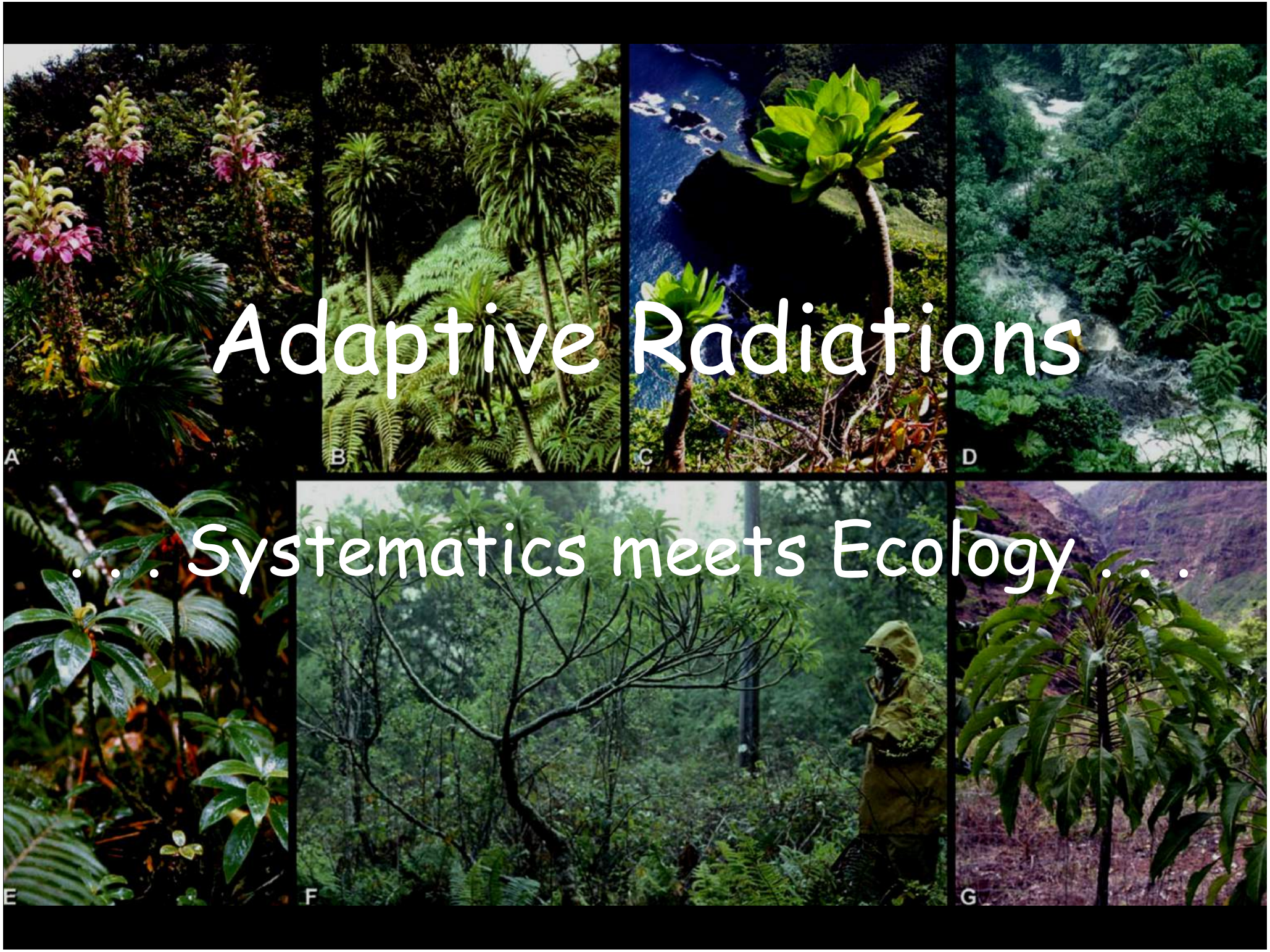
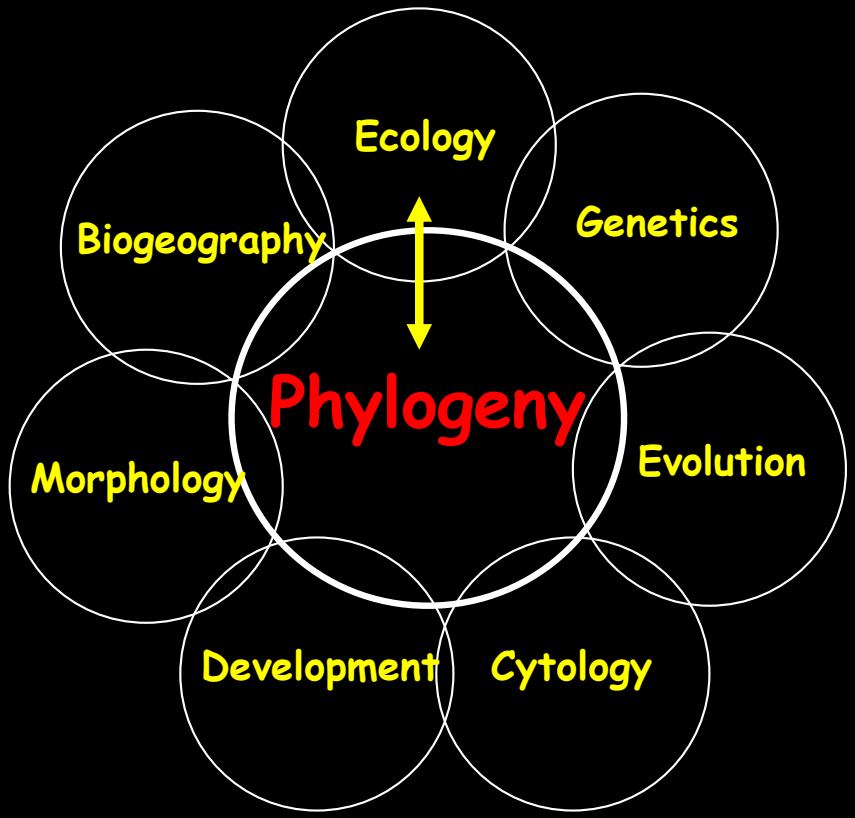


Adaptive Radiations

. . . Systematics meets Ecology . . .

Future of Systematics

1. Genomics
2. Biogeography
3. Ecology



Ecology and phylogenetics intertwined in a number of new fields of study called Phylogenetic Ecology

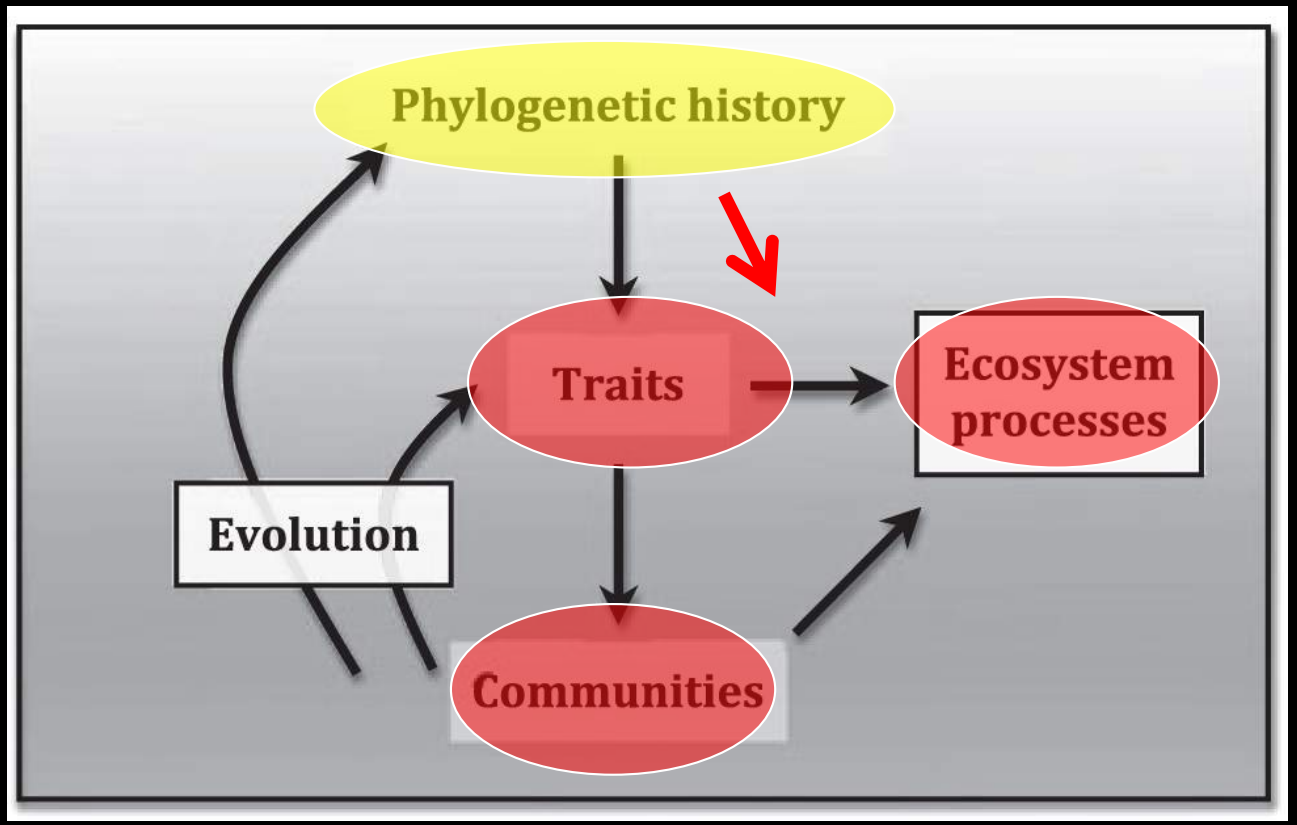
Phylogenetic Ecology

Ecology Letters, (2009) **12**: 693–715 doi: 10.1111/j.1461-0248.2009.01314.x

REVIEW AND SYNTHESIS

The merging of community ecology and phylogenetic biology

Jeannine Cavender-Bares et al.



Phylogenetics can/should **inform ecological processes** at many scales!

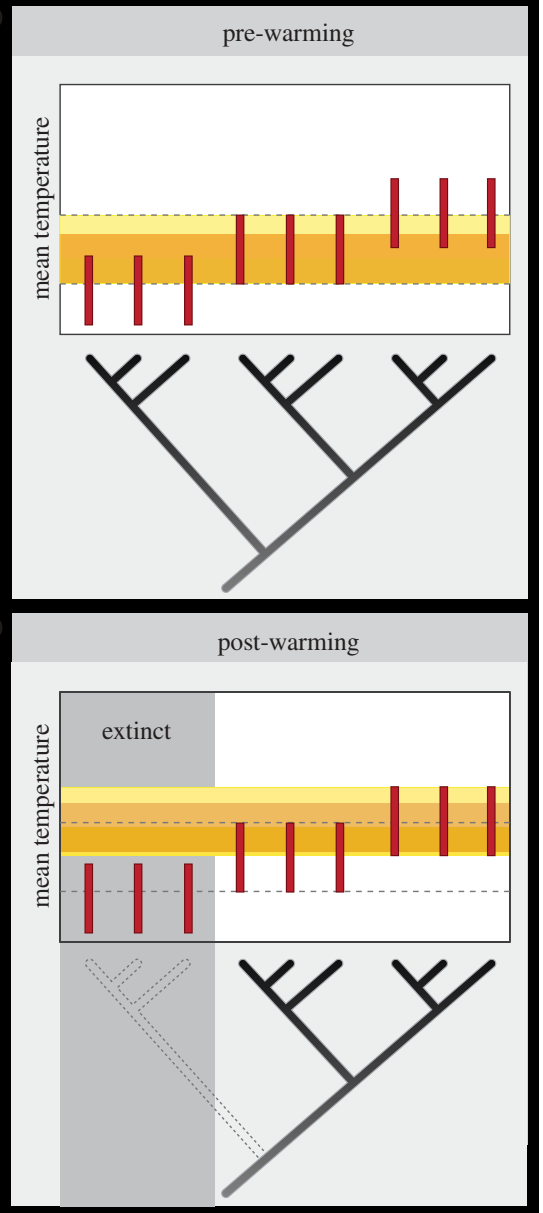
Phylogenetic Ecology

The use of phylogeny to understand species loss due to global climate change

Original habitat climate niche

Species climate niche envelope

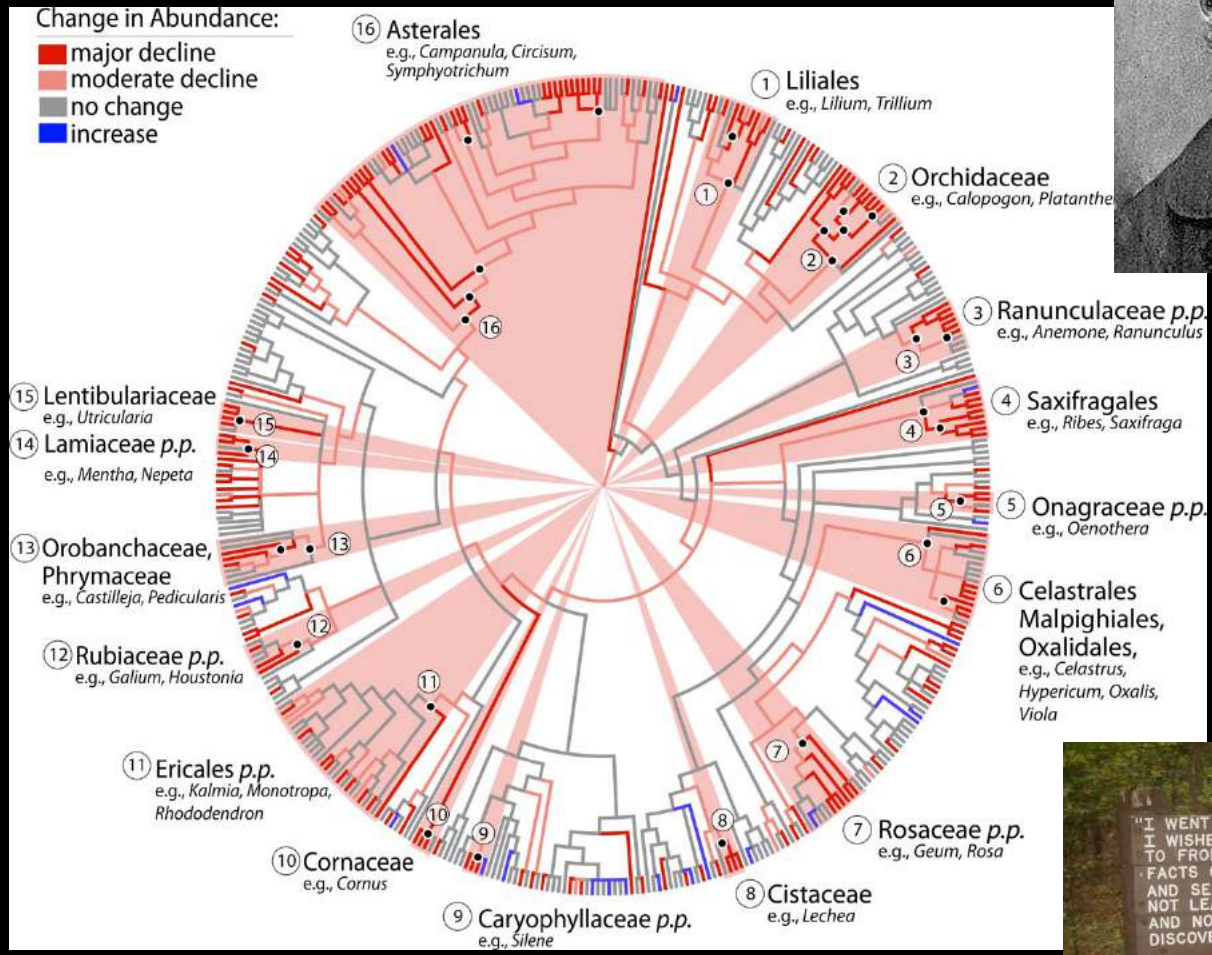
New habitat climate niche



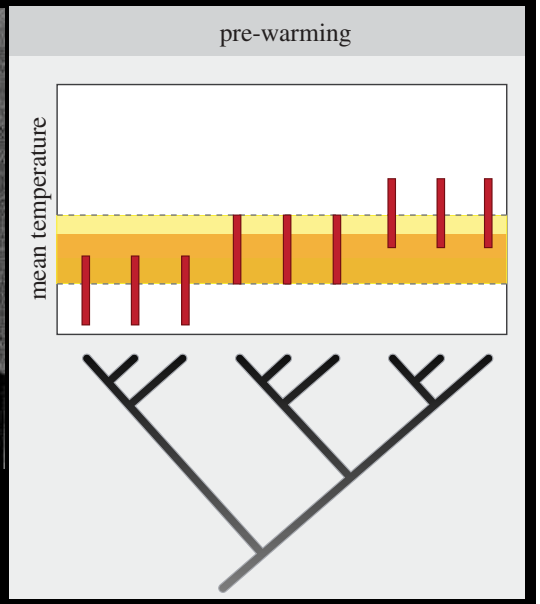
Phylogenetic Ecology

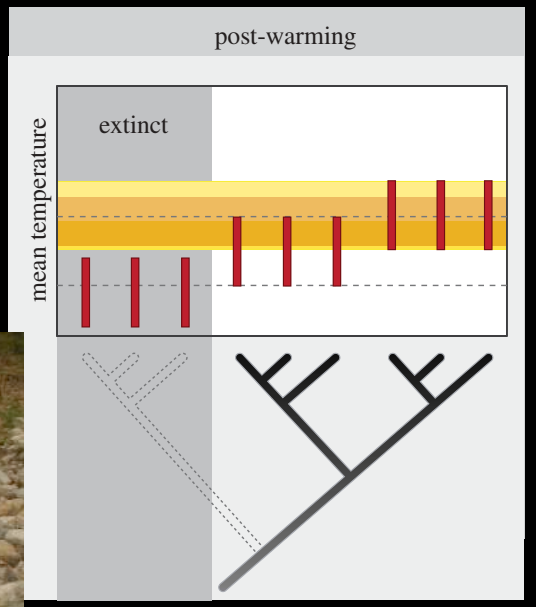
The use of phylogeny to understand species loss due to global climate change

