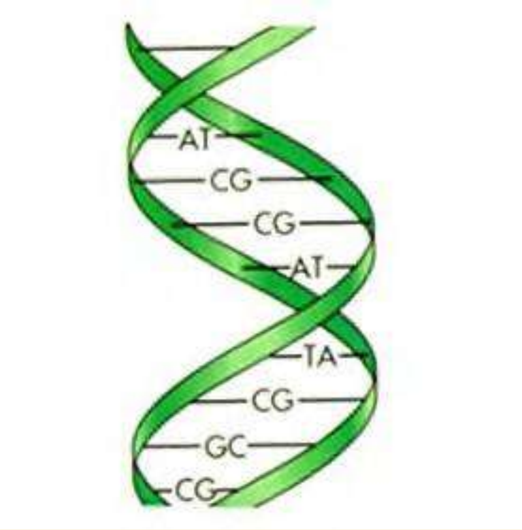
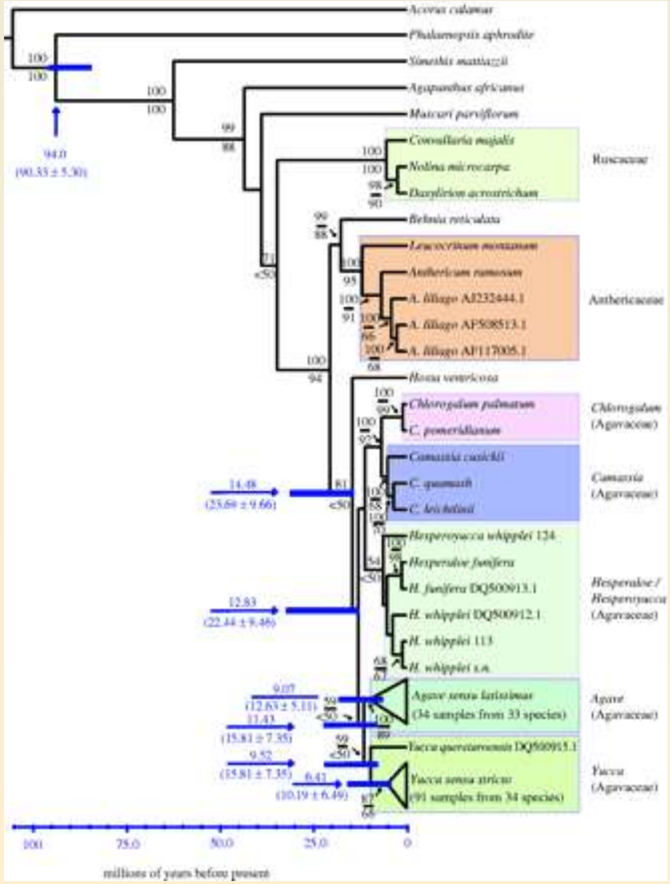
Classification and Phylogenetic Systematics:

A review of concepts with examples from the Agave Family

David Bogler

Missouri Botanical Garden





- **Taxonomy** – the orderly classification of organisms and other objects
- **Systematics** – scientific study of the diversity of organisms
  - Classification – arrangement into groups
  - Nomenclature – scientific names
  - Phylogenetics – evolutionary history
    - **Cladistics** – study of relationships of groups of organisms depicted by evolutionary trees, and the methods used to make those trees (parsimony, maximum likelihood, bayesian)

“El Sotol” - *Dasylirion*

Dasylirion wheeleri

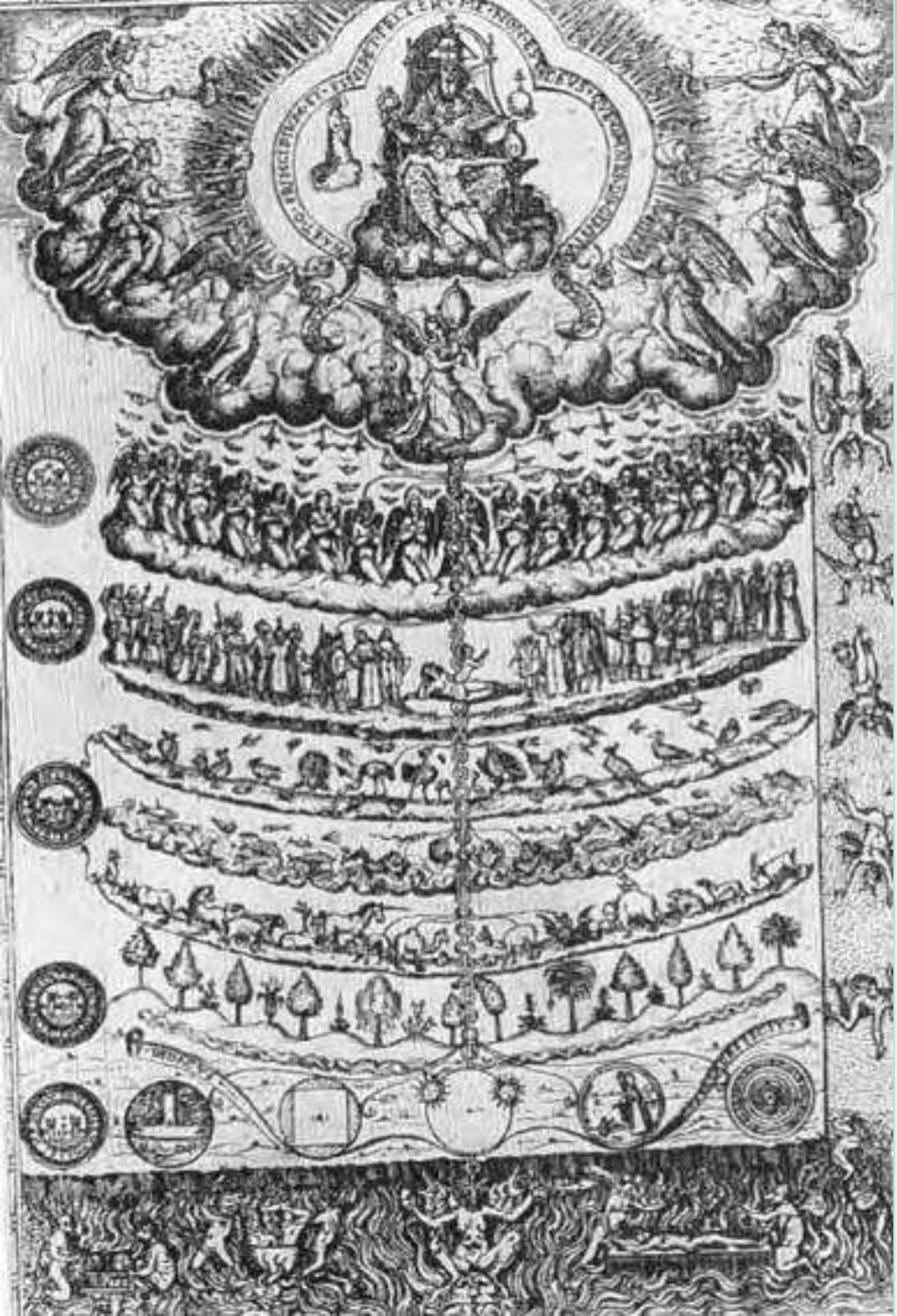
Dasylirion gentryi

Agave havardii, Chisos Mountains

Agavaceae Distribution

Aristotle's *Scala Naturae*

FIG. 18. The *Scala Naturae* or 'Ladder of Life' according to the description of Aristotle.



Great Chain of Being

1579, Didacus Valades, *Rhetorica Christiana*

hierarchical structure of all matter and life, believed to have been decreed by God

Middle Ages

Ruins of Rome

Age of Herbalists

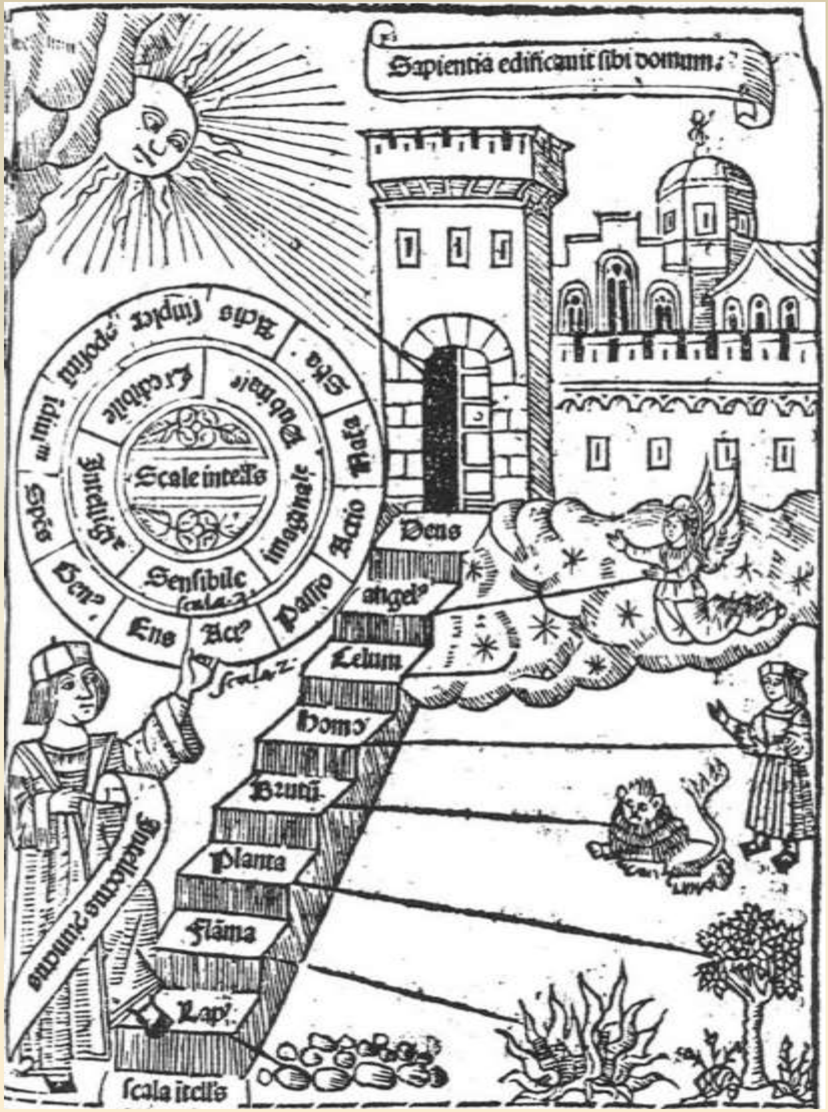
Greek Authorities

- Aristotle
- Theophrastus
- Dioscorides

Latin was the common language of scholars

Plants and animals given Latinized names

Stairway to Heaven



From Llull (1304). Note that Homo is between the plant-animal steps and the sky-angel- god steps.

Systematics - Three Kinds of Classification Systems

- **Artificial** - based on similarities that might put unrelated plants in the same category. - Linnaeus.

- **Natural** - categories reflect relationships as they really are in nature. - de Jussieu.

- **Phylogenetic** - categories based on evolutionary relationships. Current emphasis on monophyletic groups. - Angiosperm Phylogeny Group.

Carolus Linnaeus

1707 - 1778

Tried to name and classify all organism

Binomial nomenclature

Genus species

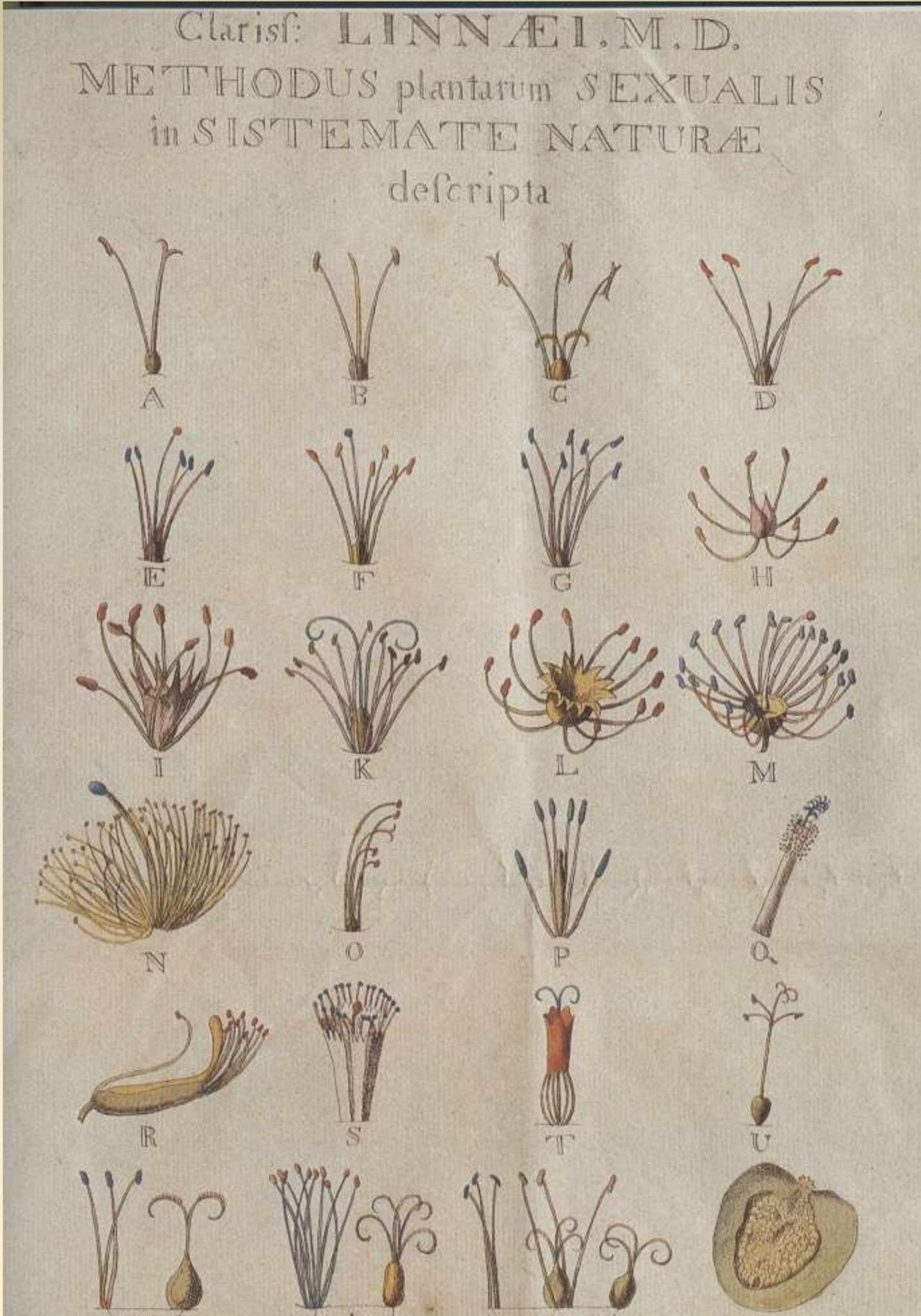
Species Plantarum - 1753

System of Classification

"Sexual System"

Classes - number of stamens

Orders - number of pistils



A View of the Twenty-four Classes of the SEXUAL SYSTEM *of* LINNÆUS, *with their Names and Characters; also the Numberand Explanation of Orders contained in each.*

Number of the Classes.	*Their Names and Characters.*	*Number of Orders in each.*	*Their Names, expressive of the Number of Female Parts or Styles.*	*Number.*
1.	MONANDRIA. One fertile stamen, i. e. having the *Anthera.*	2	1. Monogynia,	1
			2. Digynia,	2
2.	DIANDRIA. Two fruitful *Stamina* or male parts.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
3.	TRIANDRIA. Three ditto.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
4.	TETRANDRIA. Four ditto, all of equal length, by which it is distinguished from the fourteenth class.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Tetragynia,	4
5.	PENTANDRIA. Five ditto.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Triginia,	3
			4. Tetragynia,	4
			5. Pentagynia,	5
			6. Polygynia,	many
6.	HEXANDRIA. Six ditto, all of equal length, by which this is distinguished from the sixteenth class.	5	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
			4. Tetragynia,	4
			5. Polygynia,	many
7.	HEPTANDRIA. Seven ditto.	4	1. Monogynia,	1
			2. Digynia,	2
			3. Tetragynia,	4
			4. Heptagynia,	7
8.	OCTANDRIA. Eight ditto.	4	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
			4. Tetragynia,	4
9.	ENNEANDRIA. Nine ditto.	3	1. Monogynia,	1
			2. Trigynia,	2
			3. Hexagynia,	6

10. DECAN-

8. Aloë foliis ovato-lanceolatis carnosis apice triquetris: angulis inerme dentatis. *Hort. cliff.* 131. *Hort. upf.* 86. *Roy. lugdb.* 24.
Aloë africana minima atroviridis, spinis herbaceis numerosis ornata. *Boerh. lugdb.* 2. *p.* 131. *t.* 131.
Habitat in Æthiopiæ *campestribus.* ♃
Flores *in hoc genere specierum certissimi indices conjungunt Margaritiferam & Arachnoideam.*

9. ALOE floribus sessilibus reflexis imbricatis prismaticis. *Uvaria.*
Aloë foliis linearibus radicalibus membranaceis. *Hort. cliff.* 133. *Roy. lugdb.* 23.
Aloë africana folio triangulari longissimo & angustissimo, floribus luteis fœtidis. *Comm. hort.* 2, *p.* 29. *t.* 15. *Seb. thes.* 1. *p.* 29. *t.* 19. *f.* 3.
Habitat ad Cap. b. Spei. ♃

AGAVE.

1. AGAVE foliis dentato-spinosis, scapo ramoso. *Gen. nov.* 1102. *americana.*
Agave foliis spinoso-dentatis mucronatisque. *Hort. upf.* 81.
Aloë foliis lanceolatis dentatis spina terminatis radicalibus. *Hort. cliff.* 130. *Roy. lugdb.* 22.
Aloë folio in oblongum mucronem abeunte. *Bauh. pin.* 286.
Habitat in America *calidiore.* ♄

2. AGAVE foliis dentatis, staminibus corollam æquantibus. *vivipara.*
Aloë americana polygona. *Comm. rar.* 65. *t.* 65.
Habitat in America.
Confer. Aloe americana sobolifera. *Herm. lugdb.* 16. *t.* 17.

