Evidence for Common Descent

36-149 The Tree of Life

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Review: Theory of Evolution

Working Definition:

> Cross-generational change in a *population* of organisms that involves changes in *gene frequency*.

In science, labeling something a theory does not mean that it is a conjecture or hypothesis. It means a well-supported, testable framework to explain or predict some natural phenomenon.

What we call the "theory of evolution" actually encompasses several different components.

Review: Theory of Evolution (cont'd)

1. The Fact of Evolution
2. Theory of Common Descent
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

Review: Theory of Evolution (cont'd)

1. The Fact of Evolution

   Evolution happens: Cross-generational change occurs in both gene frequencies and phenotypes.

   This is observed directly. Examples:

   - antibiotic resistant bacteria, influenza, HIV
   - Fish stocks

   The Fact of Evolution does not describe *how* evolution occurs or explain how it produces the diversity of life.

2. Theory of Common Descent
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

Review: Theory of Evolution (cont'd)

1. The Fact of Evolution
2. Theory of Common Descent

   All organisms alive on earth are descendants of one (or at most a few) common ancestor(s).

   As evolutionary changes accrue over time, new forms of life are generated as lineages split, a process called *speciation*.
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

Review: Theory of Evolution (cont'd)

1. The Fact of Evolution
2. Theory of Common Descent
3. Theories of Evolutionary Mechanisms

   Explain *how* evolutionary change occurs.

   - Natural Selection
   - Genetic Drift
   - Sexual Selection
   - Developmental Plasticity

   Current thinking: Most evolutionary change is driven by natural selection.

4. Theories of Speciation

Review: Theory of Evolution (cont'd)

1. The Fact of Evolution
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   Explain how population-level changes in gene and phenotype distributions produce new species.

   Central Idea: Reproductive isolation.

   Modes of speciation: Allopatric, Parapatric, and Sympatric

Review: Theory of Evolution

What we call the "theory of evolution" actually encompasses several different propositions:

1. The Fact of Evolution
2. Theory of Common Descent ⟵ Today: the evidence
3. Theory of Natural Selection
4. Theories of Speciation

Evidence for the Theory of Common Descent

- Since we have no real hope of finding LUCA – the Last Universal Common Ancestor – what counts as evidence for this theory?
- Does it make sense to separate the theory of common descent from the mechanism of evolution within a population?
- Is the theory of common descent falsifiable?
- What are some alternative theories?
- Why did I say "or at most a few"? Is that a cop out?

Plan

Categories of evidence:

1. Fossil Record
2. Comparative Anatomy
3. Comparative Genetics
4. Development and Embryology
5. Biogeography
6. Evidence from Phylogenetic Studies (several weeks from now)

The Fossil Record

A *fossil* is the preserved, mineralized remains or traces of an organism.

Examples: skeletal remains, preserved animals, footprints, pathways, internal remains

The *fossil record* is the complete set of fossils along with their position in the layers of rock (strata) within the Earth's crust.

Key features of the fossil record:

- It is incomplete – we do not find everything.
- It is selective – not every organism is equally likely to be fossilized
- It is extensive – over the world and the span of living things
- It is structured – organized in distinct and identifiable strata.

Evidence from the Fossil Record

- Consistent ordering within strata
- Consistent patterns of change
- Transitional forms

A. Fish $\longrightarrow$ tetrapods

B. Reptiles $\longrightarrow$ birds

C. Reptiles $\longrightarrow$ mammals

D. Wasps $\longrightarrow$ ants

E. Horses

F. Whales

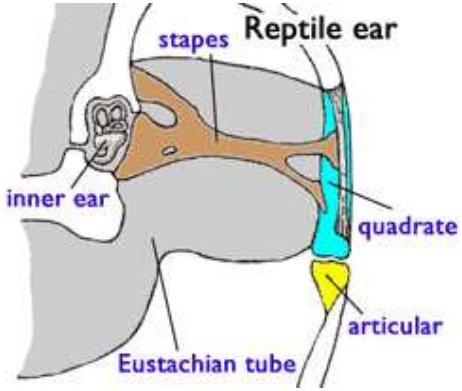
G. Hominids

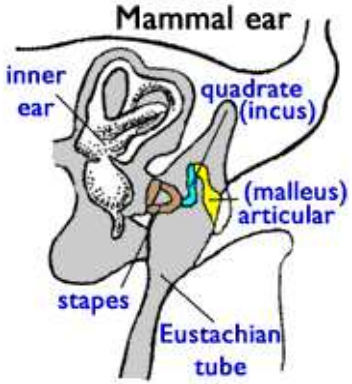
H. . . . and many others.