Thoreau

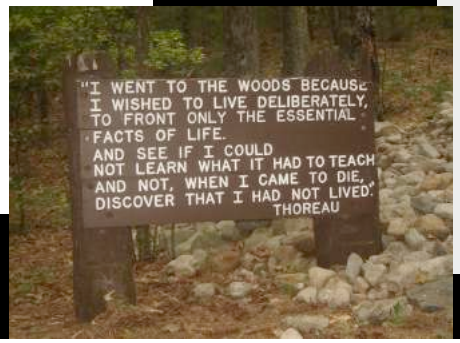


Davis et al. 2010 Phil. Trans. Royal Soc. B



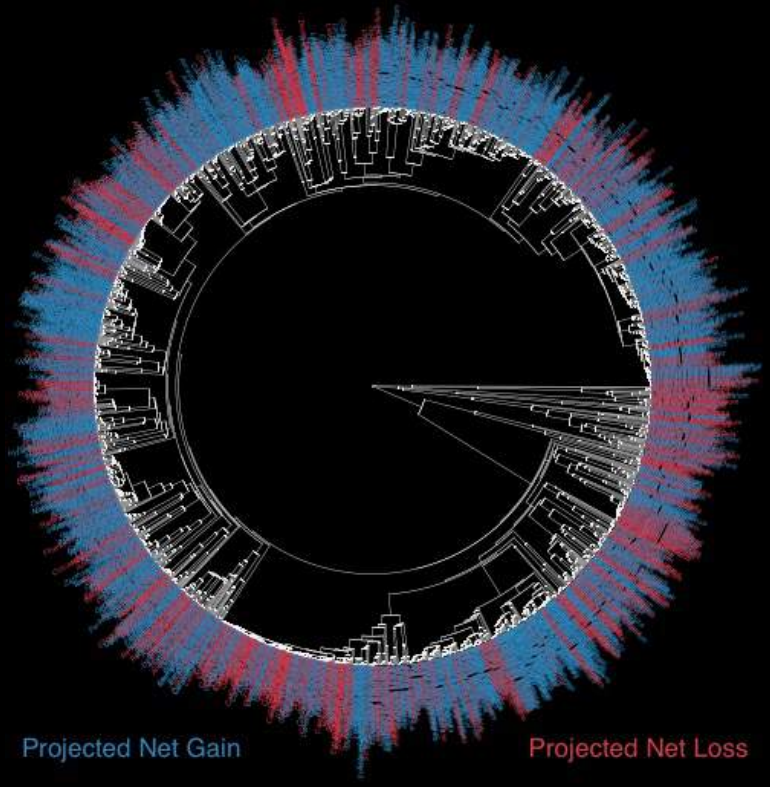


Walden Woods

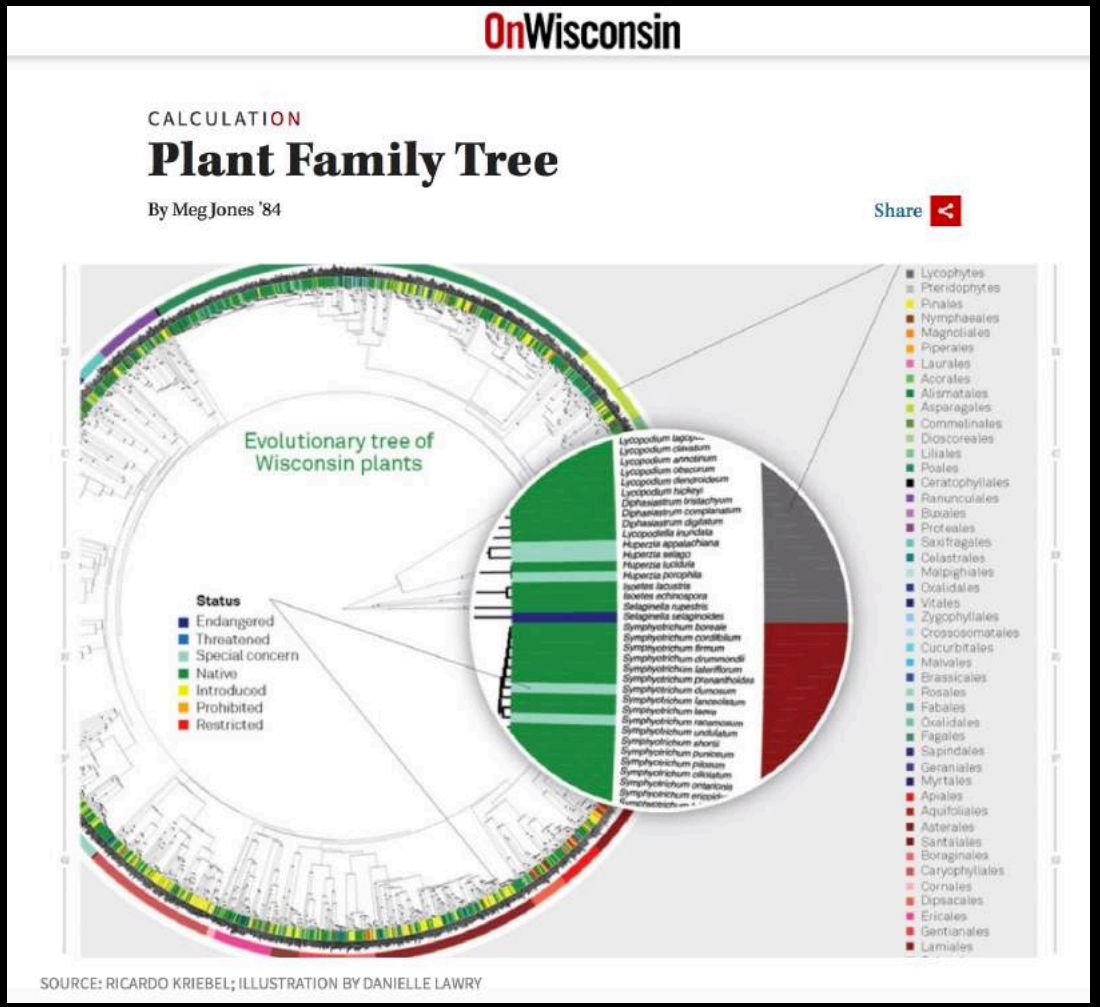


Phylogenetic Ecology

Projecting species niche models to 2070 under climate change model



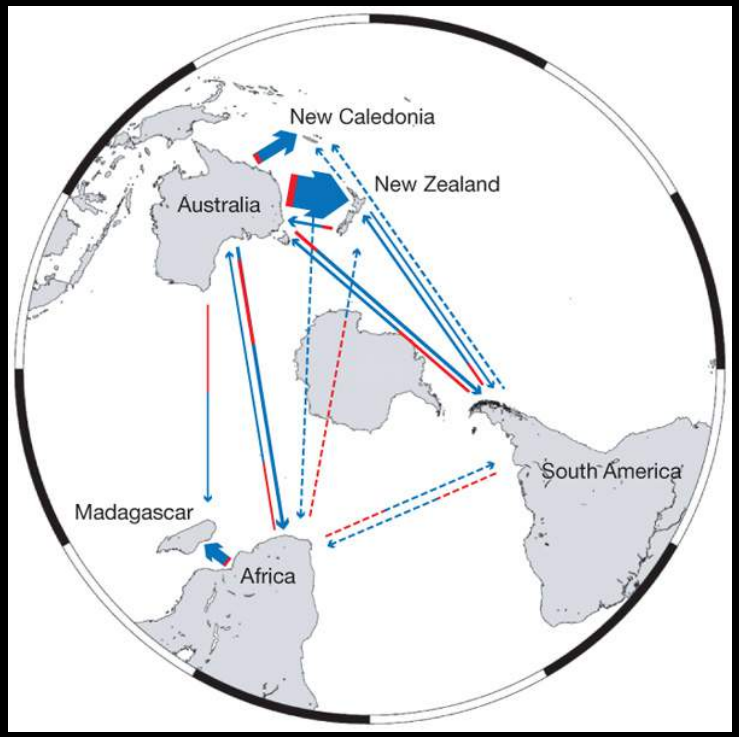
Spalink et al. 2018 American Journal of Botany



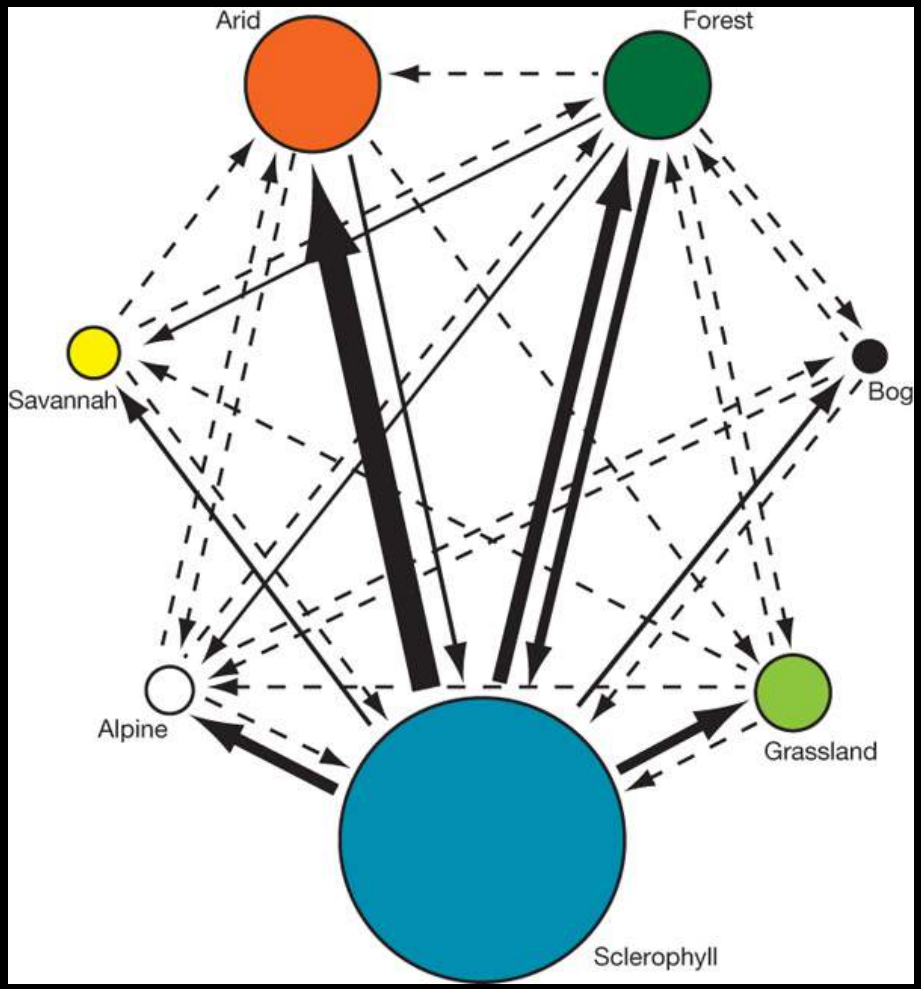
DNA Barcode phylogenetic tree of Wisconsin flora

Phylogenetic Ecology

Examined speciation events within Southern Hemisphere continental biome types



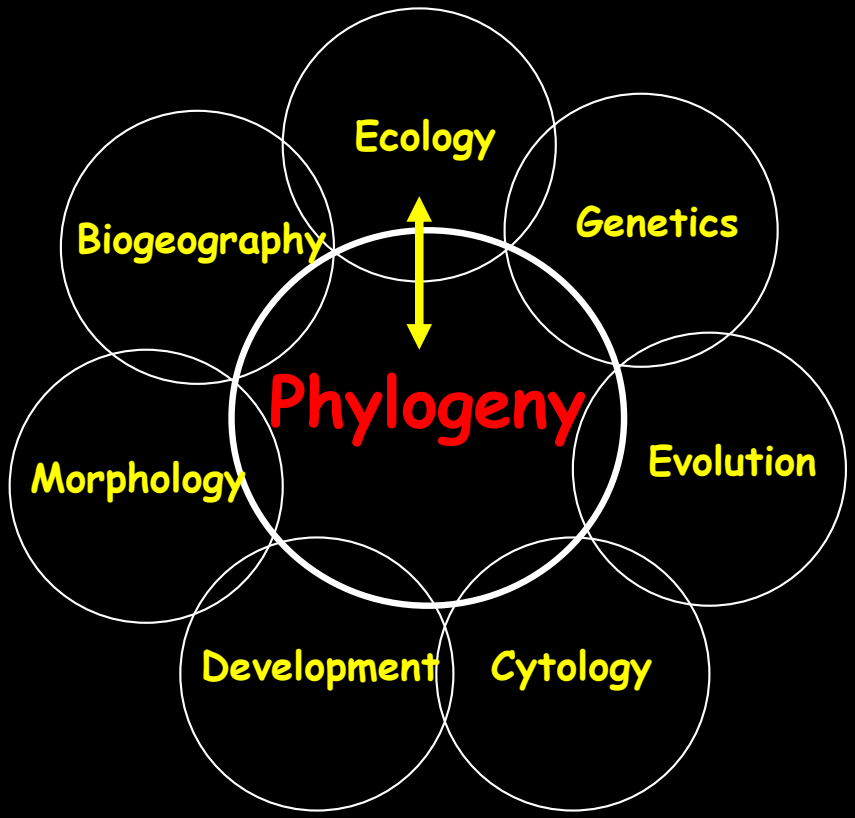
Michael Crisp et al. (2009) – read!



Do most transoceanic colonizations occur within same or different biome types?

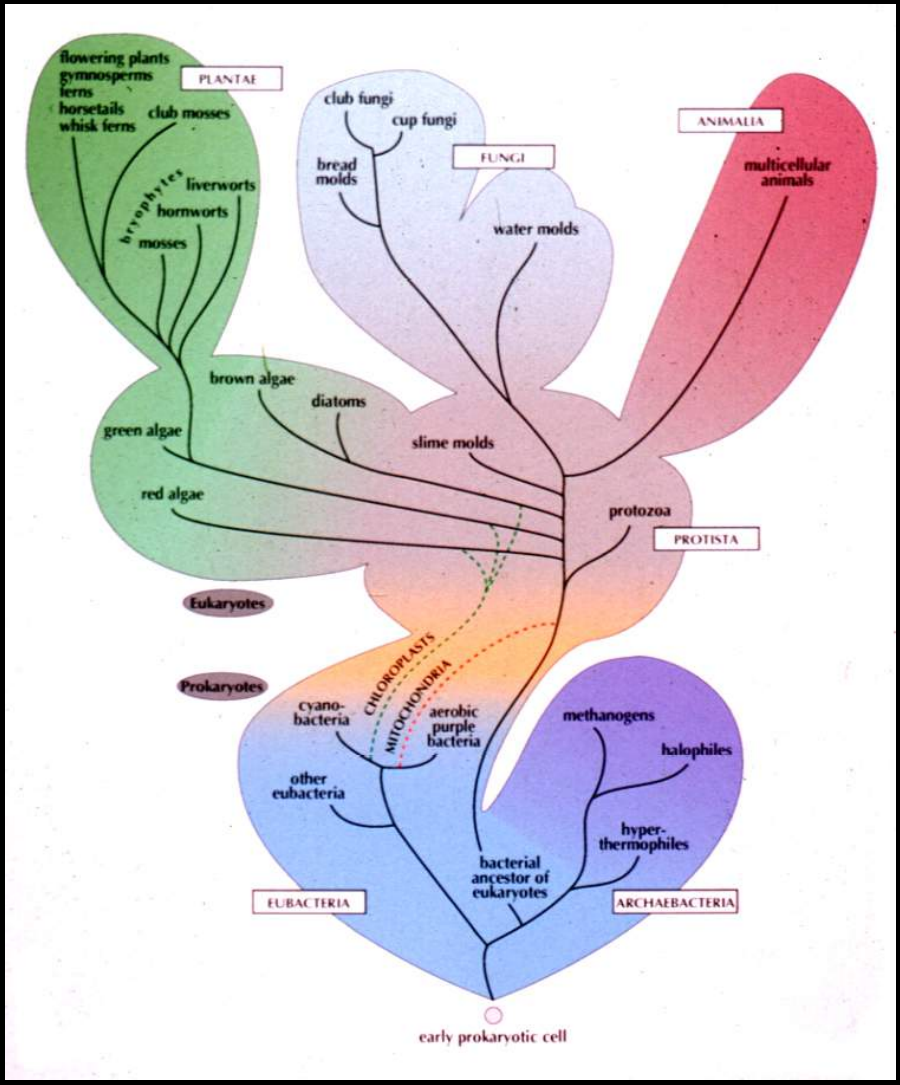
Phylogenetic Ecology

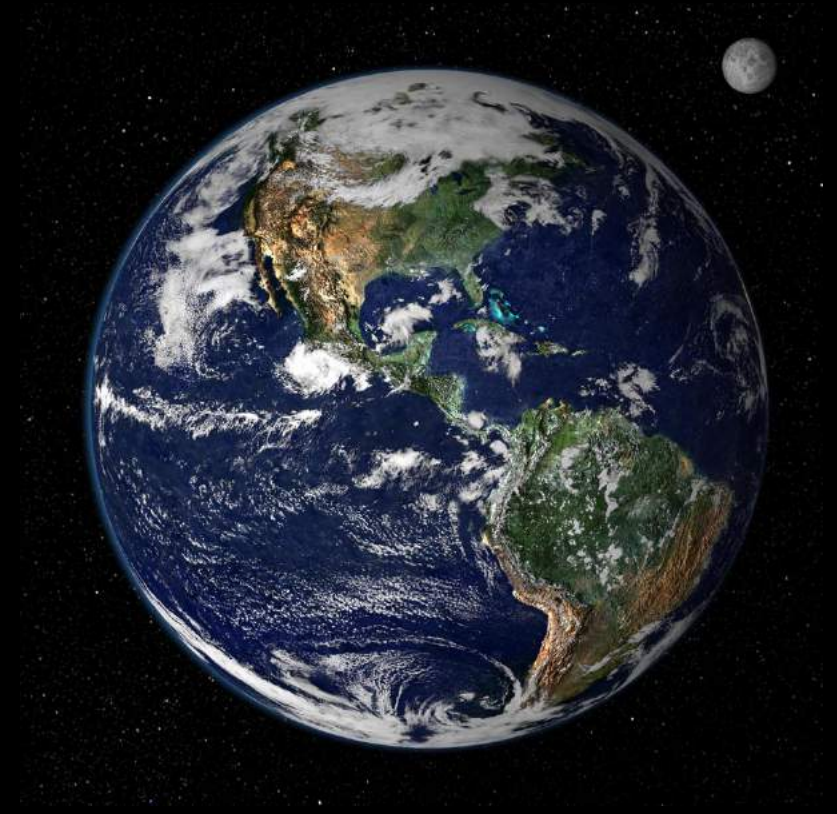
1. Genomics
2. Biogeography
3. Ecology



Ecology and phylogenetics intertwined when looking at the **emergence of life forms** on earth and their subsequent diversification

