

**TAXONOMY:
RECONSTRUCTING
THE TREE OF LIFE**

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Agenda/Outline

- Introduction
- The Tree of Life
- **Break at 11 am**
- Reconstructing and Using the TOL

Biology:

The Scientific Study of Life

- Life: The most awe-inspiring phenomenon in the universe!
 - *Arguably the most interesting and most beautiful phenomena in the in the universe*
 - *So far is ONLY known here on Earth*
 - Almost certainly occurs elsewhere...
- Obviously attractive to many scientists:
 - *We call ourselves Biologists.*



Tree of Life

The most complex phenomenon in the universe

- This complexity has resulted in astounding **diversity**, at different levels of organization:
 - **Ecosystem/Habitat diversity:** *No two places alike*
 - **Species diversity:** *Each a “masterpiece” of evolution*
 - **Genetic diversity:** *Each species is highly variable*

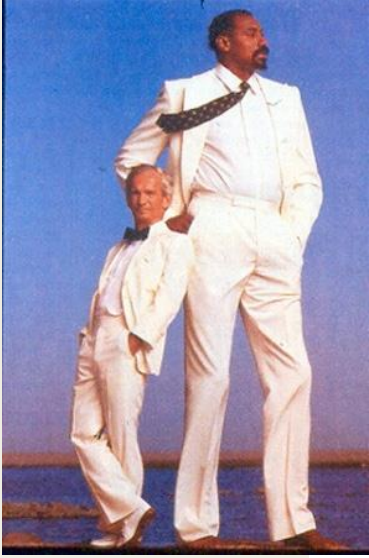


Habitat/Ecosystem Diversity




Species Diversity





Genetic Diversity



What are the most
profound and important discoveries
about life biologists have made?

What are the most **profound and important discoveries** biologists have made?

■ 1) Darwin's theory of **Evolution by Natural Selection**

- *Explains how species change over time*

Charles Darwin (1809-1889)



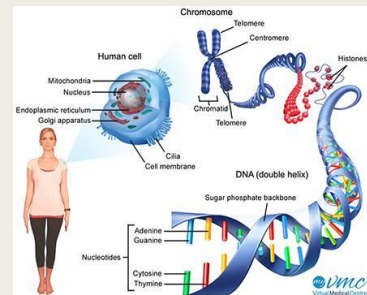
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What are the most **profound and important discoveries** biologists have made?

■ 2) Watson & Crick (and others) discover that the **heritable information evolution depends on is stored via DNA**

- *A vast, incredibly complex (and beautiful) double helix structure*

- Allows information to be stored
- Copied
- Shuffled randomly
- Changed (hopefully not too much!)



Tree of Life

10

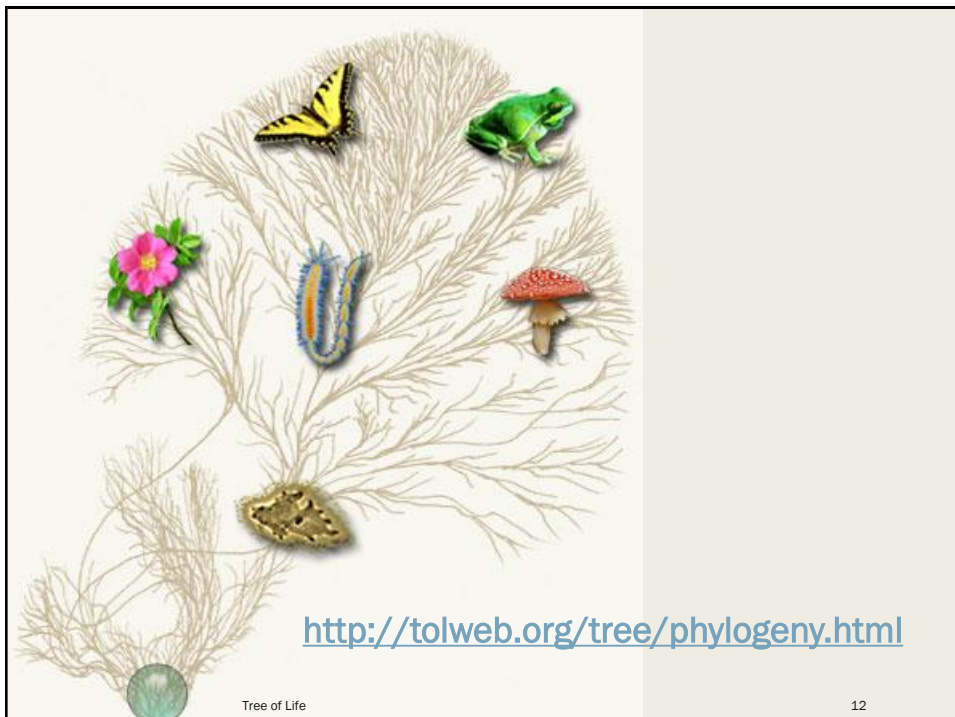
What are the most **profound and important** discoveries biologists have made?

■ 3) The Tree of Life

- ***The realization that all life on Earth is literally related***
 - Every species on Earth shares a common ancestor with every other species!
 - You are literally, genealogically related not just to chimpanzees....
- *This realization has profound philosophical implications about what humans are and what our place in the universe is.*