Example: Transitional Forms

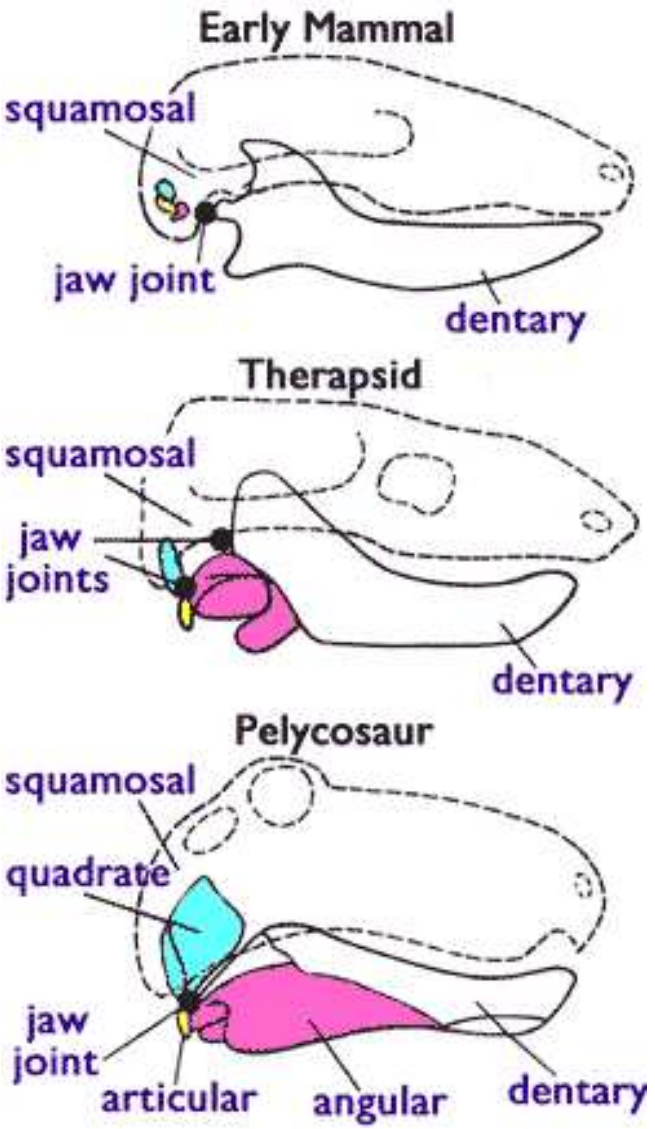
Reptiles have several in the lower jaw (quadrate, angular, articular, dentary, surangular, coronoid) and one bone in the ear (stapes).

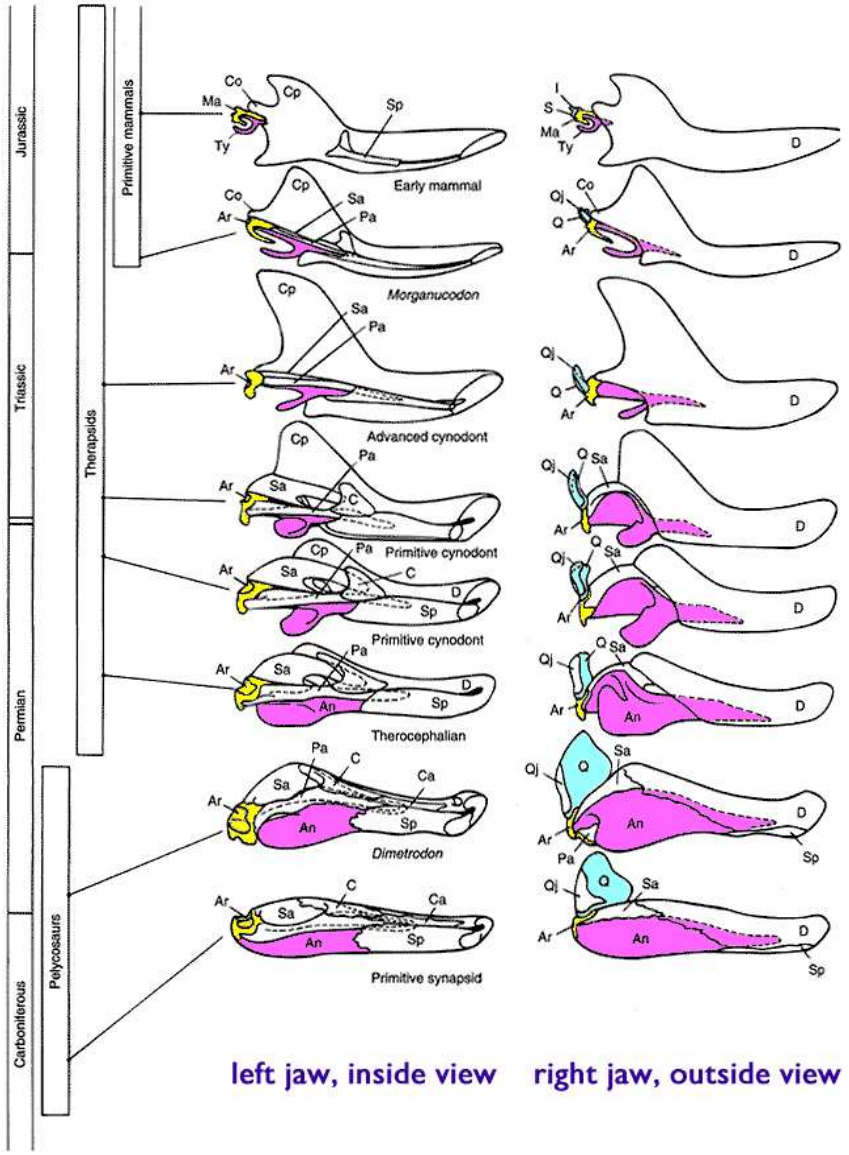
Mammals have one bone in the lowar jaw (dentary) and three in the ear (hammer, anvil, stapes)