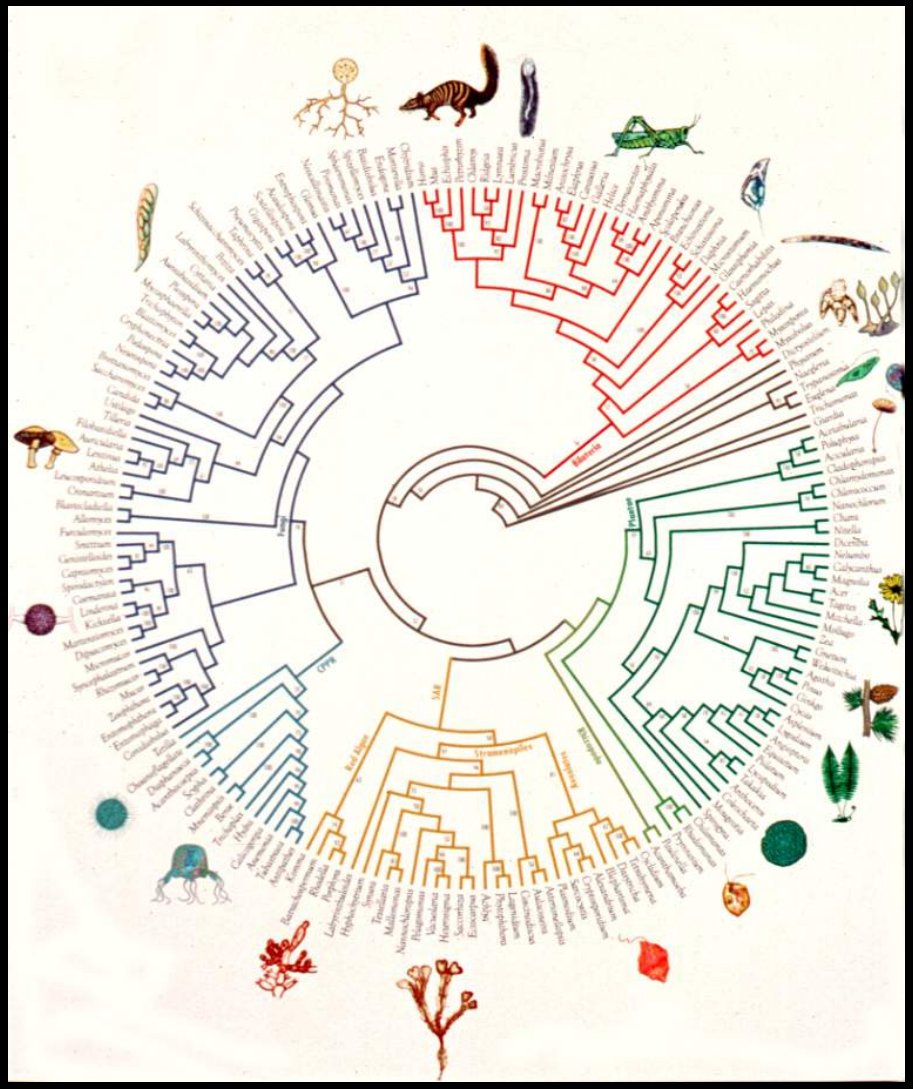
Emergence of Life Forms





- emergence of 3 domains of life with 6+ kingdoms

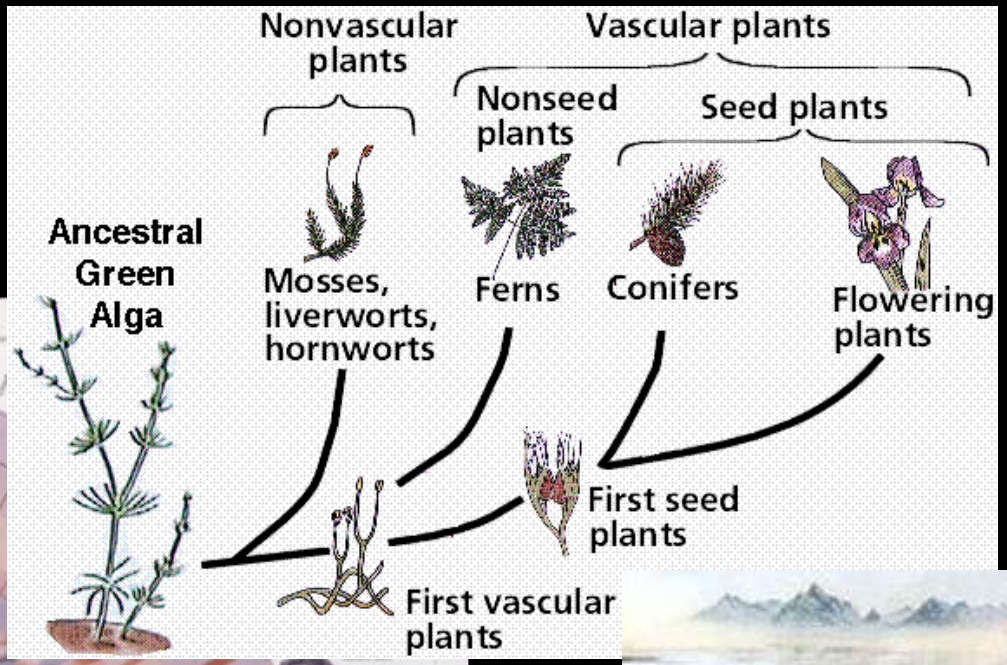
Emergence of Life Forms

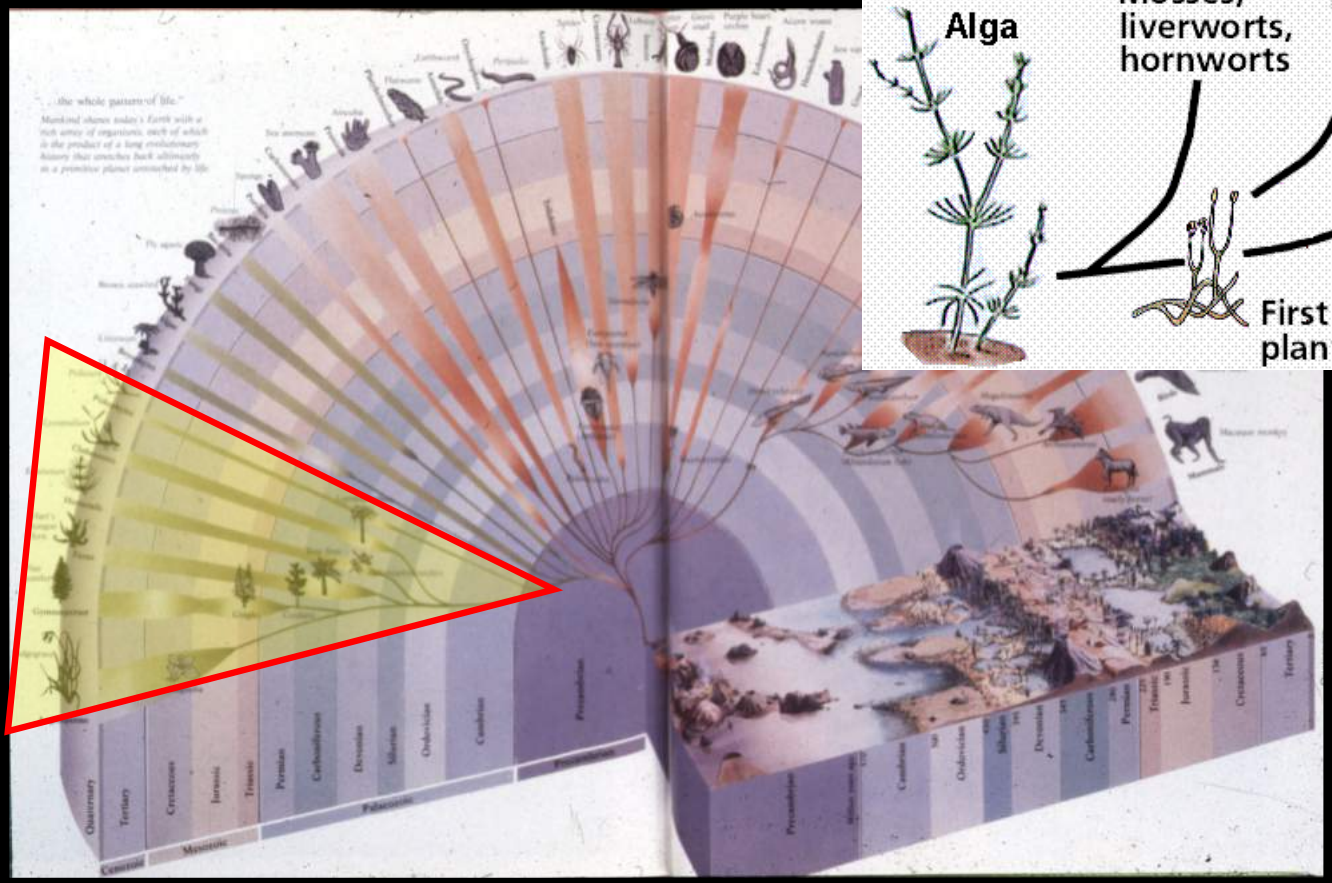


- rise of major lineages of eukaryota - many of which we do not yet know how related

Emergence of Life Forms

- movement of plants onto land and their subsequent diversification



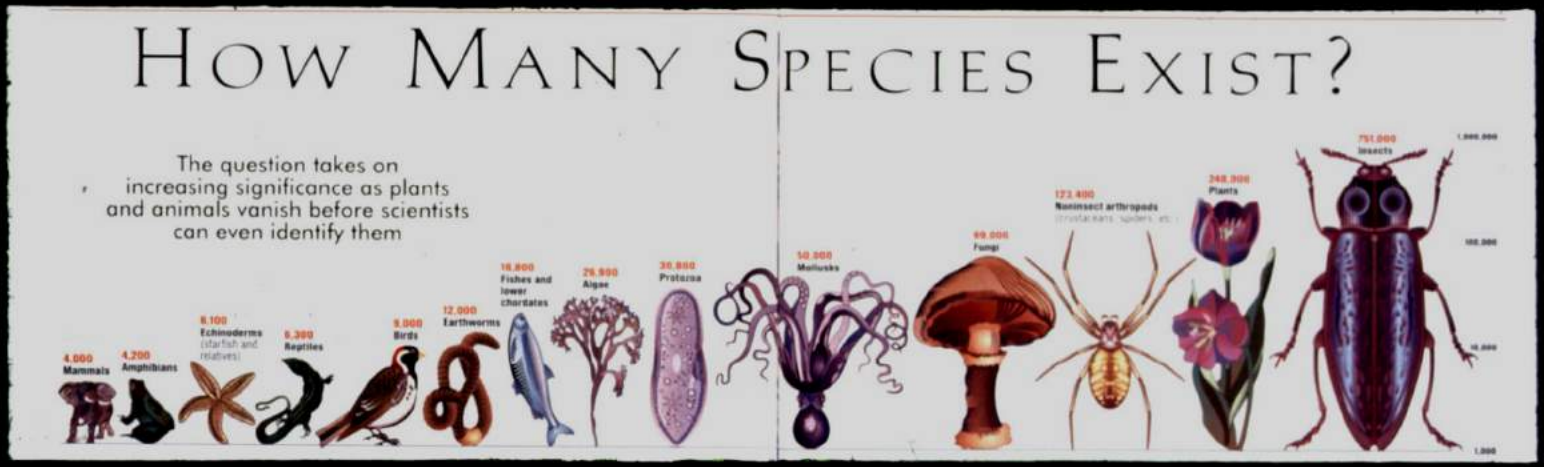


Ordovician-Devonian

Emergence of Life Forms

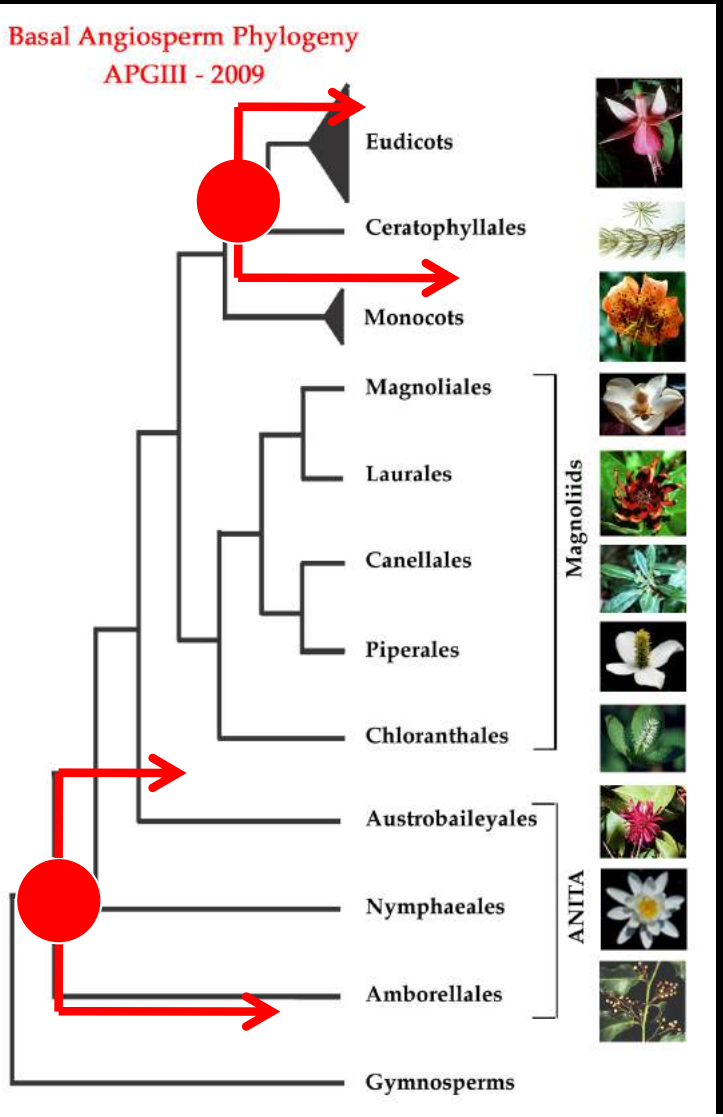



- and finally the rise and domination of flowering plants



Variation in Lineage Diversity

Variation in lineage diversity relates to the appearance of unequal numbers of species in sister lineages – unequal radiations



ca. 210,000 species — eudicots

vs.

5-30 species — coon's tails

What "causes" these imbalances despite same amount of time to radiate?

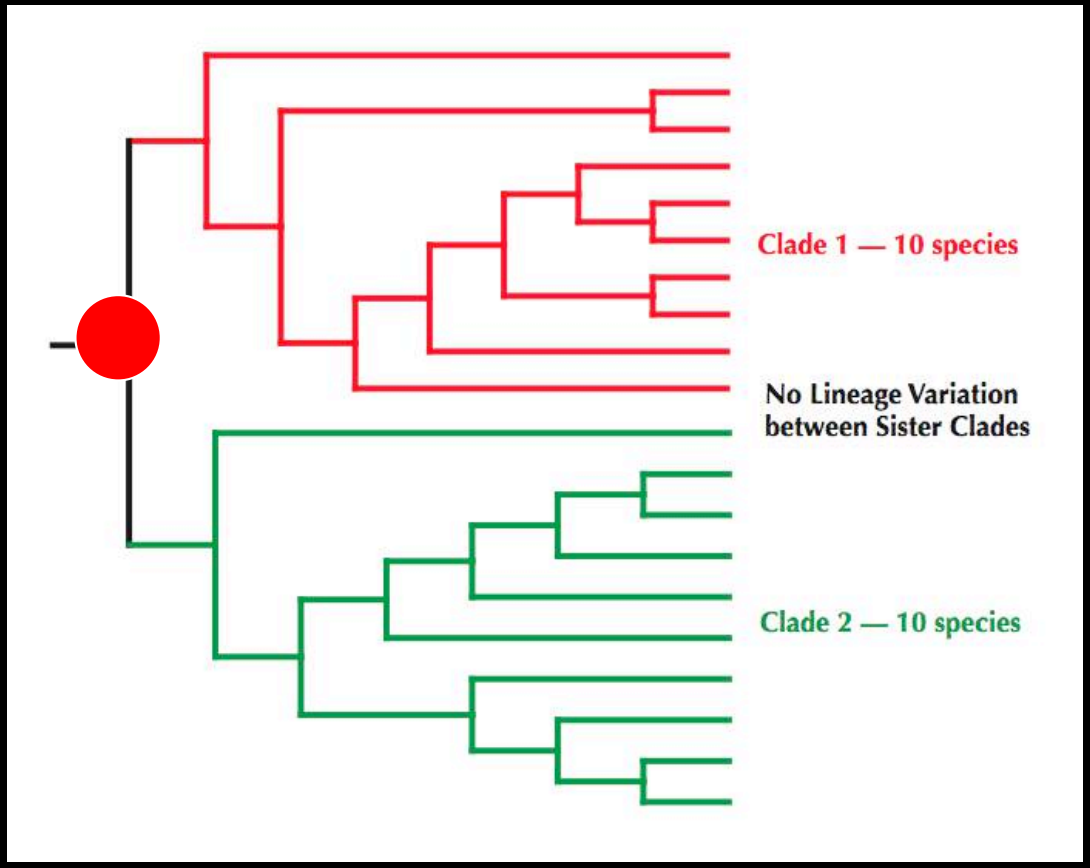
ca. 300,000 species — all flowering plants

vs.

1 species — Amborella

Variation in Lineage Diversity

Variation in lineage diversity relates to the appearance of unequal numbers of species in sister lineages

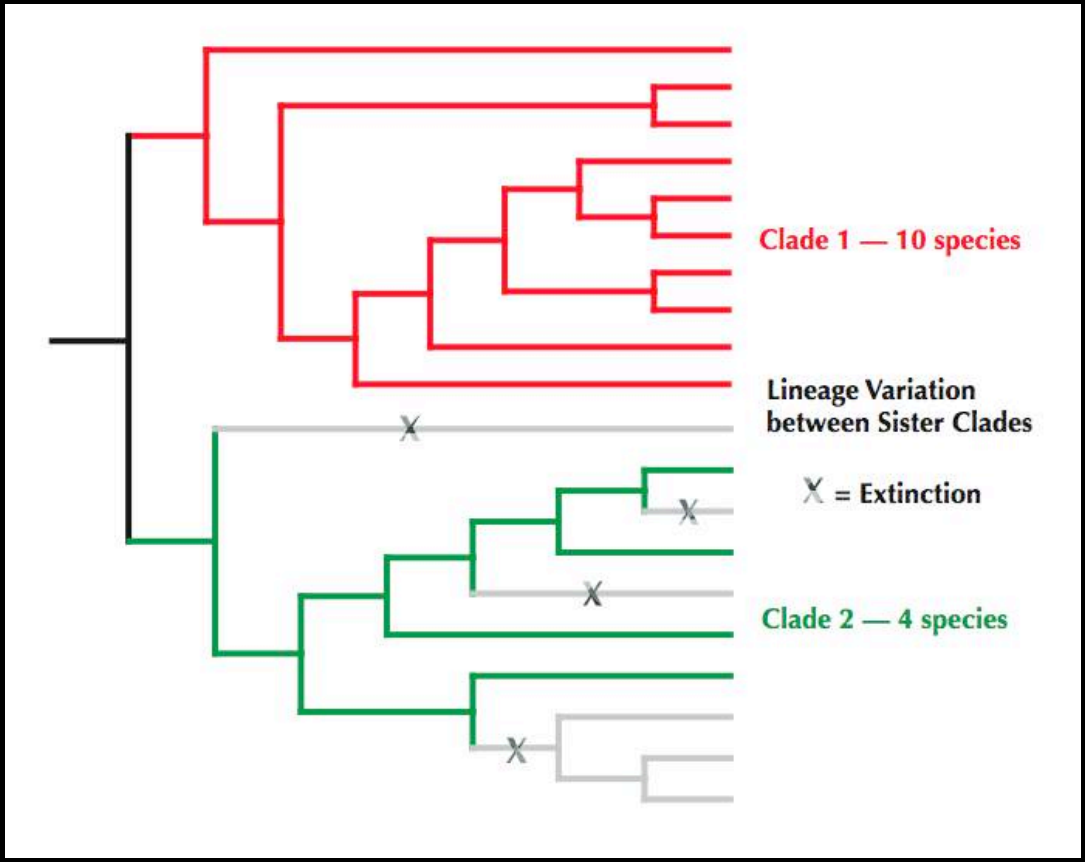


Expectation is that sister lineages should show roughly equal numbers of species - as they are equal in age

What are the exceptions?

