Evolution of ecological communities through the lens of an island chronosequence

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NSF Dimensions of Biodiversity

nature.berkeley.edu/evolab
nature.berkeley.edu/hawaiidimensions

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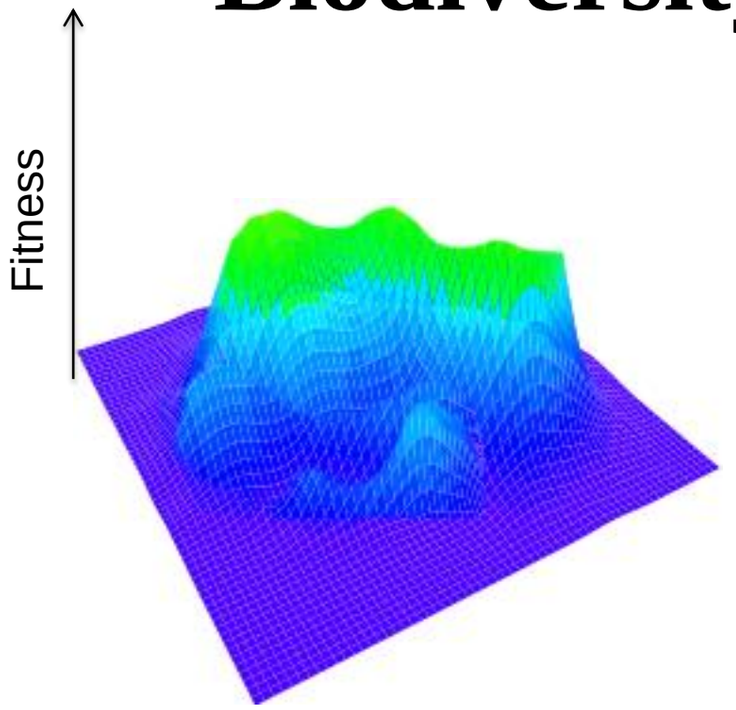
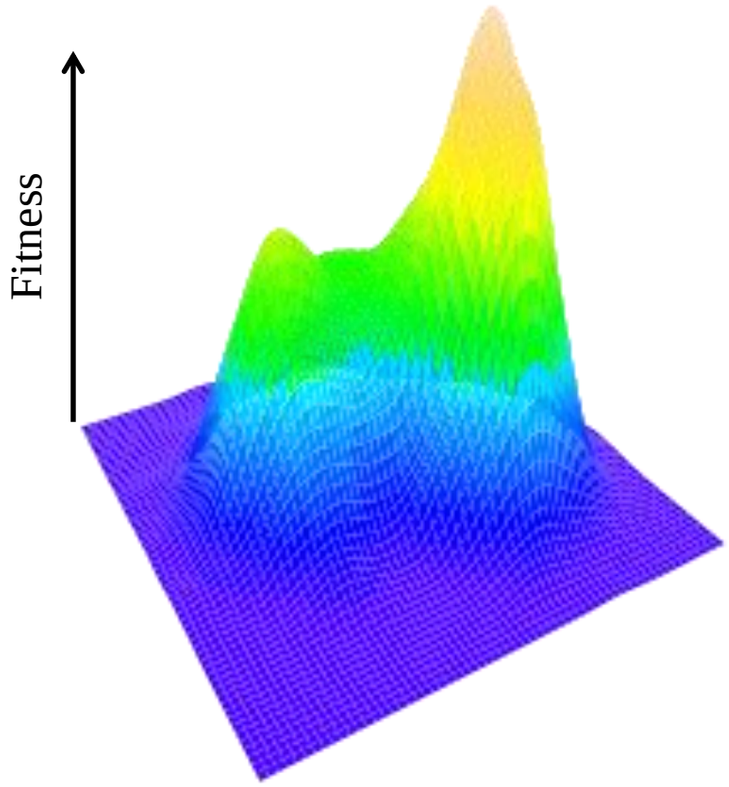
Andy Rominger, Henrik Krehenwinkel, Dan Gruner, Jun Ying Lim, Kari Goodman, Ellie Armstrong, Gordon Bennett, Michael Brewer, Darko Cotoras, Curtis Ewing, Diana Percy, Patrick O'Grady, Don Price, George Roderick, Kerry Shaw

Henrik Krehenwinkel

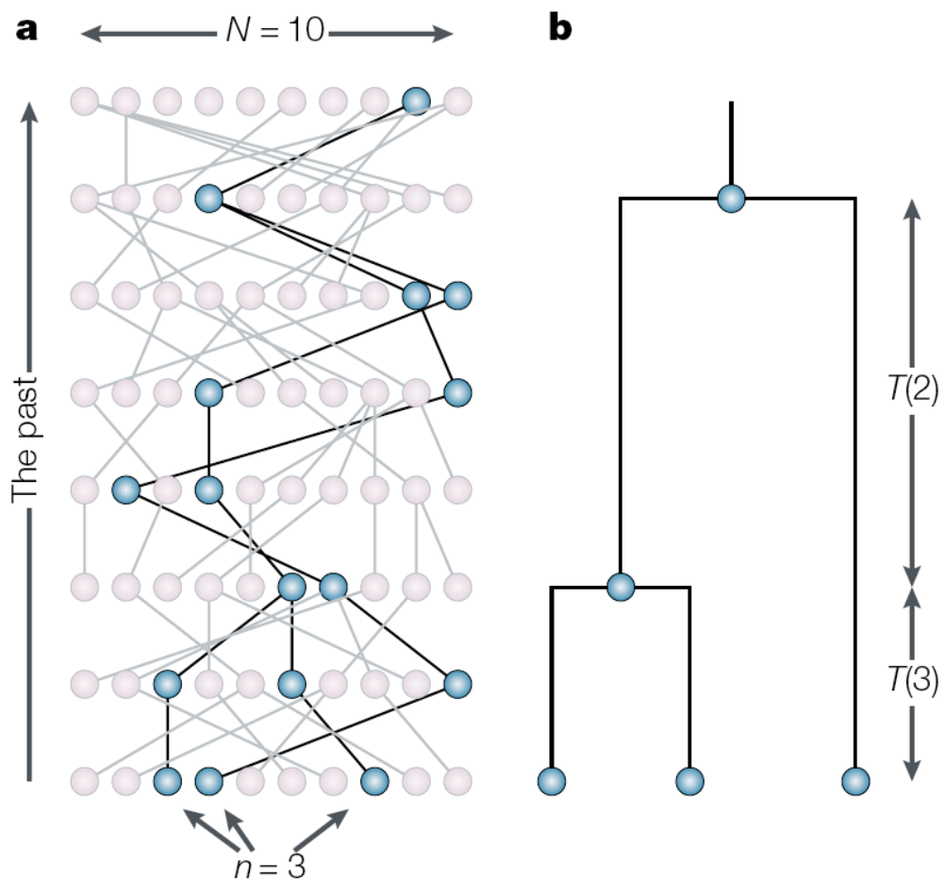
Biodiversity Dynamics

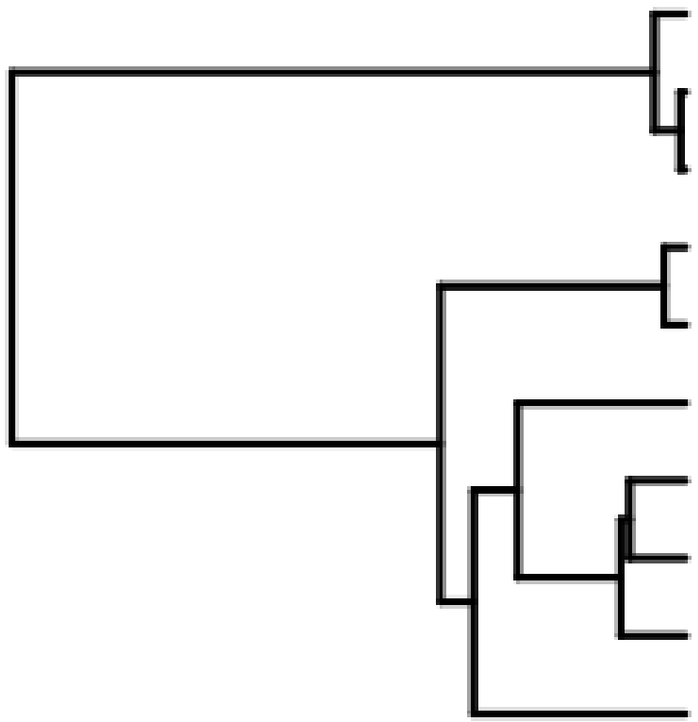


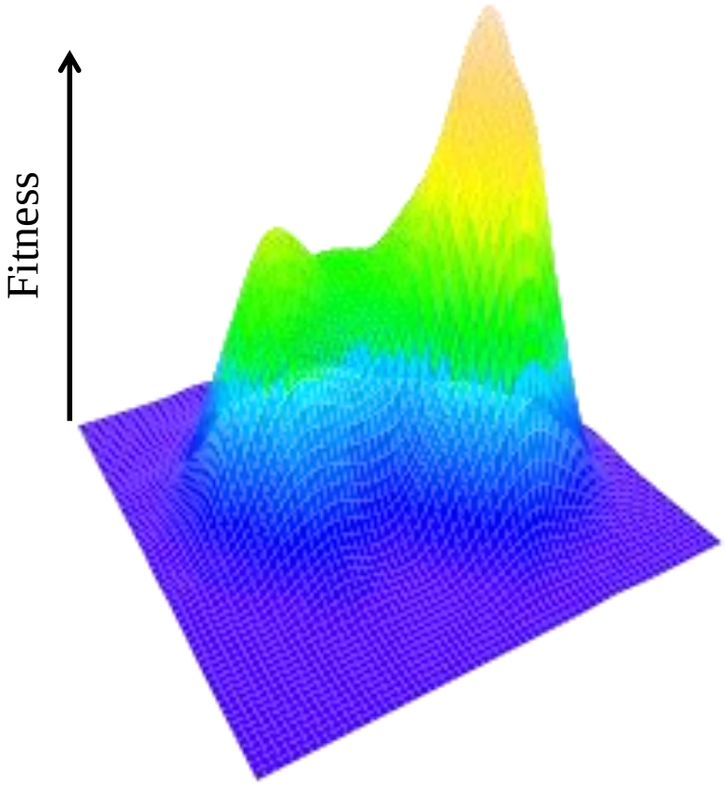


Microevolution

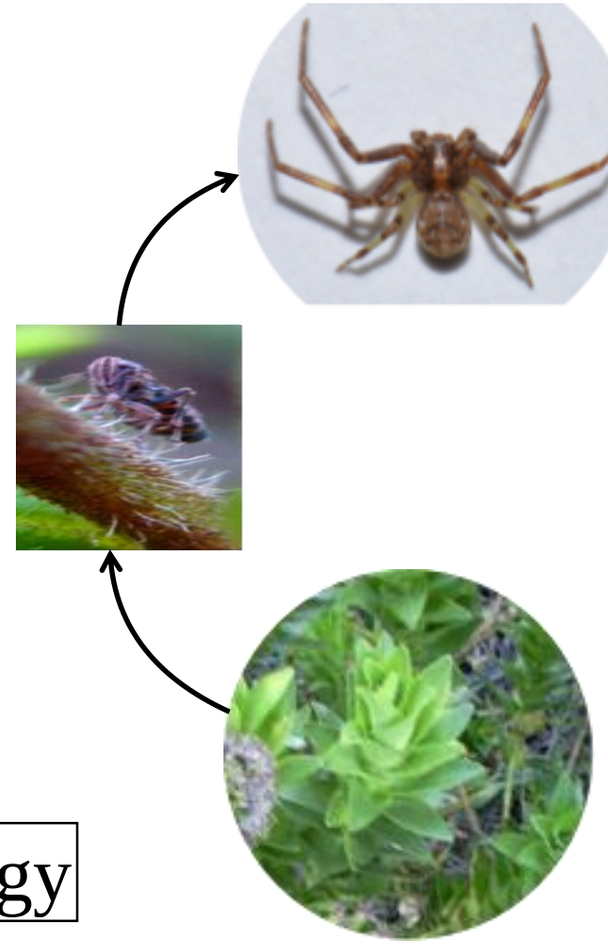
Macroevolution



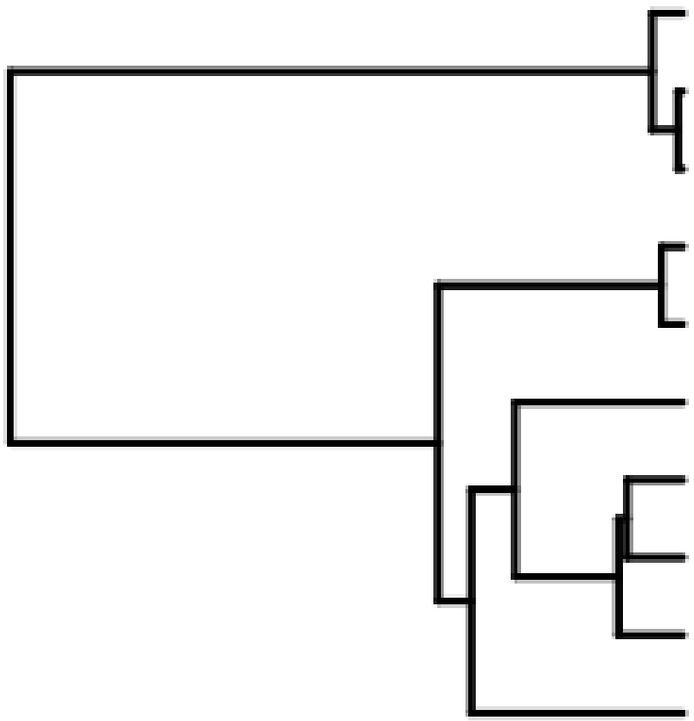


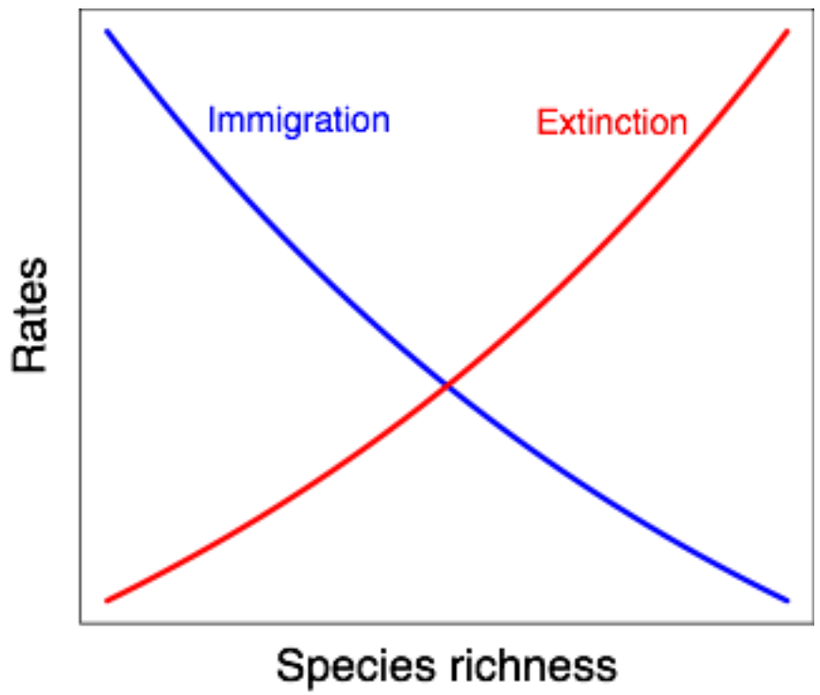


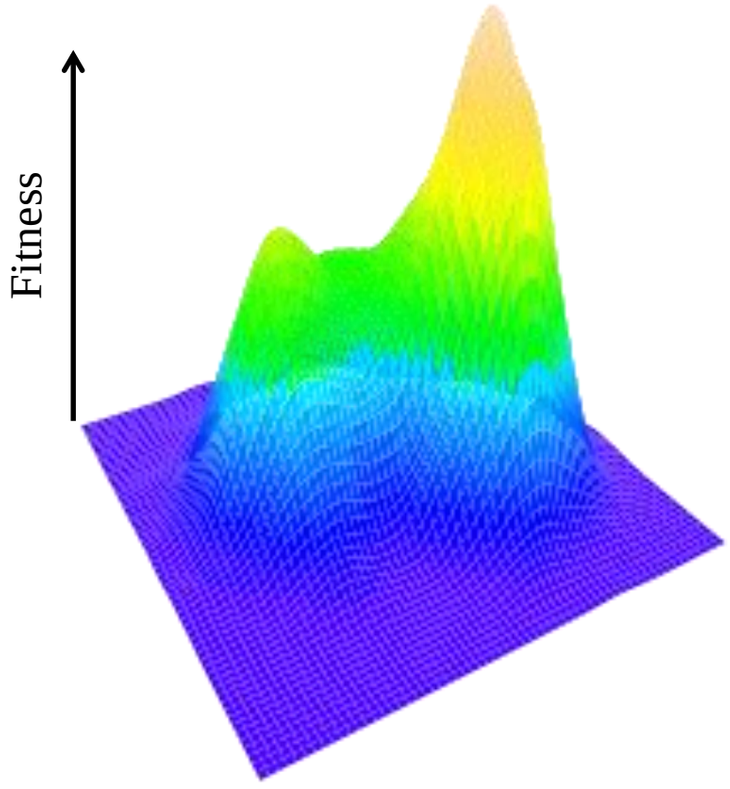
Evolution

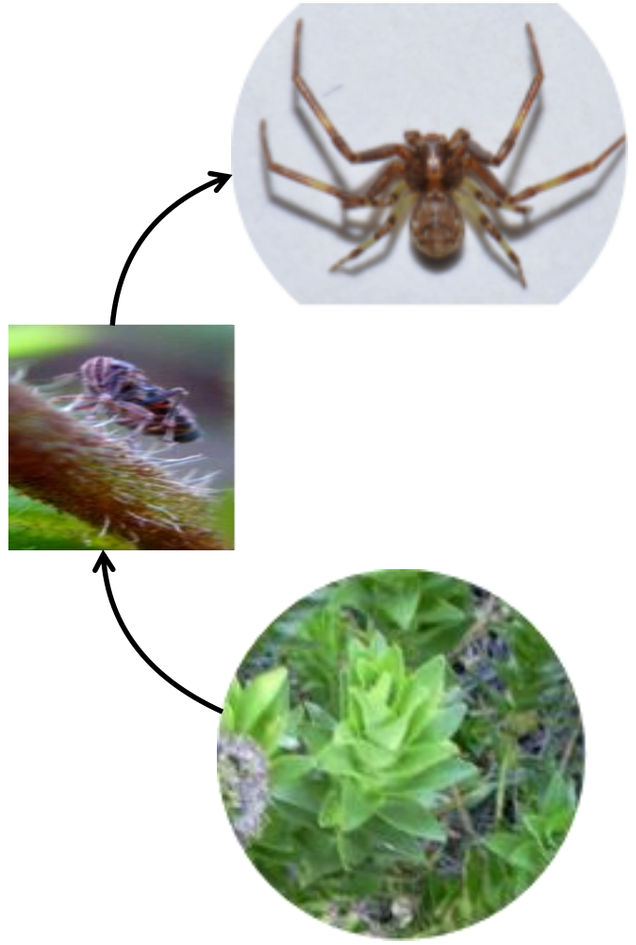


Ecology

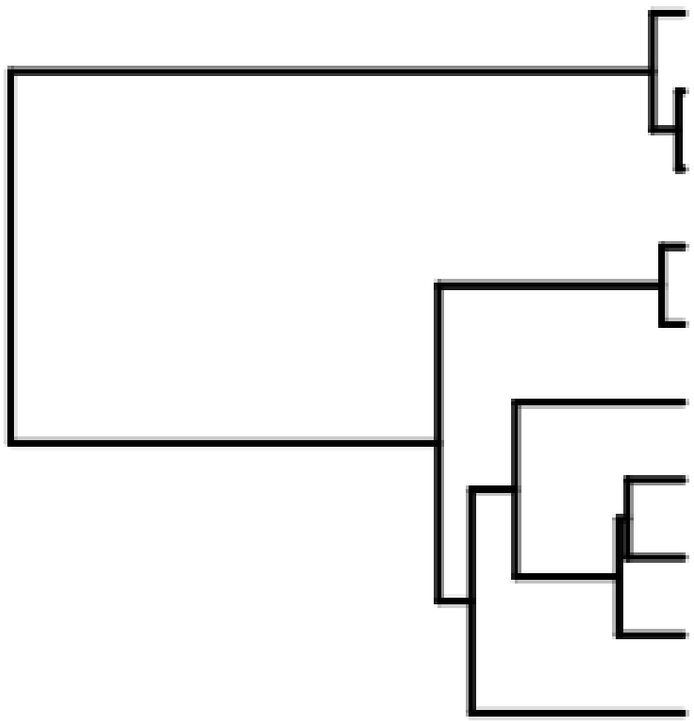


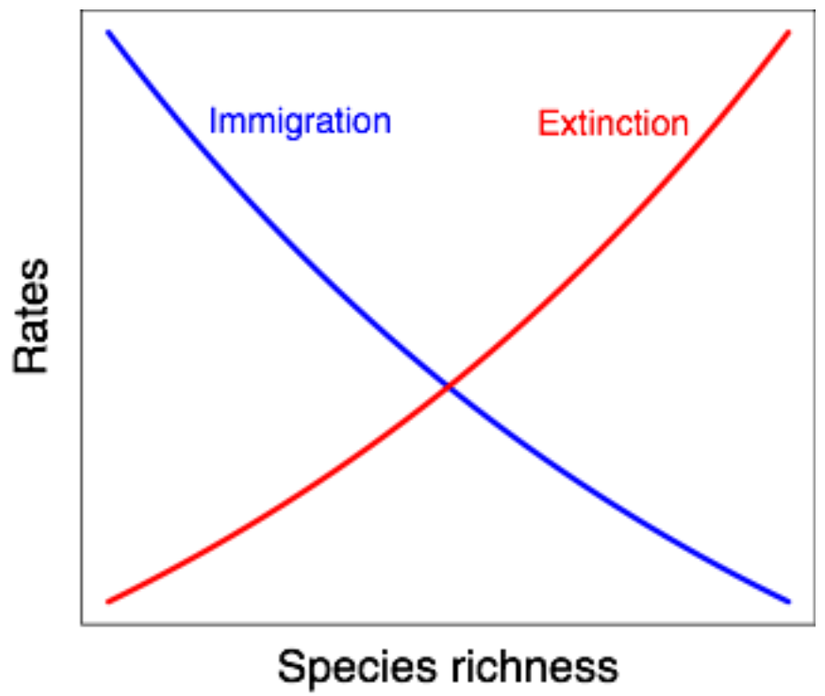






Biodiversity dynamics

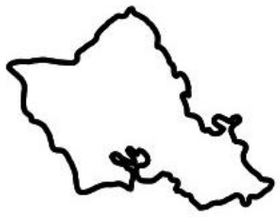




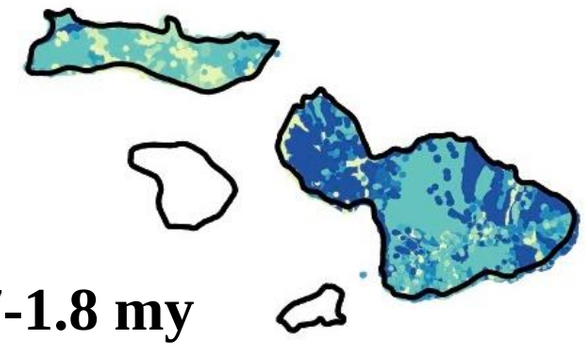
Processes occur over different scales, so how to assess dynamics?