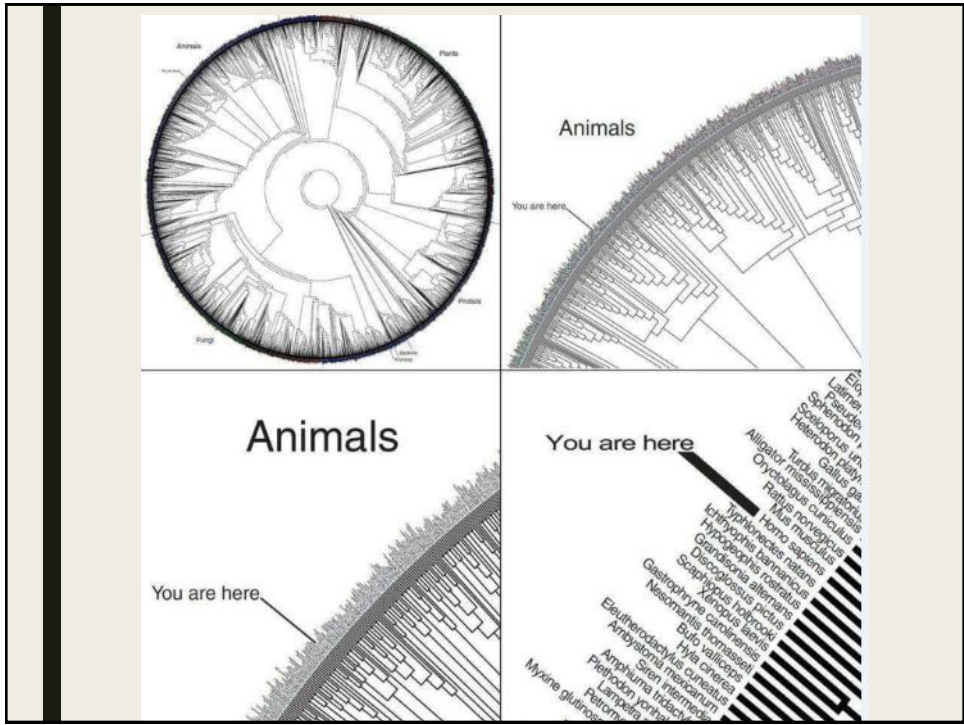
Tree of Life

11



Tree of Life

12



Science has humbled humankind...



What are the most **profound and important discoveries** biologists have made?



3) The Tree of Life

- *This concept has proven to have incredible scientific value as well*
 - It has great **predictive power**
 - *(which is the real power of science)*
- *Why? Closer relatives share more genetic similarity*
 - And so often ARE more similar
 - So we can predict a lot about creatures we haven't even studied yet, or haven't even discovered yet

Tree of Life

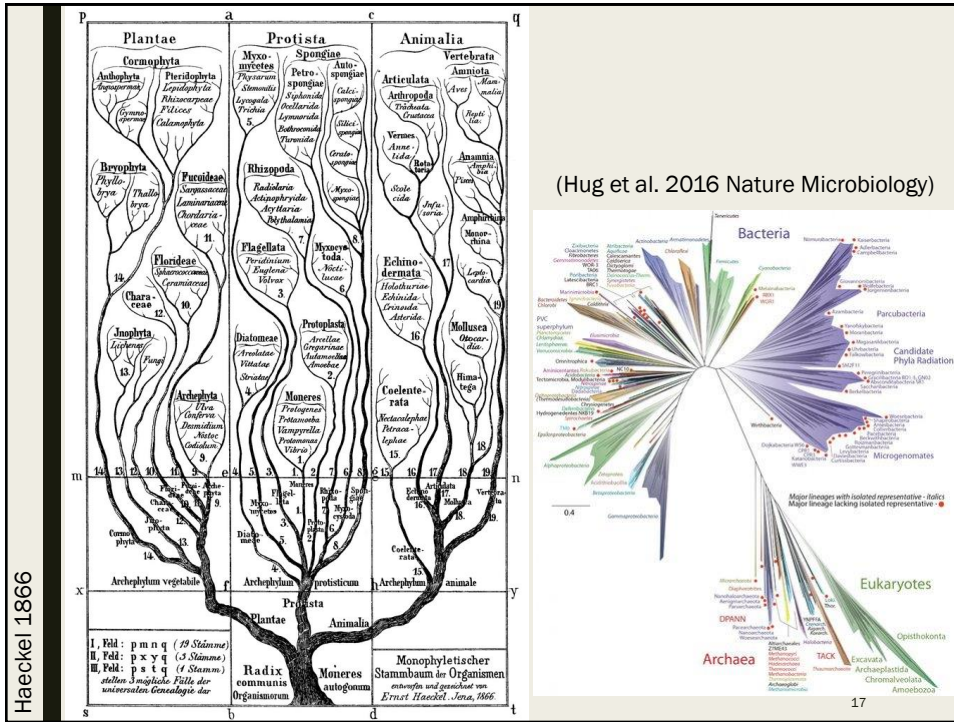
15

Who **discovered** the Tree of Life?

- No one, really!
 - *It has slowly become more clear over centuries*
 - Keeps getting more support from more kinds of evidence.

Tree of Life

16



Evidence for the Tree of Life

1) Similarity of organisms: Linnaeus' classification

Carolus Linnaeus (1707-1778)



Tree of Life

A very important chimpanzee

“in every animal there is a world of wonders; each is a microcosm or a world in it self.”

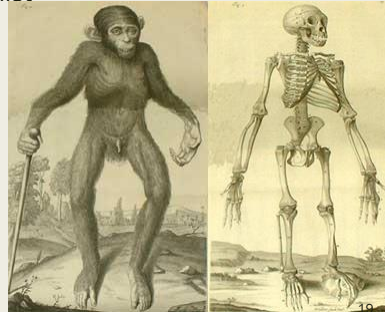
–Edward Tyson,

comparative anatomist

(1651-1708)



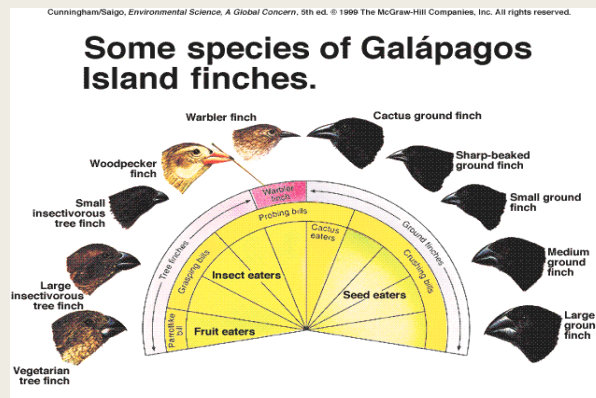
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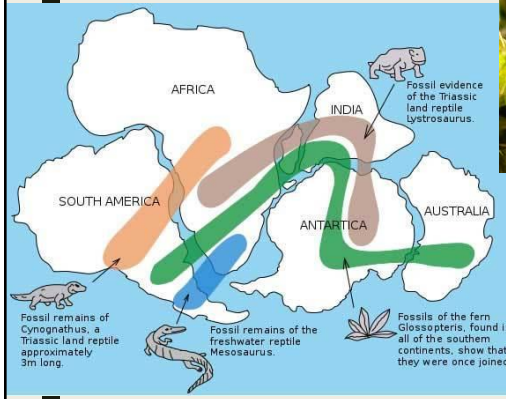
Evidence for the Tree of Life

2) Biogeography: Pattern of distribution of these species

Adaptive Radiation: Founding Species “radiates” by evolution, speciation into unoccupied ecological niches.



