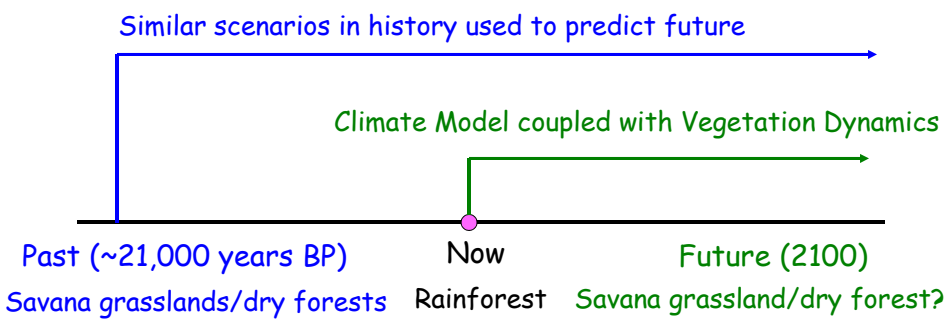
What is the future of Amazon forests under climate change?

-Increase in temperatures of ~3C

-20% reduction in precipitation over 21st cent.

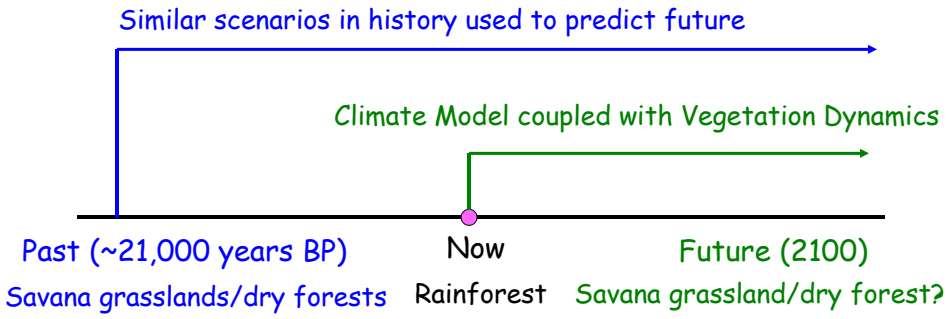
Two kinds of philosophy in predicting Amazon future



What is the future of Amazon, savana or dry forest?

What are the dis/advantages of two methods?

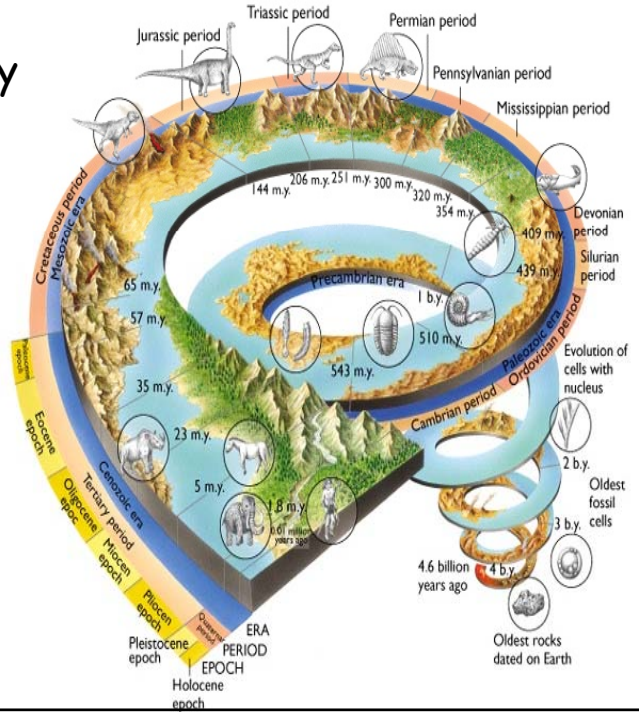
What is the key to predict Amazon future?