Island chronosequence

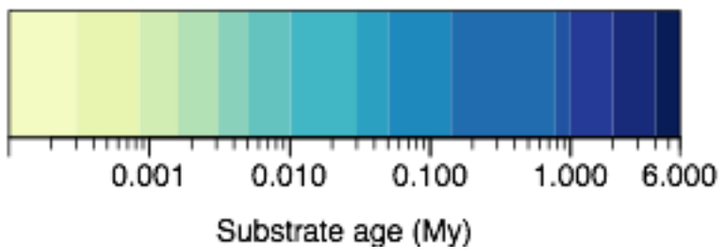
5.1 my

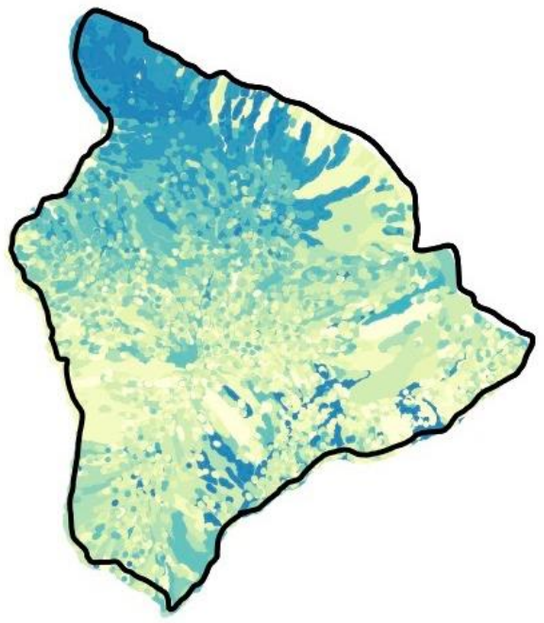


2.6-3.7 my



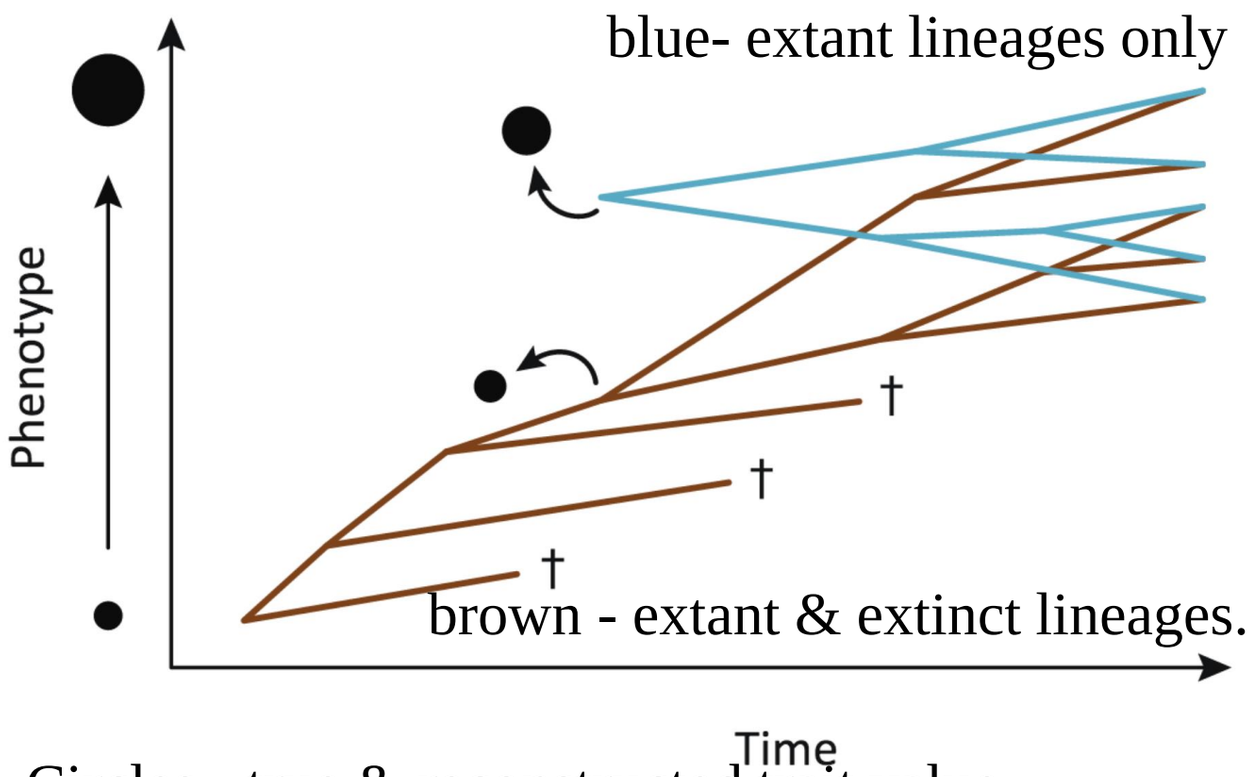
0.7-1.8 my





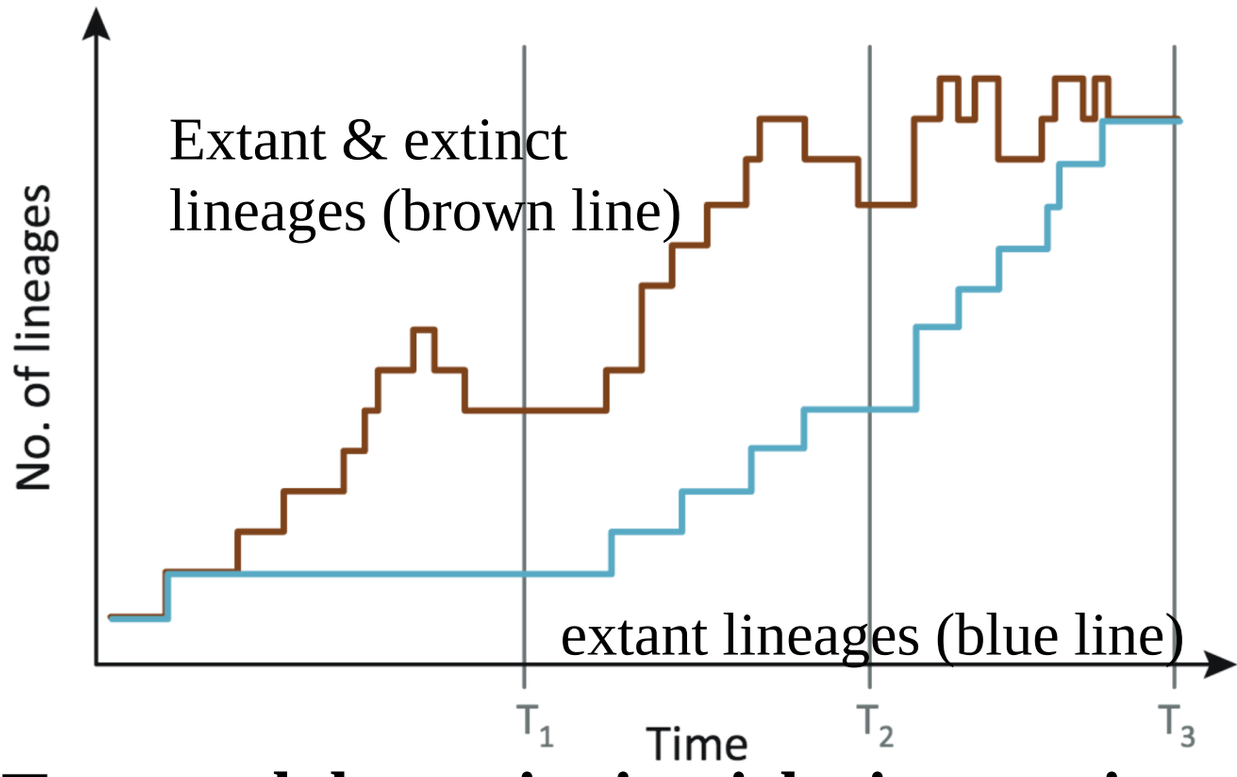
0-0.4 my

Dynamics of trait evolution

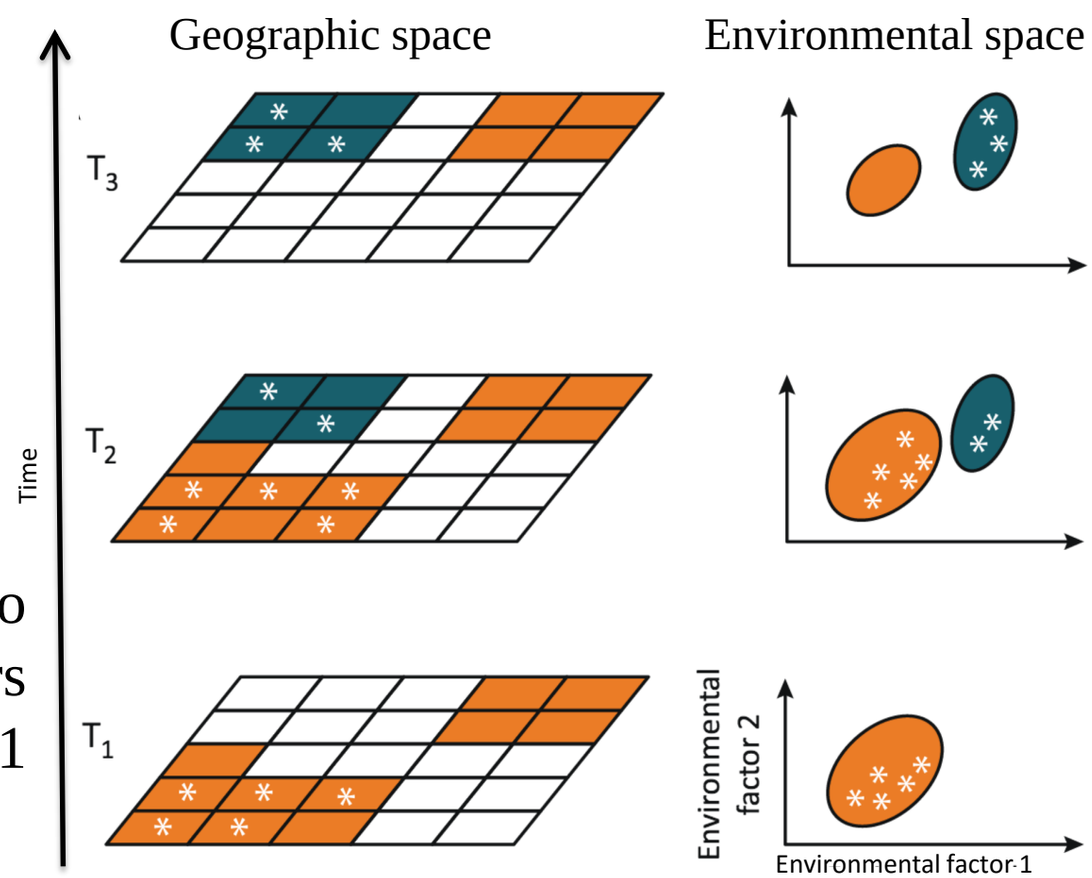


Circles - true & reconstructed trait value for the most recent common ancestor

Species diversity through time



Temporal dynamics in niche interactions

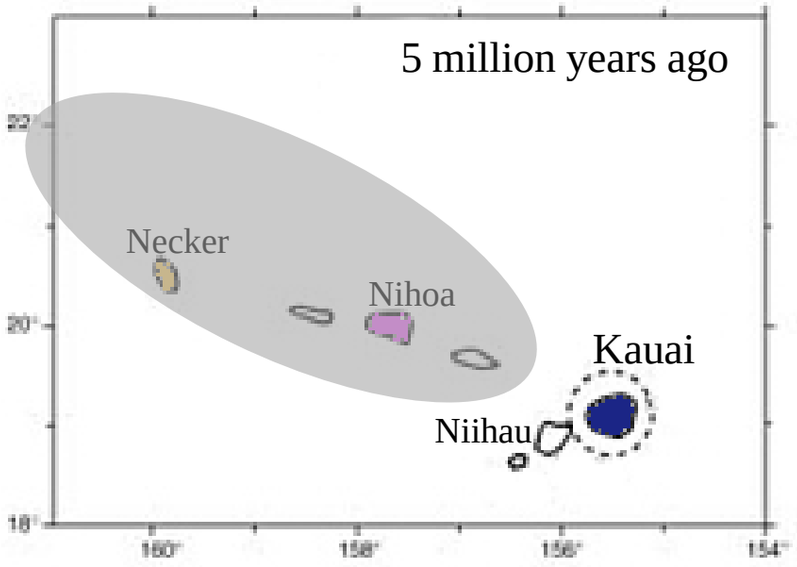


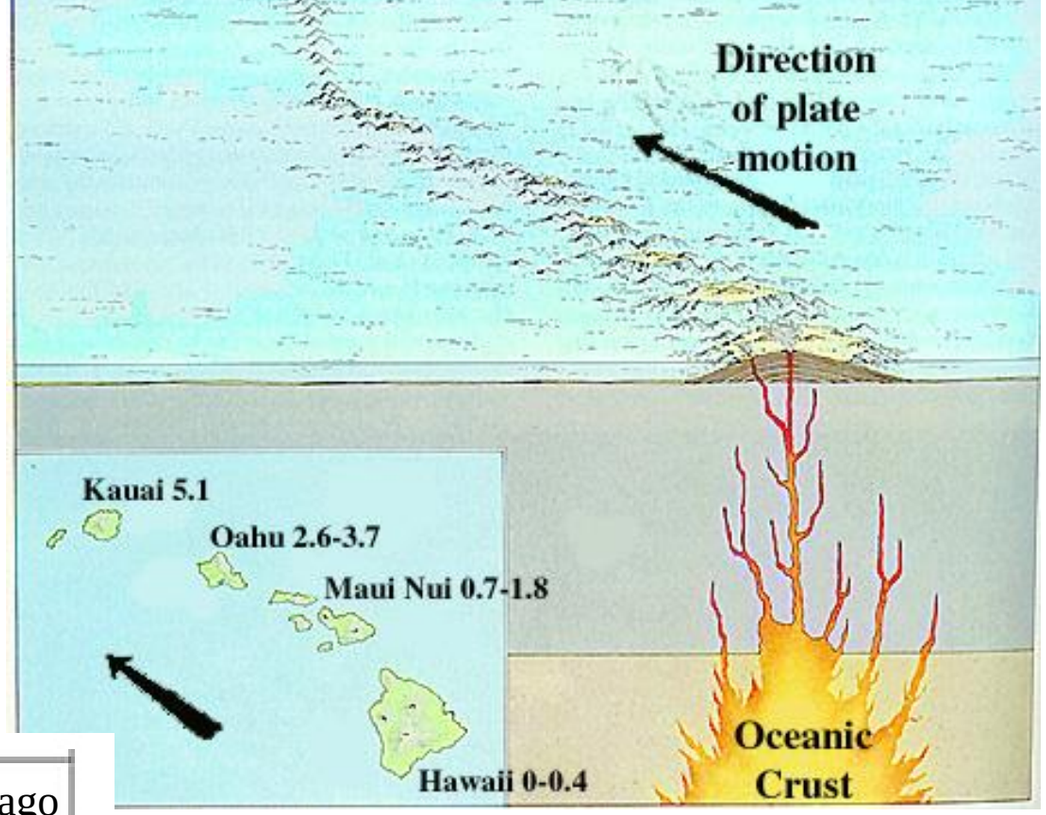
Neontological & paleontological data

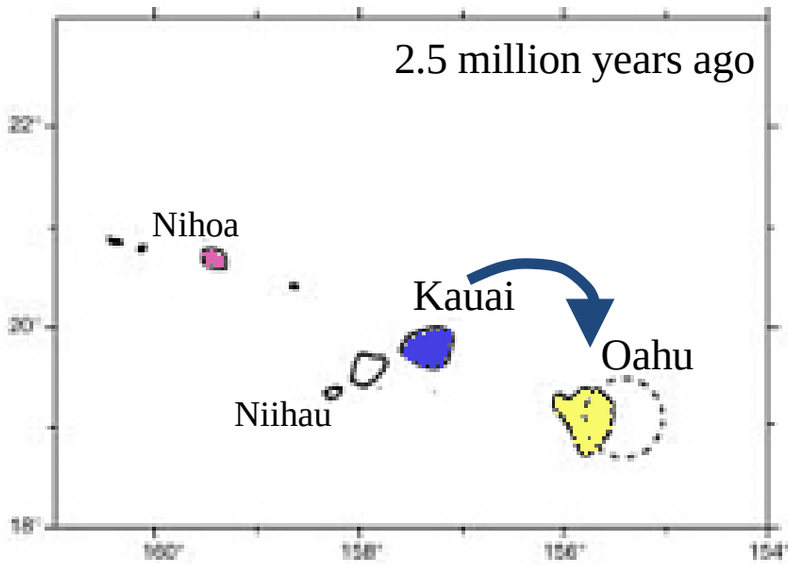
Species shifts from orange to blue environment that appears only after T1

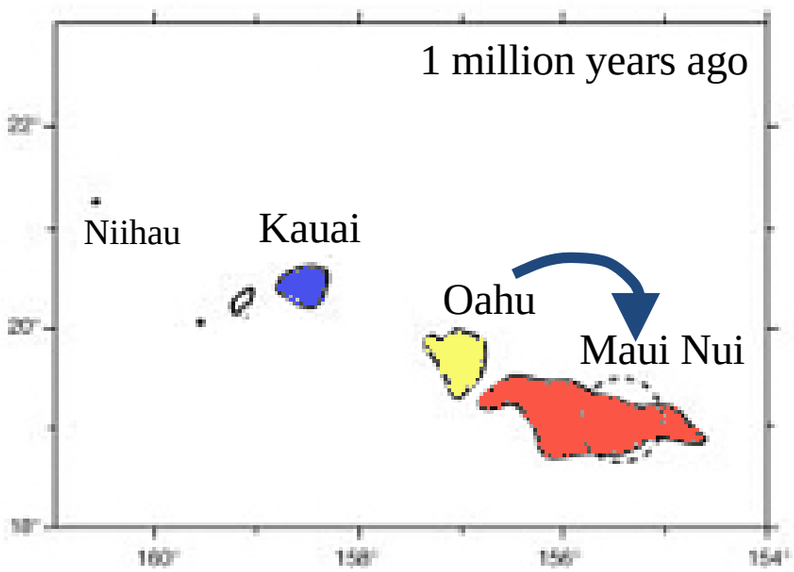
Fritz et al 2013. Diversity in time and space... TREE 28, 509-516