Distribution and the TOL: Gondwanan “Continent Riders”

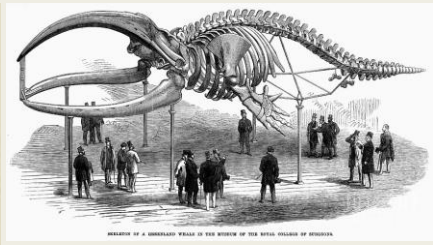
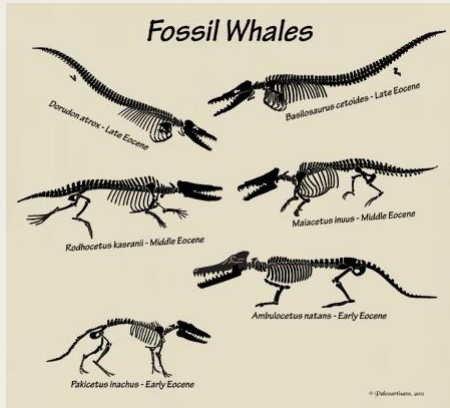


Tree of Life

Evidence for the Tree of Life

3) Fossil evidence

- Of change through time
- Of diversification of lineages through time

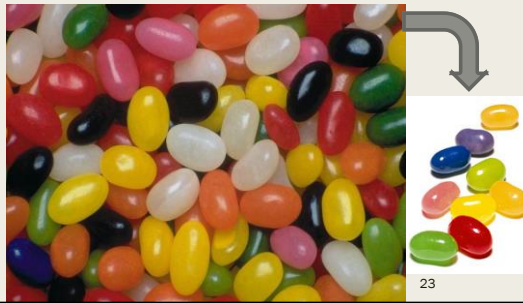


Evidence for the Tree of Life

4) Understanding of the mechanisms of evolution

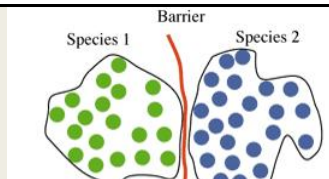
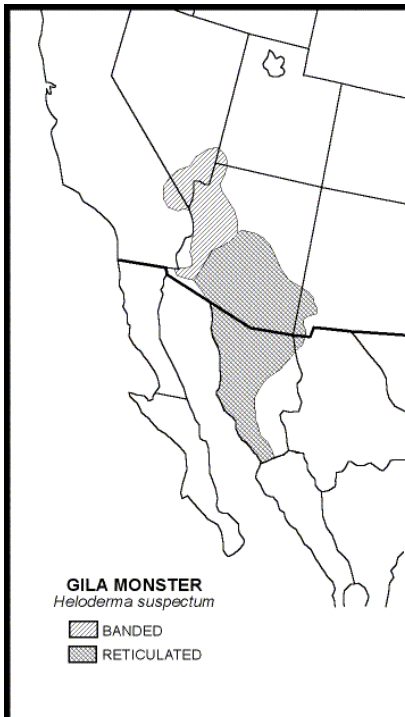
- Darwin: Natural Selection explains adaptive change
- Other processes can cause random change
 - Mutation
 - Genetic Drift
- Scientists have worked out how new species arise from existing species
 - Allopatric speciation
 - Sympatric speciation

Genetic Drift is change
Caused by sampling error →



Tree of Life

23



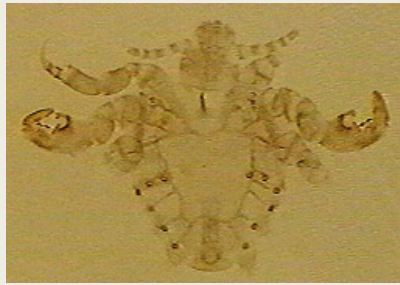
Allopatric Speciation
(due to geographic isolation)



Banded: *H. s. cinctum*

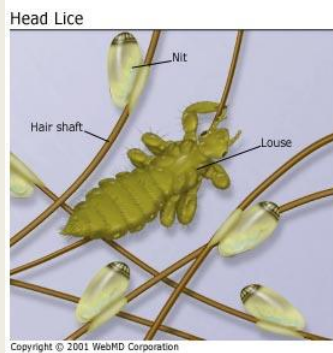


Reticulated: *H. s. suspectum*



Sympatric Speciation: Human Lice

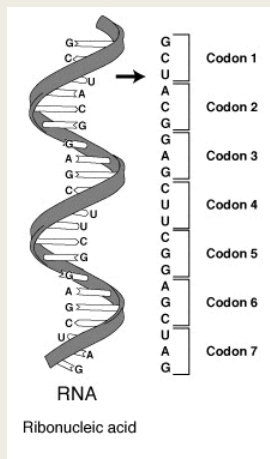
- **Crab louse**
 - *Phthirus pubis*
 - 1 other *Phthirus*: *Gorilla gorilla*: Genetic evidence suggests our ancestors acquired *Phthirus* from Gorilla about 3-4 mya
- **Human louse**
 - *Pediculus humanus*
 - The head louse
 - The body louse
 - These diverged about 107 ka ago, maybe when humans began wearing clothes!
 - Transmits Typhus, etc.
- Other *Pediculus* spp.: Chimpanzees
 - Our *Pediculus* diverged 6-7 mya, probably when *Pan* and *Homo* diverged: **Parallel phylogeny**



Evidence for the Tree of Life

5) The Clincher: At the most basic level, all organisms share the same particular **genetic language!**

20 amino acids, so you need three letters to spell them all.