3. AGAVE foliis dentato-spinosis, scapo simplicissimo. *Gen. nov.* 1102. *virginica.*
Aloe foliis lanceolatis spina cartilaginea terminatis, floribus alternis sessilibus. *Gron. virg.* 152.
Habitat in Virginia. ♃

4. AGAVE foliis integerrimis. *Gen. nov.* 1102. *fœtida.*
Aloe foliis integerrimis patentiusculis aculeo-terminatis, radice caulescente. *Hort. cliff.* 132.
Aloe americana, viridi rigidissimo & fœtido folio, Piet dicta indigenis. *Comm. hort.* 2. *p.* 35. *t.* 18.

Linnaean Hierarchy

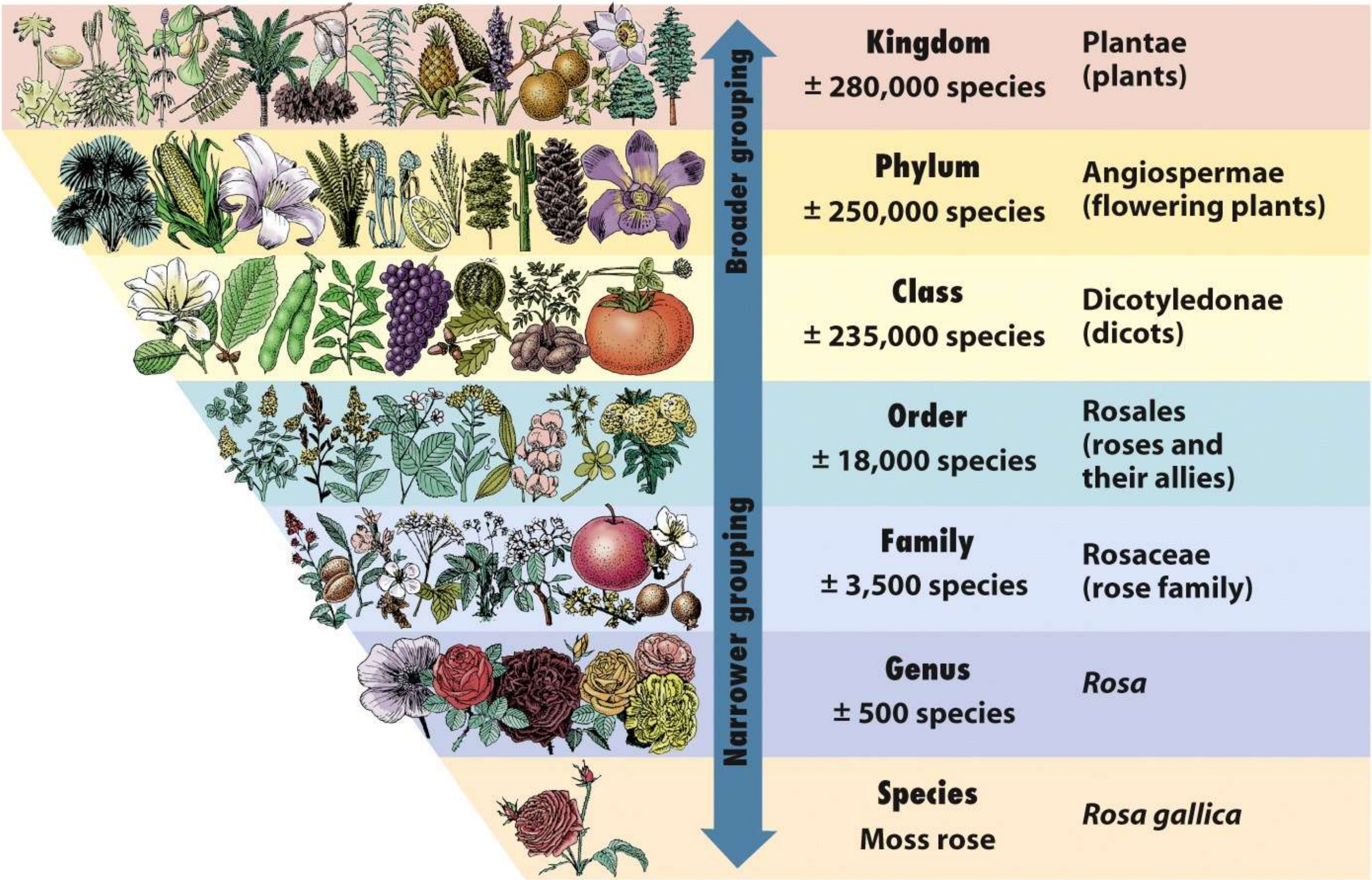
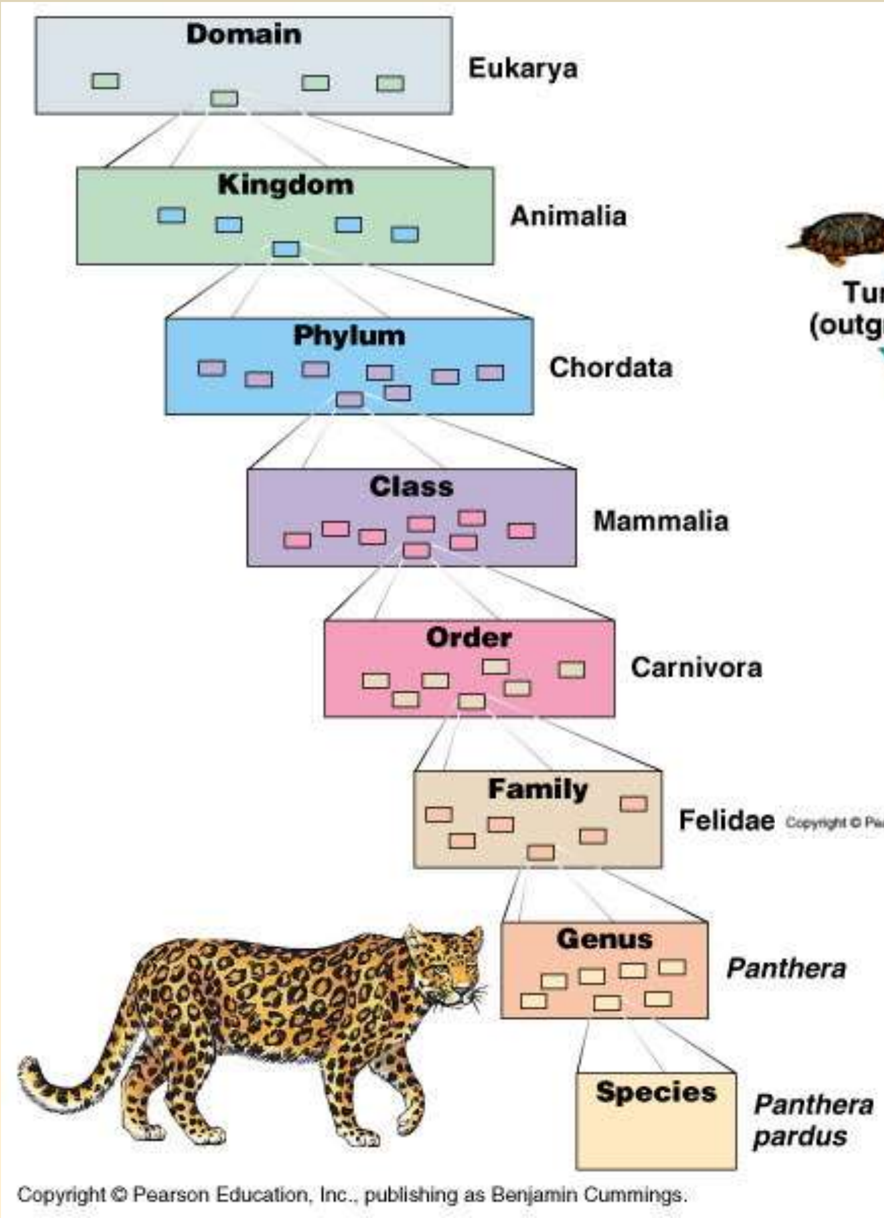
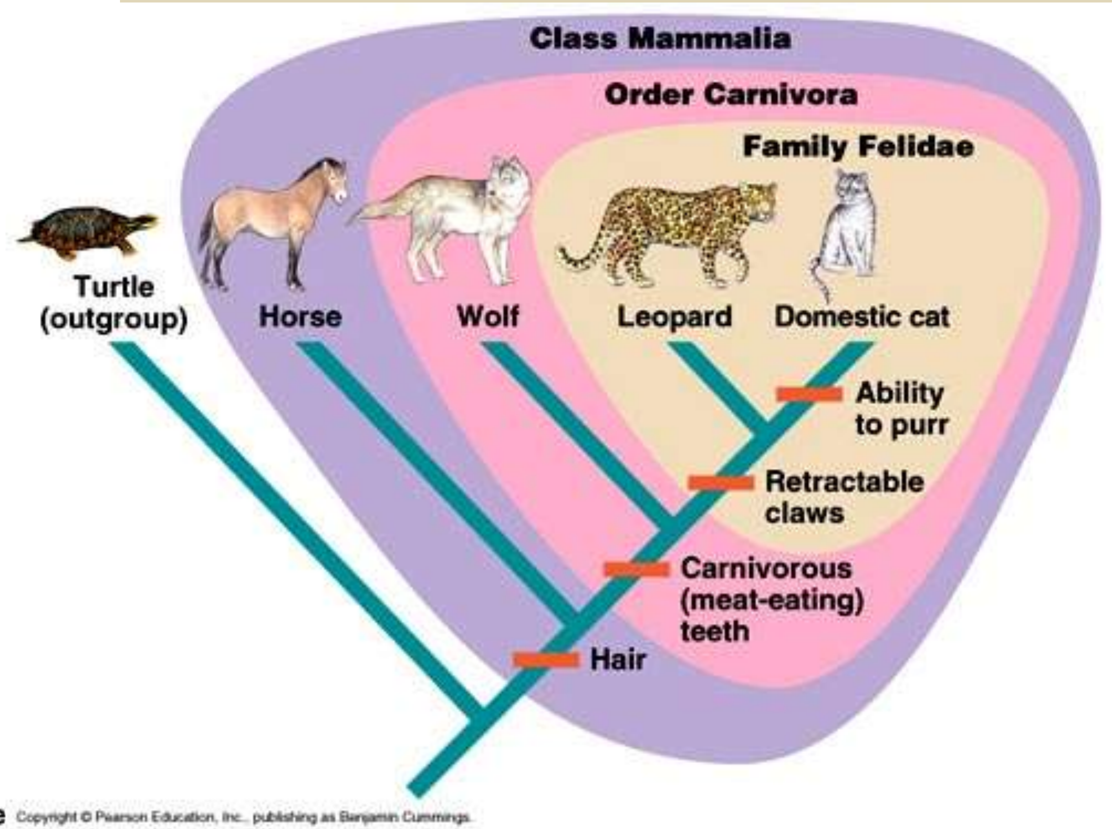


Figure 2-6 Discover Biology 3/e

Nested box-within-box hierarchy is consistent with descent from a common ancestor, used as evidence by Darwin





Nomenclature – system of naming species and higher taxa.

International Codes of Nomenclature - separate codes for plants, animals, fungi, bacteria

Binomial nomenclature – scientific name, usually Latinized

Each species has only **one scientific name**, eliminate confusion.

Priority - the correct name will be the **one that was published the earliest**, providing it is acceptable in terms of the rest of the code.

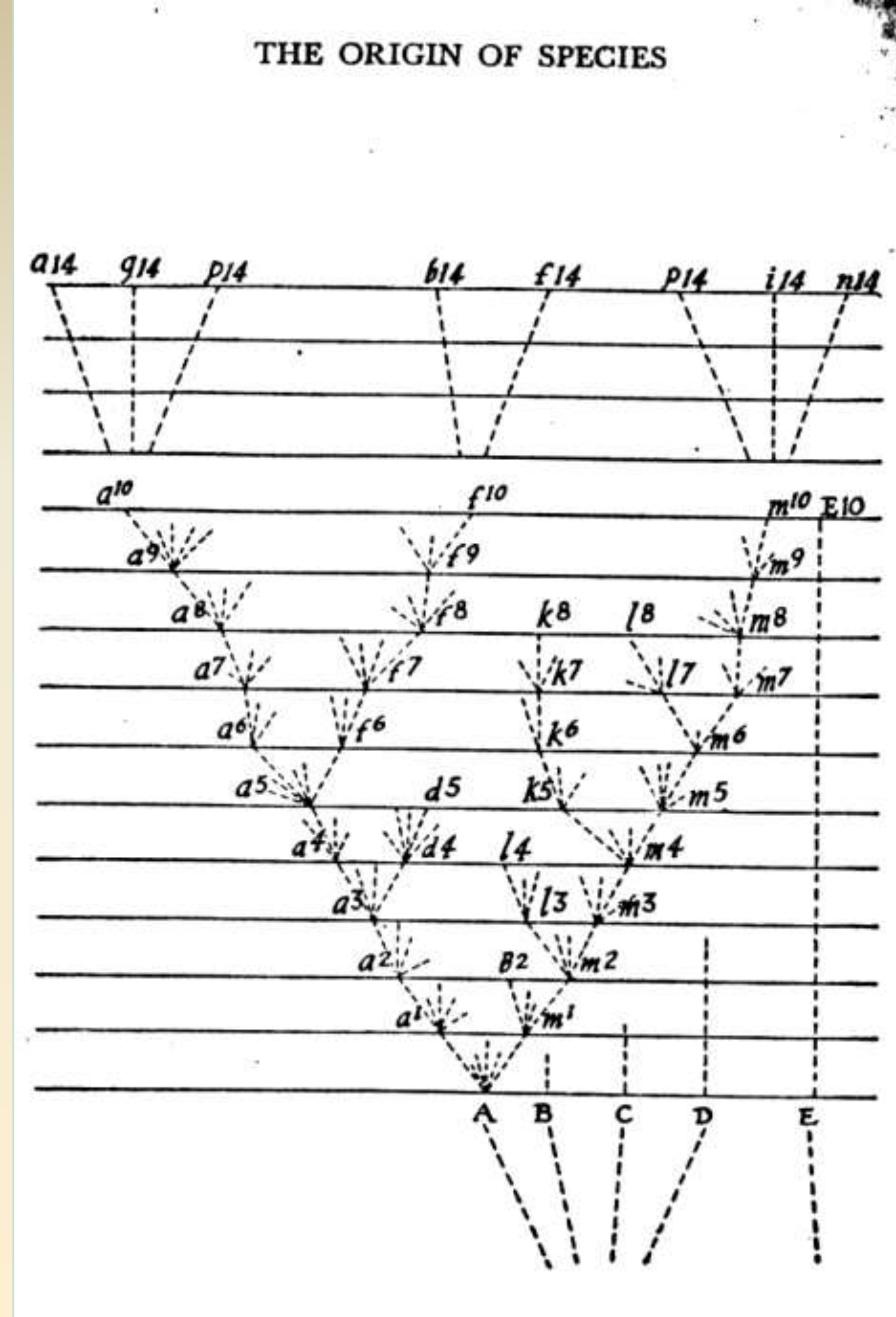
Causes discontent when it turns out that the name with priority is not the one in common usage, often because it was published in some obscure place. Invalid names = synonyms.

Starts with Linnaeus publications:

Plants - Species Plantarum (1753)

Animals - Systema Naturae (1758)

Type Concept - material on which an original description is based, fixes the meaning of a specific name. Type Specimen



Charles Darwin 1859

- Origin of Species by Natural Selection, or the Preservation of Favored Races in the Struggle for Life

- Descent from Common Ancestor

What is a Species?

"Certainly no clear line of demarcation has yet been drawn between species and sub-species – that is, the forms which…*come very near to, but do not quite arrive at, the rank of species*. …A well-marked variety may therefore be called an *incipient species*. …From these remarks it will be seen that <u>I look at the term species as one arbitrarily given</u>."

Darwin, *The Origin of Species*

Species

- The species is the basic biological unit around which classifications are based.
- However, what constitutes a species can be difficult to define and there are multiple definitions of species in use today.

Species Concepts

(Futuyma 1997)

Table 15.1 The biological species concept and some recently proposed alternatives

BIOLOGICAL SPECIES CONCEPT A species is a group of individuals fully fertile inter se, but barred from interbreeding with other similar groups by its physiological properties (producing either incompatibility of parents, or sterility of the hybrids, or both). (Dobzhansky 1935)

Species are groups of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups. (Mayr 1942)

EVOLUTIONARY SPECIES CONCEPT A species is a single lineage (an ancestral-descendant sequence) of populations or organisms that maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate. (Wiley 1978)

PHYLOGENETIC SPECIES CONCEPTS A phylogenetic species is an irreducible (basal) cluster of organisms that is diagnosably distinct from other such clusters, and within which there is a parental pattern of ancestry and descent. (Cracraft 1989)

A species is the smallest monophyletic group of common ancestry. (de Queiroz and Donoghue 1990)

RECOGNITION SPECIES CONCEPT A species is the most inclusive population of individual biparental organisms that share a common fertilization system. (Paterson 1985)

COHESION SPECIES CONCEPT A species is the most inclusive population of individuals having the potential for phenotypic cohesion through intrinsic cohesion mechanisms. (Templeton 1989)

ECOLOGICAL SPECIES CONCEPT A species is a lineage (or a closely related set of lineages) that occupies an adaptive zone minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range. (Van Valen 1976)

INTERNODAL SPECIES CONCEPT Individual organisms are conspecific by virtue of their common membership in a part of the genealogical network between two permanent splitting events or between a permanent split and an extinction event. (Kornet 1993)

Source: Coyne (1994).

Species Concepts

- There are many difficulties associated with the definition of “species.”
- Definitions that work well for some groups of organisms do not necessarily work for other organisms (extant versus fossil species).
- Some species concepts take evolution into account and attempt to address problems that are associated with a species being an evolving rather than an immutable biological entity.

Morphological Species Concept (MSC)

- A species is a group of organisms that resemble one another and are distinct from other such sets.

- More or less the same as Phenetic Species Concept. What makes two organisms members of the same species is some measure of their <u>similarity</u> across morphological, genetic or behavioral dimensions.

