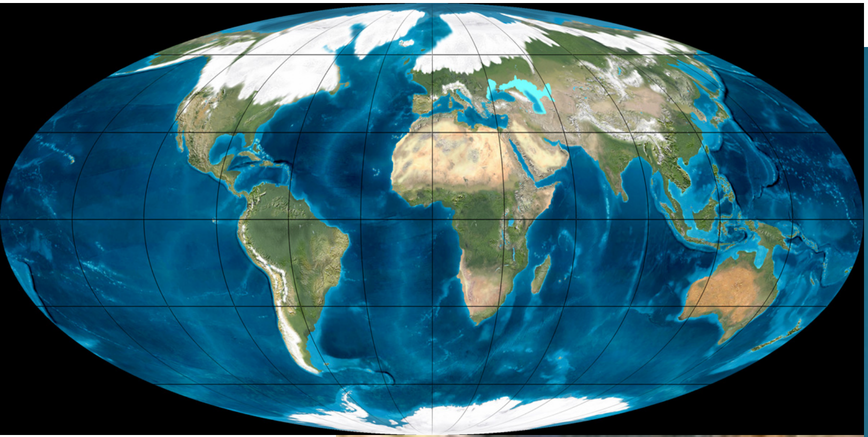
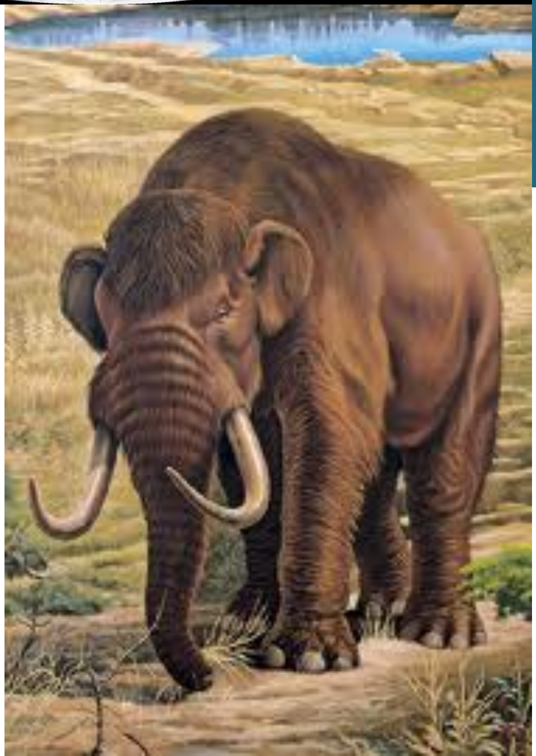
Glaciation – Part II





Glaciation

Outline of topics in this section:

1) Causes of glaciation
2) Pleistocene glaciation
3) Changes associated with glaciation
4) Biogeographic consequences
5) Evolutionary consequences
6) Extinctions

Glaciation

Outline of topics in this section:

1) Causes of glaciation
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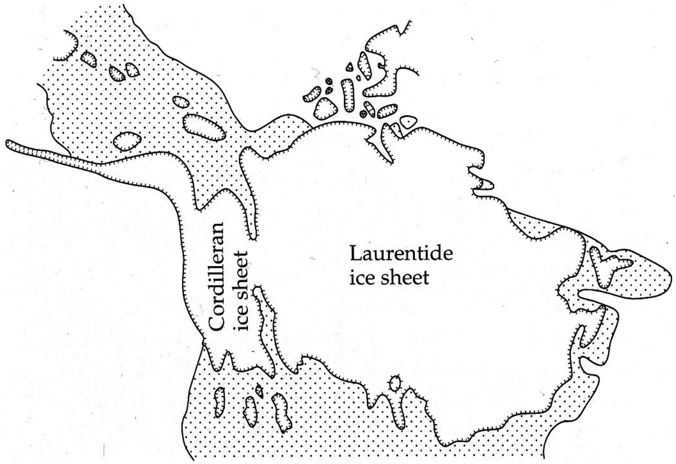
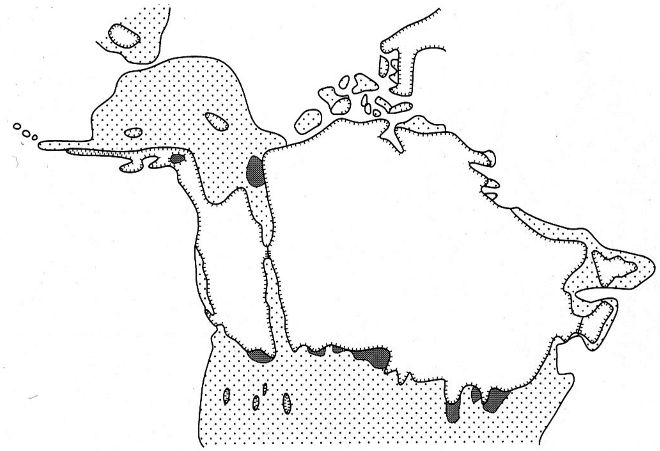
Biogeographic Consequences

Retreat of the Wisconsin Glaciers

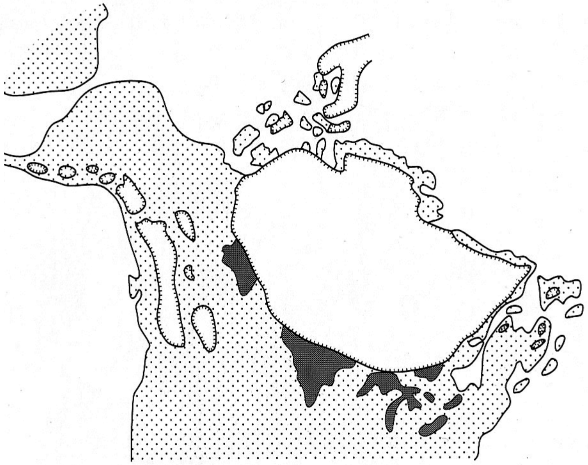
18,000 years bp



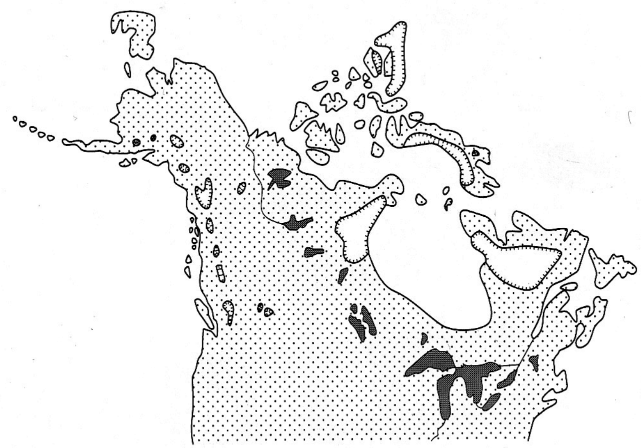
13,000 years bp



10,000 years bp



7,000 years bp

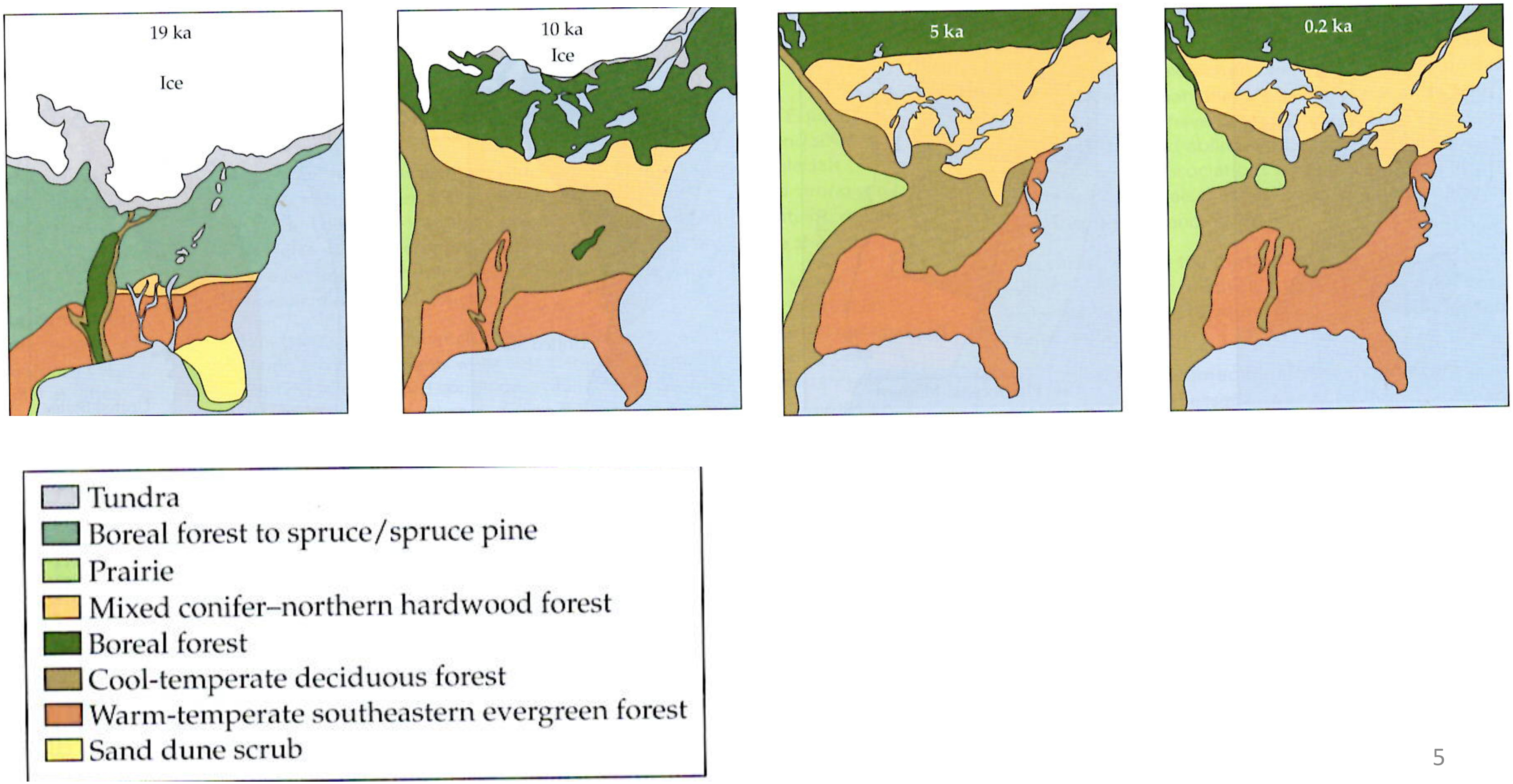


(from Lomolino *et al.* 2006)