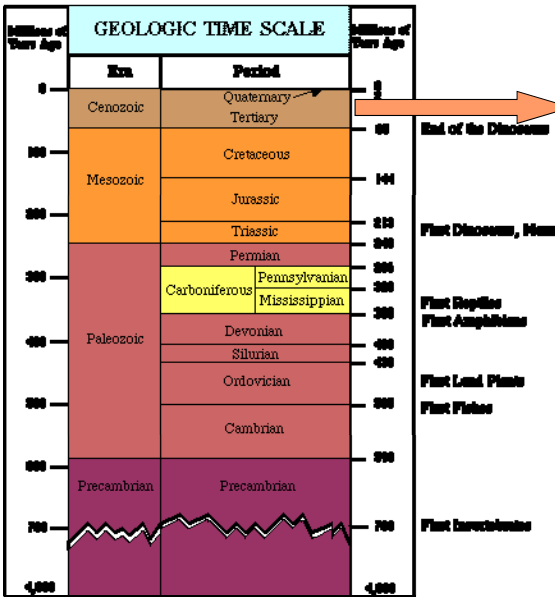


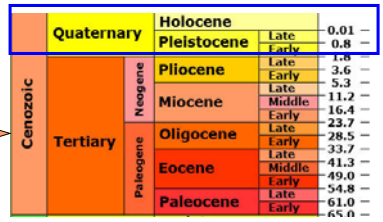
Outline

1. Some terminologies review
2. What is Pollen Analysis?
3. What kind of information can we get from pollen analysis?
4. What kind of question can we ask?
5. Further inference & discussion

Terminology Review







Holocene: a geological epoch which began approximately 12,000 years ago (10 000 14C years ago)

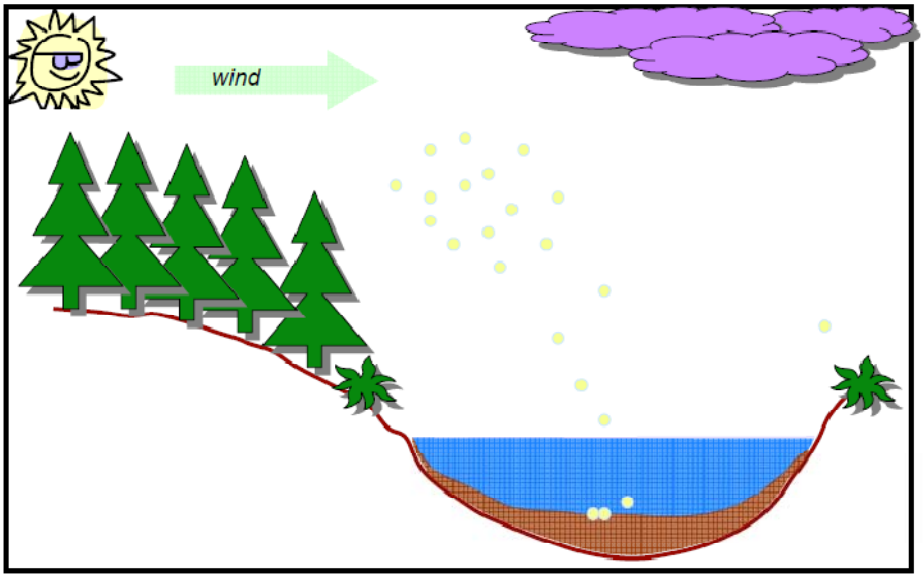
Pleistocene: the epoch from 1.8 million to 12,000 years BP covering the world's recent period of repeated glaciations

Pollen Analysis

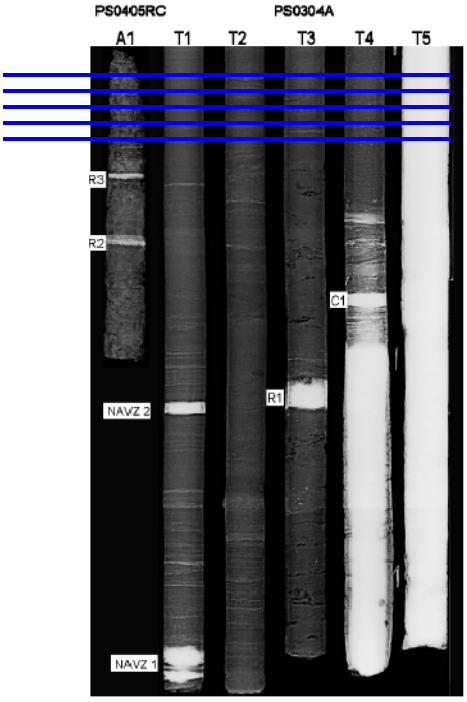
- The study of assemblages of dispersed palynomorphs such as those isolated from samples of peat (Von Post, 1916).
- A technique for reconstructing former vegetation by means of pollen grains it produced (Faegri and Iverson, 1989)
- Pollen analytical data obtained from lake and bog sediments provide direct information relevant to the reconstruction of the past flora and vegetation of the area under study (Birks and Birks 2005).