Biological Species Concept (BSC)

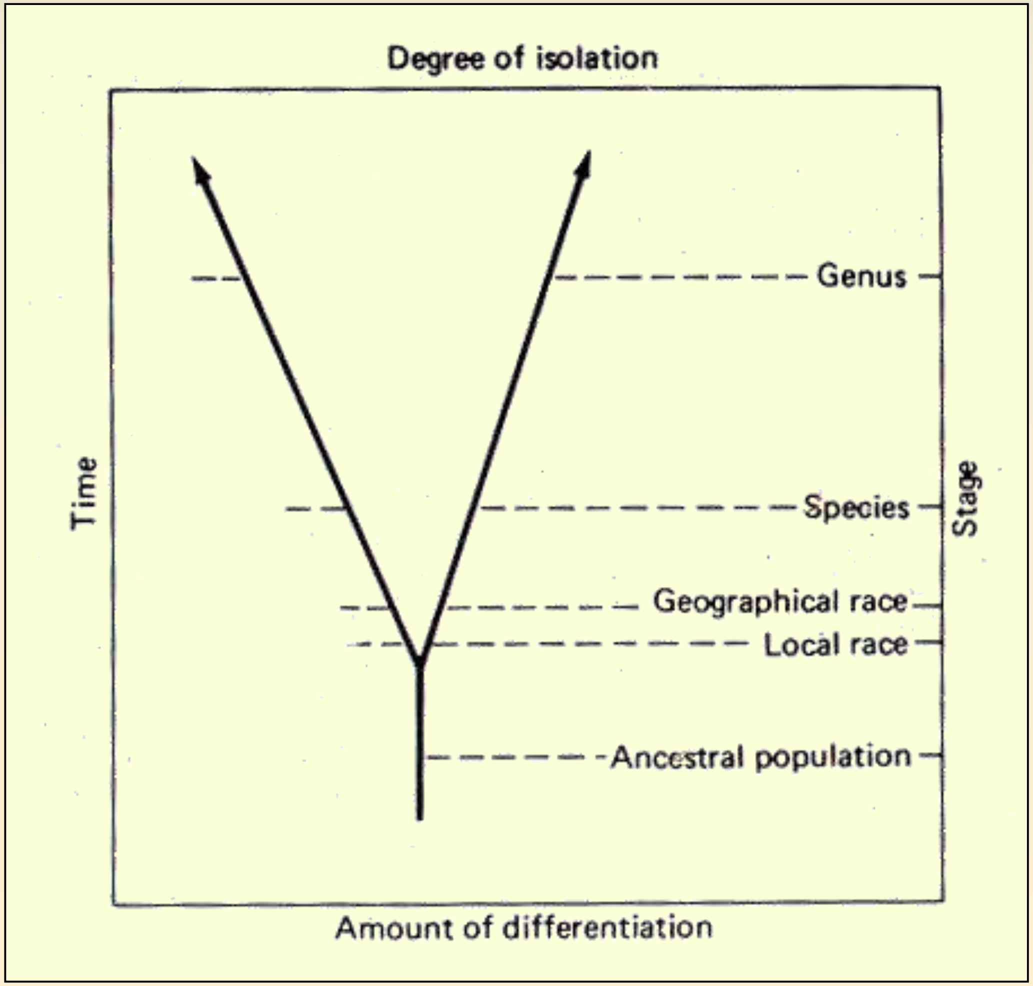
"Species are groups of actually or potentially interbreeding populations that are reproductively isolated from other such groups."

E. Mayr (1942)

Main criterion is reproductive isolation.

Biological Species Concept (BSC)

Ernst Mayr - Investigated the question of how species originate, and the importance of geographical isolation



Ernst Mayr

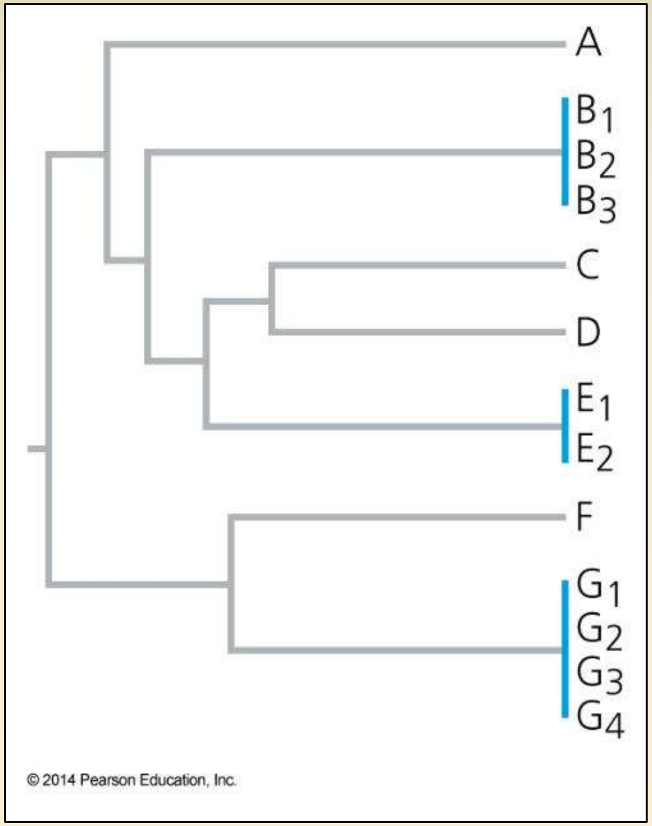
Biological Species Concept (BSC)

- A biological concept of a species is a population or group of populations that are able to *interbreed*, under *natural conditions* to produce *fertile offspring*.

- According to the BSC, speciation occurs when populations evolve **reproductive isolating mechanisms**.

Phylogenetic Species Concept (PSC)

- The phylogenetic species concept emphasizes common descent and covers both sexually and asexually reproducing organisms.
- Under the PSC any population that has become separated and has undergone character evolution will be recognized as a species.

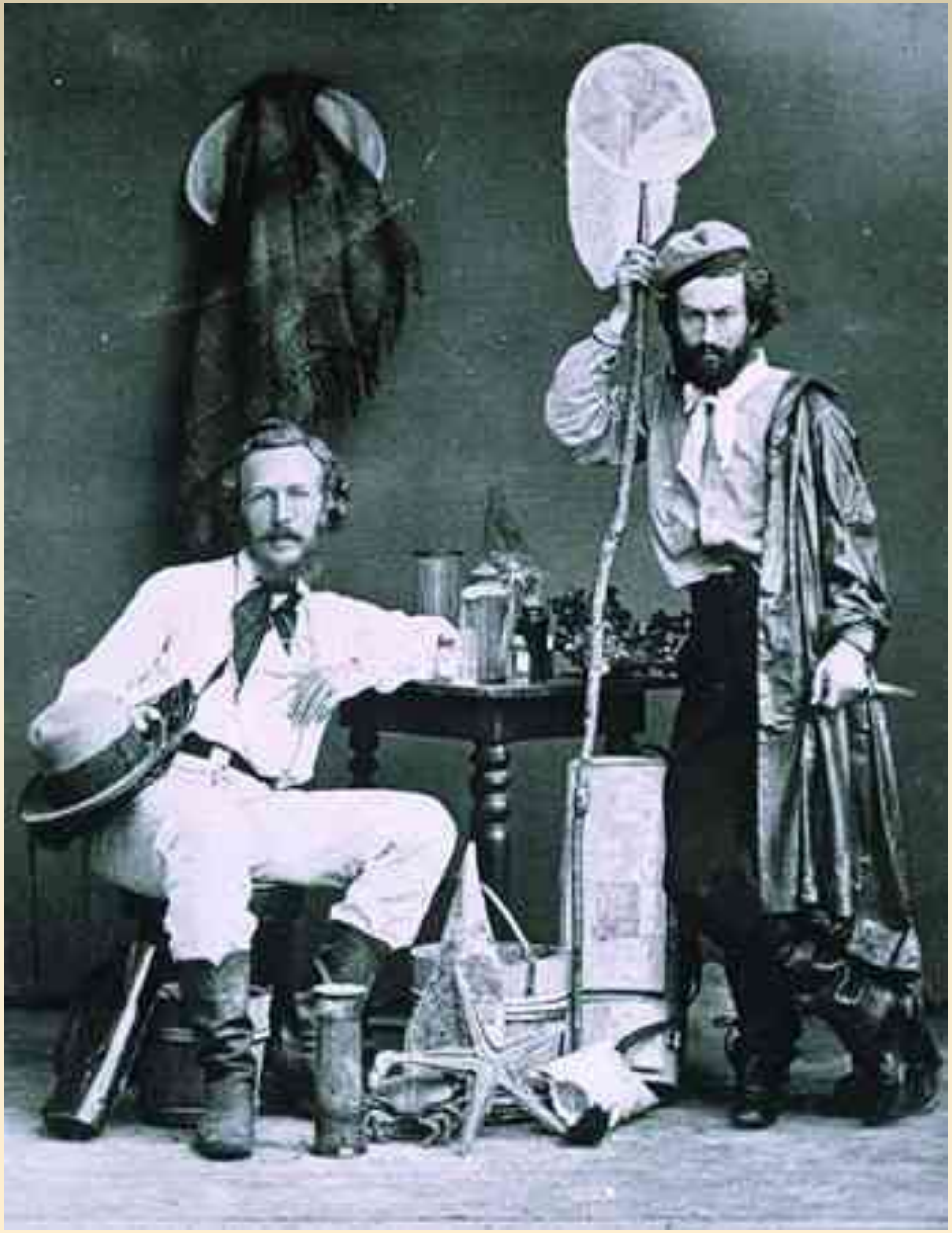


Ernst Haeckel - 1860s

Coined the terms
    Phylum, Phylogeny, Ecology

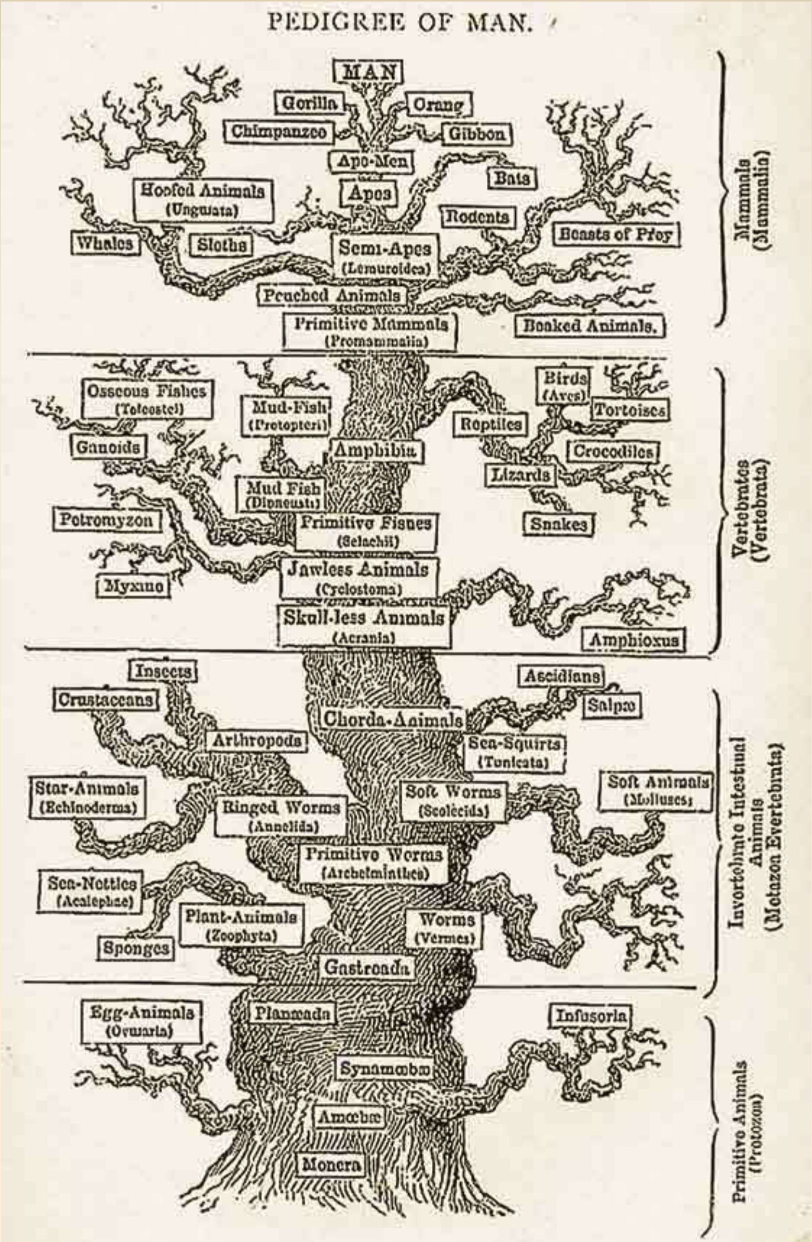
Drew complete Tree of Life

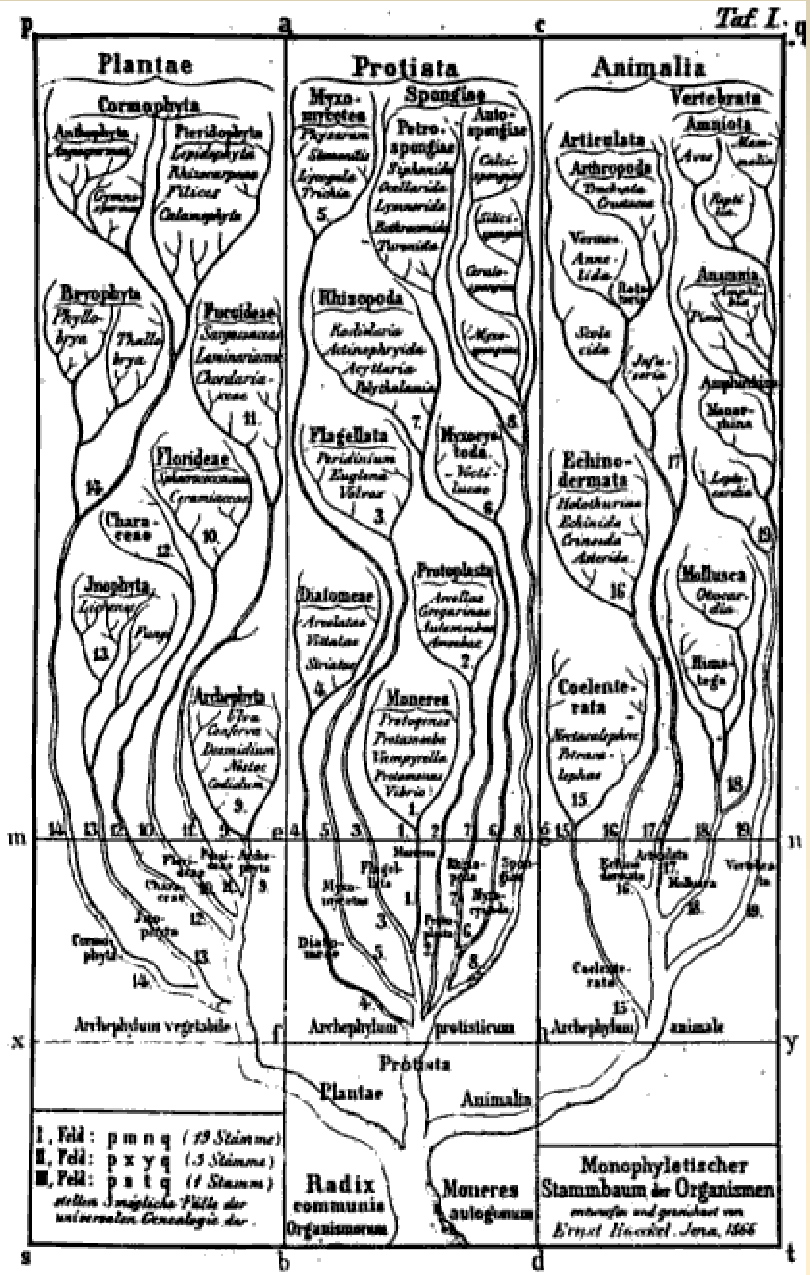
Proposed Biogenetic Law -
 “ontogeny recapitulates phylogeny”



Ernst Haeckel 1860s

Three Kingdom System





"Agavaceae" sensu stricto - The Agave Family
APG3 Asparagaceae – Agavoideae

Yucca
Hesperaloe
Beschorneria
Furcraea
Agave
Manfreda
Polianthes
Prochnyanthes

Yucca faxoniana
Big Bend N.P., *Texas*

Agave salmiana
Nuevo Leon, Mexico

Furcraea

Beschorneria

Manfreda *Polianthes* *Prochnyanthes*

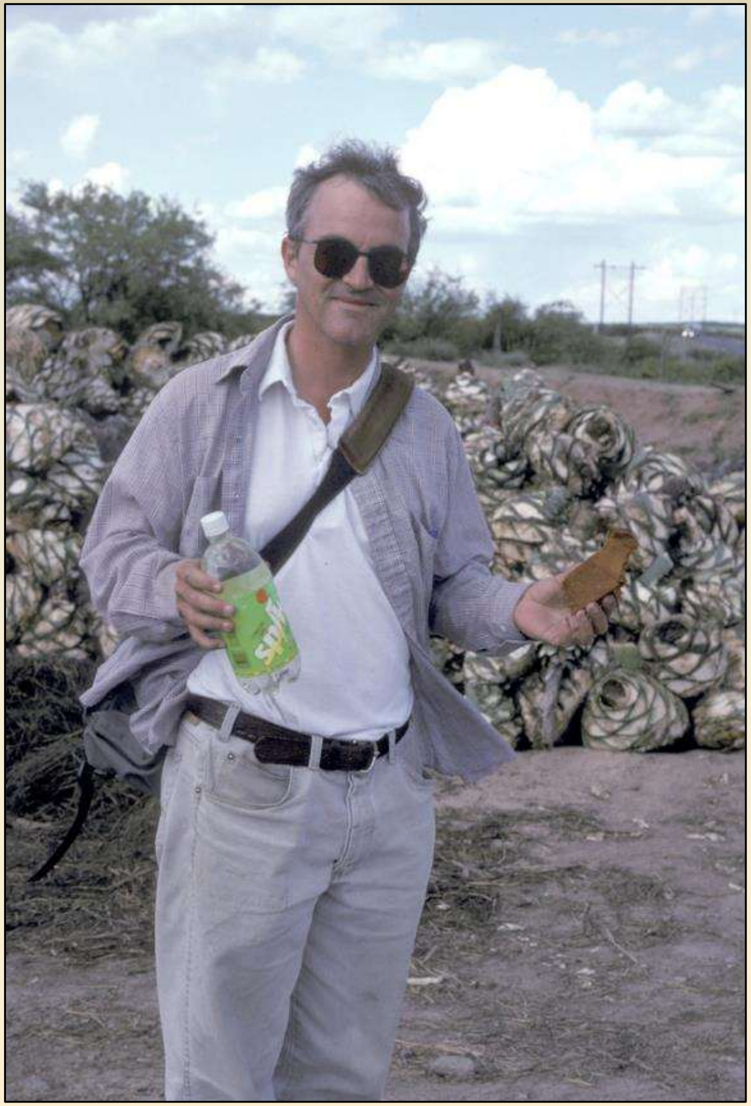
Blue Agave Tequila Plantation, Jalisco, Mexico

El Cuervo Tequila Distillery
Tequila, Jalisco

“Mescal”

Sampling mescal, Oaxaca

Mescal Distillery, Durango




GUSANO
ROJO
Mezcal
Legitimo
de Oaxaca

Dasylirion - Sotol

Dasylirion leiophyllum, Sotol Vista, Big Bend N.P.