Example: Transitional Forms (cont'd)





Example: Transitional Forms

Evidence from Comparative Anatomy

- Vestigial organs or structures – reduced and rudimentary compared to the same part in similar or related organisms.

  (Could still be functional, but if so, tend to perform simple or minor functions.)

  Examples: the human appendix and wisdom teeth, eyes in sightless species, the wings of flightless birds, python pelvises, winged weevils without flight.

  Are male nipples vestigial?

- Atavisms – the reappearance of a trait after several generations of absence

  Examples: human tails, hind limbs in living whales, lanugo

Evidence from Comparative Anatomy (cont'd)

- Homology and Homoplasy (a.k.a.analogy, false homology)

  Homology Examples: tetrapod skeletons, mammal ears, ...

  Homoplasy Examples: bird/bat/pterosaur wings, orca and shark tails, ...

  Definitions of these terms have been updated in light of common descent:

  Homology is the similarity between structures in different organisms that is attributable to their inheritance from a common ancestor.

  Homoplasy refers to similar traits in different organisms that do not share a common ancestor; convergent evolution.

- Suboptimality

  Examples: human throat, optic nerve

Evidence from Comparative Genetics

All living things share many of the basic molecular components that function within the cell.

- All living cells use chains (polymers) of nucleotides, amino acids, and simple sugars to perform the basic functions of life.
- We all use the same set of nucleosides (roughly ATCGU) out of almost 100 that occur naturally plus many more that can be synthesized.
- We all use the same set of 22 amino acids out of hundreds that occur naturally plus many more than can be synthesized.
- We all use DNA and RNA with the same left-right orientation (chirality).
- We all use the same set of "codons" – length three sequences that translate RNA to amino acids – except for a handful of simple variants that are well explained as mutations.

Amino Acids and their Codons

DNA $\xrightarrow{\text{transcription}}$ RNA $\xrightarrow{\text{translation}}$ protein

Alanine	GCU, GCC, GCA, GCG	Leucine	UUA, UUG, CUU, CUC, CUA, CUG
Arginine	CGU, CGC, CGA, CGG, AGA, AGG	Lysine	AAA, AAG
Asparagine	AAU, AAC	Methionine	AUG
Aspartic Acid	GAU, GAC	Phenylalanine	UUU, UUC
Cysteine	UGU, UGC	Proline	CCU, CCC, CCA, CCG
Glutamine	CAA, CAG	Serine	UCU, UCC, UCA, UCG, AGU,AGC
Glutamic Acid	GAA, GAG	Threonine	ACU, ACC, ACA, ACG
Glycine	GGU, GGC, GGA, GGG	Tryptophan	UGG
Histidine	CAU, CAC	Tyrosine	UAU, UAC
Isoleucine	AUU, AUC, AUA	Valine	GUU, GUC, GUA, GUG
Start	AUG, GUG	Stop	UAG, UGA, UAA

Evidence from Comparative Genetics (cont'd)

Other basic genomic and cellular components and mechanisms are widely shared, and the more closely two organisms appear to be related, the more similar these mechanisms are.