The Genetic Code

	Second Letter				Third Letter
	U	C	A	G	
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic acid	Glycine	U
	Valine	Alanine	Aspartic acid	Glycine	C
	Valine	Alanine	Glutamic acid	Glycine	A
	Valine	Alanine	Glutamic acid	Glycine	G

Tree of Life

6

Taxonomy

- **Taxonomists** are biologists trying to reconstruct the Tree of Life
 - Or more usually, parts of it.
 - **Taxa** (singular: **Taxon**) are groups of organisms
 - Now often called **Systematics (Systematists)**
- The basic procedure is the try to group species into groups (called **clades**) that share a unique common ancestor
 - **Clade**: All the descendants of an (extinct) ancestral species

27

The basics of Taxonomy: Clades and Cladograms

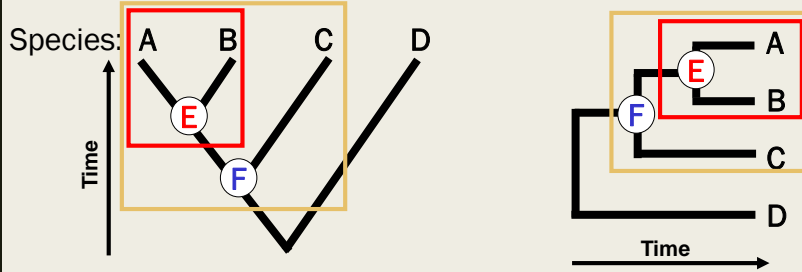
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28

Phylogeny

What is a phylogeny?

Branching diagram showing relationships between species (or higher taxa) based on their shared common ancestors

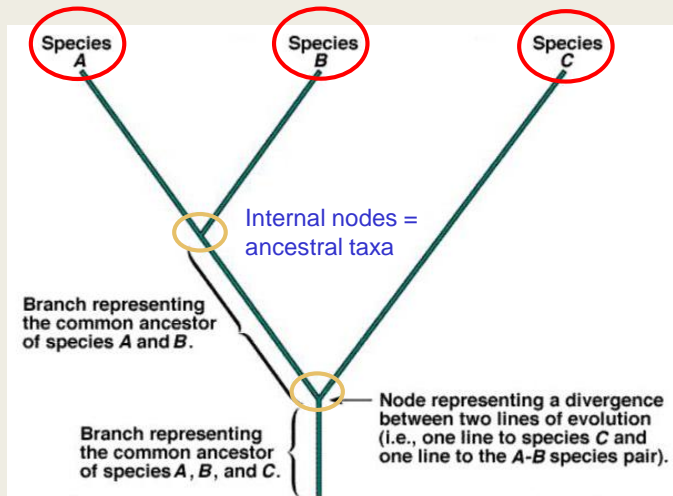


A and B are most closely related because they share a common ancestor (call the ancestor "E") that C and D do not share

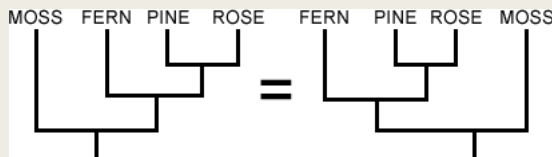
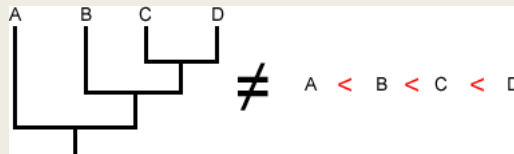
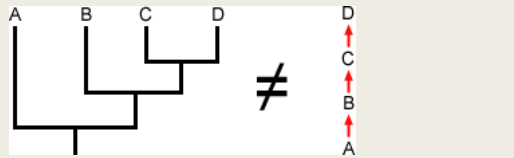
A+B+C are more closely related to each other than to D because they share a common ancestor ("F") that D does not share

Phylogeny

Terminal nodes = contemporary (extant) taxa



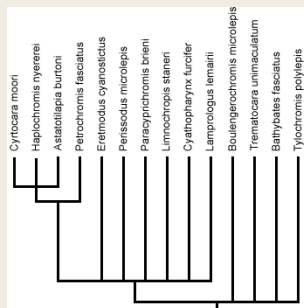
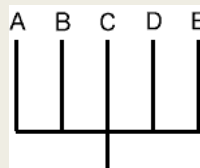
Phylogenies are bifurcating trees that reflect nested relationships



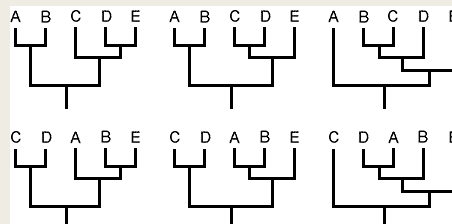
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31