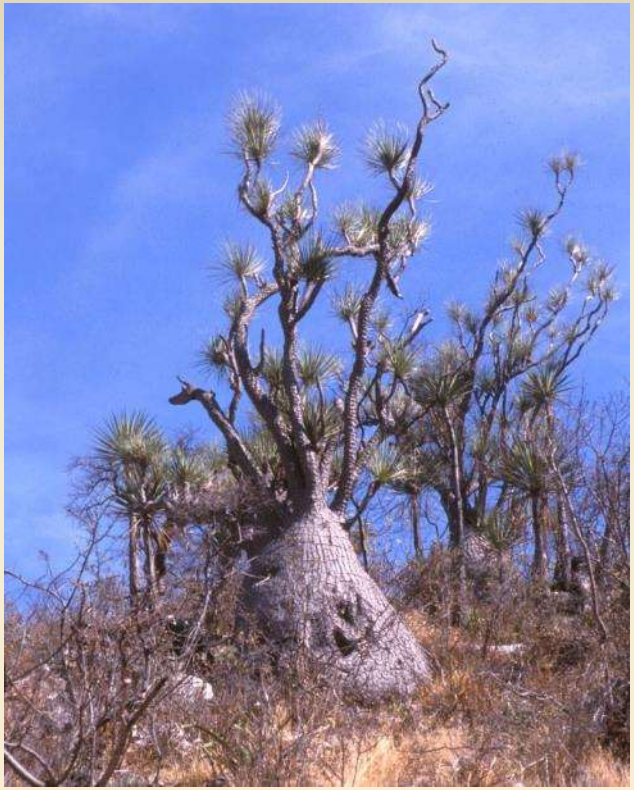
D. wheeleri, Organ Mtns, New Mexico

"Nolinaceae"
APG3 Asparagaceae – Nolinoideae

Nolina

Dasylirion

Calibanus



Beaucarnea

"Dracaenaceae"
APG3 Asparagaceae – Dracaenoideae

Dracaena draco

Sansevieria trifasciata

“Convallariaceae”

Asparagaceae – Convallarioideae

Genera Plantarum - A. L. de Jussieu, 1789

A natural system

Class III - Plantae Monocotyledones, Stamina Perigyna

Orders:

- **Palmae -** *Calamus, Phoenix* etc.
- **Asparagi -** *Dracaena, Asparagus, Trillium, Convallaria, Dioscorea* etc.
- **Junci -** *Juncus, Xyris, Commelina, Melanthium, Colchicum,* etc.
- **Lilia -** *Lilium, Uvularia, Yucca* etc.
- **Bromeliae -** *Puya, Bromelia, Agave* etc.
- **Asphodeli -** *Aletris, Aloe, Asphodelus, Allium* etc.
- **Narcissi -** *Crinum, Hemerocallis, Narcissus, Polianthes, Tacca,* etc.
- **Irides -** *Tigridia, Iris, Crocus, Gladiolus* etc.

George Bentham

Jospeh Dalton Hooker

Genera Plantarum - 1862-1883

- **All genera described anew, in Latin**
- **Recognized 202 Orders (=Families)**
- **Dicots come before monocots**
- **Ranales placed first, Apetalae last**
- **Importance of epigyny exaggerated**

Monocotyledons - 7 Series

I. Microspermae - Orchidaceae, Burmanniaceae
II. Epigynae - Bromeliaceae,Iridaceae
III. Coronariae - Liliaceae, Pontederiaceae
IV. Calycinae - Juncaceae, Palmae
V. Nudiflorae - Pandanaceae, Typhaceae
VI. Apocarpae - Alismaceae
VII. Glumaceae - Gramineae, Cyperaceae

Adolf Engler

(1844-1930)

Die naturlichen Pflanzenfamilien

Das Pflanzenreich

Treatment of all known plants

Families with simple or reduced flowers are placed first (primitive?)

Widely used system

Monocots - 10 Reihen (Orders)

Pandanales - Typhaceae, Pandanaceae
Helobiae - Alismaceae etc.
Glumiflorae - grasses and sedges
Principes - palms
Syanthae - Cyclanthaceae
Spathiflorae - Araceae
Farinosae - Bromeliaceae, Commlinaceae etc.
Liliiflorae - Liliaceae, Amaryllidaceae etc
Scitamineae - Musaceae, Zingiberaceae
Microspermae - orchids

Die Naturlichen Pflanzenfamilien (K. Krause, 1930)

Liliaceae
12 Subfamilies
Melanthioideae
Herrerioideae
Asphodeloideae
Allioideae
Lilioideae
Scilloideae
Dracaenoideae
Asparagoideae
Mondoideae
Aletroideae
Luzuriagoideae
Smilacoideae

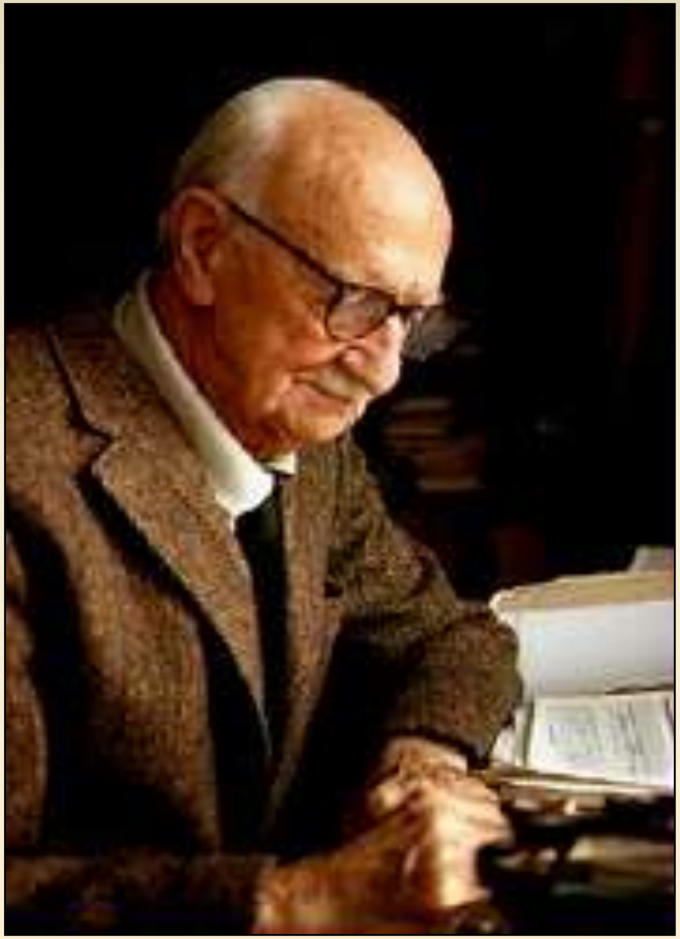
Haemodoraceae
Amaryllidaceae
Dioscoreaceae
Iridaceae

Dracaenoideae
Yucceae
Nolineae
Dracaeneae

Asparagoideae
Asparageae
Polygonatae
Convallarieae
Parideae

Agavoideae
Agave
Fourcroydes
Beschorneria
Doryanthes
Polyanthes

John Hutchinson
(1884-1972)



Families of Flowering Plants
Dicots fundamentally divided
Lignosae Herbaceae

Monocots
Derived from Ranales
3 Divisions, 29 Orders
Calyciferae
Corolliferae
Glumiflorae

Agavaceae - added *Yucca*
Yucca, Hesperaloe, Agave, Manfreda Furcraea, Beshchorneria, Dasylirion, Nolina, Dracaena, Sansevieria, Cordyline, Phormium, Doryanthes

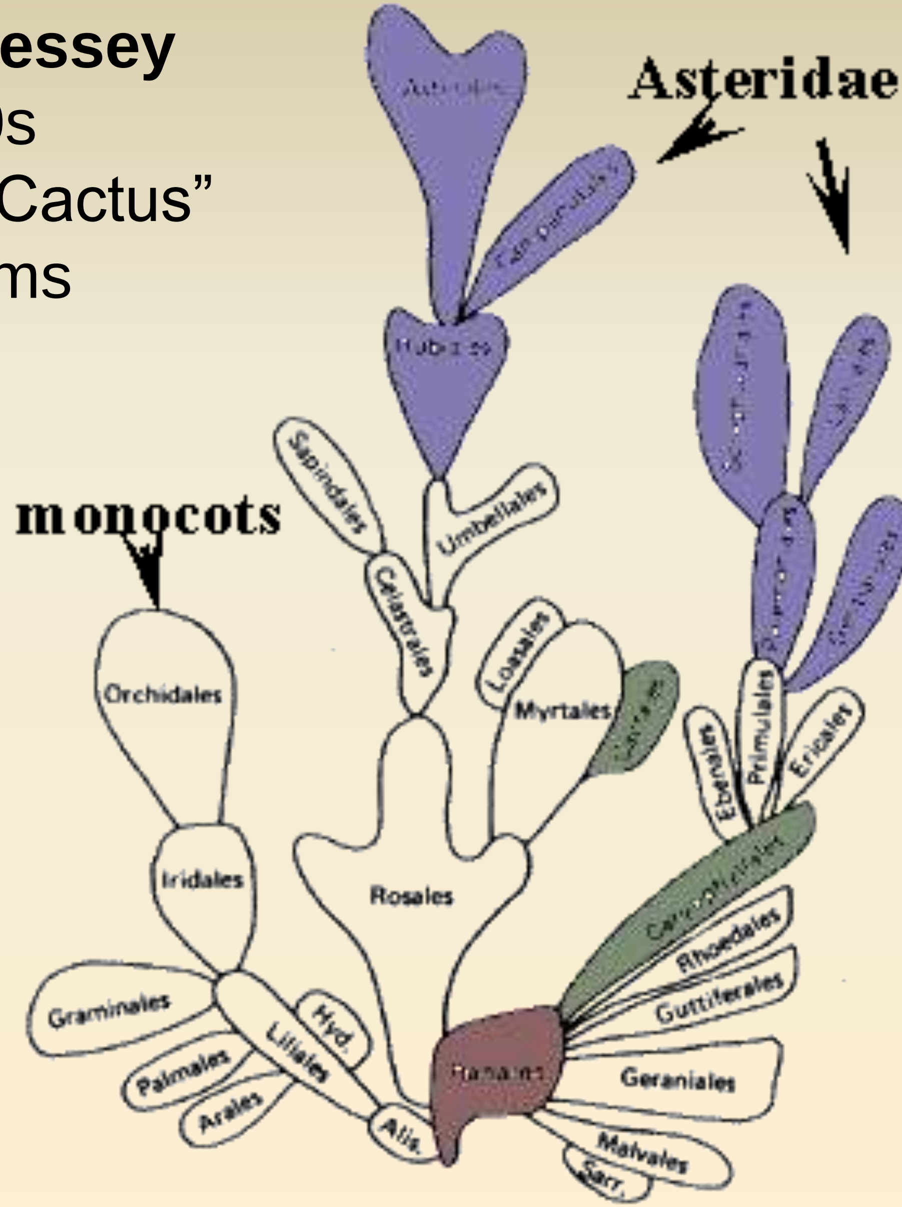
CHARLES EDWIN BESSEY
(1845–1915, American)

Charles Bessey
Early 1900s
“Bessey’s Cactus”
Angiosperms

He developed a set of "dicta" (rules) stating which characters were primitive and which were advanced in flowering plants.

Not all considered correct today but many are (as Cronquist said, "we are all Besseyans").

Magnolias primitive



Arthur Cronquist
(1919-1992)

An Integrated System of Classification of Flowering Plants, 1981

Woody Magnoliids primitive
Aquatic origin of monocots

Magnoliopsida
6 subclasses, 55 orders, 352 families

Liliopsida
5 subclasses, 18 orders, 61 families

A “Lumper”, did not agree with “cladists” about monophyletic groups

Armen Tahktajan
(1910-2009)

Diversity and Classification of Flowering Plants,1997

System similar to Cronquist
Magnoliopsida - Dicots
7 Subclasses, 20 Superorders
Liliopsida - Monocots
3 Subclasses, 8 Superorders
Woody Magnoliids primitive
Monocots derived from aquatic herbs

A “Splitter”
Lilliidae split into many families
Agavaceae included *Hosta*

Cronquist's System

Liliales
Phylydraceae
Pontederiaceae
Haemodoraceae
Cyanastraceae
Liliaceae
Iridaceae
Velloziaceae
Agavaceae
Aloeaceae
Xanthorrhoeacea
Hanguanaceae
Taccaceae
Stemonaceae
Smilacaceae
Dioscoreaceae

Orchidales
Geosiridaceae
Burmanniaceae
Orchidaceae

Takhtajan's System

Melanthiales
Tofieldiaceae
Melanthiaceae
Japonoliriaceae
Xerophyllaceae
Nartheciaceae
Heloniadaceae
Chionographidaceae

Colchicales
Tricyrtidaceae
Burchardiaceae
Uvulariaceae
Campynemataceae
Scoliopaceae
Colchicaceae
Calochortaceae
Trilliales
Trillaceae

Liliales
Liliaceae
Medeolaceae

Alstroemeriales
Alstroemeriaceae

Iridales
Isophysidaceae
Geosiridaceae
Iridaceae
Tecophilaeales
Ixioliriaceae
Lanariaceae
Walleriaceae
Tecophilaeaceae
Cyanastraceae
Eriospermaceae

Burmanniales
Burmanniaceae
Thismiaceae
Corsiaceae

Hypoxidales
Hypoxidaceae

Orchidales
Orchidaceae

Amaryllidales
Hemerocallidaceae
Hyacinthaceae
Alliaceae
Hesperocallidaceae
Hostaceae
Agavaceae
Amaryllidaceae

Asparagales
Convallariaceae
Ophiopogonaceae
Ruscaceae
Asparagaceae
Dracaenaceae
Nolinaceae
Blandfordiaceae
Herreriaceae
Phormiaceae
Dianellaceae
Doryanthaceae
Asteliaceae
Asphodelaceae
Aloaceae
Anthericaceae
Aphyllanthaceae

Xanthorroeales
Baxteriaceae
Lomandraceae
Dasypogonaceae
Calectasiaceae
Xanthorrhoeaceae

Hanguanales
Hanguanaceae

Stemonales
Stemonaceae
Croomiaceae
Pentastemonaceae

Smilacales
Luzuriagaceae
Philesiaceae
Ripogonaceae
Smilacaceae
Petermanniaceae

Dioscoreales
Stenomeridaceae
Trichopodiaceae
Avetraceae
Dioscoreaceae

Rolf Dahlgren
(1932-1987)

The Families of the Monocotyledons,
Dahlgren, Clifford, and Yeo, 1985

System based on work of Huber, 1969

Examined micro-characters of seed coat, cuticle, endosperm, embryo etc

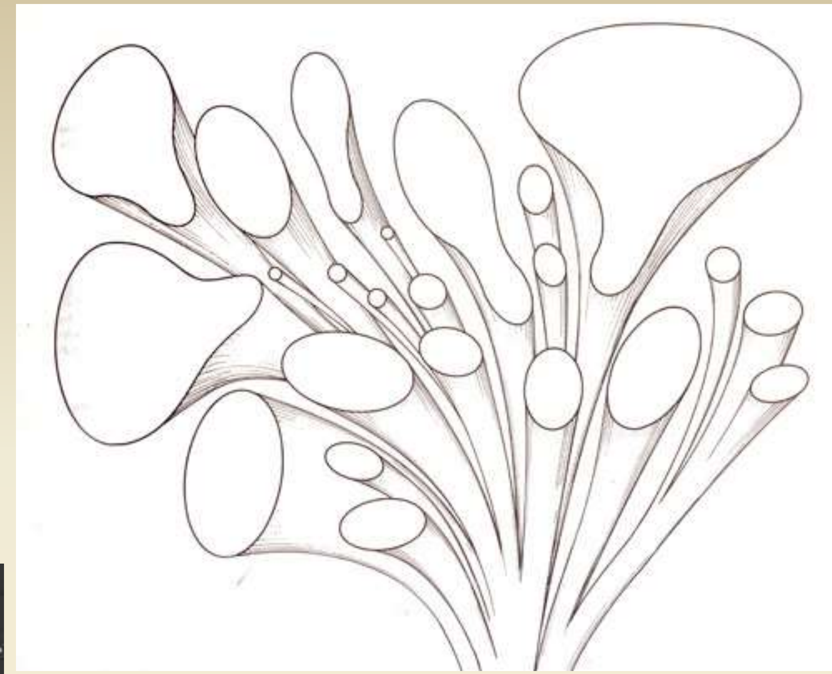
Monocots derived from Dioscoreales-like dicot ancestor

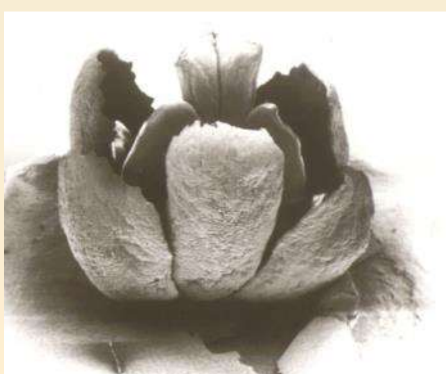
Liliiflorae divided into major groups
- Dioscoreales - 7 families
- Asparagales - 31 families
- Liliales - 10 families
- Melanthiales - 2 families