- "Ancient" genes conserved across lineages
- Novel genes produced from old

  Examples: observations from *S. cerevisae* and *C. elegans* genomes

  Many more examples from studying organisms' genomes
- Protein structures and sequences are similar across lineages despite differences in protein function.
- Vestigial systems: vitamin C production in primates versus other mammals, marsupial eggshells and caruncles, bird and anteater teeth.
- Conserved DNA sequences between genes

  Example: transposons and pseudo-genes

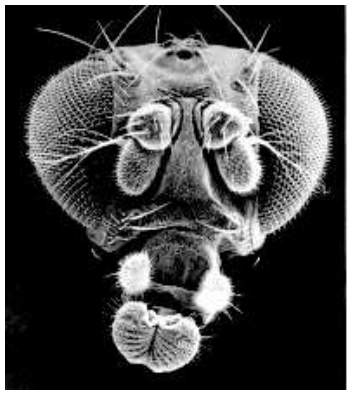
Evidence from Development

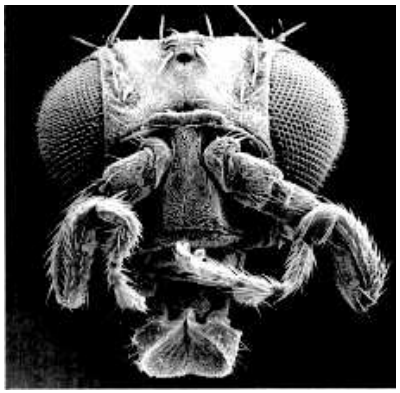
Genes determining basic body plans are conserved and then elaborated across lineages.

Example: Hox genes

Linked set of genes that regulate developmental fates of different regions and structures in the body. They act as a network of genetic switches.

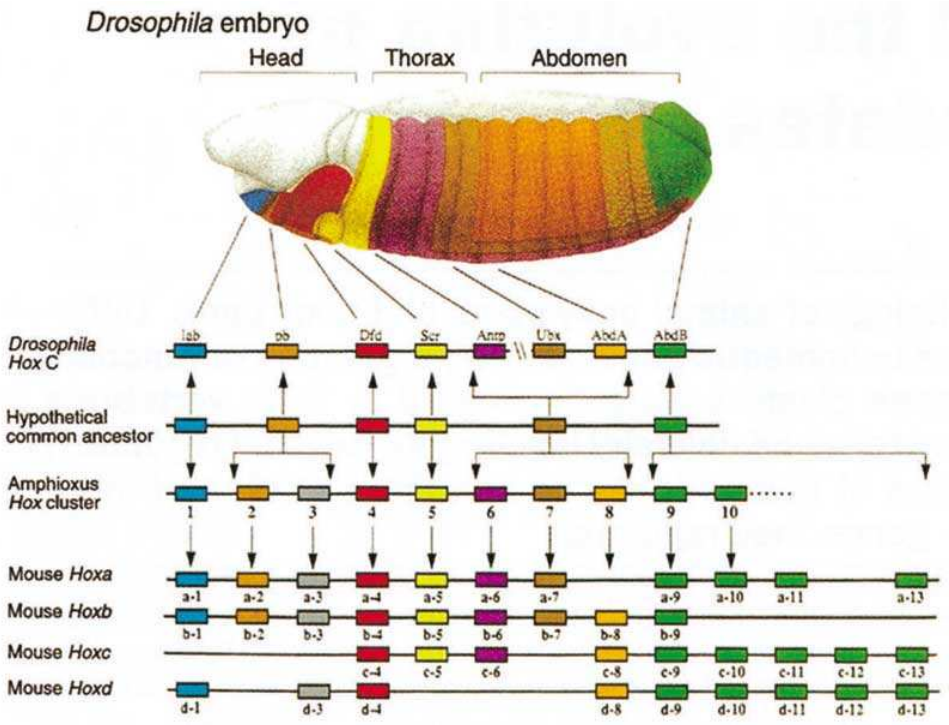
Hox short for Homeobox, because mutations in these genes cause various "homeotic" transformations with structures growing in the wrong place.

