The Biogeography of Life

...Earth and Life Evolve Together...

"Nothing in evolution makes sense except in the light of molecular phylogenetics?"

Yes, in part
But, it is a two-way interaction

Future of Molecular Systematics

1. Biogeography
2. Ecology
3. Genomics
Future of Molecular Systematics

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Nature Genetics
27 Oct. 2011

The Anhorn Genomics X Prize has been declared for January 2013. Larry Kreis and Grant Company explain the selection of automation genome for the contest and provide the rules by which the contest will be judged.

A head-to-head competition will take place from 3 January to 2 February 2013. The $10 million grand prize will be awarded to the team(s) able to sequence 100 human genomes within 30 days in an accuracy of 1 error per 10,000 bases, with 35% completeness, including all insertions, deletions, and rearrangements, and a complete haplotype at an audited total cost of $1,000 per genome. The complete rules for the Anhorn Genomics X Prize made by MeDico are available as a supplement to this Commentary (Supplementary Note) at the competition website: http://genomics.xprize.org.

Future of Molecular Systematics

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Svante Paabo – Max-Planck Institute

Entire Genome of Extinct Neandertal Decoded
7 Feb 2012

Nature
November 2013

The oldest human DNA

The oldest human DNA

The oldest human DNA

The oldest human DNA

The oldest human DNA
Refined demography of archaic and modern humans

Together with evidence of adaptive introgression of genetic variants from archaic hominins to humans and emerging ancient genome data sets for domesticated animals and plants, these studies provide novel insights into human evolution and the evolutionary consequences of human behaviour.

Future of Molecular Systematics

1. Biogeography
2. Ecology
3. Genomics

Explicit marriage between phylogenetics and genomics now — phylogenomics
Future of Molecular Systematics

Explicit marriage between phylogenetics and genomics now — phylogenomics

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Ancient polyploidy in seed plants and angiosperms

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The coffee genome provides insight into the convergent evolution of caffeine biosynthesis

Future of Molecular Systematics

1. Biogeography
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The Biogeography of Life

“. . . that grand subject, that almost keystone of the laws of creation, Geographical Distribution”

[Charles Darwin, 1845, in a letter to Joseph Dalton Hooker, later Director of the Royal Botanic Garden, Kew]

The Biogeography of Life

“. . . that grand subject, that almost keystone of the laws of creation, Geographical Distribution”

Darwin needed two chapters in the *Origin of Species* to cover his ideas on geographical distributions of organisms

“I am prepared to go to the stake, if requisite, in support of the chapters on the geological and geographical distribution of life.”

Thomas Huxley after reading the *Origin of Species*

What is Biogeography?

1. *How* are organisms and their attributes distributed over the surface of the earth, and over the history of the earth?
2. *Why* do organisms and their attributes show these patterns of distribution?

*Argyroseriphium sandwicense* - Haleakala silversword

Approaches to Biogeography

- Biogeography is a broad field - requires information from:
  - ecology, systematics, evolutionary biology, population biology, genetics, cytology, morphology and anatomy, physiology, paleobiology, the geosciences, and natural history

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- 3 main flavors of biogeography

  - Argyroxiphium sandwicense - Haleakala silversword

Floristic (or Faunistic) Biogeography

- Where various taxa are distributed

  Where are members of the Cactaceae (cactus family) found?

Ecological Biogeography

- Distributions of attributes of organisms without concern to their classification

  Why do rainforests occur where they do?

  The plants that dominate the rain forests of southeast Asia are taxonomically distinct from those of South America, but forests are physiognomically similar (e.g. giant buttress-rooted emergent trees)

  Vegetation looks the same, but the floras are different (Alexander von Humboldt!)

Historical Biogeography

- Combines organismal history with geological events to explain past and present distributions

  "Earth and Life Evolve Together"

  Requires information from previous two branches of biogeography plus phylogenetics and earth history
The interplay of geological and biological evolution is critical in understanding why the Haleakala silversword is found in Maui, when and where it or its ancestors came from, and why it has specific features of morphology, chromosome number, and physiology.

Historical Biogeography

— Combines organismal history with geological events to explain past and present distributions

Biogeography includes . . . island biogeography

Biogeography includes . . . dispersal biogeography

Biogeography includes . . . plate tectonics
Biogeography includes . . . plate tectonics

Alfred Wegener (1920) described both plant and animal fossil examples supporting his theory — he believed that this biogeographic data was the strongest evidence for his theory.

- Geological strata continuous between continents
- Fossil disjunct distributions between continents

Biogeography includes . . . paleobiogeography

Jurassic Period (208 - 146 mya)

"Modern" genera are first seen for Ginkgo

Biogeography includes . . . glacial history

The final shaping of North American (and Great Lakes) flora and vegetation occurs during the Recent Epoch (Holocene) following the glaciation of the Pleistocene.

Biogeography + Phylogenetics

"If philosophy is the devil’s whore, as Martin Luther once quipped, then biogeography and biological systematics are fast becoming Old Nick’s bordello" (Craw, 1988b)

Phylogenetics and historical biogeography are now intimately intertwined . . .
Disjunctions: how are these distribution patterns explained?