Variation in Lineage Diversity

Variation in lineage diversity relates to the appearance of unequal numbers of species in sister lineages



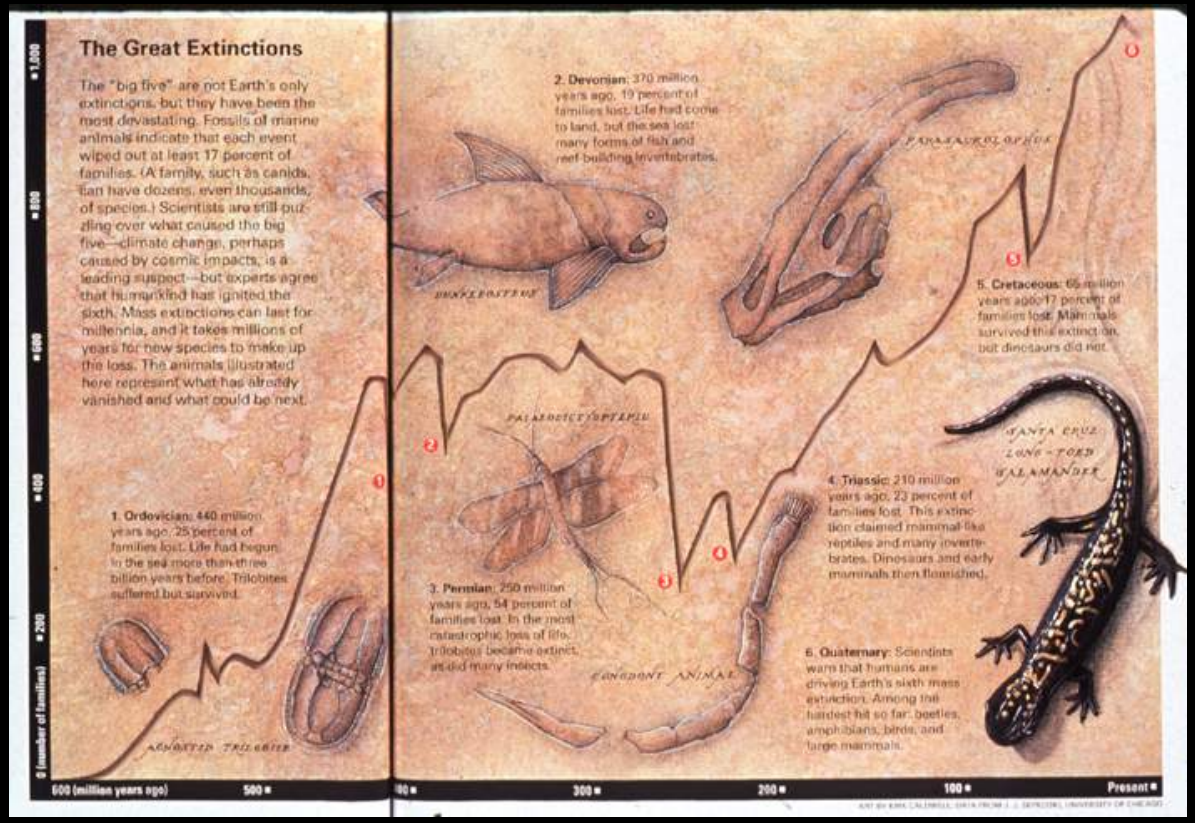
1. Differential extinction

One lineage (clade 1) is more diverse simply because the other was maladapted perhaps to a changing environment

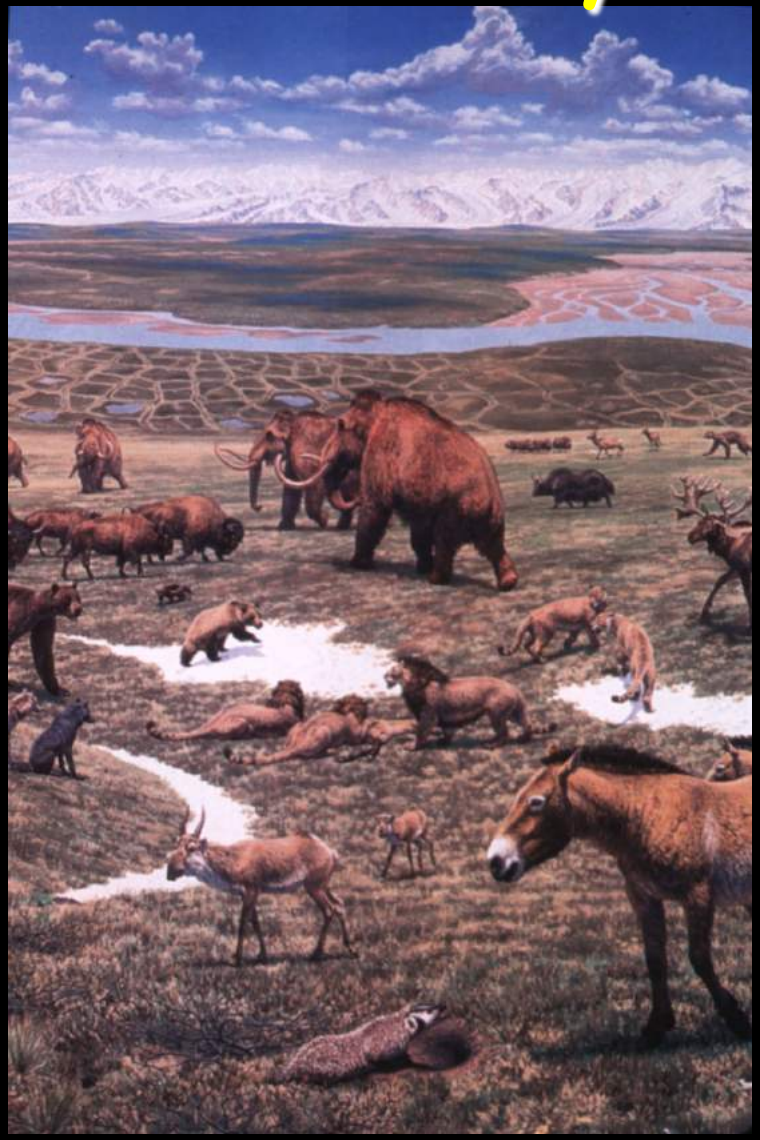
Variation in Lineage Diversity

Differential extinction is well known in the fossil record:

6 great extinction events



Pleistocene megafauna



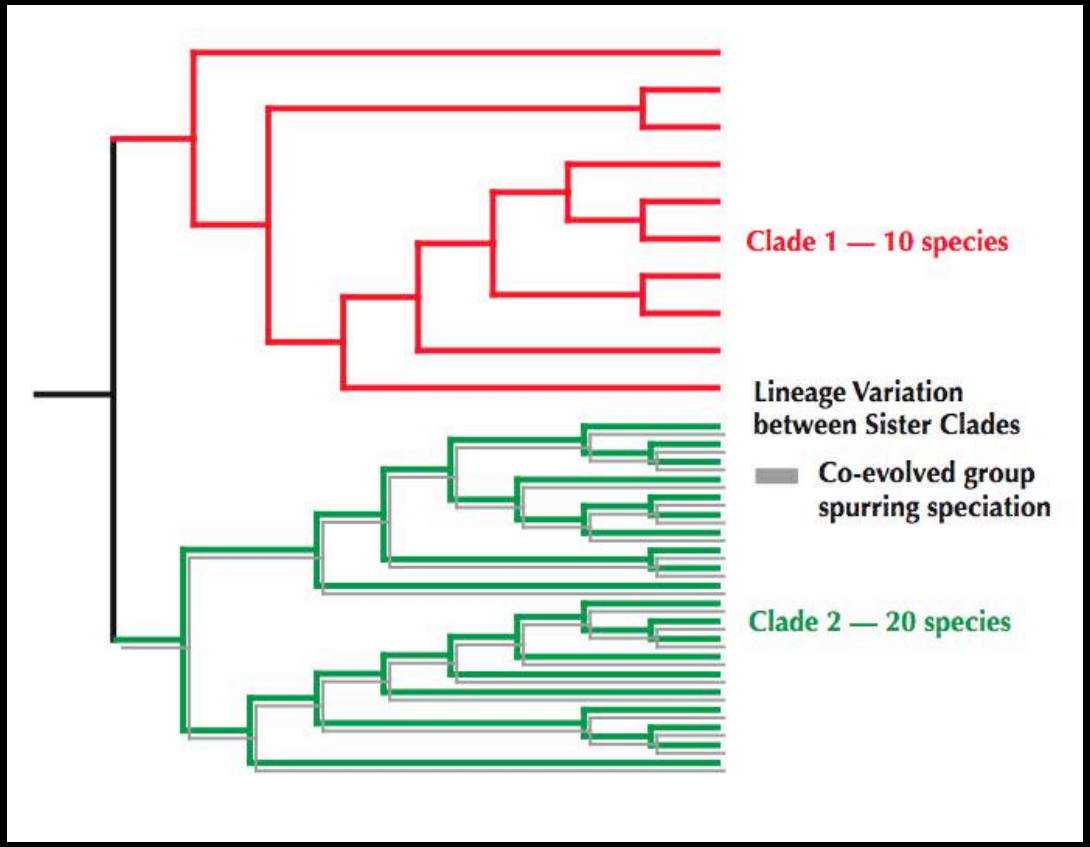
Variation in Lineage Diversity

Differential extinction is well known in the fossil record:

Diverse lycopods & horsetails in Carboniferous

Variation in Lineage Diversity

Variation in lineage diversity relates to the appearance of unequal numbers of species in sister lineages



2. Coevolution

One lineage (clade 2) is more diverse because of the ability to co-evolve with other organisms

Variation in Lineage Diversity

Flowering plants show remarkable ability to co-evolve with other organisms: **Pollination**

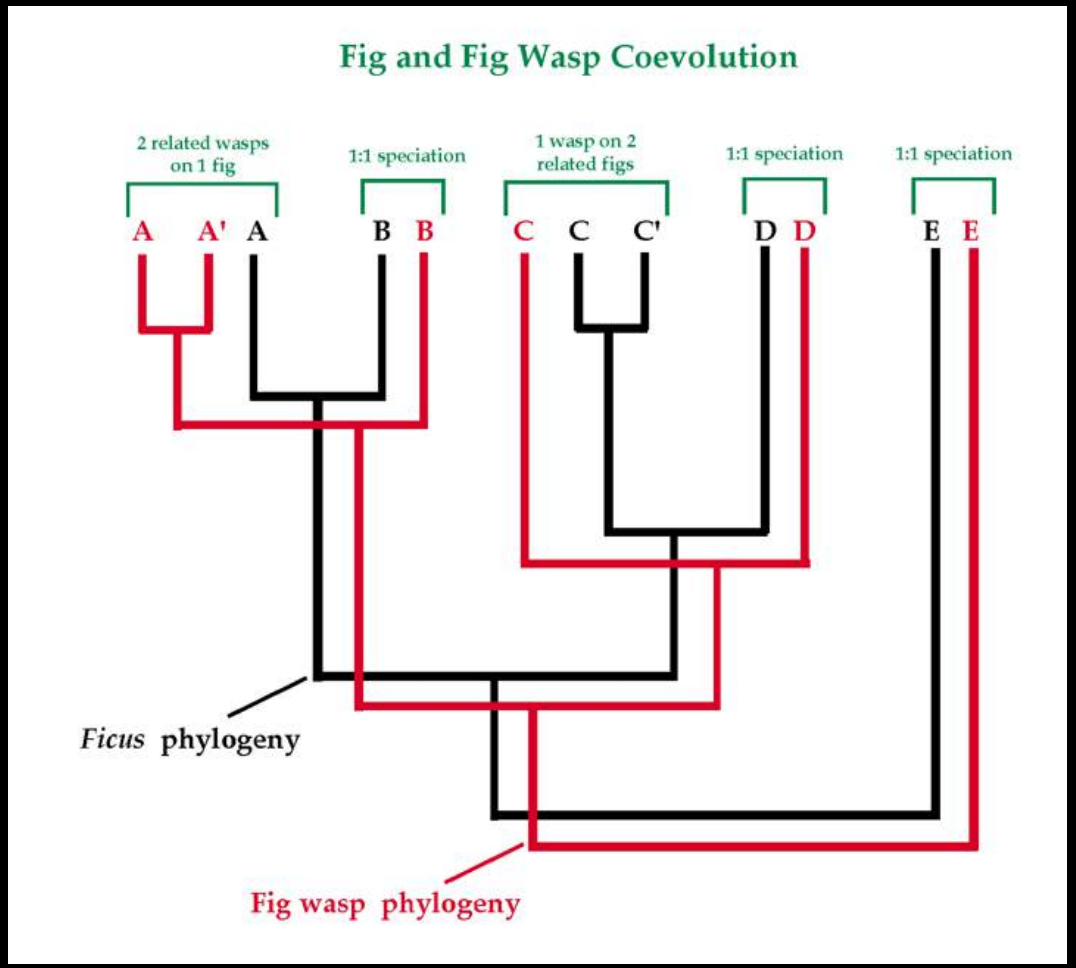
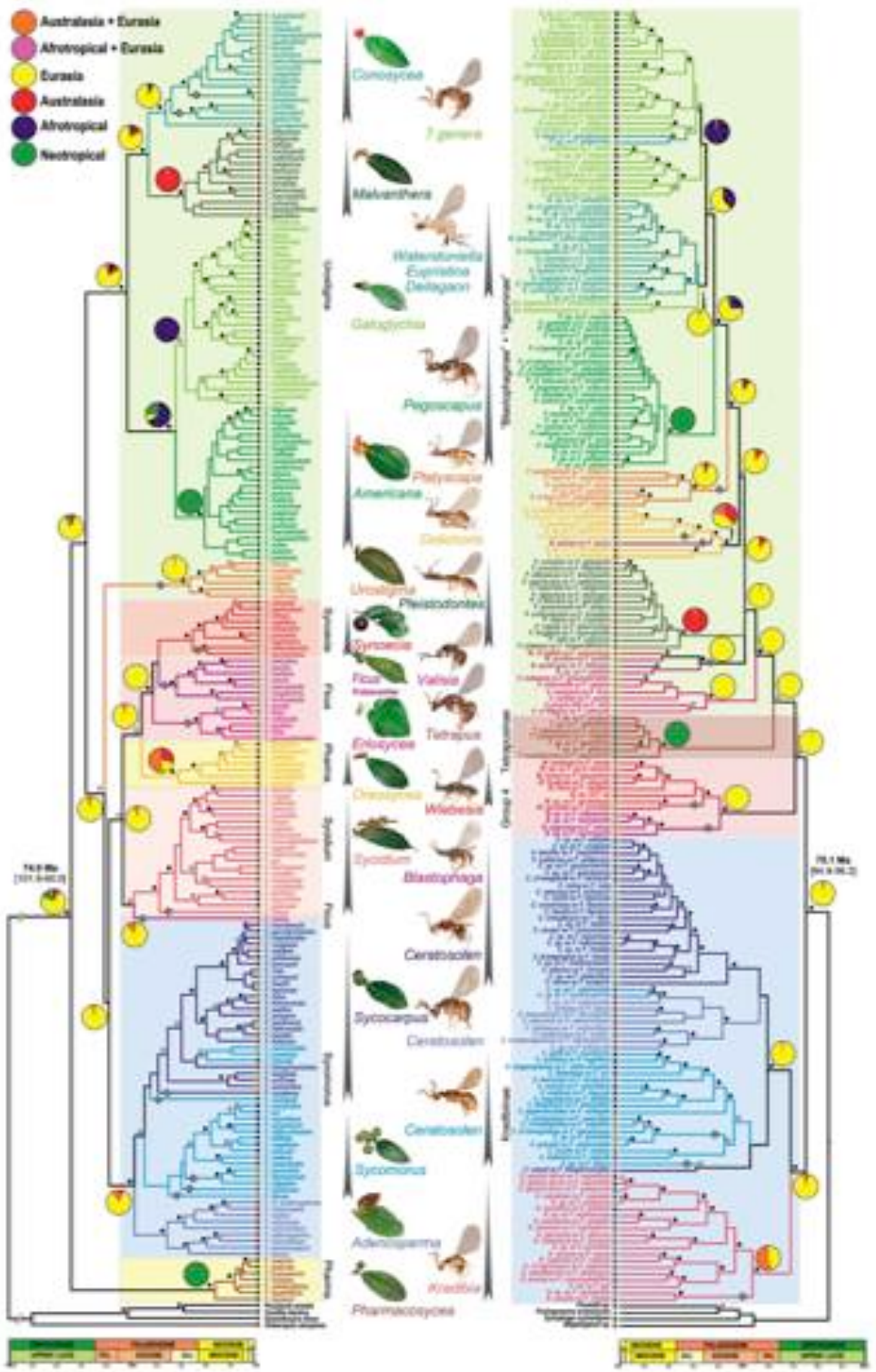


Fig wasps

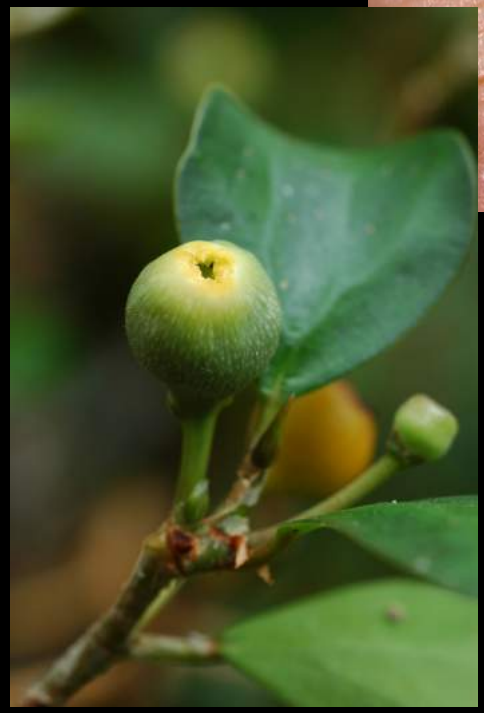
Figs



A 2012 paper showing extreme co-evolution of figs and fig wasps:

Pollination

Fig wasps



Figs

Variation in Lineage Diversity

Flowering plants show remarkable ability to co-evolve with other organisms:

Chemical arm's race

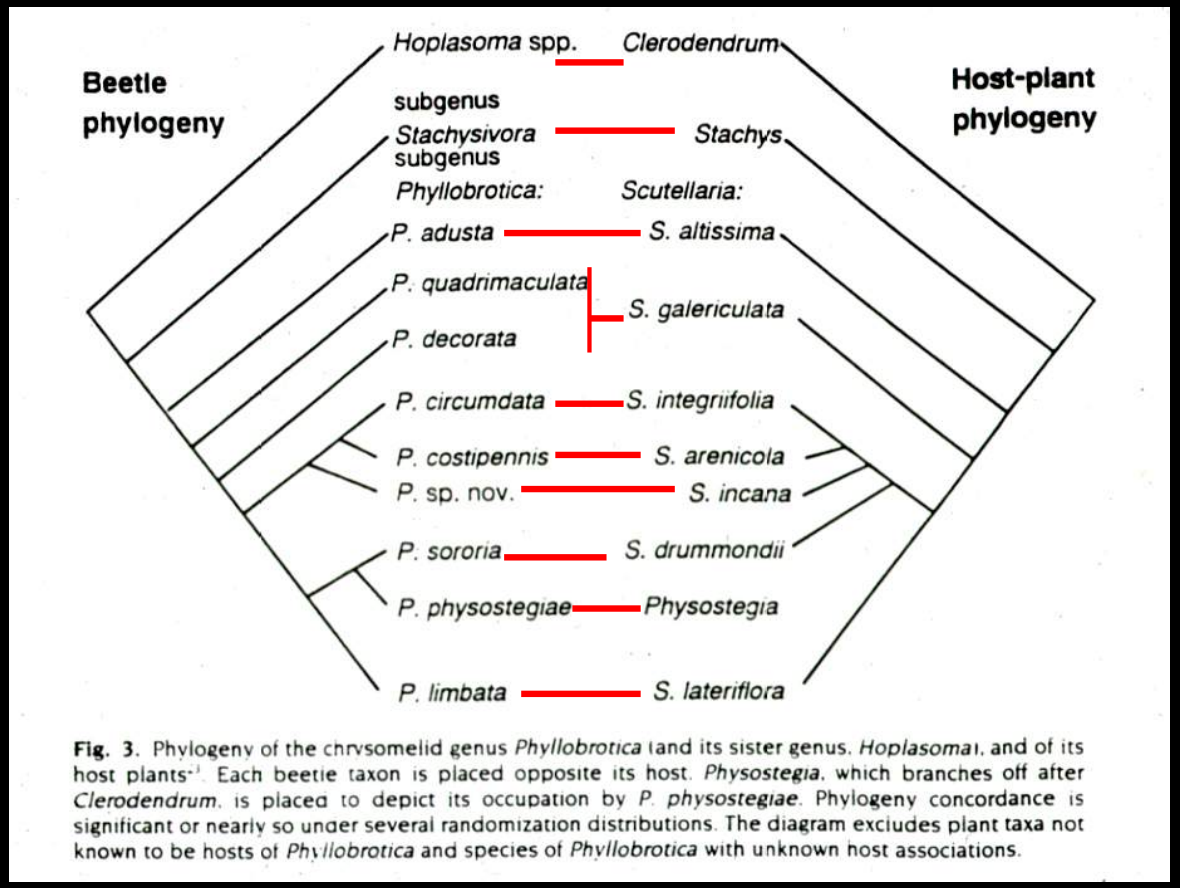


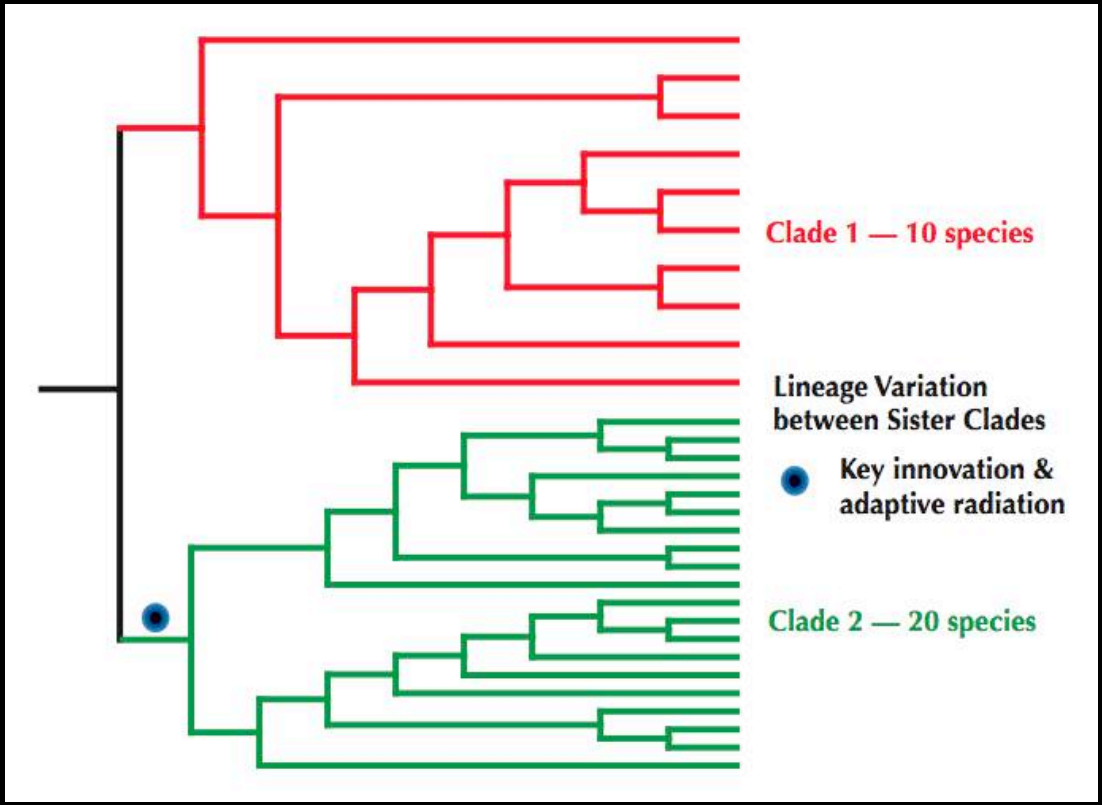
Fig. 3. Phylogeny of the chrysomelid genus *Phyllobrotica* (and its sister genus, *Hoplasoma*), and of its host plants[3]. Each beetle taxon is placed opposite its host. *Physostegia*, which branches off after *Clerodendrum*, is placed to depict its occupation by *P. physostegiae*. Phylogeny concordance is significant or nearly so under several randomization distributions. The diagram excludes plant taxa not known to be hosts of *Phyllobrotica* and species of *Phyllobrotica* with unknown host associations.