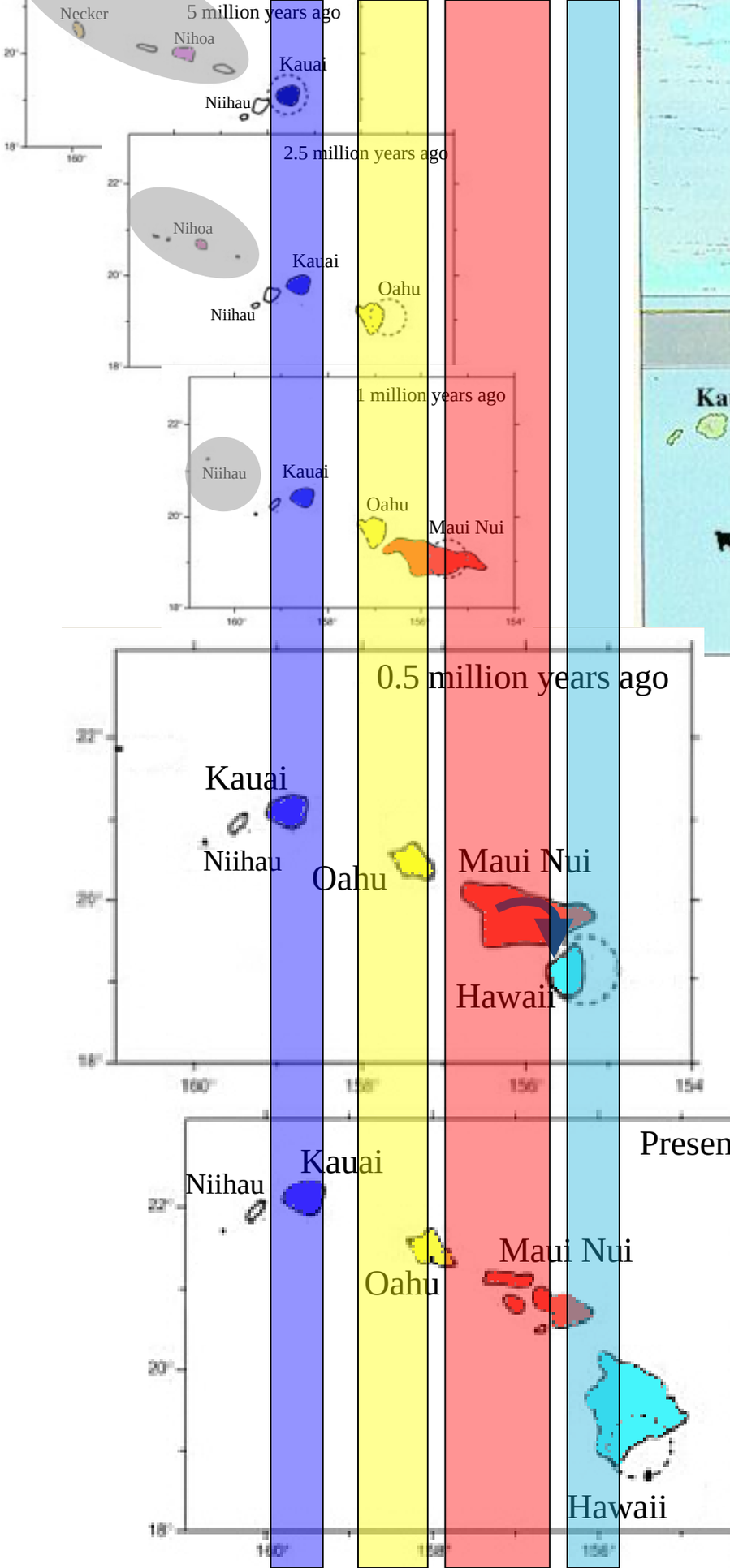
Chronosequence

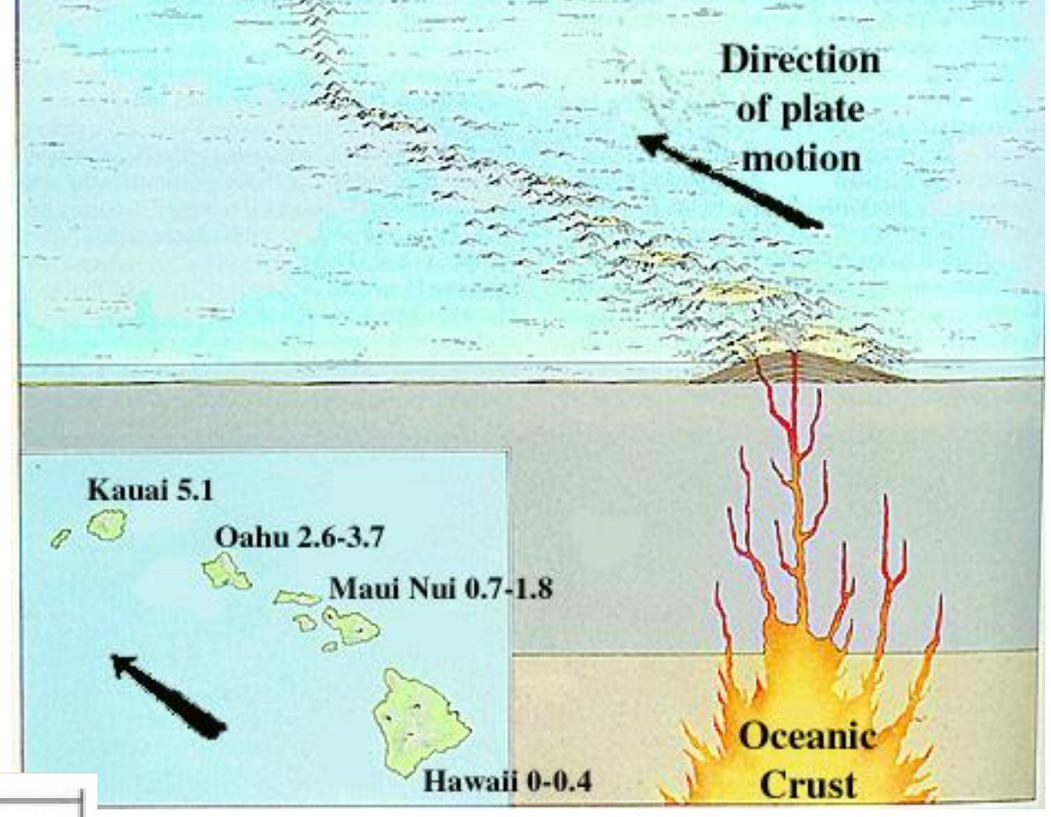












Can read chrono-sequence as a fossil record to look at:

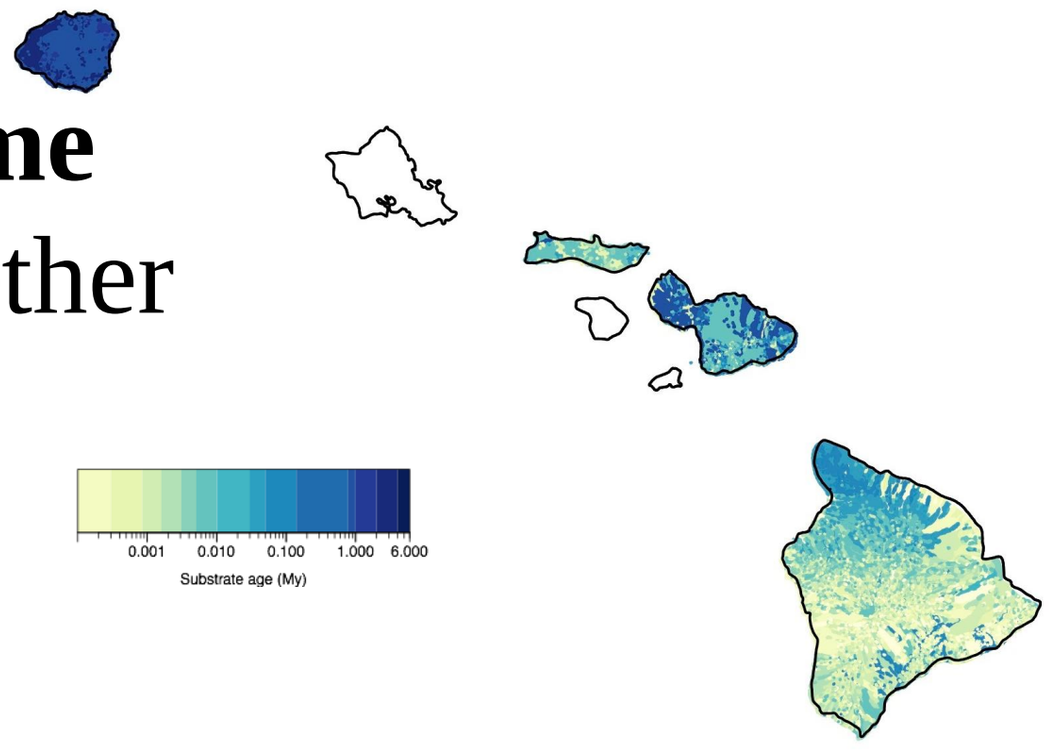
- **Dynamics of trait evolution**
- **Species diversity through time**
- **Temporal dynamics in niche interactions.**

Island chronosequence

1. **Microevolution 2 macroevolution**

1. **Evolutionary dynamics over time**
   - Repetition of evolutionary process

2. Species diversity through time
   - How communities come together over time

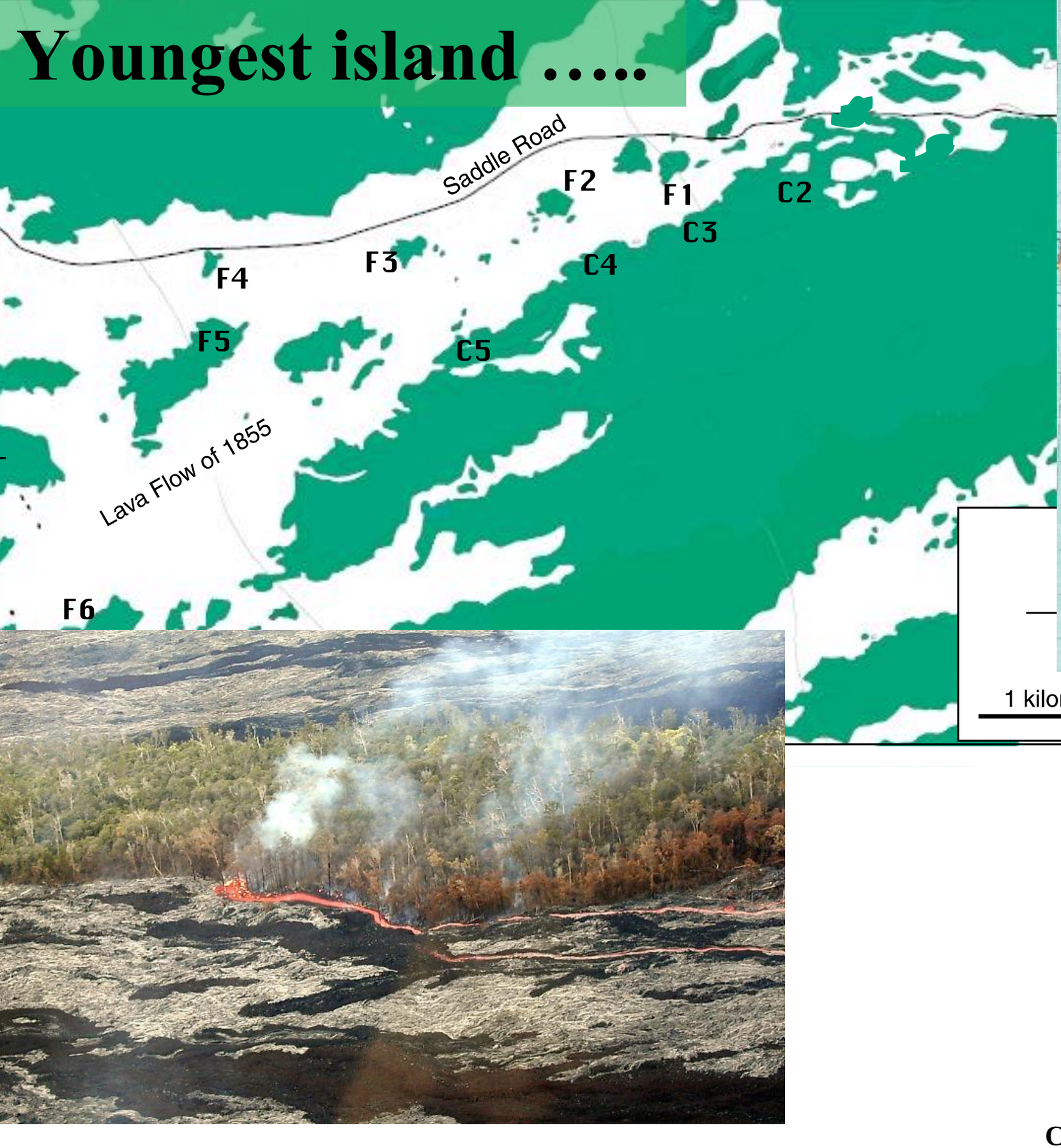


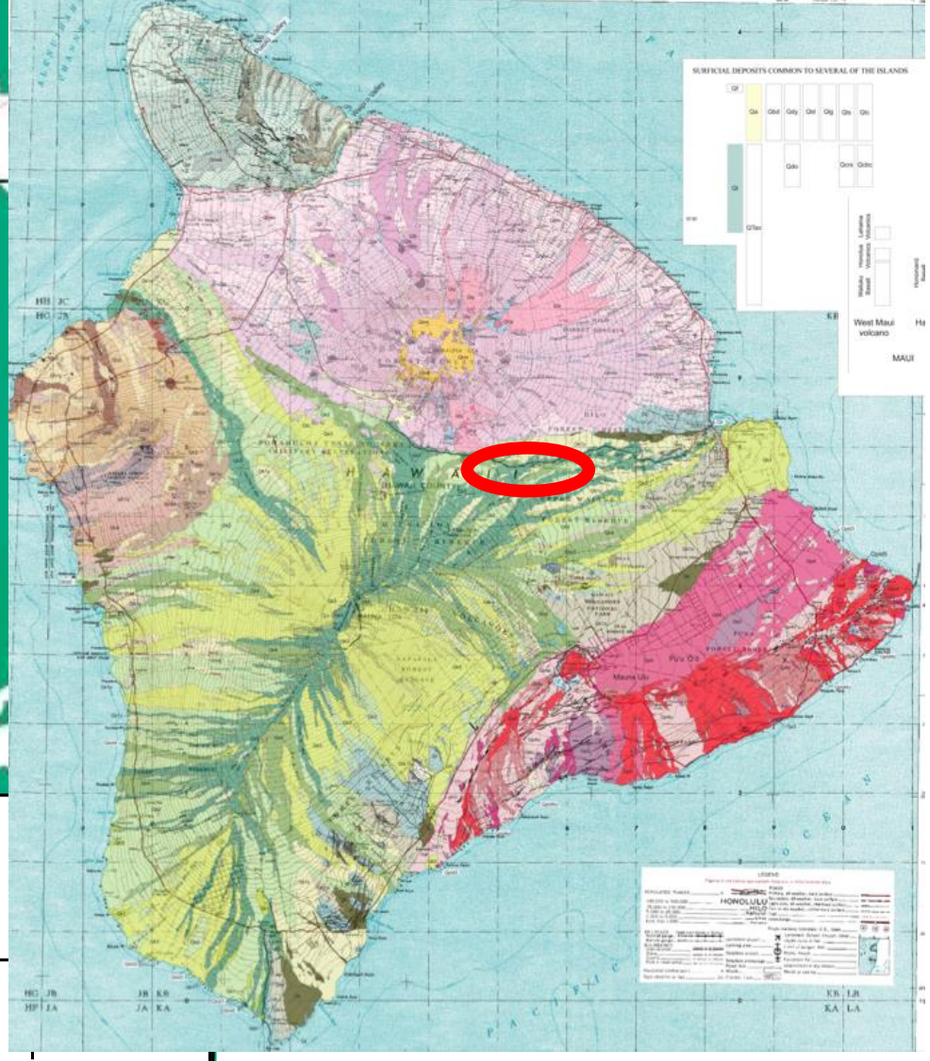
3. Ecological interactions
   - Measurement of ecological metrics (space for time)

1. Micro- to macro-evolution

- the early stages

Youngest island …..

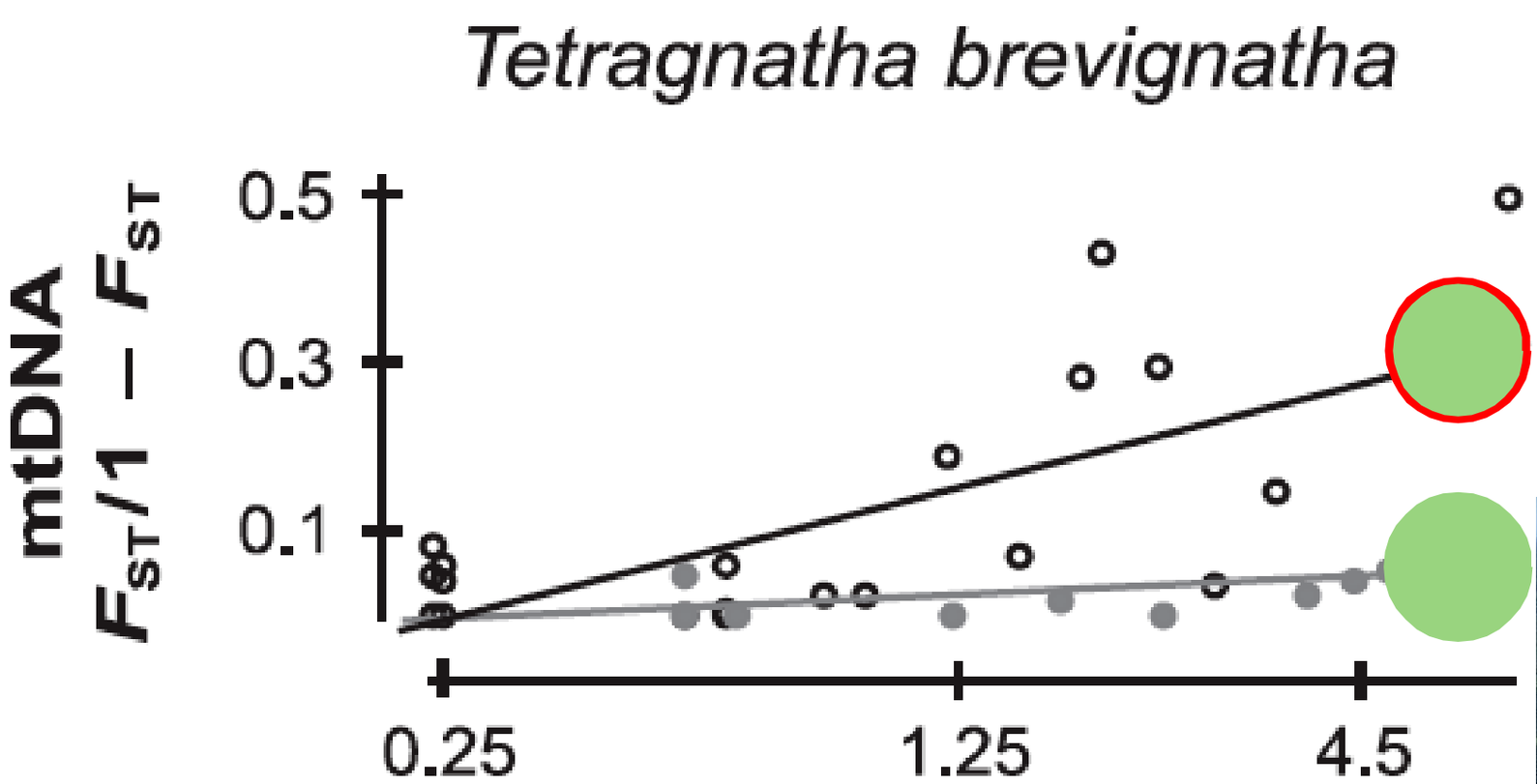




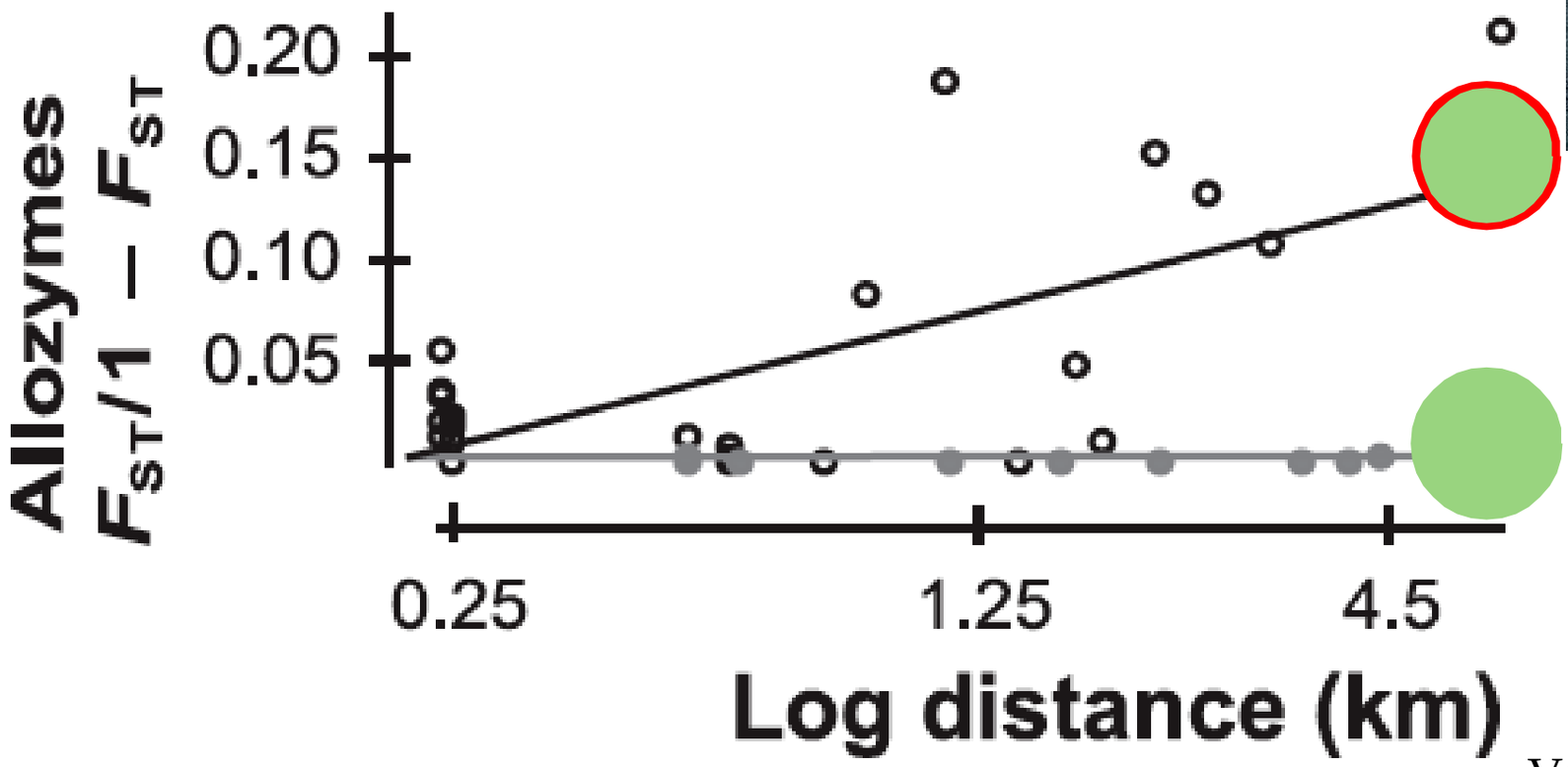
Dynamics on Hawaii Island as the “crucible of evolution”