Assumption of Pollen Analysis

- The basic assumption of the technique is that the number of pollen grains deposited per unit time, at a given point, is directly related to the abundance of the associated species in the surrounding vegetation (Davis 1963).


wind


Coring
Coring platform
Coring cable is hand-cranked onto spool
Hammer weight cable is held by this spool
Coring cable
Water Column
Core hole
Hammer weight
Core barrel
Sediment
Sediment goes into the bottom of the core barrel here



Lake Sediment & Pollen Analysis

Sample: every two centimeters

Chronology: Accelerator Mass Spectrometry (AMS) 14C dates

Palynology: vegetation type & abundance

Pollen Analysis & Paleoclimate

- As both modern floras and modern vegetation are related in a broad way to modern climate, pollen analysis can provide indirect information relevant to the reconstruction of past climates over particular time spans (10^2-10^5 years) with a sample resolution of 10-1000years.

Pollen Analysis & Paleoclimate

- John Imbrie and Nilva Kipp (1971) "transfer function"

$$Y_m = f(X_m)$$

where Ym is modern pollen data, Xm is modern climate data

- Then apply the inverse of f to **fossil pollen data** Yf to infer **past climate** Xf

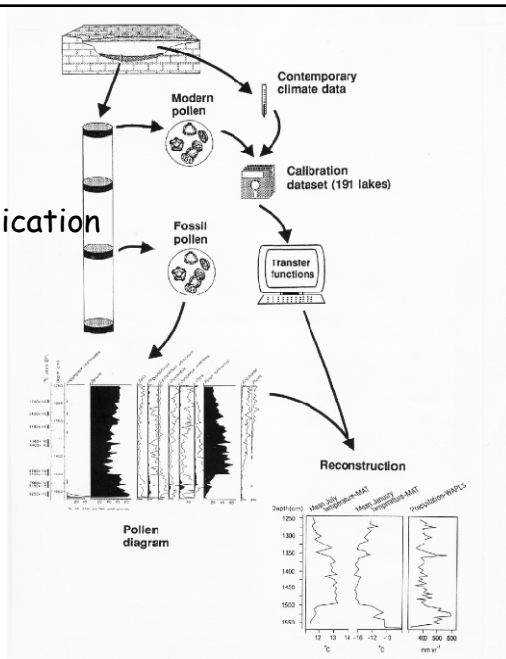
$$\hat{X}_f = f^{-1}(Y_f)$$

Step 1: Get lake sediment

Step 2: Sample and identification

Step 3: Paleo-Vegetation Reconstruction

Step 4: Paleo-Climate Reconstruction



Disadvantages of Pollen Analysis

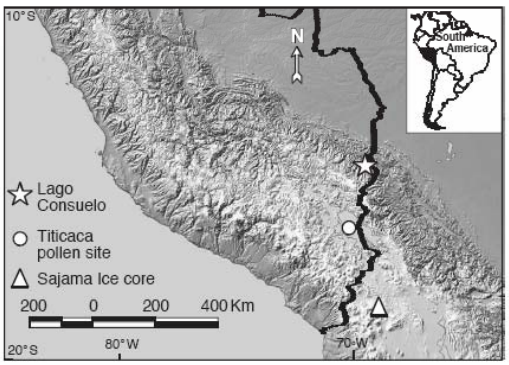
- **Poor Representatives**
  - pollen data are presented as proportions of a total pollen sum, rather than as discrete numbers (Davis 1963)
  - Therefore, difficulties with the representativity both between and within species are experienced, as some taxa produce far greater quantities of pollen, which are more widely dispersed than others (Birks and Birks 2005).
  - Data representativity will be biased due to the differences in pollen productivity, dispersal and preservation (Faegri and Iverson 1989).
- **Circular Reasoning**
  - Paleo-Vegetation & Paleo-Climate are reconstructed by same data set

What kind of questions can we ask?

