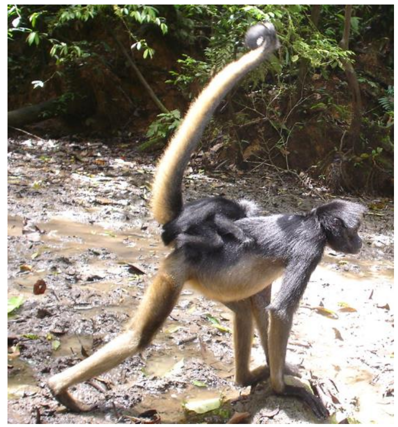
The world conservation community has focused much of its attention on the plight of tropical forests. Many authors have lamented the loss of forest cover and the destruction of the forest and speculated on the extent of the tropical forest left intact. Throughout the discussion, tall, majestic, tropical trees are used as a symbol for the complete

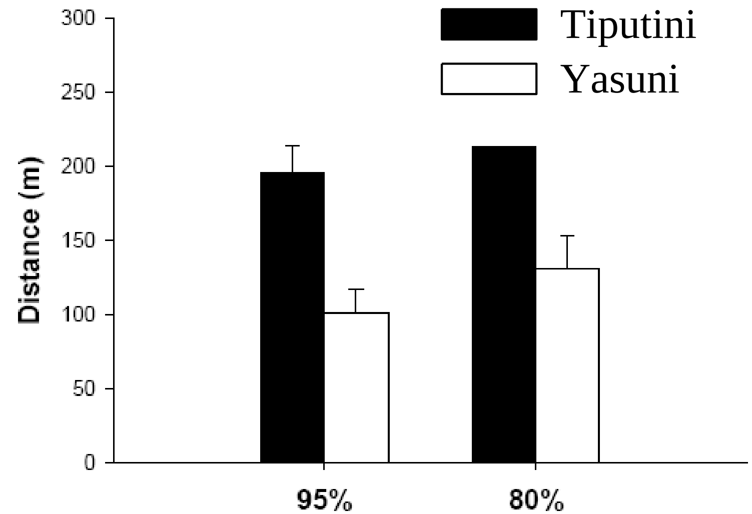
We must not let a forest full of trees fool us into believing all is well

With few exceptions, researchers have concentrated on direct alteration of vegetation, not discussing the ways in which human activities have affected the animals of tropical forest ecosystems. In this article, I expand the focus to include defaunation of tropical forests, concentrating on the forests of the Amazon basin, and I show that the long-term preservation