Carson et al. 1990 PNAS 87, pp. 7055-7057,

1. Micro-macro evolution 2. Evolutionary dynamics 3. Species diversity 4. Ecological interactions

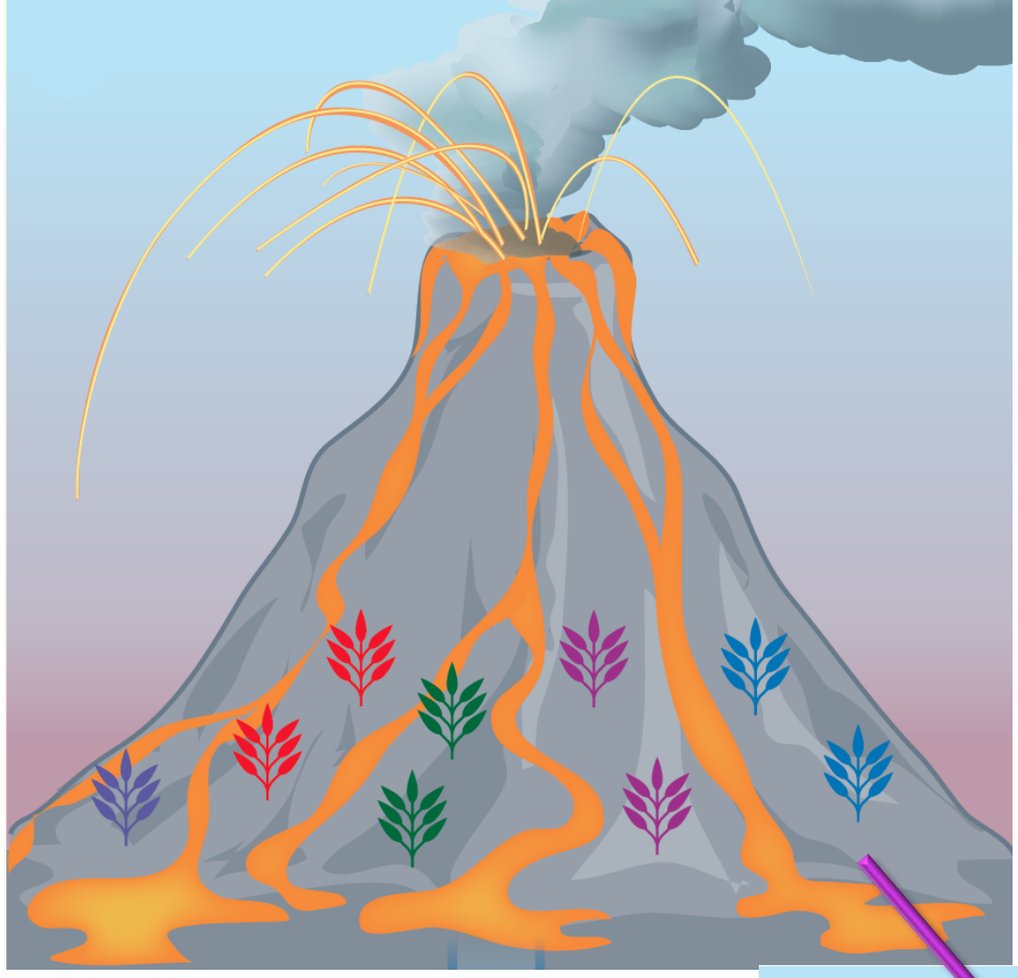


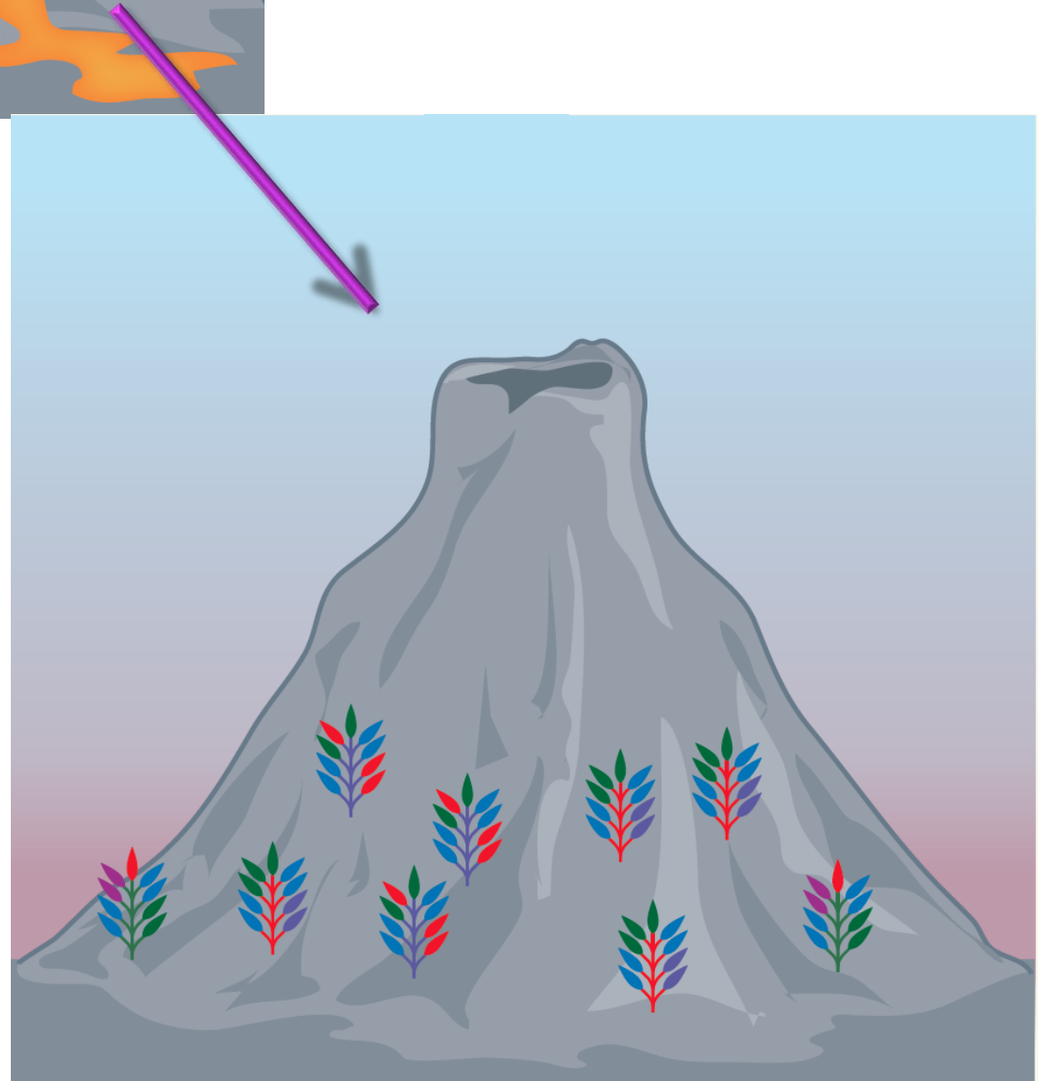
Habitat fragmentation clearly limits gene flow



Forest habitat specialist

Vandergast et al. 2004. *Mol Ecol* 13: 1729-1743



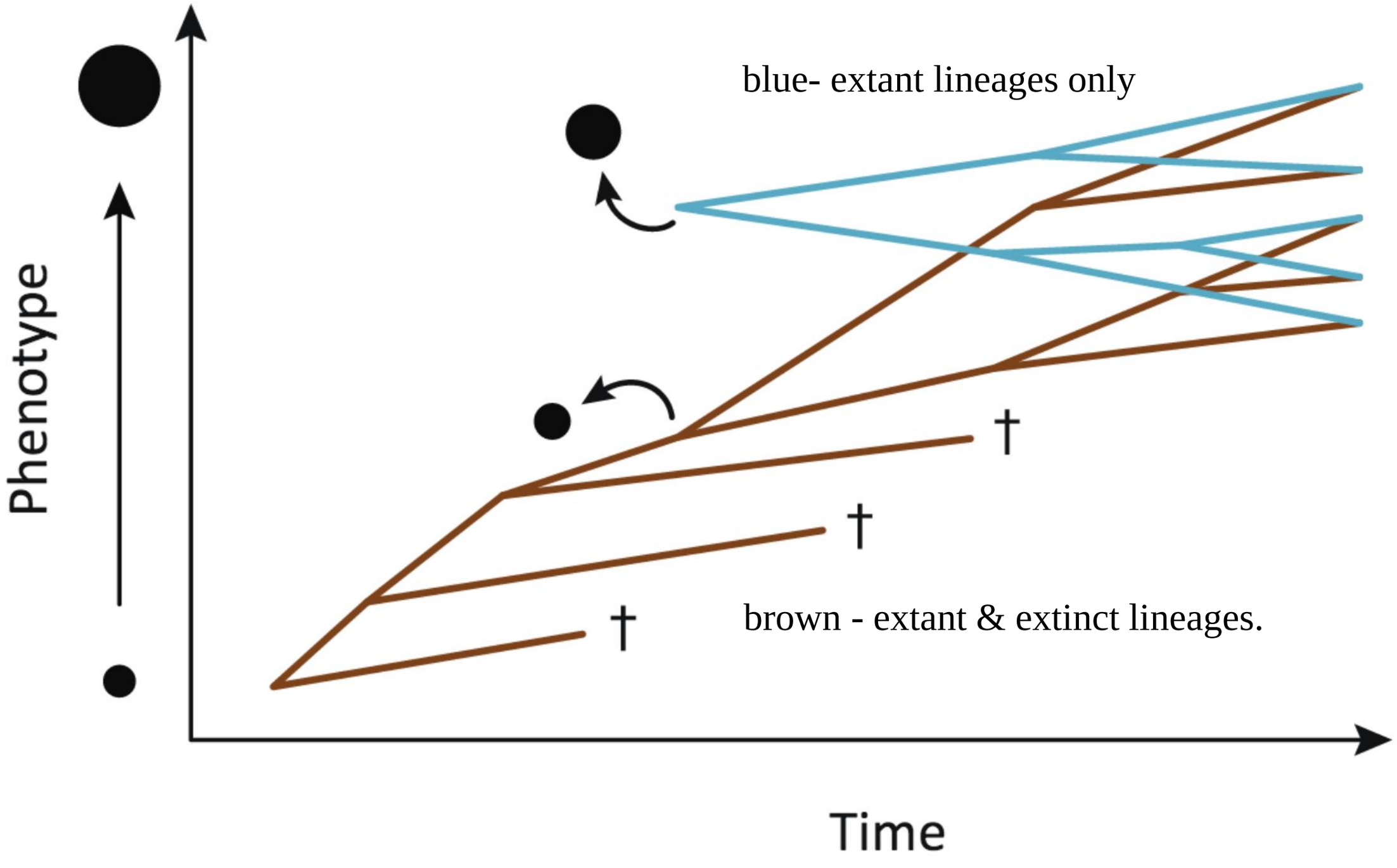


Balance between isolation & time

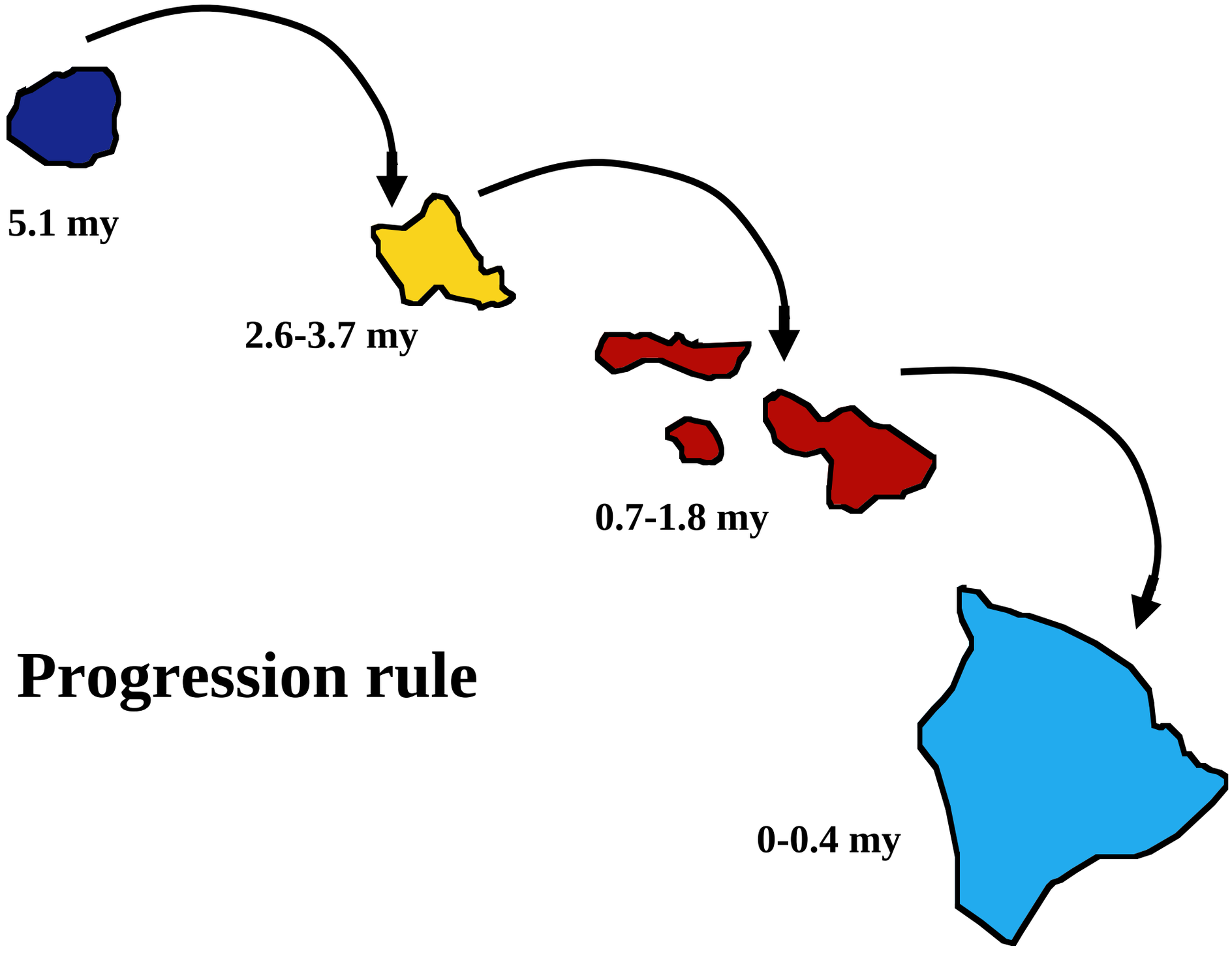
Isolation separates populations
Fusion injects diversity

How does this play out over time?