Polytomies express lack of knowledge about phylogenetic relationships

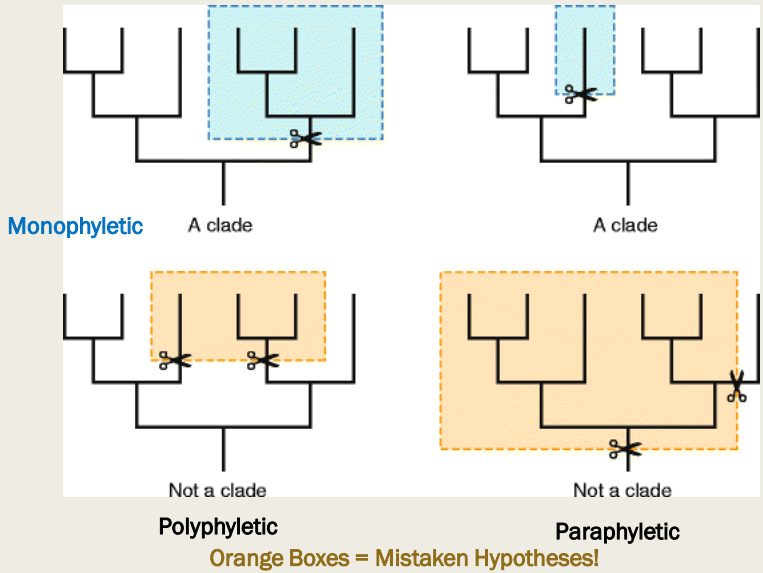


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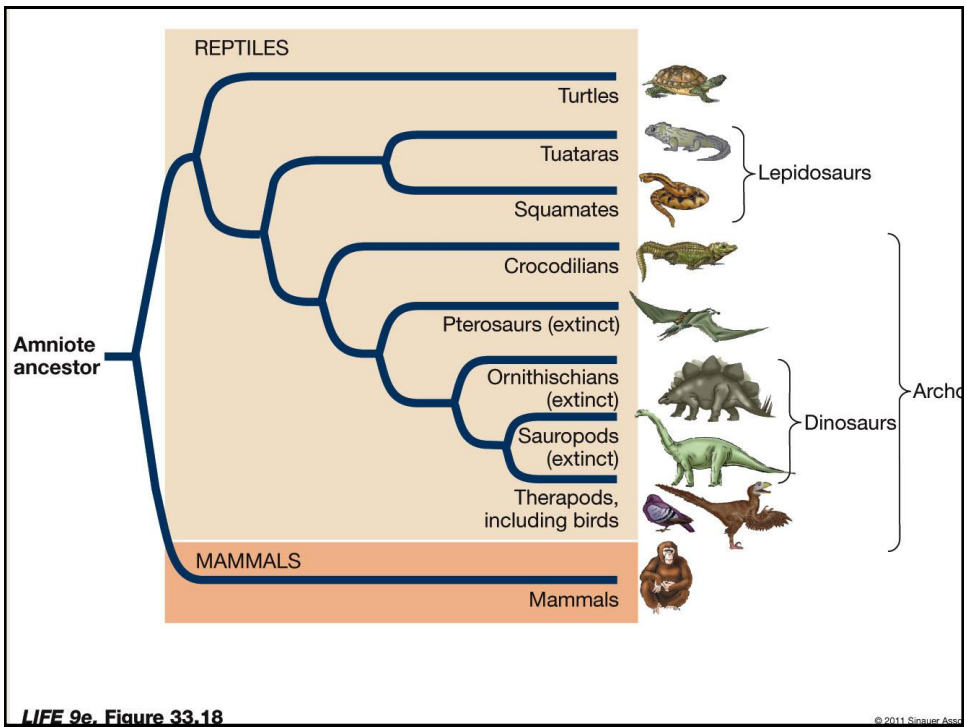
32

Sometimes our previous concept of membership of a lineage does not accurately reflect evolutionary history



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33



Relationship of Linnaeus' Classification to the Tree of Life



- Linnaeus' classification provides unique names for **SOME** (but not all possible) clades
 - A nested hierarchy of sets (like Russian Dolls)

Biological Classification: Categories

- | | |
|-----------|------------|
| ■ Kingdom | Animalia |
| - Phylum | Chordata |
| ■ Class | Mammalia |
| - Order | Carnivora |
| ■ Family | Canidae |
| ■ Genus | Canis |
| ■ species | familiaris |




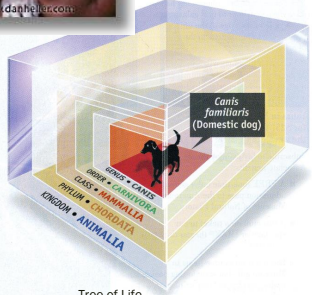
Biological Classification: Linnaeus' Dog

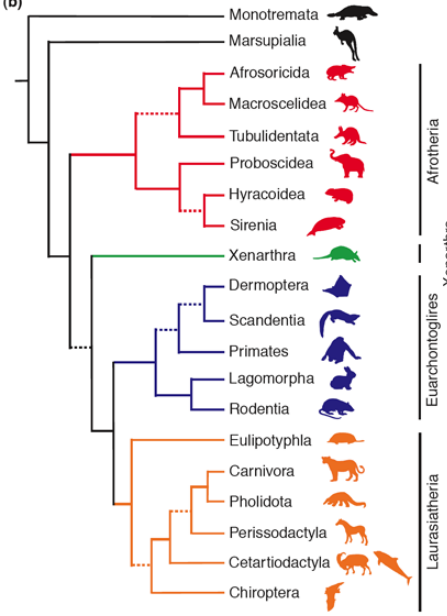
Linnaeus's classification scheme can be visualized as a series of nested boxes in which the species is the irreducible category.

Tree of Life 37

Biological Classification: Linnaeus' Dog

(b)



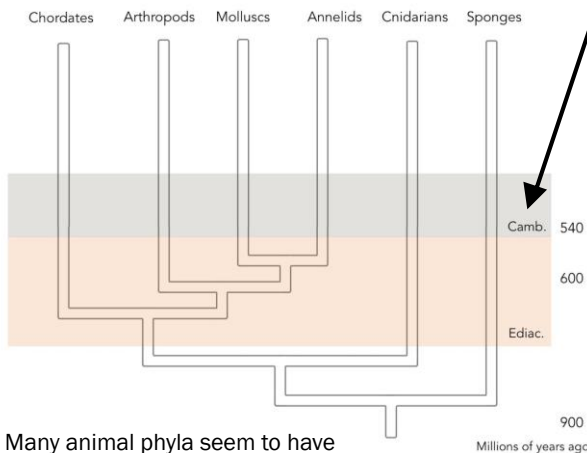
- Monotremata
- Marsupialia
- Afrotheria
 - Afrosoricida
 - Macroscelidea
 - Tubulidentata
 - Proboscidea
 - Hyracoidea
 - Sirenia
- Xenarthra
- Euarchontoglires
 - Dermoptera
 - Scandentia
 - Primates
 - Lagomorpha
 - Rodentia
 - Eulipotyphla
 - Carnivora
 - Pholidota
 - Perissodactyla
 - Cetartiodactyla
 - Chiroptera
- Laurasiatheria

Linnaeus's classification scheme can be visualized as a series of nested boxes in

Tree of Life

Reconstructing the Tree of Life is **not easy to do!** Why?