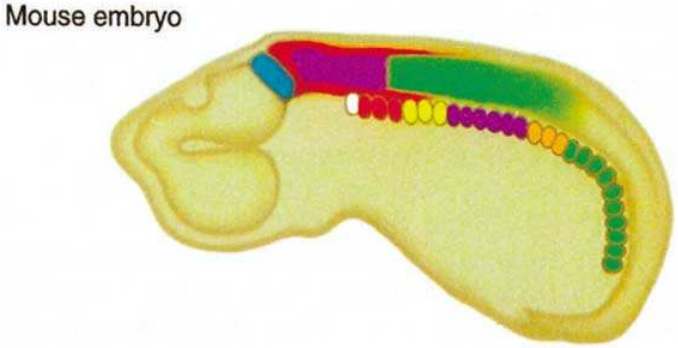


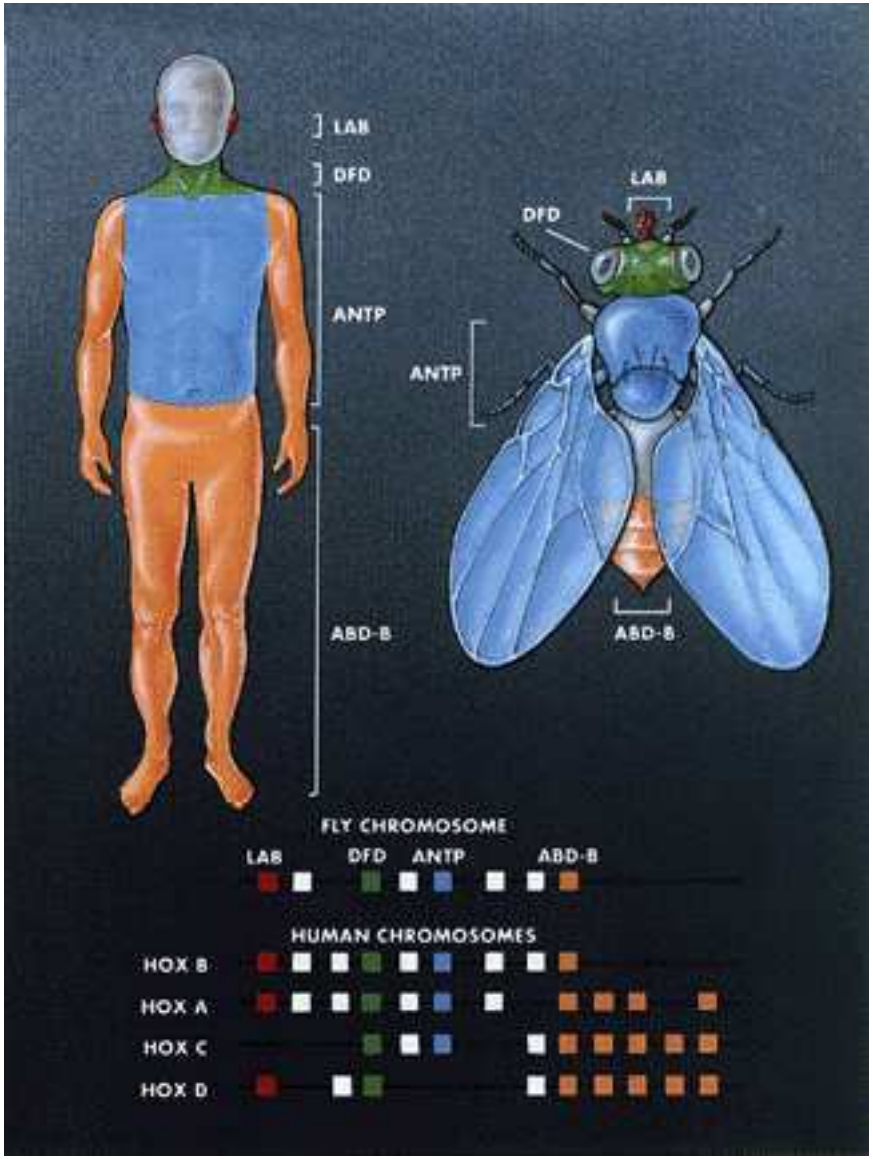


This family of genes discovered in *D. melanogaster* but is dispersed much more broadly.

Hox Gene Comparisons



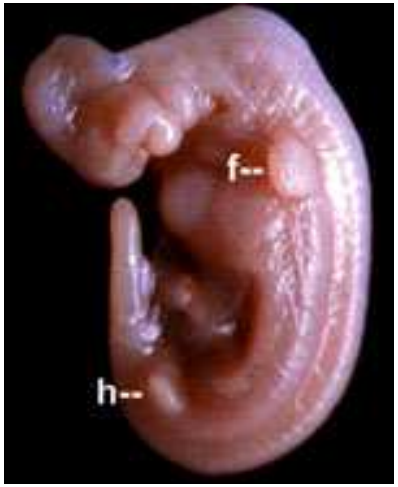


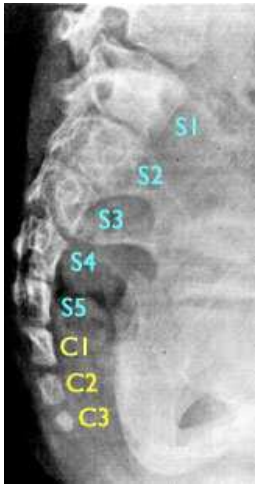


Evidence from Development (cont'd)

- Similar pattern of development across species (cf. von Baer)
- Embryonic features

  Examples: legs on legless creatures, human tails, marsupial's transient eggs and caruncles, birds and anteaters with teeth, lanugo.





- Similar development of "homologous" structures

  Example: Ear development in Mammals and Reptiles

Evidence from Biogeography

Biogeography is the study of the geographic distribution of species.