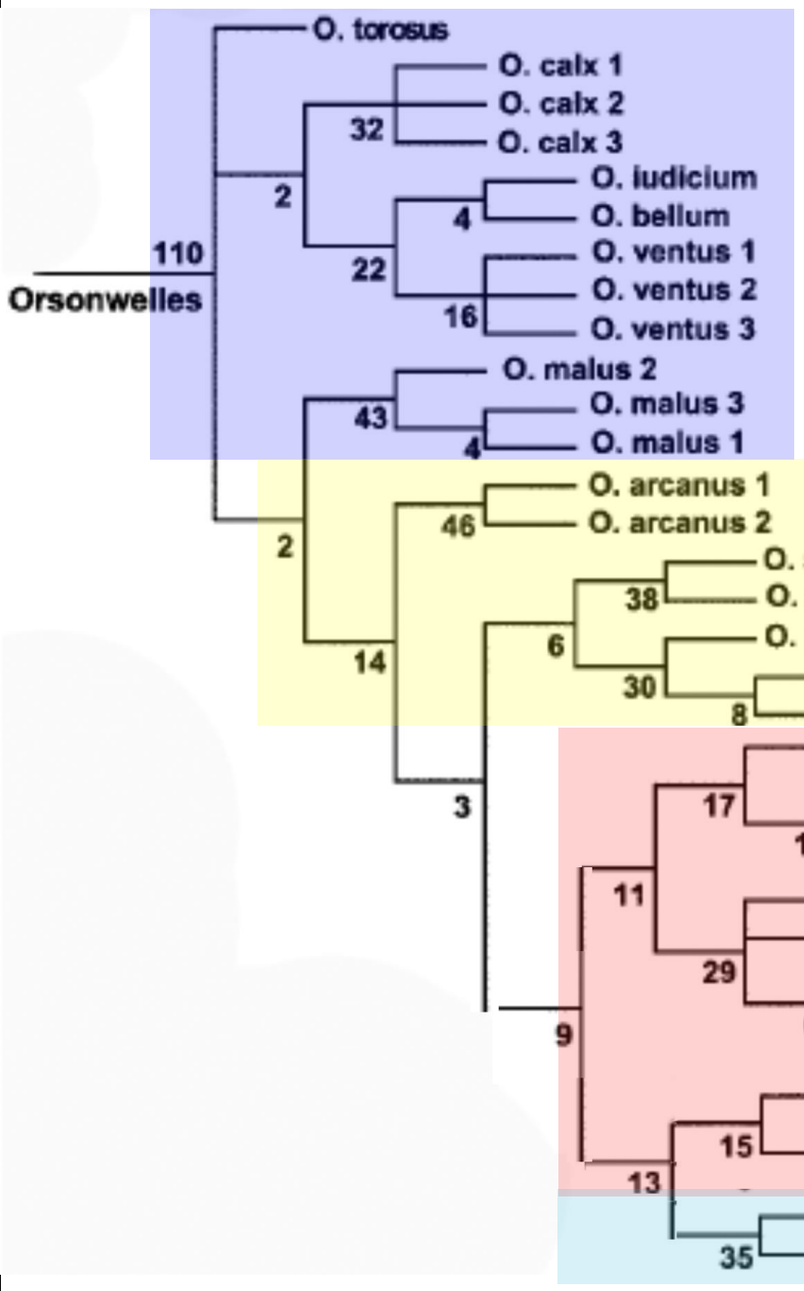
2. Evolutionary dynamics

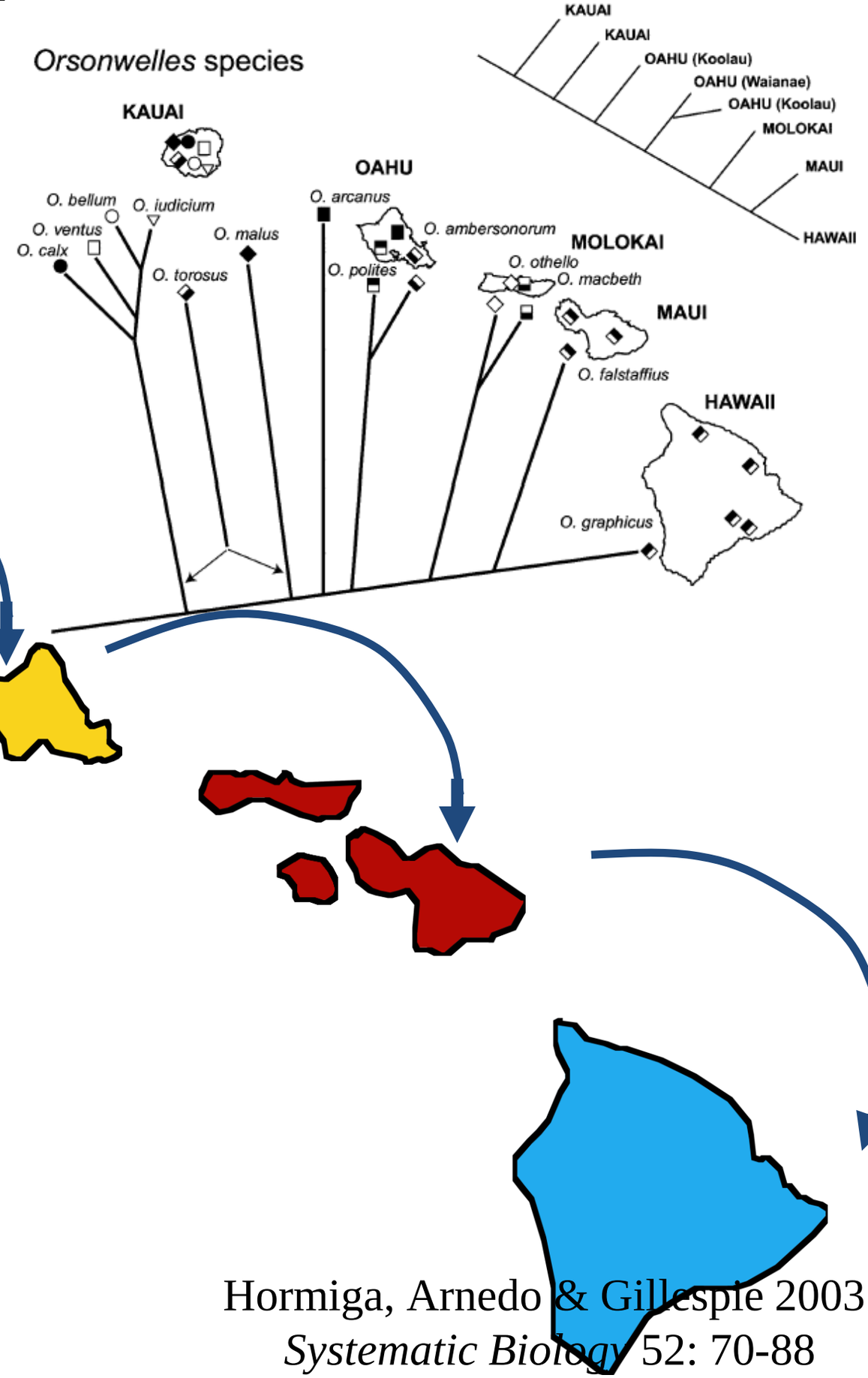


Evolutionary Dynamics



Progression rule

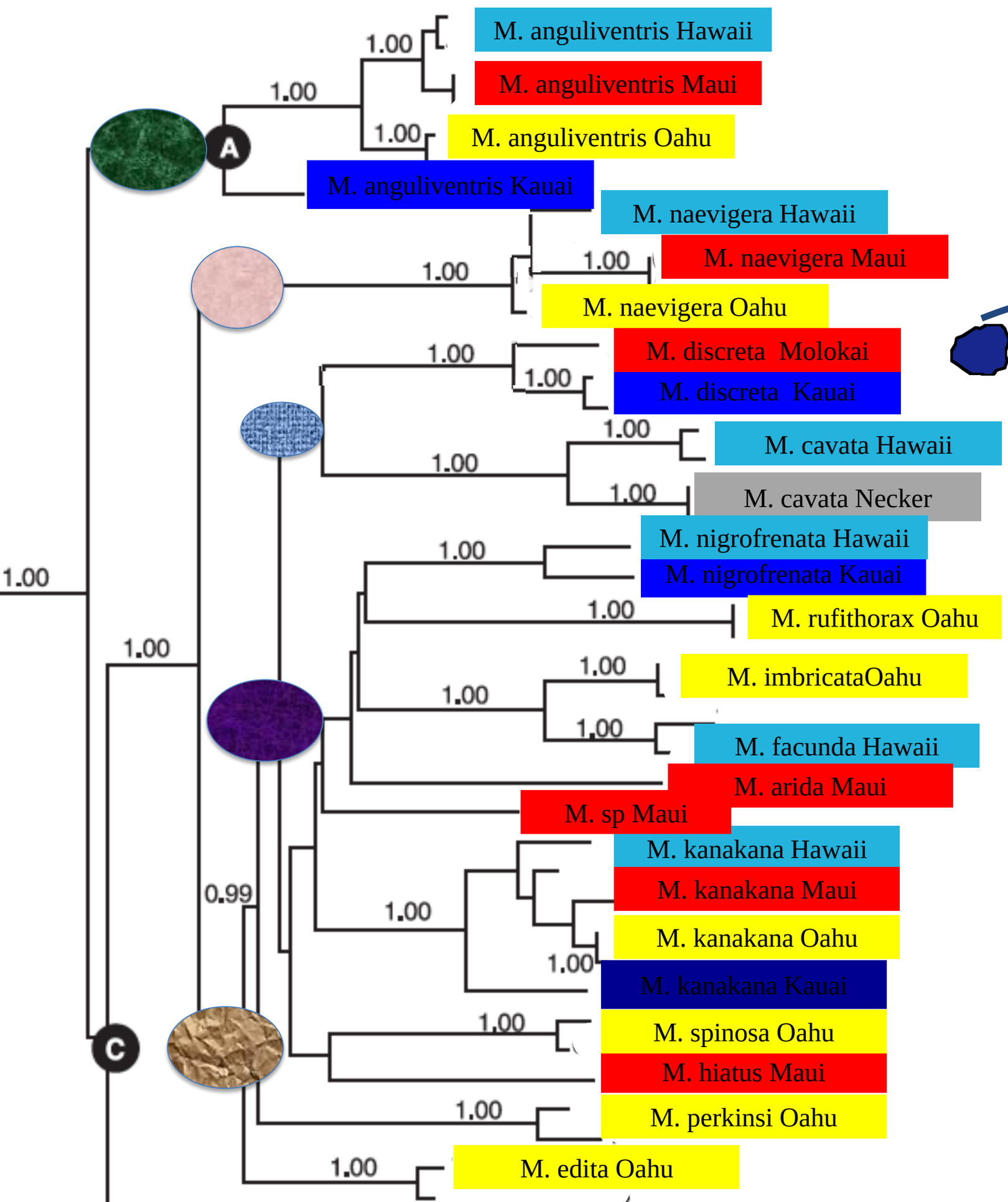


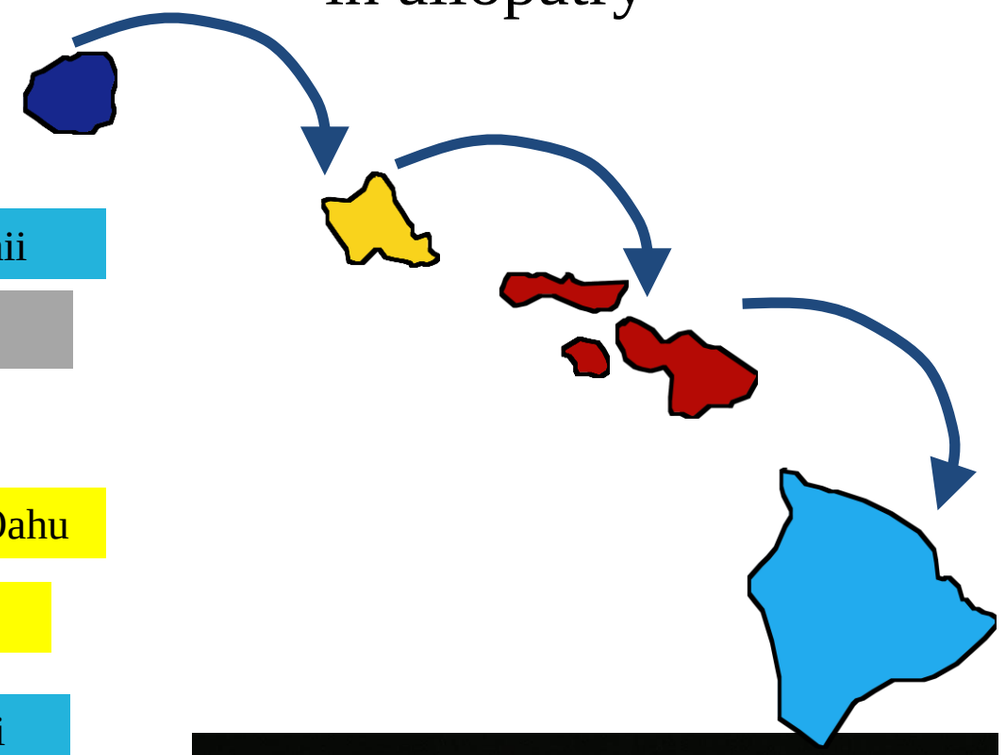


Hormiga, Arnedo & Gillespie 2003. *Systematic Biology* 52: 70-88

Diversification early in radiation

- Adaptive
- Populations diverge in allopatry





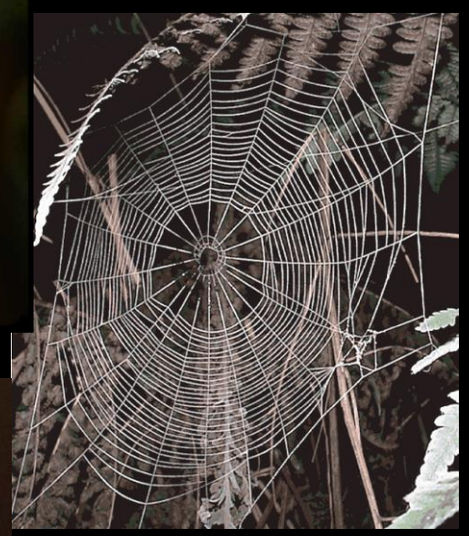
Garb & Gillespie, 2009.
Molecular Ecology







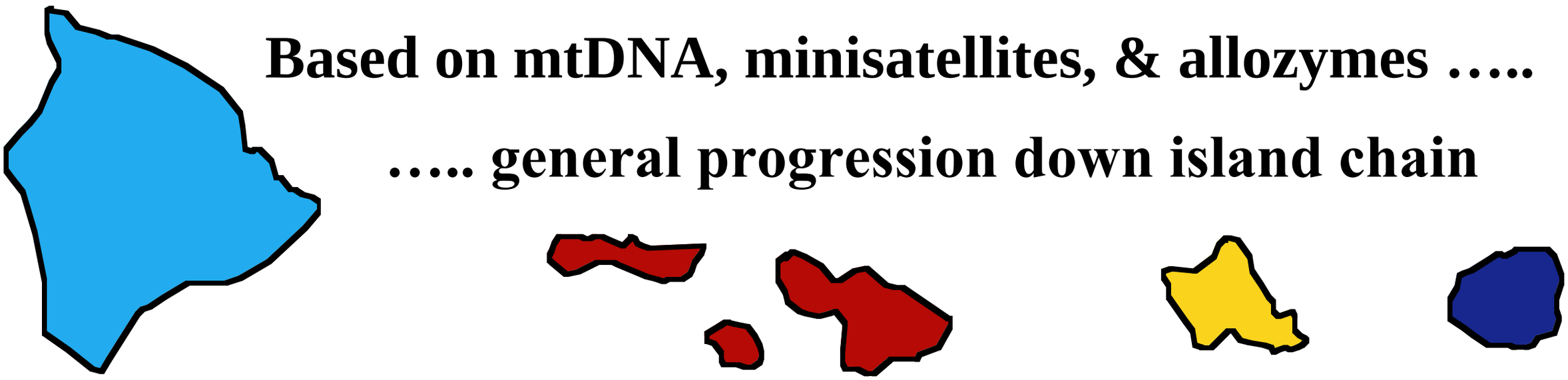






Radiation of long-jawed spiders, *Tetragnatha*, in Hawaii

1. Micro-macro evolution **2. Evolutionary dynamics** 3 Species diversity 4. Ecological interactions



Independent evolution of ecomorphs

Hawaii **Maui Nui** **Oahu** **Kauai**

Gillespie 2004, *Science*; Pons & Gillespie 2004. *J. Mol Evolution* **59**: 632-641

1. Micro-macro evolution **2. Evolutionary dynamics** 3. Species diversity 4. Ecological interactions

Argyrodes trigonum

A. huinakolu Kauai

A. kahili Kauai

A. uwepa Oahu

A. sp (white) Oahu

A. makue Oahu

A. sp (black) Molokai

A. sp (gold) Molokai

A. sp Molokai
(like mele- kalikimaka)

A. poele Molokai

A. melekalikimaka Maui

A. laau Maui

A. alepe Maui

A. corniger Maui

A. waikula Hawaii

A. hiwa Hawaii

Gene-tree (mt COI & nuclear EF1 seqs); output by Beast. Posterior probabilities above nodes

Rhomphaea metaltissima

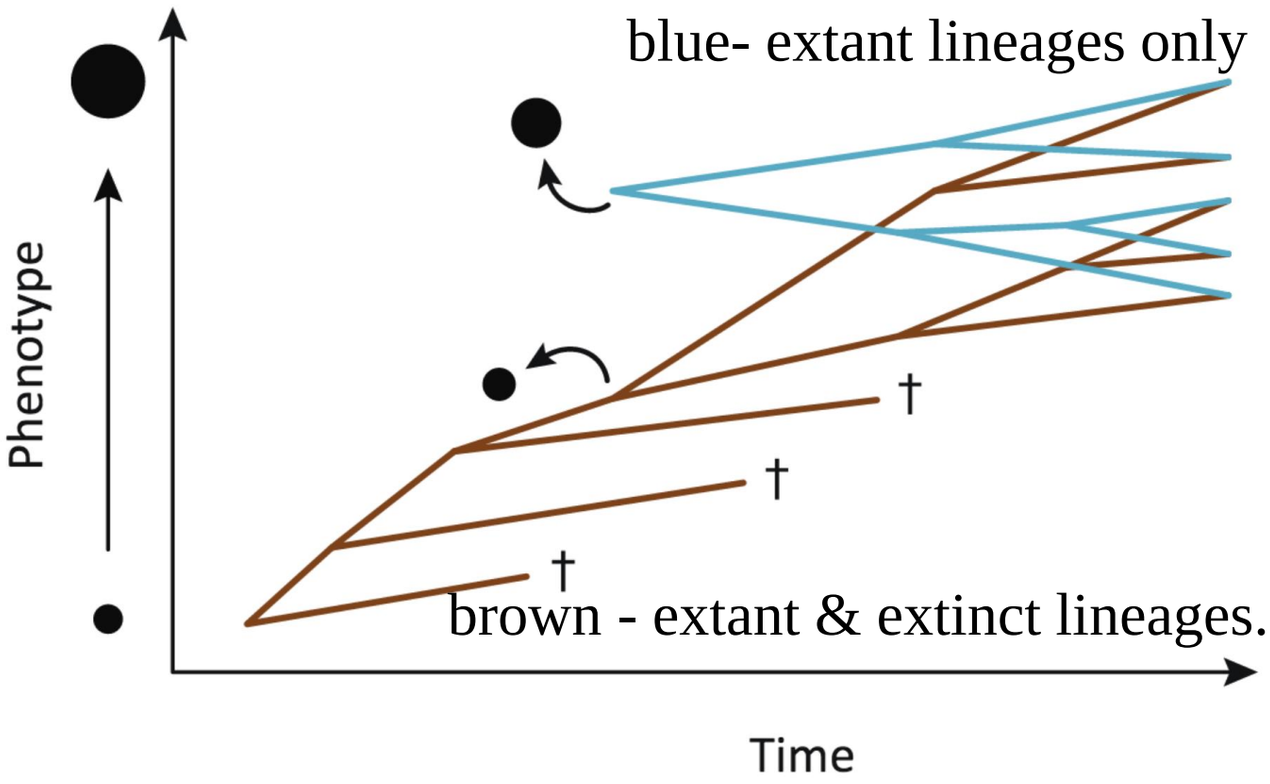
Ariamnes attenuata

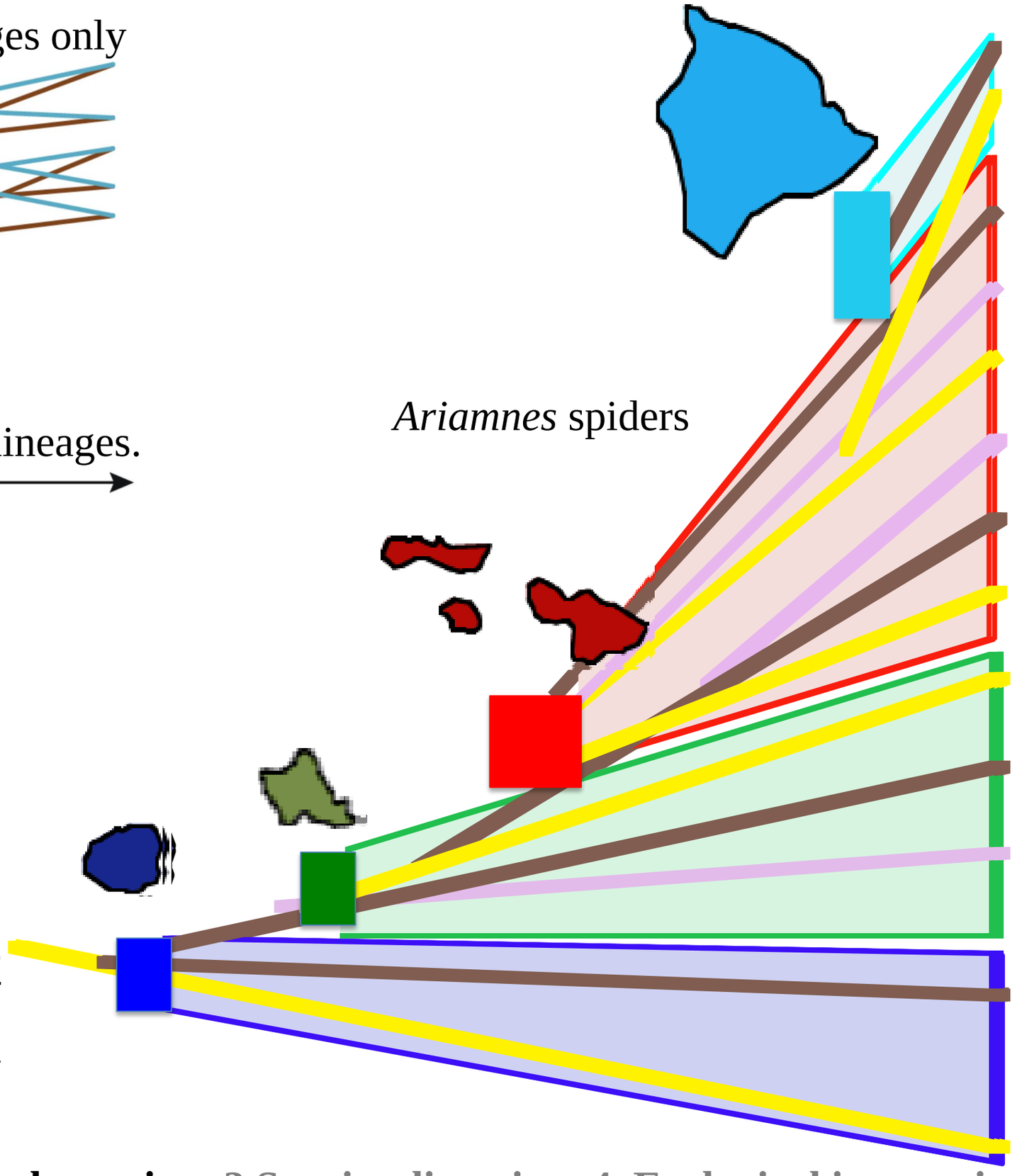
Spintharus flavidus

Evolution of "ecomorphs"

Repeated evolution

2. Evolutionary dynamics





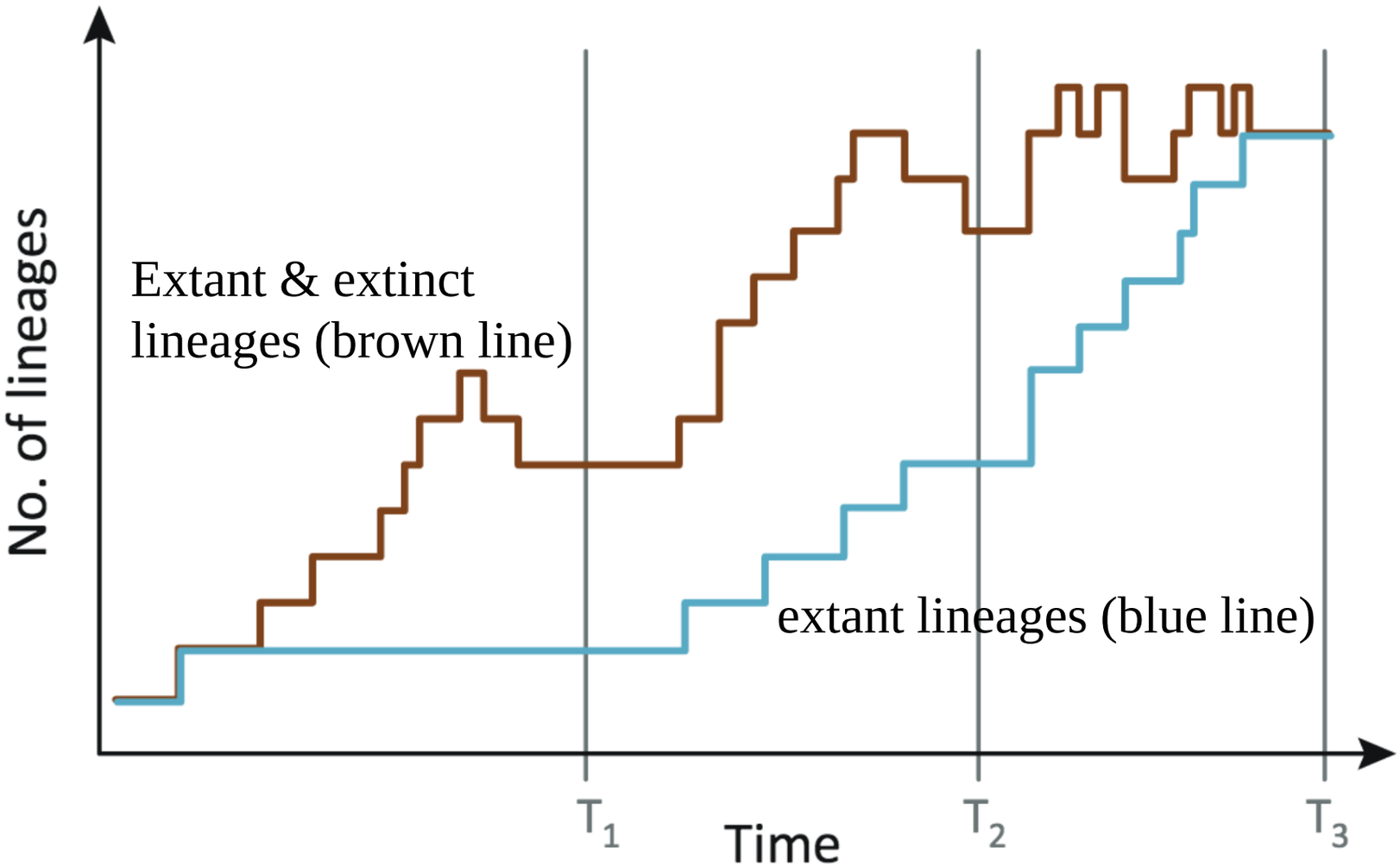
"Onset" of diversification in a given lineage is reset on each island