Challenge: Much evolution occurred a **VERY long time ago**



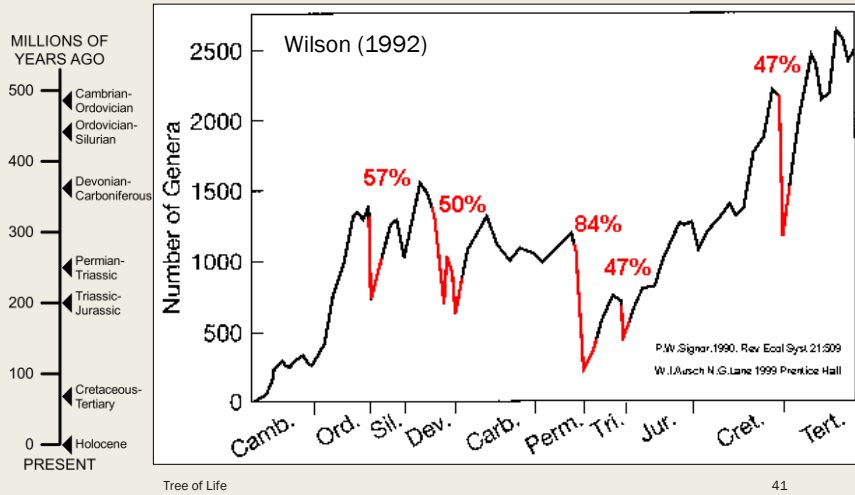
Cambrian "Explosion":
Many animal groups
Suddenly appear! Why?

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
		Cretaceous	138
	Mesozoic	Jurassic	205
		Triassic	240
		Permian	290
	Paleozoic	Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
Ordovician		500	
Proterozoic	Early Proterozoic	Cambrian	570
			2500
Archean	Late Archean		3800?
Pre-Archean			

Many animal phyla seem to have
Diverged in the **Ediacaran** period (635-542 mya)
But: They were small, and often soft!

- First land animals: Silurian
- First land vertebrates: late Devonian

Challenge: most organisms are extinct



Challenge: many organisms don't leave fossils



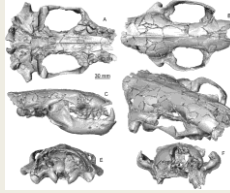
Also: Is the organism's habitat **depositional** or **erosional**?



Challenge: fossils remain undiscovered



Wolf-sized otters
Siamogale mellutra sp. nov.
 (Lutrinae: Mustelidae:
 Carnivora)
 Published Jan 22 2017
J of Systematic Palaeontology



(Wang et al. 2017)

Challenge: there are still many unknown extant species



Perhaps the Biggest Challenge: convergent evolution



Cactaceae
Columnar cacti
Cylindropuntia columnaris

Euphorbiaceae
Canary Island Spurge
Euphorbia canariensis

Tree of Life

45

Reconstructing the Tree of Life is not easy to do! Why?

- Similarity can be misleading!
 - **Biggest Problem:** *Convergence masquerading as Homology*
 - **Homology:** Similarity due to inheritance...family resemblance
 - **Convergence:** Similarity due to similar evolution acting on unrelated organisms



Reconstructing the Tree of Life is not easy to do! Why?

- Similarity can be misleading!
 - *Biggest Problem: Convergence masquerading as Homology*
 - **Homology:** Similarity due to inheritance...family resemblance
 - **Convergence:** Similarity due to similar evolution acting on unrelated organisms
 - *How to tell them apart? It is not easy! But not impossible*
 - Fossil evidence
 - Comparison of many extant forms
 - Clusters of similar traits are evidence of homology

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47

Reconstructing the Tree of Life is not ea Why?

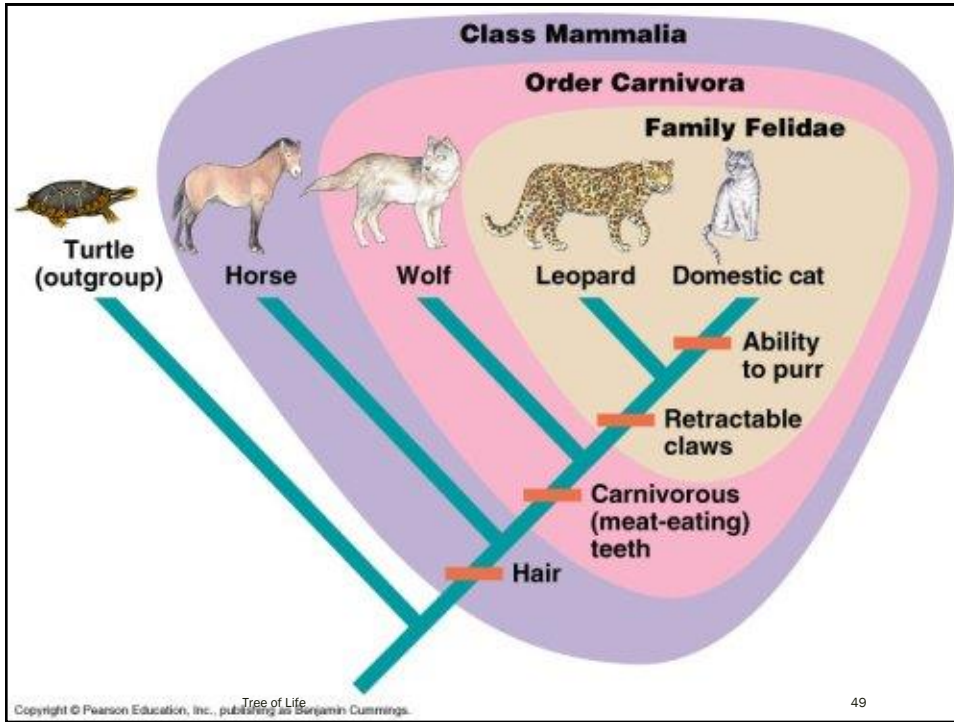


- Similarity can be misleading, part 2!
 - *Another Problem: Inherited characters are not always useful as evidence!*
 - **Shared basal characters** can be inherited from a distant ancestor, and don't prove a closer relationship.
 - Only **shared derived characters** (those different from a recent ancestor) are evidence of close relationship
- Example: Cats and Dogs...should they be in separate families of mammals?
 - *Shared basal characters?*
 - *Shared derived characters?*
 - Harder to come up with!