Biogeographic Consequences

Latitudinal Shift in Biomes – the Mississippi valley and Eastern North America

19,000 years bp | 10,000 years bp | 5,000 years bp | 200 years bp



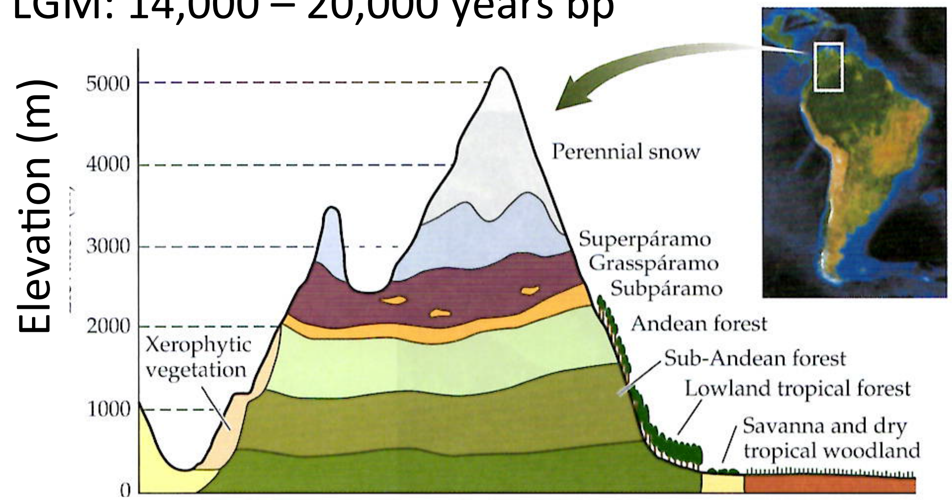
Biogeographic Consequences

Elevational Shift in Biomes – the Andes

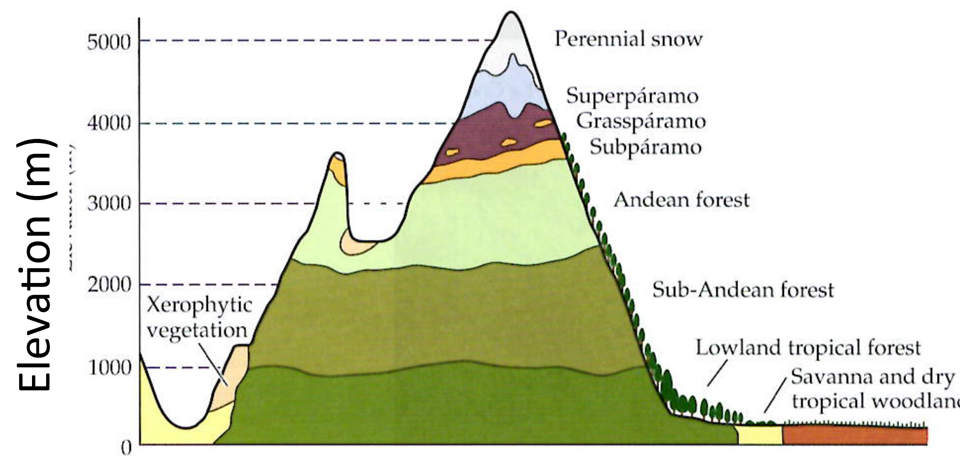
Shifts in vegetation zones in Eastern Cordillera of Colombian Andes Mountains following last glacial maximum

(from Lomolino *et al.* 2010)

LGM: 14,000 – 20,000 years bp



Present



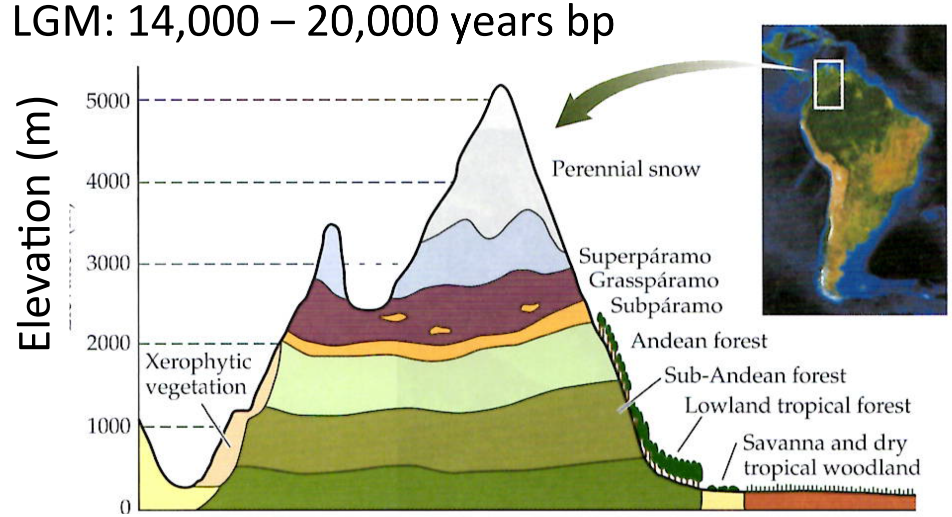
Biogeographic Consequences

Elevational Shift in Biomes

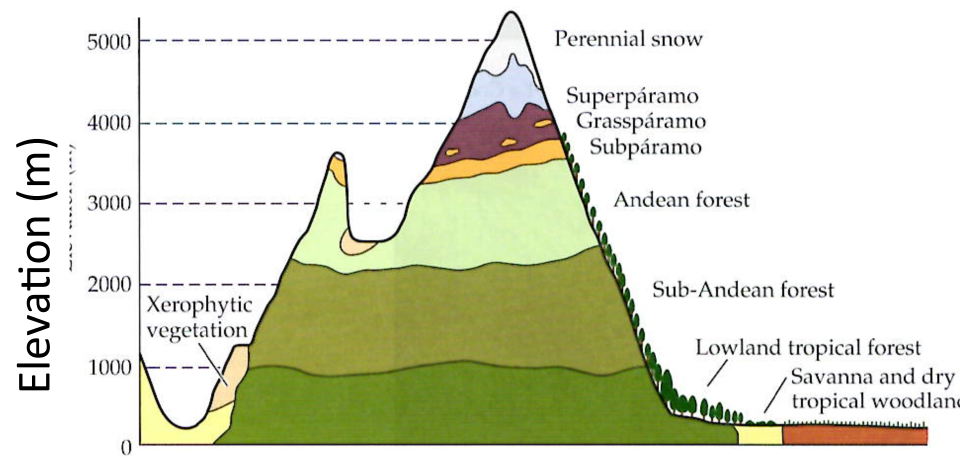
Zone shifts ranged from 150 – 1500 m between glacial and interglacial periods

Typically much more rapid than latitudinal shifts

LGM: 14,000 – 20,000 years bp



Present



(from Lomolino *et al.* 2010)

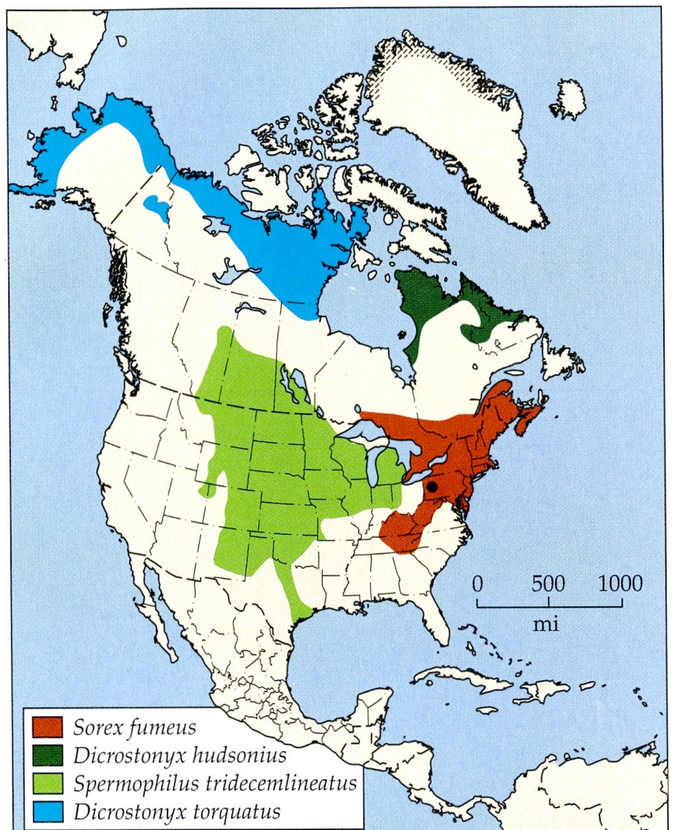
Biogeographic Consequences

Range shifts in mammals

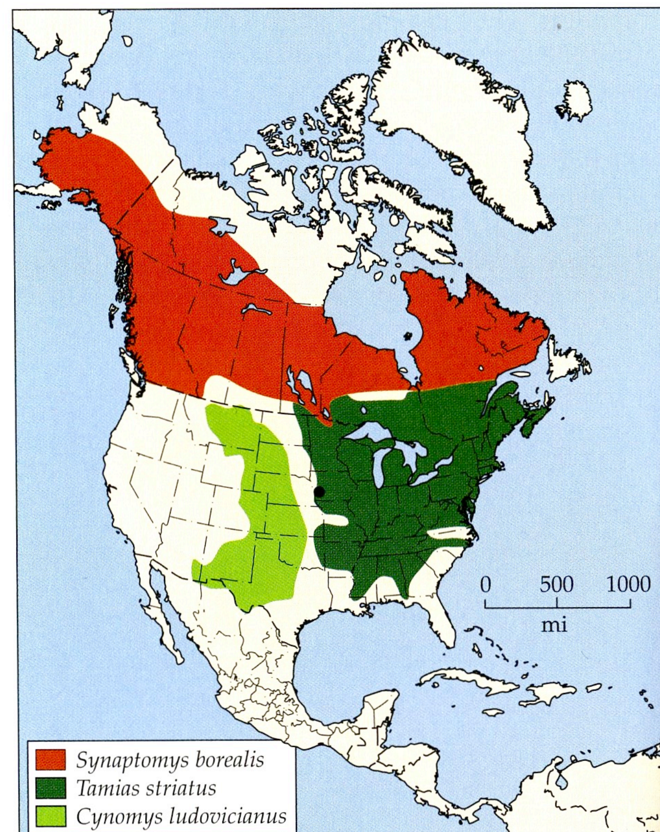
With resulting differences in extent and direction of range shifts during the Holocene, species that co-occurred during the last glacial maximum exhibit disjunct ranges today.