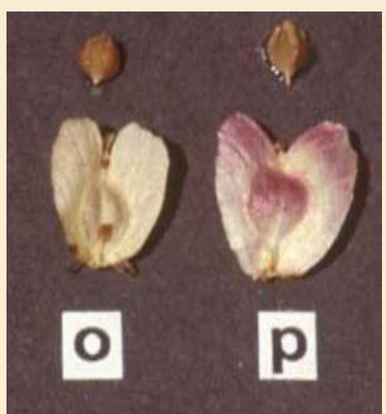
Rolf Dahlgren

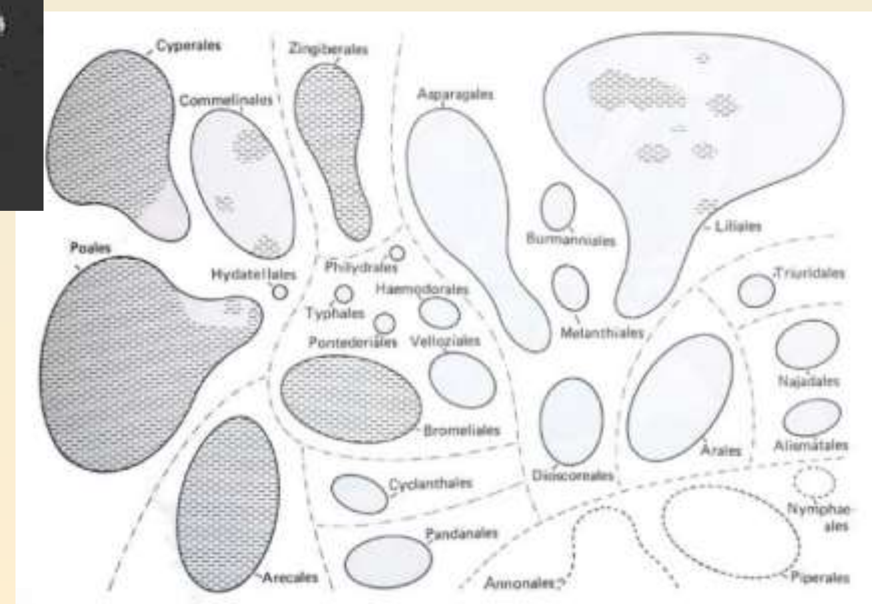
1980s
Microcharacters
“Lacrymograms”