1. What is the vegetation dynamics from past to now?
2. How did vegetation respond to past climate change?
3. What is the inference of the past to future (prediction)?
4. Can this data set resolve the debate on the origin of Amaznonian biodiversity?

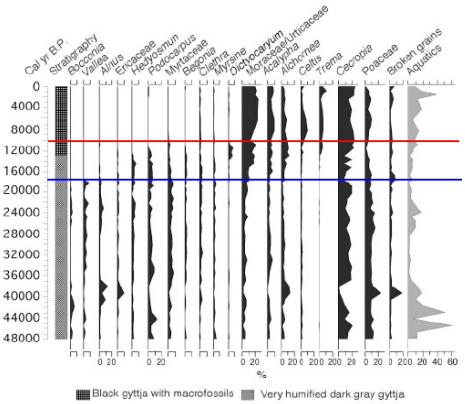
Bush et al. 2004

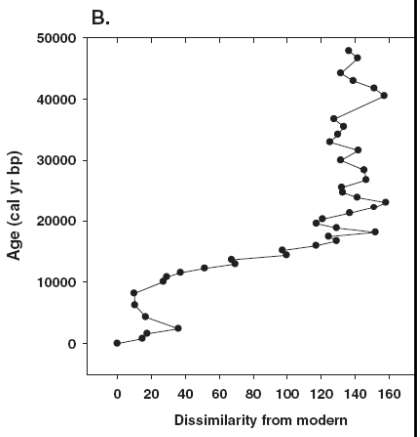
- Location:
  - Lower montane cloud forests of Peru
  - Lago Consuelo
  - Elevation = 1360m
- Proxy
  - Sediment cores
    - Chronology based on 10 AMS ^{14}C dates
    - **Pollen analyses**



Bush et al.