Black dots show areas where species co-occurred during late Pleistocene (based on fossils)

Shrews, lemmings, and squirrels



Lemmings, chipmunks, prairie dogs



(from Lomolino *et al.* 2010)

Biogeographic Consequences

Biotic Exchanges

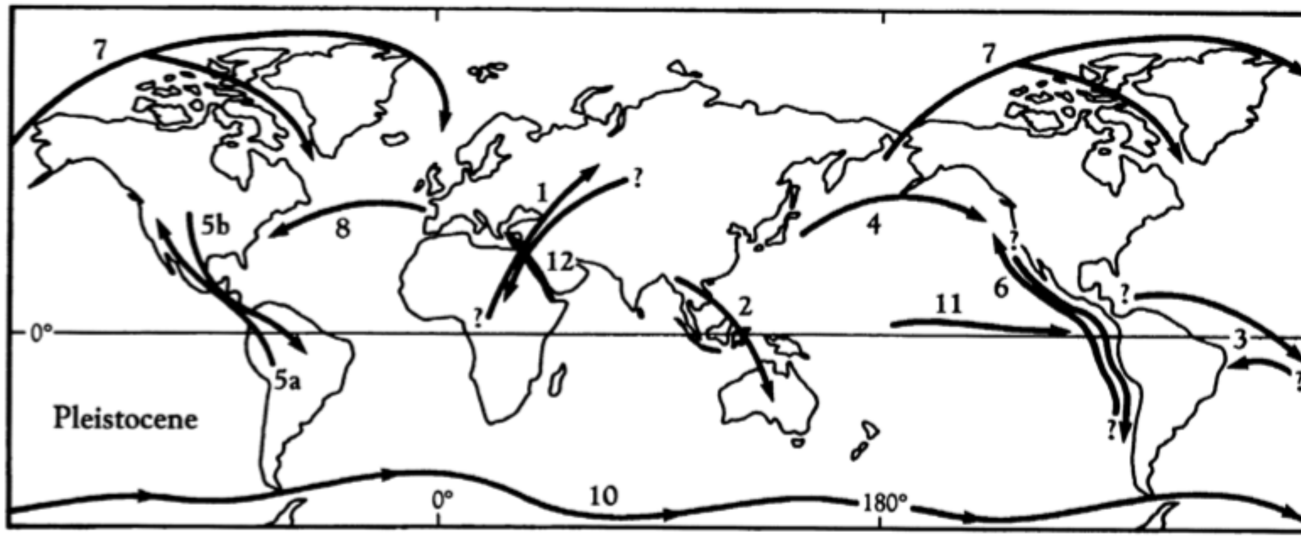
Key

1. Terrestrial interchange between Africa and Asia
2. Terrestrial interchange, chiefly from southeast Asia to Australia and New Guinea
3. Marine interchange across the tropical Atlantic
4. Marine interchange across the North Pacific, mainly from west to east

5a. Great American interchange for lowland rain-forest organisms, chiefly from south to north

5b. Great American interchange for savanna and upland organisms, symmetrical during the Pliocene, mainly north to south subsequently

6. Transequatorial marine interchange in the eastern Pacific, mainly from north to south during the Pliocene, of unknown directionality subsequently
7. Marine trans-Arctic interchange
8. Marine interchange across the North Atlantic, mainly from east to west
9. Transequatorial marine interchange in the eastern Atlantic
10. Circum-Antarctic marine interchange
11. Marine interchange across the tropical Pacific, mainly from west to east
12. Trans-Suez interchange (Recent only)



Great American Interchange: Exchange of mammals between North and South America following formation of Central American land bridge ~ 3.5 million years ago.

(from Vermeij 1991)

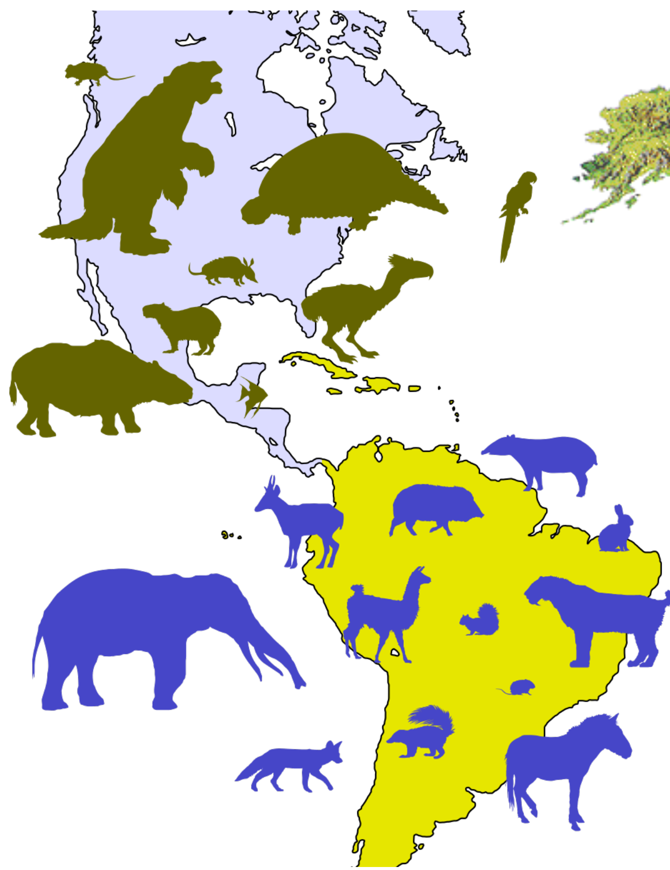
Biogeographic Consequences

Biotic Exchanges

With Great American Interchange, Central American land bridge was more of a filter than a highway. Interchange was greater during glacial periods when savanna habitats covered much of Central and South America.

Southern Origin
Porcupines
Glyptodonts
Armadillos
Giant ground sloths
Opossums

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



Biogeographic Consequences

Biotic Exchanges

Filtering dispersal route lead to *asymmetric biotic exchange*

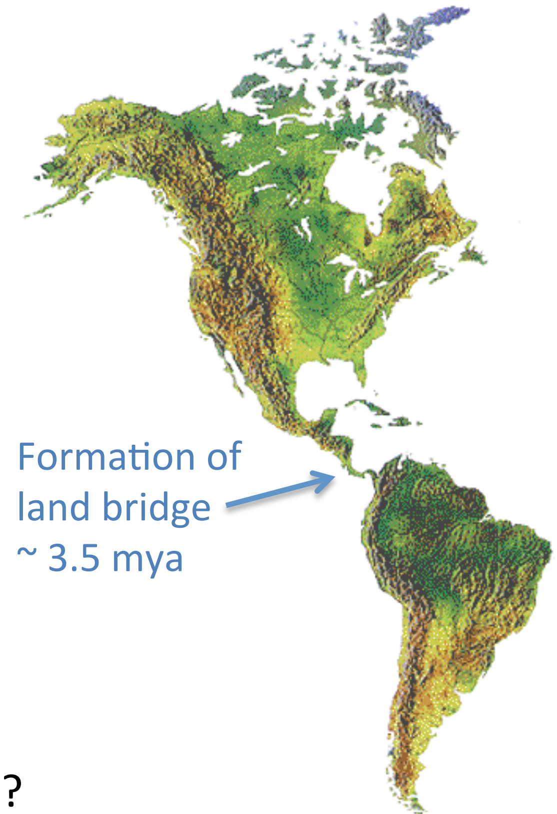
Three potential advantages leading to bias of northern forms in South America:

1) They were better migrators

2) They were better survivors and diversified more readily

3) They were better competitors

* What predictions could we make based on Janzen's Hypothesis?



Formation of land bridge ~ 3.5 mya

Evolutionary Consequences

Speciation

The major evolutionary consequence of glaciation was the abundance of opportunities for isolation and subsequent divergence through genetic drift and novel selection pressures.