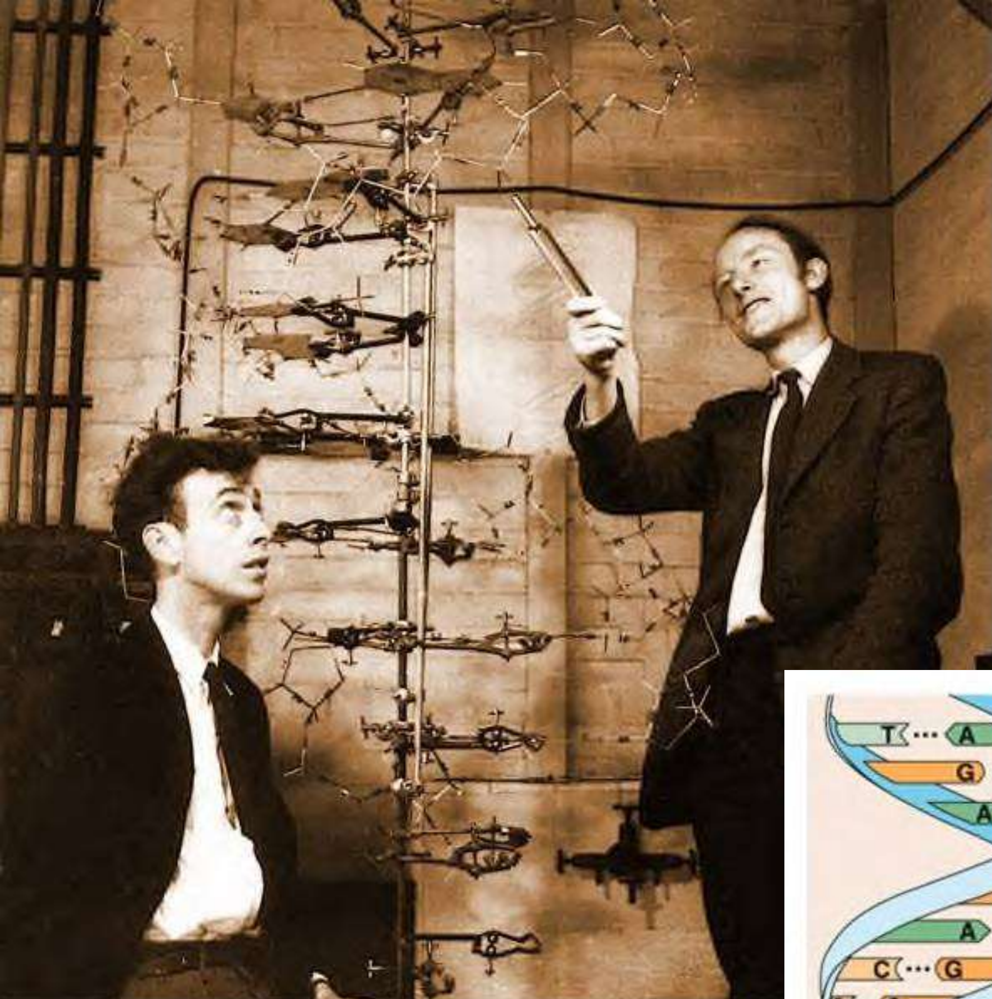
Helped define
Asparagales
and families



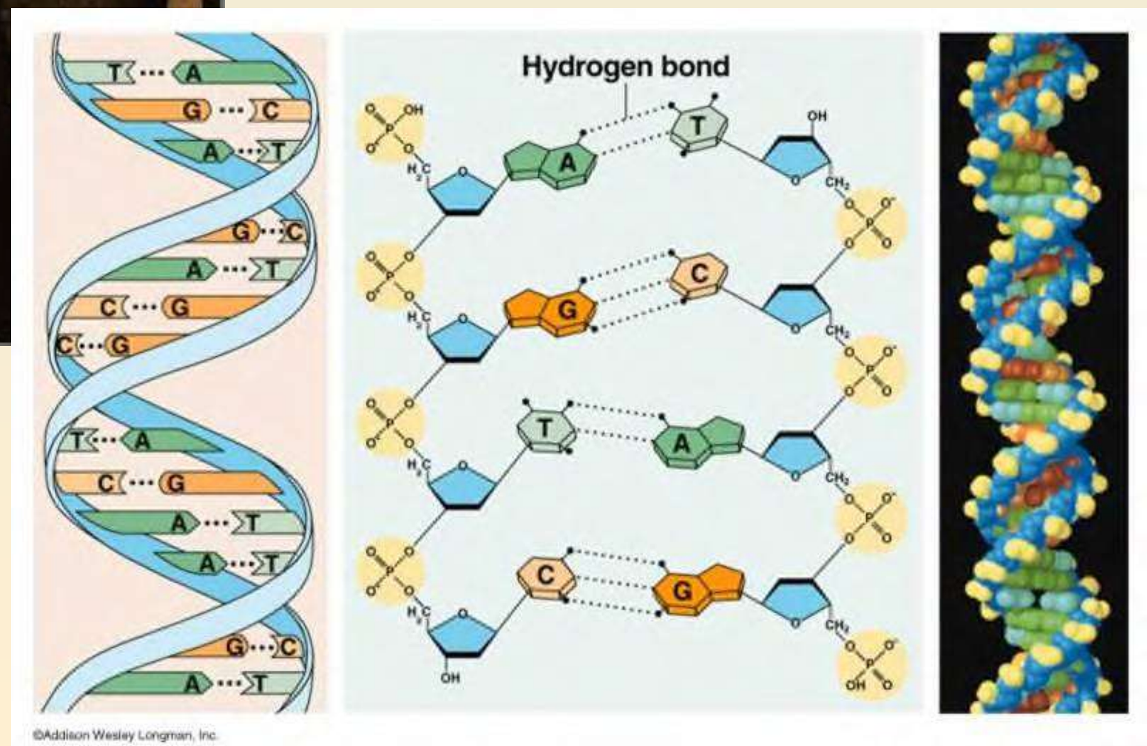




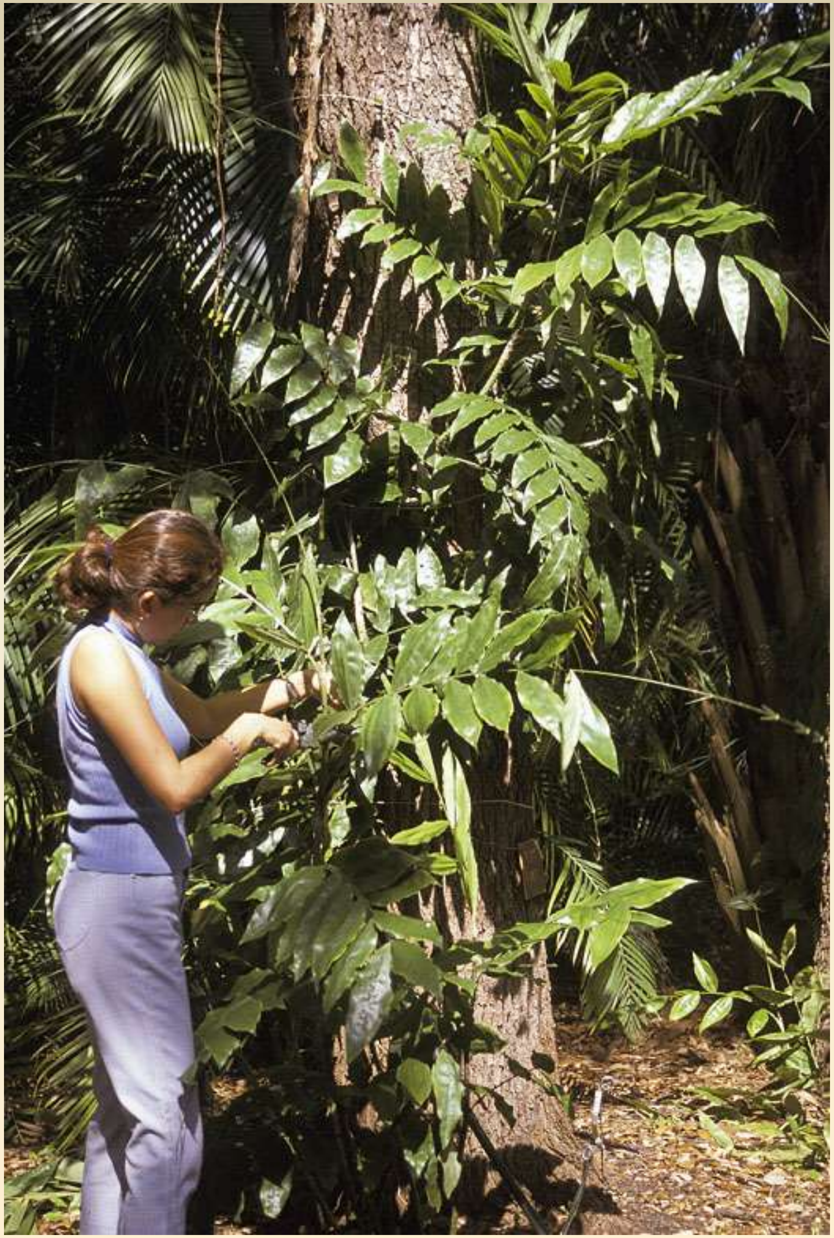




Watson and Crick
1953
Structure of DNA



Working with Plant DNA



Sample Collection

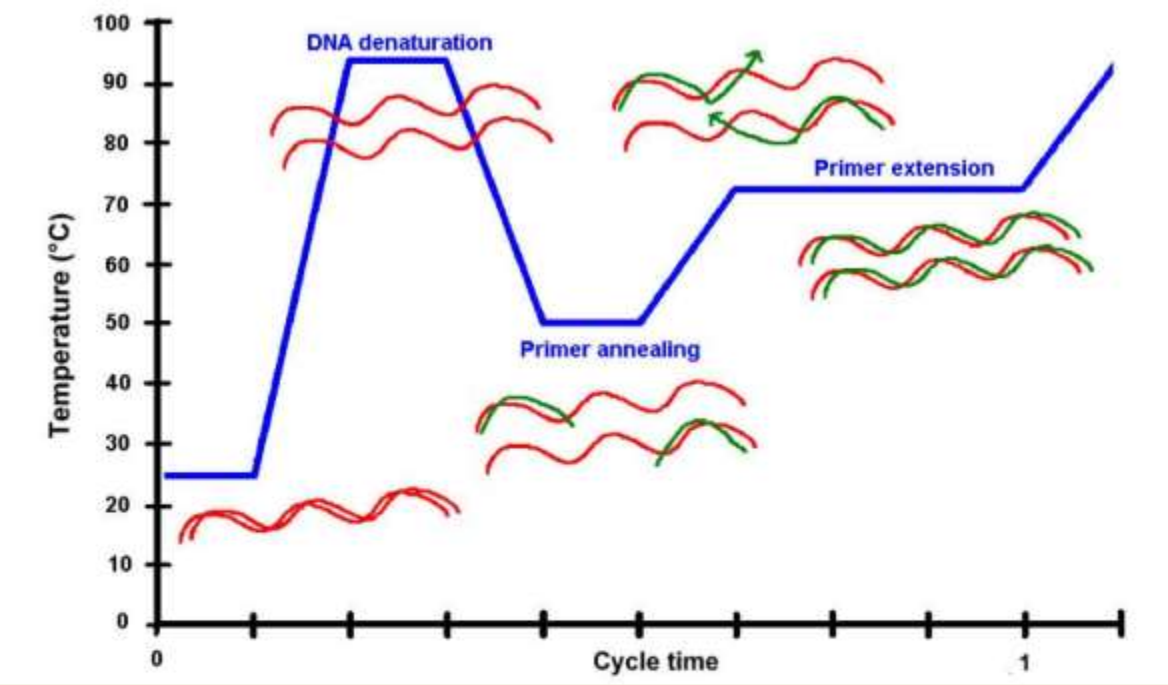
Voucher Specimens

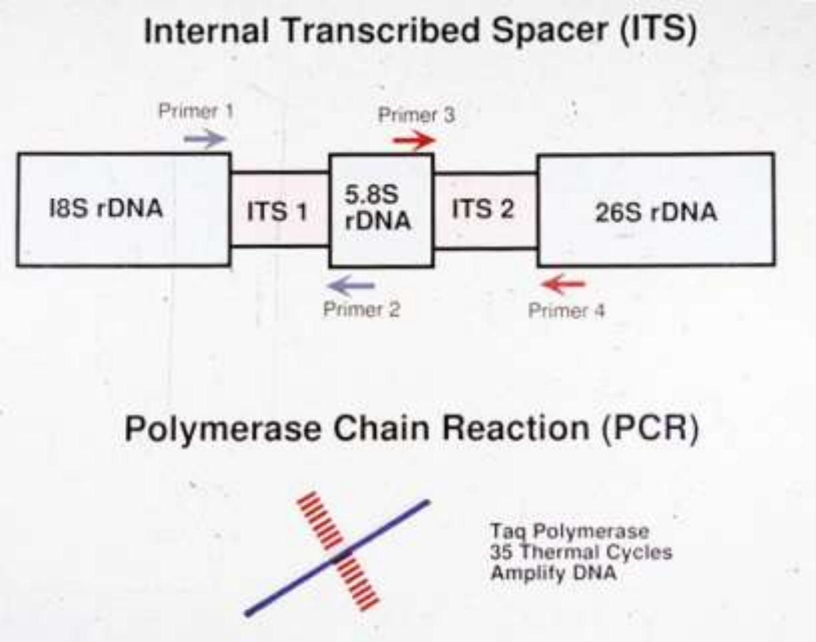
Working with Plant DNA

Grinding Tissue

Extracting DNA

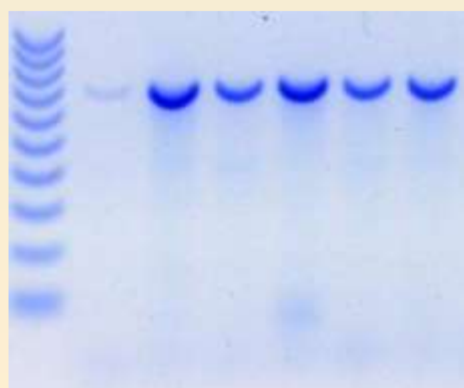
DNA Amplification





DNA Amplification: PCR

Kelsey Huisman, 2013 REU

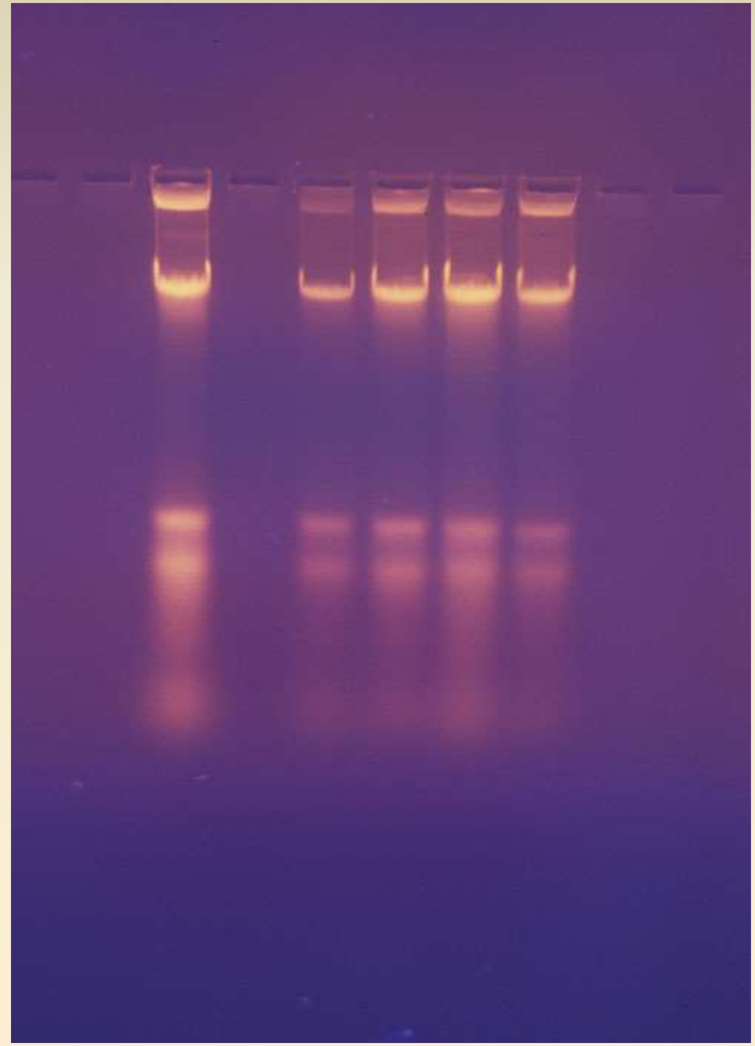


Sequencing Facility

PCR Product Gel Electrophoresis – check size

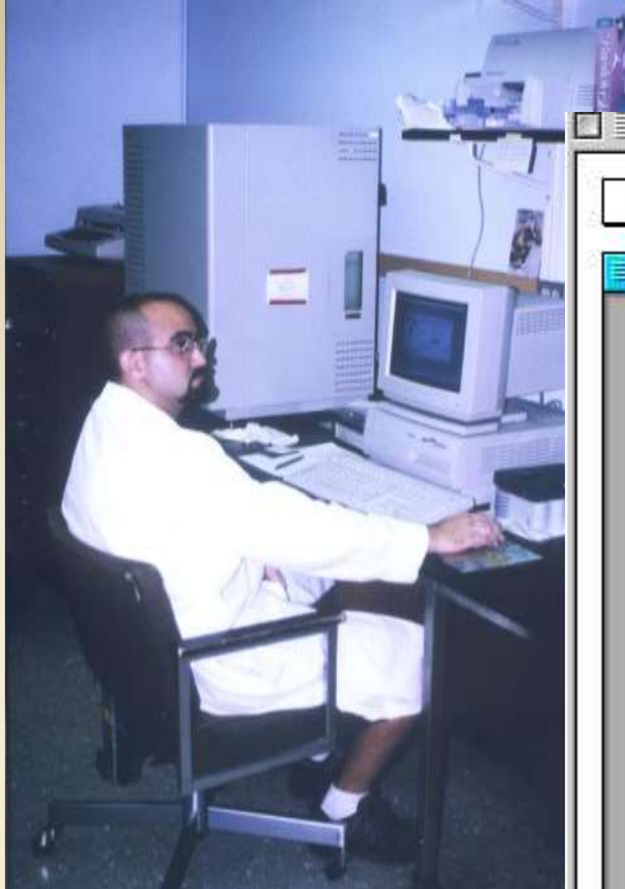
Working with Plant DNA

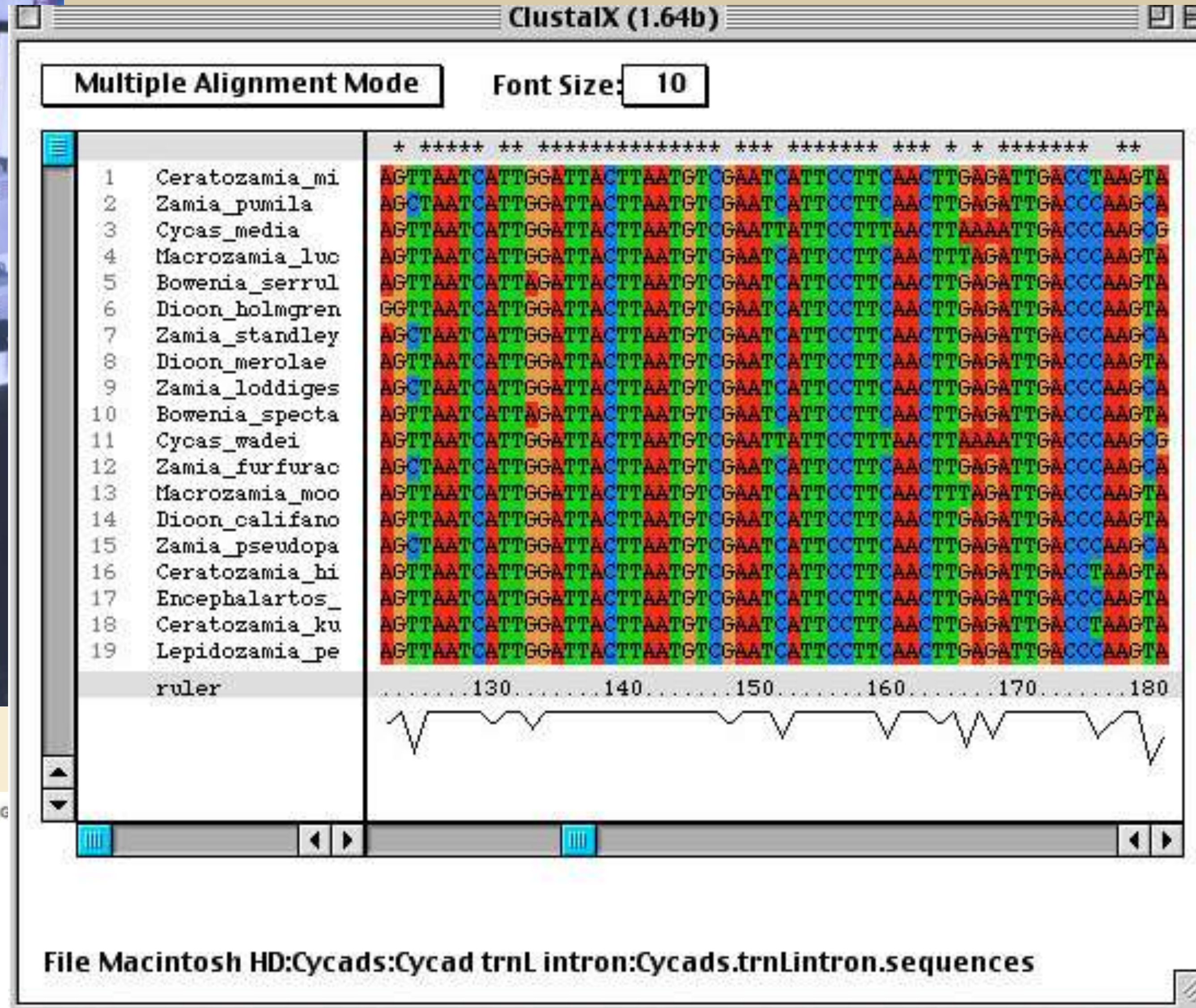
Loading DNA on Agarose Gel

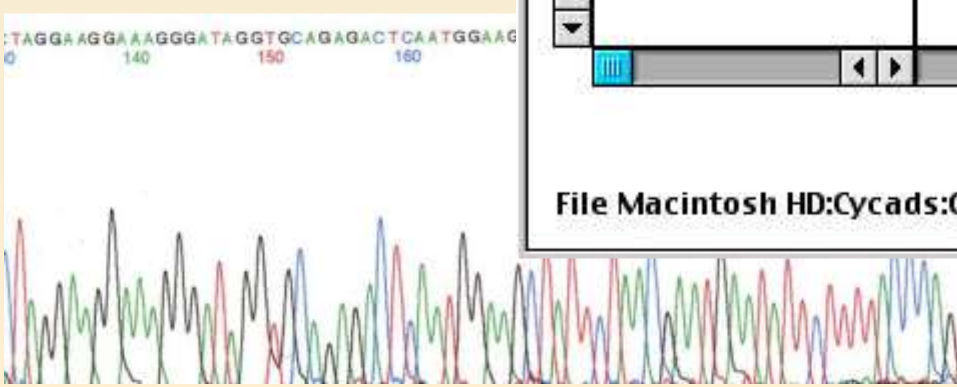


Visualizing DNA

DNA Sequencing

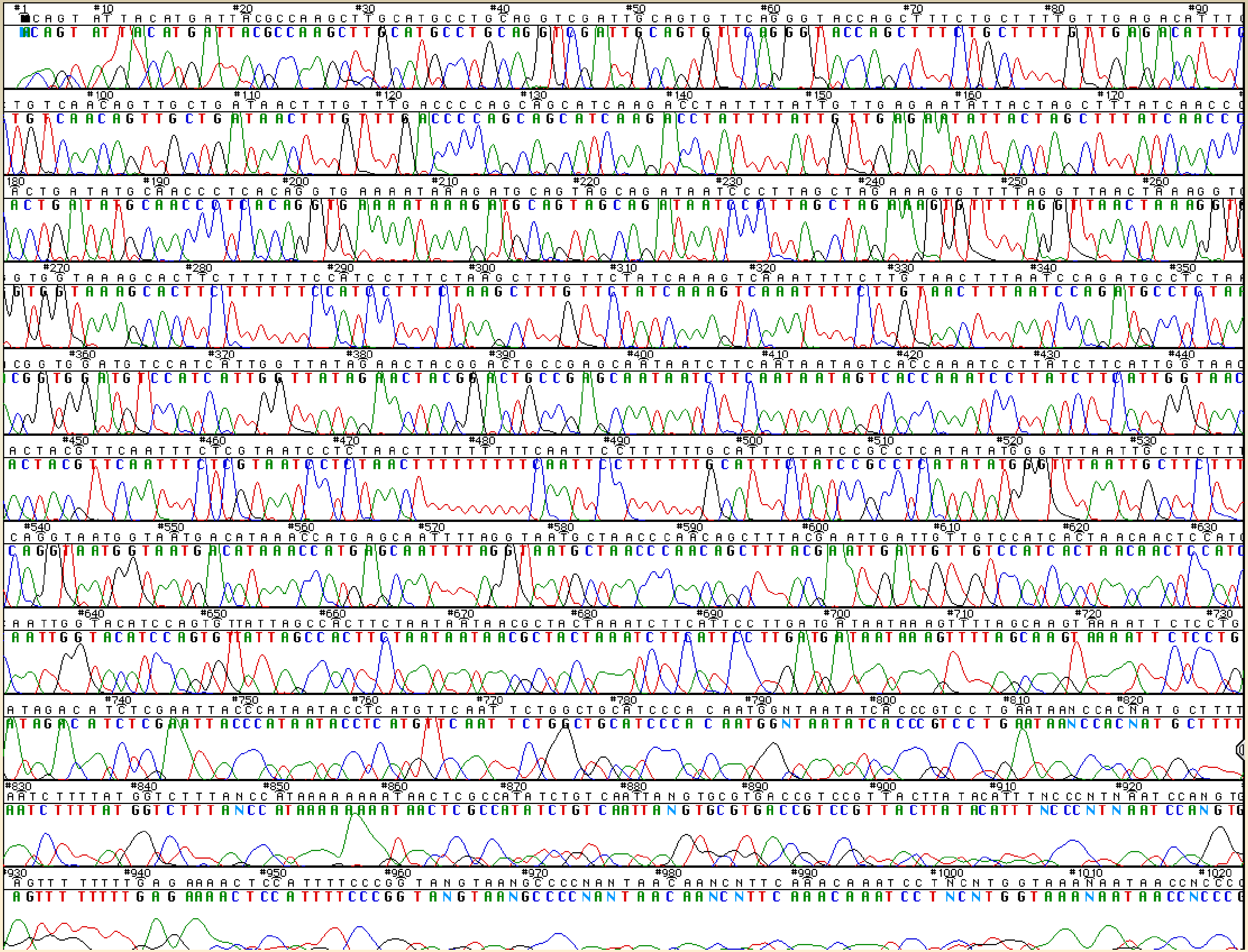


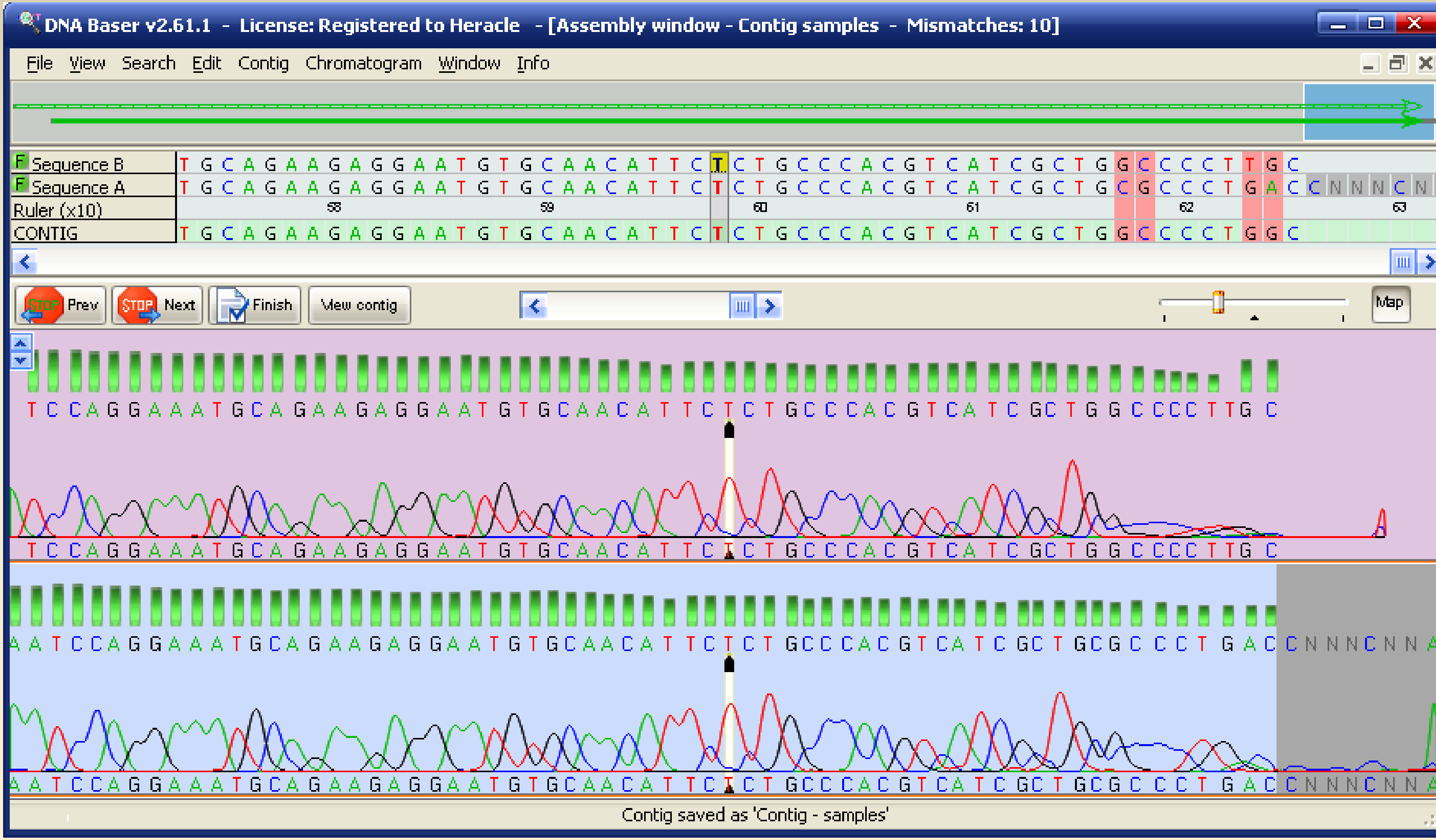




Sequence Alignment

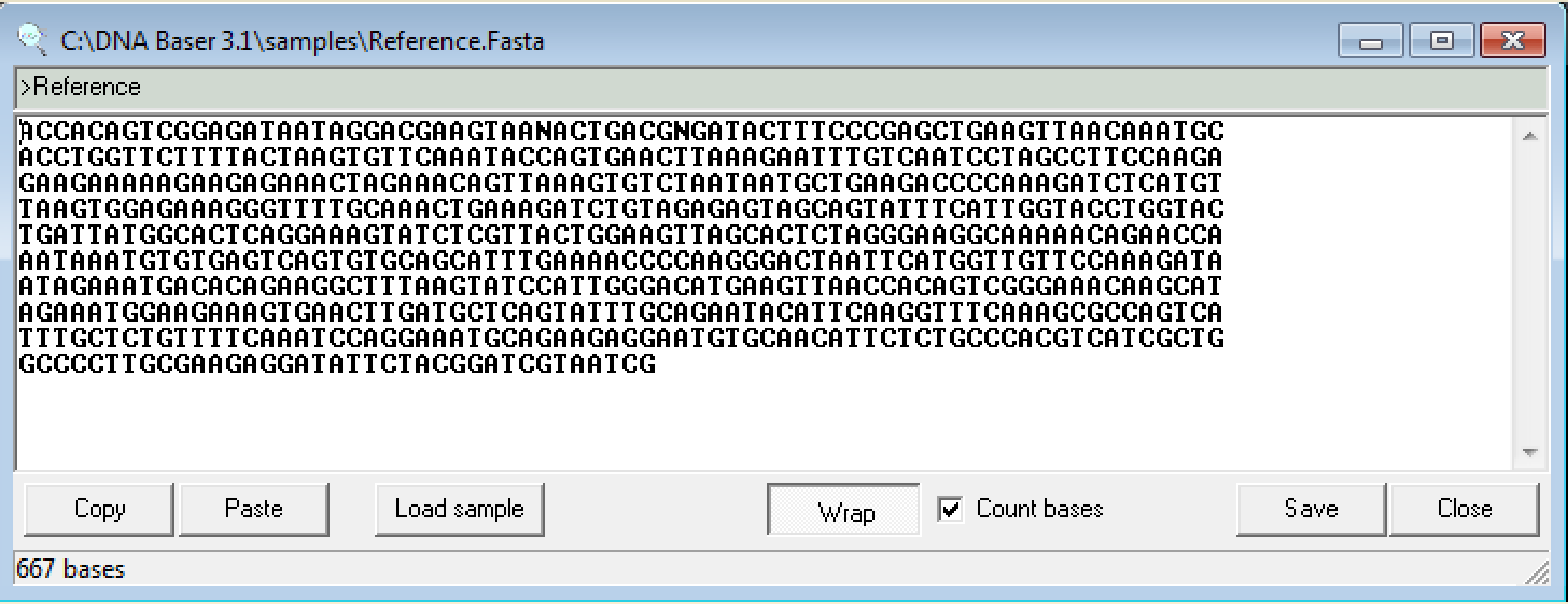
Chromatogram for One Sequence





DNA Baser v2.61.1 - License: Registered to Heracle - [Assembly window - Contig samples - Mismatches: 10]
File View Search Edit Contig Chromatogram Window Info
Sequence B
Sequence A
Ruler (x10)
CONTIG
T G C A G A A G A G G A A T G T G C A A C A T T C T C T G C C C A C G T C A T C G C T G G C C C C T T G C
T G C A G A A G A G G A A T G T G C A A C A T T C T C T G C C C A C G T C A T C G C T G C G C C C T G A C C N N N C N N
58 59 60 61 62 63
T G C A G A A G A G G A A T G T G C A A C A T T C T C T G C C C A C G T C A T C G C T G G C C C C T G G C
Prev
Next
Finish
View contig
Map
Contig saved as 'Contig - samples'

