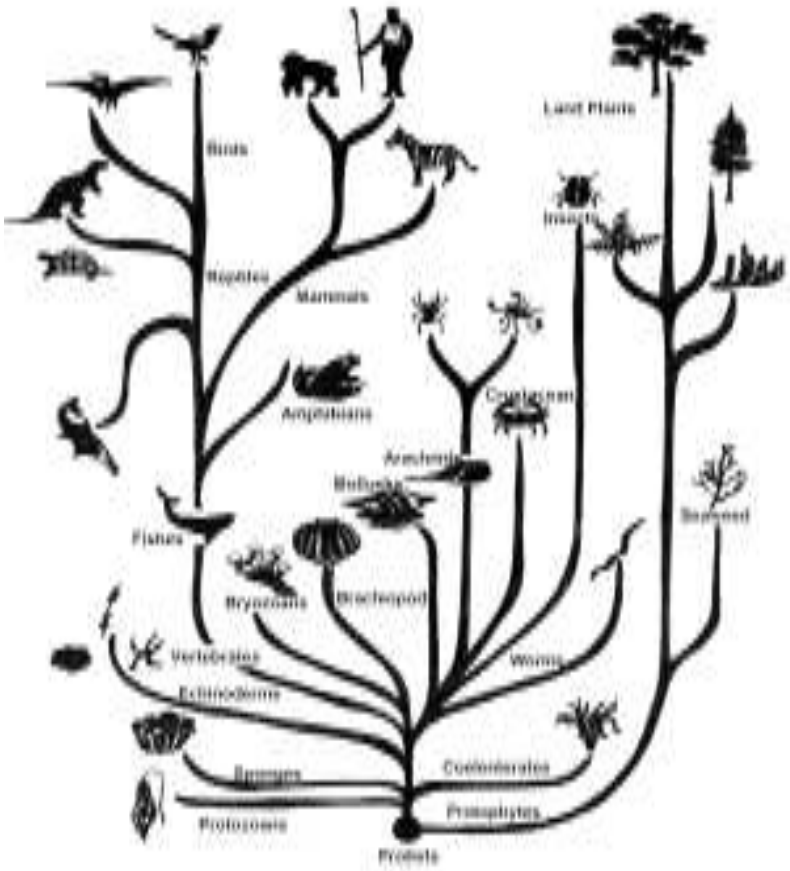
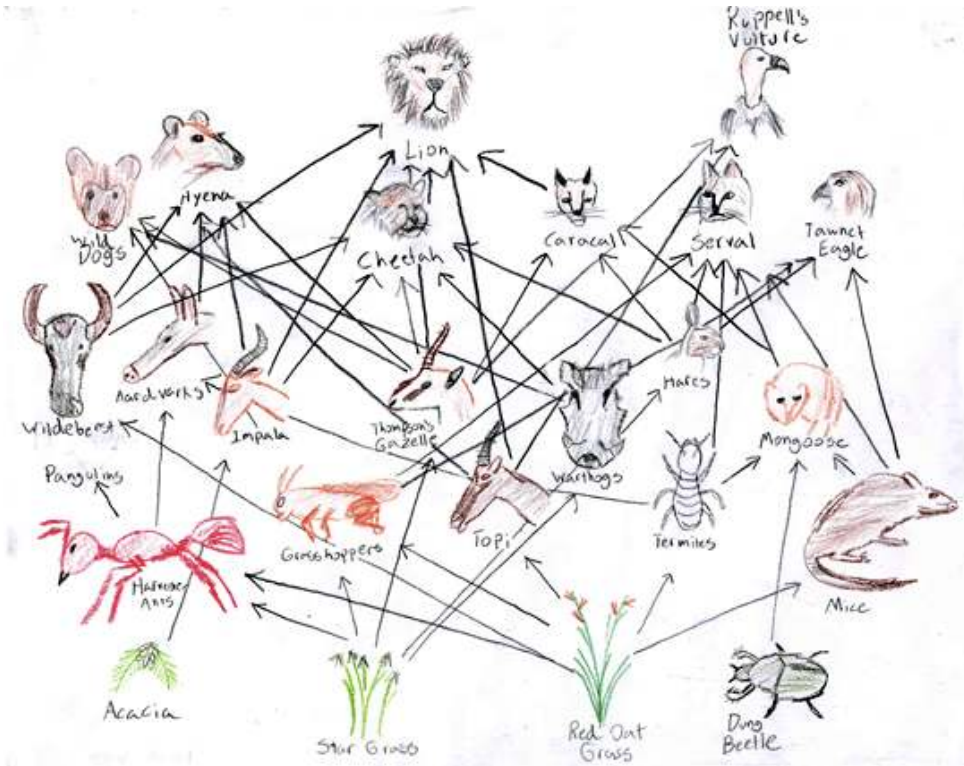
Reconnecting Ecology and Evolution to Understand Biodiversity and Global Change

Michael Donoghue, Yale University

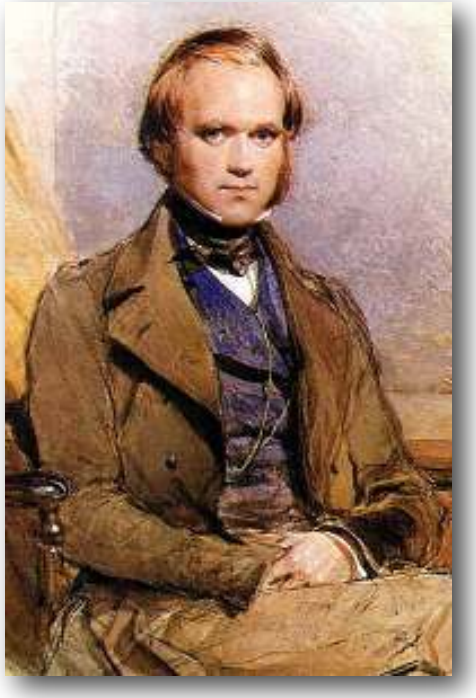
Biology's Metaphors



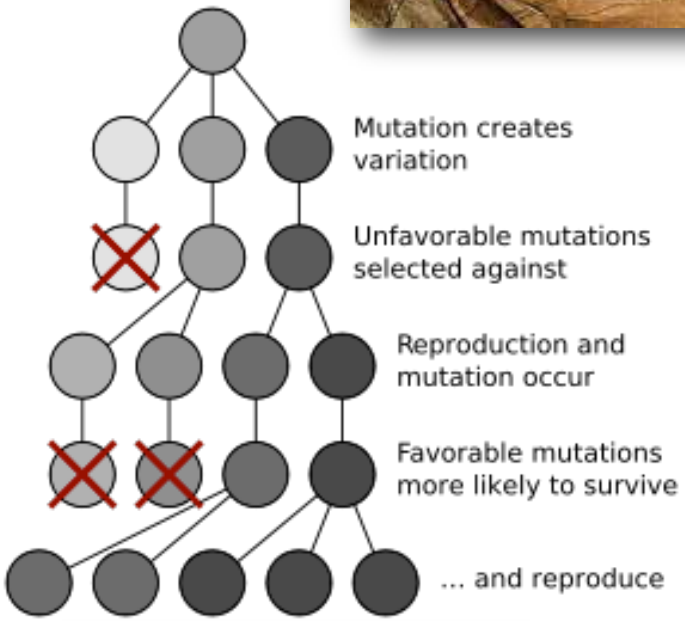


"Tree of Life"

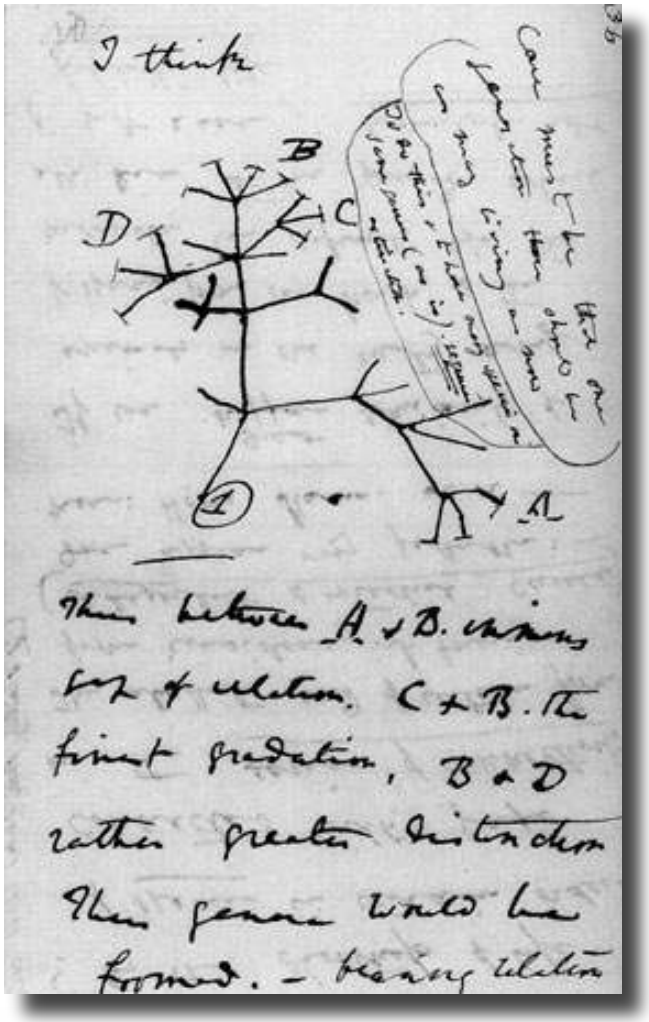
"Web of Life"



Charles Darwin
1809-1882



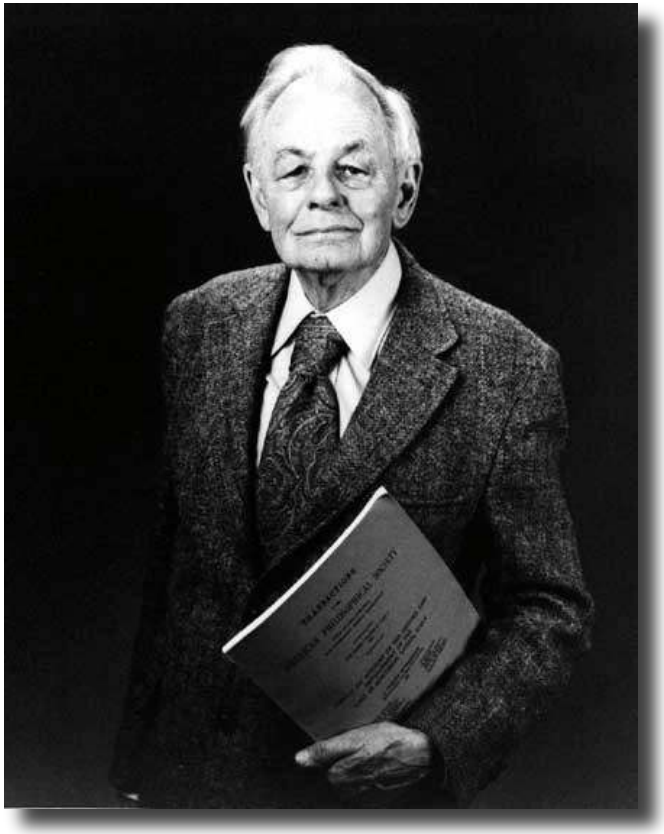
Natural Selection



The Tree of Life (Phylogeny)

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, **and dependent upon each other in so complex a manner**, have all been produced by laws acting around us."

Charles Darwin, 1859



"It is evident that at any level in **the structure of the biological community** there is a set of complicated relations between species, which probably tend to become less important as the species become less closely allied. These relations are of the kind which insure niche separation. They are probably balanced by another set of relationships expressing the fact that **organisms of common ancestry are more likely to inherit a common way of life**…"

G. E. Hutchinson, 1964

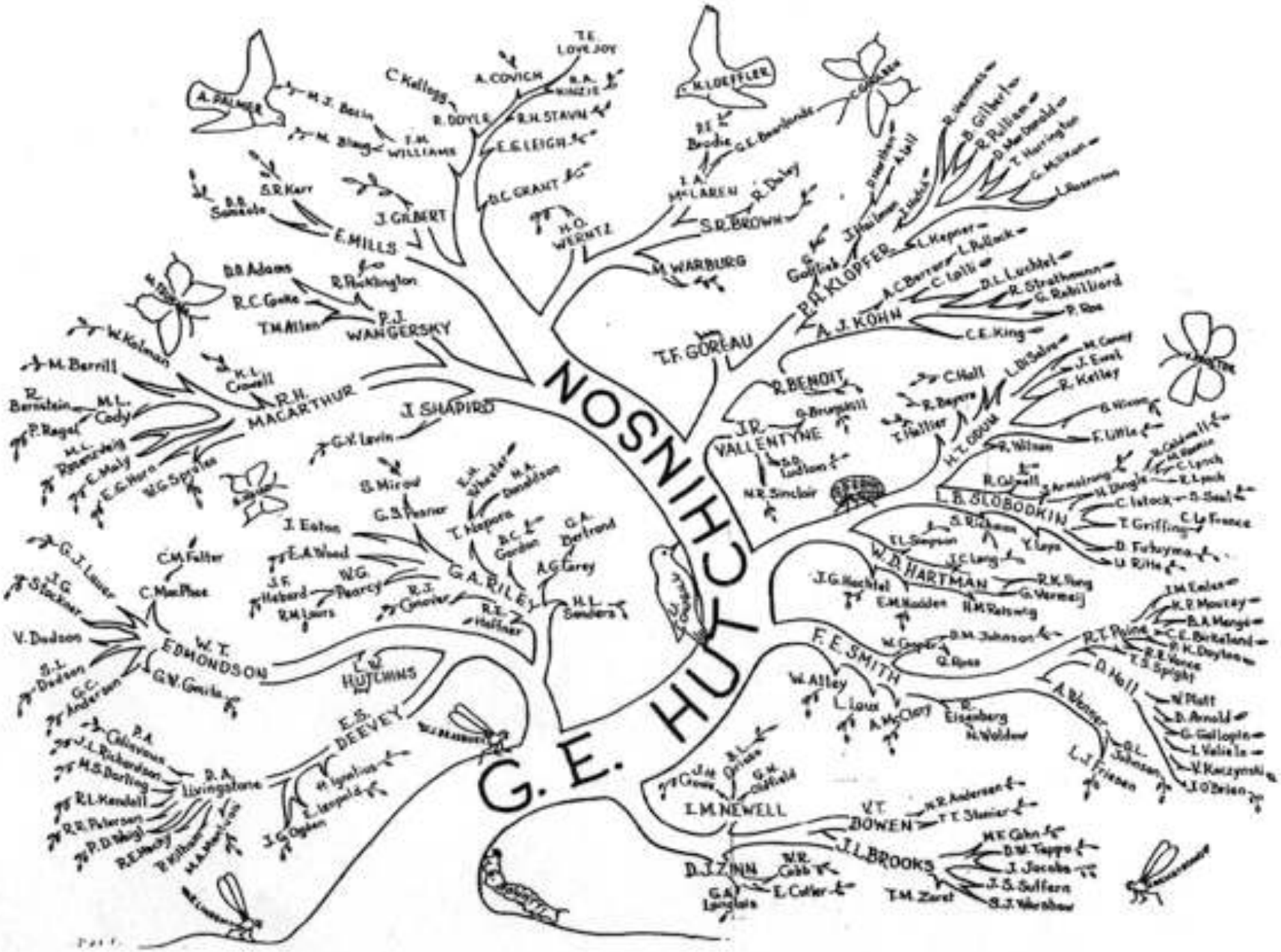


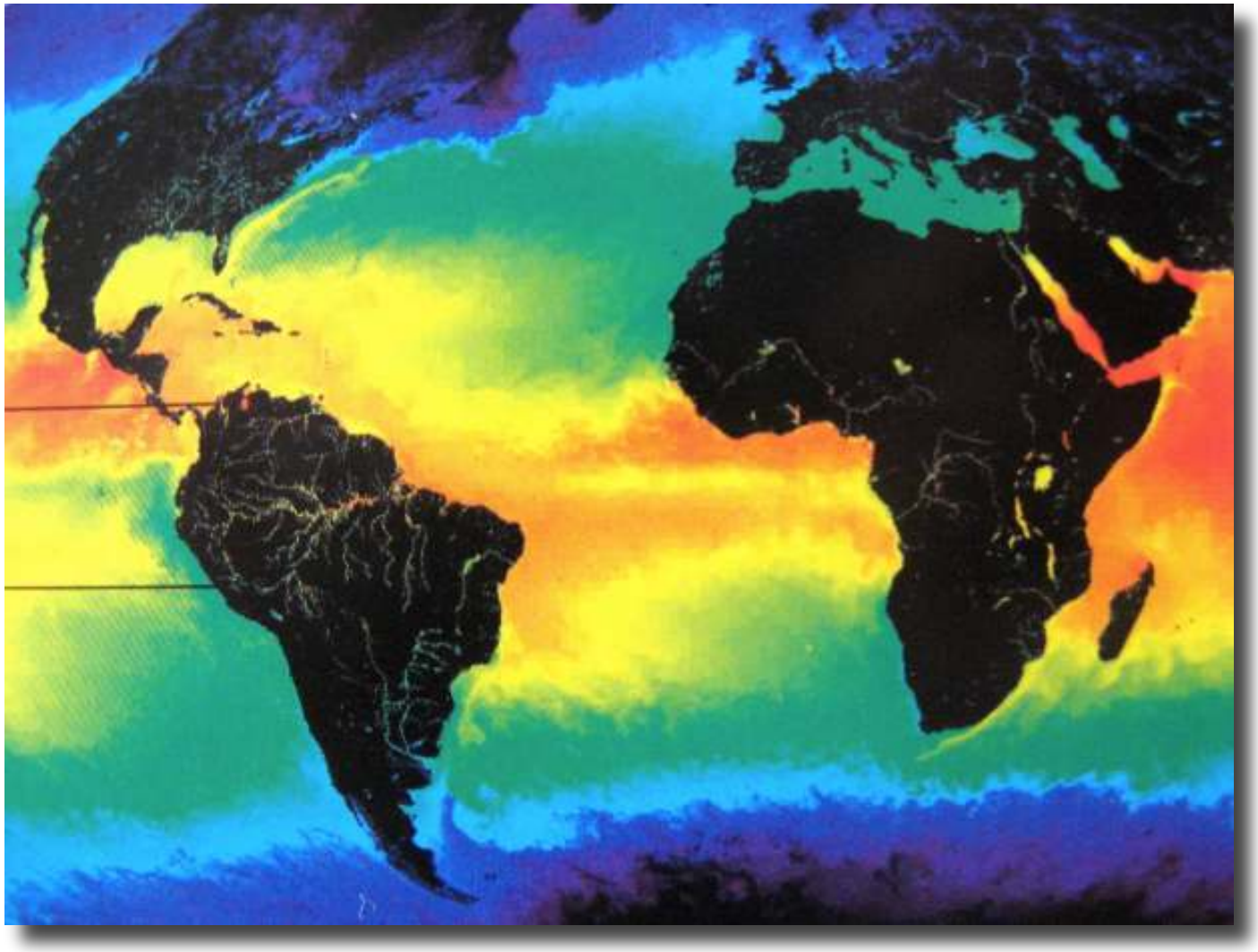
FIG. 9. Phylogenetic tree of intellectual descendants of G. E. Hutchinson, restricted to those pos-

Rapid evolution in Darwin's finches

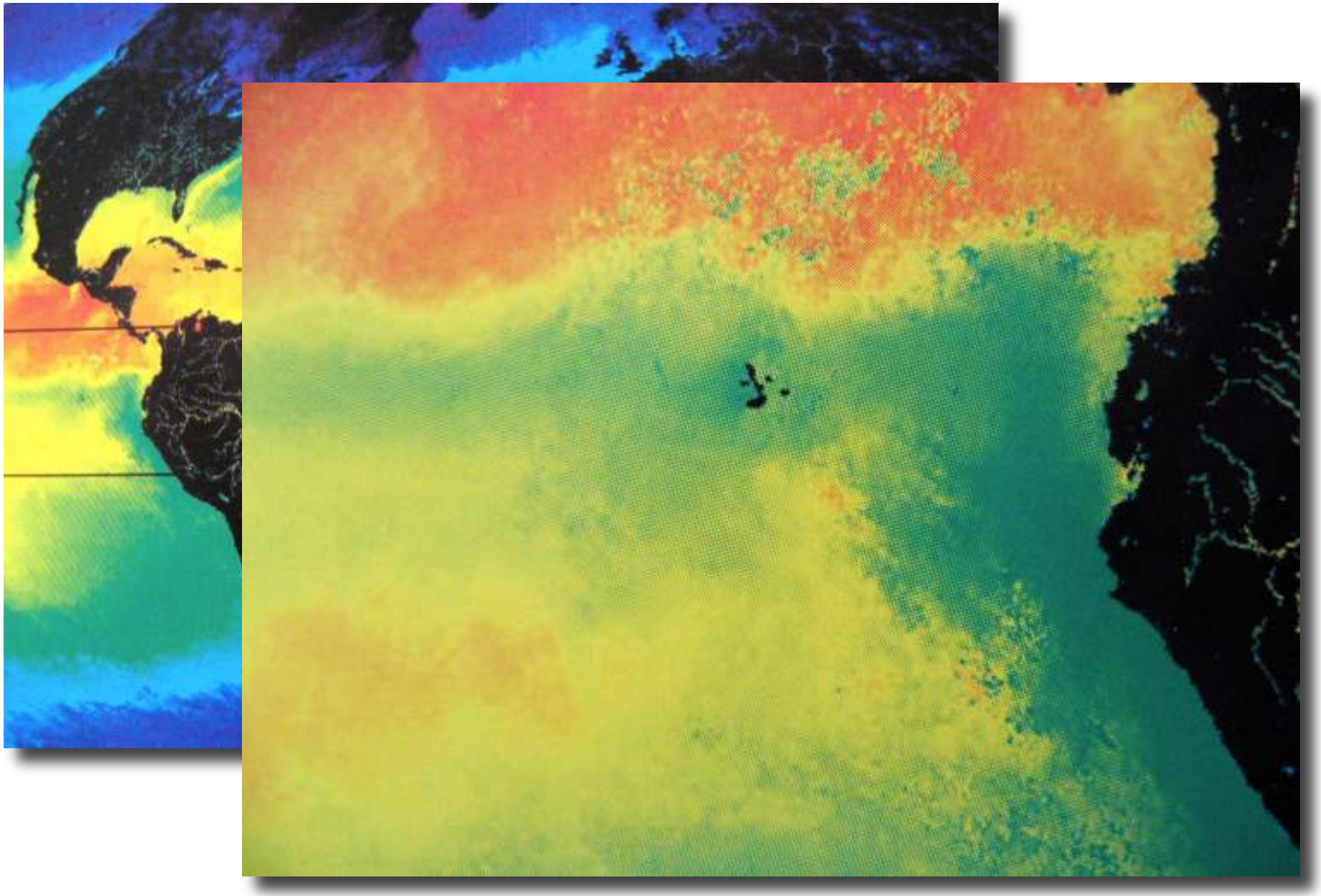
Peter and Rosemary Grant, Princeton University