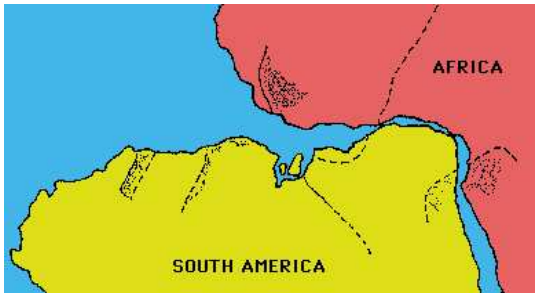
- Darwin's "Law of Succession" – organisms living in an area most closely resember fossils found in the same location.

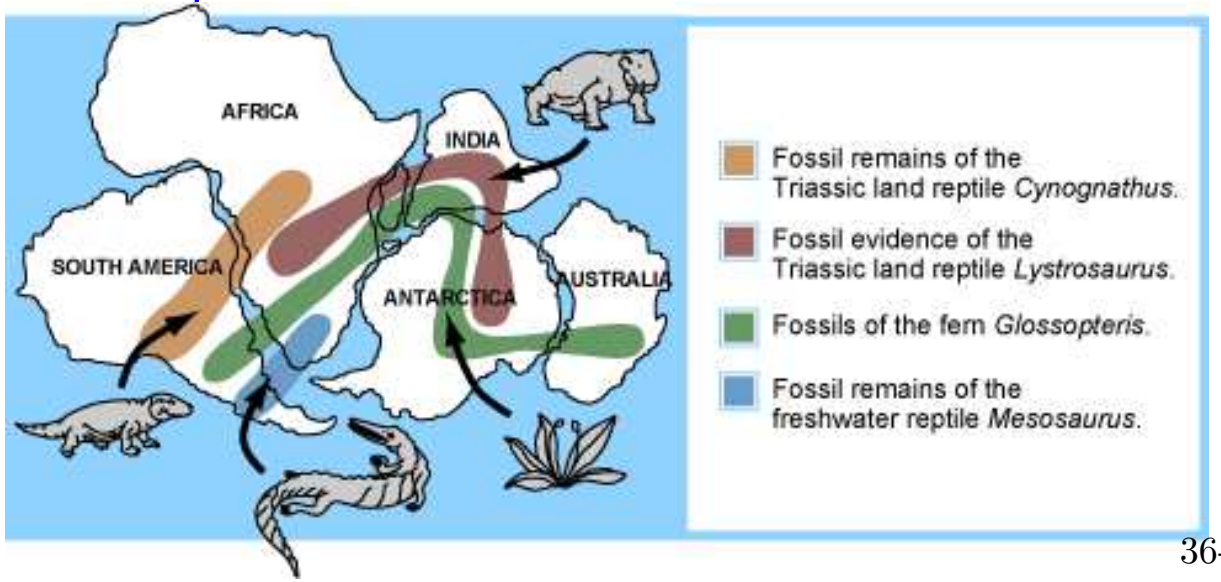
  Example: armadillos and glyptodonts

- Similarities across past continental conjunctions

  Examples: Army and Driver ants,

  marsupials in Australia and South America