Finally, the Sequence Data for alignment and analysis…



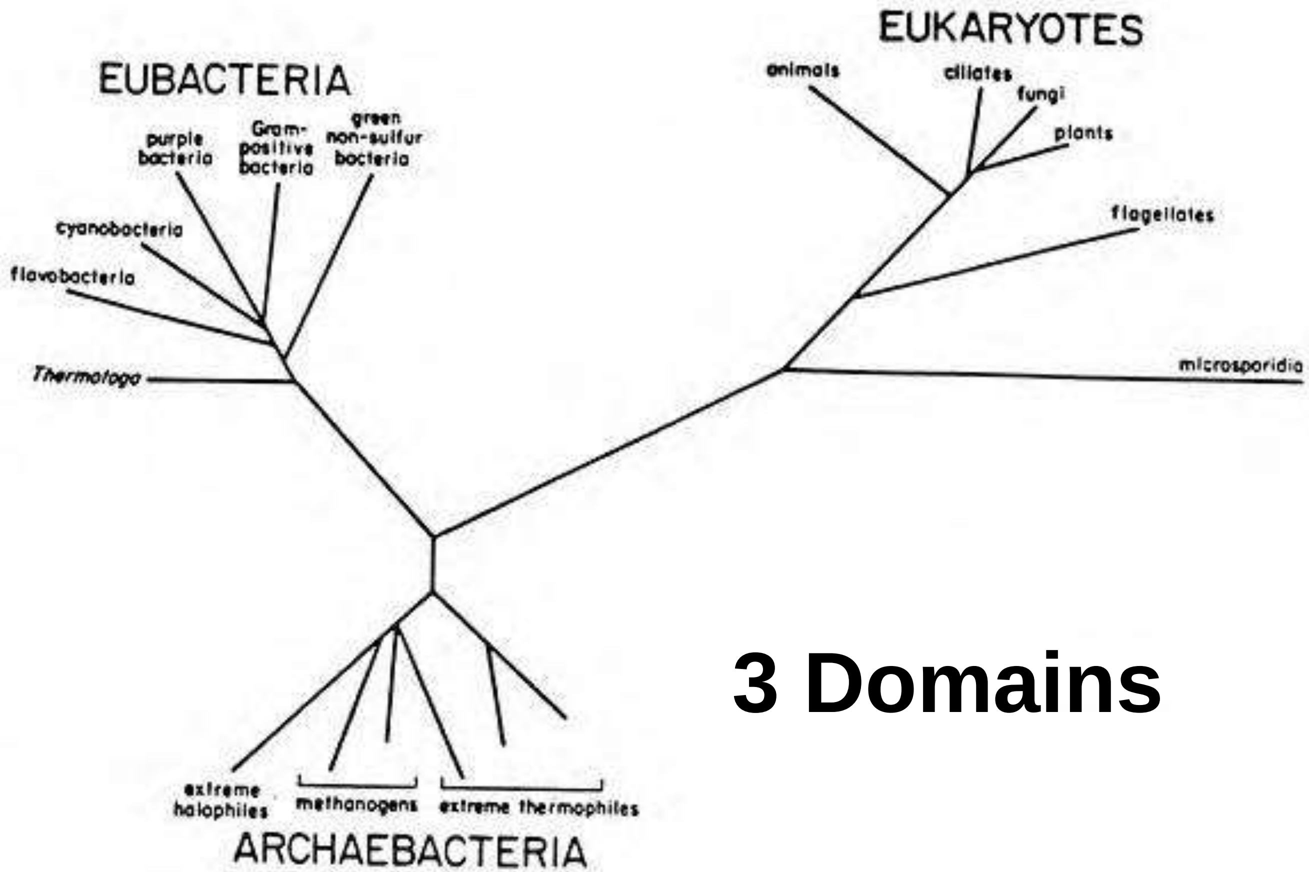
Pairwise alignments

```
43.2% identity;                   Global alignment score: 374

                10        20        30        40              50
alpha  V-LSPADKTNVKAAWGKVGAHAGEYGAEALERMFLSFPTTKTYFPHF-DLS-----HGSA
       : :.: .:. : : ::::  .. : :.::: :... .: :. .:  : :::      :.
beta   VHLTPEEKSAVTALWGKV--NVDEVGGEALGRLLVVYPWTQRFFESFGDLSTPDAVMGNP
               10          20        30        40        50

            60        70        80        90        100       110
alpha  QVKGHGKKVADALTNAVAHVDDMPNALSALSDLHAHKLRVDPVNFKLLSHCLLVTLAAHL
       .::.:::::  :.....::.:.. .....::.::  ::.::: ::.::.. :. .:: :.
beta   KVKAHGKKVLGAFSDGLAHLDNLKGTFATLSELHCDKLHVDPENFRLLGNVLVCVLAHHF
       60        70        80        90        100       110

           120       130       140
alpha  PAEFTPAVHASLDKFLASVSTVLTSKYR
         :::: :.:. .: .:.:...:. ::.
beta   GKEFTPPVQAAYQKVVAGVANALAHKYH
      120       130       140
```

Methods of tree estimation

- Character based
  - Maximum parsimony (MP)
    - Fewest character changes
  - Maximum likelihood (ML)
    - Highest probability of observing data, given a model
  - Bayesian
    - Similar to ML, but incorporates prior knowledge
- Distance based
  - Minimum distance
    - Shortest summed branch lengths

Carl Woese, 1980s

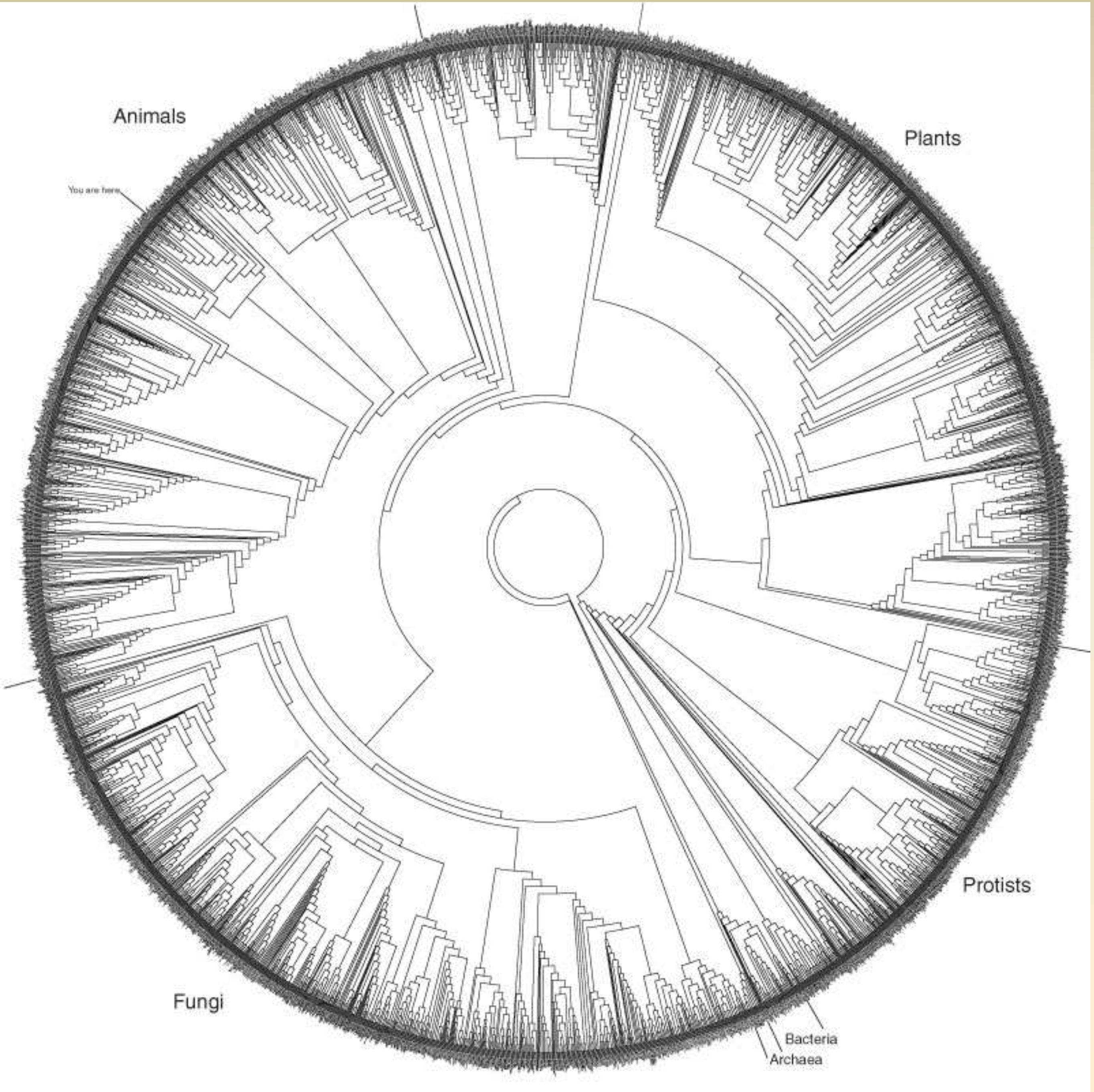


3 Domains

Phylogeny based on ssRNA Sequences

Originally the Bacteria and Archaea were thought to be one large diverse family of prokaryotes until Carl Woese and others investigated the evolutionary tree of ribosomal RNAs and found that there were three distinct founding evolutionary domains, then named eubacteria, archaebacteria, and the eukaryotes.

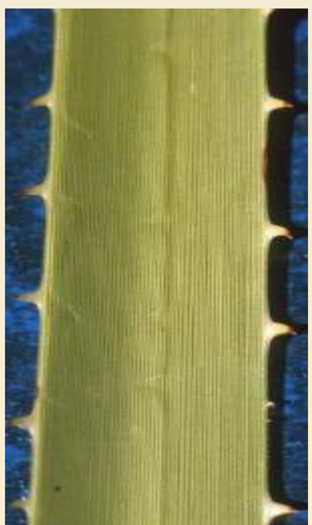
ssRNA
3,000 species



Constructing Phylogenetic Trees

Characters – observations about organisms

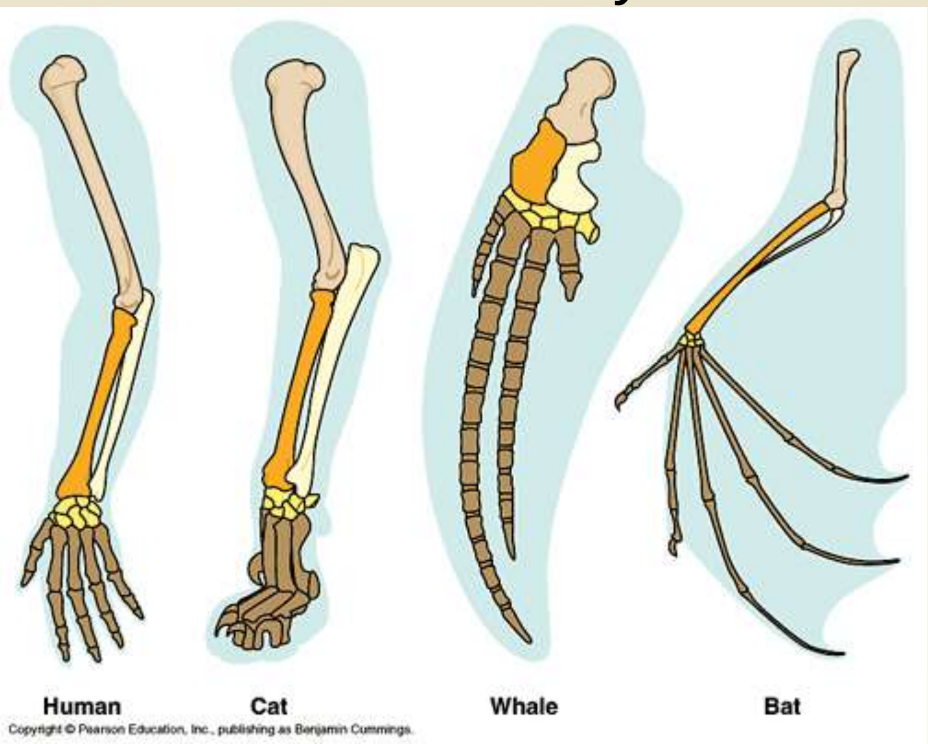
- morphological structures
- anatomy
- chromosomes
- chemistry
- DNA base sequences



Characters

Homologous characters

similarity due to common ancestry



Vertebrate limbs

Analogous characters

similarity due to convergent evolution

Euphorbs Cacti

Phylogenetic Trees

- The **phylogeny** of a group of taxa (species, etc.) is its evolutionary history.
- A **phylogenetic tree** is a graphical summary of this history — indicating the <u>sequence</u> in which lineages appeared and how the lineages are related to one another
- Because we do not have direct knowledge of evolutionary history, **every phylogenetic tree is an hypothesis** about relationships
- Of course, some hypotheses are well supported by data, others are not

Evolutionary Systematics – 1950s to 1970s

Linnaean system incorporated with the Darwinian modern synthesis

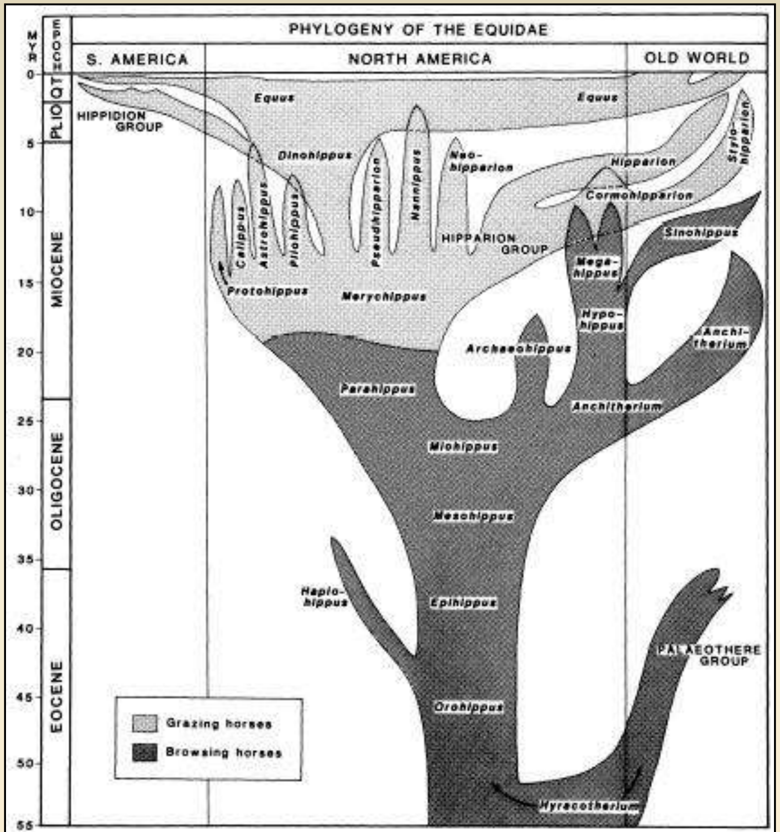
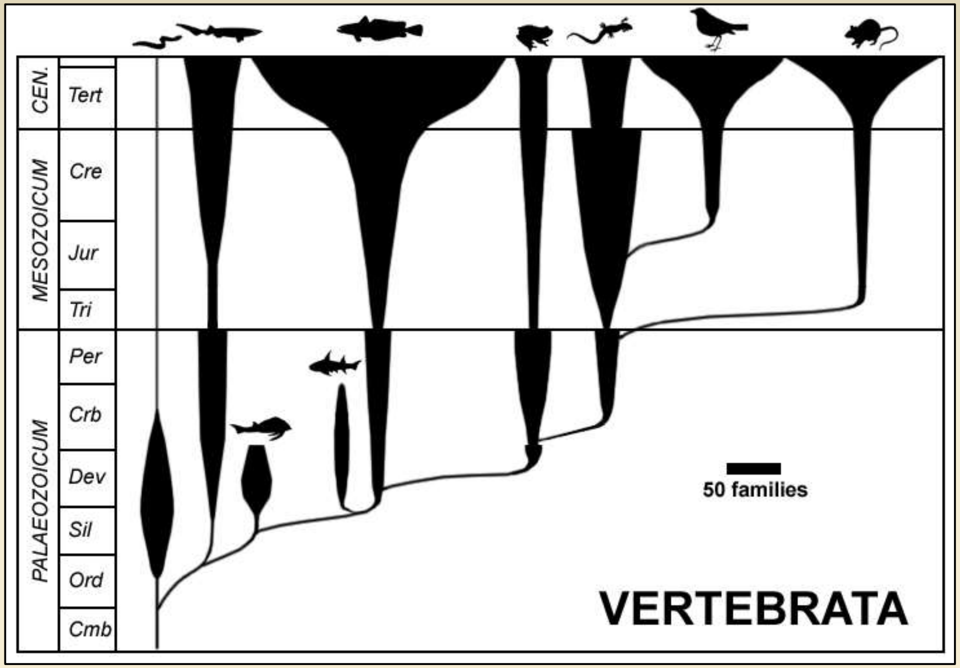


FIGURE 1. Current phylogeny of the Equidae, with particular emphasis on the North American taxa.