Scutellaria

Phyllobrotica

Variation in Lineage Diversity

Variation in lineage diversity relates to the appearance of unequal numbers of species in sister lineages



3. Adaptive radiation

One lineage (clade 2) is more diverse due to combination of species radiation and adaptation into many ecological zones perhaps due to the origin of a novel feature - key innovation

Adaptive Radiations




Emergence of flowering plants has two important facets:

1. Radiation - large number of species resulted
2. Adaptive - exploited incredible array of ecological strategies or niches

Adaptive Radiations

- in 130 my, angiosperms dominate biomes from tropical forests to arctic tundra . . .

Adaptive Radiations

- . . . rainfall gradients from the wettest to the most arid habitats on earth . . .

Adaptive Radiations

- . . . life forms from giant emergent tropical trees to the tiniest aquatic duckweeds . . .

Adaptive Radiations

- . . . and exploited reproductive biology in elaborate outcrossing and seed dispersal methods to forgoing sex altogether via apomixis and parthenogenesis

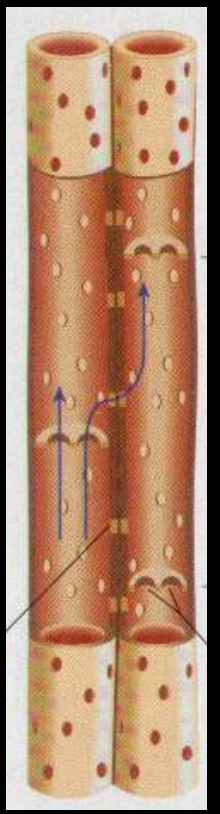
Adaptive Radiations

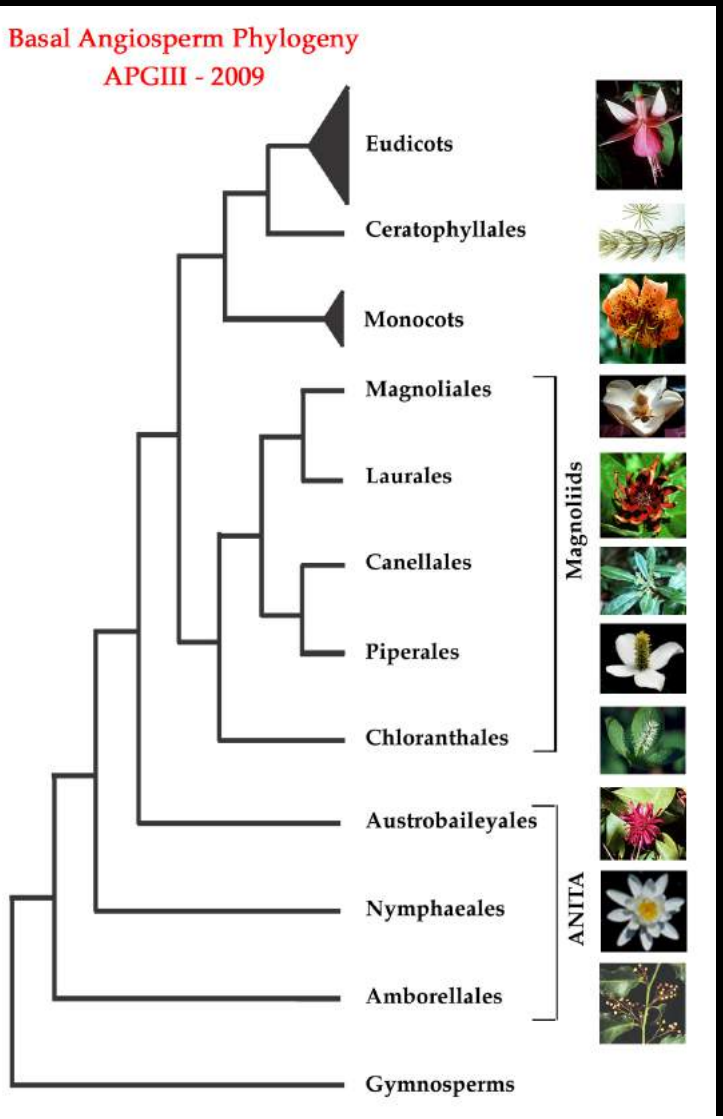
- Angiosperms show all necessary characteristics of an adaptive radiation

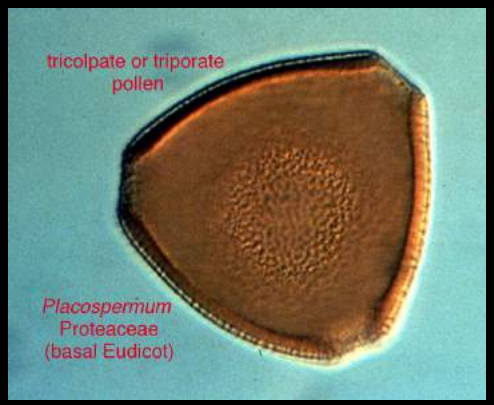
- Key innovation(s) spurring this adaptive radiation?

flowers? triaperturate pollen?

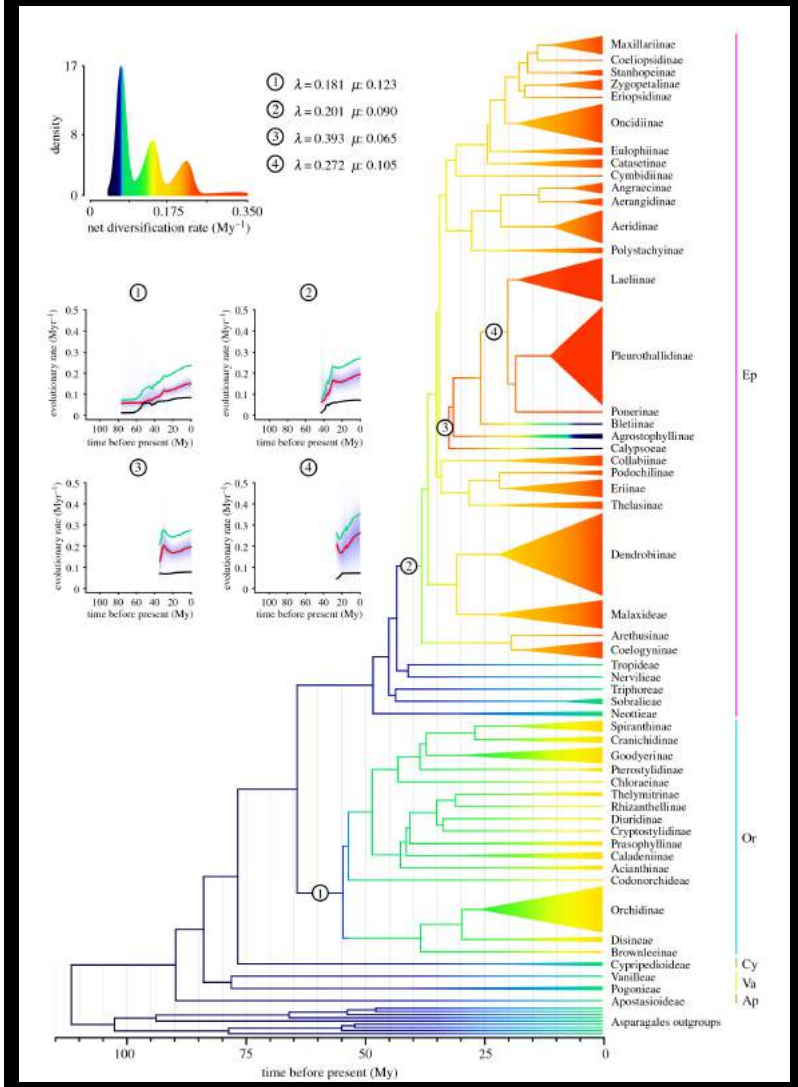
vessels? whole genome duplications?







Adaptive Radiations



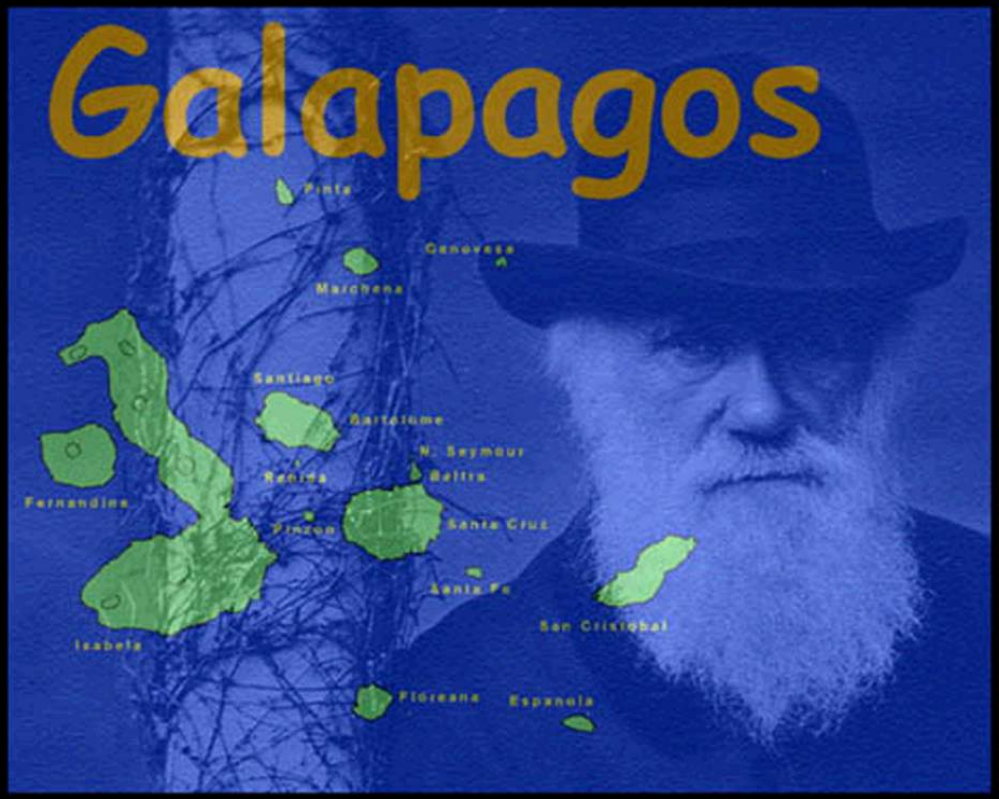
Givnish et al. (2015) – read!

- Orchids show all necessary characteristics of an adaptive radiation

- Key innovation(s) spurring this adaptive radiation?

Adaptive Radiations

a defintion?

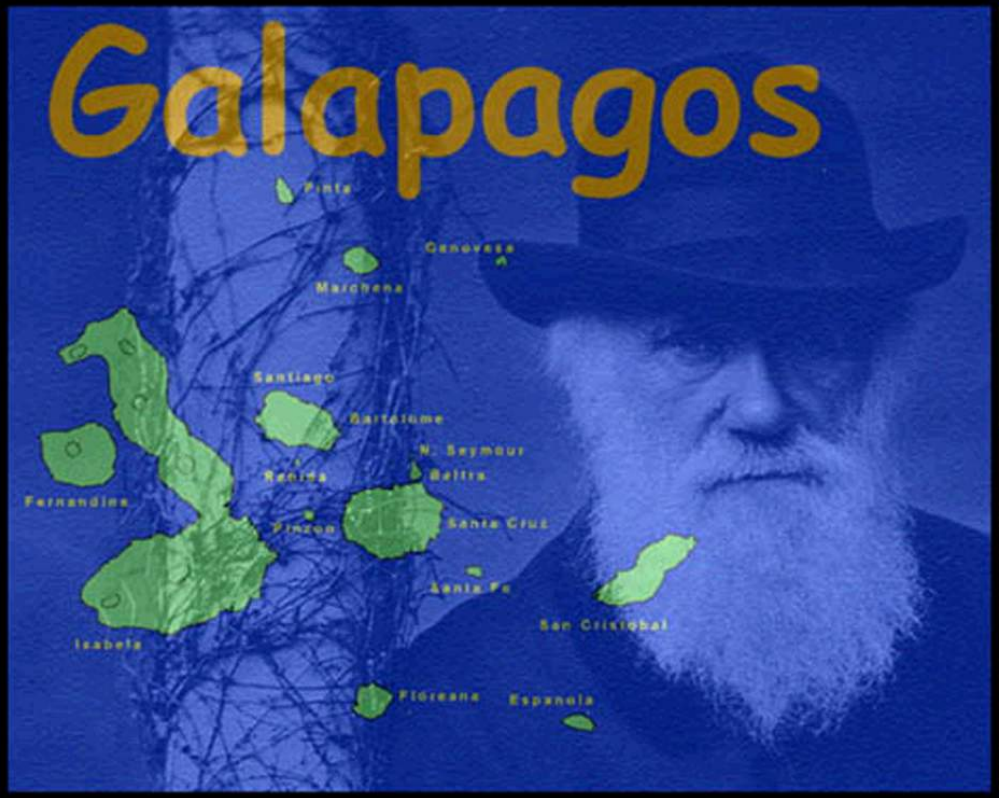


The natural history of these islands is emminently curious and well deserves attention....Both in space and time, we seem to be brought somewhat near to that great fact -- that mystery of mysteries -- the first appearance of new beings on this earth.

Charles R. Darwin

Adaptive Radiations

". . . species occasionally arriving after long intervals in a new and isolated district, and having to compete with new associates, will be eminently liable to modification, and will often produce groups of modified descendants" [Darwin, 1859]



The natural history of these islands is emminently curious and well deserves attention....Both in space and time, we seem to be brought somewhat near to that great fact -- that mystery of mysteries -- the first appearance of new beings on this earth.

Charles R. Darwin

Adaptive Radiations

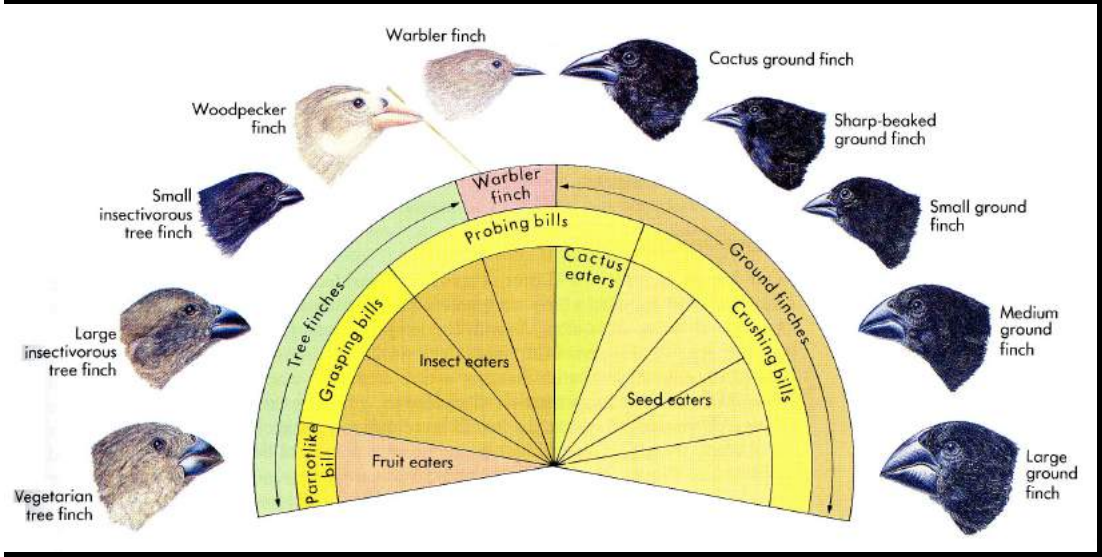
". . . an isolated region, if large and sufficiently varied in its topography, soil, climate and vegetation, will give rise to a diversified fauna according to the *law of adaptive radiation* from primitive and central types. Branches will spring off in all directions to take advantage of every possible opportunity of securing food." [Henry Osborn, 1900]

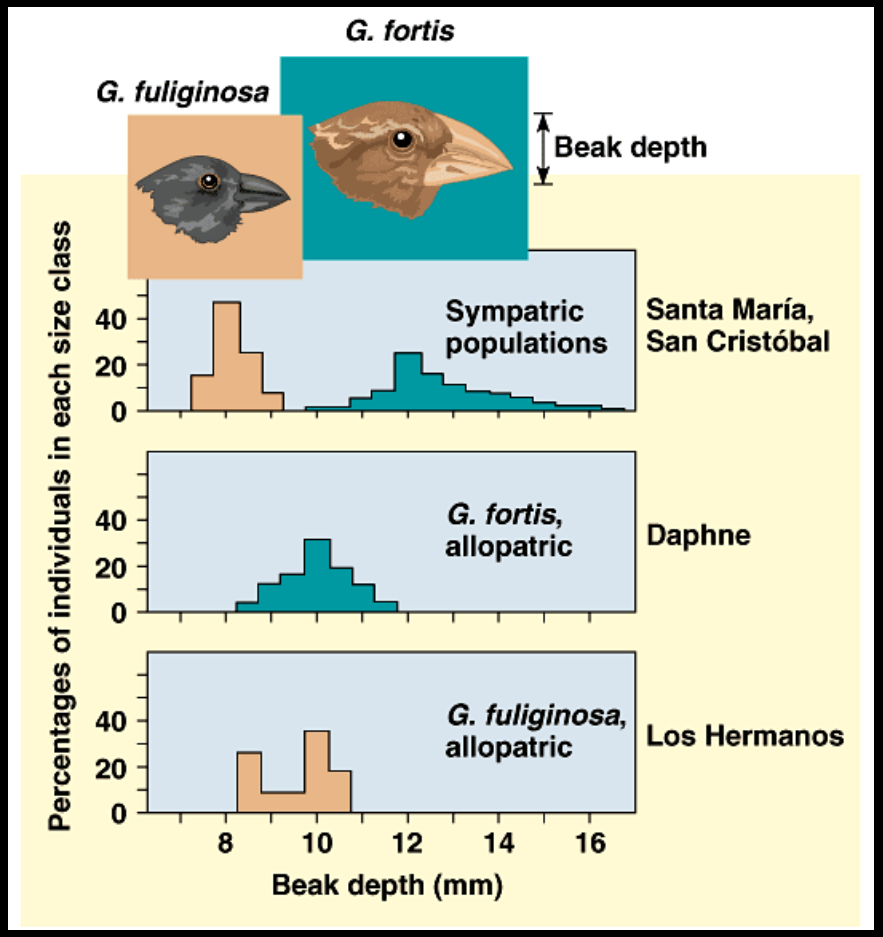
First use of term **adaptive radiation**