- Pollen Diagram
  - Different Pleistocene and Holocene forest types

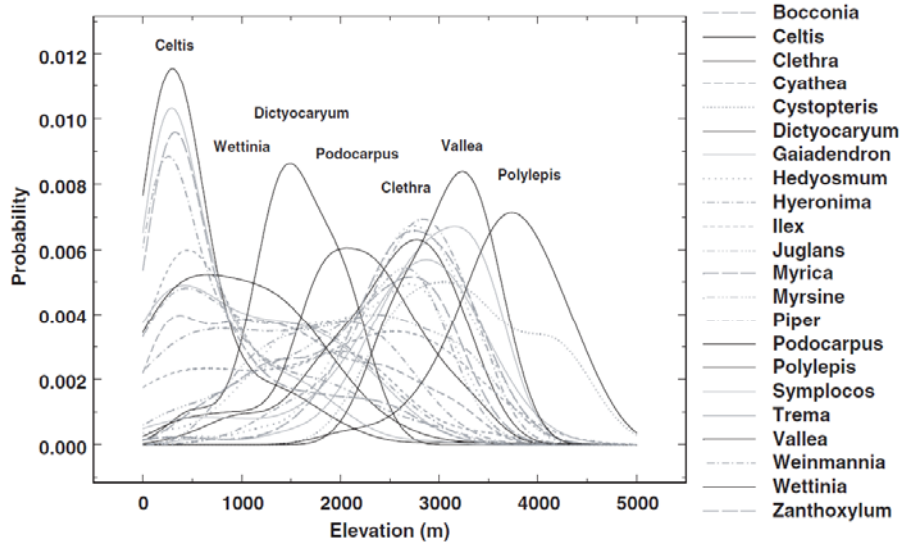




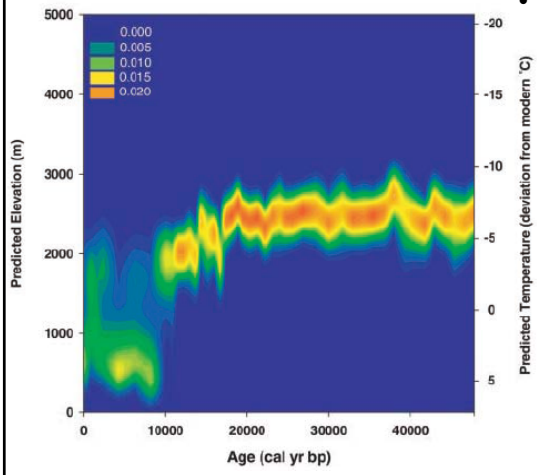
- Composition similarity analysis based on DCA analysis (Detrended Correspondence Analysis)

Bush et al. 2004

From Titicaca pollen site, we can get:



Bush et al. 2004



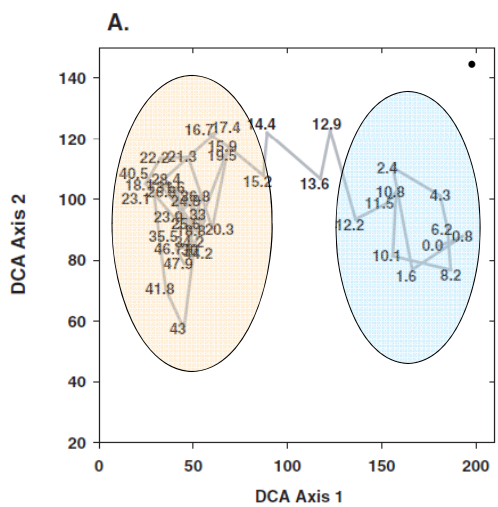
- Purpose-designed transfer functions
  - Way to infer past temperature from pollen
  - 2 periods of relatively stable temperatures
  - No substantial deviation from surrounding Pleistocene conditions
  - Late Pleistocene at least 5 C colder than today

1000 m of elevation increase=6 C of temperature decrease

Bush et al. 2004

- Nearly constant sedimentation rate, absence of abrupt changes in sediment
  - Lago Consuelo never dried out
  - No major drought episodes
- Wet Andean cloud forest continuous
- Rate of change in forest composition indistinguishable from stochastic changes of stable periods

Bush et al. 2004



- Detrended Correspondence Analysis (DCA)
  - Two stable periods
  - Directional change rather than random drift

Bush et al. 2004

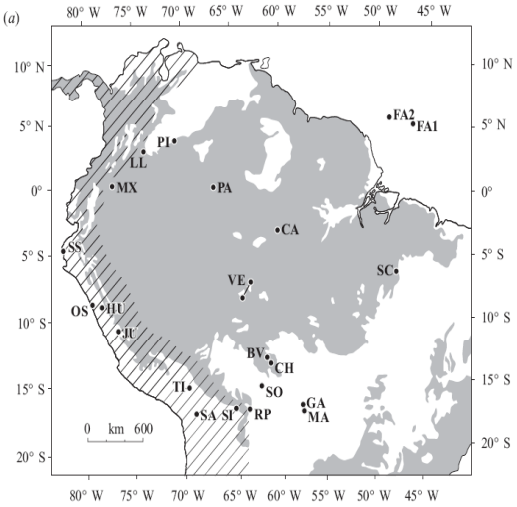
- Key Points
  - Cloud forest existed at or close to Lago Consuelo elevation for the past 48,000 years
  - Temp change from Pleistocene to Holocene began ~19 ka
  - "rates of forest community change during the most substantial climate change of the past were no greater than during the relative stability of the pre-Industrial Holocene"

Bush et al. 2004

- Implications for future climate change
  - Climate changes in these systems gradual
    - 5-9 C/10000years
    - No precipitation information?
  - Projected climate change in next 100 years fundamentally different from any in the last 50ky
    - 3 C increase by 2100
    - 20% decrease in precipitation
  - Andean plants with broad elevational distributions should survive climate changes
    - Plants can safely shift under such a rapid rate of temperature increase?
    - What is the threshold value of climate variability for plants to survive?
  - Plants with narrow ranges may be moved outside of their niche