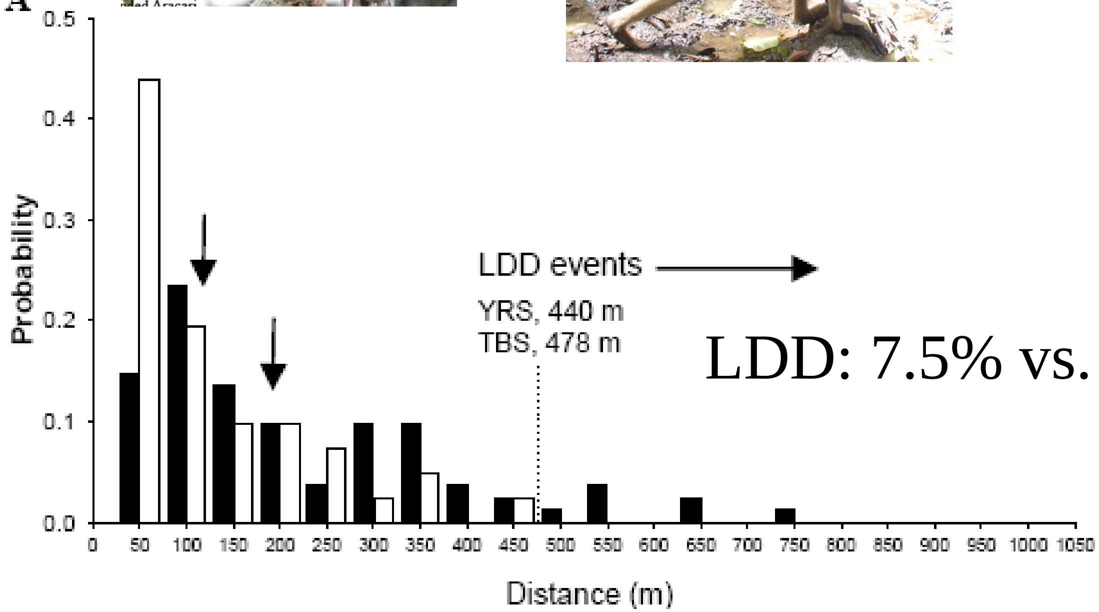


Reductions in large frugivores impacts long distance seed dispersal





95%



LDD: 7.5% vs. 0%

Holbrook & Loiselle in review
Holbrook et al. 2007

Some Thoughts about Change in the Amazon

"Running to keep up with climate change"

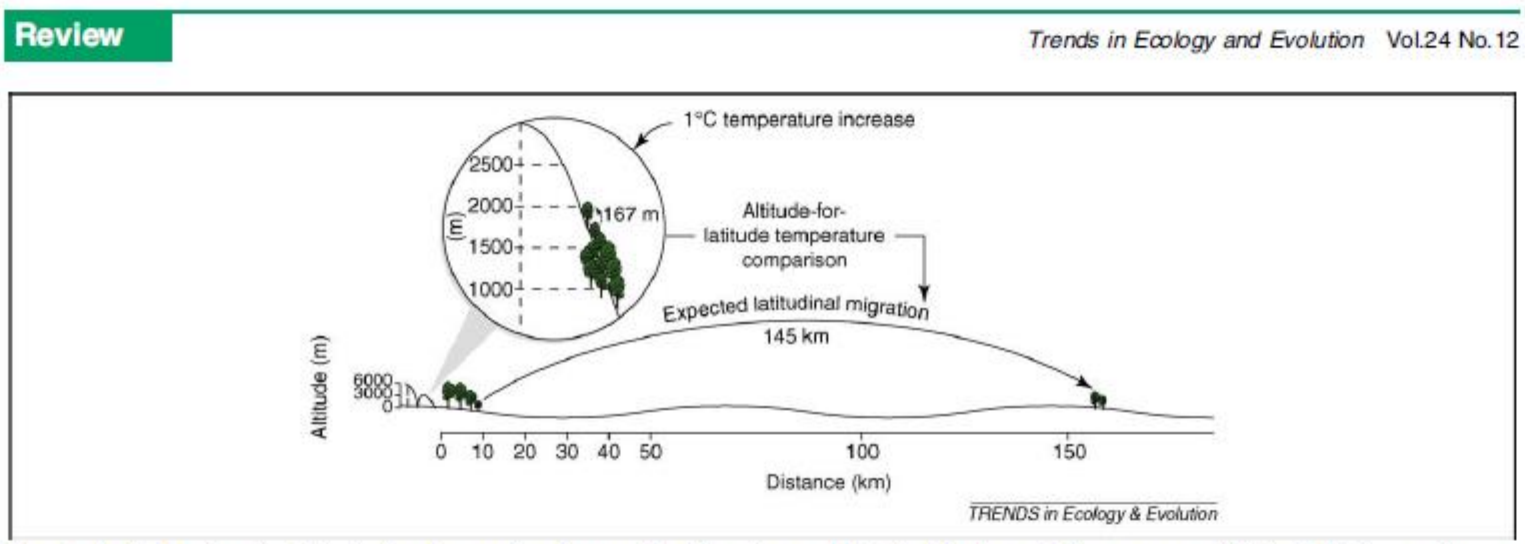


Figure 1. Equivalent migrations in lowland and mountain regions predicted based on an altitude-for-latitude model of temperature similarity. A 1 °C increase in mean annual temperature results in a range change of ~167 m in altitude but ~145 km in latitude (based on a temperature lapse rate of -6 °C km^{-1} altitude and -6.9 °C 1000 km^{-1} latitude from data in Refs [3,14]). Trees are not to scale.

Large declines in Amazon birds a consequence of climate change?