Two main ideas:
- geological events separate once continuous biota (vicariance)
- dispersal events over geological barriers (dispersalism)

Vicariance paradigm:
- unrelated sets of species show repeated pattern of area relationships via geological events (e.g., rafting of continents)

Dispersalist paradigm:
- species move independently via long distance dispersal over pre-existing geological barriers

Disjunctions: how are these distribution patterns explained?

Vicariance vs. Dispersal similar pattern, different process

Vicariance
- Erection of ocean barrier
- Divergence in isolation

Dispersal
- Dispersal across ocean barrier
- Divergence in isolation

Species limited to one area
Disjunct continental areas

Widespread species
Continuous continental area

Disjunct (vicariad) species
Disjunct continental areas

Disjunct species
Disjunct continental areas
Vicariance vs. Dispersal
how do you decide?

Historical Biogeography has relied on two sources of information
1. Phylogenetic trees - clades
2. Knowledge of splitting events of areas - continents, mountain erection, etc.

Vicariance

Disjunct (vicariad) species
Disjunct continental areas

If multiple groups of organisms show congruence in the pattern - then vicariance is assumed

Dispersal

Disjunct species
Disjunct continental areas

Vicariance vs. Dispersal
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Dispersal is often relegated to “geographical noise”, ad hoc, untestable, and thus even non-scientific

Vicariance

Disjunct (vicariad) species
Disjunct continental areas

Southern Hemisphere Temperate Flora

- Southern Hemisphere temperate plants, animal, and fungi are classic in vicariance vs. dispersal arguments

Southern Hemisphere Temperate Flora

Nothofagaceae - 35 species of trees and shrubs, evergreen and deciduous, restricted to South America, New Zealand, Australia, Tasmania, New Caledonia, New Guinea, and fossilized in Antarctica

Absent from Africa! — “odd continent out”
Connections between South America and Australasia pronounced:

• Subg. Nothofagus — South America
• Subg. Fuscospora — S. Am., N. Zeal., Tasmania
• Subg. Lophozonia — S. Am., N. Zeal., Tasmania, Austr.
• Subg. Brassospora — New Caledonia, New Guinea

Proteaceae comprise 1700 species of woody plants placed in 79 genera predominantly of the southern hemisphere. Unlike Nothofagaceae, occurs in south Africa and Madagascar, and extends into southern China.

The 16 genera from Africa are endemic and comprise only 3 lineages. In comparison, South America and Australasia share roughly half of the genera in common. All tribes within the latter two areas are shared.

Africa — “odd continent out”!

Restionaceae comprise 520 species of grass-like plants placed in 58 genera predominantly of the southern hemisphere.

The 350 species from Africa are unique and belong only to 11 genera of the Restio group. In contrast, South America and Australasia share many genera including some species. Africa — “odd continent out”!
Why is Africa the "odd continent out" when it comes to the temperate southern hemisphere flora?

Three reasons:

1. All three continents separated from Gondwana at about 100-110 mya in the early Cretaceous, but South America and Australia linked with temperate Antarctica until about 50 mya (and via small water passages until 27 mya).

2. Africa drifted further north and experienced greater climatic change through this latitudinal journey. Greater extinction of temperate biota in Africa, which is now restricted to small area of south Africa.

3. Africa made secondary contact with temperate Eurasia around 17 mya; long contact further differentiated the temperate flora of Africa relative to South America and Australia.

Estimates in millions of years BP when migration routes between land masses were broken or made.
Are all these southern hemisphere disjunct patterns best explained by vicariance (i.e., continental drift)?

We can get information about continents, the relationships of organisms or clades, but we still have little knowledge about timing of events or a clock.

Southern Hemisphere Temperate Flora

Bromeliaceae

Rapateaceae

Continents, Clades, and Clocks

Historical Biogeography has relied on two sources of information

1. Phylogenetic trees - clades
2. Knowledge of splitting events of areas - continents, mountain erection, etc.

What is missing?

3. Times for branching events of clades - "clocks"!

Vicariance vs. Dispersal

how do you decide?

Continents, Clades, and Clocks

Re-thinking the "classic" vicariance stories...
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Continents, Clades, and Clocks — Putting it all together for Fuchsia

25-30 mya Diporites (Fuchsia) pollen fossils

Fuchsia diversifies at 32 my in South America

Old world Fuchsia divergence dated at 30 my, consistent with oldest Australian fossils (25-30 my)

Long-distance Dispersal to New Zealand dated at 20 my
Long-distance Dispersal to Tahiti at 10 my
Old world \textit{Fuchsia} divergence dated at 30 my, consistent with oldest Australian fossils (25-30 my)
Long-distance Dispersal to New Zealand dated at 20 my
Long-distance Dispersal to Tahiti at 10 my
\textit{Fuchsia} diversifies at 32 my in South America

Species relationships and timing indicate Gondwanan break-up (vicariance) followed by dispersal events to New Zealand and later Tahiti.

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Explosive radiation of sect. \textit{Fuchsia} dated at 20 my, consistent with initial orogeny of the Andean mountains . . .

\ldots and of their pollinators

Rapid radiation of hummingbirds – McGuire et al. 2015
Disjunctions: how are these distribution patterns explained?

Synthesis:
- vicariance explains some but not all disjunct patterns
- dispersalism requires numerous (but likely!) events
- many disjunctions are complex and involve both

"... that grand subject, that almost keystone of the laws of creation. Geographical Distribution"

If you are still around: Botany 422 – Biogeography
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