Rapid evolution in Darwin's finches

Peter and Rosemary Grant, Princeton University

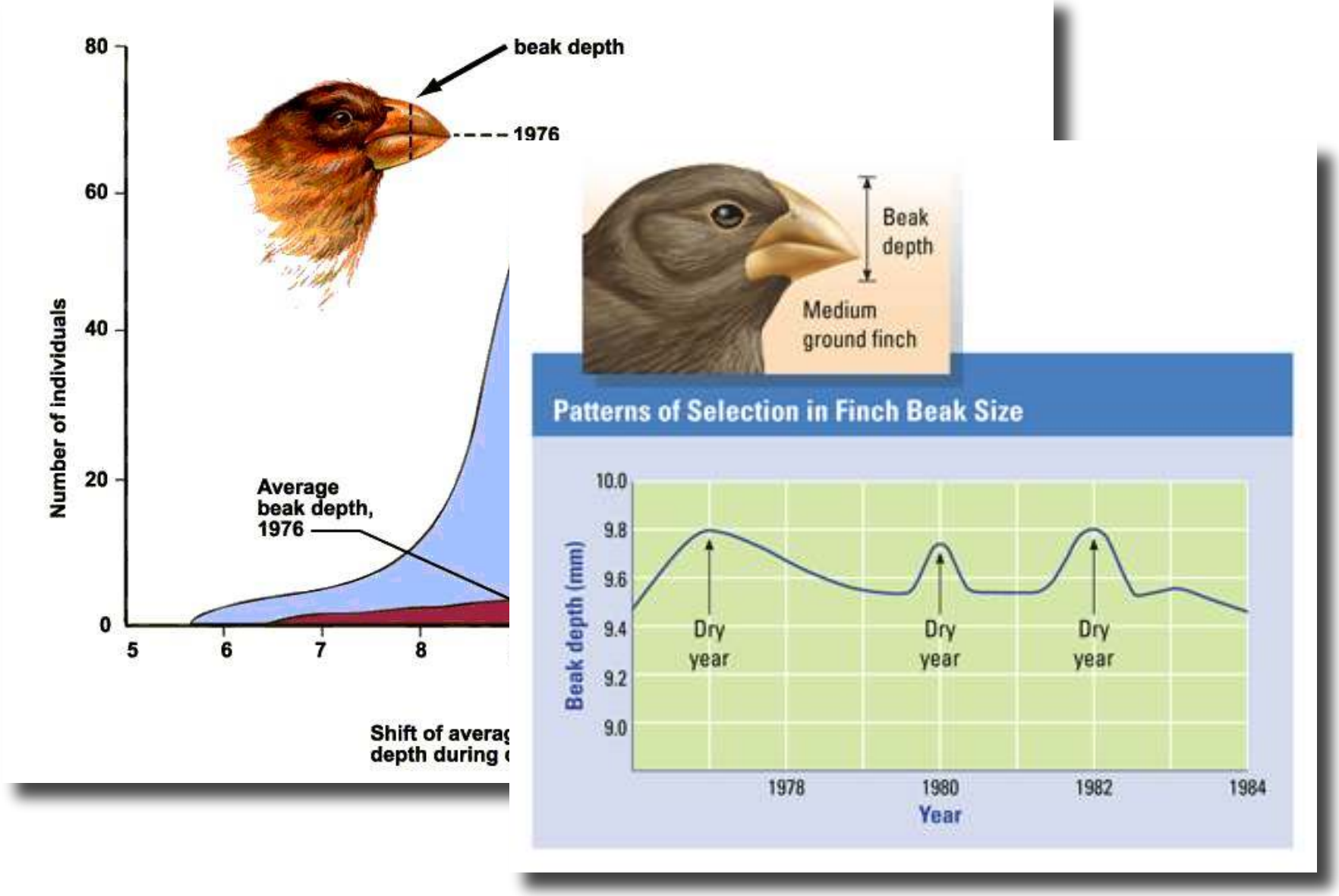


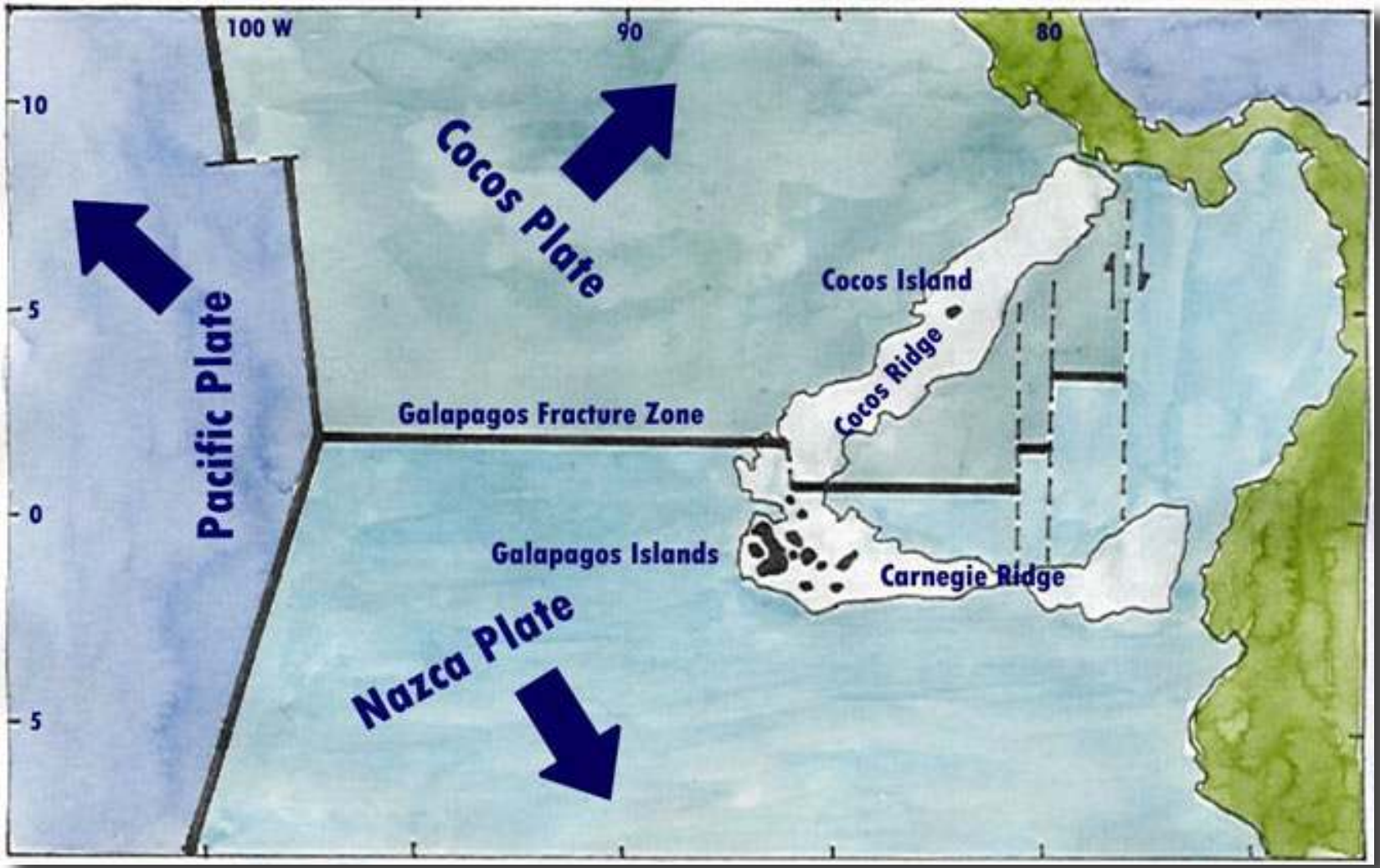
Water temperatures from outer space

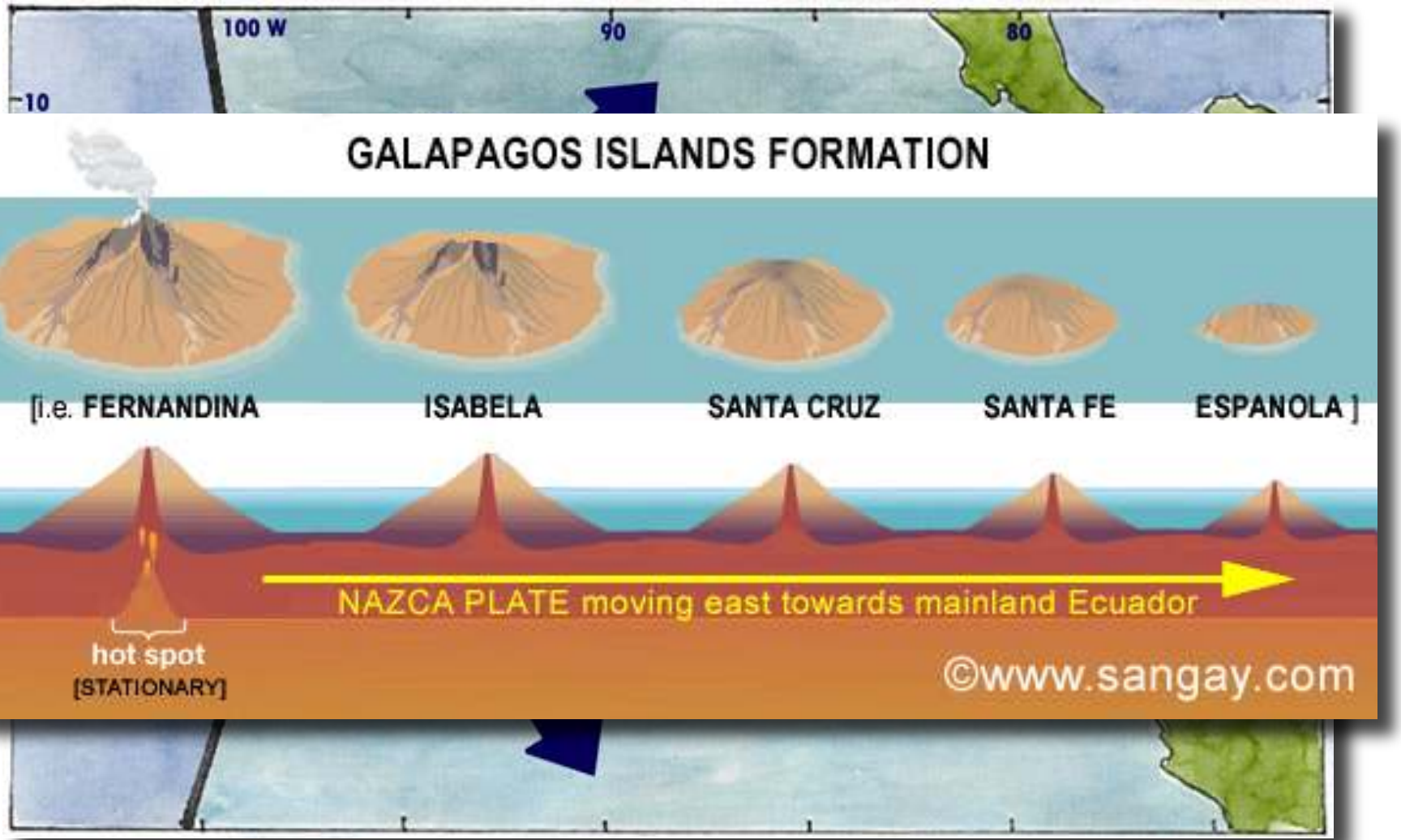


Water temperatures from outer space

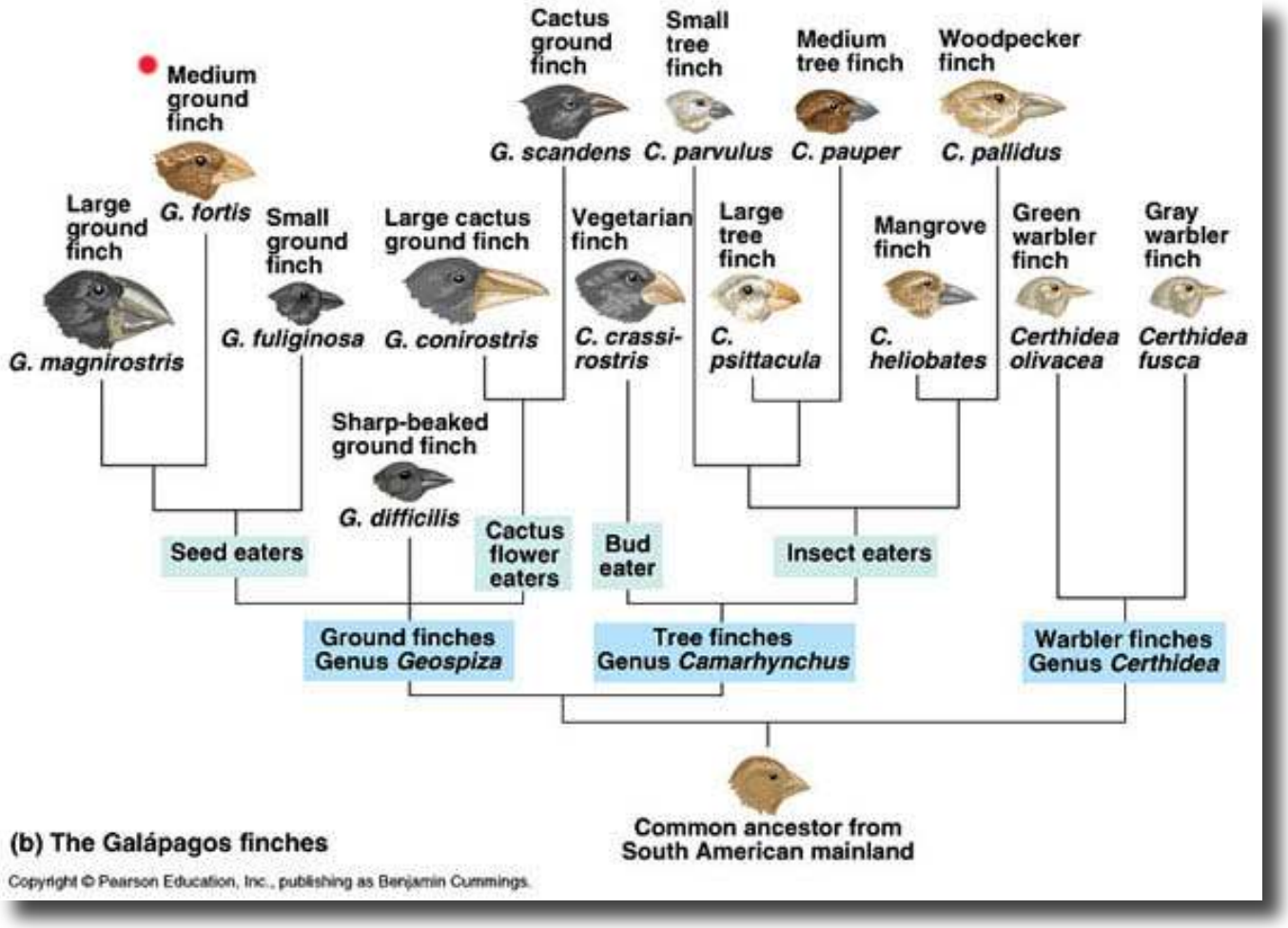
Rapid evolution in Darwin's finches




100 W
90
80
10
5
0
5
Cocos Plate
Pacific Plate
Cocos Island
Cocos Ridge
Galapagos Fracture Zone
Galapagos Islands
Carnegie Ridge
Nazca Plate

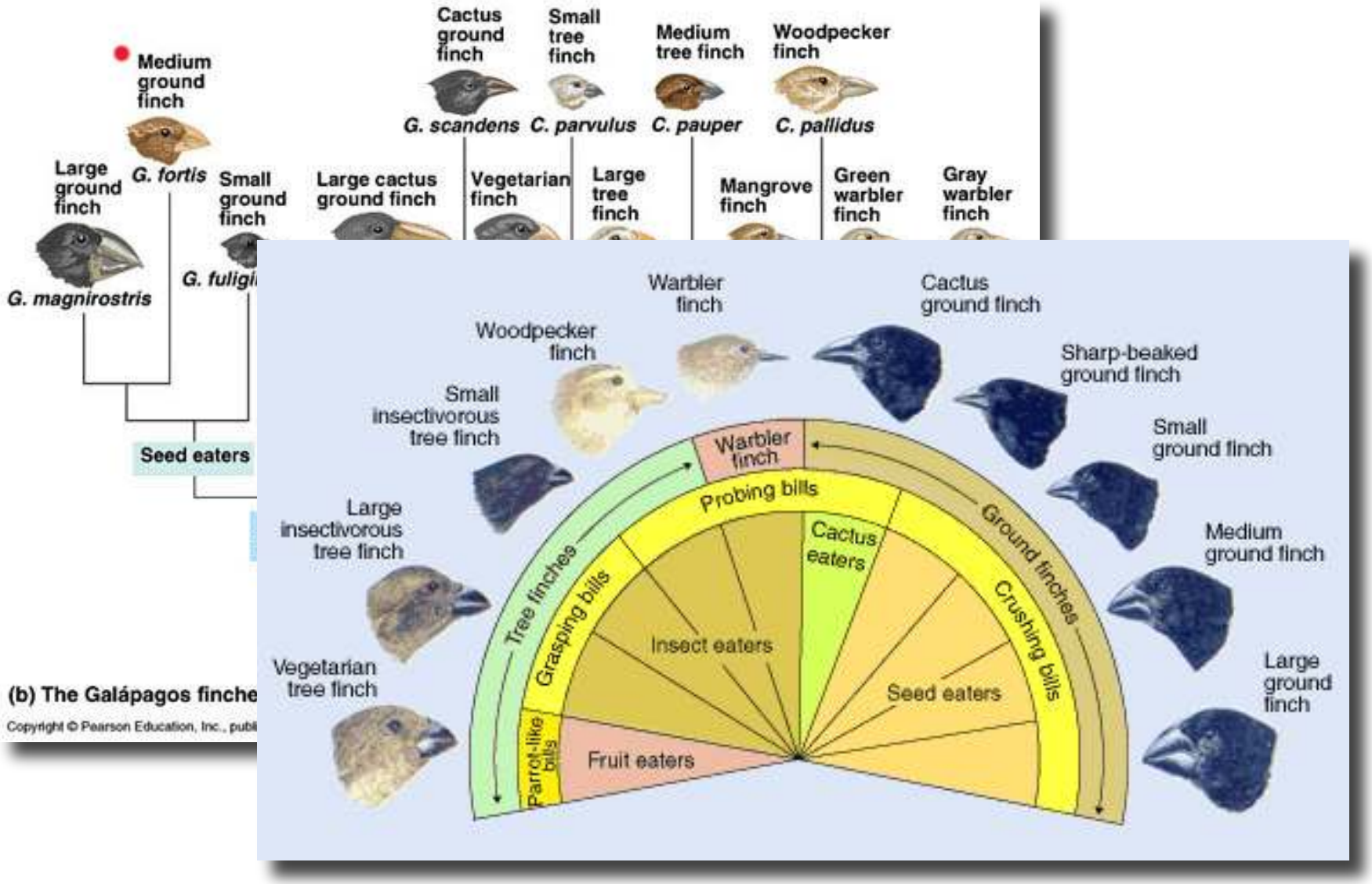

100 W
90
80
10
GALAPAGOS ISLANDS FORMATION
[i.e. FERNANDINA
ISABELA
SANTA CRUZ
SANTA FE
ESPANOLA]
NAZCA PLATE moving east towards mainland Ecuador
hot spot
[STATIONARY]
©www.sangay.com

Rapid evolution in Darwin's finches

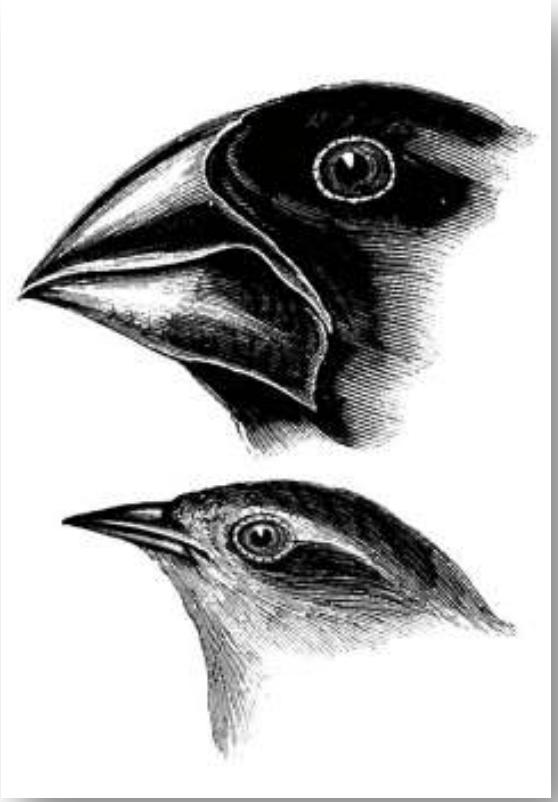


(b) The Galápagos finches

Rapid evolution in Darwin's finches



De León, Raeymaekers, Bermingham, Podos, Herrel, and Hendry. 2011. *Exploring possible human influences on the evolution of Darwin's finches. Evolution* 65:2258-2272.



"These results are consistent with the hypothesis that the rugged adaptive landscapes promoting and maintaining diversification in nature can be smoothed by human activities, thus hindering ongoing adaptive radiation."

Rapid evolution in red squirrels in the Yukon

Bradshaw W and Holzapfel C. 2001. Genetic shift in photoperiodic response correlated with global warming. PNAS 98:14509-14511.

Réale D, McAdam AG, Boutin S and Berteaux D. 2003. Genetic and plastic responses of a northern mammal to climate change. Proc. Roy. Soc. London B 270:591-596

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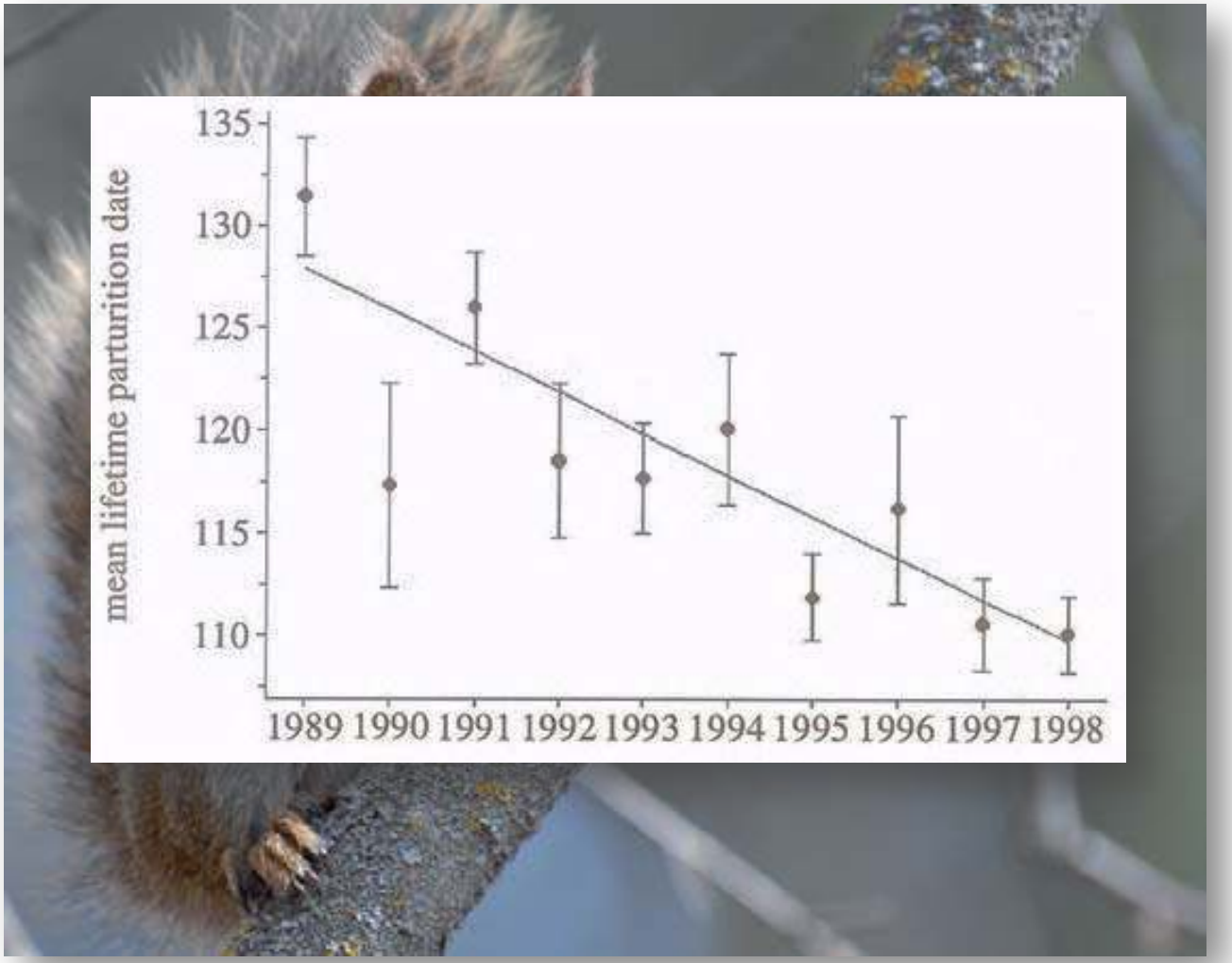

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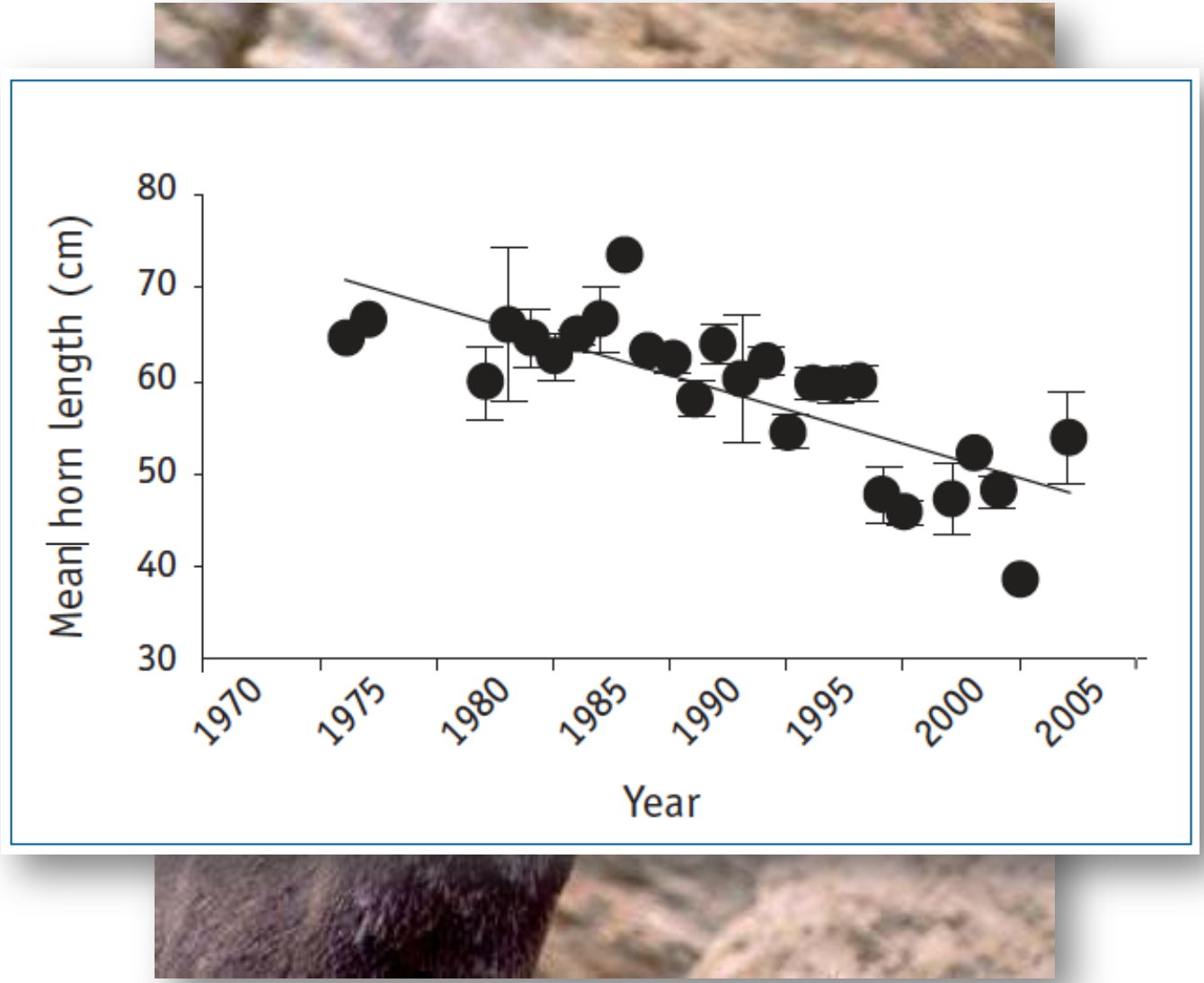
Rapid evolution in bighorn sheep