Mayle et al. 2004

- Aim:
  - Determine responses of Amazonian ecosystems to changes in T, P, and atmospheric CO_2 since LGM (21 ka)
  - Synthesize to predict vegetation responses to future climate change
- What they did:
  - Reviewed previously published:
    - Paleovegetation datasets
    - Pollen rain datasets
    - Independent multi-proxy paleo data
- Dynamic vegetation model simulations
  - Present new pollen rain data and vegetation simulations



Mayle et al. 2004

- Climate at Last Glacial Maximum (LGM)
  - CO_2 concentration – 180-200 ppm (Today?)
  - Temperature – 5C cooler than today
  - Precipitation – less well understood
    - Likely to have been spatially variable
    - Direction of precip change likely to have differed across Amazonia
    - Paleolimnological data
      - Altiplano & Lake Pata, Verde, Dragao (Northern Amazonia)
        - » Lake levels relatively high
        - » Absence of charcoal - Humid conditions
      - Lowlands & Lake Serra dos Carajas (Southern Amazonia)
        - » Precip lower than today
        - » Some lakes dried up

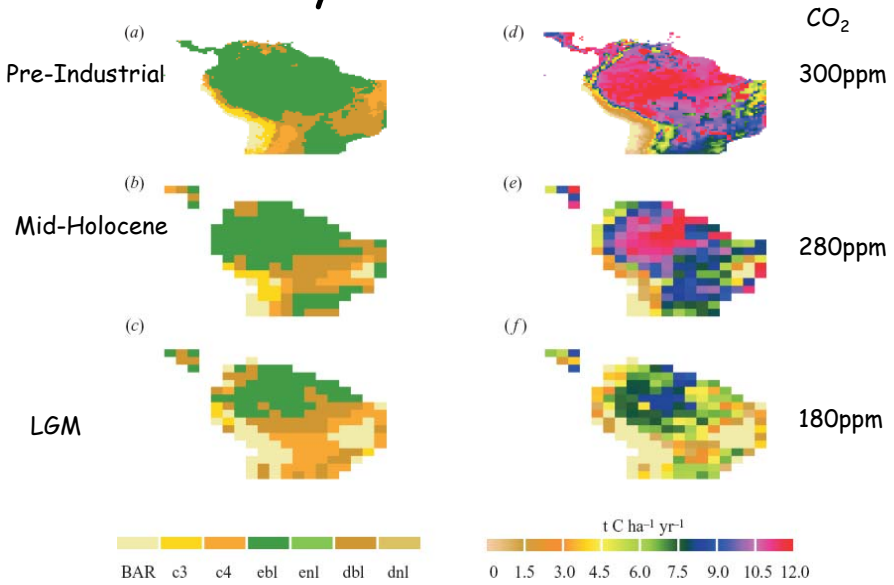
Mayle et al. 2004

- Vegetation responses to LGM climate
  - Paleoecological evidence
    - Evidence for widespread savannahs at northern and southern basin margins
    - Majority of basin remained forested
    - Taxa currently restricted to the Andes spread throughout basin
    - Amazon fan
      - More reliable indicator of basin-wide changes in vegetation (what do you think?)
      - Pollen data = no significant changes in proportions of forest vs. savannah taxa from LGM-Holocene

Mayle et al. 2004

- SDGVM (Sheffield Dynamic Global Vegetation Model)
  - Calculates vegetation properties under steady-state climate and CO_2 conditions
  - Represents physiological processes of:
    - plant nutrient uptake
    - C3 and C4 photosynthesis
    - Respiration
    - Stomatal control of canopy transpiration
  - Predicts distribution of plant functional types on the basis of:
    - Competition for light and other resources
    - Annual NPP and net biomass
    - Probability of disturbance
    - Succession after disturbance