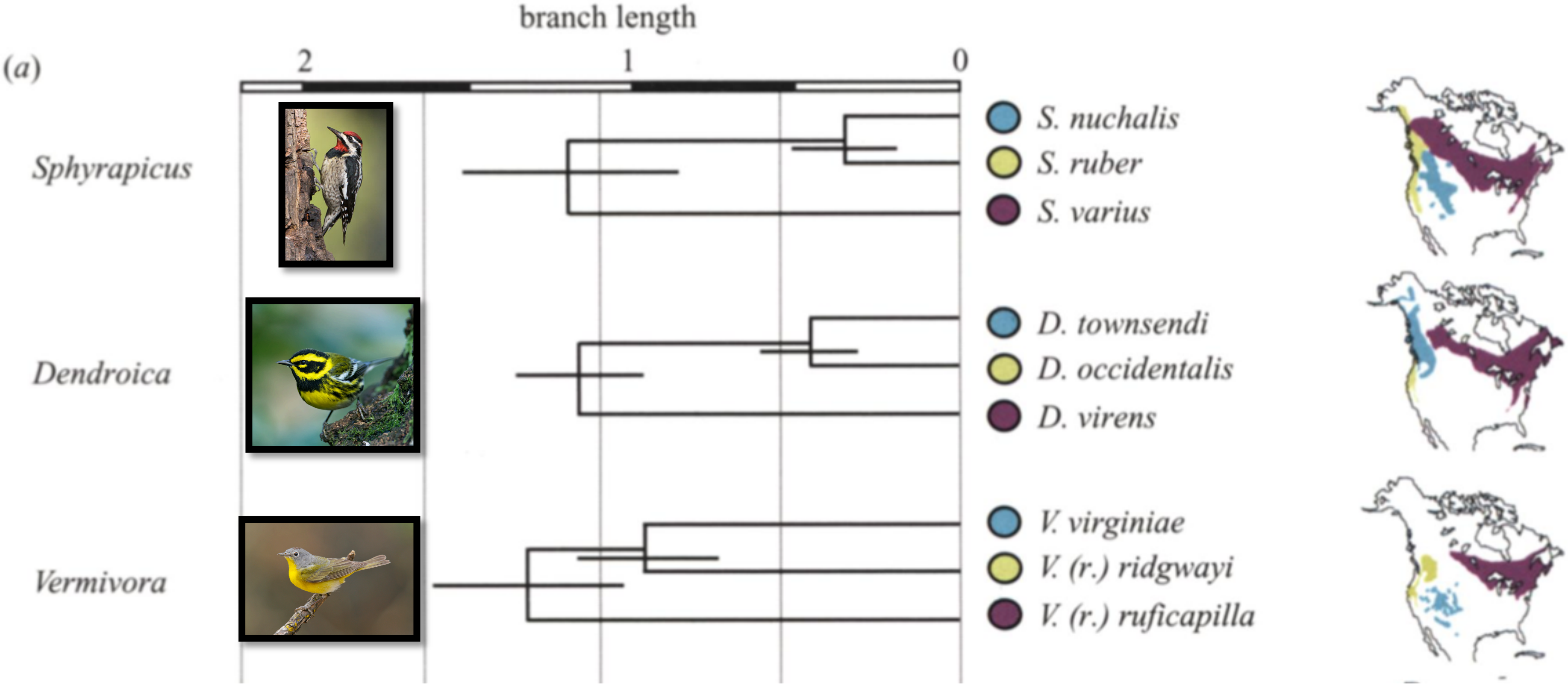
Speciation Pump: the generation of diversity due to repeated fragmentation, allopatric speciation, and reconnection of fauna during the glacial/interglacial cycles of the Pleistocene.

(from Haffer 1969)

Evolutionary Consequences

Pleistocene Speciation Pump

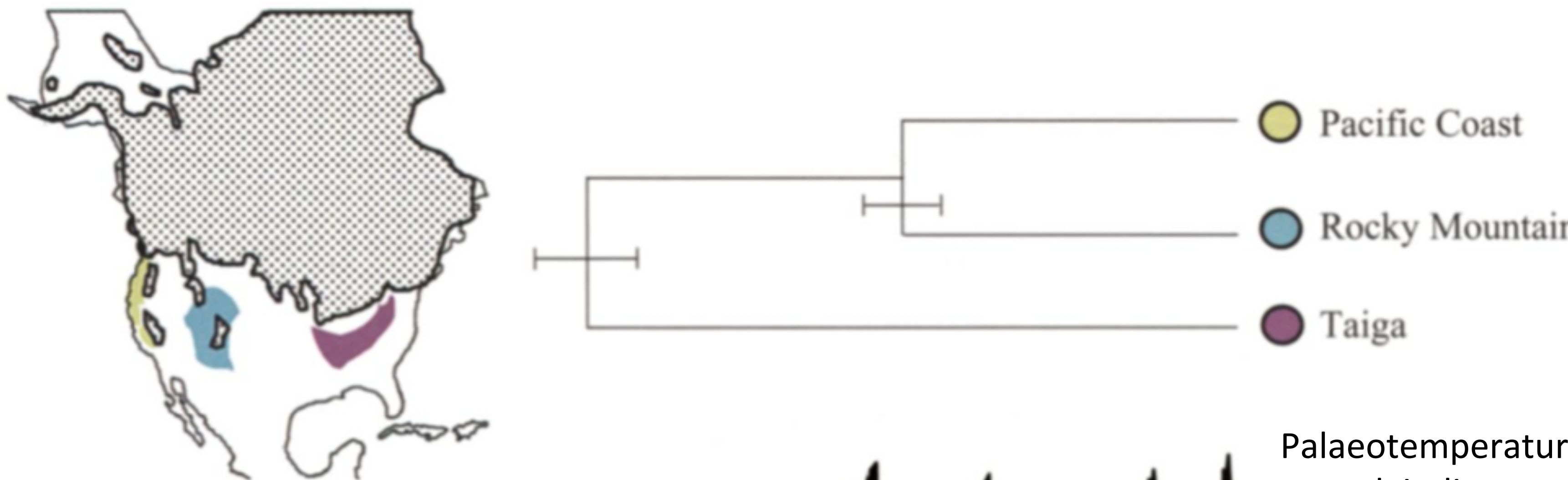
Superspecies: monophyletic group of two or more allospecies (geographically separated) or semi-species (connected geographically by a narrow hybrid zone) that have just crossed the species threshold and are presumed to be the youngest species in an avifauna (Weir & Schluter 2004).

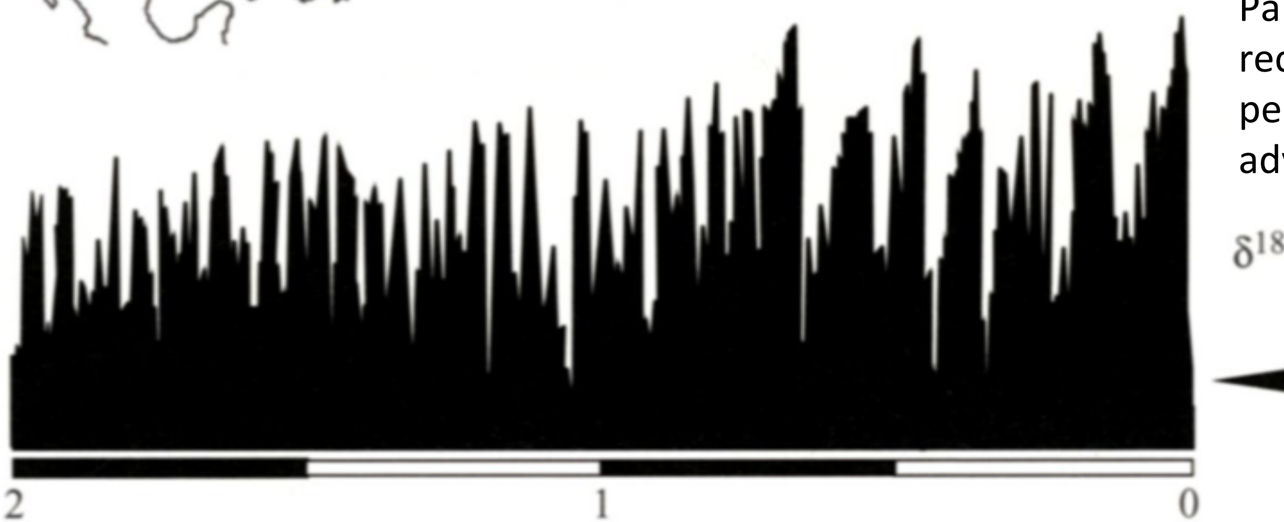


(from Weir and Schluter 2004)

Evolutionary Consequences

Pleistocene Speciation Pump





Palaeotemperature record, indicates cold periods of glacial advance

δ^{18} O record

present-day interglacial

(from Weir and Schluter 2004)

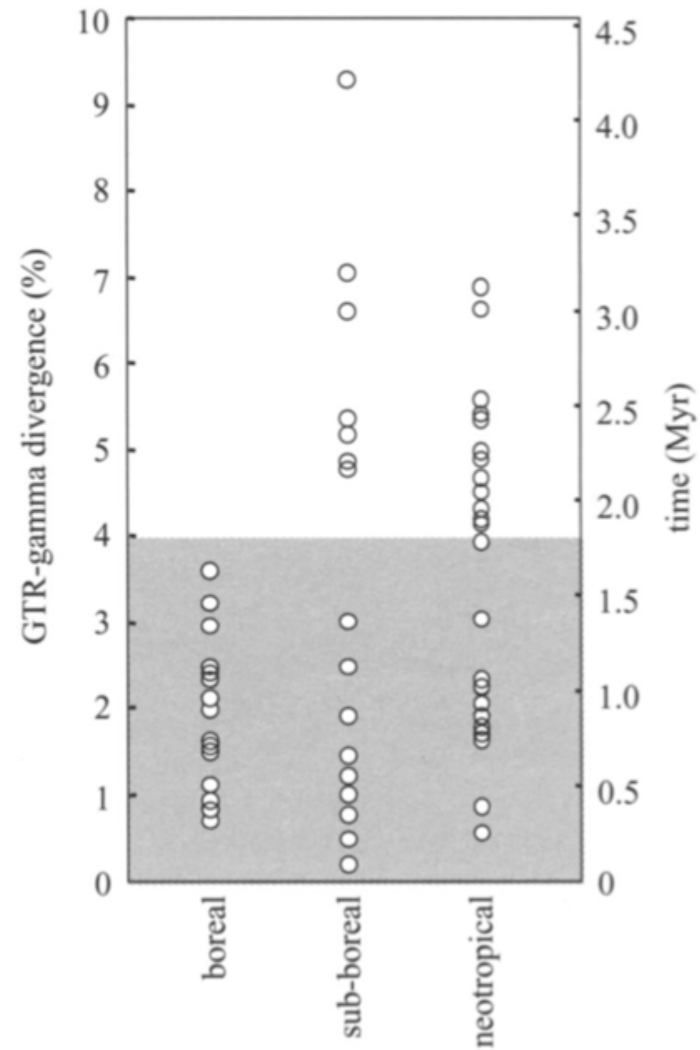
Evolutionary Consequences

Pleistocene Speciation Pump

Percent sequence divergence in superspecies groups residing in different regions

Shaded area indicates Pleistocene

More recent divergence in boreal superspecies during Pleistocene (during time of glacial cycles)