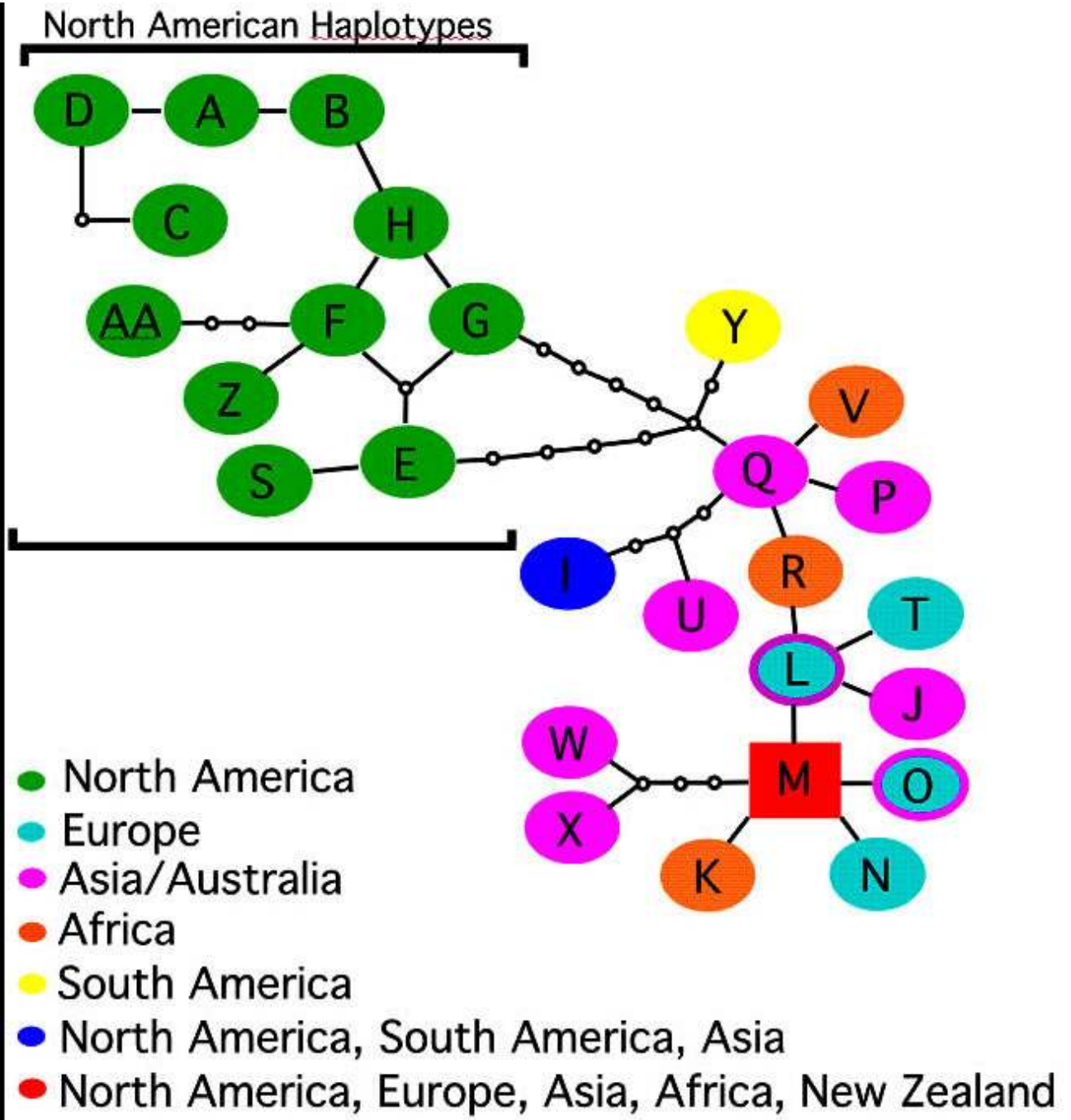
Coltman DW, O'Donoghue P, Jorgenson JT, Hogg JT, Strobeck C and Festa-Bianchet M. 2003. Undesirable evolutionary consequences of trophy hunting. Nature 426:655-658

Rapid evolution in bighorn sheep



Coltman DW, O'Donoghue P, Jorgenson JT, Hogg JT, Strobeck C and Festa-Bianchet M. 2003. Undesirable evolutionary consequences of trophy hunting. Nature 426:655-658

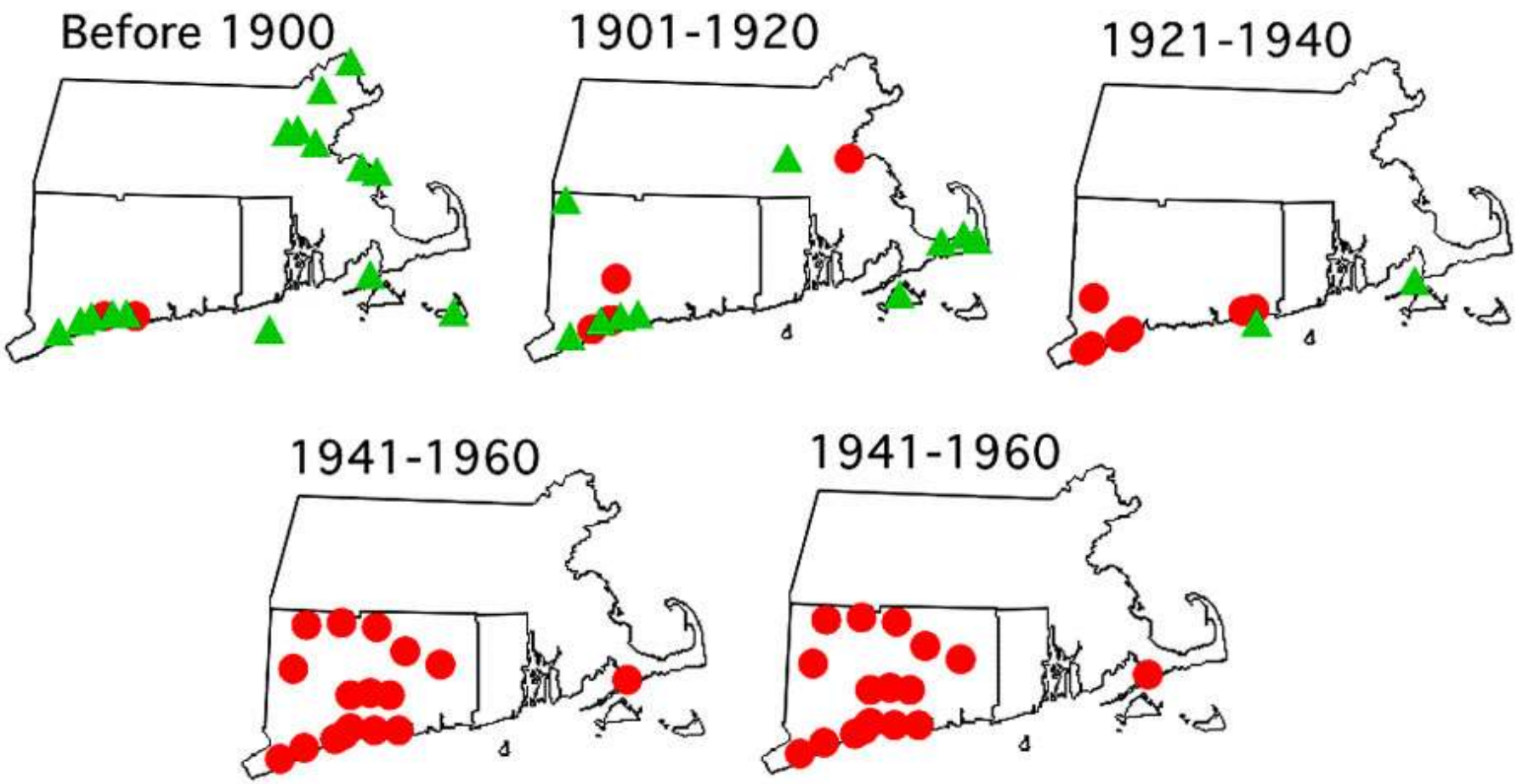
Rapid evolution in the reed grass, *Phragmites*



SALTONSTALL, 2002

Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America

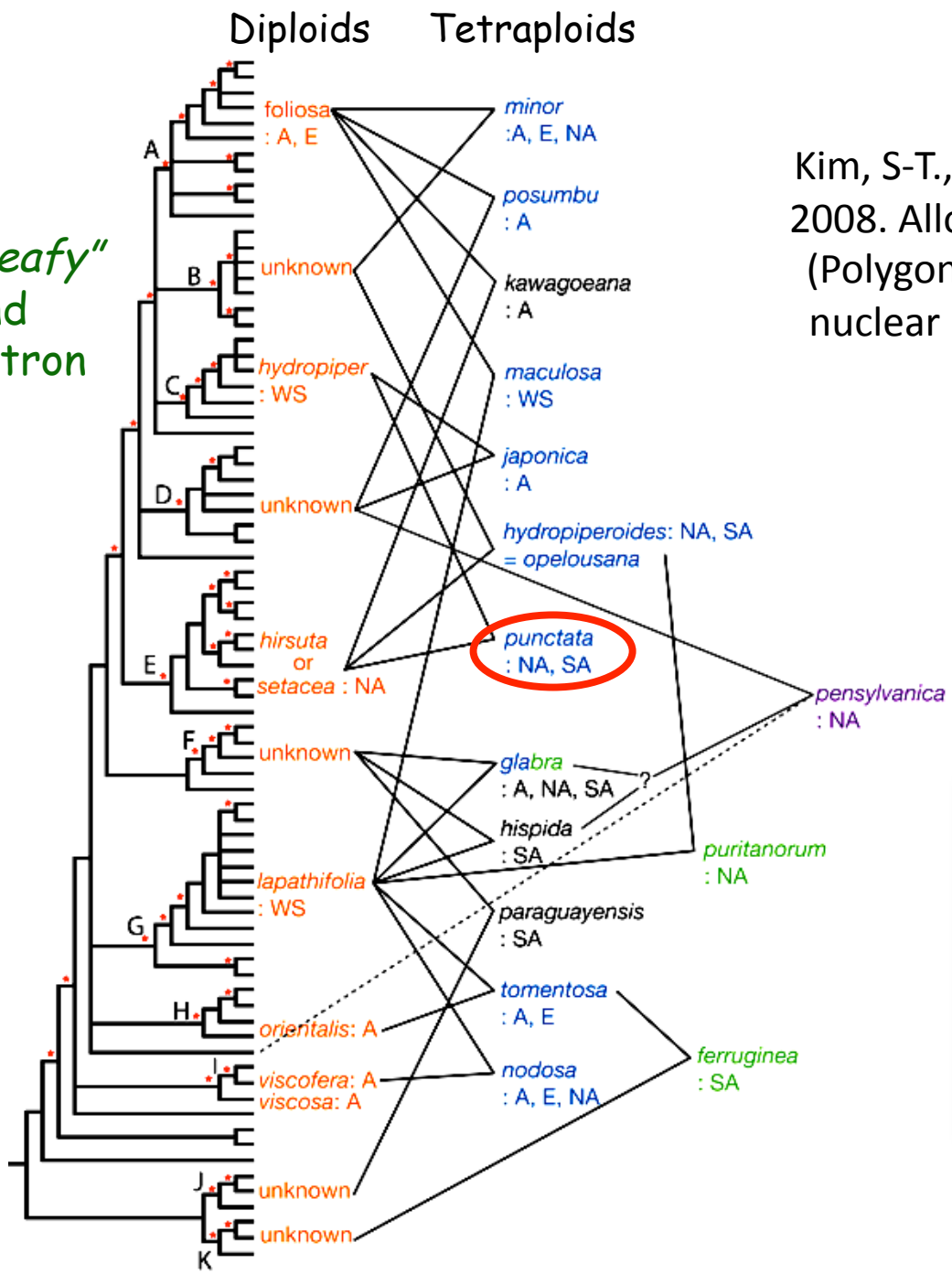
Kristin Saltonstall*



Rapid speciation in knotweeds

Persicara (*Polygonum*, Polygonaceae)

"Leafy"
2nd
Intron



Kim, S-T., S. E. Sultan, and M. J. Donoghue. 2008. Allopolyploid speciation in *Persicaria* (Polygonaceae): Insights from a low-copy nuclear marker. Proc. Nat. Acad. Sci. USA 105: 12370-12375.

Sang-Tae Kim, Yale/Tubingen

Rapid recent allotetraploid origin of a "superweed," *Persicaria punctata*

♂

P. hydropiper (2x)
widespread

♀

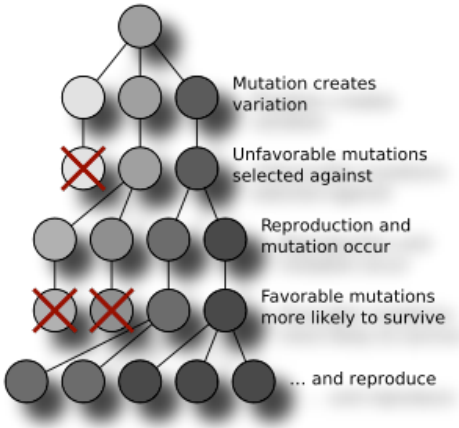
P. hirsuta (2x)
North America

P. punctata (4x)

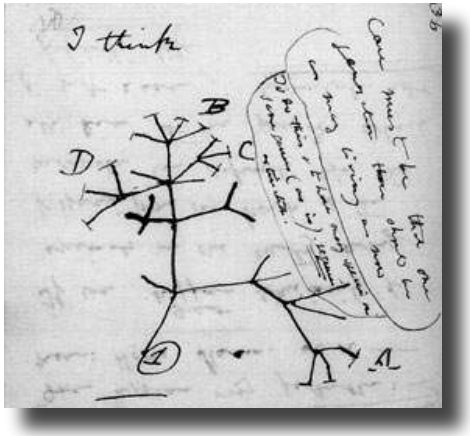
North and South America
abundant weed

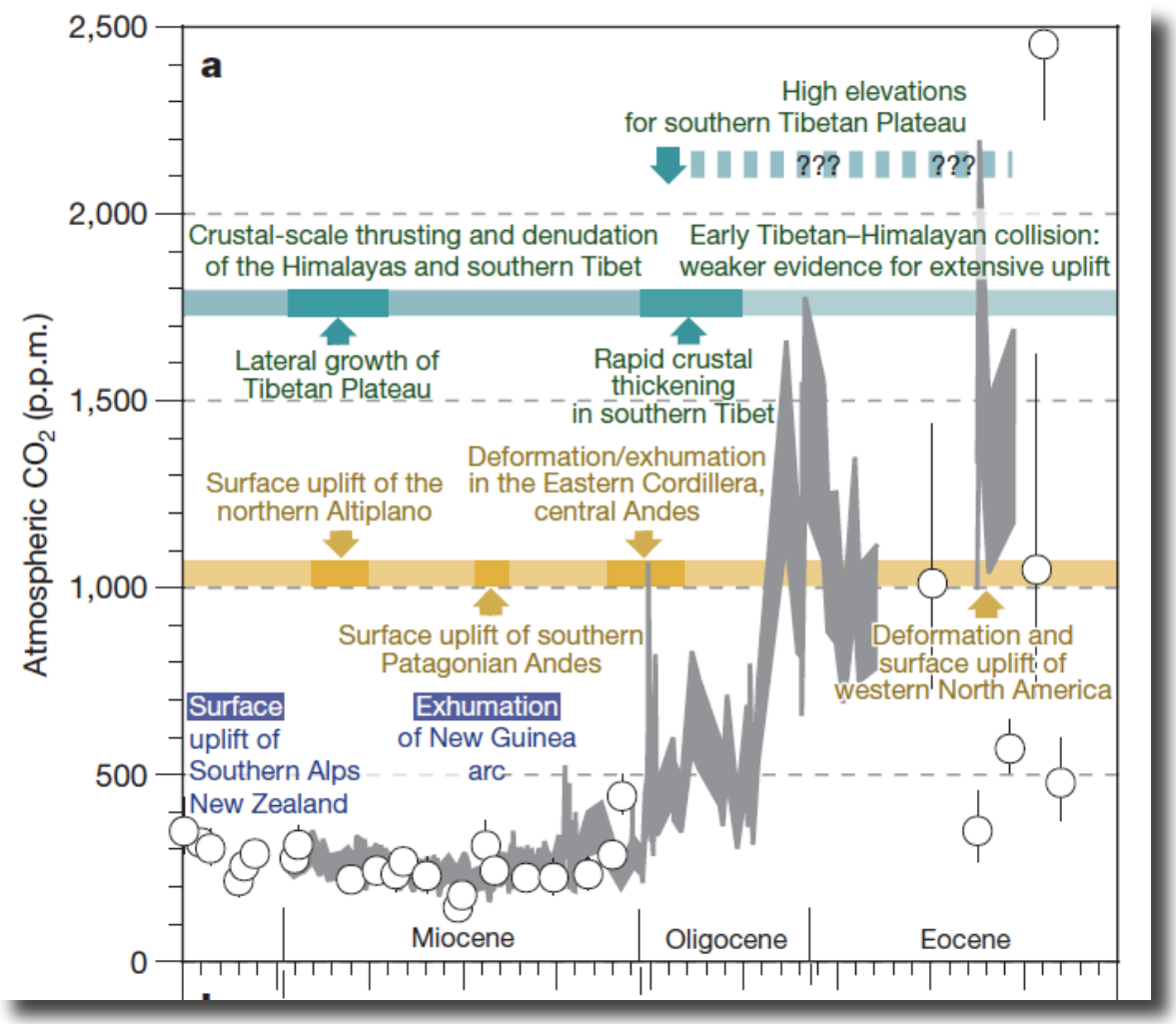
To understand biodiversity and global change ecology & evolution **should be reconnected on every level**

- rapid, population-level evolution – e.g., contemporary adaptive responses to climate change, invasive species, etc. Obviously important, getting much more attention. Montreal is an epicenter!

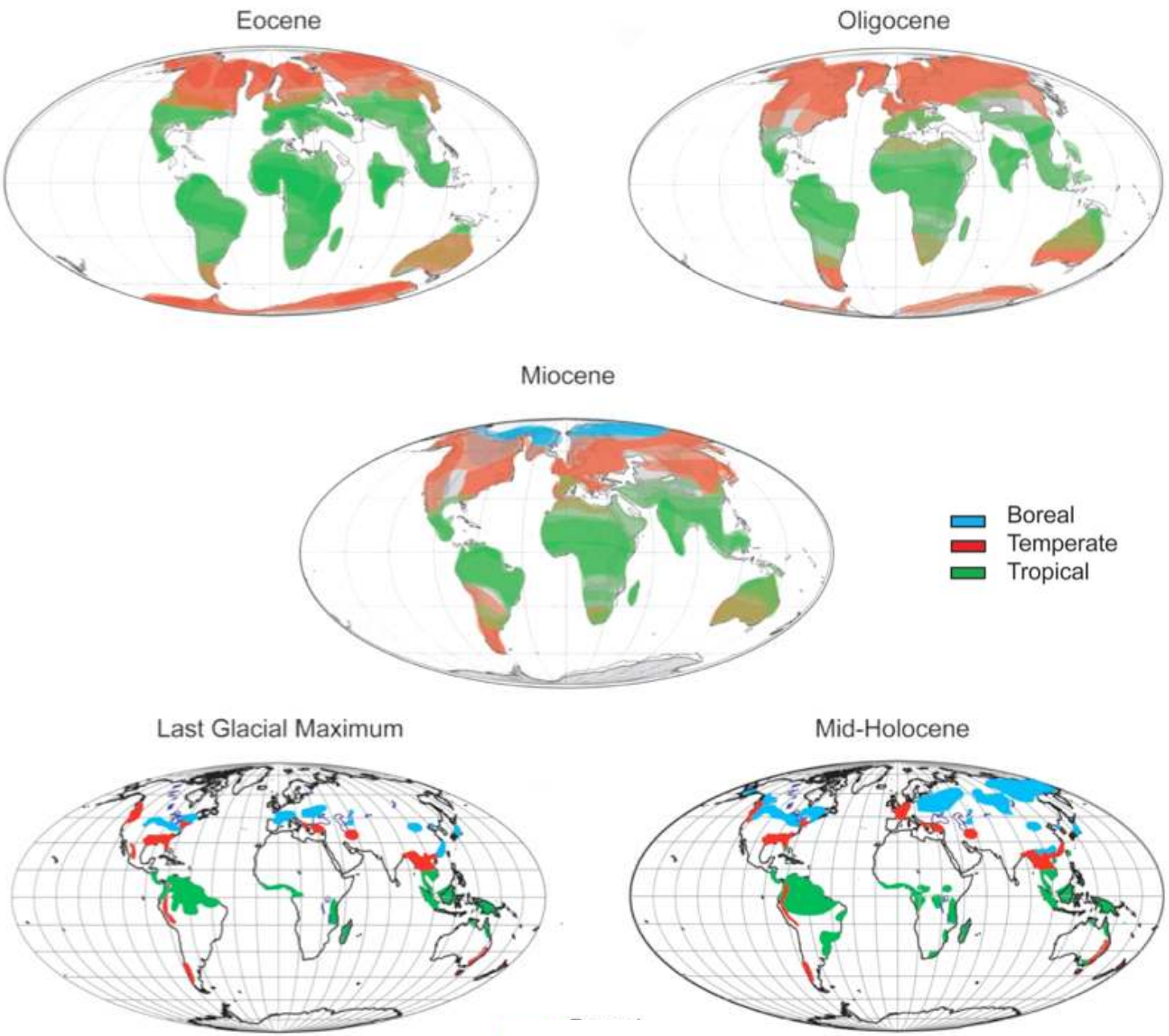


- slow, phylogeny-level evolution. Relevance much less obvious!

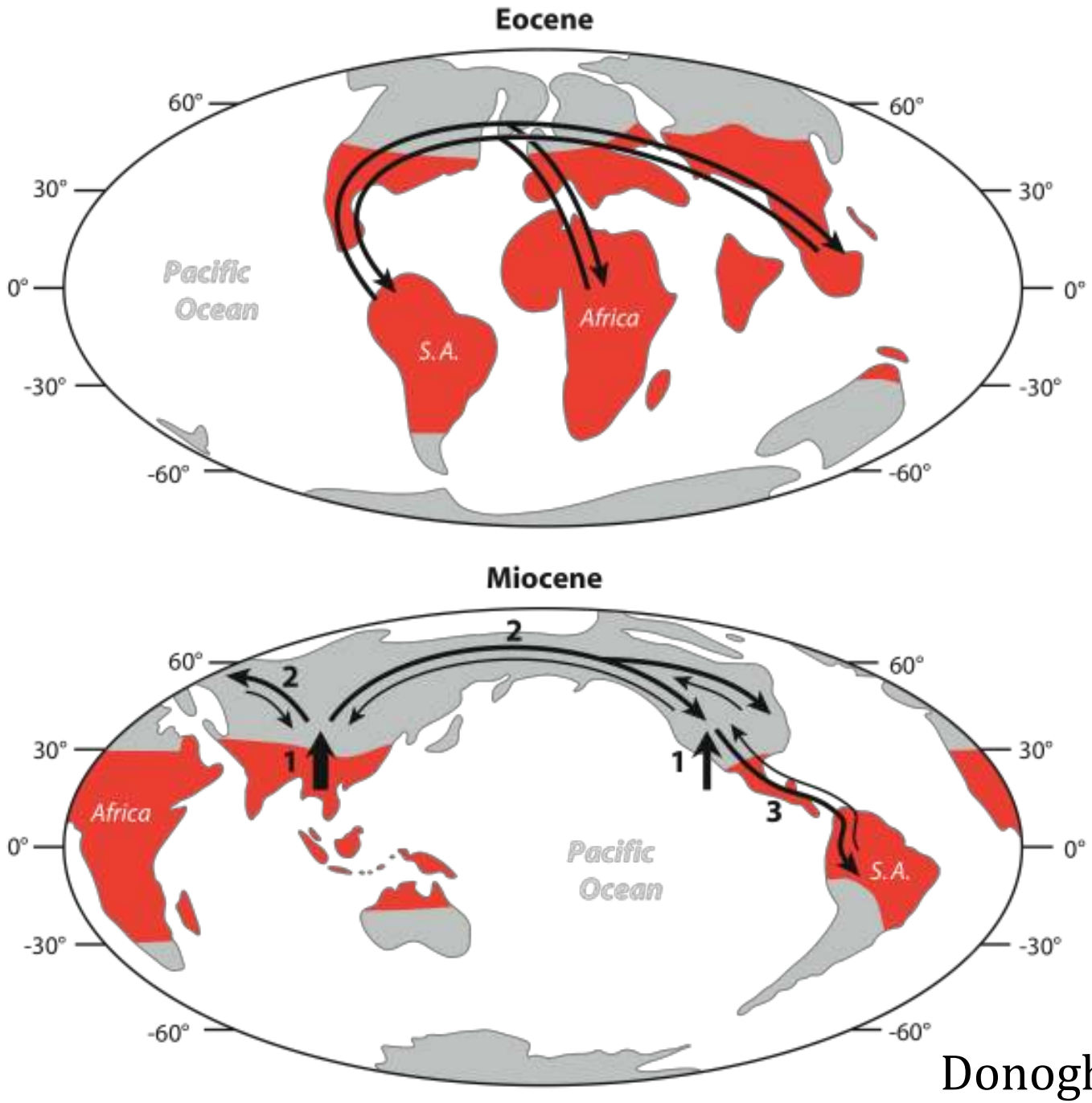




Since the Eocene (35 mya), lots of rock has been uplifted – rock weathering draws down C02, and the climate cools down!