Issues in Adaptive Radiations

- It is clear that few of the classic cases of adaptive radiation had been studied rigorously from a combined systematic and ecological point of view

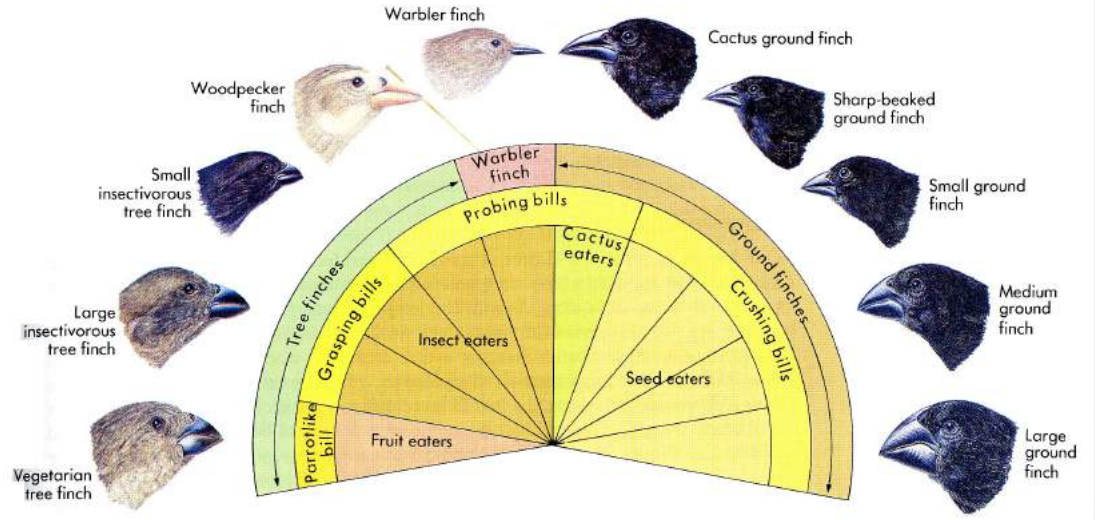
Two main issues:

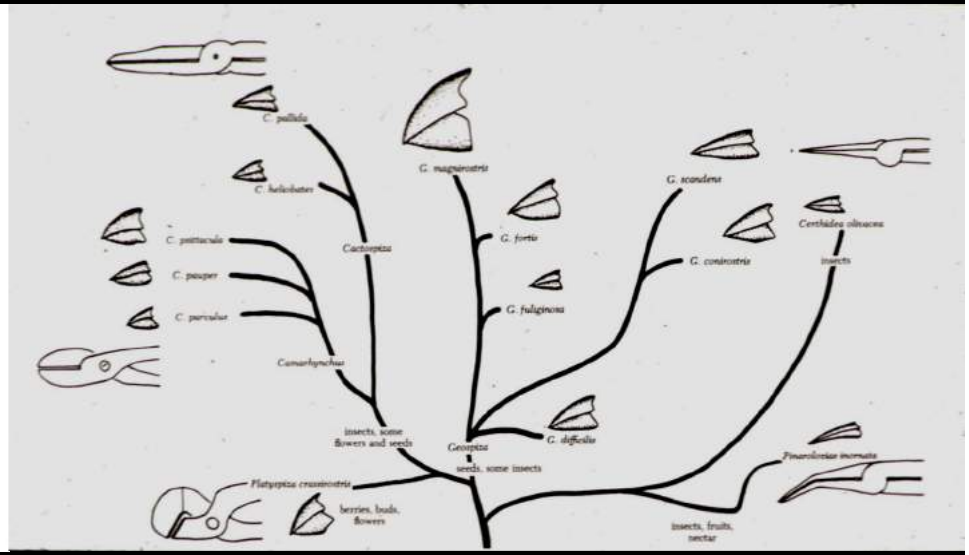




Issues in Adaptive Radiations

1. The very characters whose diversification is being examined (e.g. beak size, shape, function in Darwin's finches), also were used to determine relationships of and classify the organisms possessing them - potentially circular!





Issues in Adaptive Radiations

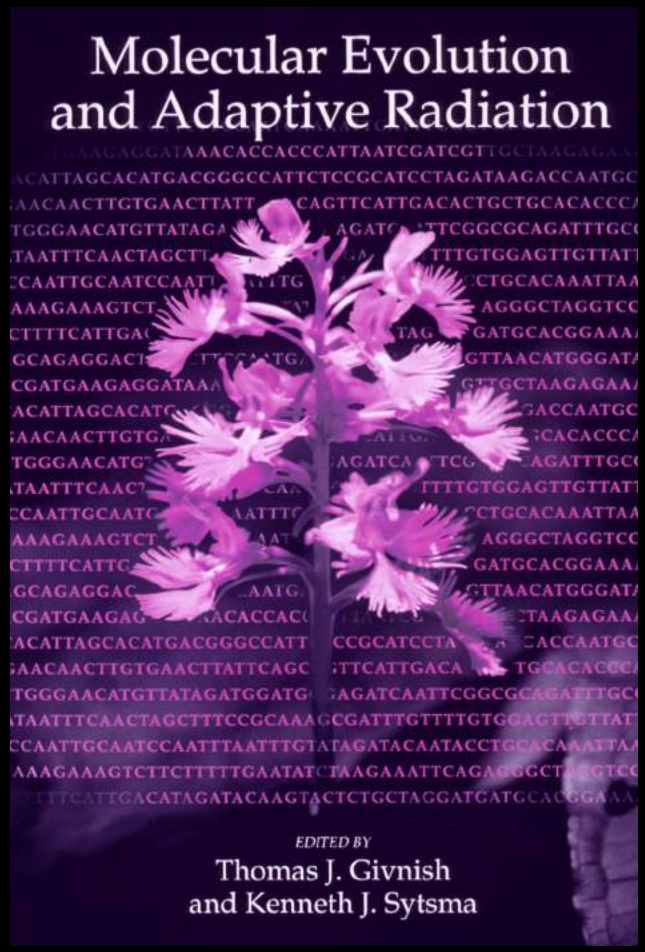
2. Extreme convergence and divergence is likely in groups that are undergoing adaptive radiations

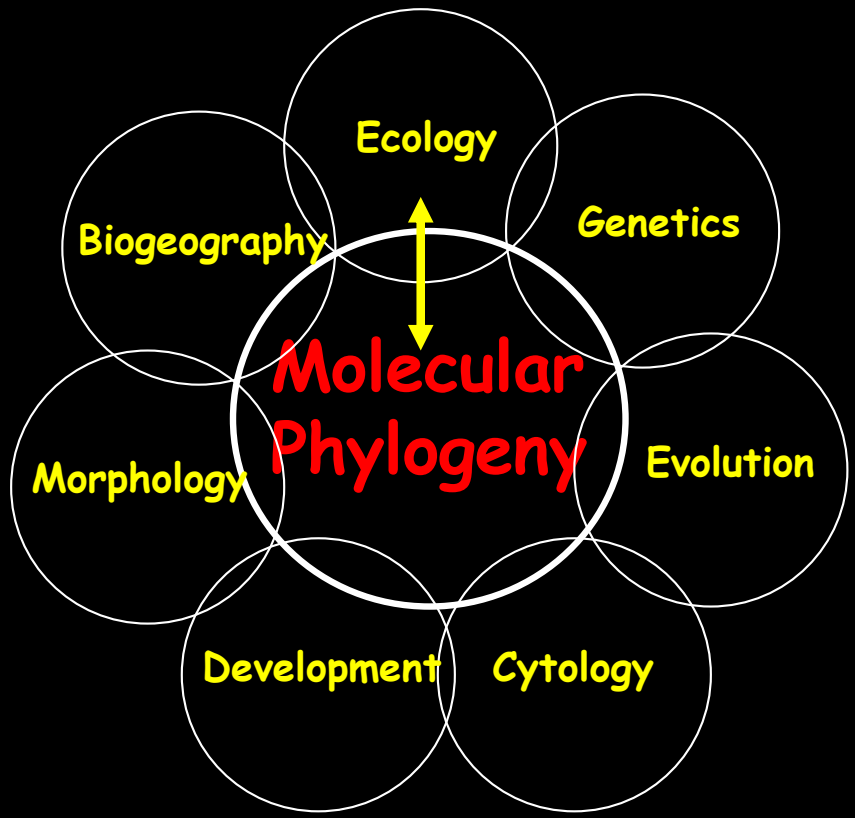
Divergence: changes in homologous structures **among related species**; changes permit each species to specialize in different environments

Convergence: changes in analogous structures **among unrelated species**; changes permit each species to specialize in the same environment

Issues in Adaptive Radiations

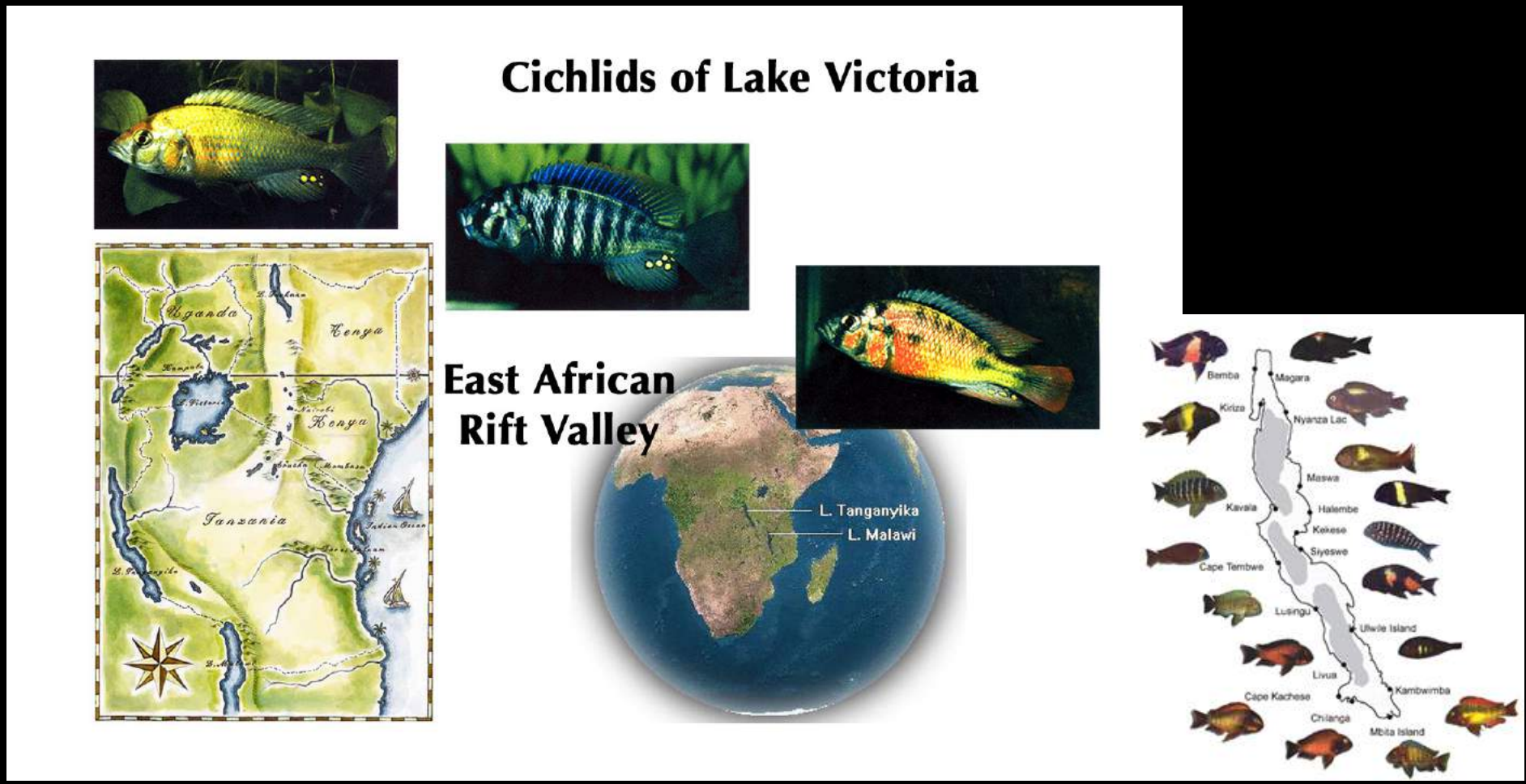
These two issues in studying adaptive radiations are best addressed by using an **independent source of information** - molecular phylogenetic characters





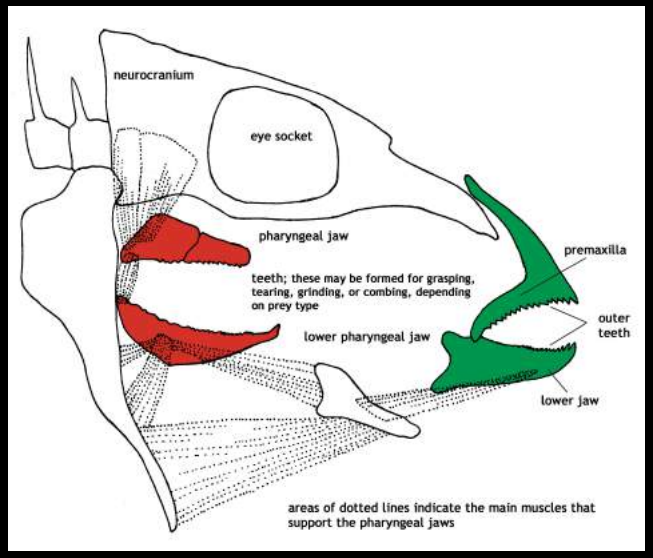
Adaptive Radiations

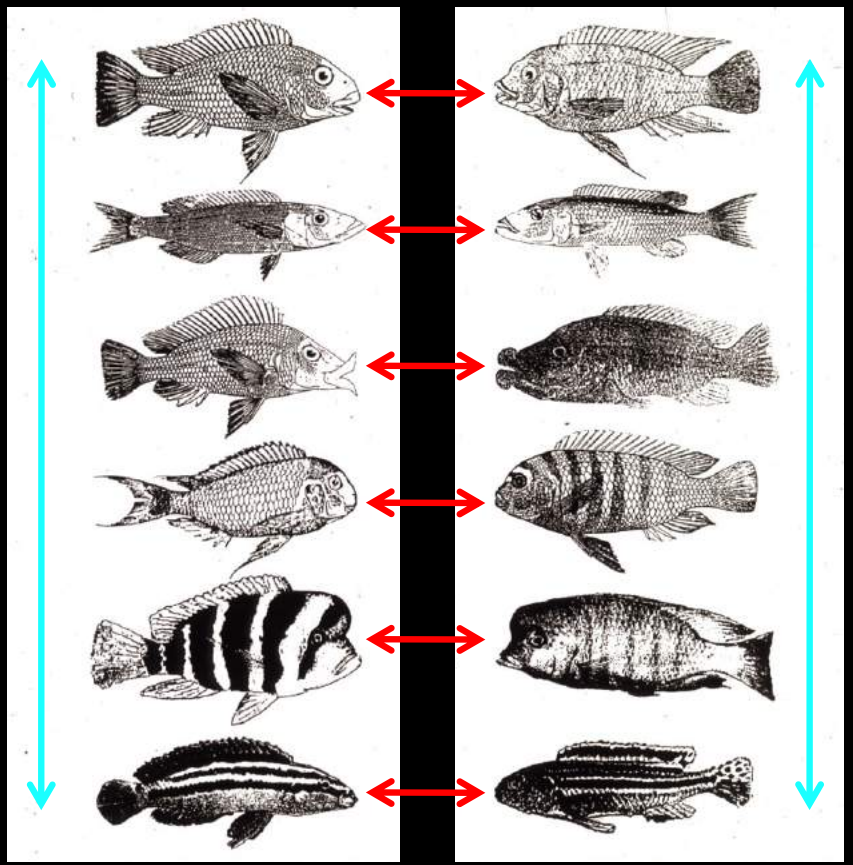
Illustration of these problems with 2 examples of adaptive radiation – African cichlid fishes and Hawaiian lobeliads



Rift Valley Cichlids

Cichlids possess a double jaw system, the **pharyngeal jaw** is thought to be a **key innovation** for species proliferation and divergence in feeding strategies



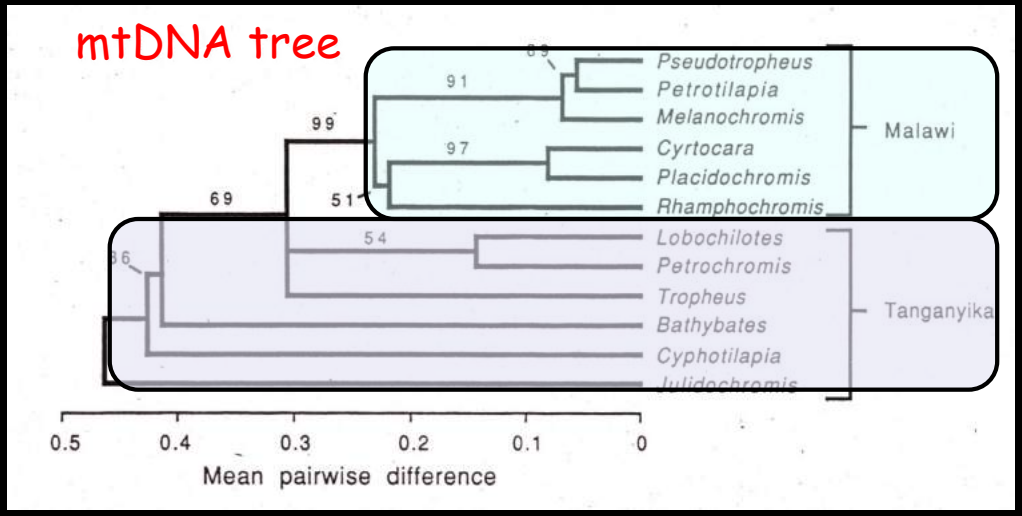


Lake Tanganyika Lake Malawi

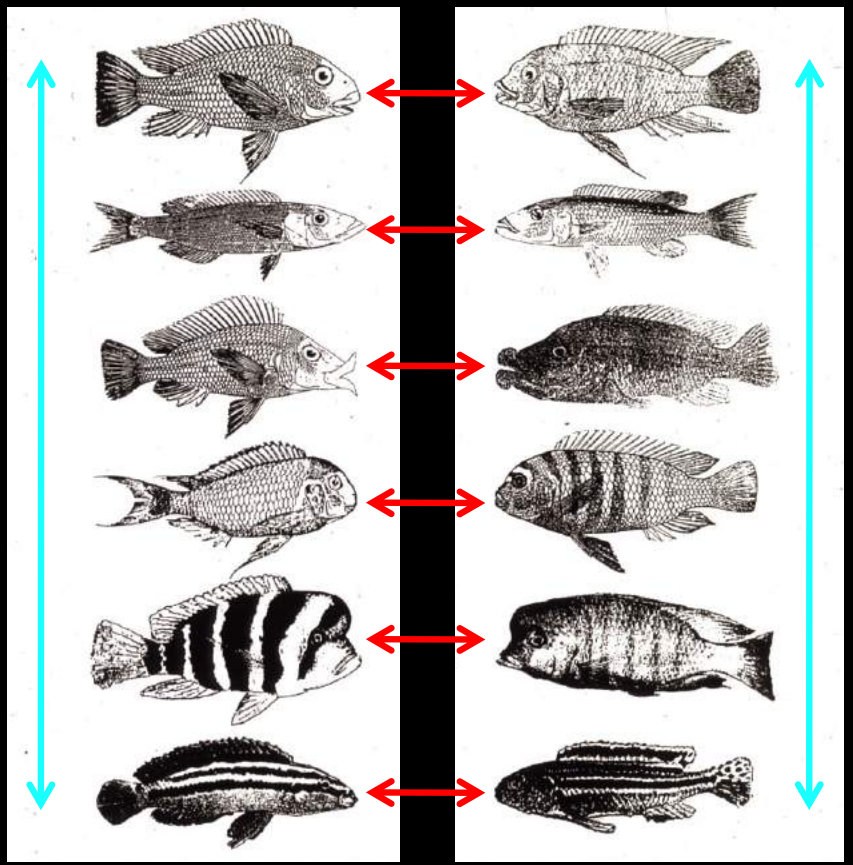
- species with similar feeding strategies between lakes related?
- species showing different feeding strategies within a lake related?