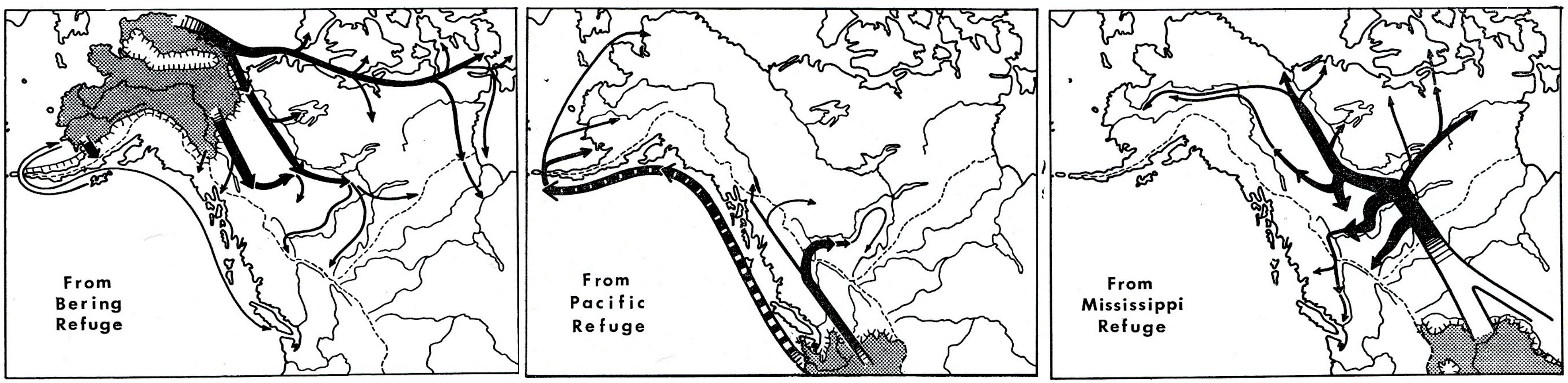
* Applied a GTR-gamma model of mtDNA sequence evolution: 2.2% divergence for every 1 million years of separation

(from Weir and Schluter 2004)

Evolutionary Consequences

Glaciation and the origin of phylogroups (or superspecies)

e.g., All of British Columbia's fish fauna must have come from refugial populations. Some species were isolated in multiple refugia (about 21 species in total), giving potential for intraspecific divergence.

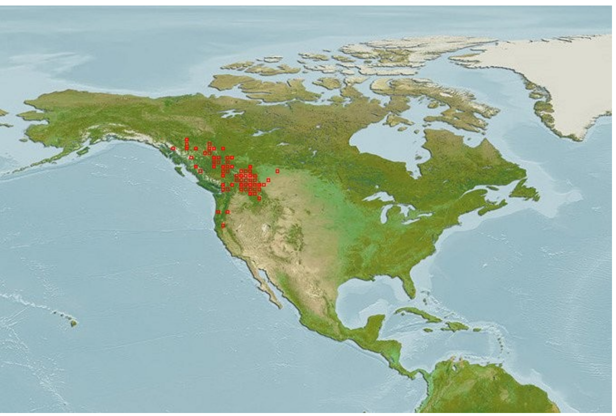


(from McPhail and Lindsey 1970)

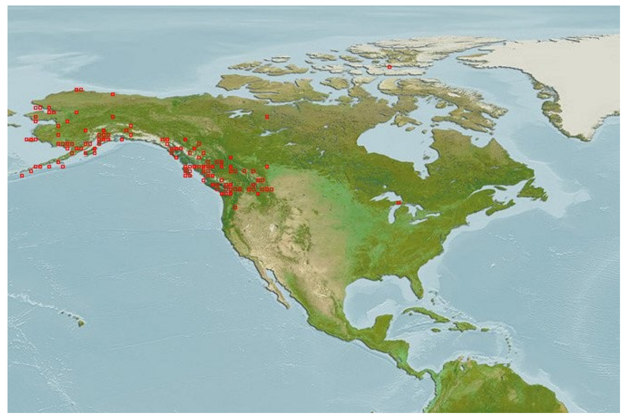
Evolutionary Consequences

Glaciation and the origin of phylogroups (or superspecies)

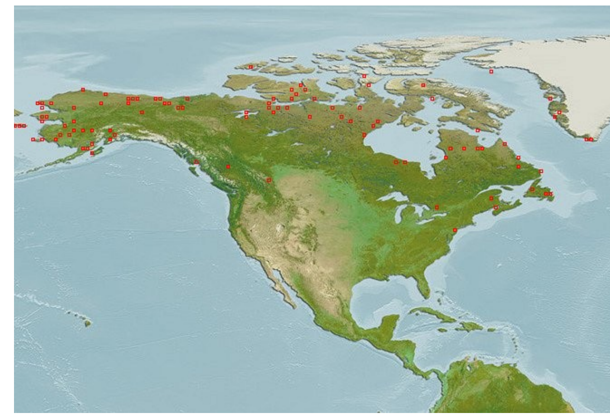
Bull Trout (*Salvelinus confluentus*)



Dolly Varden (*Salvelinus malma malma*)



Arctic Char (*Salvelinus alpinus alpinus*)



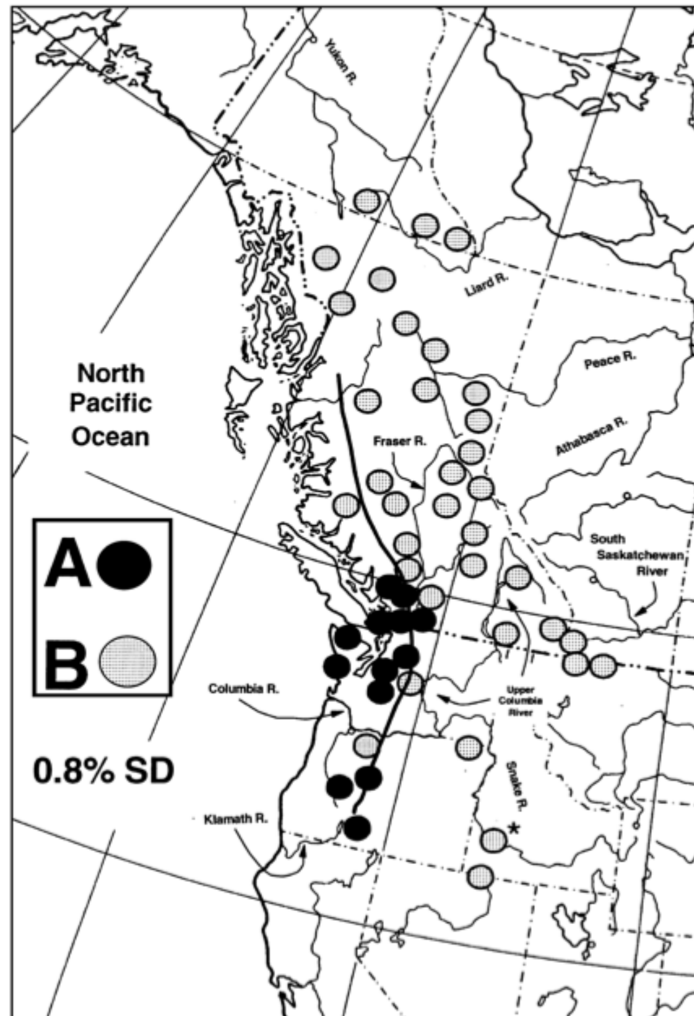
Evolutionary Consequences

Glaciation and the origin of phylogroups (or superspecies)

e.g., bull trout (*Salvelinus confluentus*)

● Chehalis River refuge

○ Columbia River refuge



(from Taylor *et al.* 1999)

Evolutionary Consequences

Glaciation and the origin of phylogroups (or superspecies)

e.g., Anadromous fish species have given rise to freshwater populations that do not go to sea and may differ greatly from the parental species in appearance and ecology.

(In BC we see this in salmon, lampreys, sticklebacks and smelt)

Pygmy smelt in Pitt Lake, Harrison Lake, and Lake Washington.

Longfin smelt (*Spirinchus thaleichthys*) in the ocean.

Evolutionary Consequences

Glaciation and the origin of phylogroups (or superspecies)

e.g., Anadromous fish species have given rise to freshwater populations that do not go to sea and may differ greatly from the parental species in appearance and ecology.

(In BC we see this in salmon, lampreys, sticklebacks and smelt)

Benthic (top) and limnetic stickleback (*Gasterosteus aculeatus*) from Paxton Lake on Texada Island, BC

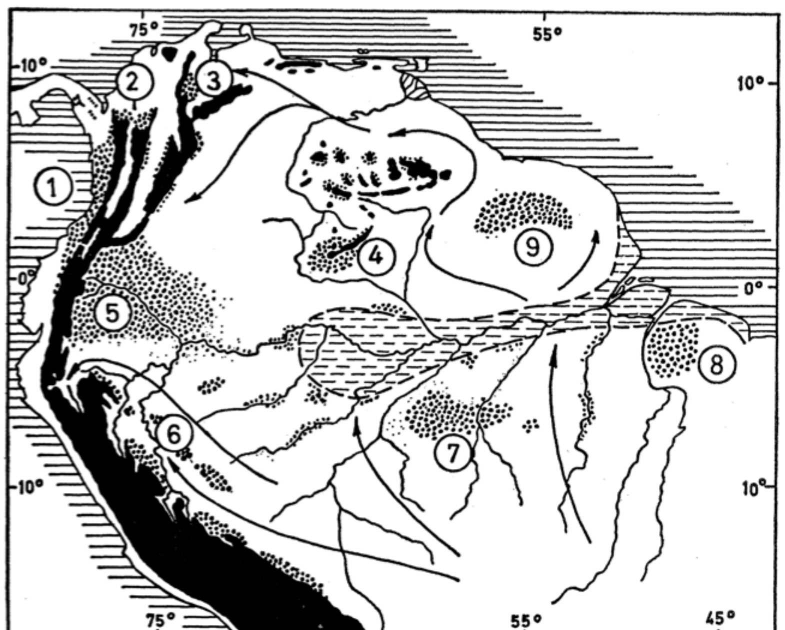
Evolutionary Consequences

What was happening in the tropics during the Pleistocene?