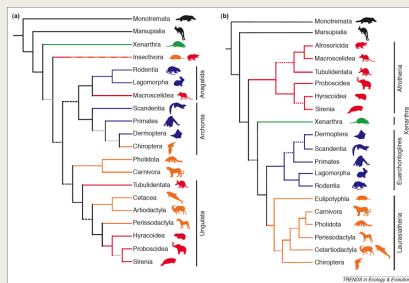
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48



The problem of multiple trees

- All the characters you have for a set of clades might be consistent with multiple trees (**multiple hypotheses**).
 - Which to favor?
- The main tool is still **parsimony** (aka **Occam's Razor**)
 - All else being equal, **the simpler hypothesis is more likely**
 - We are beginning to figure out how to quantify that likelihood, but it remains a probability, not a certainty.



Traditional Sources of Evidence

“Traits” are features that vary between taxa

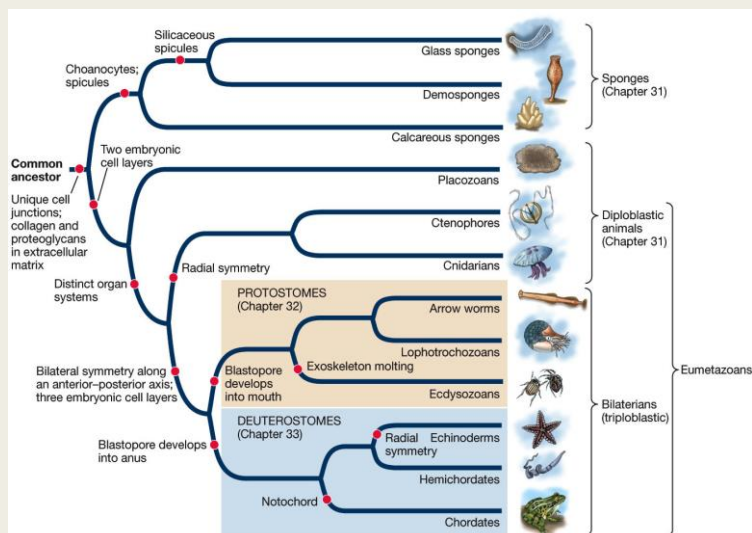
- **Morphology:** Shape, size, number of body parts.
 - *By far the most important traditionally*
- **Development:** Process of going from a single cell zygote to a multicellular adult
 - *Important to distinguish higher level clades (where morphology has changed too much to be useful)*
- **Behavior and Ecology:** Where it lives, what it eats, etc. etc.
 - *Including “fossilized behavior” (spider webs, bird and wasp nests, etc.)*
- All this has recently been eclipsed by a huge new source of “traits”