Rift Valley Cichlids

Cichlids possess a double jaw system, the **pharyngeal jaw** is thought to be a key innovation for species proliferation and divergence in feeding strategies



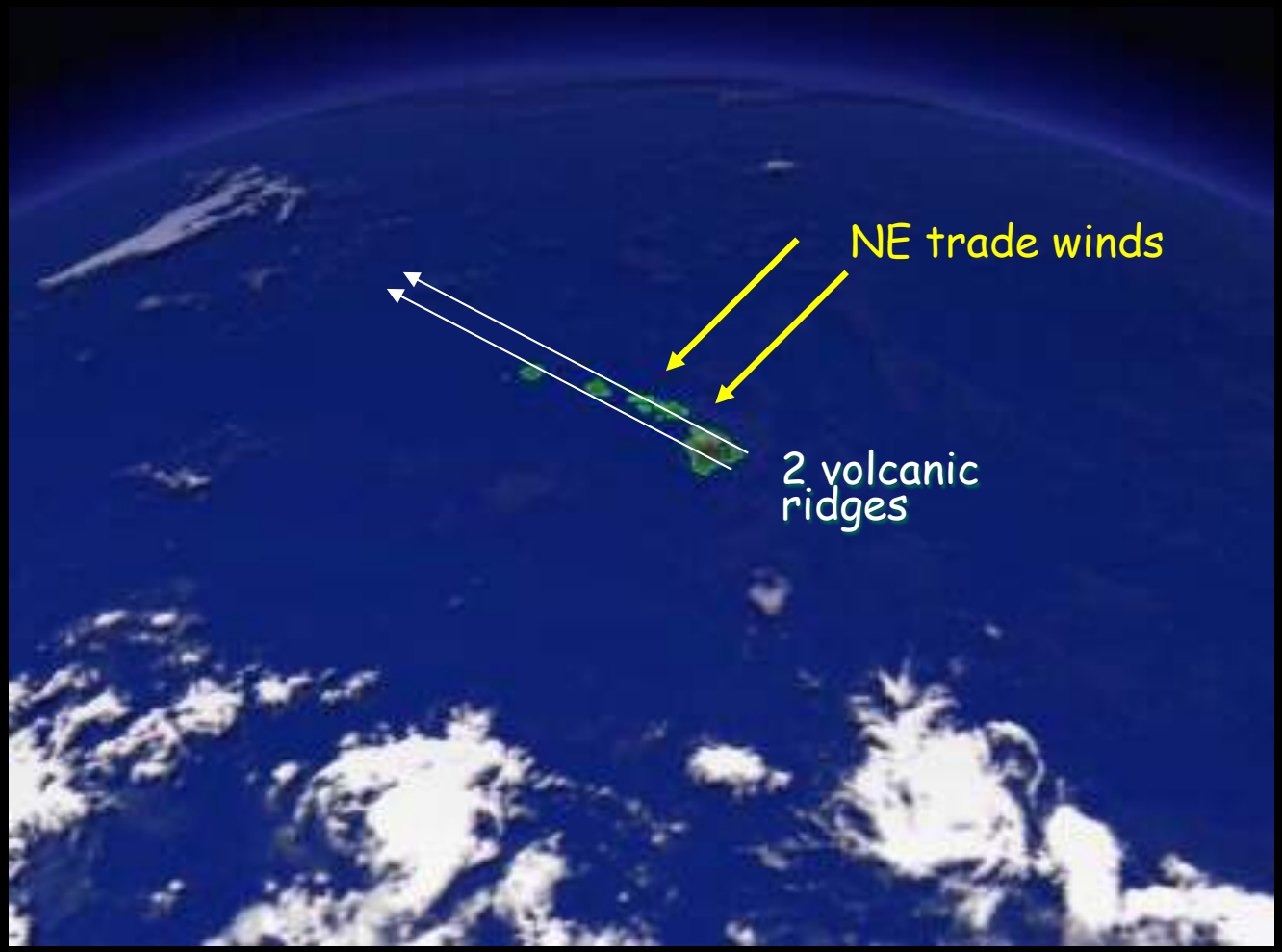
- Species within each lake related!
- divergence within each lake!
- convergence between lakes!



Lake Tanganyika Lake Malawi

Hawaiian Island Radiations

Isolated, oceanic islands provide some of the most classic examples of adaptive radiation



- **isolation** - once you get there, you can't go back
- **great ecological diversity** - many niches to exploit
- **low diversity** - many niches open
- **low competition, predation, herbivory** - you can be different

Hawaiian Island Radiations

Kauai
(5.8 mya)

Oahu
(3.9 mya)

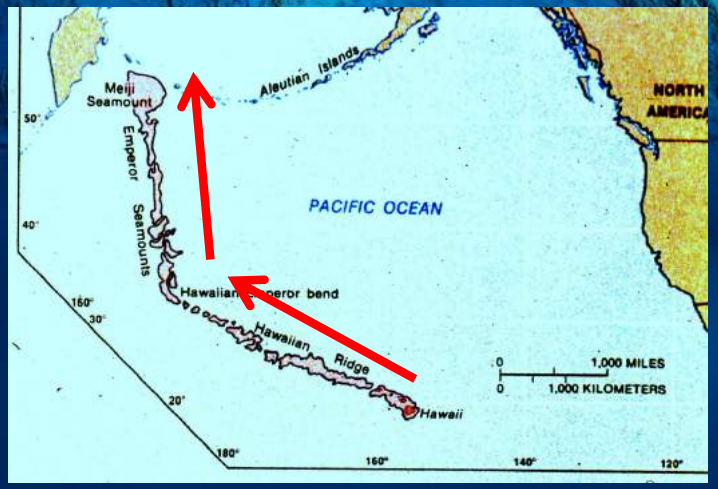
Molokai
(2.1 mya)

Maui Nui
(2.0 mya)

Hawaii
(1.1 mya)

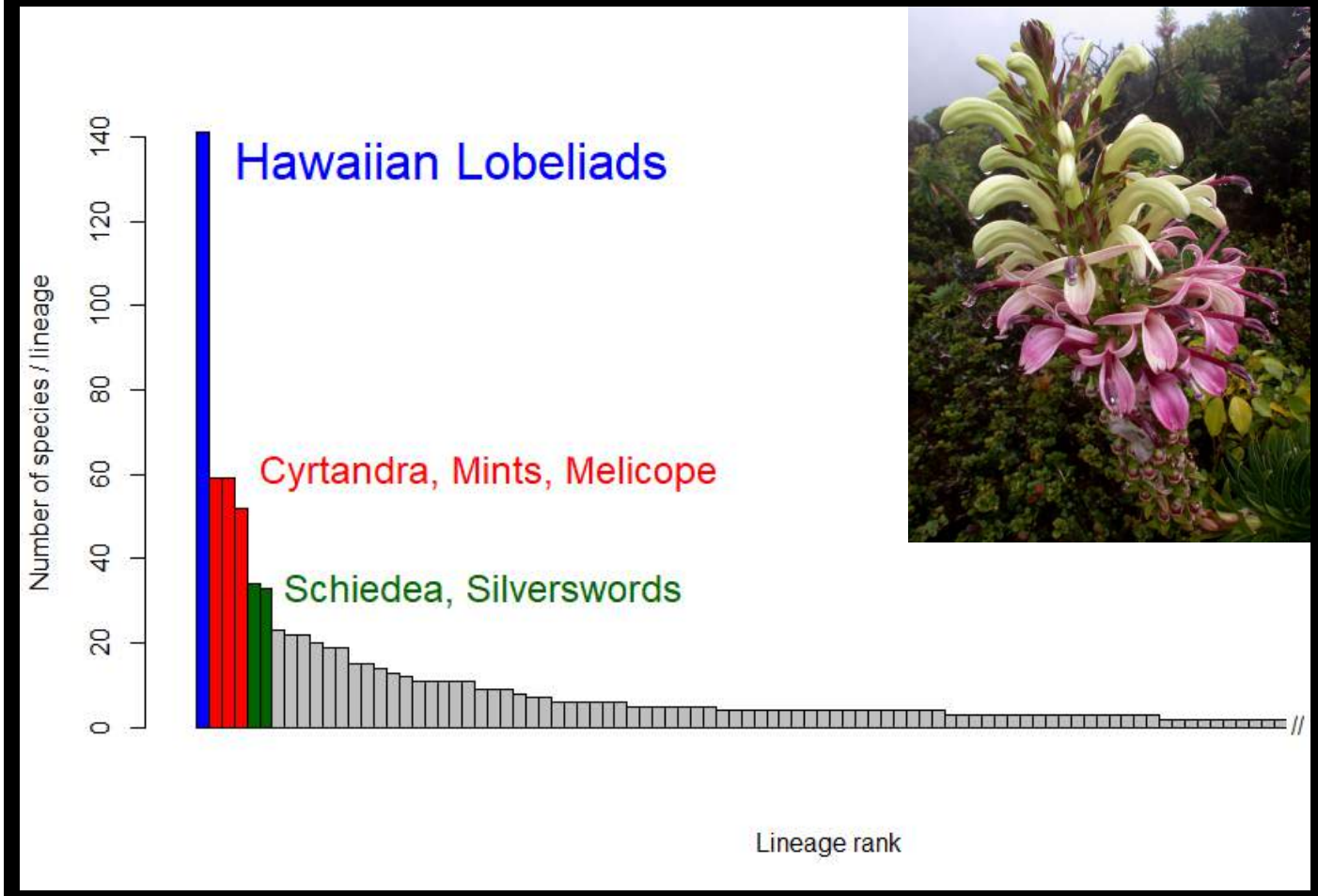
Loihi
(0 mya)

- archipelago is a series of **geologically dated islands**
- fixed **volcanic hotspot** but Pacific plate **conveyor belt**



Hawaiian Lobeliads

Why the Hawaiian lobeliads?



- **largest group**: 6 genera, 140 species
- **1/8th** of native flora

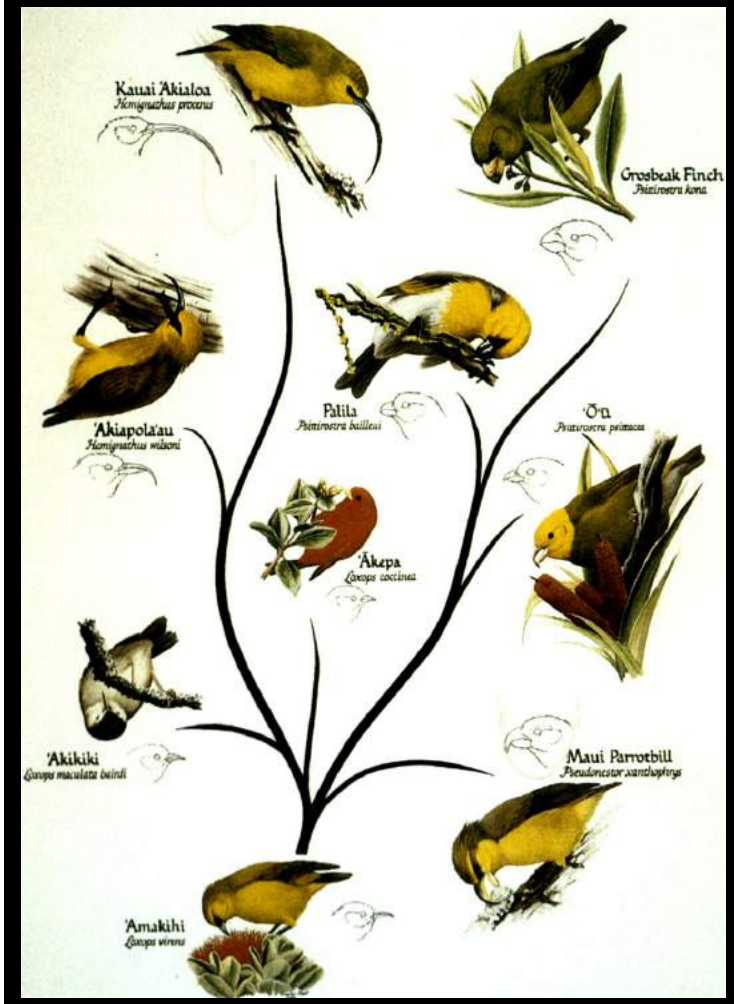
Hawaiian Lobeliads

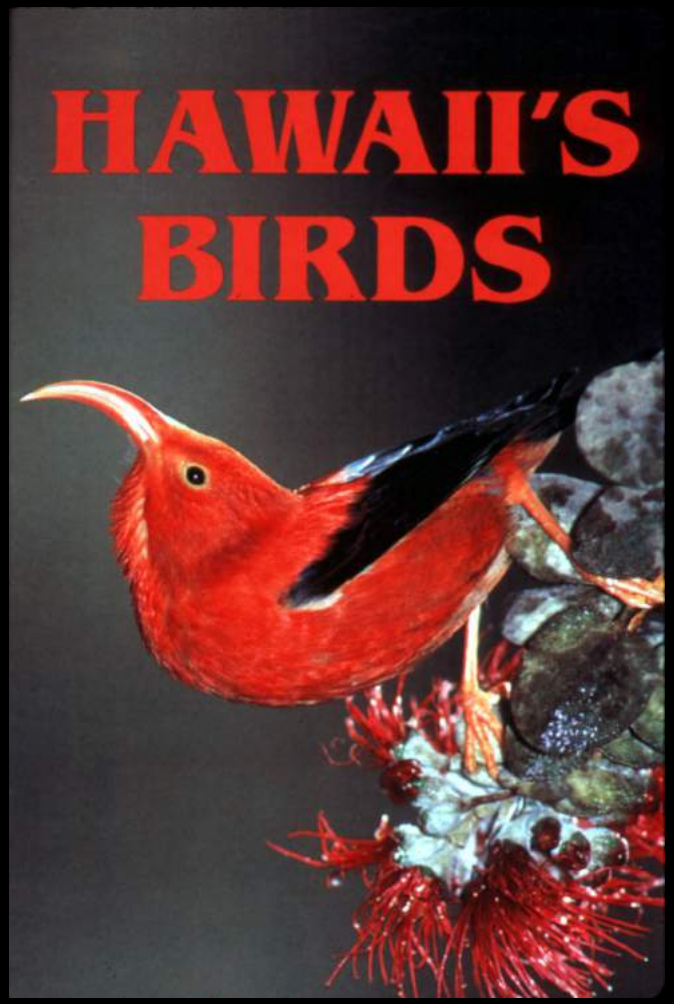
Why the Hawaiian lobeliads?

- **largest group**: 6 genera, 140 species
- **1/8th** of native flora
- **phenomenal variation** in habitat, life form, flowers, and fruits
- considered derived from **3-5 separate colonizations**

Hawaiian Lobeliads

Why the Hawaiian lobeliads?

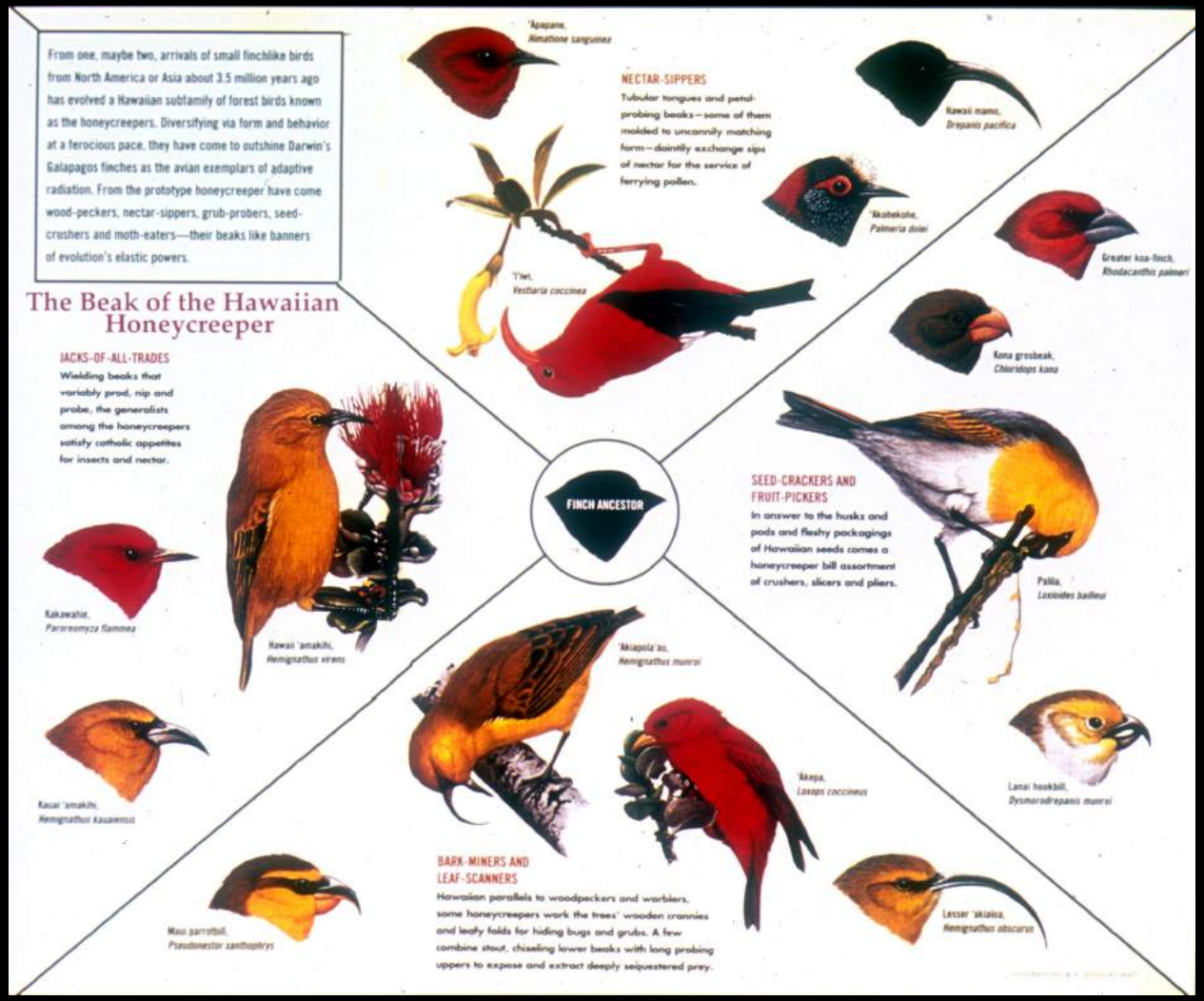




- appear to have co-evolved with the endemic Hawaiian honeycreepers

Hawaiian Lobeliads

Why the Hawaiian lobeliads?



- appear to have co-evolved with the endemic Hawaiian honeycreepers
- honeycreepers represent a separate adaptive radiation

Hawaiian Lobeliads

What are the Hawaiian lobeliads?