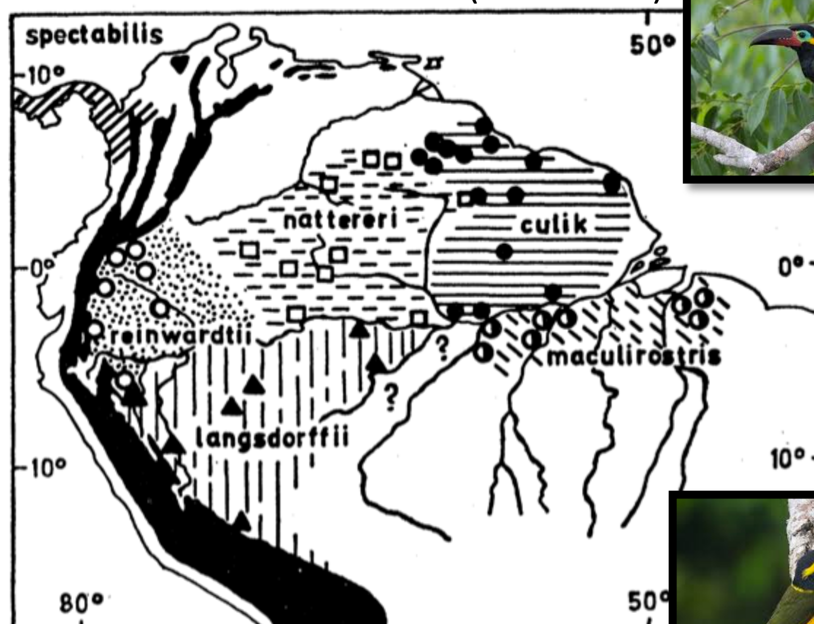
Old view:

Refugia hypothesis (Haffer 1969): Islands of lowland rain forest persisted during glacial maxima. Developed a model of “cyclic vicariance” where species were separated through fragmentation during dry glacial periods.

Pleistocene rainforest refugia



Distribution of *Selenidera* (toucanets)

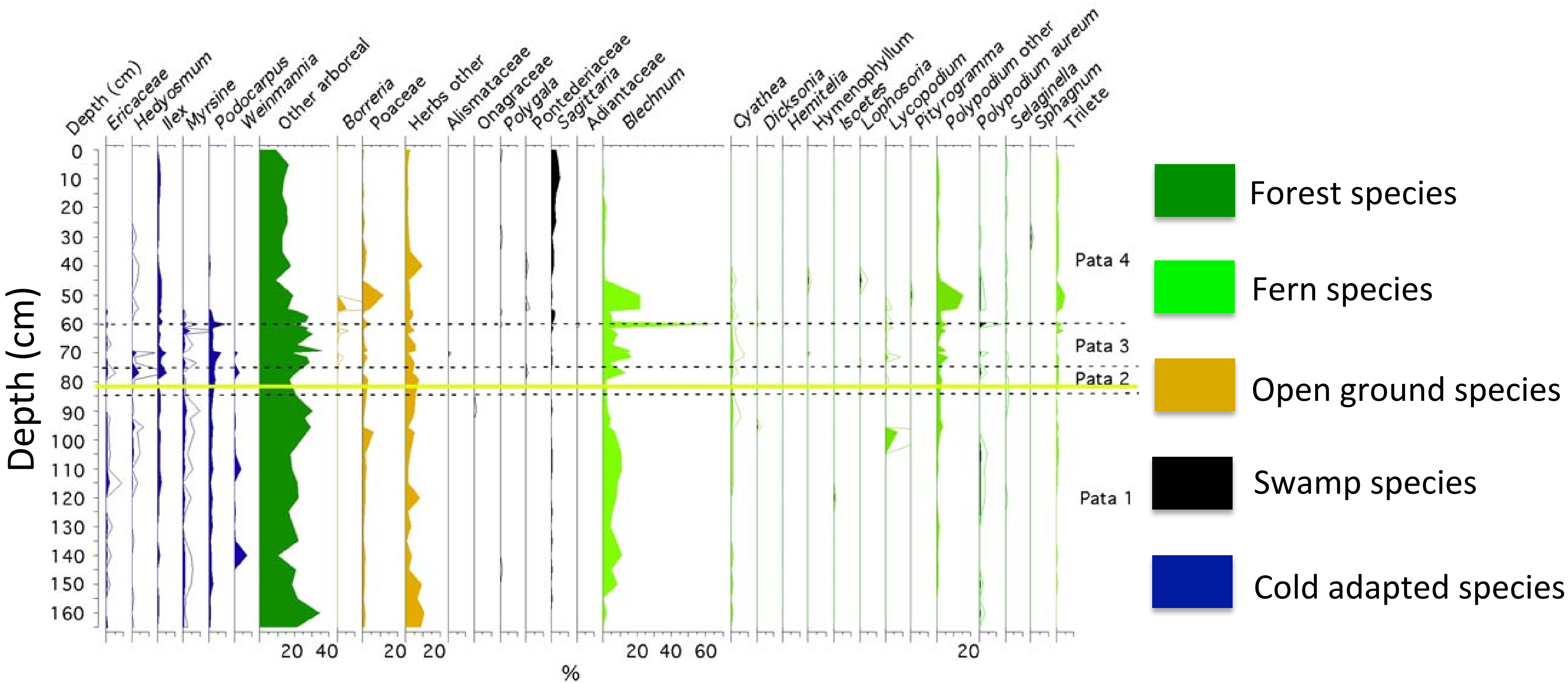


Evolutionary Consequences

What was happening in the tropics during the Pleistocene?

Developing view:

Refugia hypothesis was largely based on inferences from current species distribution patterns, but *not based* on paleoecological data.

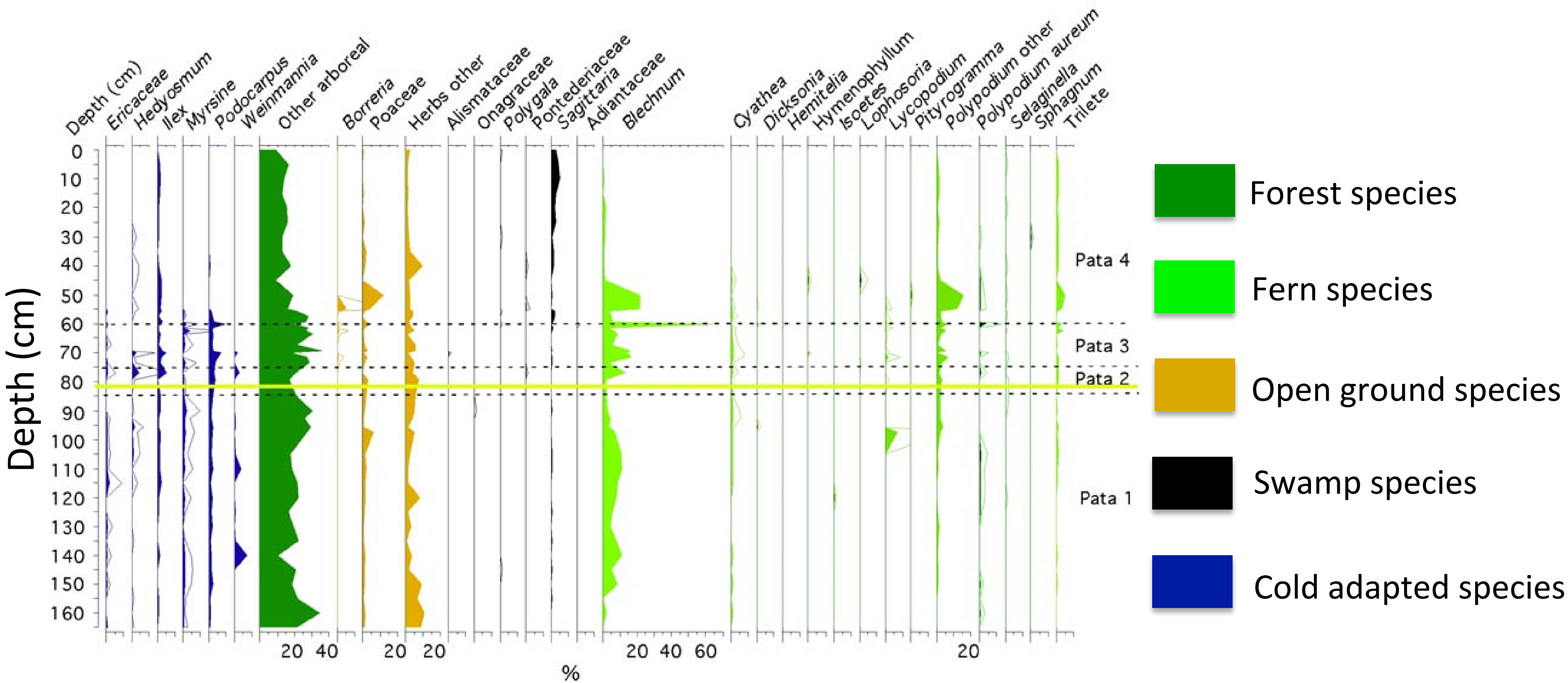


Evolutionary Consequences

What was happening in the tropics during the Pleistocene?