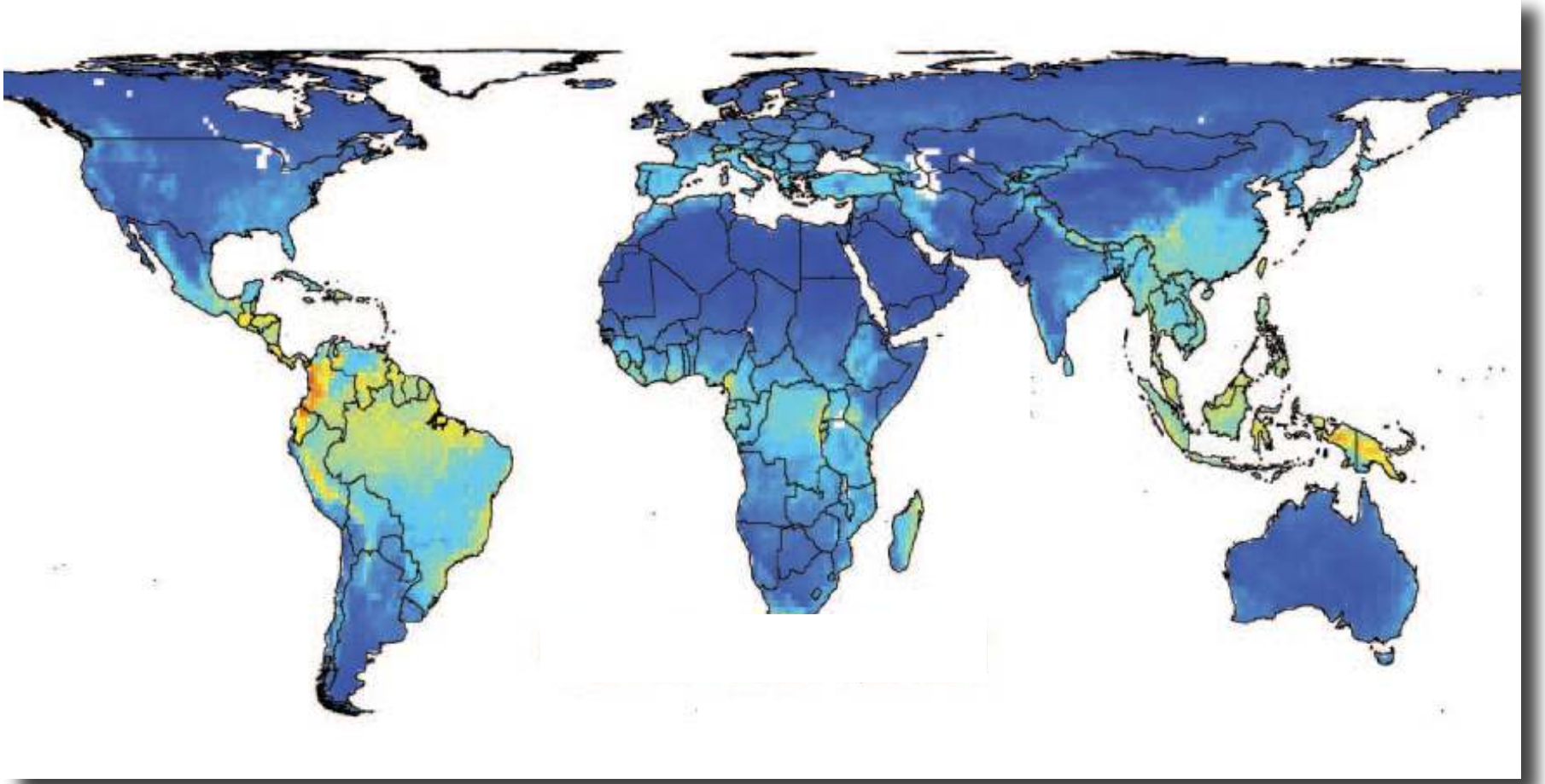


Fine & Ree, 2006



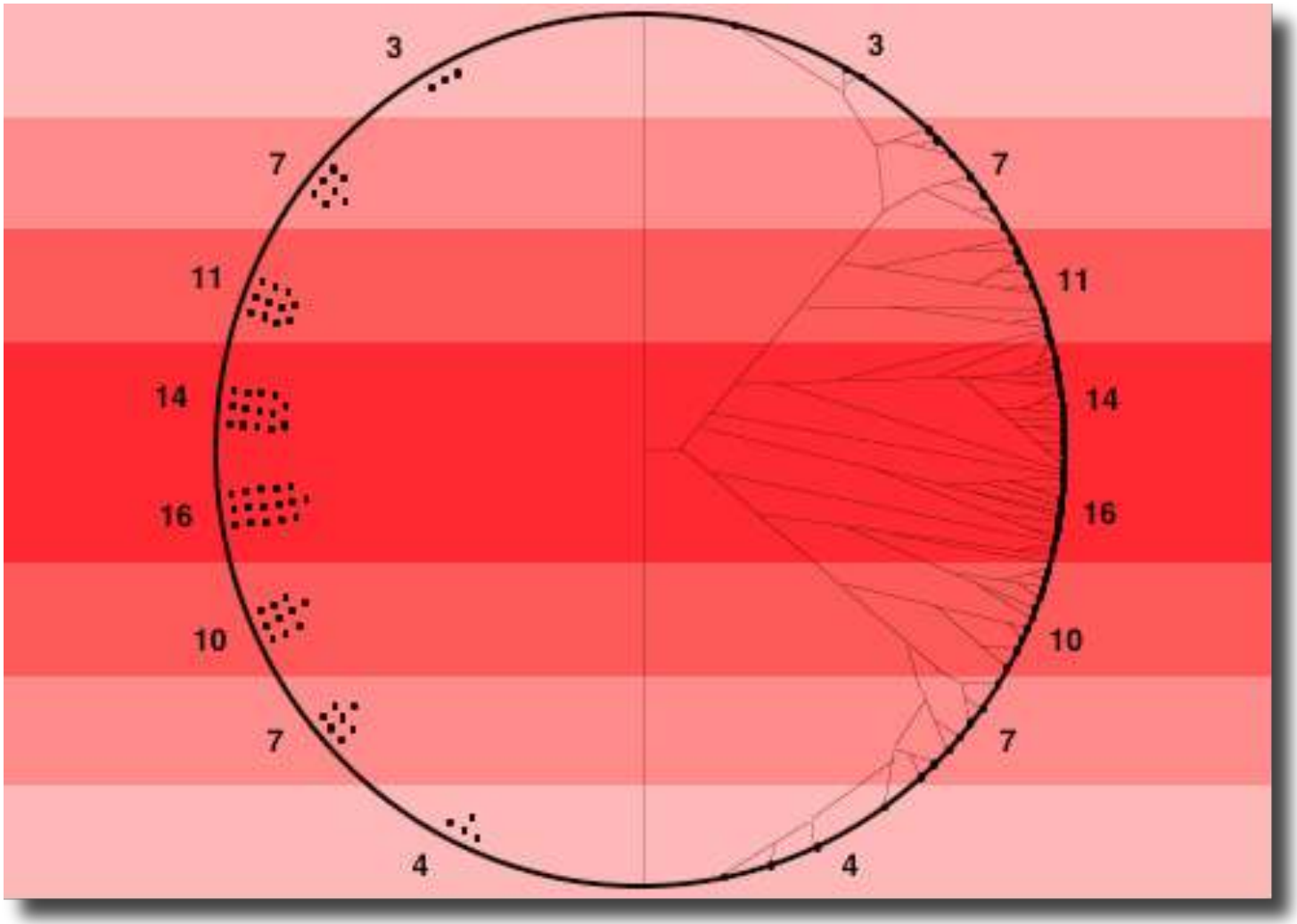
Donoghue, 2008

The latitudinal species richness gradient in plants



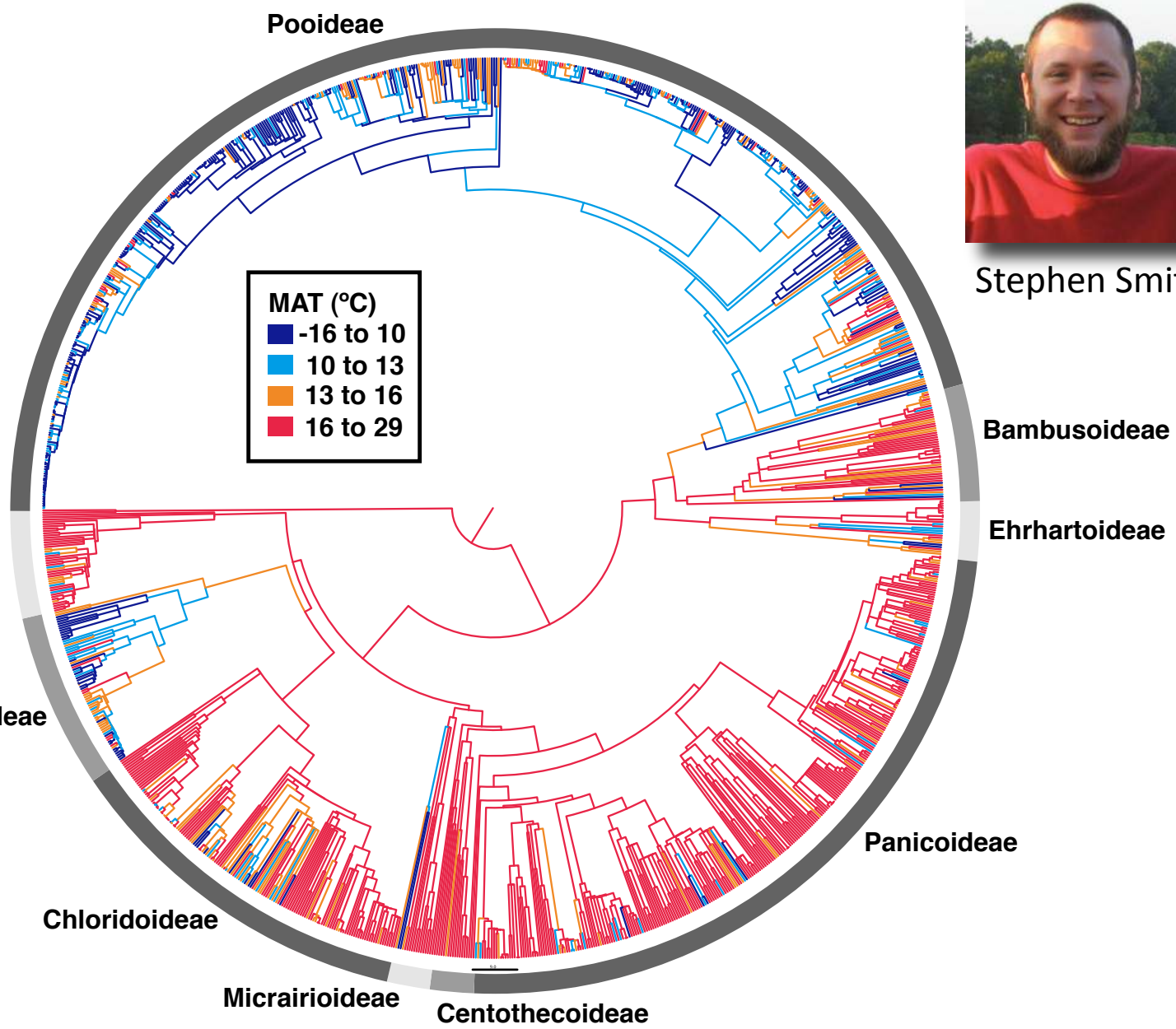
Kreft and Jetz, 2007

An historical explanation of the latitudinal richness gradient



Wiens and Donoghue, 2004
(see Ricklefs and Latham)

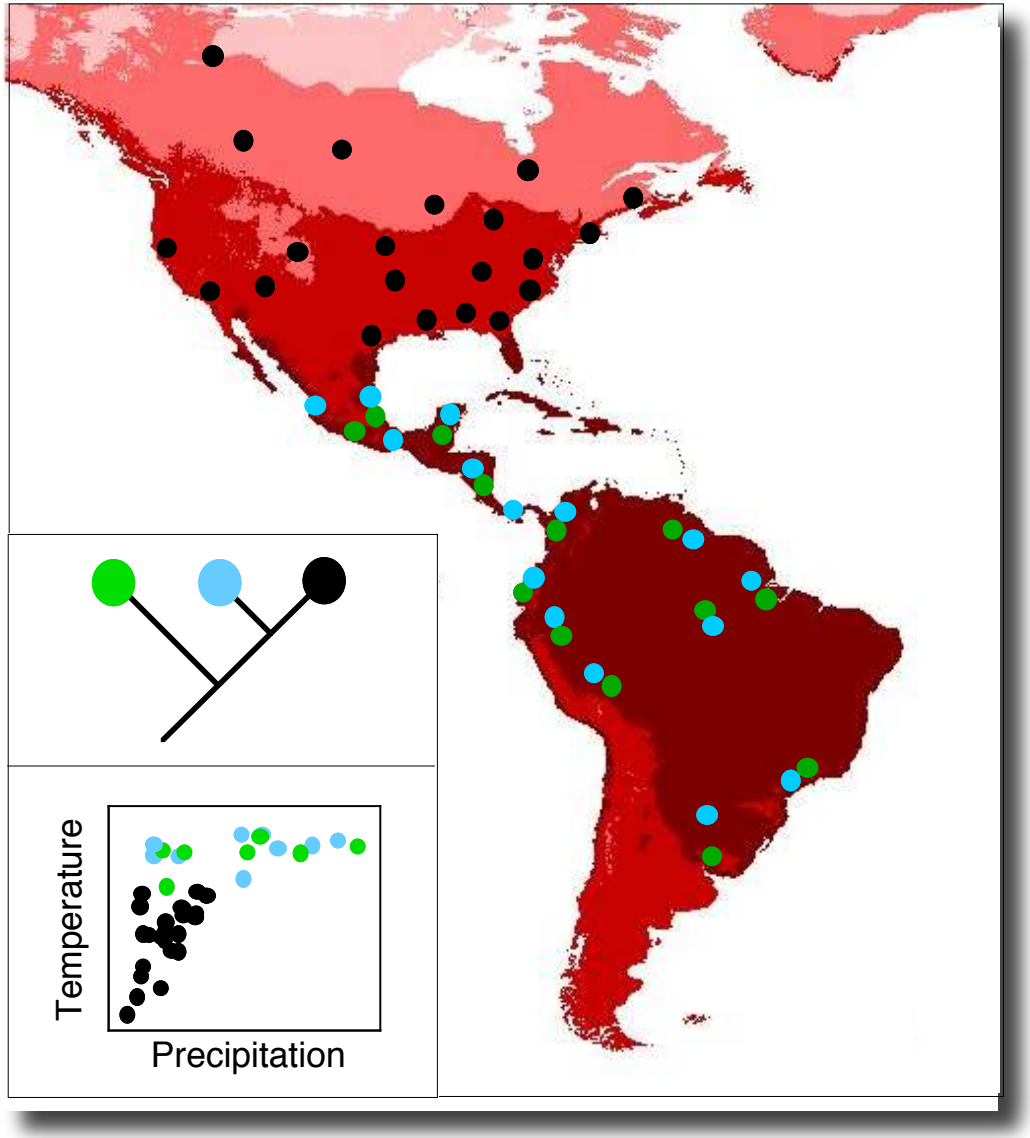
Erika Edwards



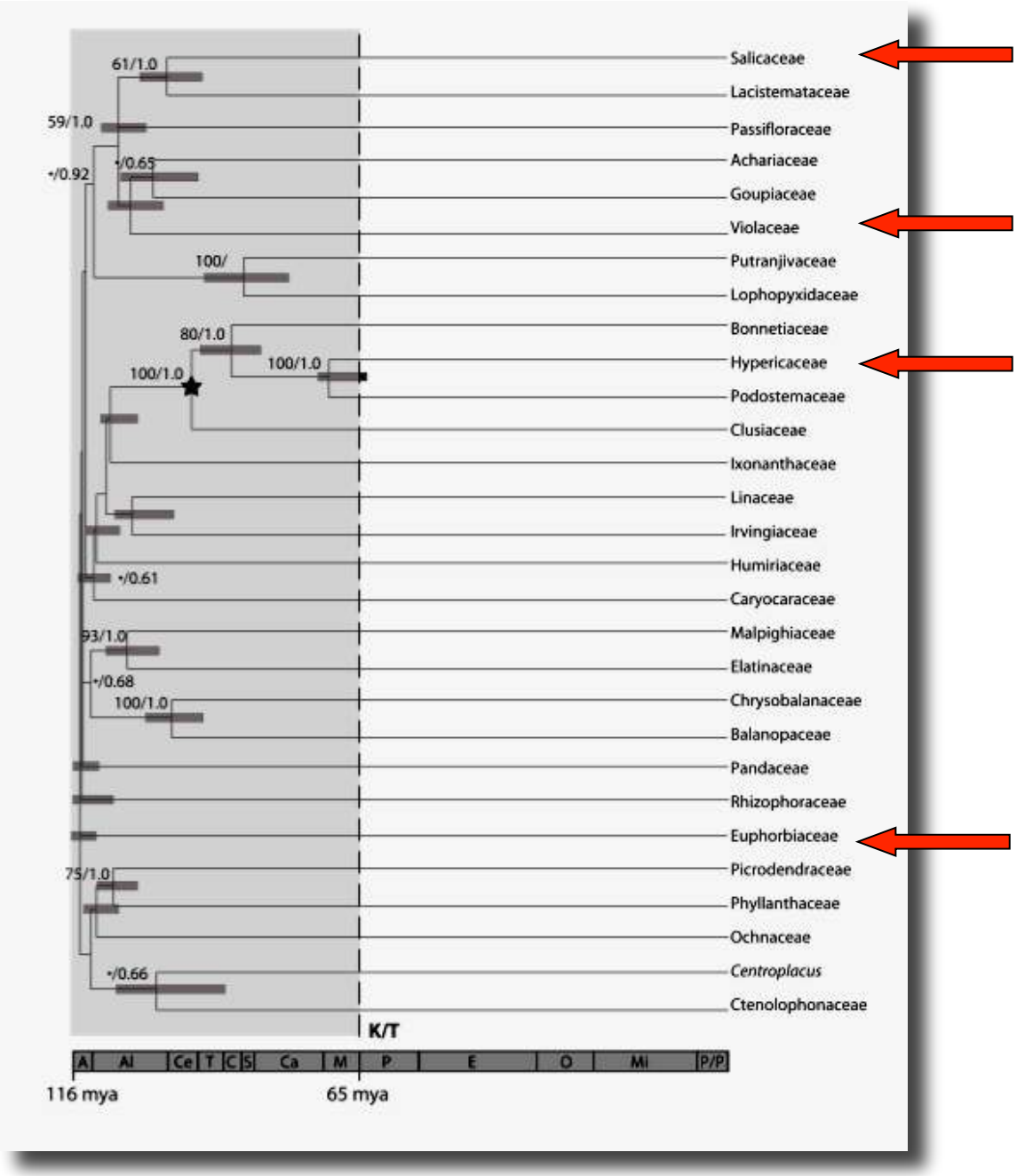
Stephen Smith

Edwards and Smith, 2009, PNAS

Only some lineages make it out of the tropics



Wiens and Donoghue, 2004
(tropical niche conservatism)

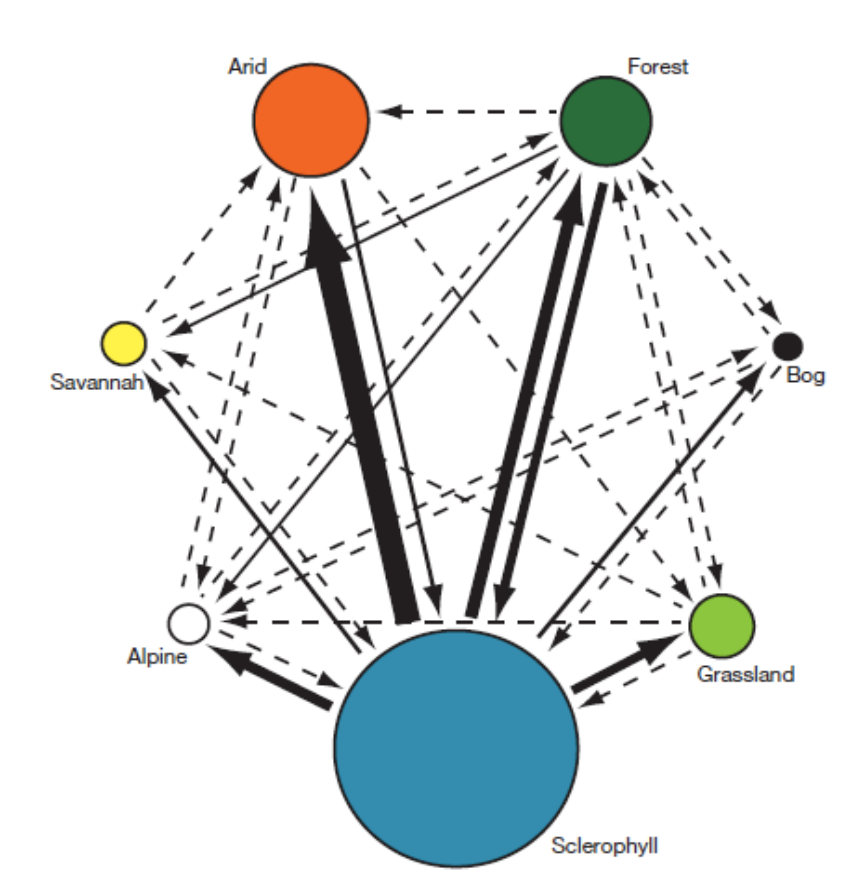


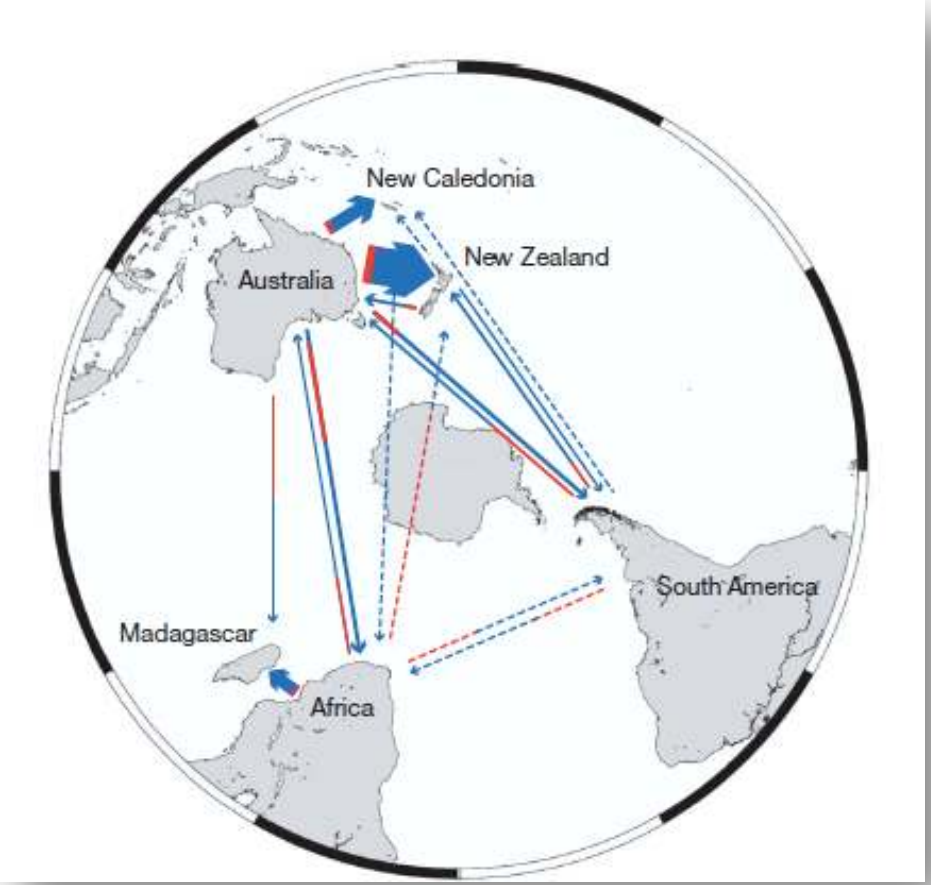
Malpighiales diversified in the tropics, and later moved only a few times into the temperate zone.