Therefore, we know that:

- **Taxa differ in**
  - **The interplay between ecological & genetic shifts during diversification**

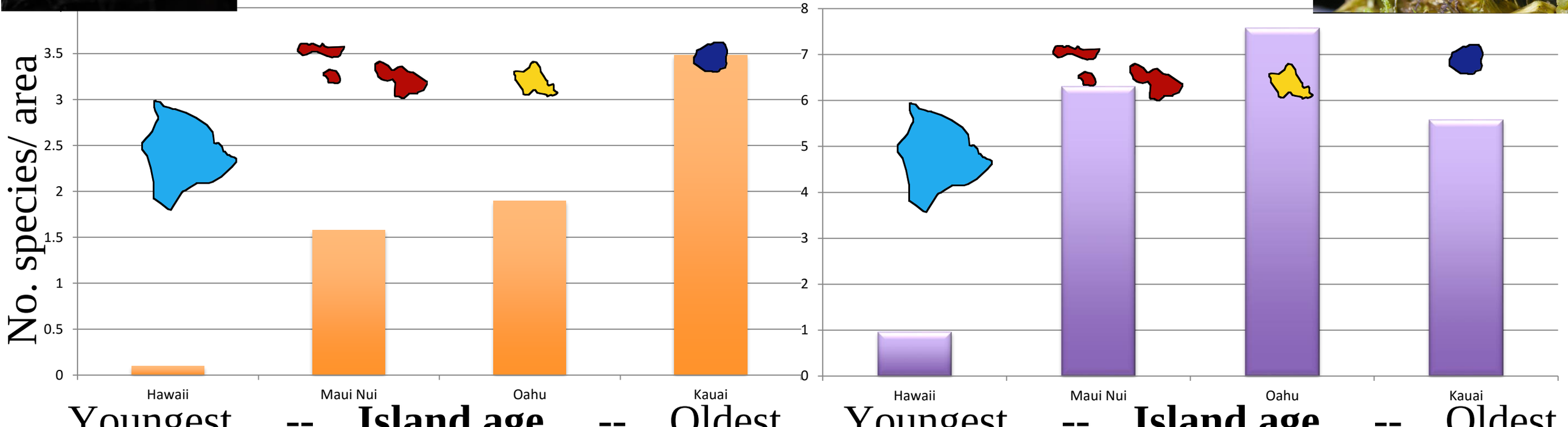
- …. Can now look at patterns of diversity over time; whole communities

3. Species Diversity



Insights from chronosequence

Orsonwelles ***Mecaphesa***

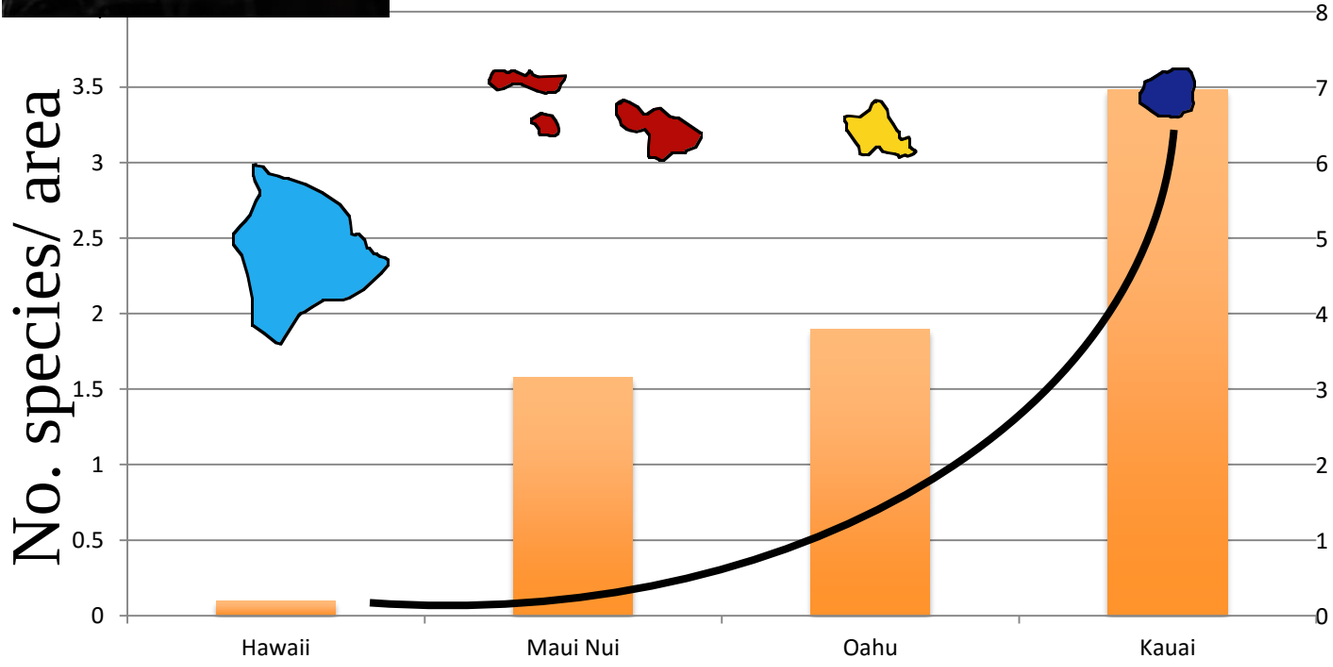


Youngest -- **Island age** -- Oldest Youngest -- **Island age** -- Oldest

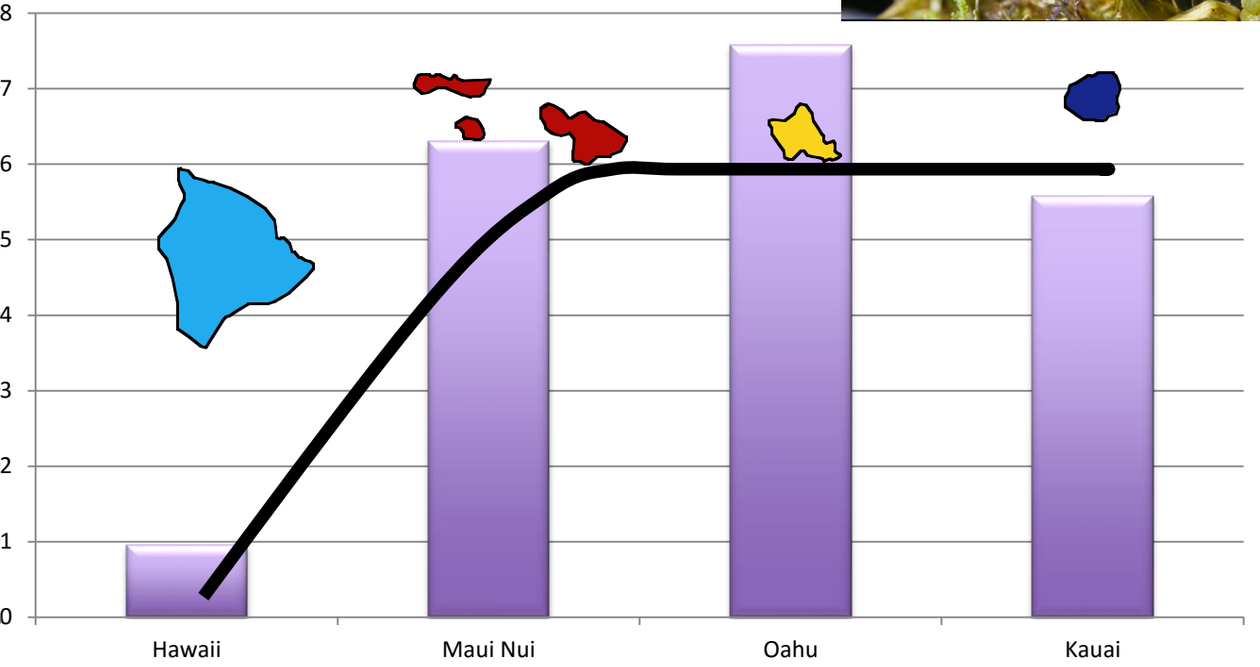
1. **Micro-macro evolution** 2. **Evolutionary dynamics** **3.Species diversity** 4. **Ecological interactions**

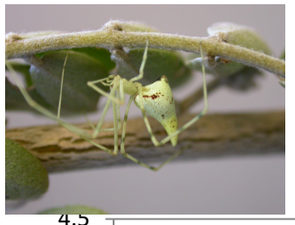
Insights from chronosequence

Orsonwelles

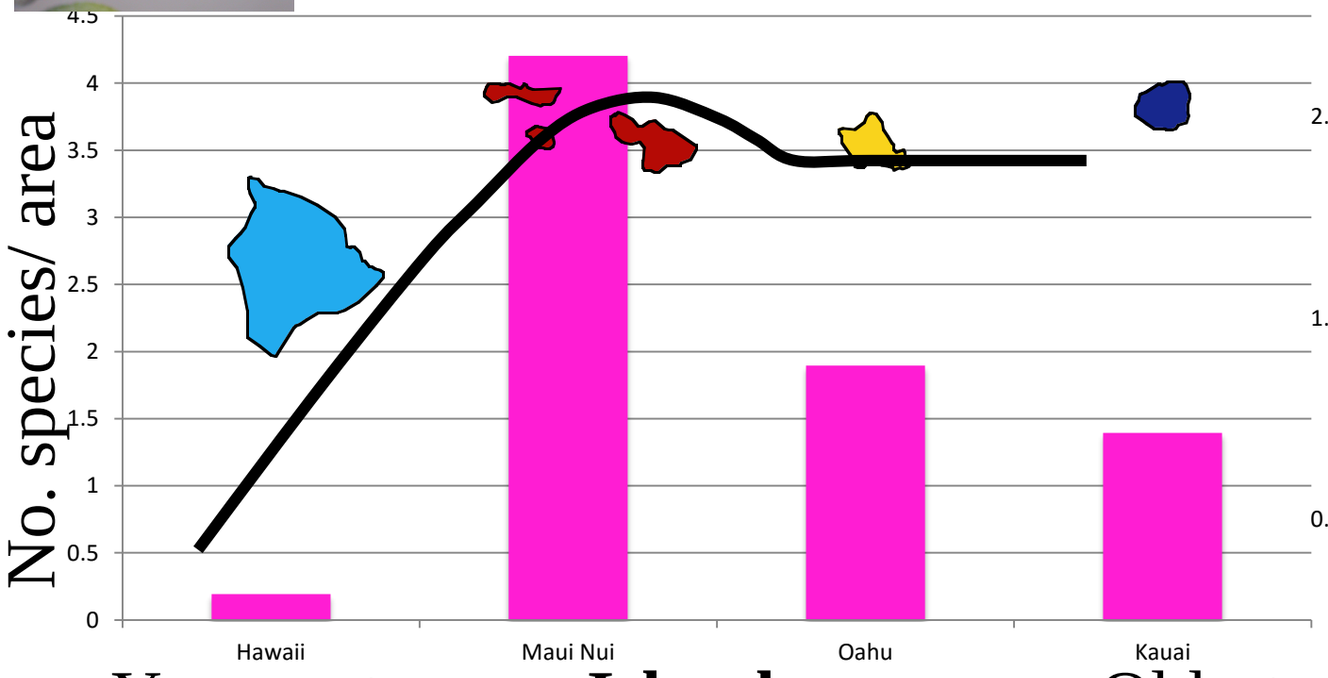


Mecaphesa



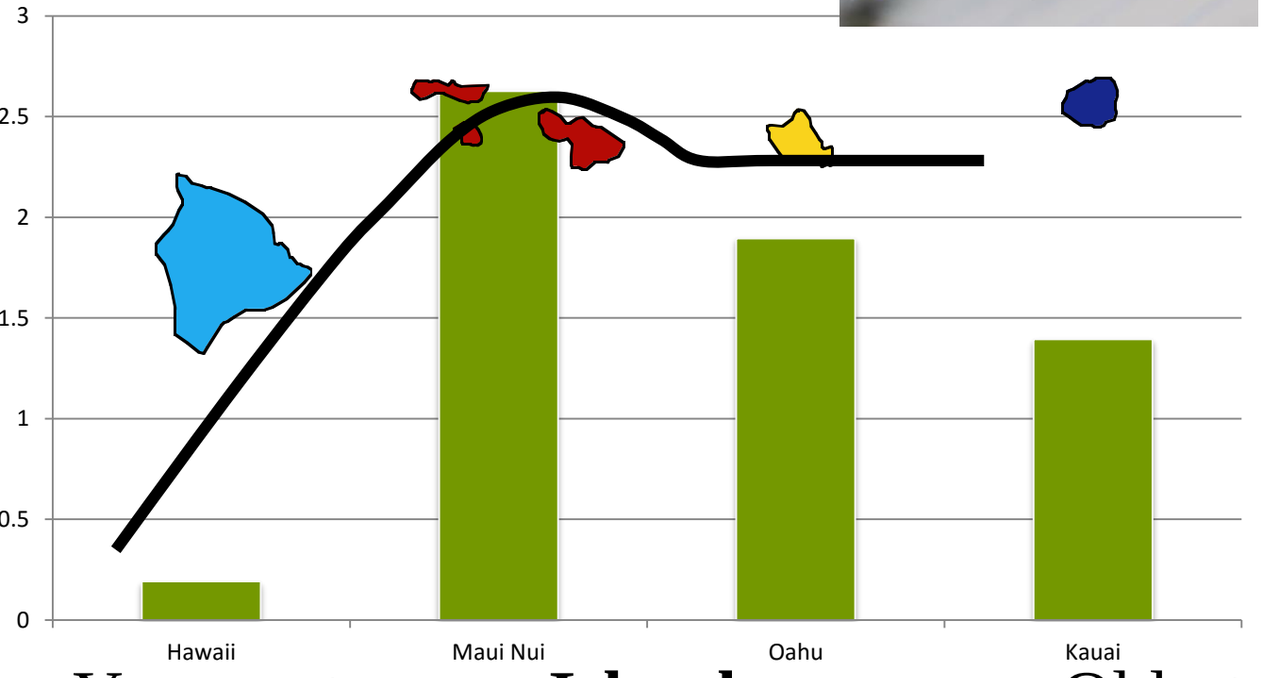


Ariamnes



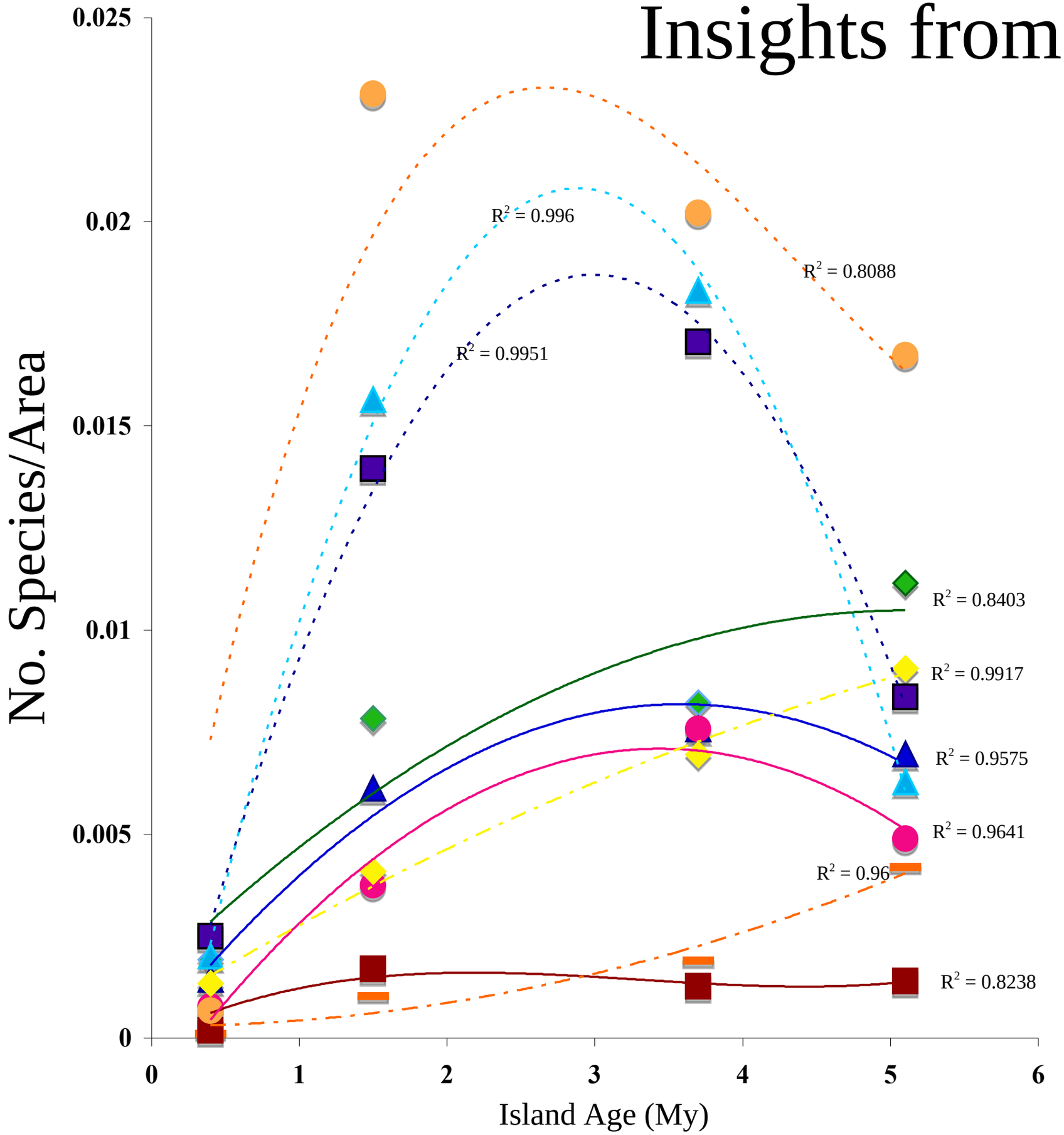
Youngest -- **Island age** -- Oldest

Tetragnatha **– spiny leg clade**



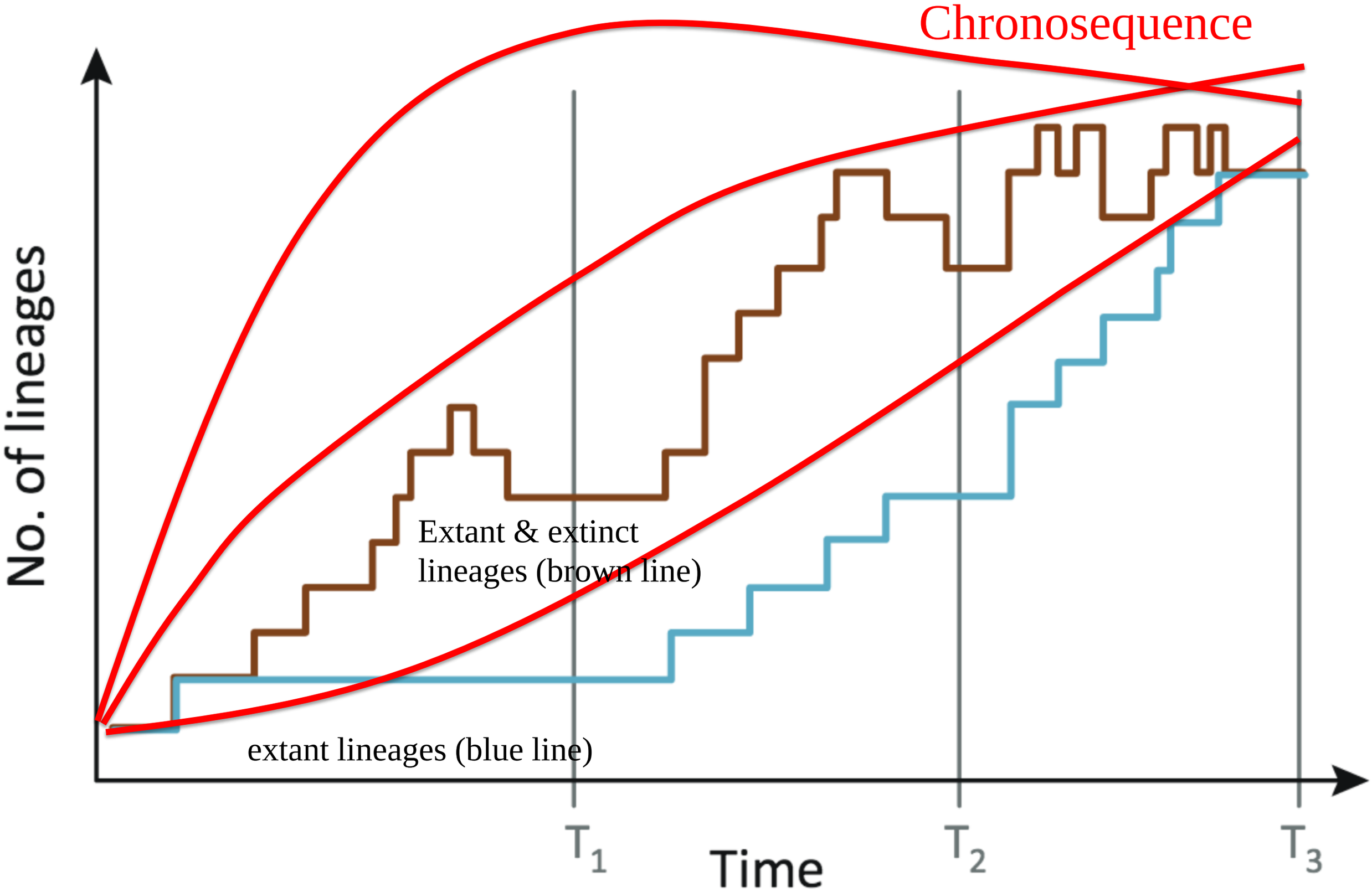
Youngest -- **Island age** -- Oldest

Insights from chronosequence



Gillespie & Baldwin 2009

Species diversity over time



Therefore, we know that:

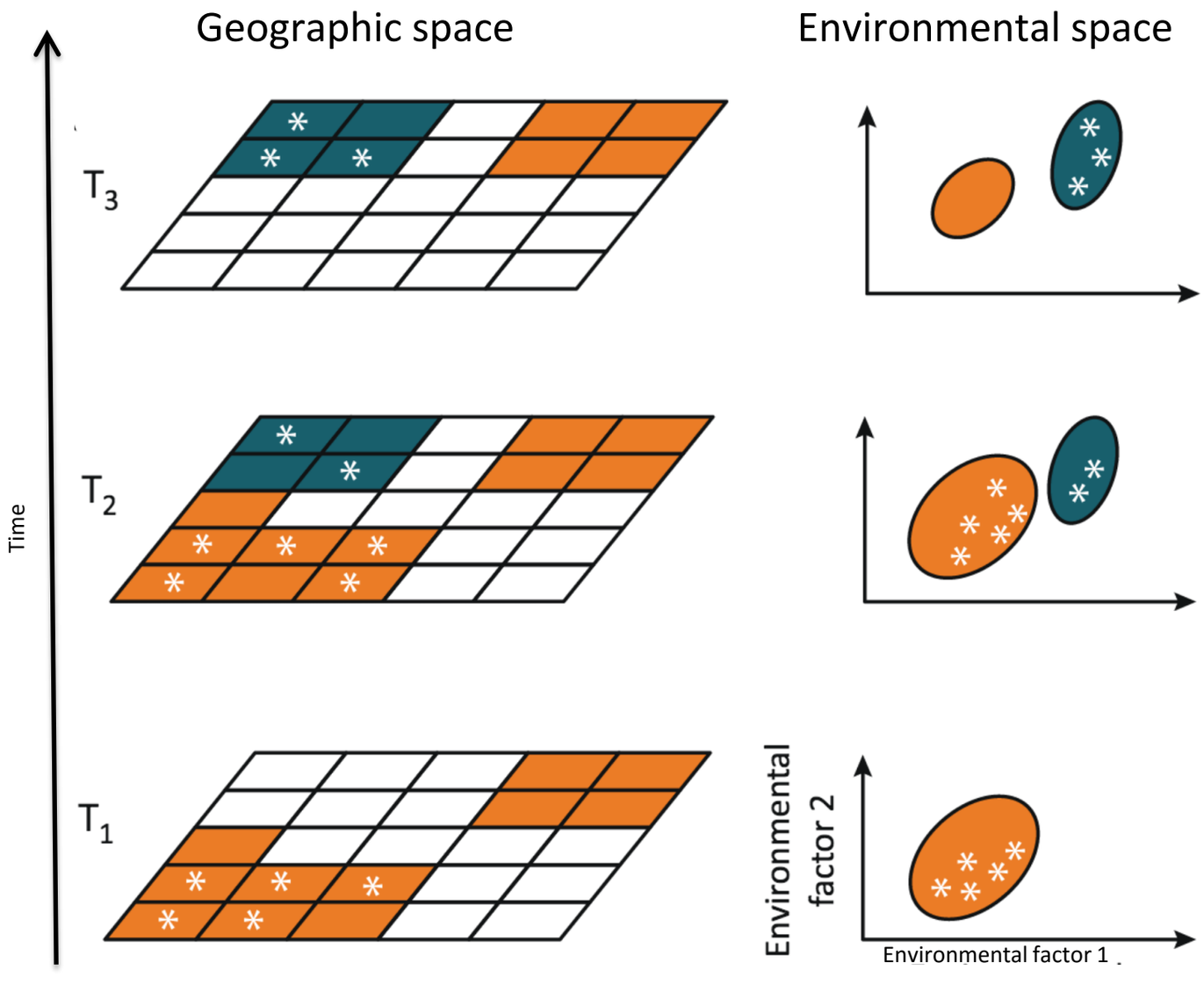
- **Taxa differ in**
  - The interplay between ecological & genetic shifts during diversification
  - **Rate of accumulation of species**
  - **Patterns of diversity over time**

- Highlights how different groups **perceive** the chronosequence

- …. and **ecological theory** can give us a guide as to what's novel

4. Ecological Interactions

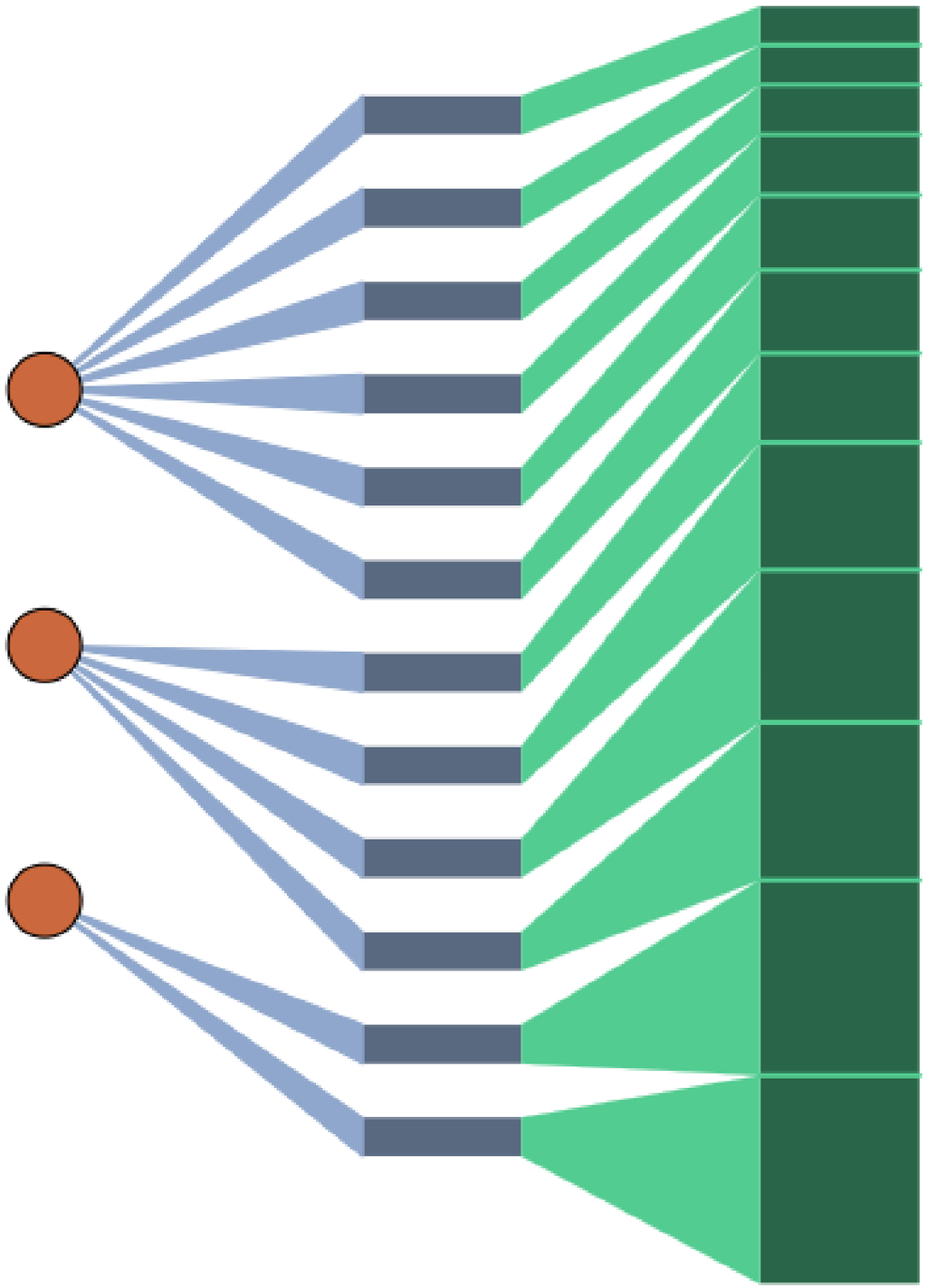
- Measurement of ecological metrics
- Space for time



Different environmental conditions (colors)

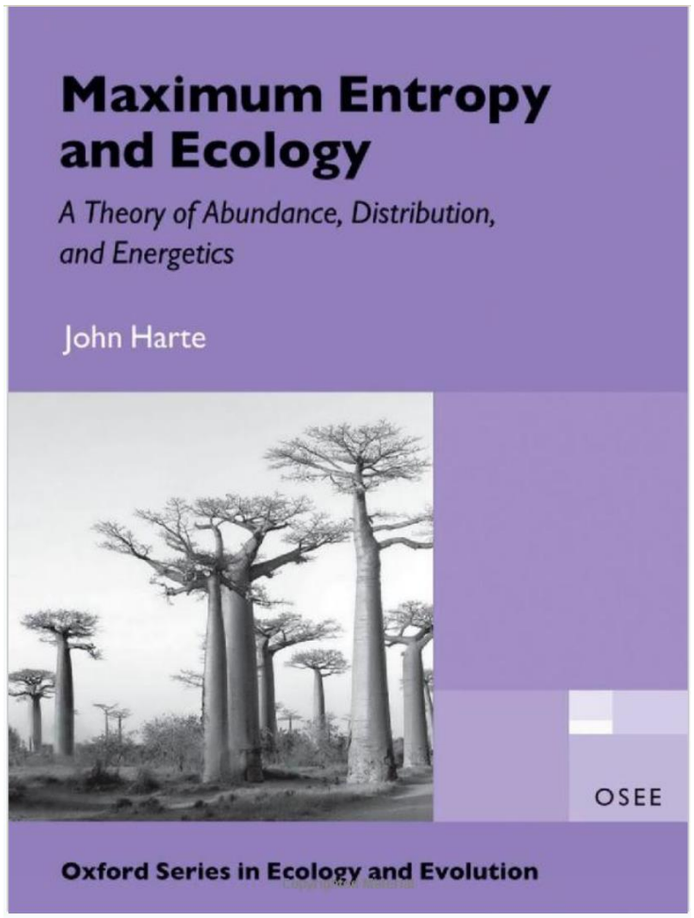
Species (*) shifts from orange to blue environment that appears only after T1

Maximum Entropy Theory of Ecology



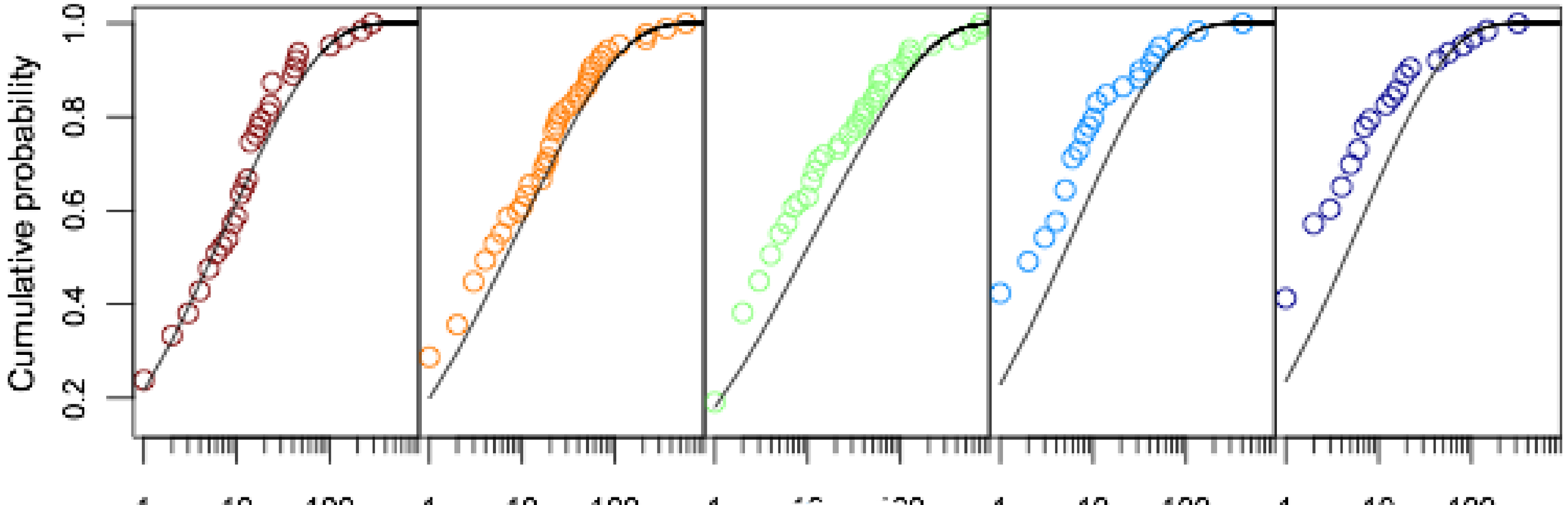
Species Individuals Energy

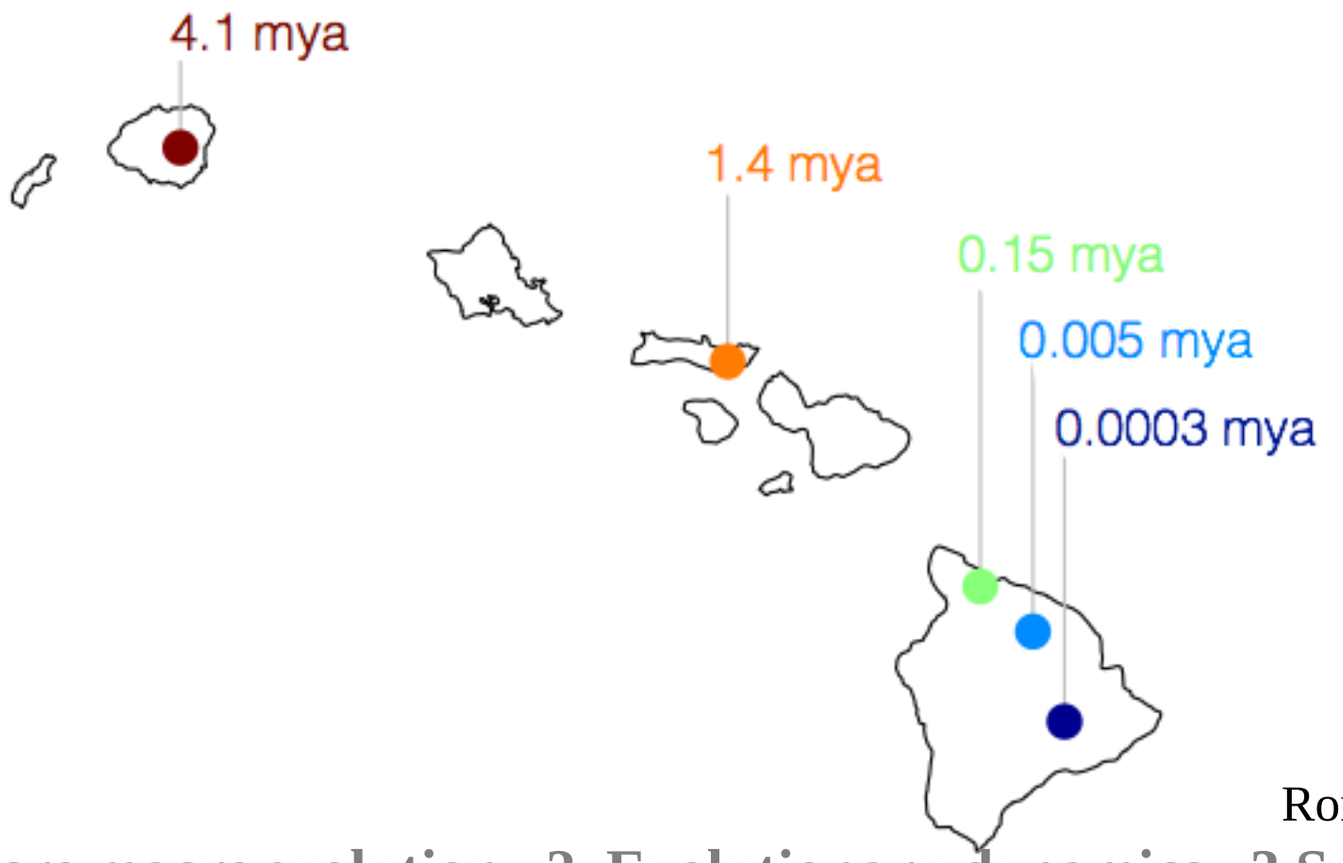
- Community-wide genetic divergence across space, environment and time (chronosequence)
- Testing novel theory



Harte (2011) Oxford University Press.

Fitting species abundance data to METE predictions

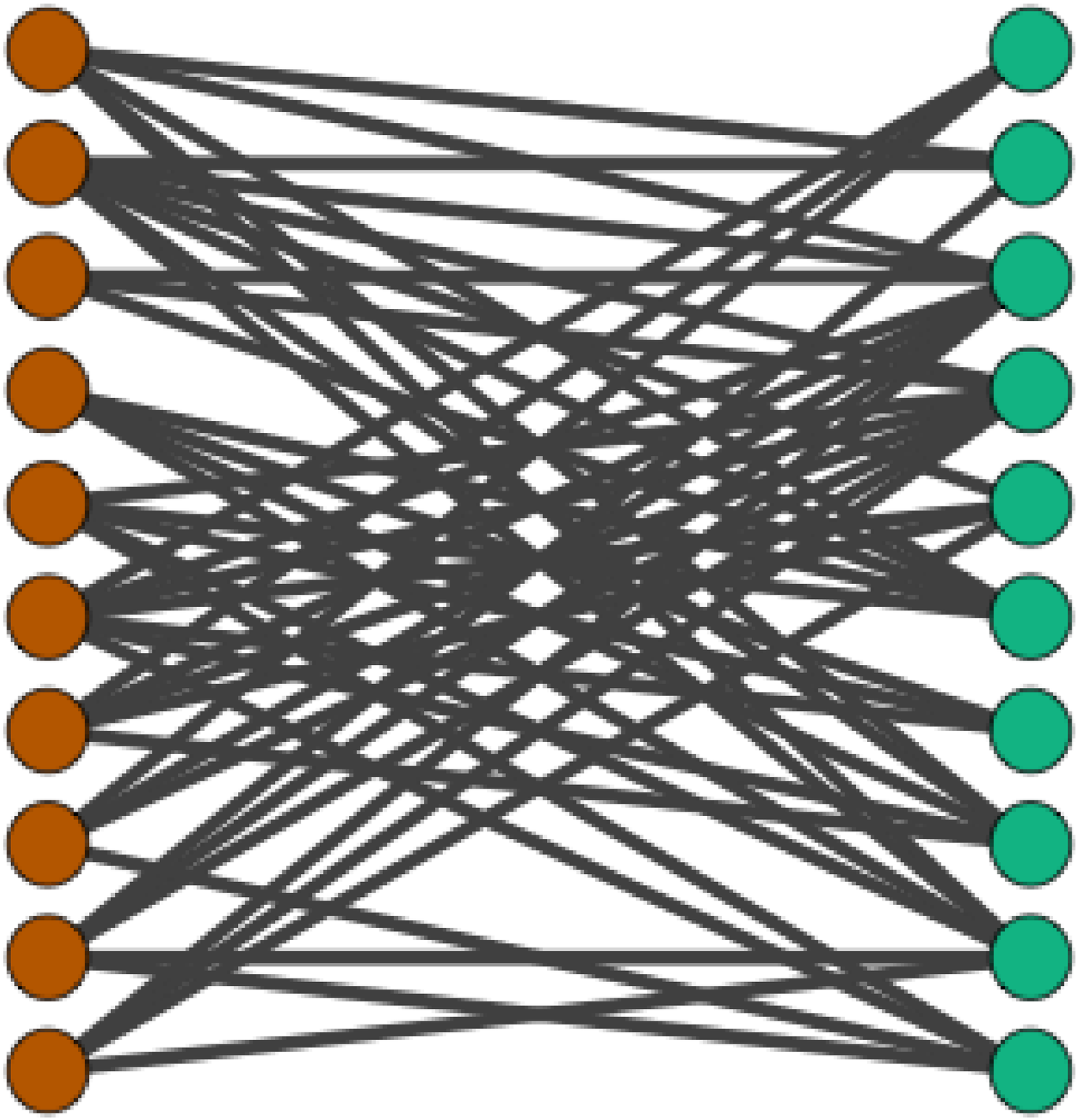




Deviation from predictions on youngest substrates may indicate that community has not yet reached steady state