Developing view:

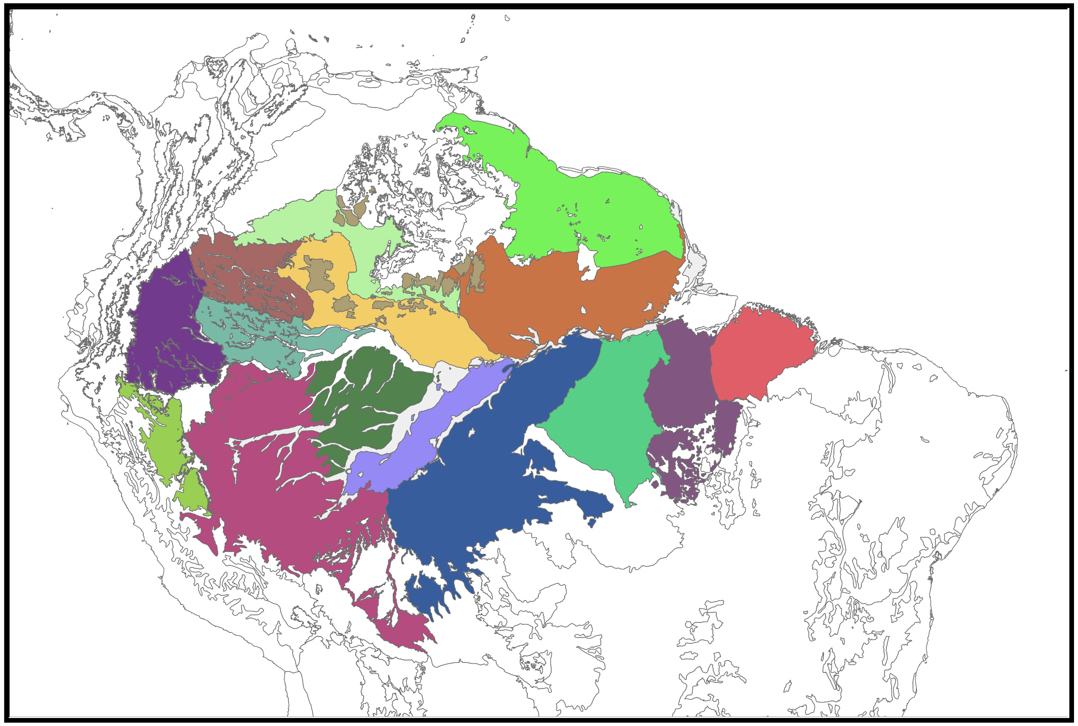
Fossil pollen data from lake cores show continuous forest cover and invasion by cold-adapted species during last glacial maximum.



Evolutionary Consequences

Alternative hypotheses for Refugia-like distributions?

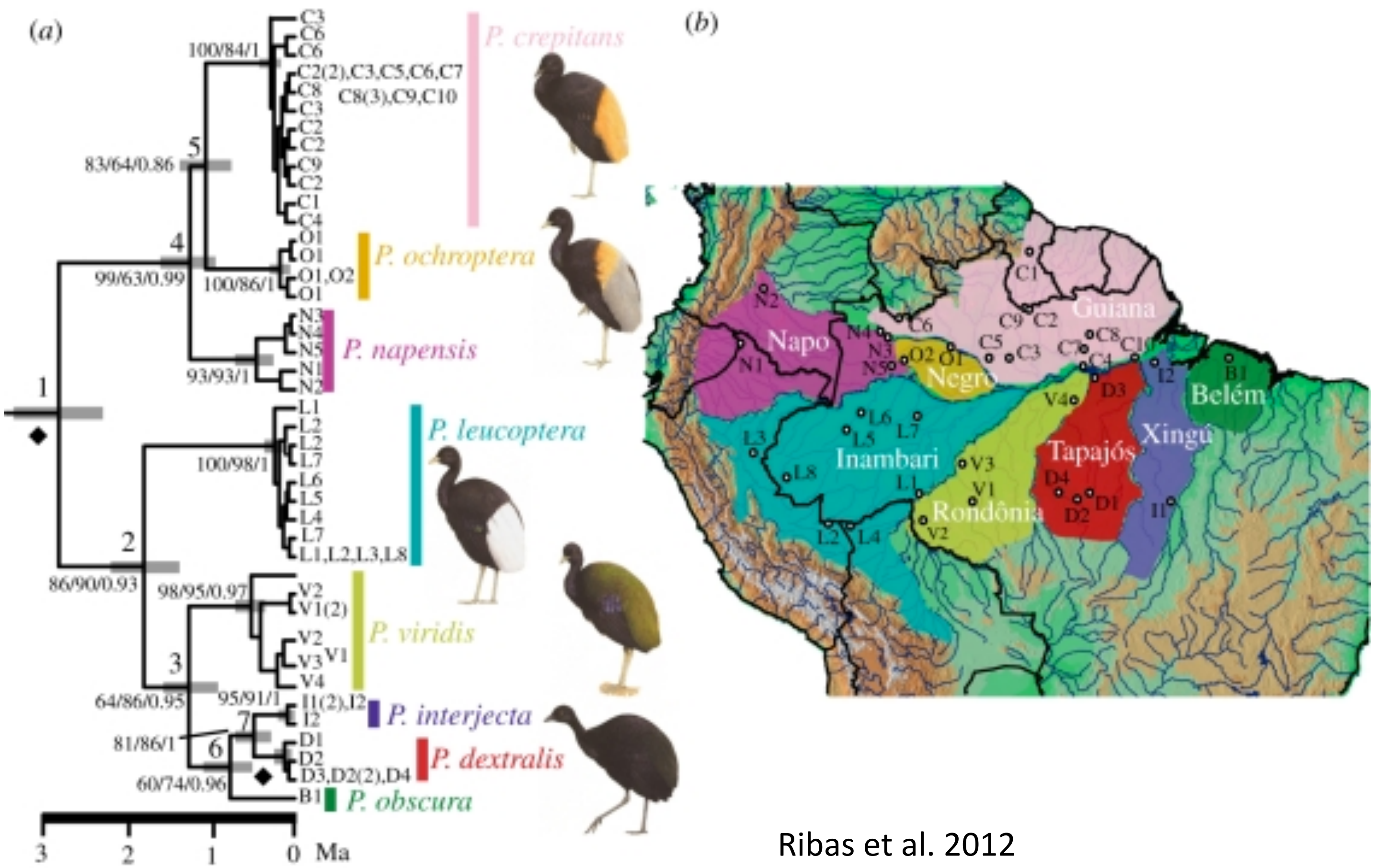
Amazonian Ecoregions divided by large river systems are also consistent with range limits across species group



Evolutionary Consequences

Alternative hypotheses for Refugia-like distributions?

Phylogenetic relationships of trumpeter species in South America.
Distributions show that species ranges are separated by large river systems.

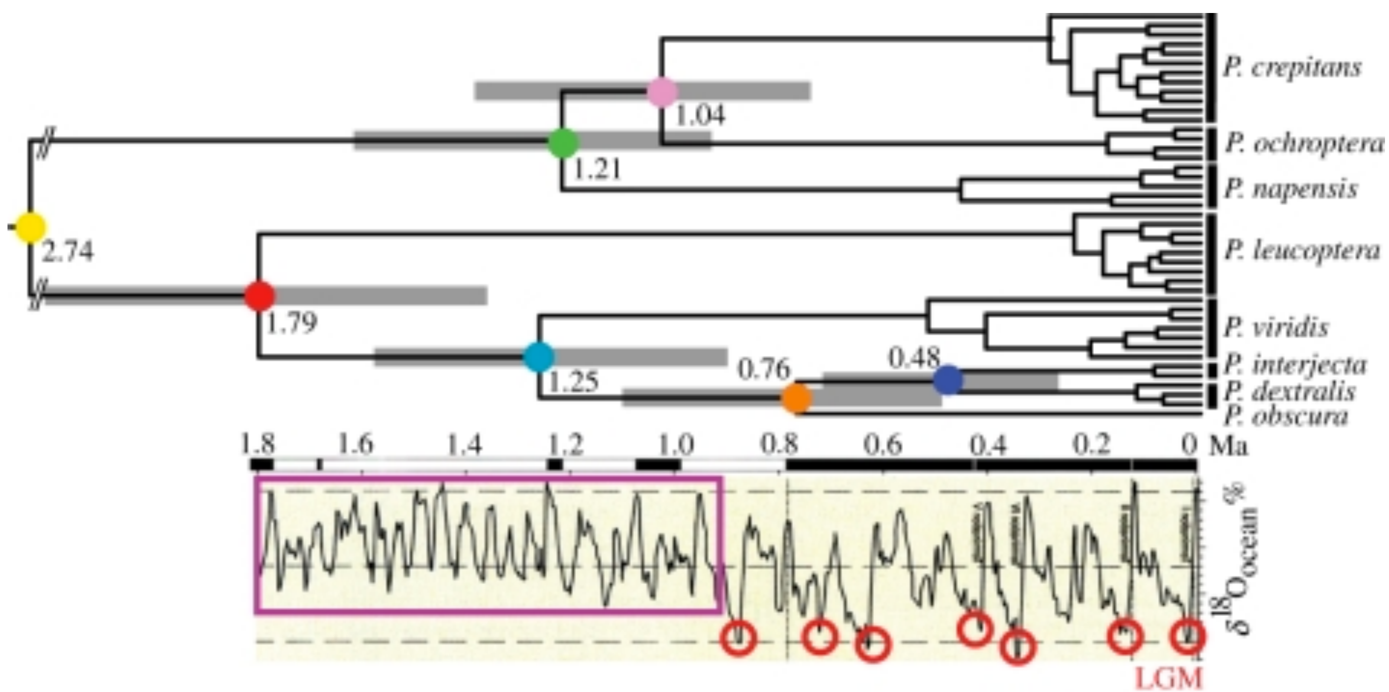


Ribas et al. 2012

Evolutionary Consequences

Alternative hypotheses for Refugia-like distributions?

Phylogenetic relationships of trumpeter species in South America.
Timing of diversification events indicates speciation prior to most recent glacial maxima.



Ribas et al. 2012

Evolutionary Consequences

Alternative hypotheses for Refugia-like distributions?