Davis et al., 2005

Plant radiations around the Southern Hemisphere

Closely related species tend to occupy the same biome --
i.e., there are few shifts from one biome to another





"Phylogenetic biome conservatism on a global scale"
Crisp et al., Nature 2009

One of the greatest regulators of global biodiversity through time has been the transition rate between tropical and temperate biomes

– *the evolution of adaptations to environments characterized by prolonged, seasonal cold.*

To understand global biodiversity patterns we need to understand the nature of such transitions

– *we need case studies!*

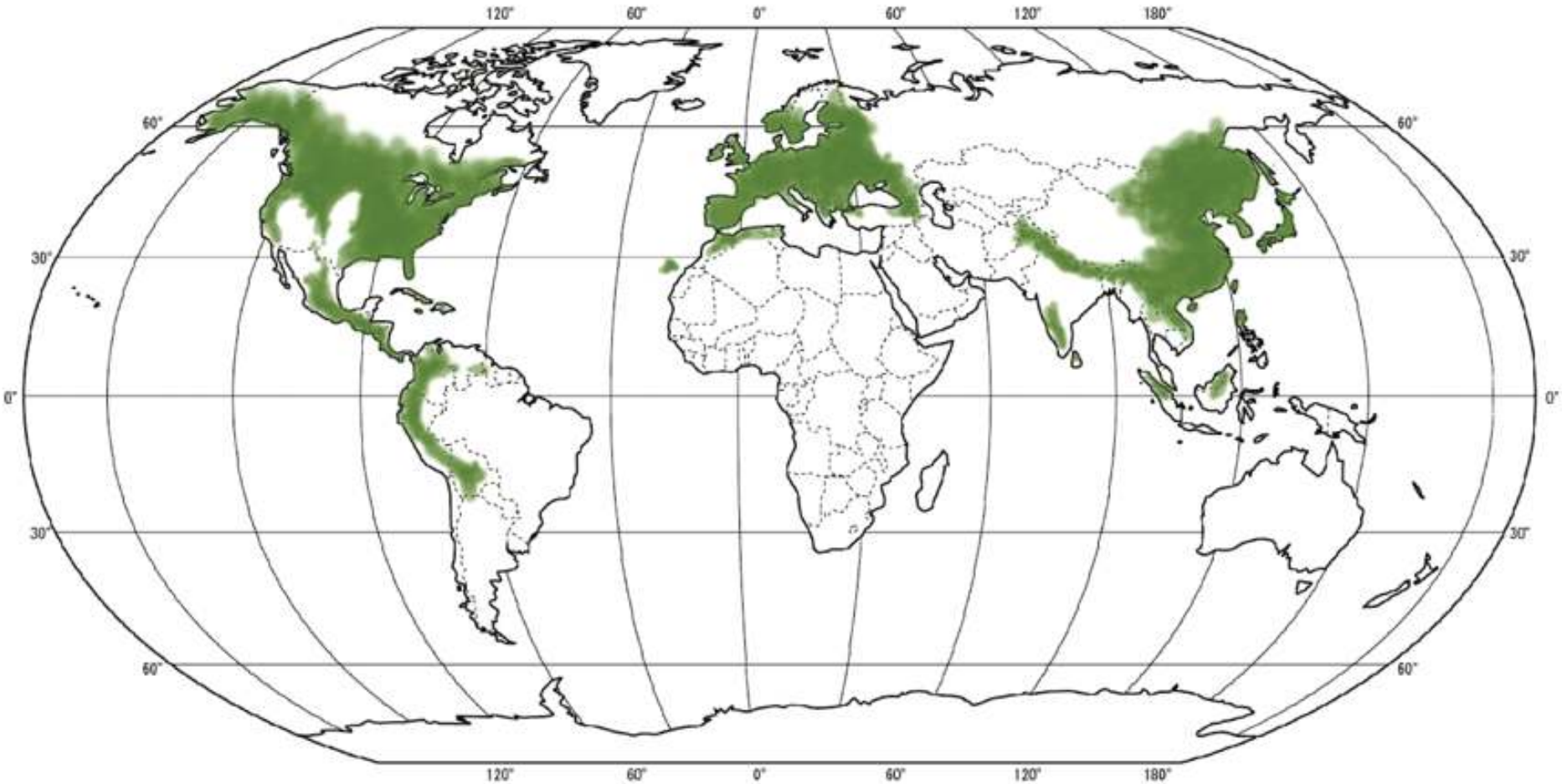


Viburnum






Viburnum
~ ca. 170 species of woody plants



Viburnum
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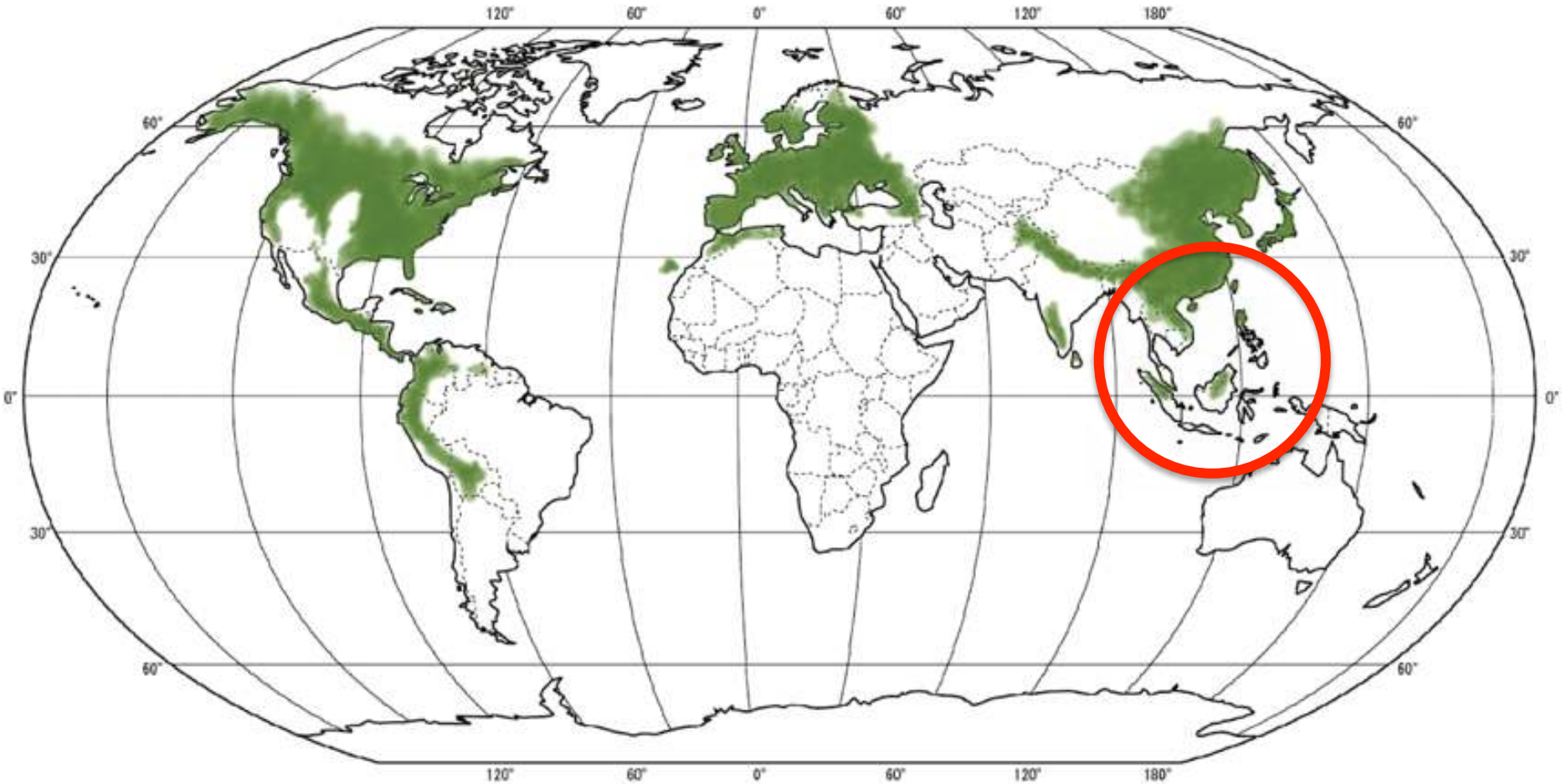
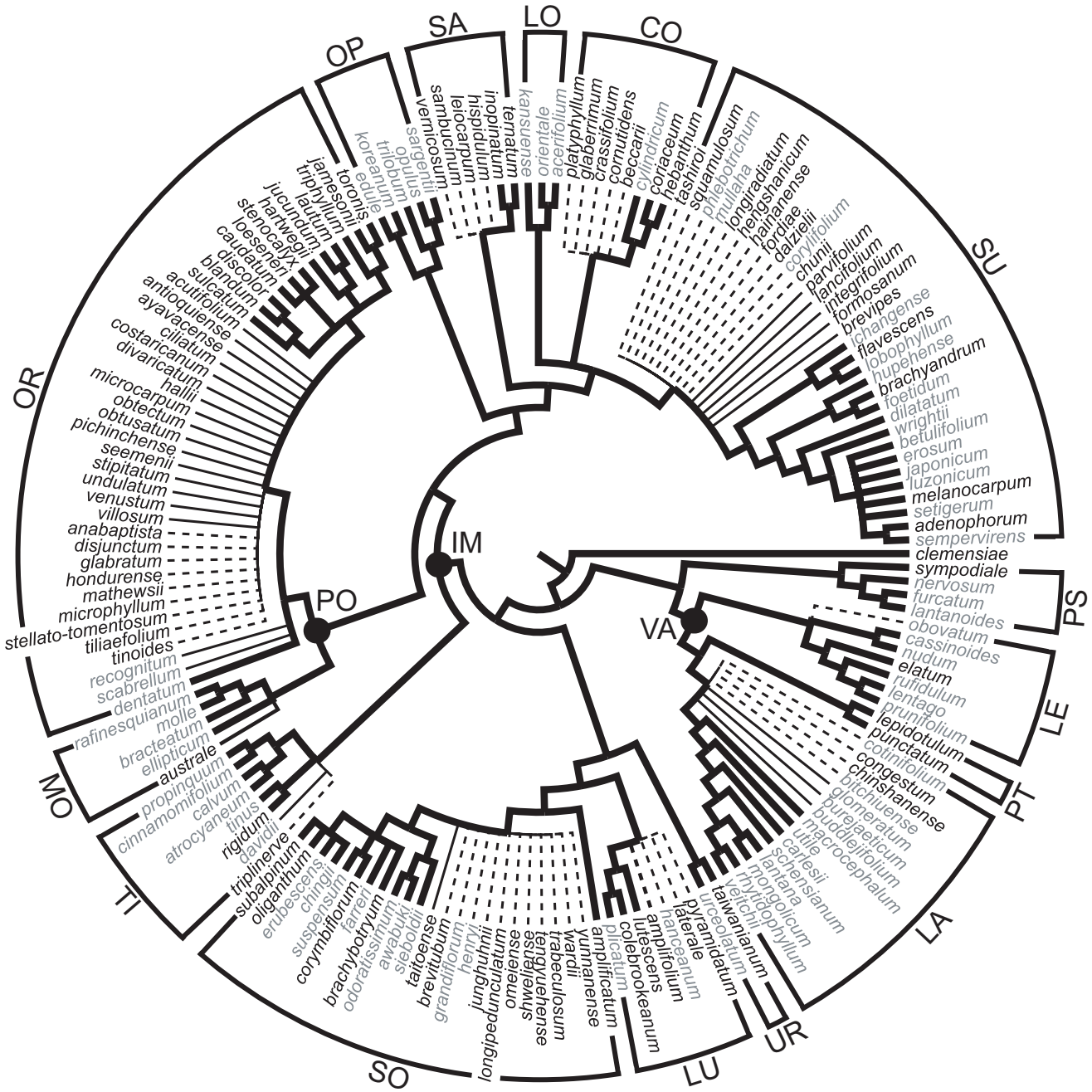
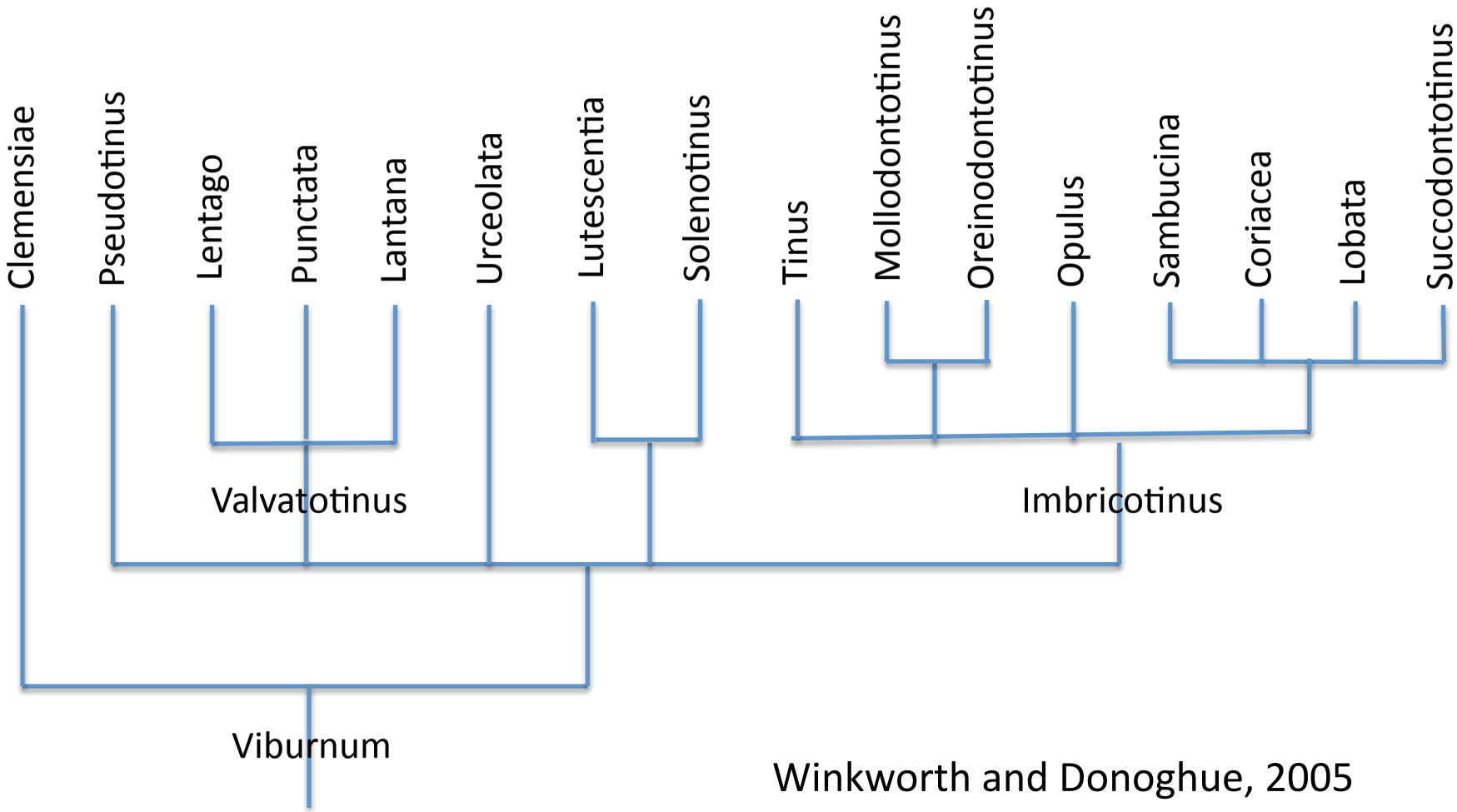


Viburnum phylogeny

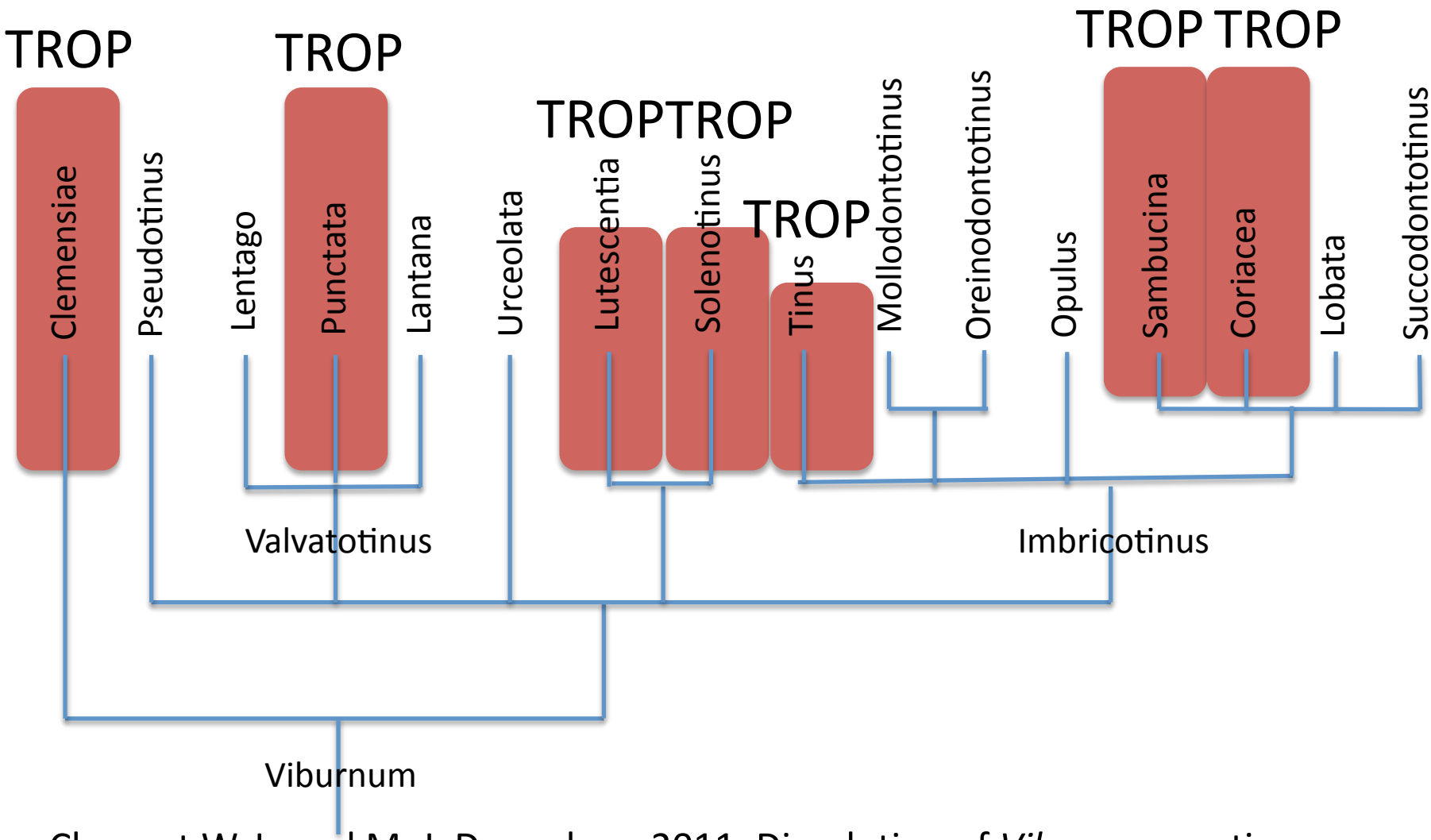


Relationships among the major lineages of *Viburnum*



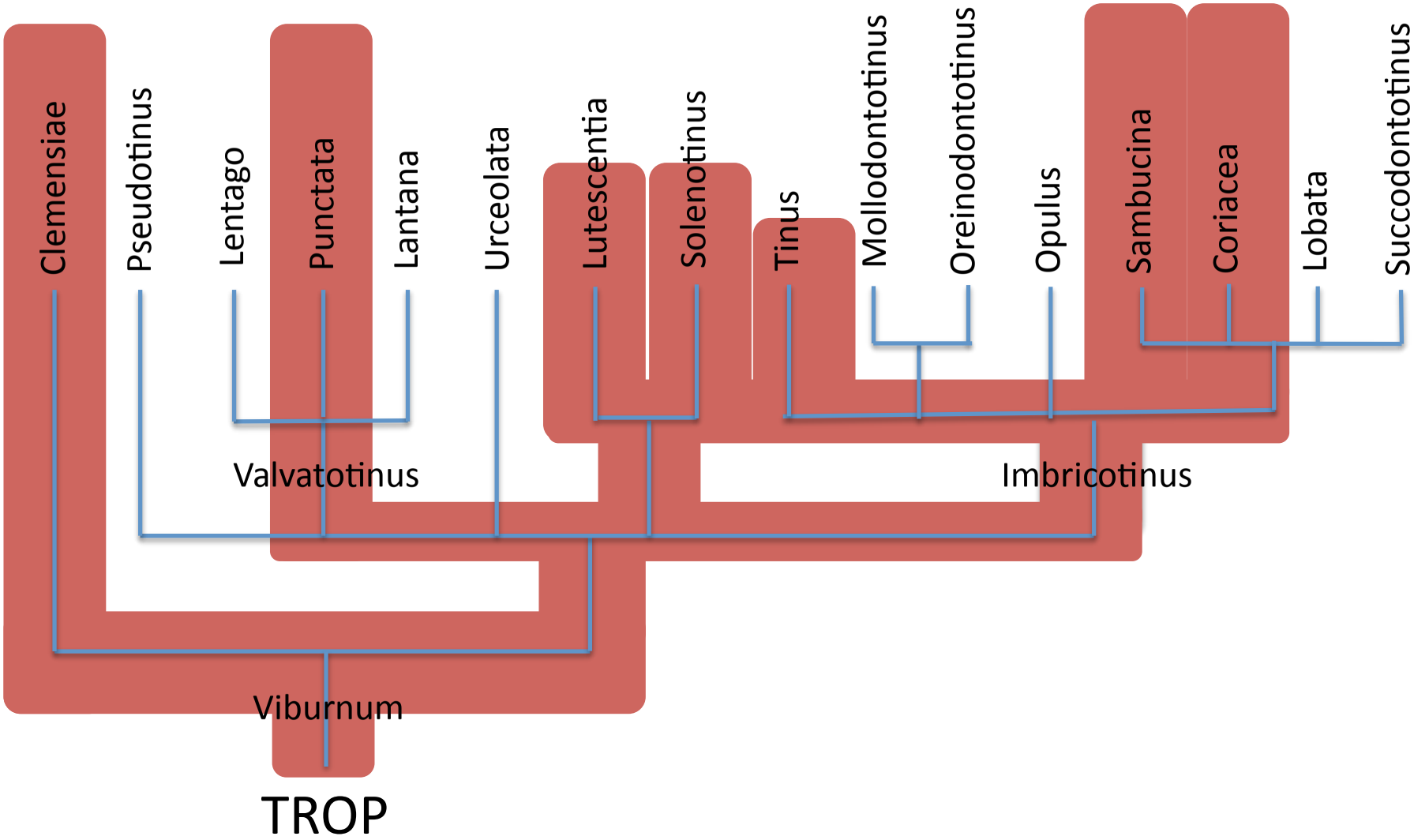
Winkworth and Donoghue, 2005
Clement and Donoghue, 2011

Tropical viburnums are rare, but widespread in the phylogeny

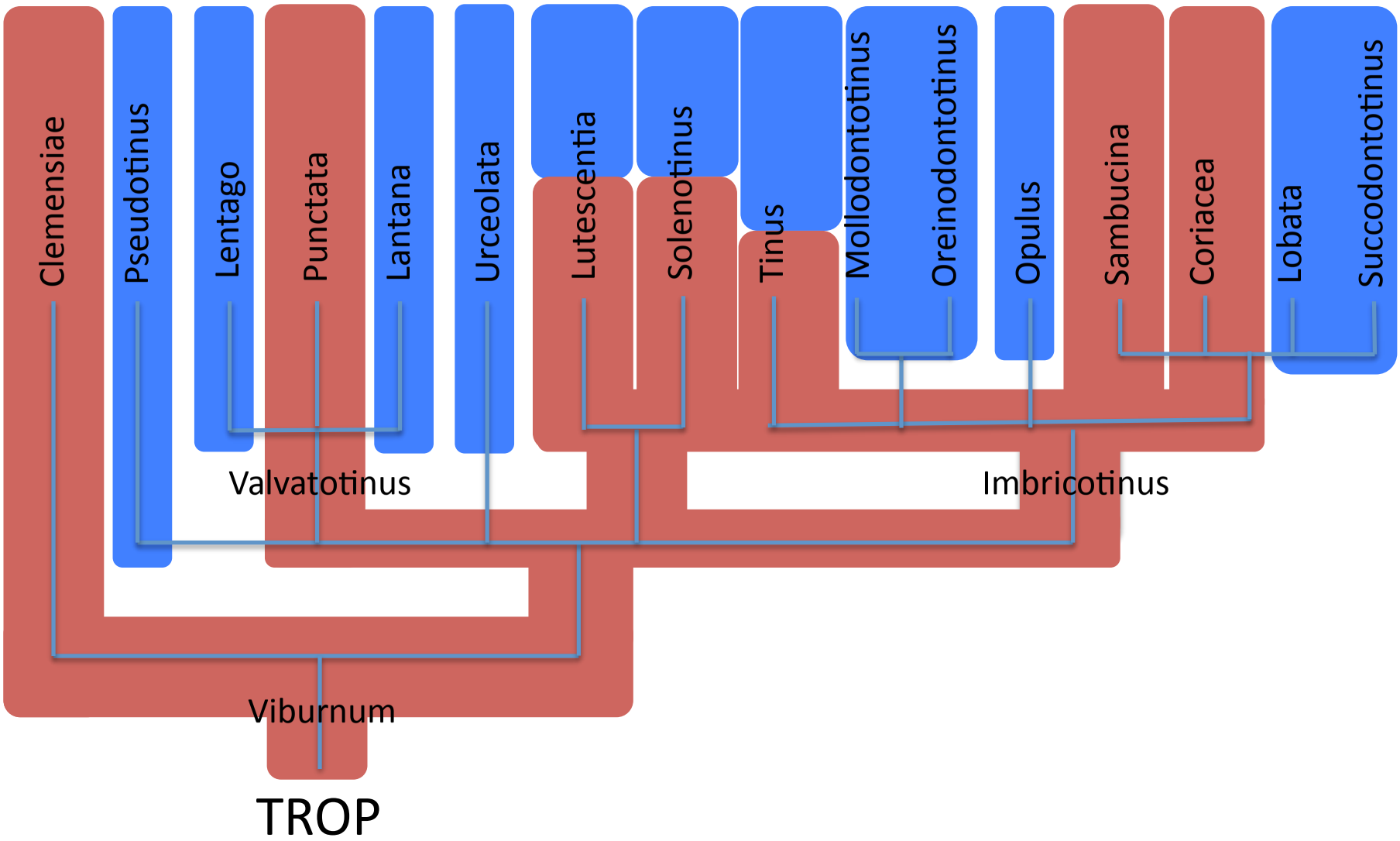


Clement W. L. and M. J. Donoghue. 2011. Dissolution of *Viburnum* section *Megalotinus* (Adoxaceae) of Southeast Asia and its implications for morphological evolution and biogeography. Int. J. Plant Sci. 172: 559-573.