Mayle et al. 2004



Mayle et al. 2004

- Key findings of model
  - Vegetation at LGM
    - Basin predominantly forested
    - Northern half = evergreen broad-leaf forests
    - Southern half = deciduous broad-leaf forests
  - NPP lowered with respect to the Holocene
    - The cool, low CO2 environment severely restricted vegetation carbon uptake
  - Consistent with Cowling et al. models, sensitivity simulation
    - Show changes in vegetation structure and forest type responses to carbon limitation and water stress due to lowered atmospheric CO_2 rather than precip
- "Our simulations may underestimate the actual spatial cover and productivity of the rainforests that existed at the LGM" because they do not contain vegetation-climate feedbacks

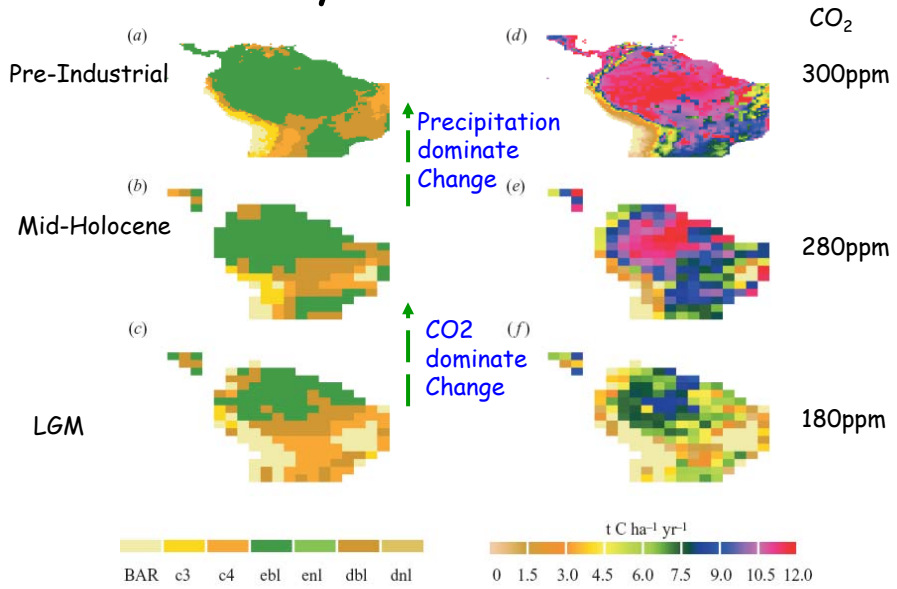
Mayle et al. 2004

- Climate at late-glacial and Holocene
  - CO_2 conc.
    - Rose by ~76ppm across transition, and ~25ppm through the Holocene to the Industrial Period
  - Temperatures (very complex, southwest Amazonia)
    - After LGM, cold, wet conditions until 15,500 yr BP
    - Temp. and aridity increases until 14,300 yr BP
    - Temp. then decreased and precip. Increased until 13,000 yr BP
    - Cold, wet climate 13,000-11,500
      - *Accompanied by most arid conditions over entire period of study in low land Amazonia
    - Rapid, large increase in temps. At 11,500 to modern values
      - Marks onset of Holocene ~10ka
  - Precipitation
    - Early-Mid Holocene significantly lower than preceding and subsequent periods
    - Increased in latter half of Holocene

Mayle et al. 2004

- Vegetation responses to late-glacial/Holocene climate
  - Forests expanded during transition (21ka – 10ka)
    - Most likely owing to increasing temps. and CO_2
  - Expansion of savannah islands during arid episode of early-mid holocene
  - Increased fire frequency from 7800-3200 yr BP, shift community composition, especially increase drought-tolerant lianas and semi-deciduous tree species
  - Precipitation increase in late holocene = renewed expansion of moist evergreen forest

Mayle et al. 2004



Mayle et al. 2004

- Model
  - Shows greater evergreen broad-leaf forest and NPP at mid-holocene than LGM
    - Contradicts paleodata for mid-holocene aridity
  - CO_2 control on vegetation between LGM and mid-holocene
  - Increase in precipitation control on NPP and expansion of rainforest between mid-holocene and Pre-Industrial