Rominger *et al.* 2015 *Global Ecology and Biogeography*

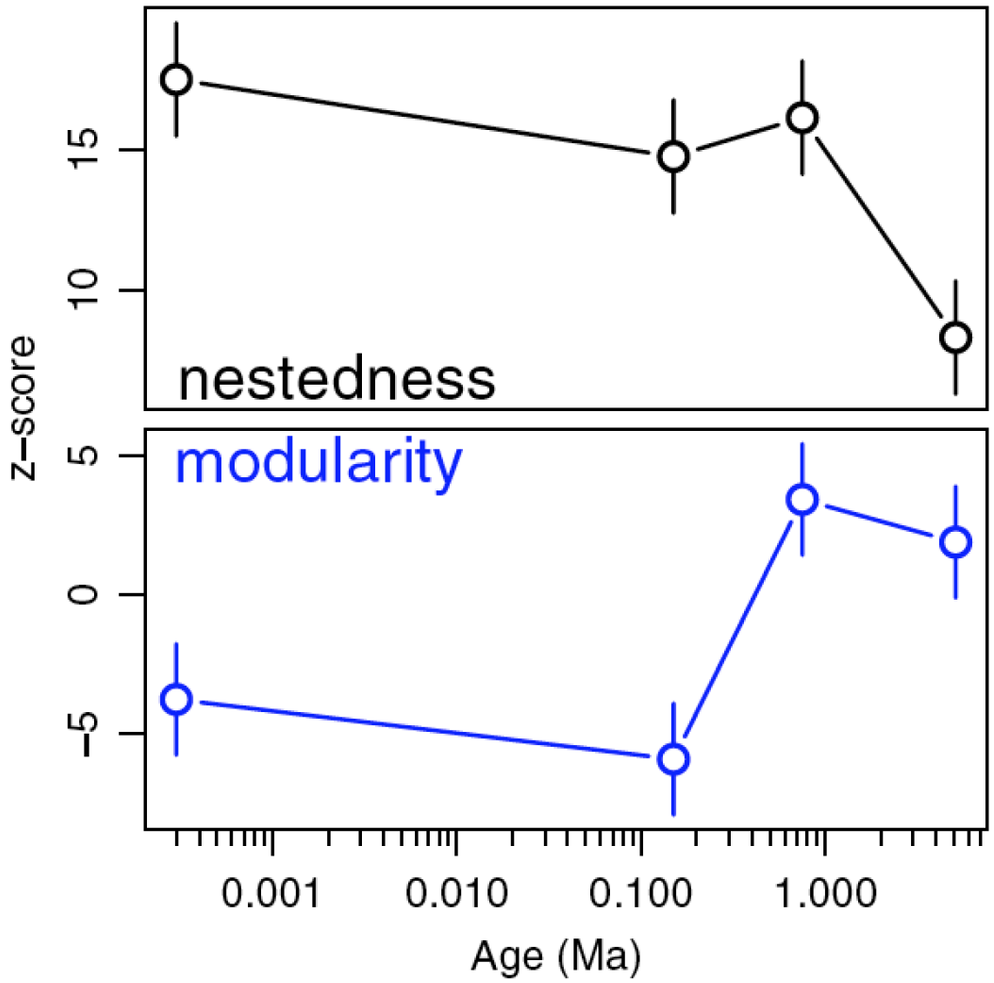
Interaction Networks



Modularity - degree to which species interact in semi-autonomous modules

Nestedness - degree of asymmetry in interaction between specialists and generalists

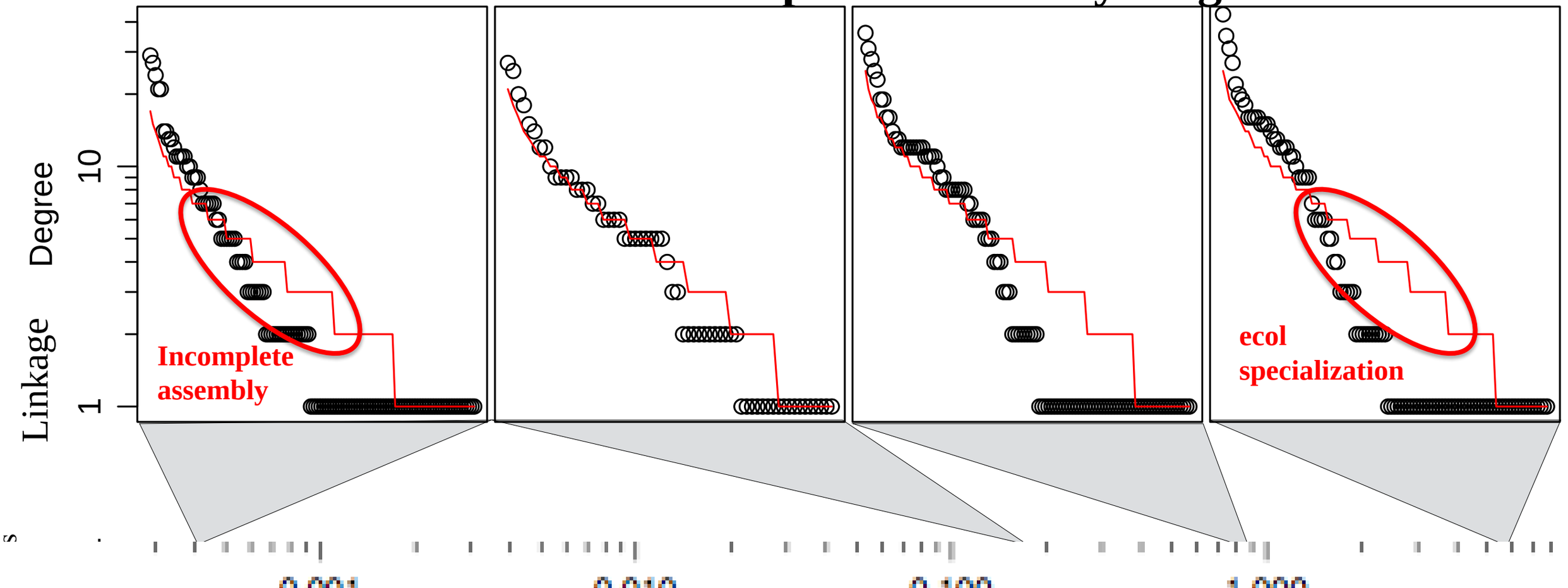
- **Nestedness decreases** with site age. *Perhaps due to high immigration of new species with high probabilities to eat / be eaten by generalist species already present*



- **Modularity increases**, *likely due to coevolution*

Rominger *et al.* 2015 *Global Ecology and Biogeography*

Networks deviate most from METE predictions on youngest & oldest sites



Broussaisia arguta

Melicope spp.

Coprosma spp.

Dodonea viscos.

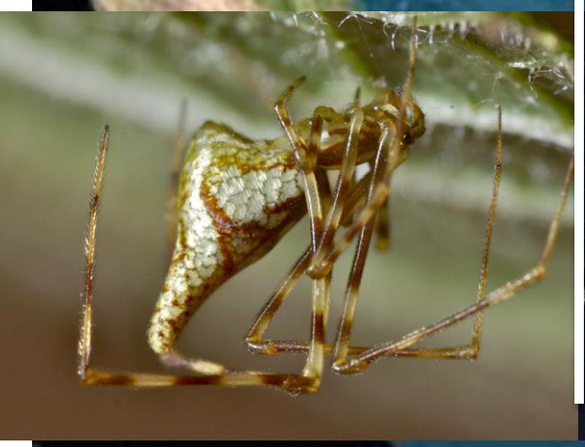
Bennett & O'Grady 2012 Mol. Phylo. Evol.

- ecological theory can give us a guide as to what's novel

Rominger *et al.* 2015 *Global Ecology and Biogeography*

Across the chronosequence we've found:

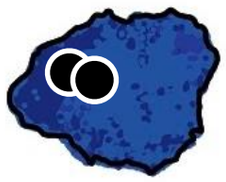
- Different arthropod groups perceive, colonize and diverge across evolving landscapes differently
- Results in different patterns of species accumulation over time
- Deviation from statistical steady state varies across groups and substrate ages.
- Interaction of ecological & evolutionary strategies, isolation & mixing, likely interact to produce patterns

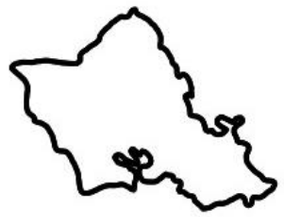




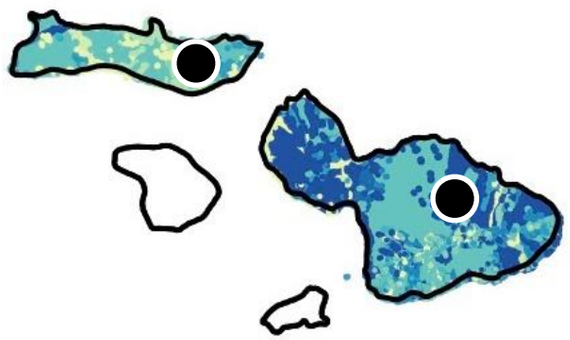

1. **Micro-macro evolution** 2. **Evolutionary dynamics** 3. **Species diversity** 4. **Ecological interactions**

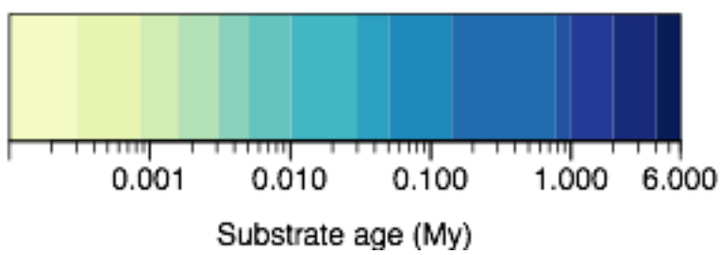
Research Underway ……

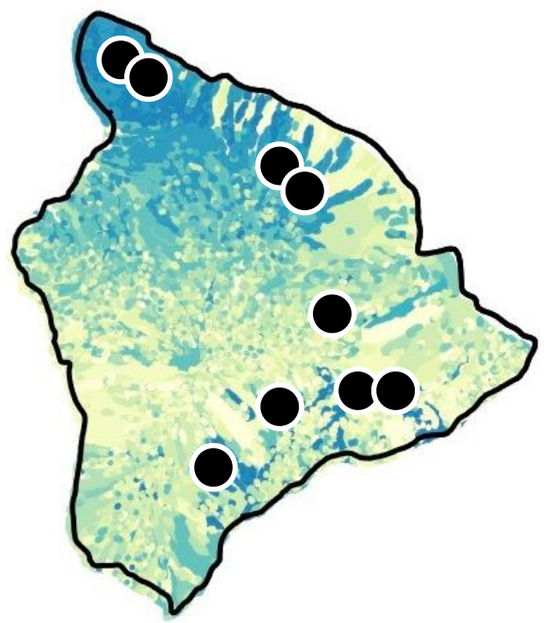




Looking at sites of similar **elevation**, **precipitation**; all in ***Metrosideros*** **forest** and accessible in **reserves**

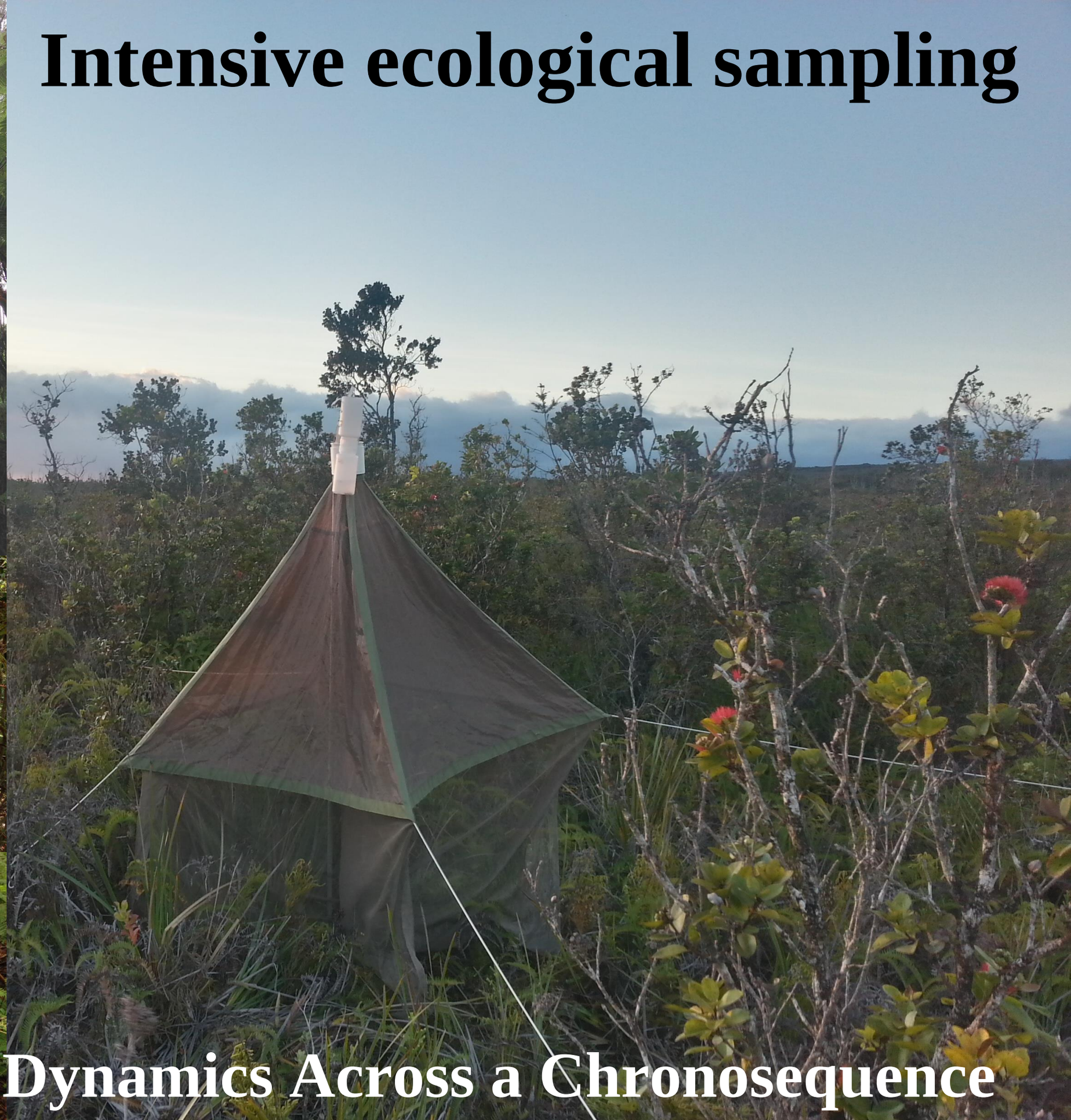






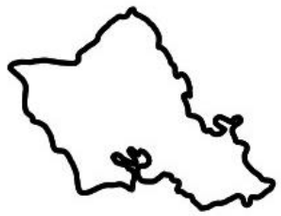
Biodiversity Dynamics Across a Chronosequence

Intensive ecological sampling



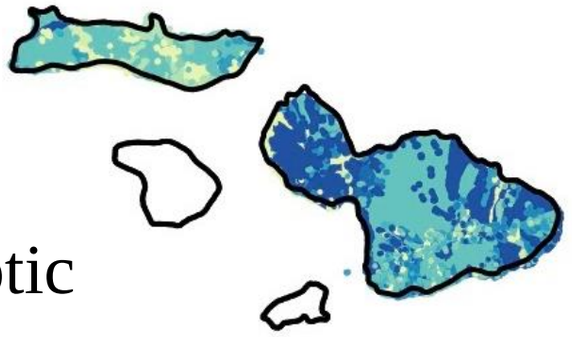
Biodiversity Dynamics Across a Chronosequence

Metagenomics across the chronosequence



Changes in Community Structure & Dynamics

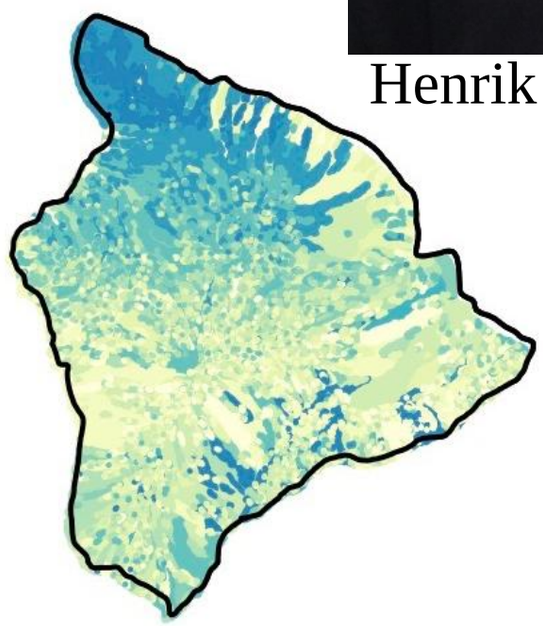
- Rapid identification of taxa & cryptic diversity
- Relative abundances
- Using metabarcoding of whole predators to identify
  - prey-predator interactions
  - food plants of herbivores



Changes in Evolutionary Dynamics

- Genetic structure of **all** lineages in the ecosystem
- Which factors drive divergence of lineages

Henrik Krehenwinkel



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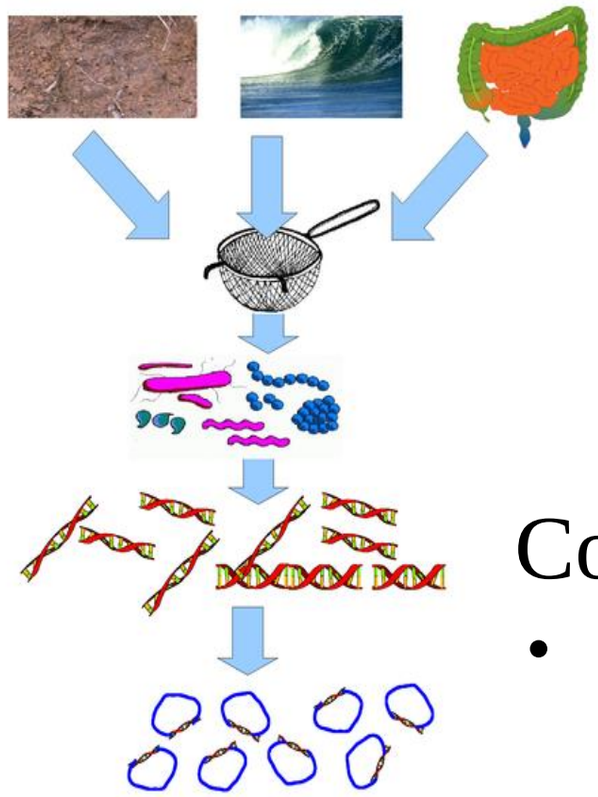
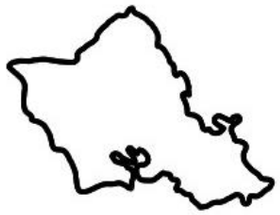
Pinol, J. et a. 2013. A progmatic approach to the analysis of diets of generalist predators …. Mol Ecol Resources 14: 18-26

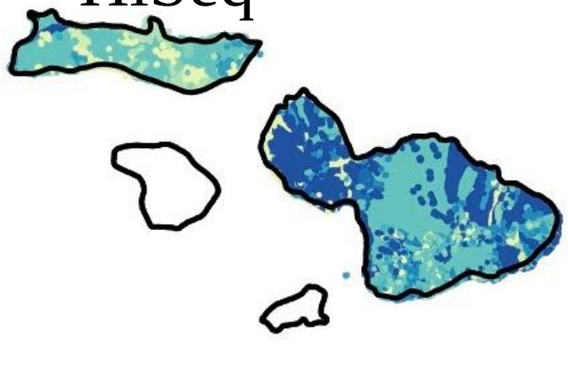
Kozich et al. 2012 Applied & Environmental Microbiology

Metagenomics across the chronosequence





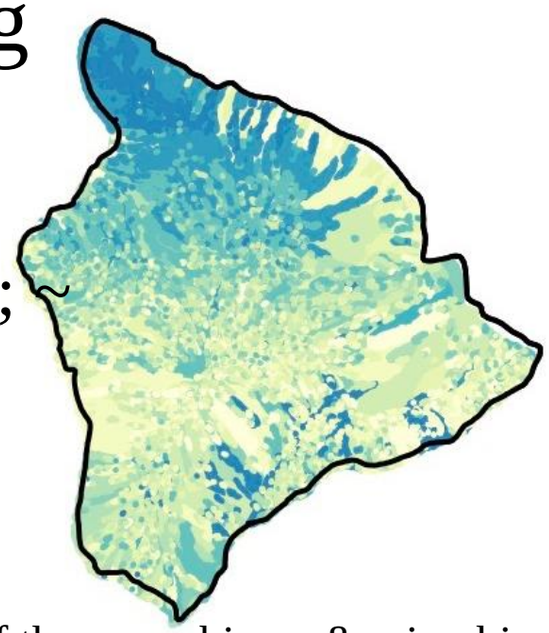
- 16s based taxon identification
- Molecular community studies
- Also functional genomic studies
- Initially on 454, now on MiSeq or HiSeq

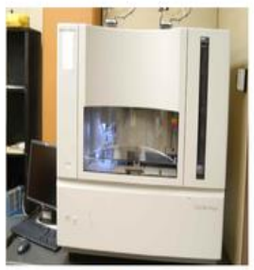


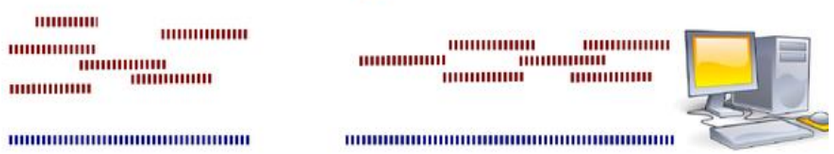
- ITS in fungi
- COI in animals

Cost-effective mass-multiplexing

- MiSeq protocol developed for microbiome sequencing
- Applicable to any other PCR fragment; 400 microbiome samples /run; sequencing right after PCR







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Mahalo! Thank you!

nature.berkeley.edu/hawaiidimensions

Visualization by Thorsten Andresen, Nils Sparwasser, S Reiniger & R Meisner; data from DLR, NGDC, GLCF & USGS