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51

Developmental Traits: Especially important at high levels

Example: **Protostomes** and **Deuterostomes**



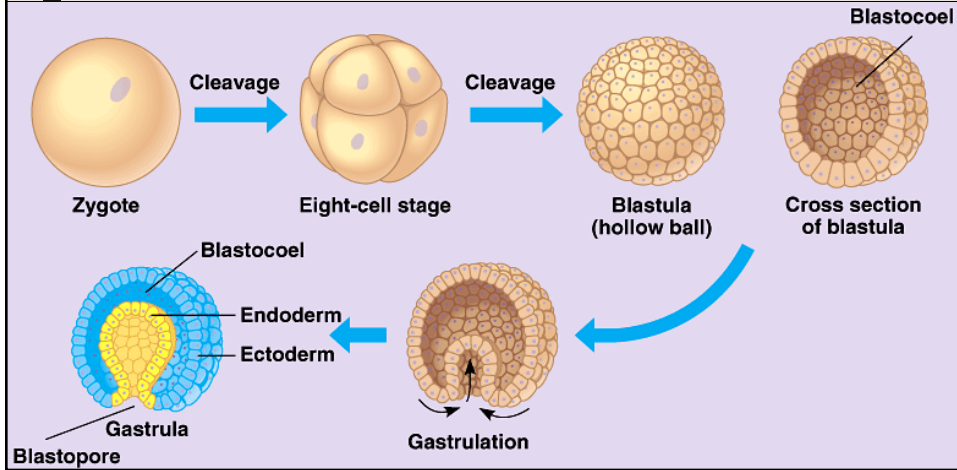
LIFE 9e, Figure 31.1

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52

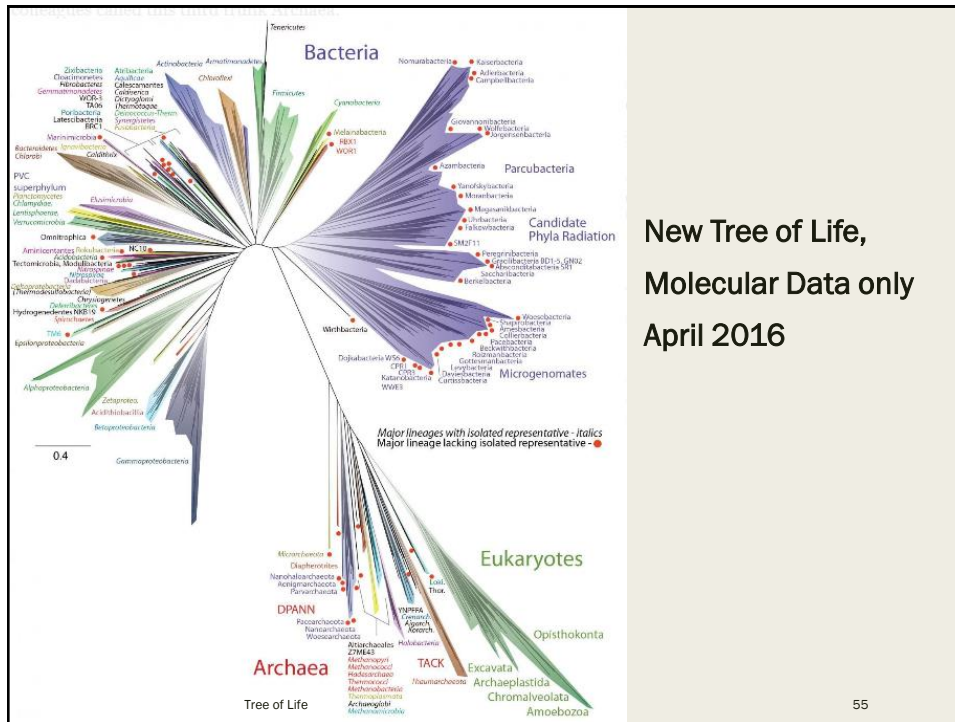
Gastrulation: Synapomorphy of Eumetazoa (true animals)

- **Protostomes** (insects and close relatives): Mouth from blastopore
- **Deuterostomes** (us and our relatives): Mouth **NOT** from blastopore



Molecules

- Especially: **Nuclear DNA**
 - Also, **DNA and RNA from organelles like mitochondria and chloroplasts** (often inherited mainly from mother)
- This has become **VASTLY** cheaper to do in recent decades
 - **1998: We used protein electrophoresis to examine differences in dozens of genes**
 - **Today: Entire genome of an organism can be sequenced for about the same price: Thousands or tens of thousands of genes!**
 - Yielding **terabytes** of data: Almost too much to deal with!
 - **Sequence alignment...**

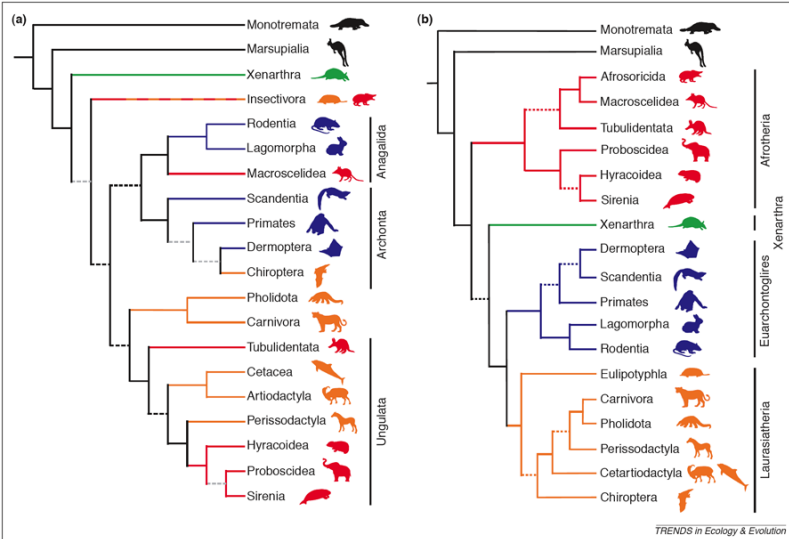


What if two lines of evidence yield different trees?

- **Happens all the time!**
 - Traditional evidence used to rule: *Intuition. If the species look similar, shouldn't they be related?*
 - Now, DNA is beginning to rule: *The brute power of more data.*
- Why not use both? Many systematists favor “**Total Evidence**”
 - But how to compare the **apples** of morphology and the **oranges** of molecules?
 - Morphological data: Fewer traits, some very obvious
 - *Presence/Absence, for example*
 - Molecular Data: Only 4 Nucleic Acid base pairs
 - *Huge amounts of “convergence”*
 - More data makes up for lower data quality?

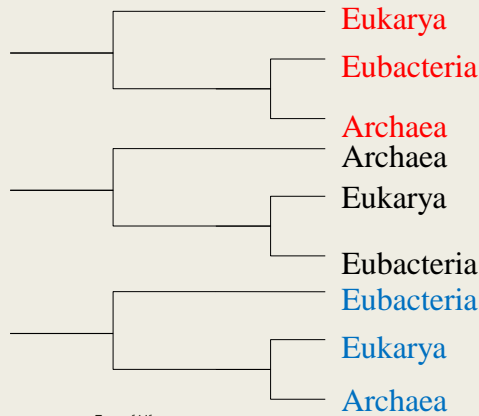
Mammal Relationships

Morphology Genetics.



Domains: Three Possibilities

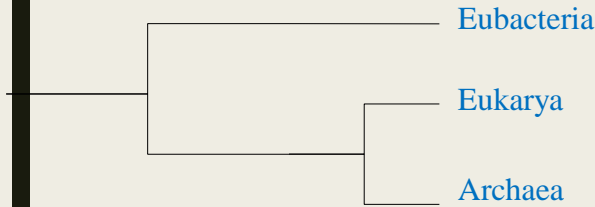
Consider the morphological evidence...



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58

Domains: Emerging Consensus Including genetic evidence



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59

**One more interesting bit:
Non-treelike Evolution!**

Lynn Margulis (1938-2011)

The Tree of Life

tolweb.org

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60

The Future of Taxonomy



- **We'll never be "done"**
 - *Constant refinement and reanalysis as*
 - Techniques improve
 - More specimens come to light
- Increasingly sophisticated **algorithms** to deal with more traits, more specimens: Increasingly automated analysis.
- Increasing **importance of museum specimens**
 - *Old specimens can often be analyzed using tiny samples*
 - *An archive of what we are losing...*
- **Importance of Taxonomy for Conservation**
 - *You can't conserve what you don't know*
 - *Taxonomy can aid in deciding what to focus on*
 - Phylogenetic distinctness: ***Drosophila*** versus ***Ornithorhynchus***

Tree of Life

61

Thank you!