Mayle et al. 2004

- Predictions for responses under future climate change
  - Frequent widespread fires throughout southern and eastern Amazonia
  - Competitive replacement of lowland evergreen rainforest taxa with drought and fire-tolerant semi-deciduous taxa and savannahs
  - Early-mid Holocene NOT AN ANOLOGUE
    - CO_2 projected to be 2x mid-holocene levels by 2050
    - ENSO? Anthropogenic influence?
    - Any others?
  - Cloud forests largely eliminated on eastern flank of Bolivian Andes

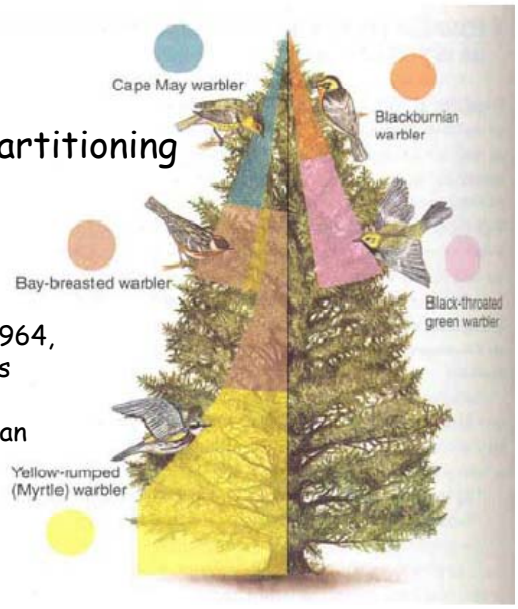
Mayle et al. 2004

- Amazonia remained forested at the LGM
- Vegetation composition and structure change during transition from LGM to Holocene
- CO2 conc. were the primary control on Amazon vegetation between the LGM and Mid-Holocene
- Increase in precipitation was the primary driver of rainforest expansion from Holocene to pre-industry
- A marked decrease in precipitation (8500-3600 BP) increased fires, and caused expansion of drought tolerant lianas and semi-deciduous taxa
- Inference to future?

Bush and Oliveira, 2006

Origin of tropical diversity,
Refugia Hypothsis,
Paleo Evidence

Niche & Resource Partitioning



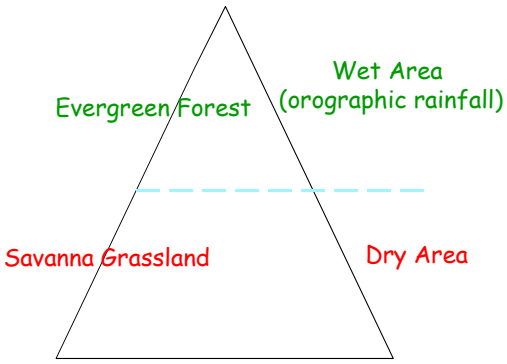
Robert MacArthur, 1964, Environmental factors affect bird species diversity, the American Naturist.

Bush and Oliveira, 2006

- Refugia Hypothesis
  - 1969, Jurgen Haffer observed the same pattern of bird distribution
  - He noted that there should be a **predictable pattern** in which **certain areas** held more **endemic species** than others
  - Further, he proposed that for these **species** to have **speciated** they must have been **spatially separated from** their parapatric **counterparts** at some time in the past

Bush and Oliveira, 2006

Haffer (1969): Amazon Basin was **arid** during pleistocene, and it was **seas of savanna surrounding islands of forest** that provide the genetic isolation required for **speciation**



A Hill in Amazonia

Bush and Oliveira, 2006

What do you think about Refugia Hypothesis?

What do you think about Bush and Oliveira's paper?

Bush and Oliveira, 2006

- Is paleo-evidence from Bush and Oliveira long enough to test Refugia Hypothesis?
  - pleistocene last for nearly 2 million years, but now we just focus on 21000years long data set; is it long enough for species to evolve or speciation?
- Logic of Refugia Hypothesis
  - Origin of species & species coexistence maintenance
  - Niche->species resource partitioning->occupy different space
  - Refugia->landscape fragmentation->special niche space->species evolve

This is like chickens and eggs!?

Further Discussion

- What is a better way to predict future climate change?
  - Believe past? Believe model projection? Combined?
- What is the key to predict future?
- Can we use this data to test the model hindcast the paleo-climate/vegetaion information?
- What is the big message from these papers?
- Other questions?