Viburnum might have originated in tropical environments



And then moved several times into temperate forests



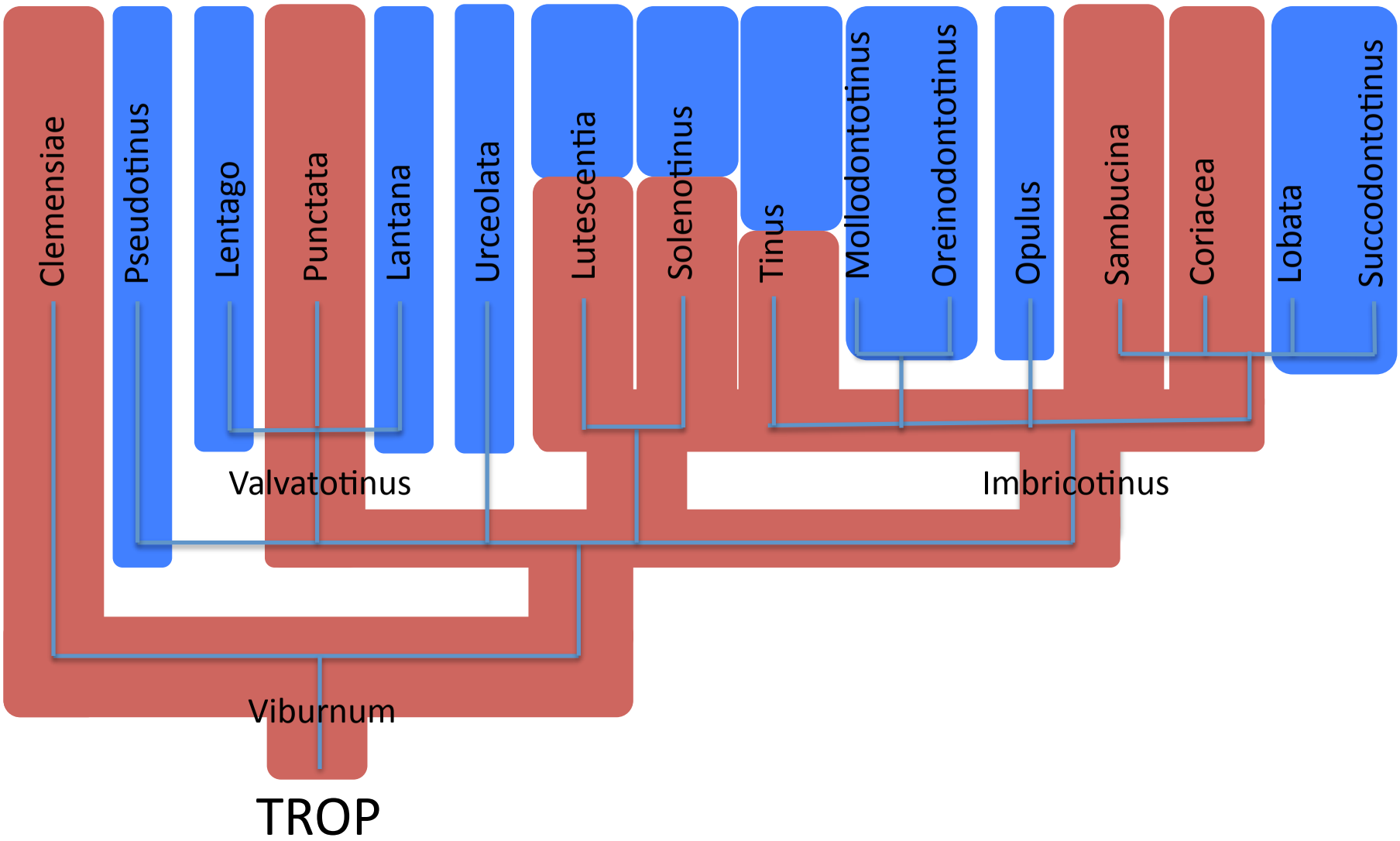

V. beccarii

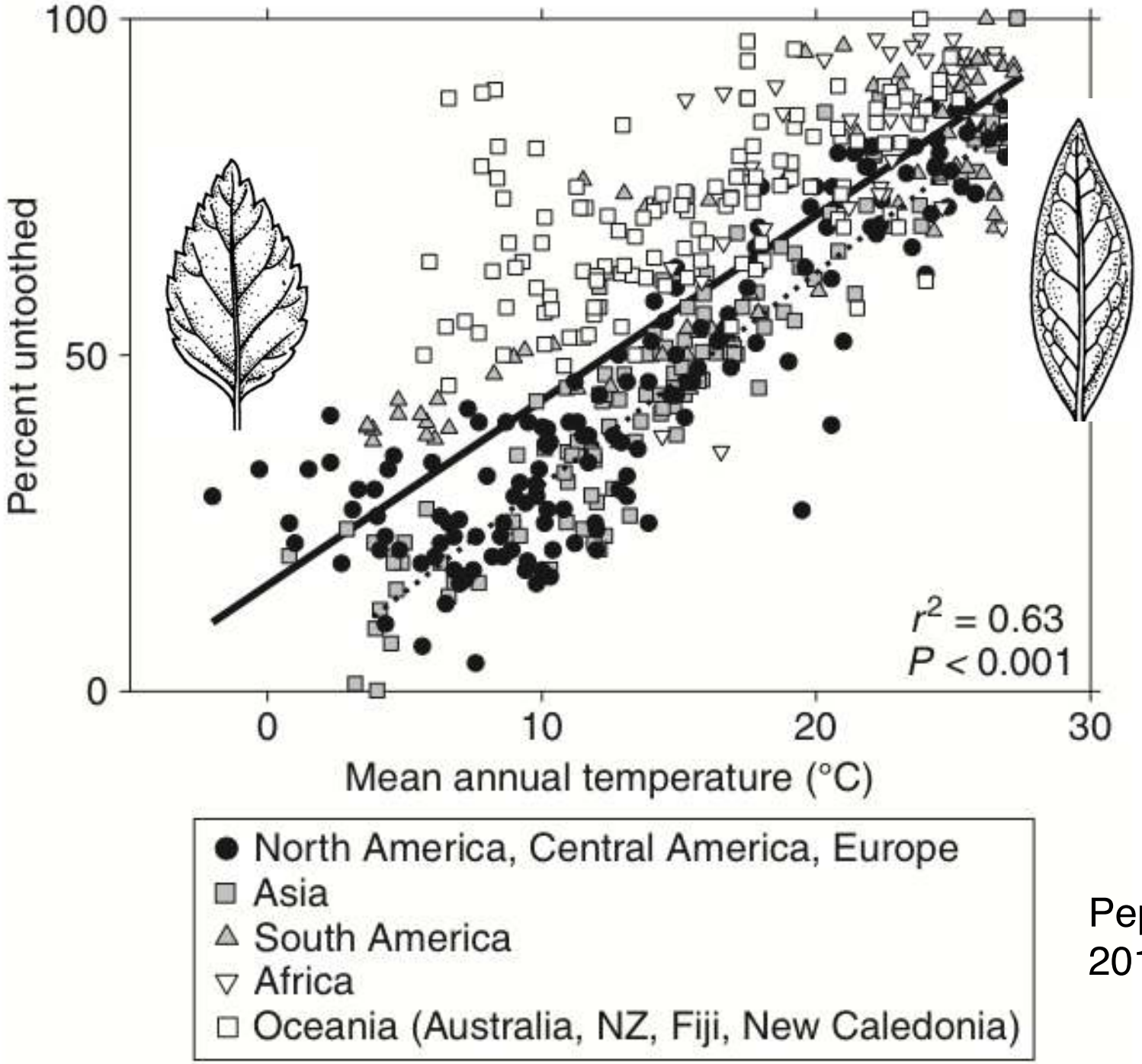
Viburnum clemensae, north Borneo

Viburnums are not at the tops of the mountains . . .

but in the wet warm lowland forests.

And then moved several times into temperate forests





Peppe et al 2011

Viburnum leaf margins and shapes

Viburnum kansuense

Viburnum scabrellum

Viburnum propinquim

Viburnum furcatum

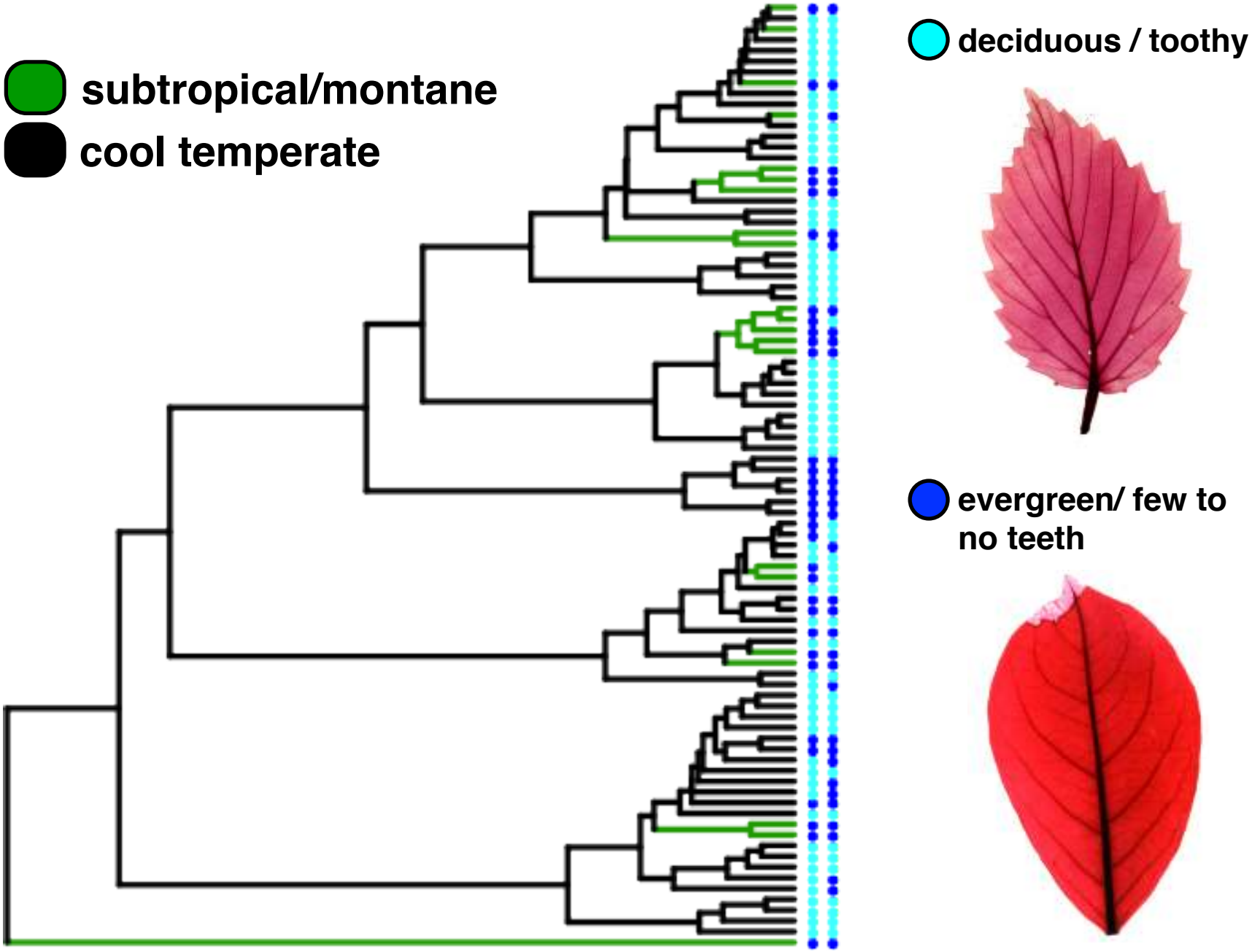
Viburnum punctatum

Viburnum foetidum

Viburnum orientale

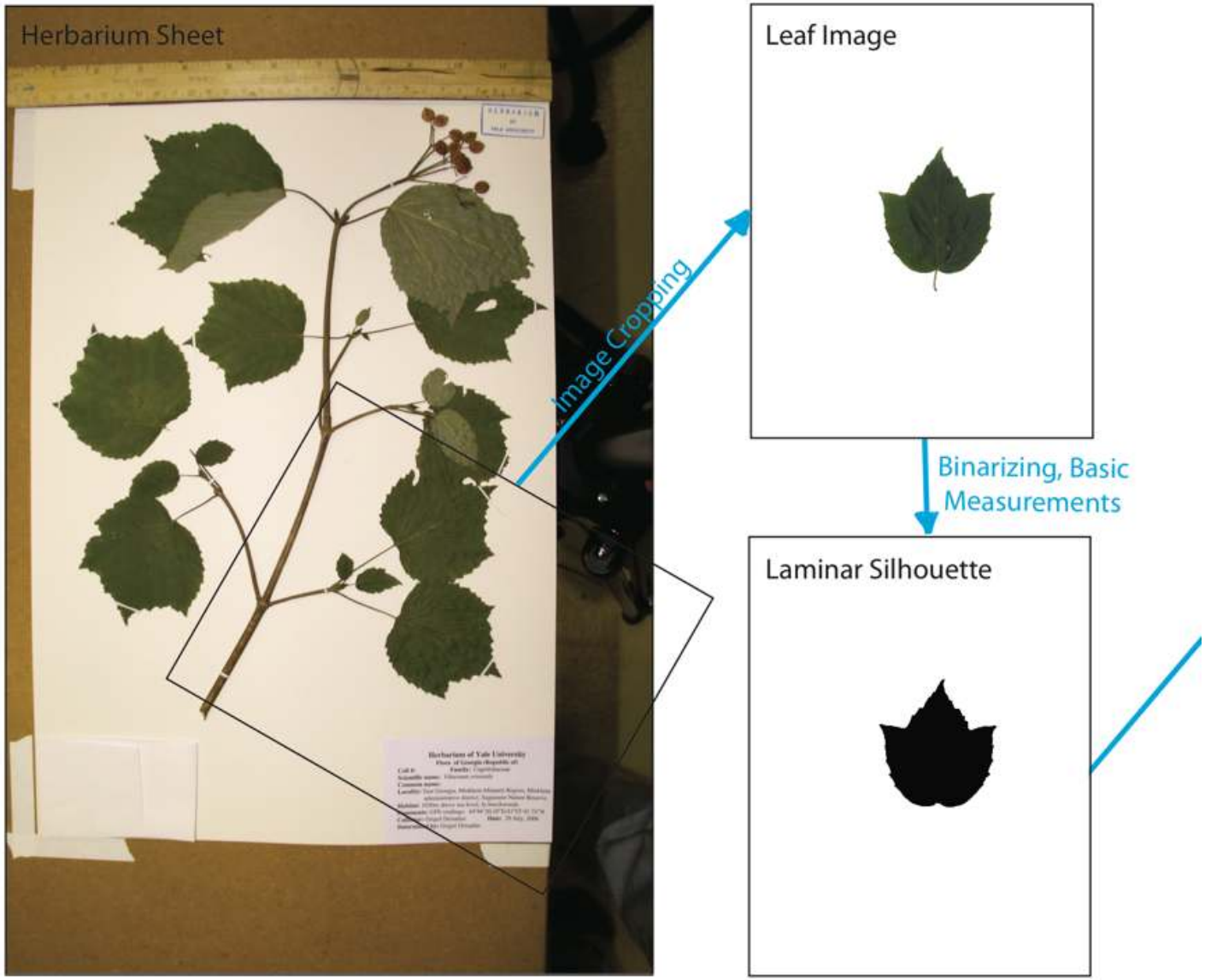
Erika Edwards

Schmerler, Clement, Donoghue, and Edwards, MS in prep.

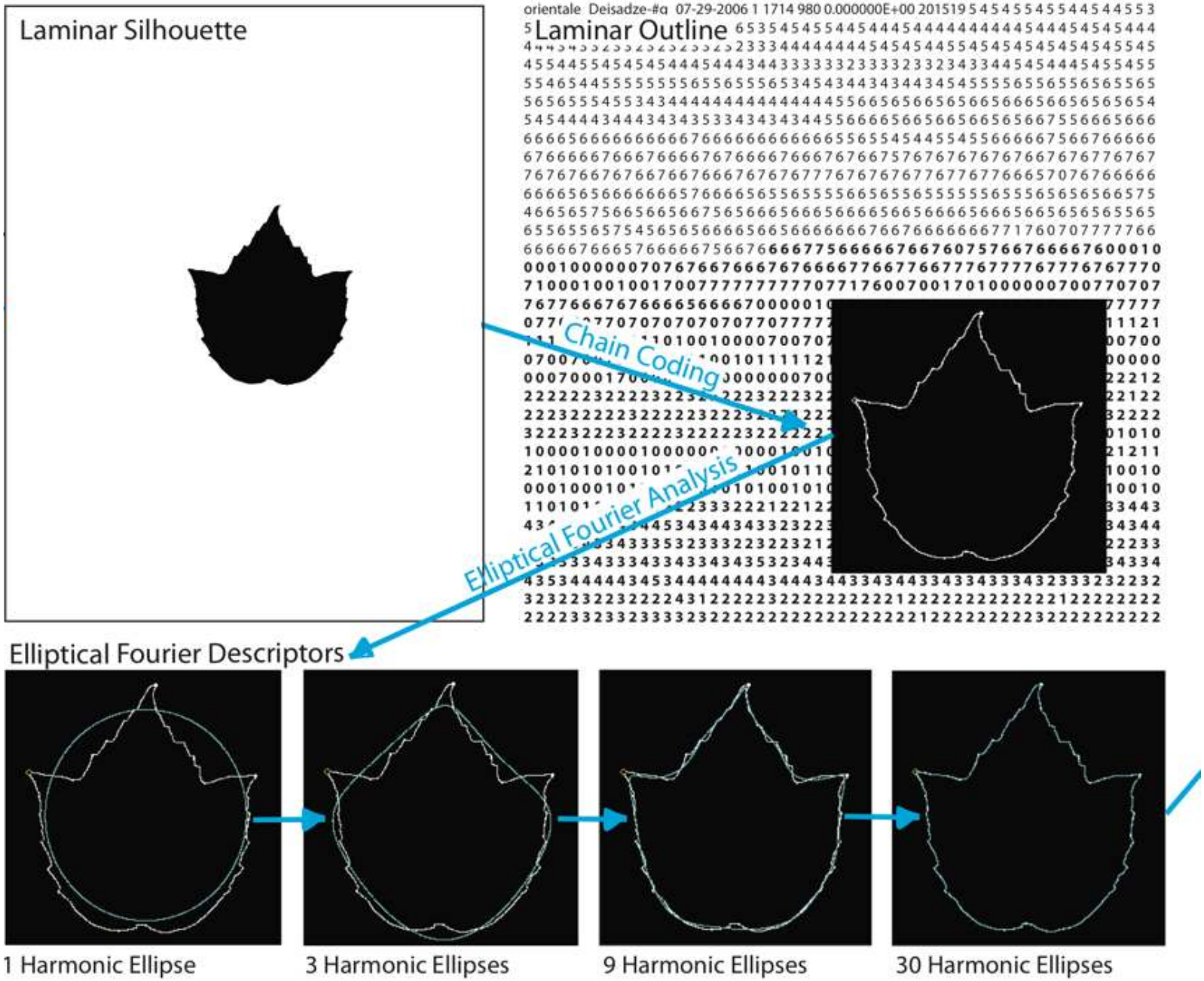

subtropical/montane
cool temperate
deciduous / toothy
evergreen/ few to no teeth

Sam characterized 88 taxa and processed >3000 LEAVES!!

Sam Schmerler,
Brown University

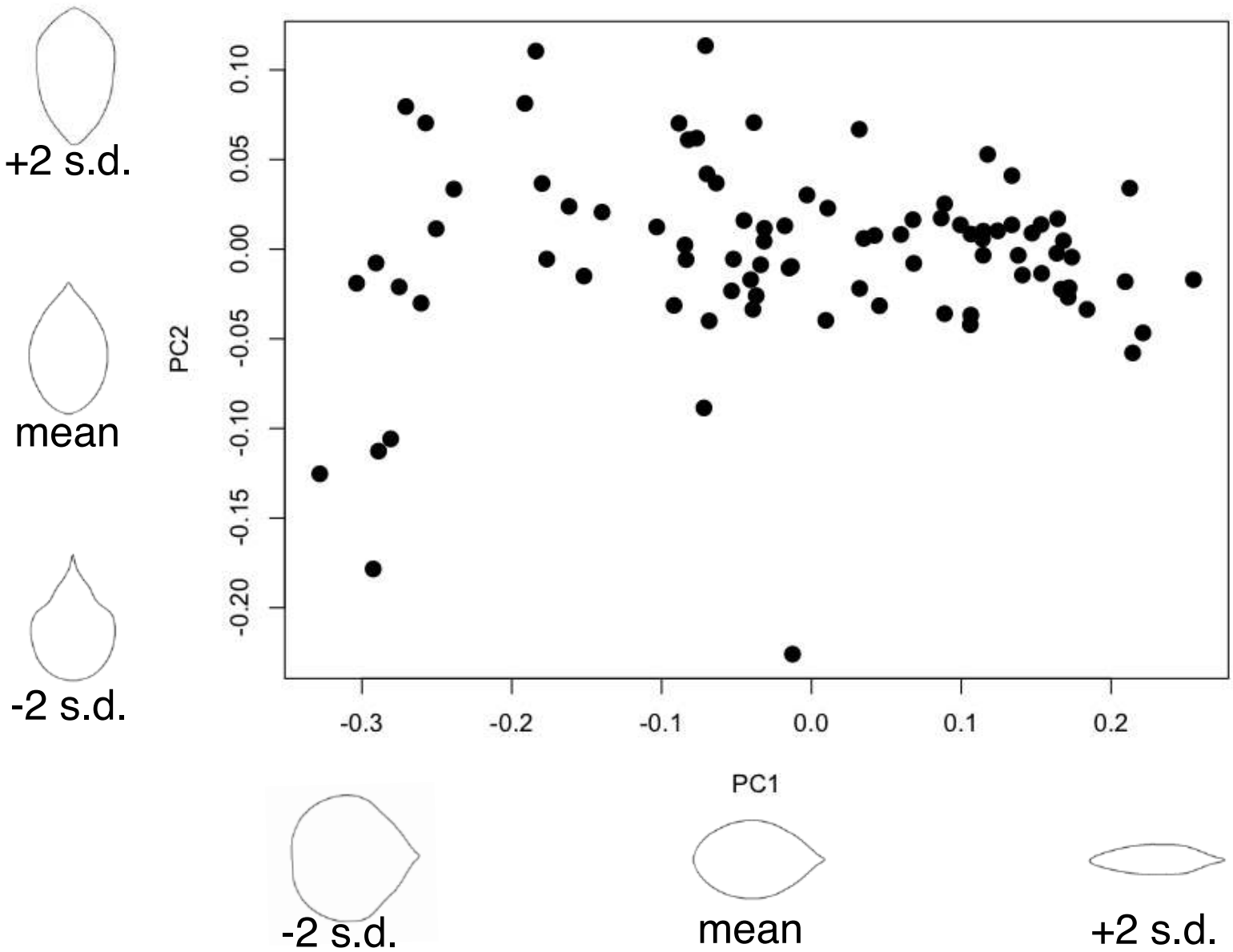


Quantifying gross laminar form: elliptical Fourier analysis

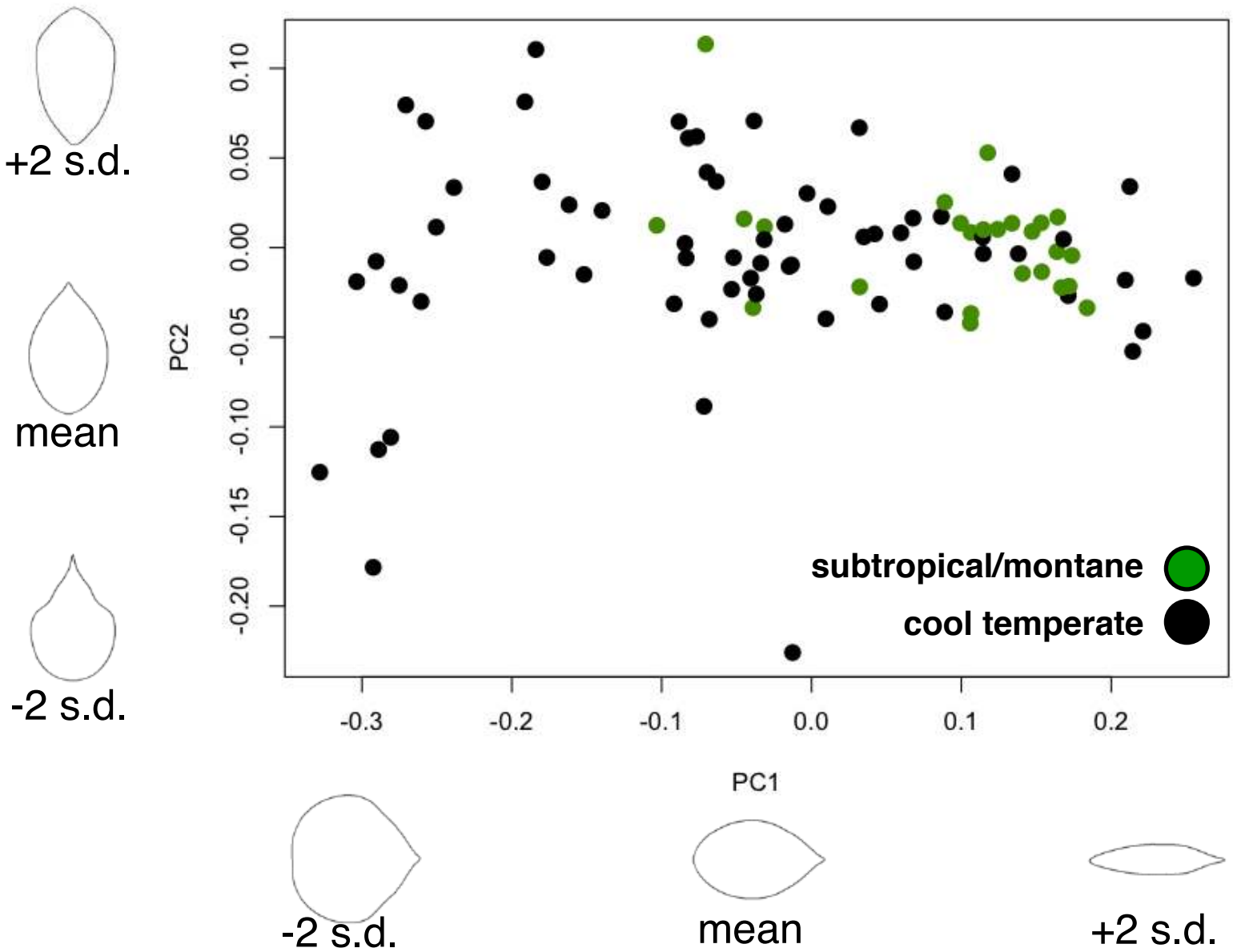


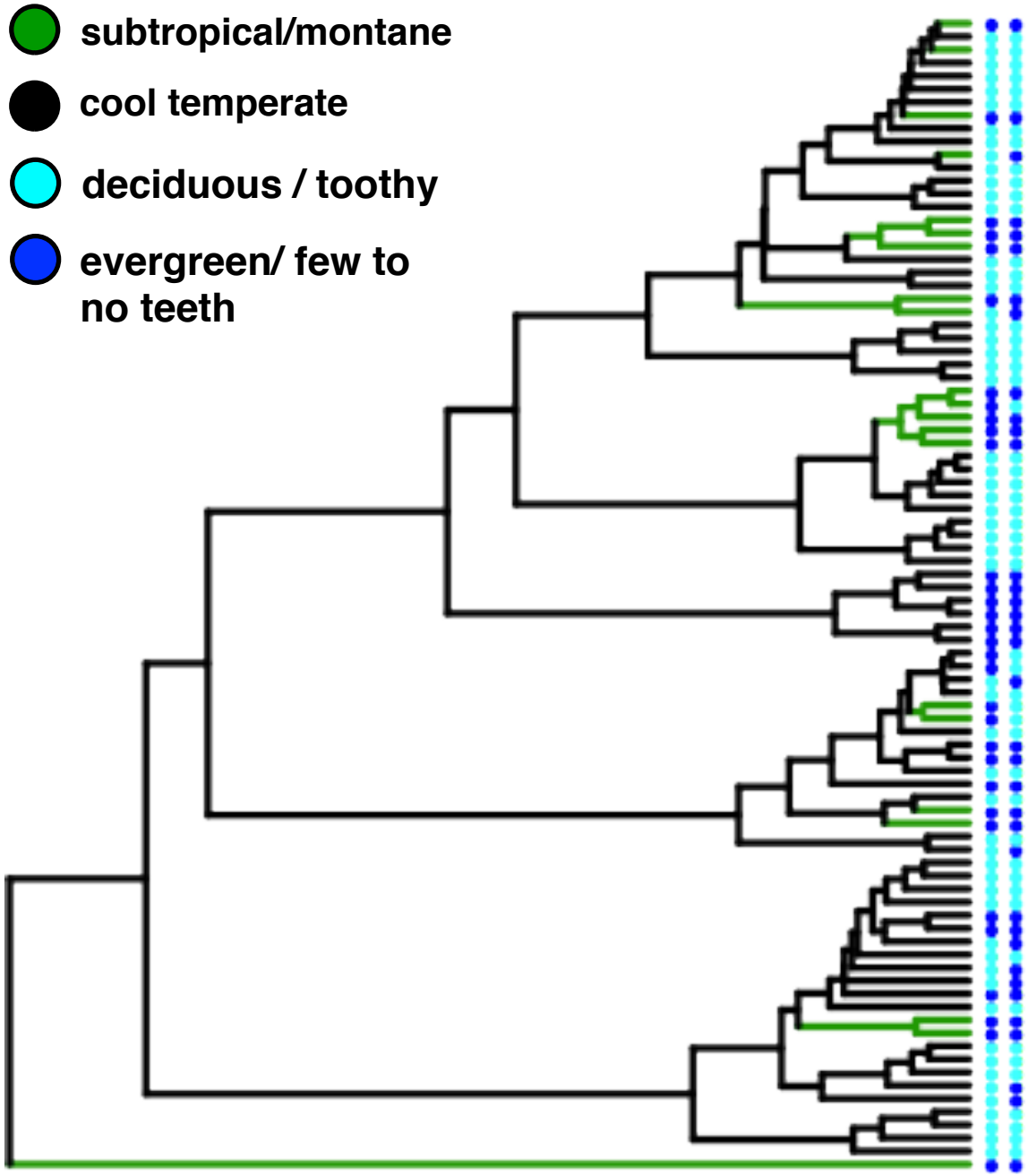
PC 1 explains > 85% of leaf shape variation in *Viburnum*