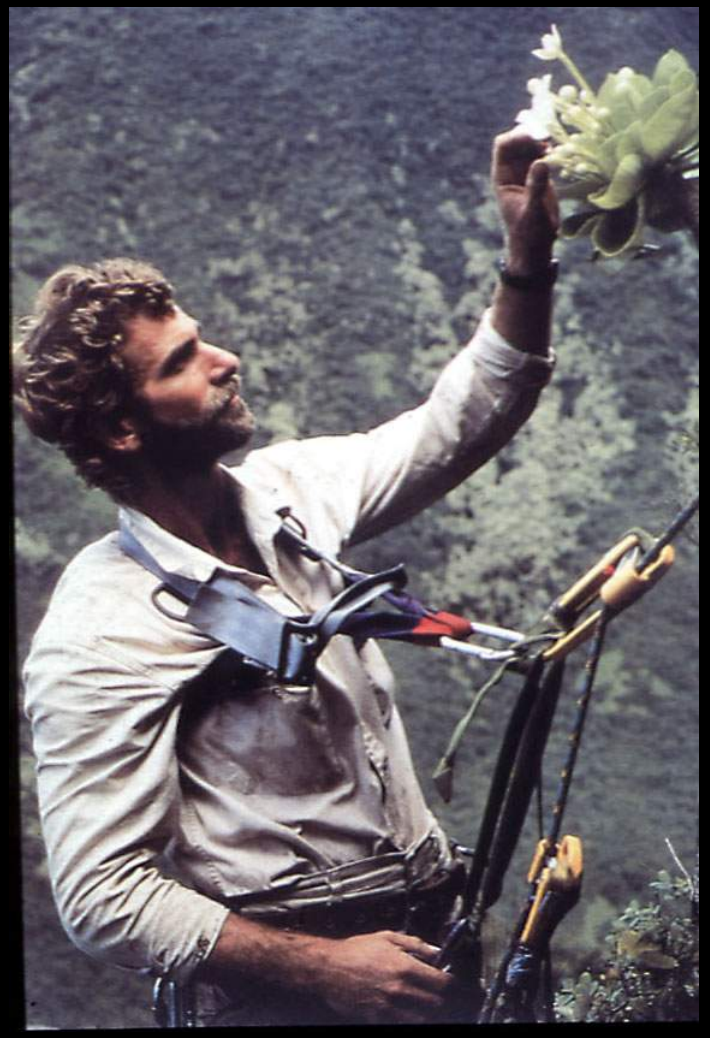
Lobelia gloria-montis

Lobelia telekii - Mt. Kenya

Hawaiian Lobeliads

What are the Hawaiian lobeliads?

Brighamia



Hawaiian Lobeliads

What are the Hawaiian lobeliads?

Delissia

Hawaiian Lobeliads

What are the Hawaiian lobeliads?

Trematolobelia

Hawaiian Lobeliads

What are the Hawaiian lobeliads?

Clermontia

Hawaiian Lobeliads

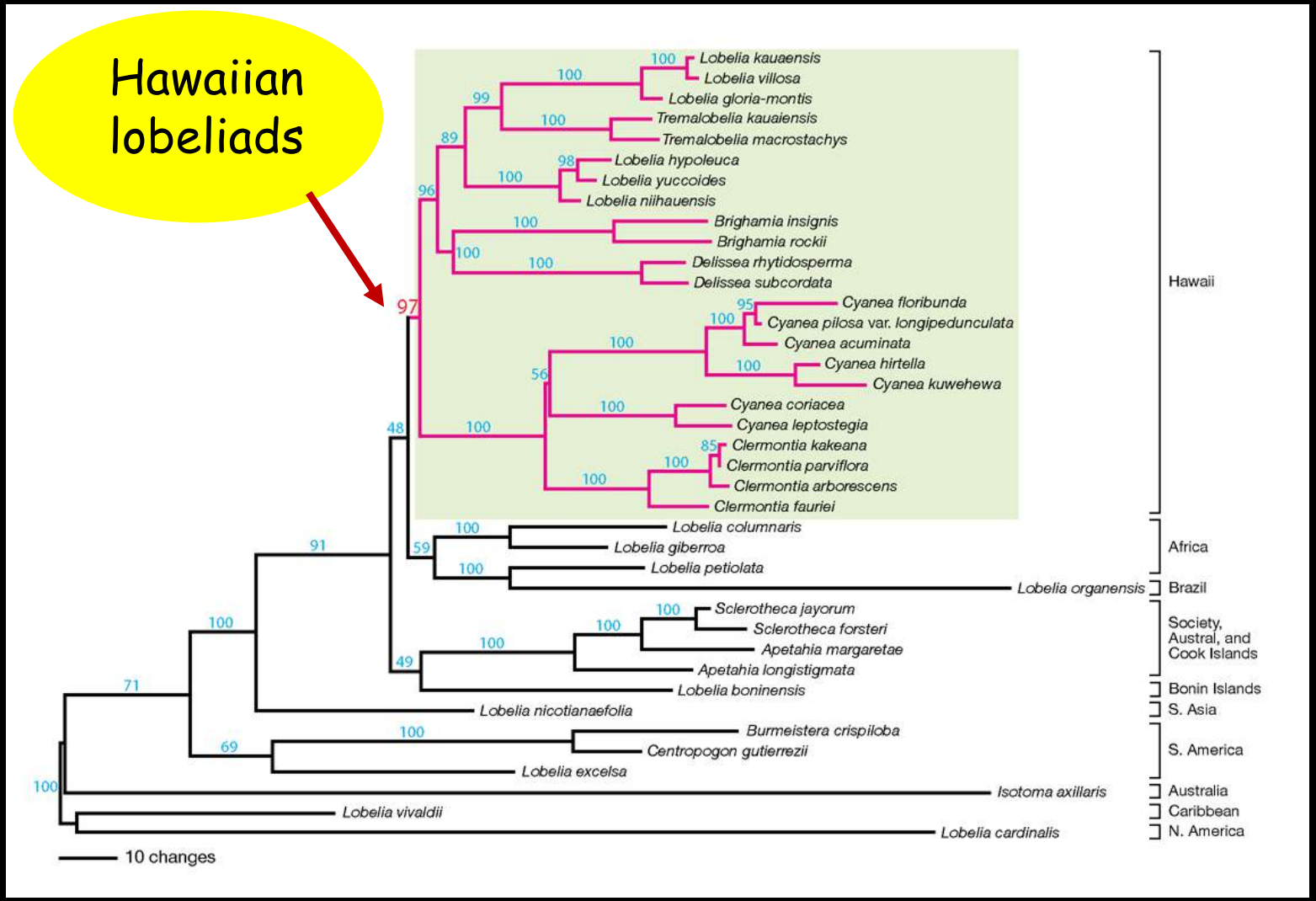
What are the Hawaiian lobeliads?

Cyanea

Hawaiian Lobeliads

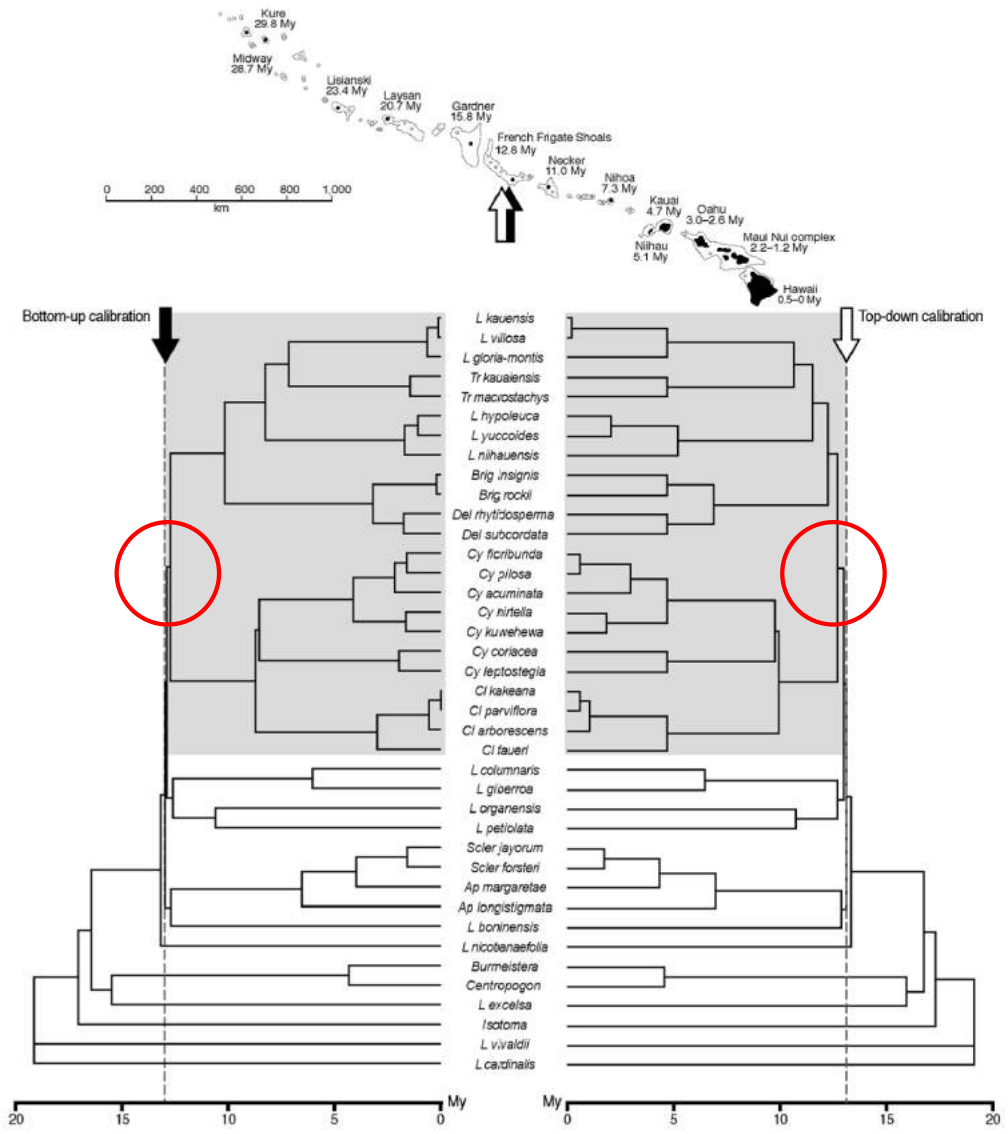
- sequenced over 6 million base pairs of DNA in each of about 100 species – to test for "finger print" of ancestry

Hawaiian Lobeliads



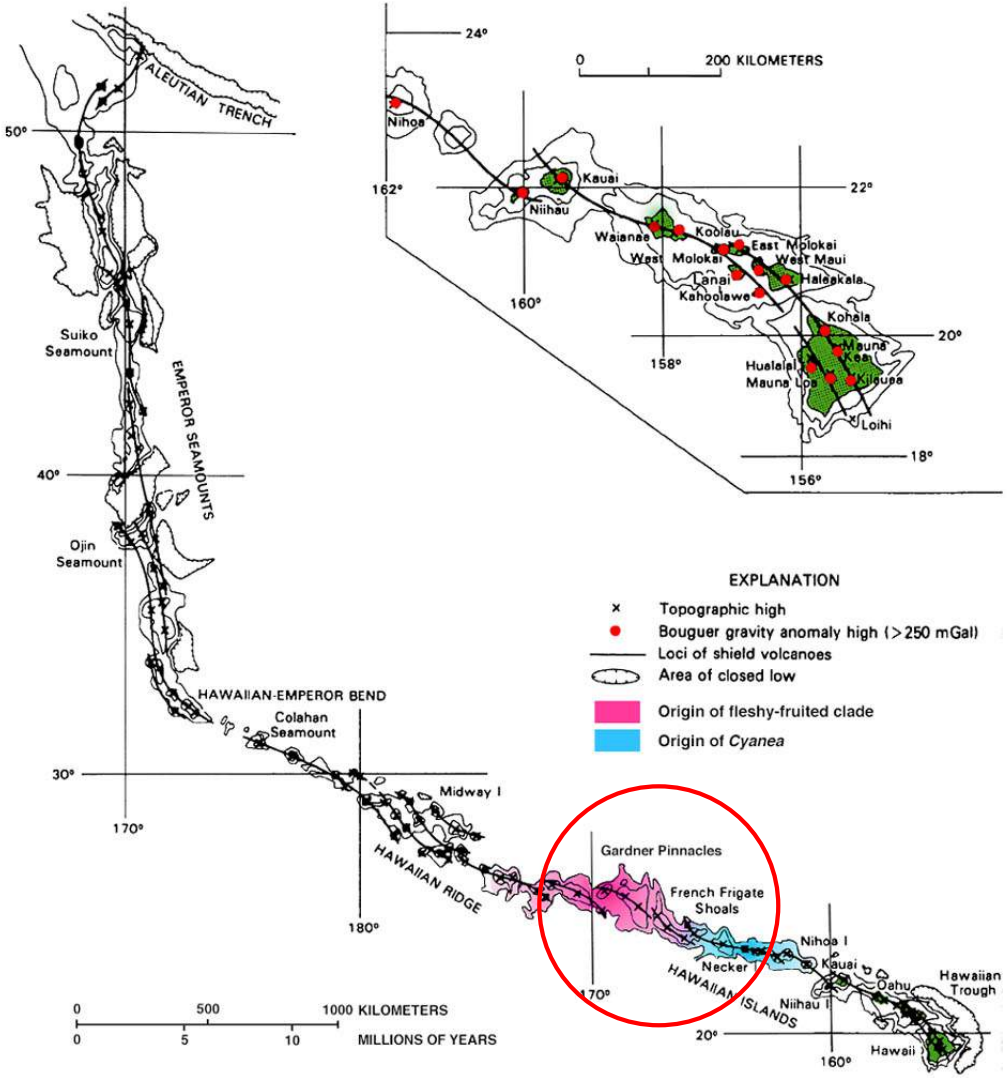
- DNA supports common ancestry of ALL Hawaiian lobeliads – one single ancestral seed dispersed to Hawaii & radiated into the more than 140 species

Hawaiian Lobeliads



Two clock calibrations - using Asterid fossils or using Hawaiian Island ages - place the differentiation of **Hawaiian lobeliads at 13-14 mya**

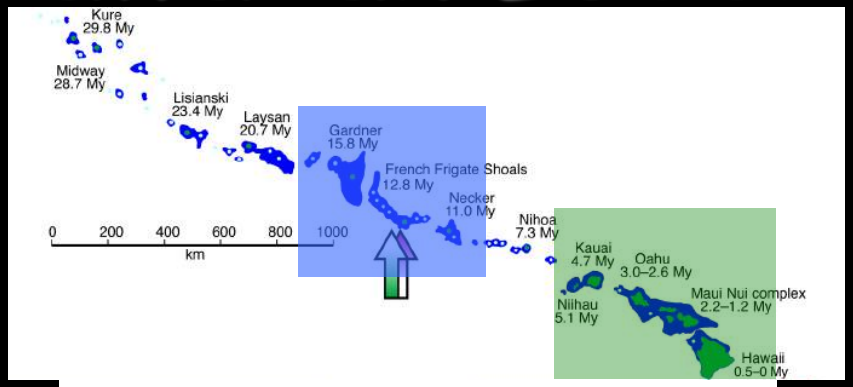
Hawaiian Lobeliads

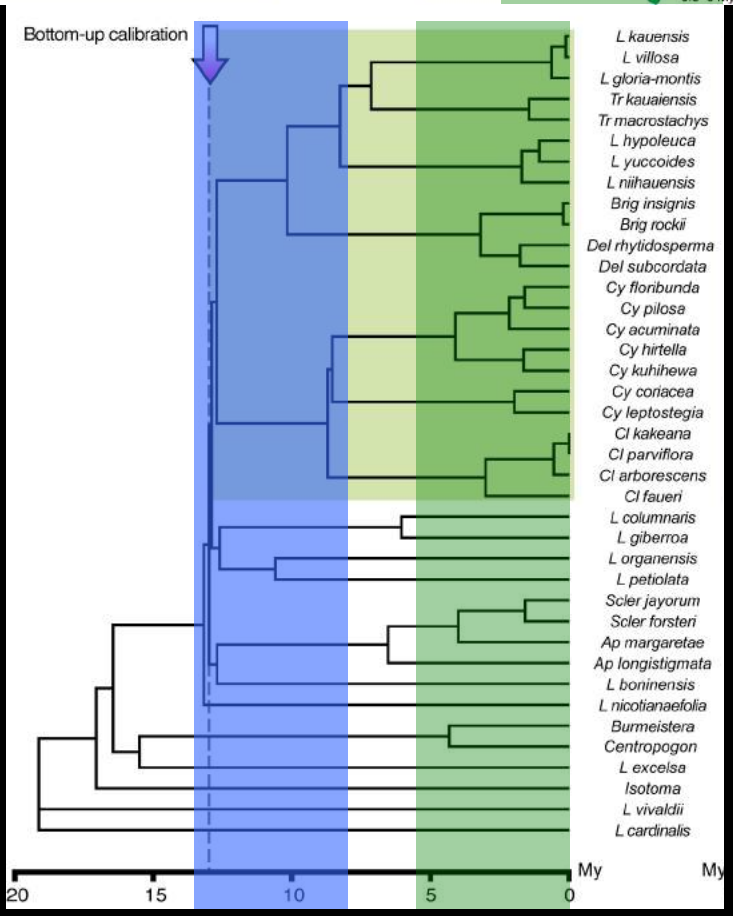


Two clock calibrations - using Asterid fossils or using Hawaiian Island ages - place the differentiation of **Hawaiian lobeliads at 13-14 mya**

Original colonist arrived in Gardner Pinnacles or French Frigate Shoals - large volcanic islands 12-16 mya

Hawaiian Lobeliads

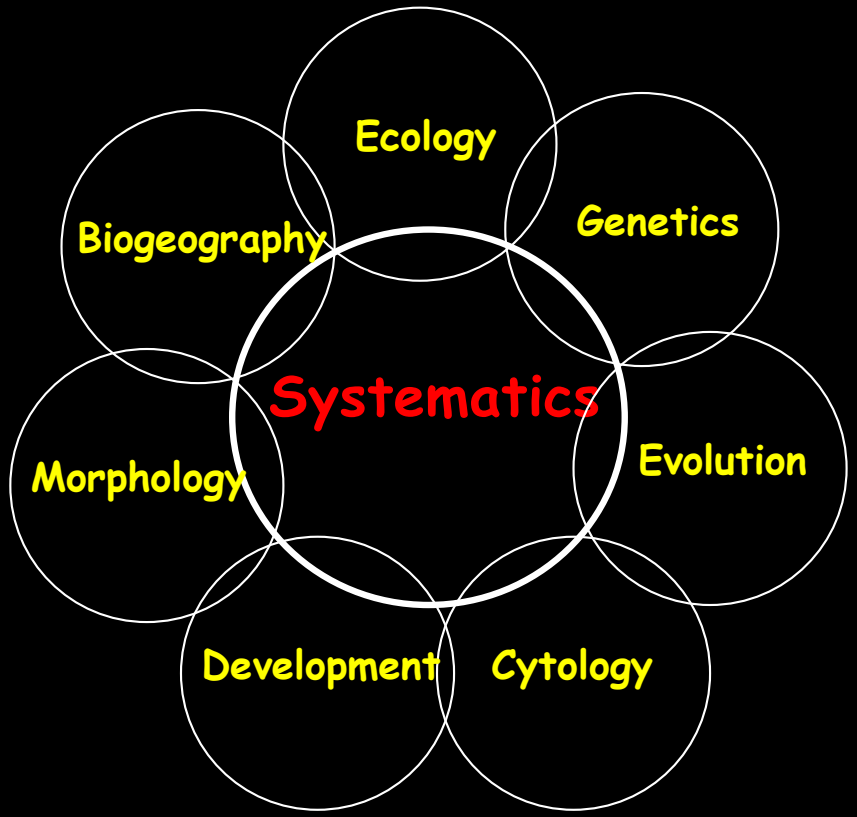




- **Early lobeliads** had initial radiation with **Hawaiian honeyeaters** now extinct

- **More recent radiation** of lobeliads pimarily with **Hawaiian honeycreepers** now going extinct

Future of Systematics



. . . it is central to biological sciences!

Concluding thoughts . . .

The field of plant systematics epitomizes the work of all other branches of biology centered on the organism itself, and brings the varied factual information from them to bear on the problems of interrelationships, classification, and evolution.

Thus, systematics is at once the alpha and omega of biology.

Reed Rollins 1957

Concluding thoughts . . .

Plant systematics has not outlived its usefulness; it is just getting under way on an attractively infinite task.

Lincoln Constance, 1957