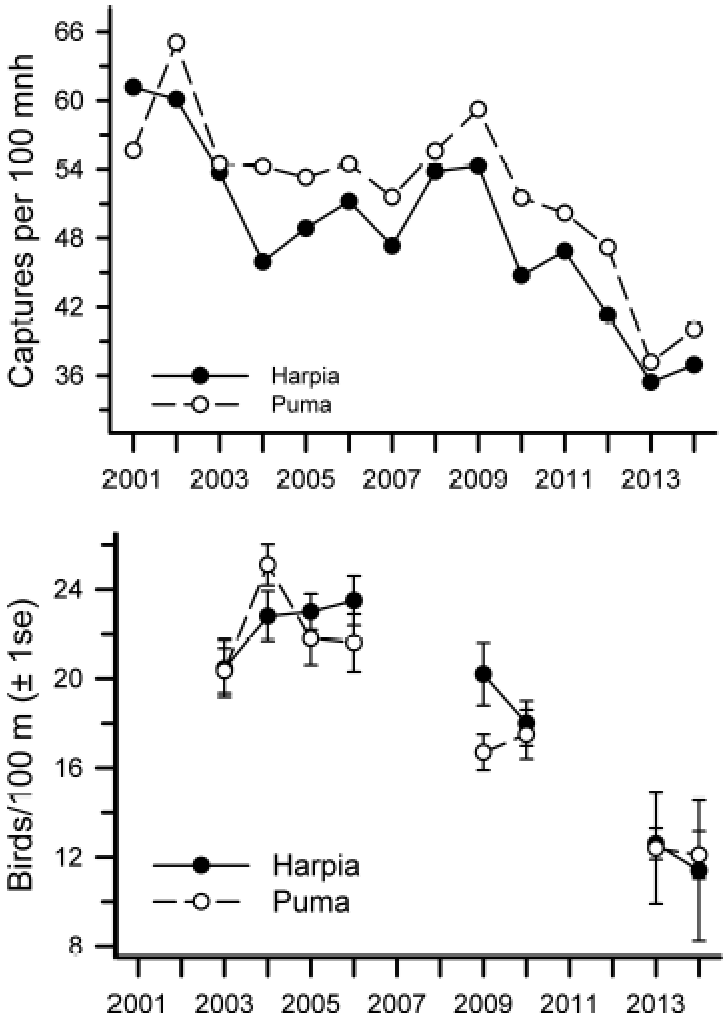


Figure 1 Capture rates and observations of birds at Tiputini Biodiversity Station. Capture rates (A) and observations (B) of birds on two 100-ha plots (Harpia, Puma) at Tiputini Biodiversity Station, Ecuador, from 2001 to 2014.

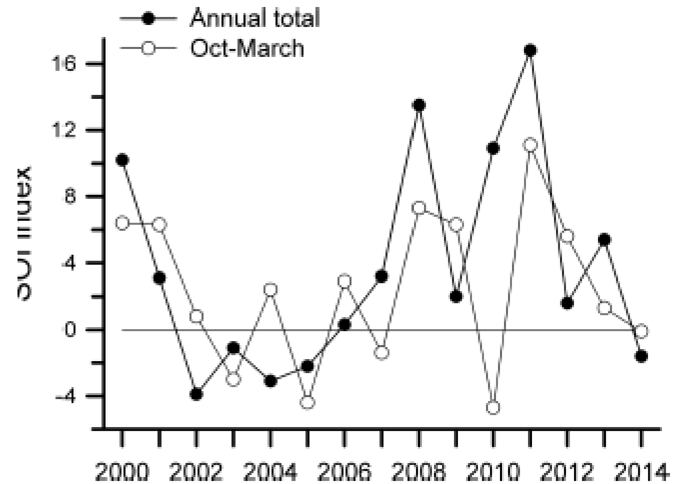


Figure 5 Southern Oscillation Index values. Southern Oscillation Index (SOI) values based on annual totals or on totals from Oct–Dec of previous year and Jan–Mar of current year. Positive values indicate La Niña-type events; negative values reflect El Niño.

Blake and Loiselle 2015