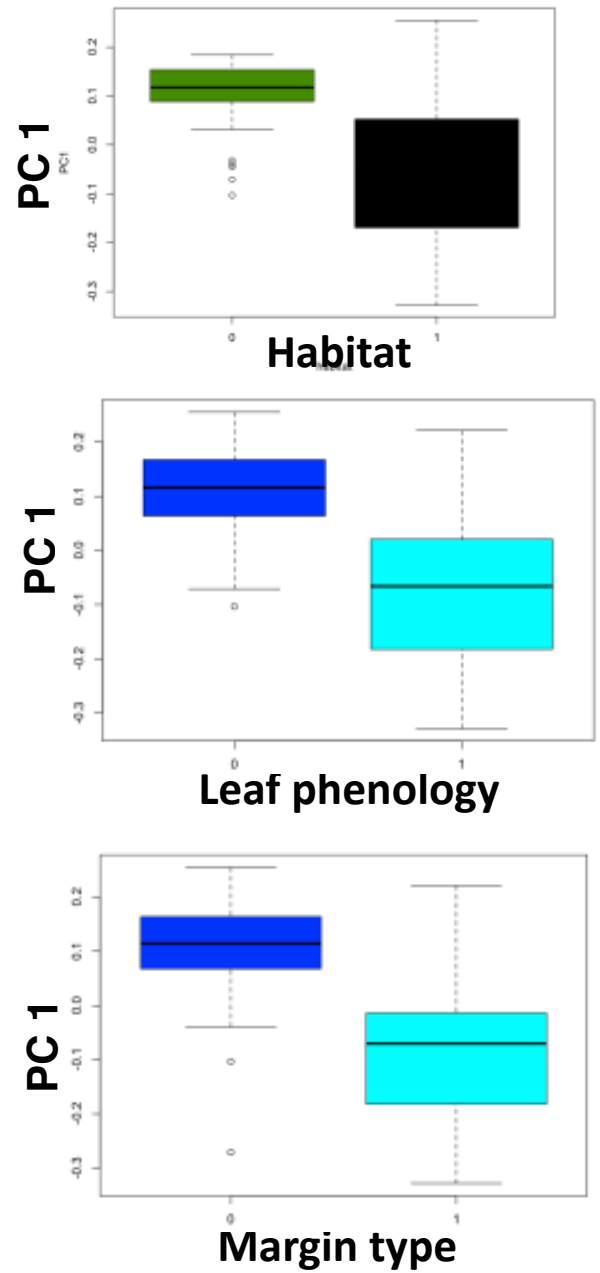
PC 1 + PC2 explain > 95% of variation



subtropical/montane species are clustered on high end of PC1







All highly significant with phylogenetic regression ($p<0.01$)

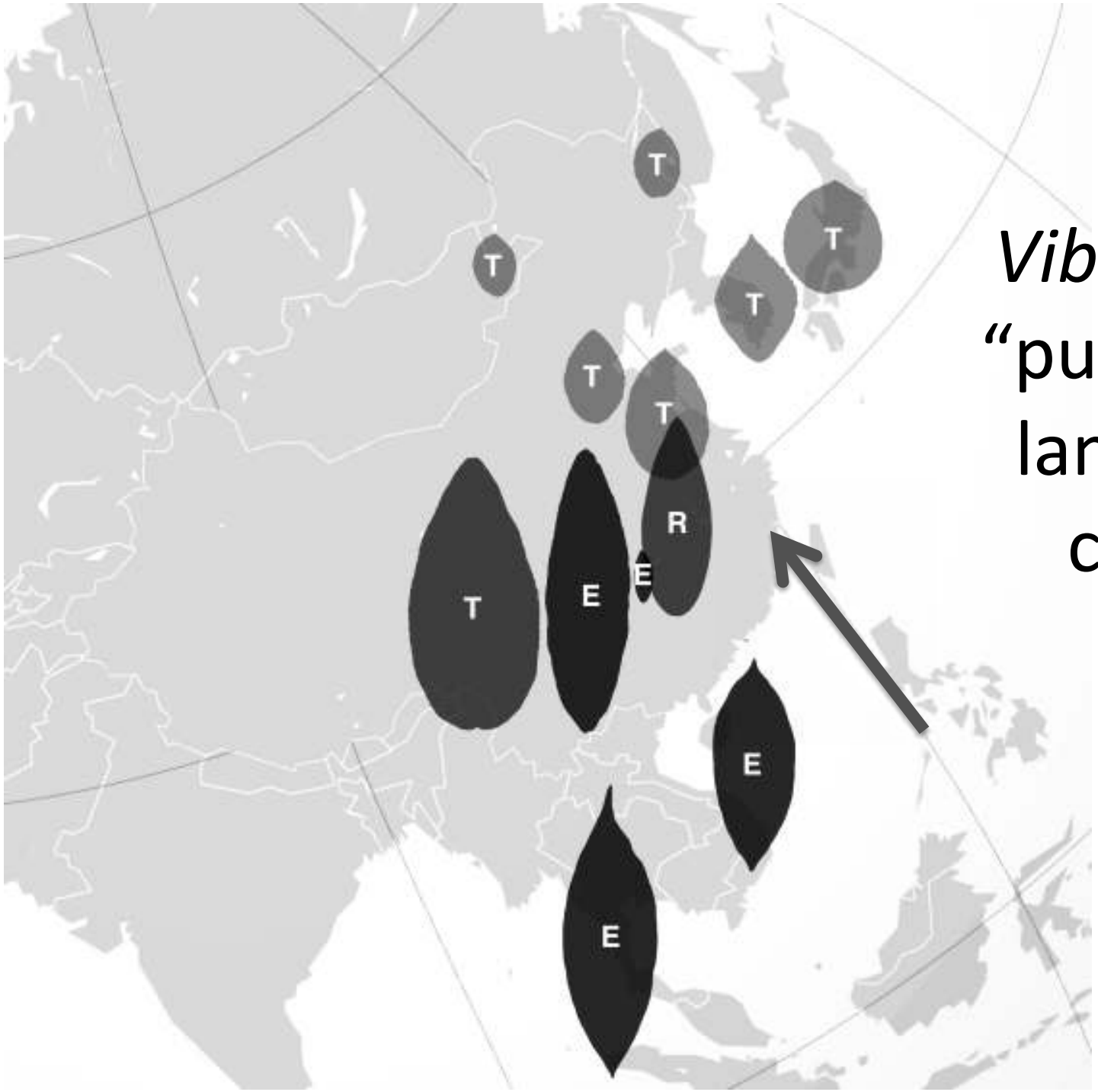
Two emerging leaf syndromes in *Viburnum*

tropical/subtropical/montane

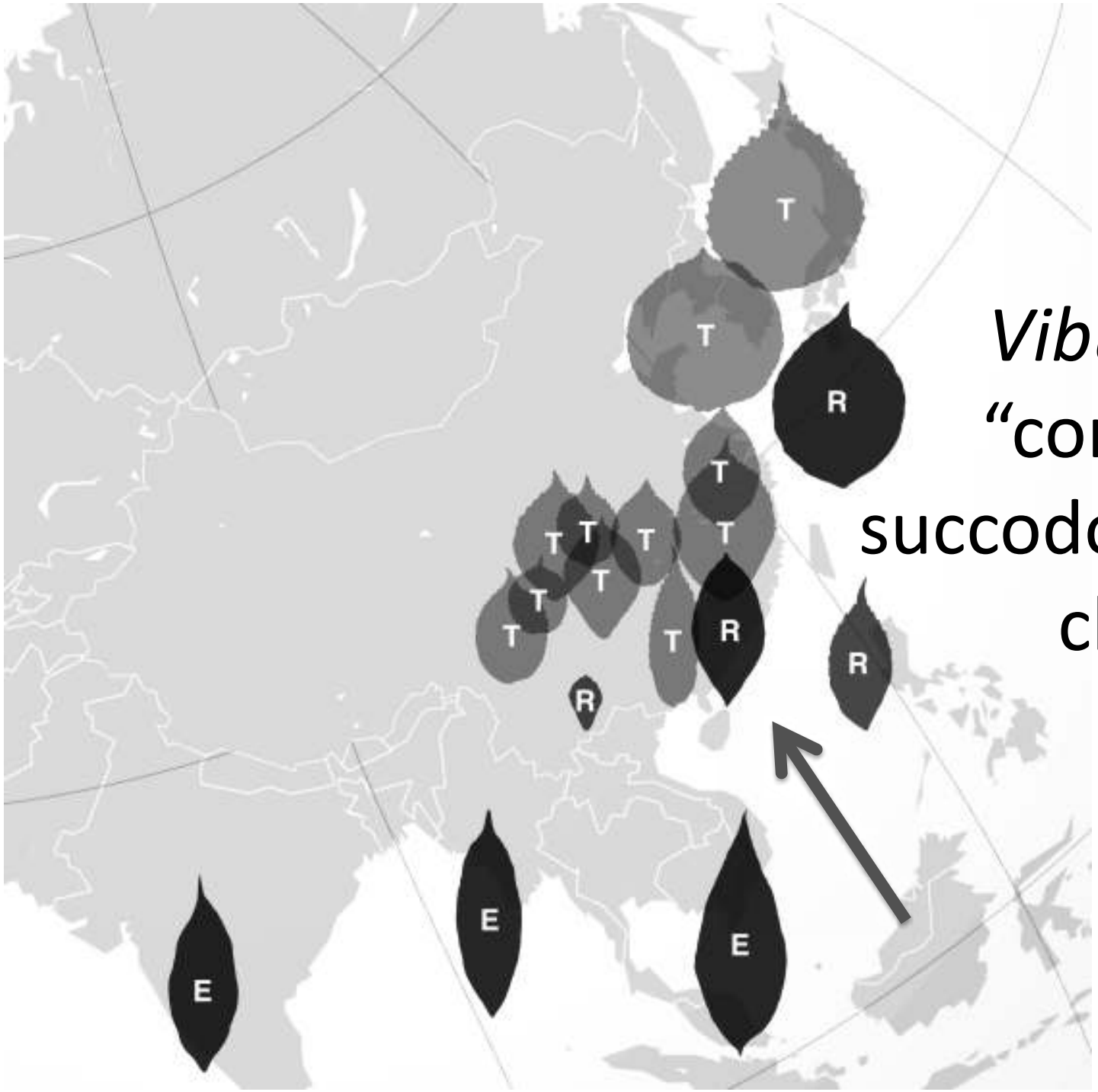
evergreen,
reduced or no teeth,
narrow elongate shape

temperate/boreal

Deciduous,
toothed margins,
shorter rounder leaves

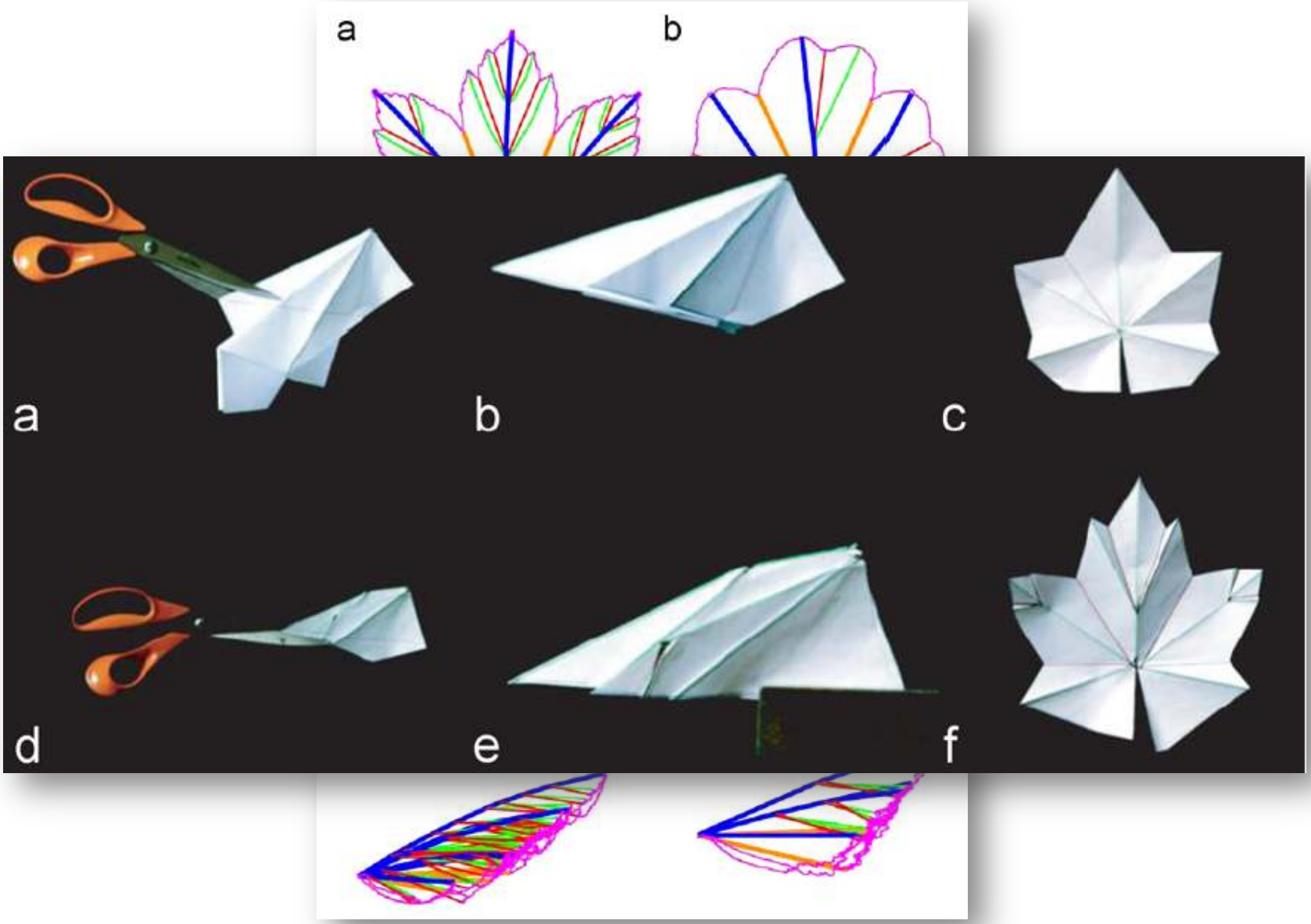


Viburnum "punctata-lantana" clade



Viburnum "coriacea-succodontotinus" clade

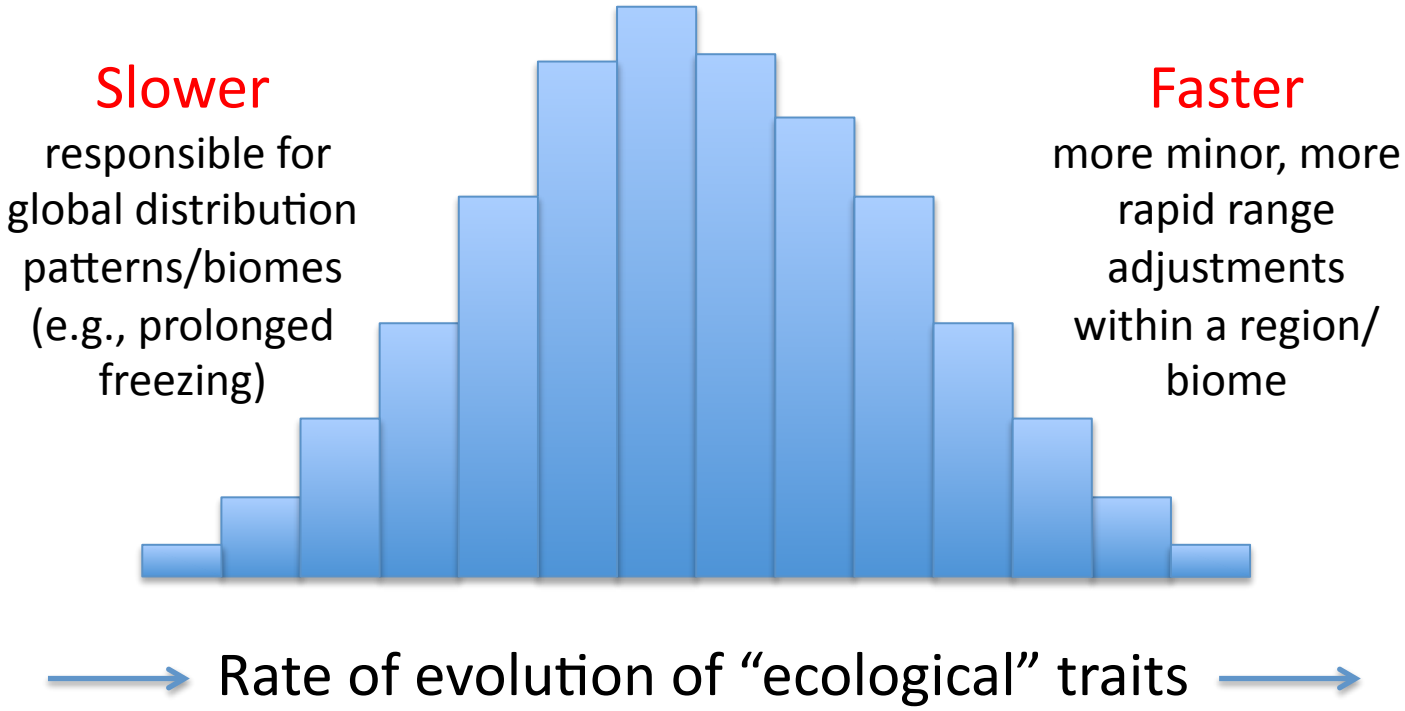

Viburnum luzonicum
Taiwan, November 14, 2011



Couturiere et al., 2011. The filling law: A general framework for leaf folding and its consequences for leaf shape diversity. Jour. Theoretical Biology.


Preformed in the bud
Neoformed later in the season
Viburnum luzonicum
Taiwan, November 14, 2011

There is a distribution of rates of trait evolution



Fast and slow are <u>both</u> important for understanding biodiversity and global change!

Global Change

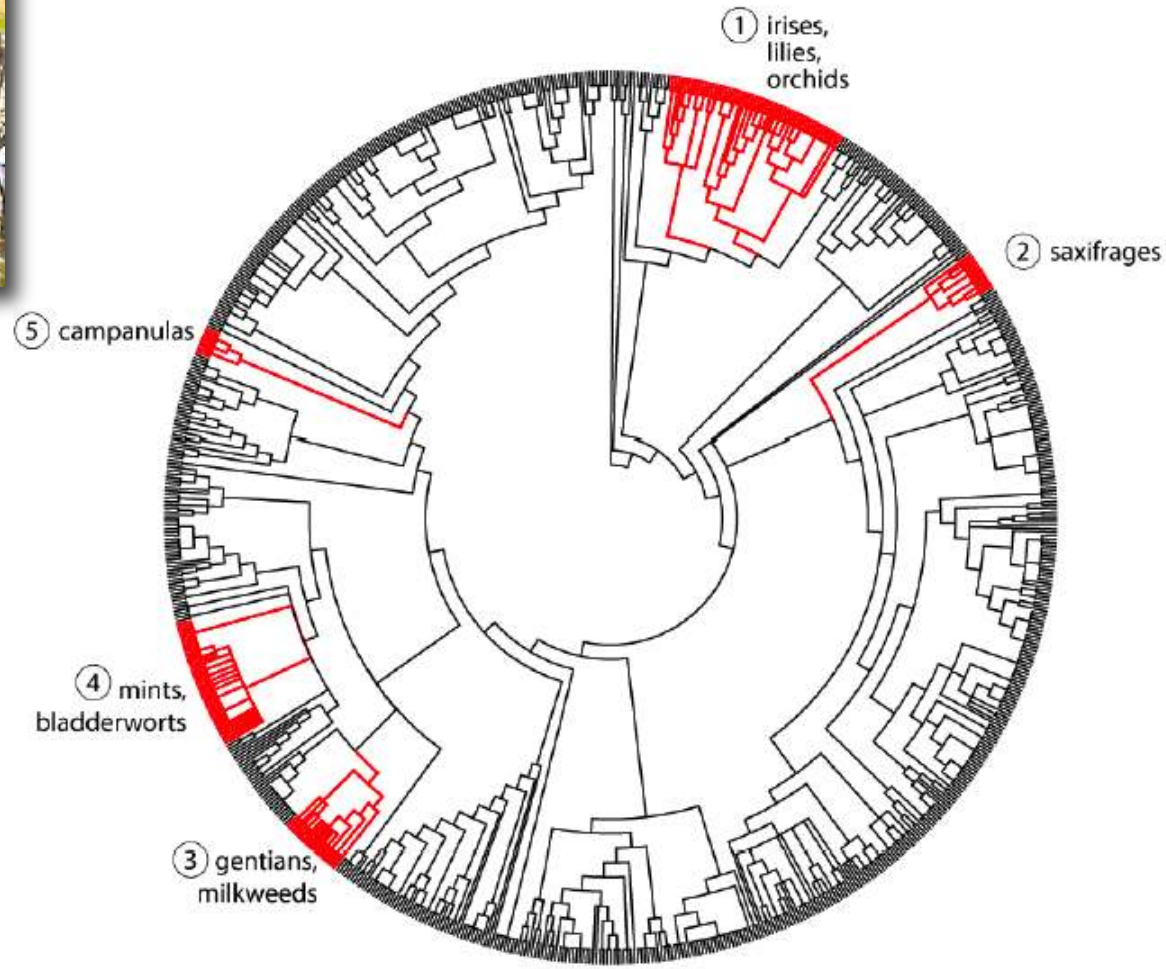
Walden Pond, Concord, Mass.