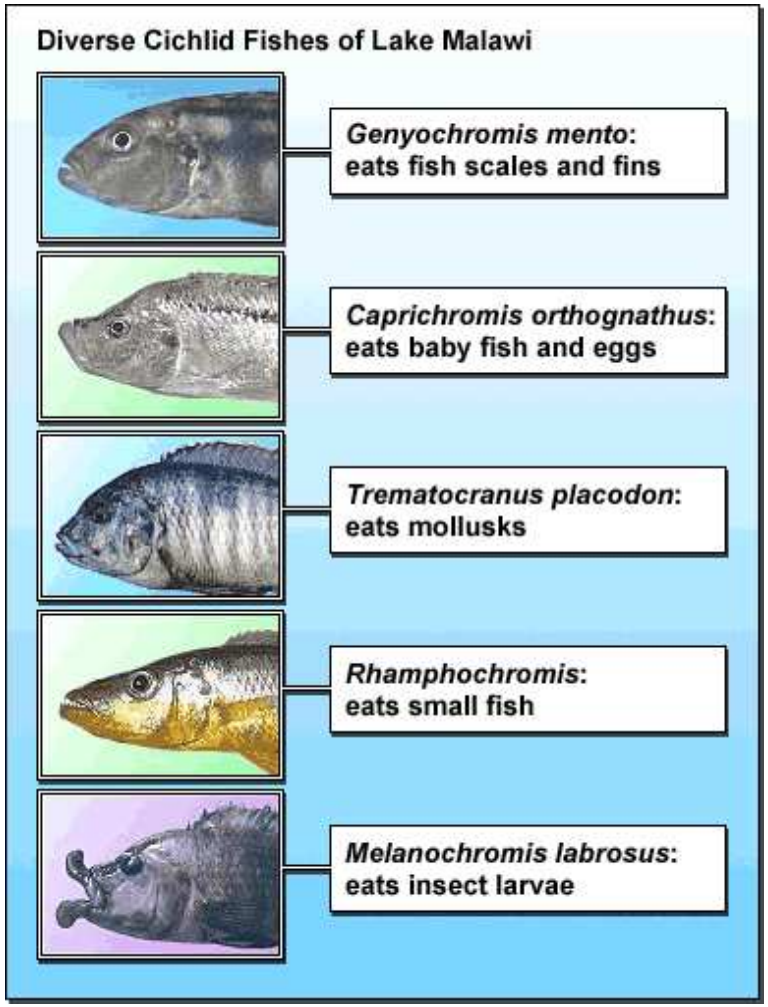


Evidence from Biogeography (cont'd)

– Wallace's line and biogeographical regions

Evidence from Biogeography (cont'd)

– Cichlid fishes in east African lakes.



Evidence from Biogeography (cont'd)

– Galapagos finches

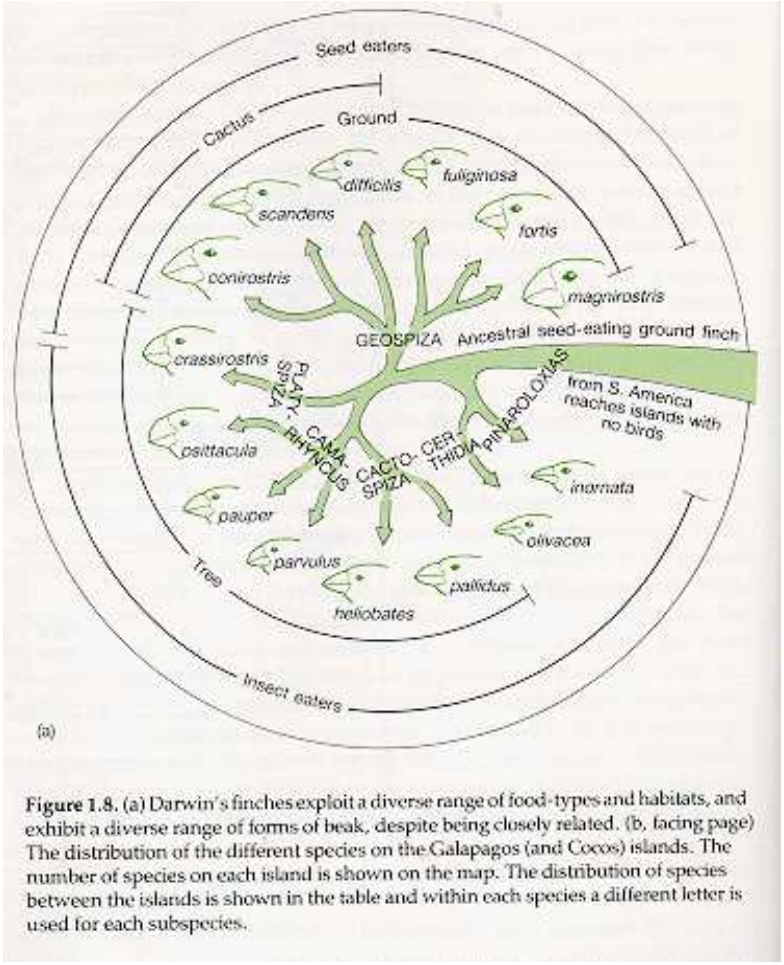
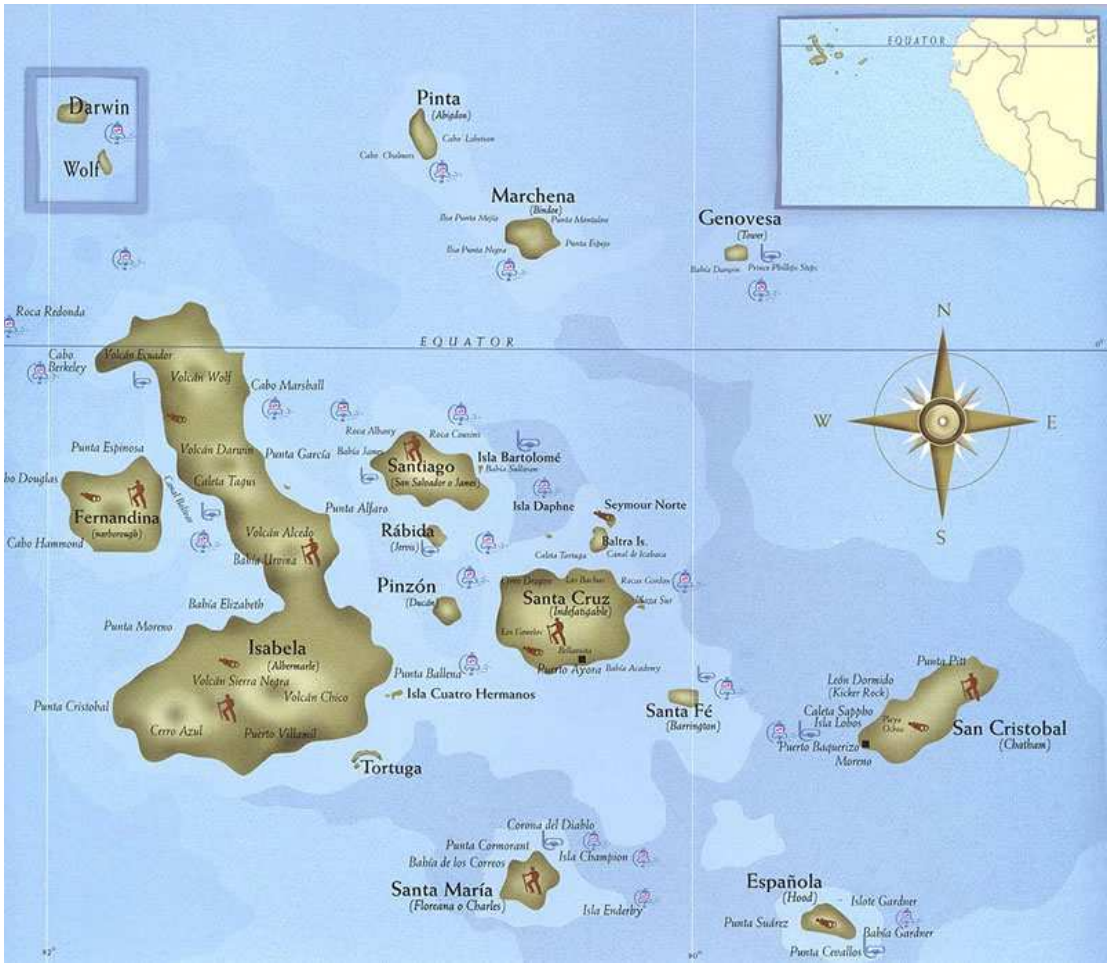