Phylogenetic relationships of trumpeter species in South America.
Hypothesis for diversification of trumpeters following establishment of river barriers

a) 3.0 – 2.7 mya: western lowland Amazon is a large interconnected wetland system

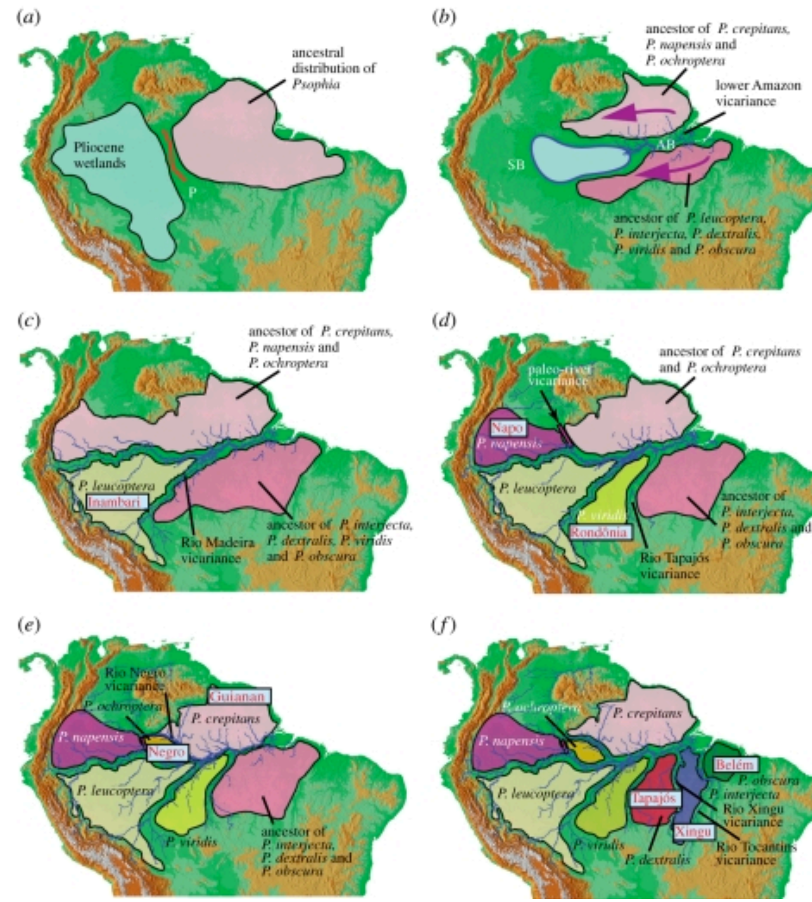
b) 2.7 – 2.0 mya: wetland system drained and lower Amazon River was established

c) 2.0 – 1.0 mya: Rio Madeira drainage established

d) 1.3 – 0.8 mya: Rio Tapajos drainage established

e) 1.0 – 0.7 mya: isolating barrier with lower Rio Negro formed

f) 0.8 – 0.3 mya: two drainage systems on Brazilian shield (Rio Tocatins and Xingu) established



Ribas et al. 2012

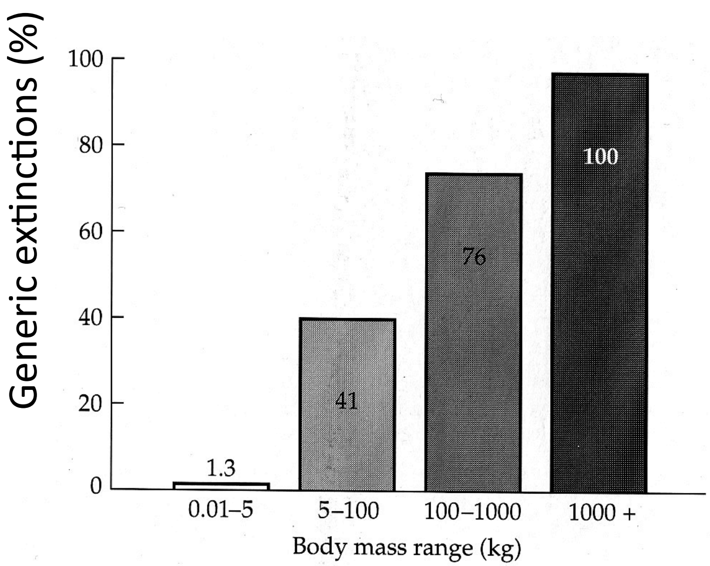
Extinctions

Massive extinctions of terrestrial mammals occurred during late Pleistocene in both North and South America. Large-bodied mammals appear to have been particularly vulnerable.

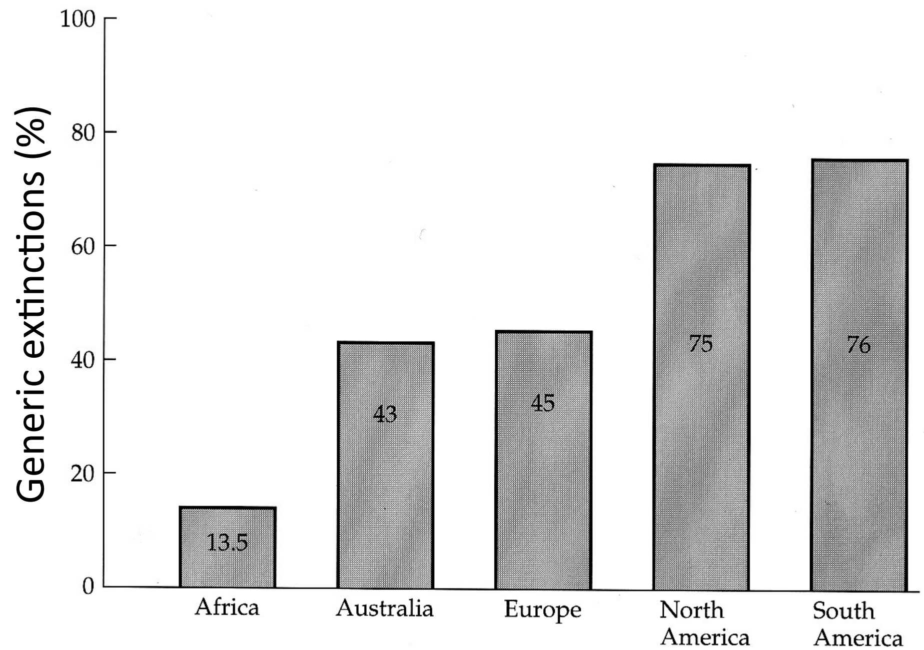
(images from www.mauricioanton.com)

Extinctions

Note that North and South American species appeared to suffer much greater extinctions than comparable-sized mammals on other continents (up to 76% of all genera).



Global rates of late Pleistocene extinction among mammalian herbivores

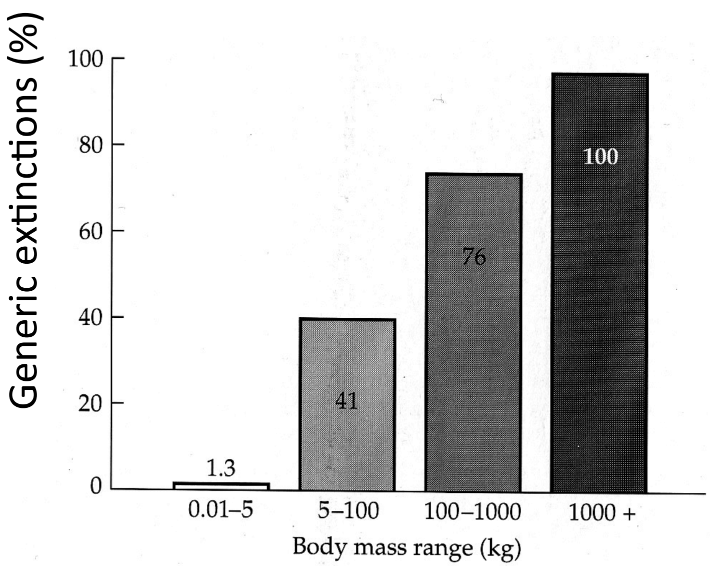


Late Pleistocene extinction rates among mammalian herbivores with body mass > 5kg

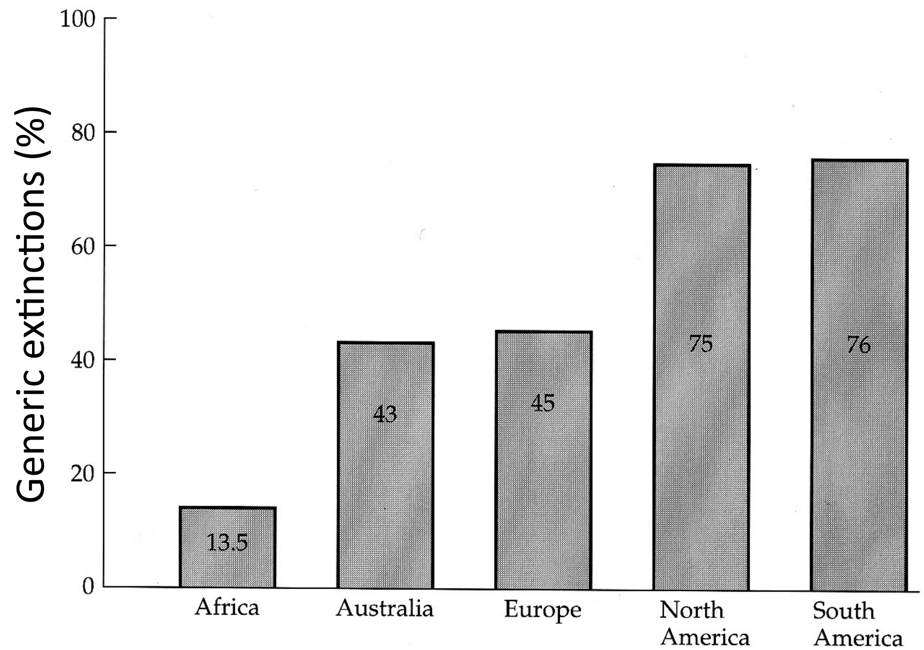
(from Lomolino *et al.* 2006)

Extinctions

These mass extinctions have been suggested to occur as a result of glaciation-induced climate changes and/or "overkill" by human hunters that colonized North America (and subsequently South America) via the Bering land bridge (the latter is a contentious idea).



Global rates of late Pleistocene extinction among mammalian herbivores



Late Pleistocene extinction rates among mammalian herbivores with body mass > 5kg

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Glaciation

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