Henry David Thoreau
1856

Richard Primack,
Boston University

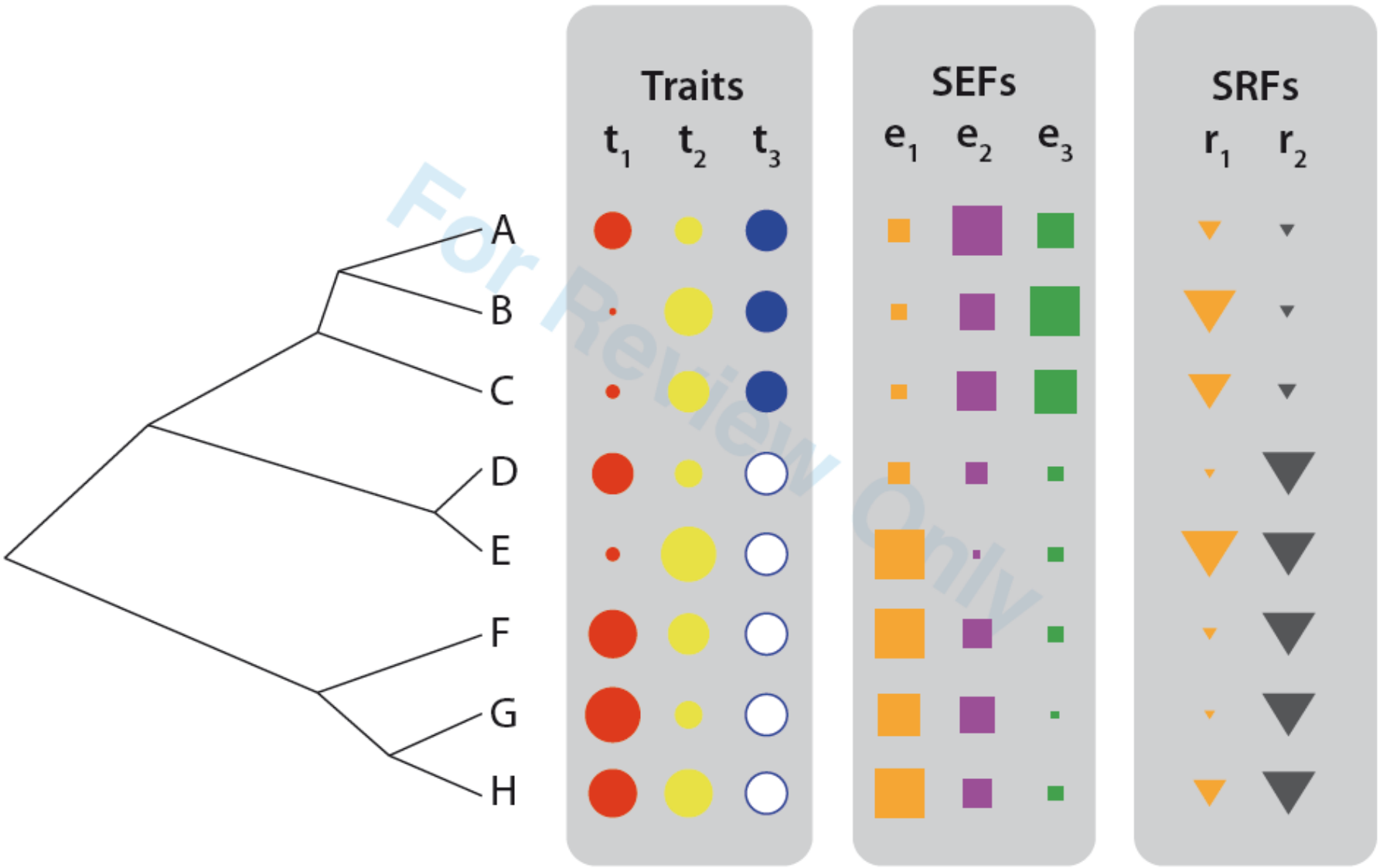
Charles Davis, Harvard

Phylogeny as a vulnerability predictor!

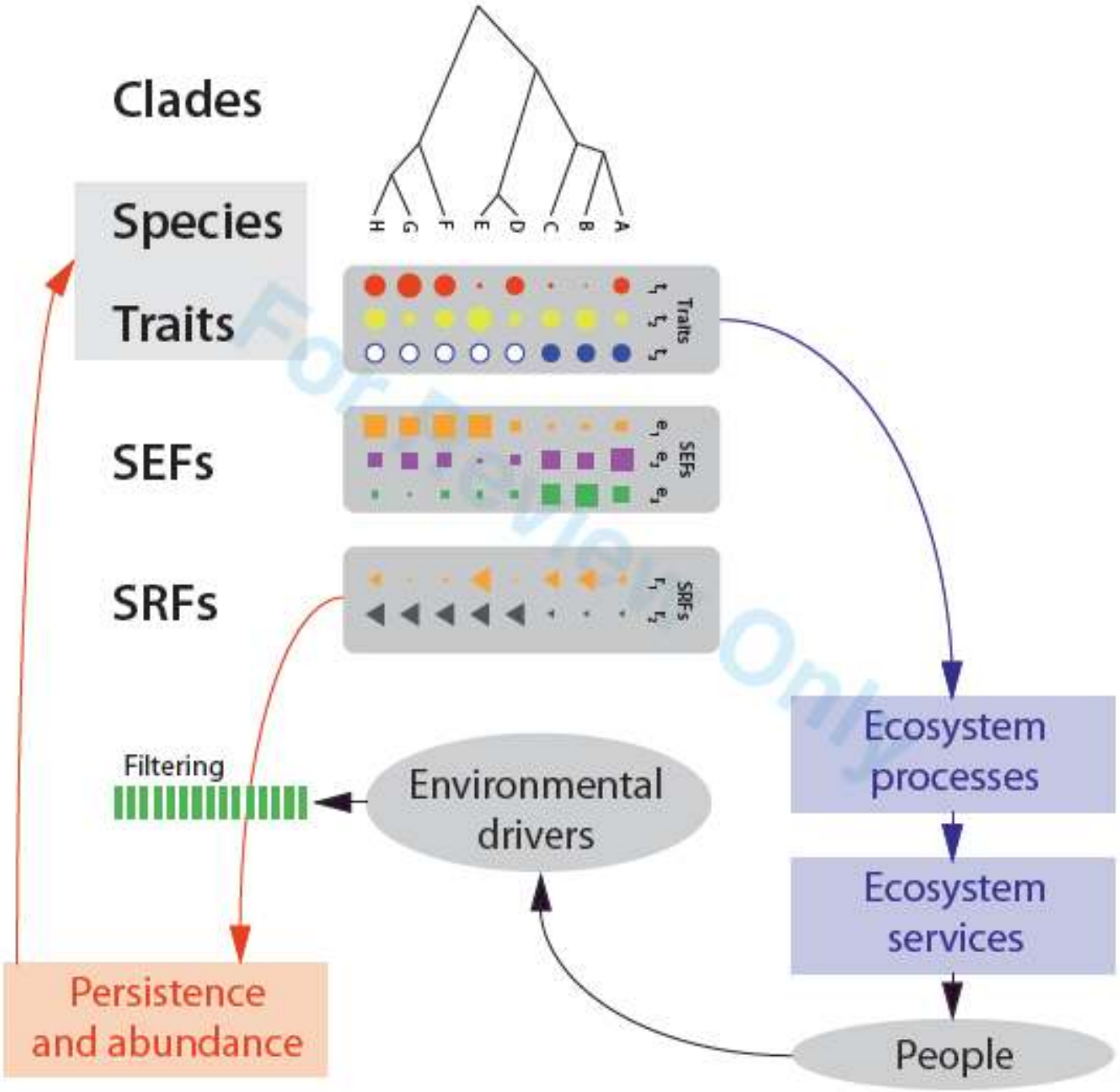


"Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change"
C. G. Willis . . . R. Primack, C. Davis, PNAS, 2008

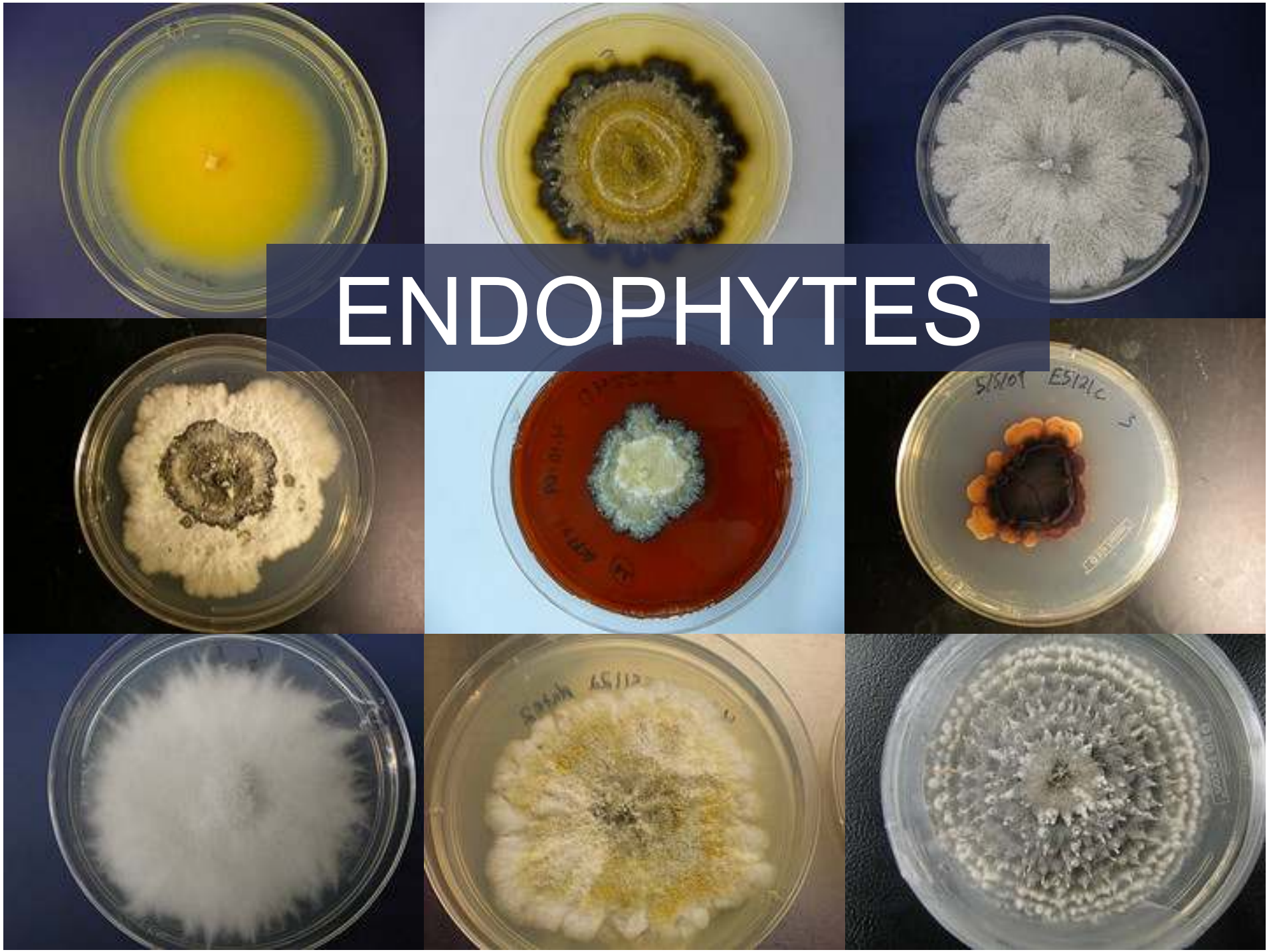
Clade-specific differences in the adaptability of an ecological trait (phenology) influence the fate of species in the face of climate change.



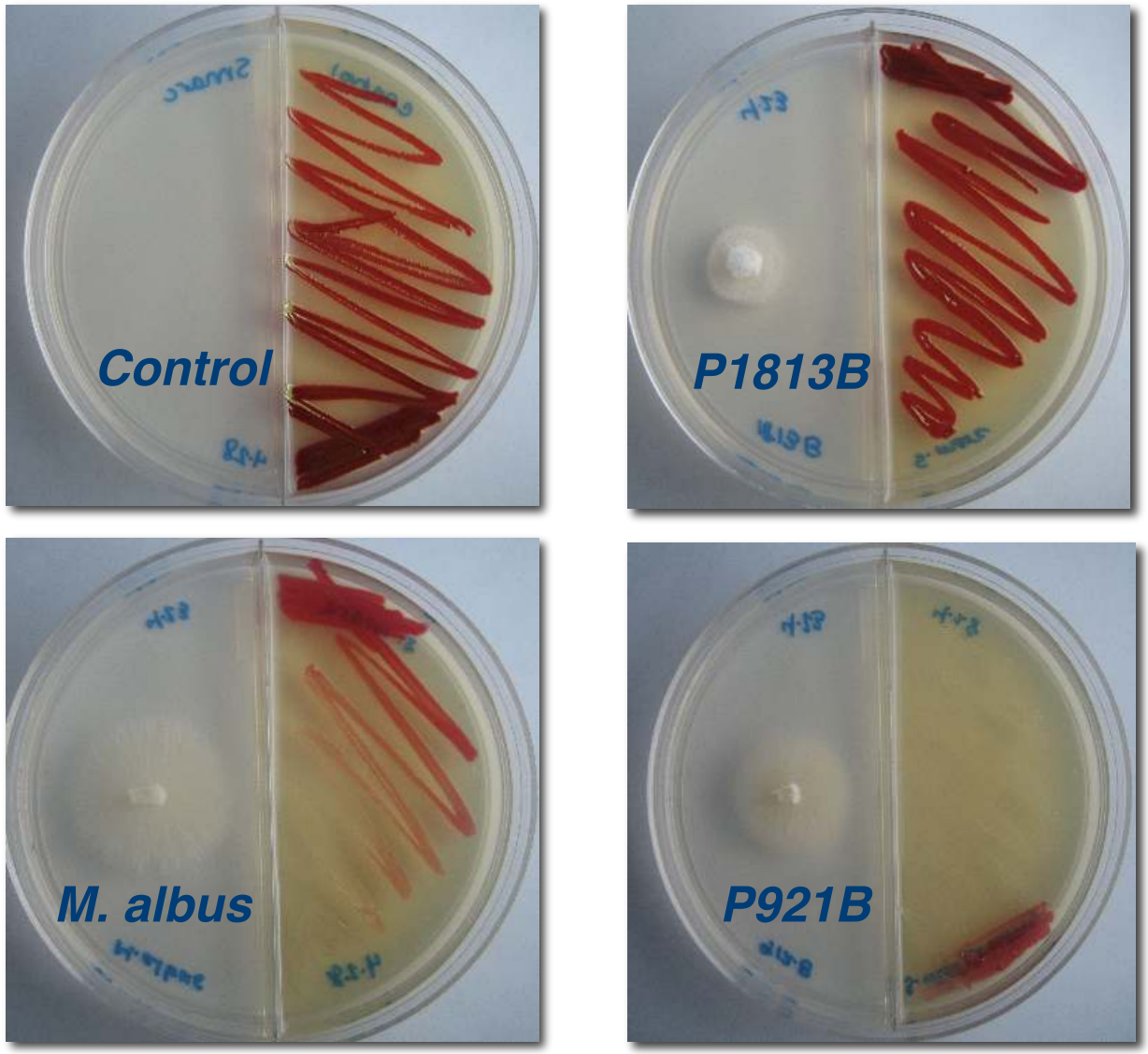
Diaz, S., A. Purvis, J. H. C. Cornelissen, G. M. Mace, M. J. Donoghue, R. M. Ewers, P. Jordano, and W. D. Pearse. 2011. Phylogeny of function and the vulnerability of ecosystems. Current Biology (in review).




“Evosystem” services lost

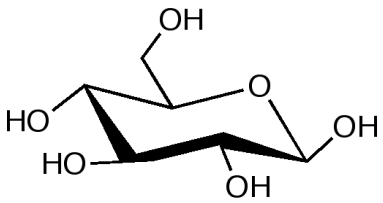


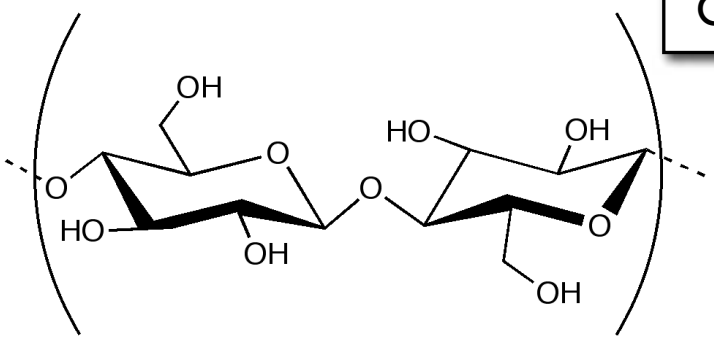
ENDOPHYTES



Bioassays

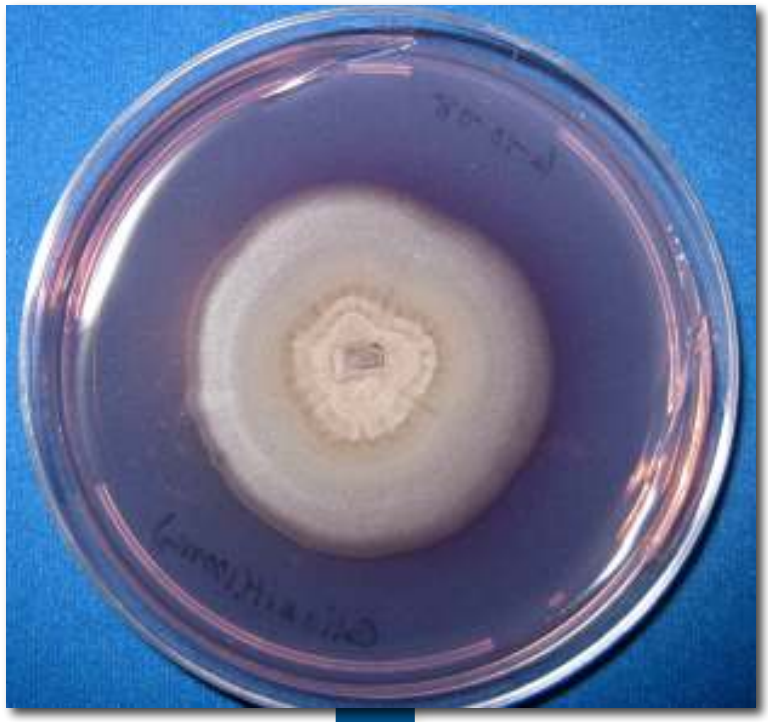
Yale

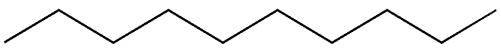




Glucose

Cellulose





C_6-C_{16}

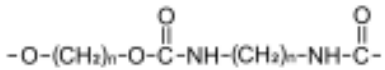
Octane!

"Myco-diesel" biofuels?

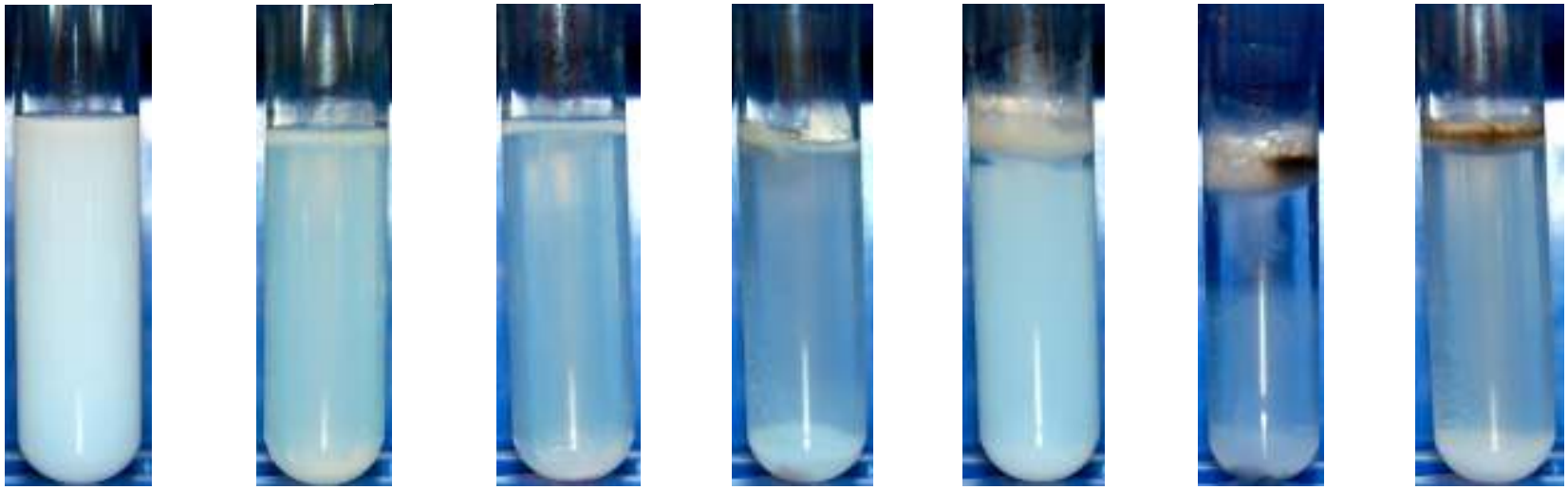
Yale

Can endophytes degrade plastic?

IMPRANIL DLF
Polyurethane Dispersion



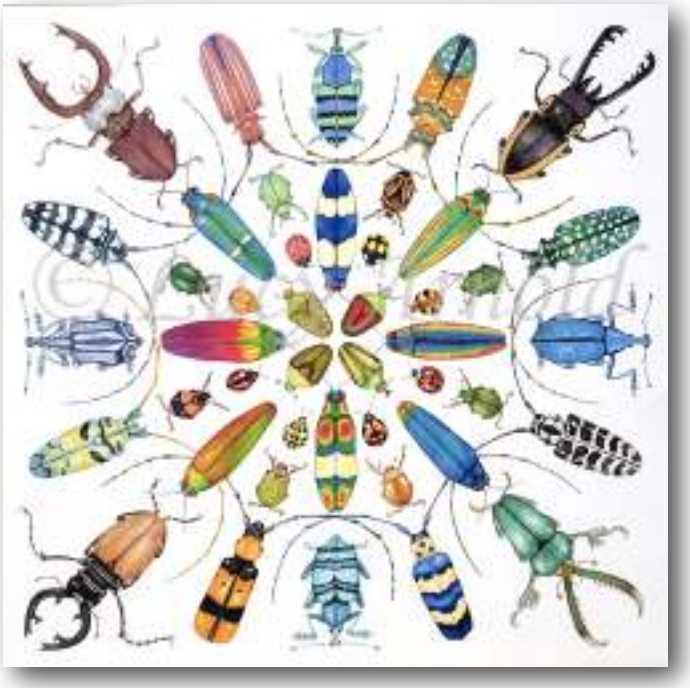
Top 5 endophytic fungi

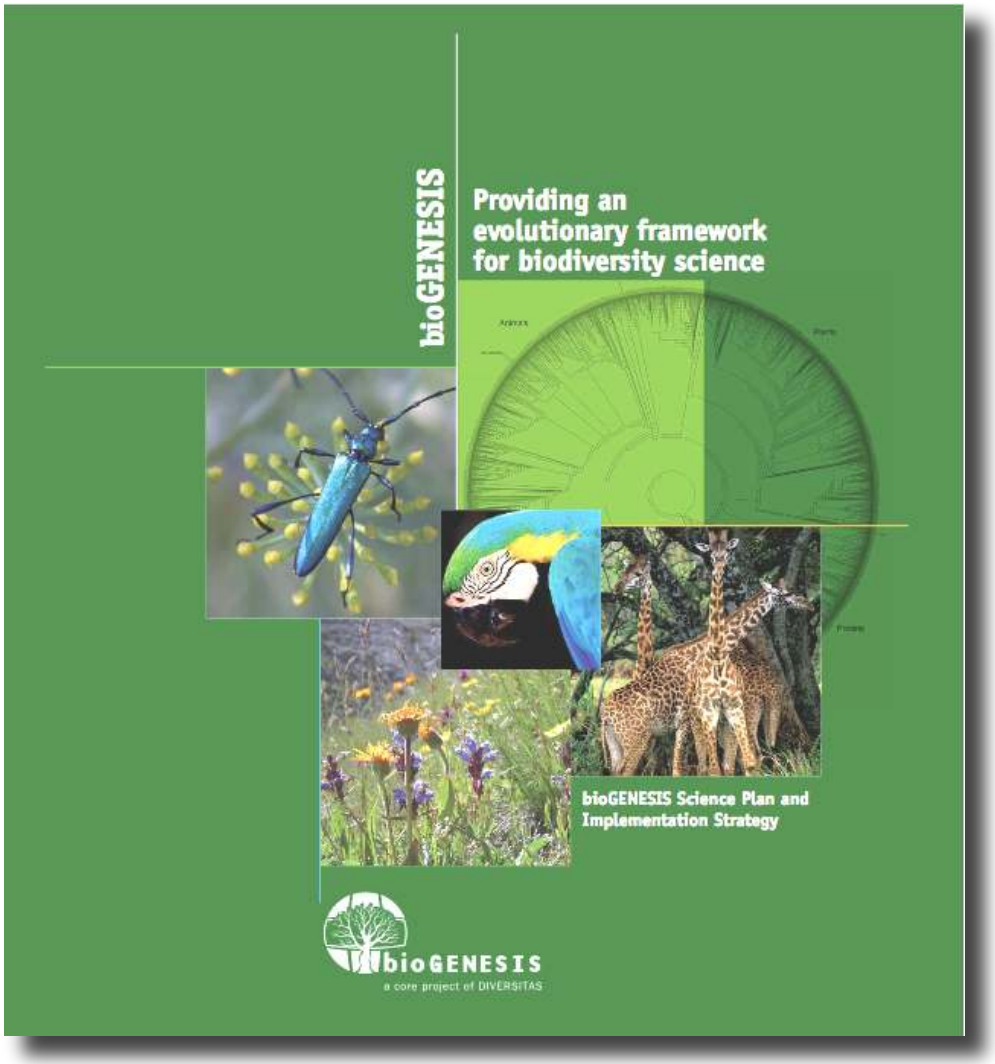


(-) control | *P. chlororaphis* | E2812a | E2708a | E2910b | E2611a | E3317b

Nothing left!

Biodiversity >> Innovation >> Solutions





bioGENESIS
a core project of DIVERSITAS

Providing an Evolutionary Framework for Biodiversity Science

Donoghue, Yahara et al. 2009. BioGENESIS: Providing an Evolutionary Framework for Biodiversity Science. DIVERSITAS Report NO. 6, 52 pp.

DIVERSITAS
an international programme of biodiversity science

Thank you!

Merci beaucoup!