Figure 1.8. (a) Darwin's finches exploit a diverse range of food-types and habitats, and exhibit a diverse range of forms of beak, despite being closely related. (b, facing page) The distribution of the different species on the Galapagos (and Cocos) islands. The number of species on each island is shown on the map. The distribution of species between the islands is shown in the table and within each species a different letter is used for each subspecies.

Galapagos Finches (cont'd)



Distribution of Darwin's Finches on Visitor Islands

	Santa Cruz	Plaza	Santa Fe	San Cristobal	Espanola	Floreana	Isabela	Fernandina	Santiago	Rabida	Genovesa
Small Ground Finch	●	●	●	●	●	●	●	●	●	●	
Medium Ground Finch	●	●	●	●		●	●	●	●	●	
Large Ground Finch	●						●	●	●	●	●
Cactus Ground Finch	●	●	●	●		●	●		●	●	
Large Cactus Ground Finch					●						●
Sharp-beaked Ground Finch								●	●		●
Vegetarian Finch	●			●		●	●	●	●	●	
Small Tree Finch	●		●	●		●	●	●	●	●	
Medium Tree Finch						●					
Large Tree Finch	●					●	●	●	●	●	
Woodpecker Finch	●			●			●		●		
Mangrove Finch							●	●			
Warbler Finch	●		●	●	●	●	●	●	●	●	●

Evidence from Biogeography (cont'd)

Other examples:

- Horses
- Humans, hominids, and apes
- Islands

Island Biogeography

Oceanic islands, that form anew from volcanic activity in the ocean, are powerful laboratories for evolutionary studies.

- Oceanic islands are missing or impoverished in many types of species

  Examples:

  - Hawaii has no native mammals, reptiles, or amphibians
  - St. Helena, in the south Atlantic, has no native freshwater fish.
  - Australia has virtually no native placental mammals

  It is not a matter of fitness because introduced species thrive.
  (e.g., brown tree snake, cane toad, rabbits).

Island Biogeography (cont'd)

- Species inhabiting oceanic islands most closely resemble species found on the nearest mainland even if the environments are vastly different.

  Example: Galapagos diversity in very selective groups: finches, tortoises, iguanas, etc.

- Species commonly found on oceanic islands are those that can get there

  Insects, birds, plant seeds spread by wind and current, Hawaiian monk seal and hoary bat