Evolution of Horses summary of data tree, width shows geographic distribution



Spindle Diagram, showing evolution of the vertebrates, showing the relative importance of the major groups through time. The vertical axis represents geological time, and the horizontal axis represents the diversity of each group, in terms of number of families.

Phylogenetic Systematics = “Cladistics”

Willi Hennig about 1970

Put forward his ideas in 1950,wrote in his German, so these were completely ignored until 1966 when an English translation of a manuscript was published under the title “Phylogenetic Systematics” (Hennig 1966).

Willi Hennig - 1913-1976

Germany, military entomologist, malaria prevention

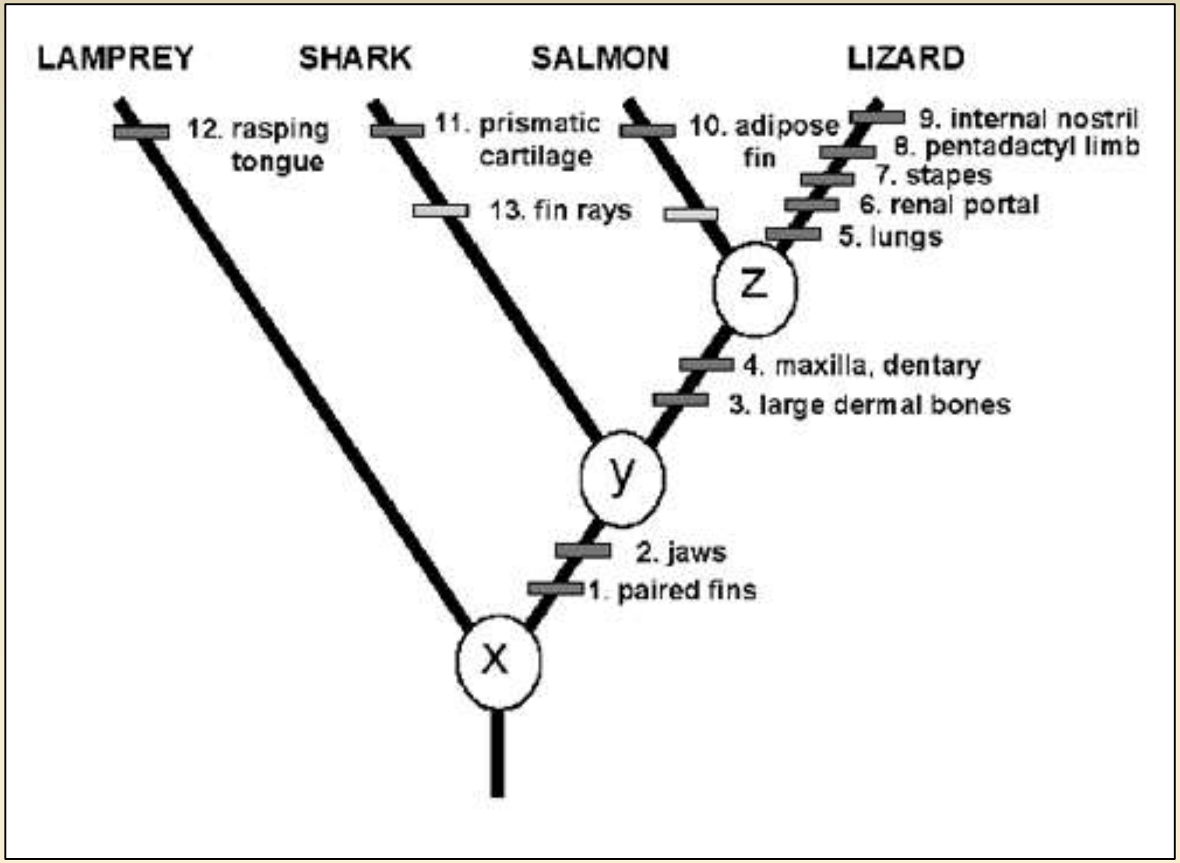
Taxonomist, specialist in Dipterans (flies)

1950 - *Basic outline of a theory of phylogenetic systematics*

1. Relationships interpreted as sister-lineages (clades)
2. Synapomorphies determine common ancestry
3. Best tree determined by greatest amount of evidence
4. Taxonomy/classification should based on inferred pattern of historical relationships (monophyly)

*population genetics, natural selection and adaptation have little to do with the discovery of genealogical relationships

Hennig's Method Phylogenetic Tree
based on shared derived characters = "Cladogram"

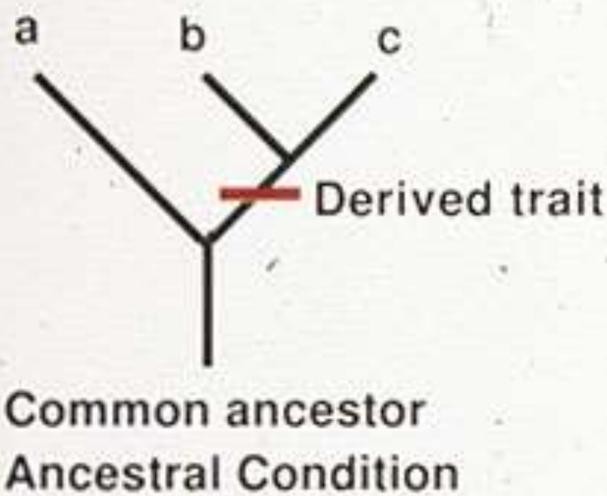


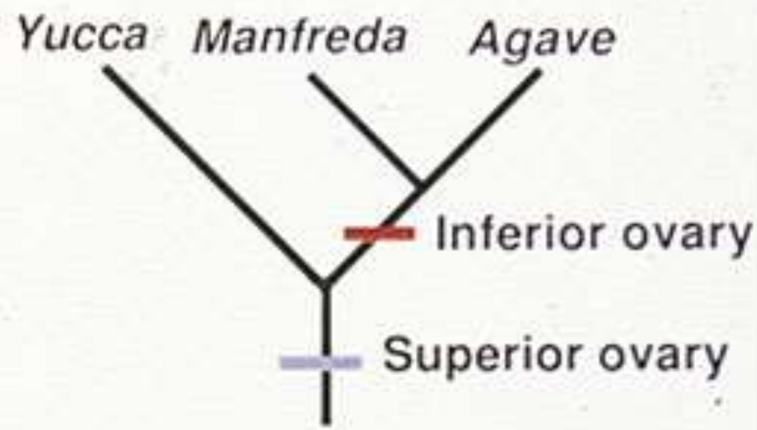
An example of a phylogeny showing characters by which taxa are recognized. Characters 1 – 4 are synapomorphies, 5 – 12 are autapomorphies and 13 is an attribute seen in the salmon and the shark.

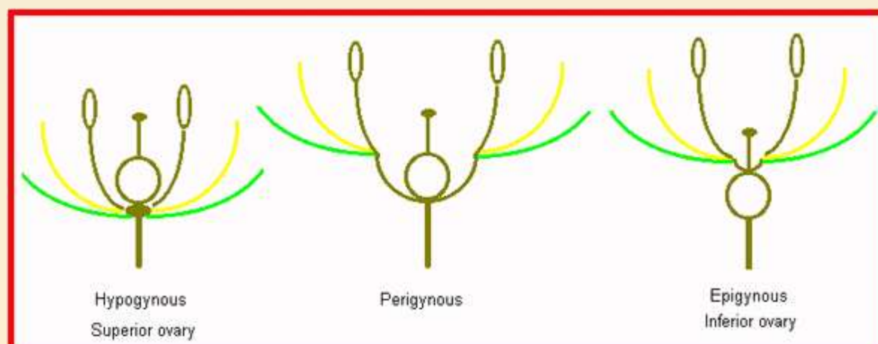
Cladistics

Phylogeny reconstruction

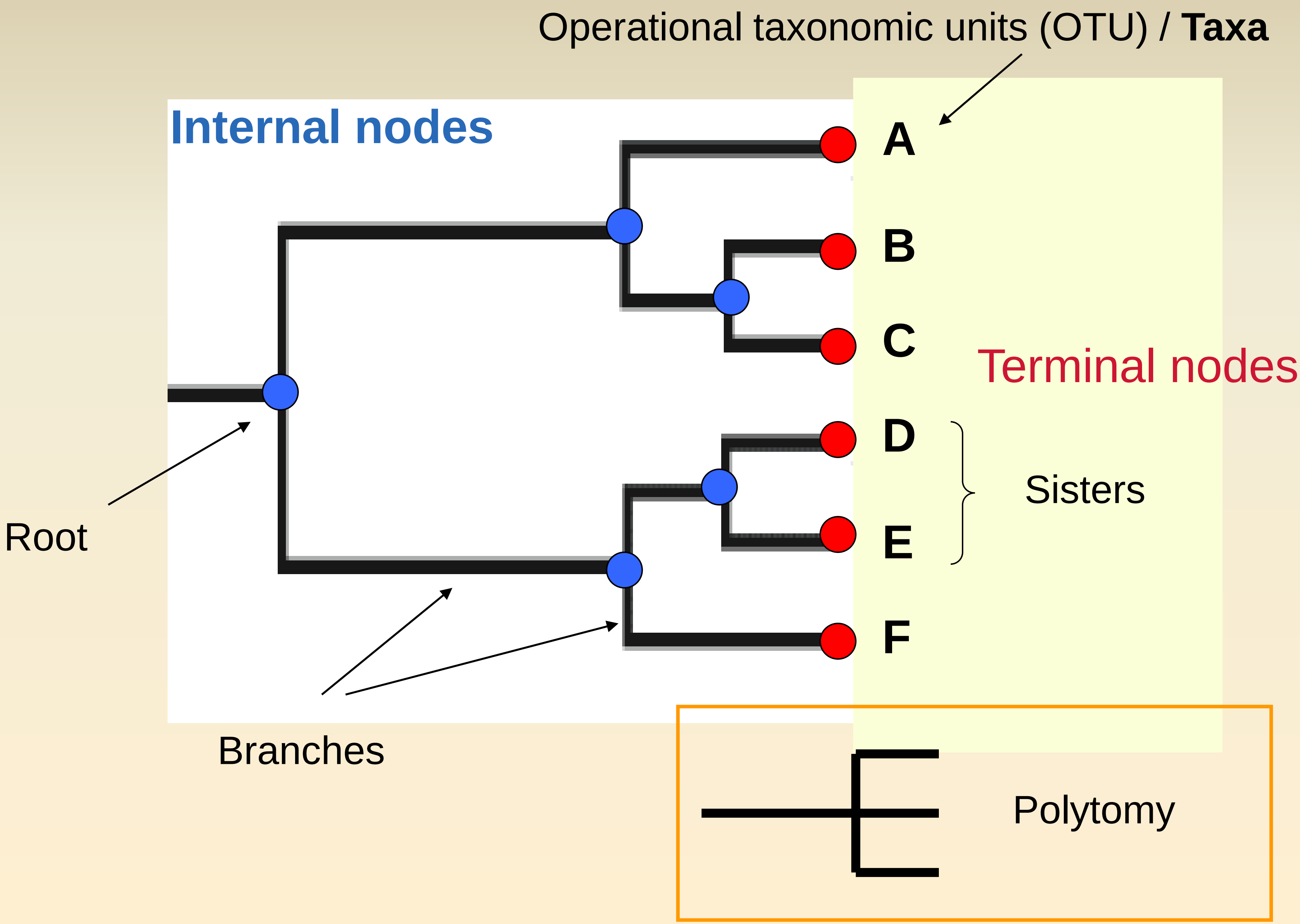
Shared derived characters







Tree Terminology



Dendrogram is a broad term for the diagrammatic representation of a phylogenetic tree.

Cladogram is a phylogenetic tree formed using cladistic methods. This type of tree only represents a *branching pattern*; i.e., its branch spans do not represent time or relative amount of character change.

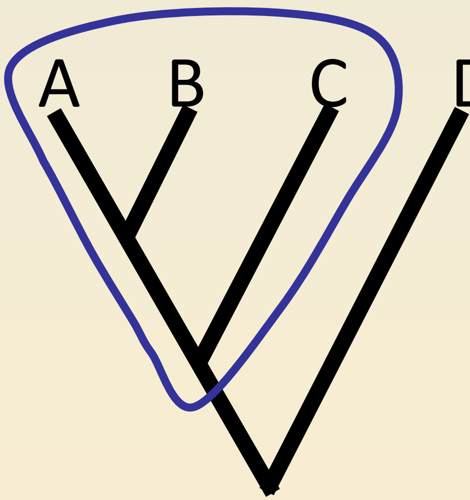
Phylogram is a phylogenetic tree that has branch *spans proportional to the amount of character* change.

Chronogram is a phylogenetic tree that explicitly represents *evolutionary time* through its branch spans.

Phylogeny and Classification

Monophyletic group

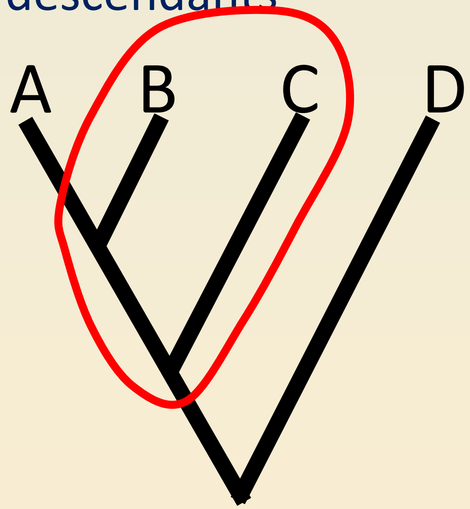
Includes an ancestor and all of its descendants



How could this happen?

Paraphyletic group

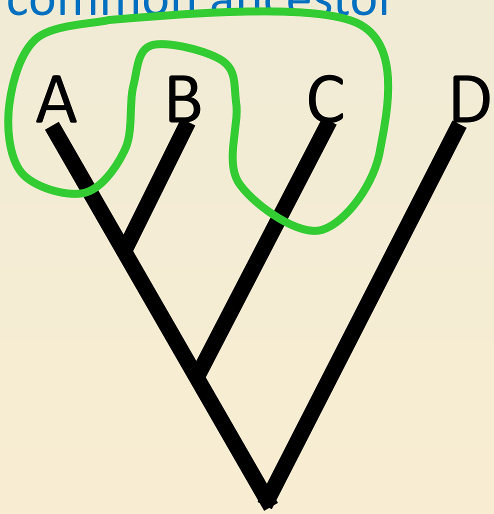
Includes ancestor and some, but not all of its descendants



Taxon A is highly derived and looks very different from B, C, and ancestor

Polyphyletic group

Includes two convergent descendants but not their common ancestor



Taxon A and C share similar traits through convergent evolution

Only <u>monophyletic</u> groups (**clades**) are recognized in cladistic classification

cp DNA Restriction Site Analysis

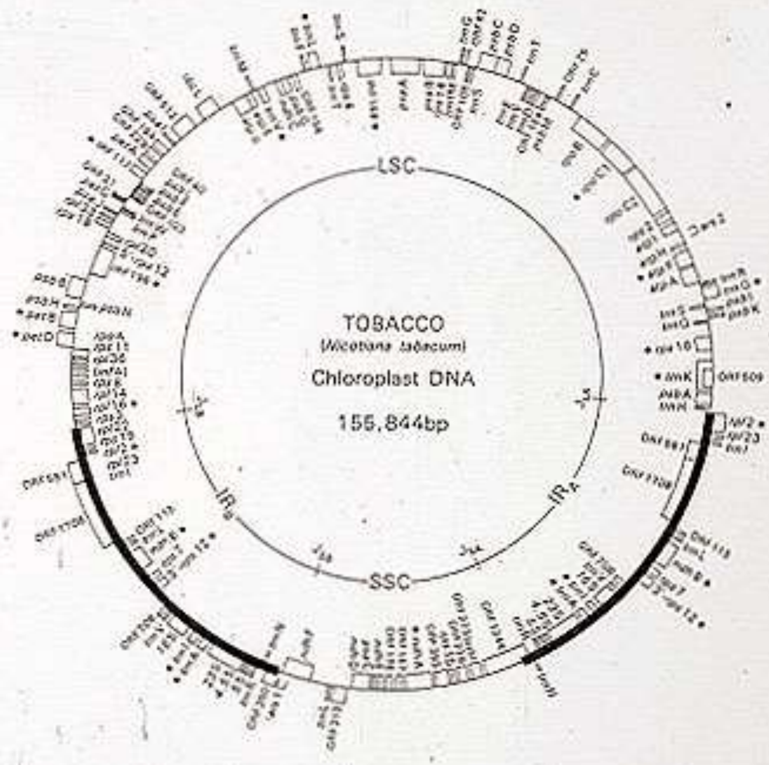
Restriction Enzymes Used:

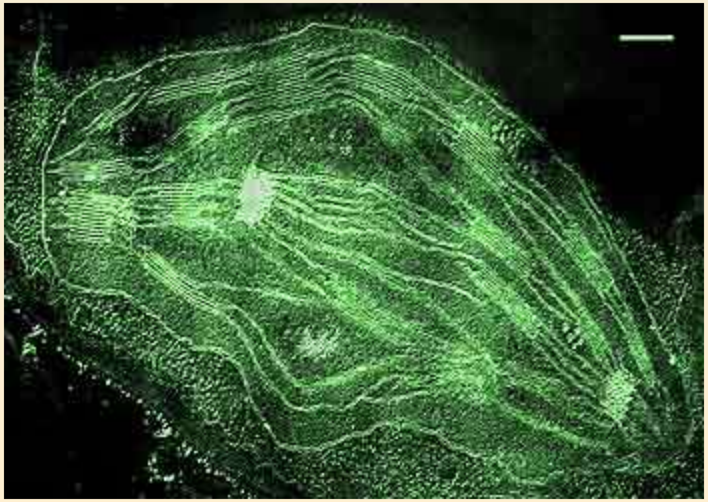
- Bam HI
- Bcl I
- BstN I
- Dra I
- Eco RI
- Eco RV
- Hae II
- Hae III
- Hha I
- Hind III
- Msp I
- Xho I

Total # Tobacco cpDNA Probes - 40
Subset of Probes Used for this Analysis - 20

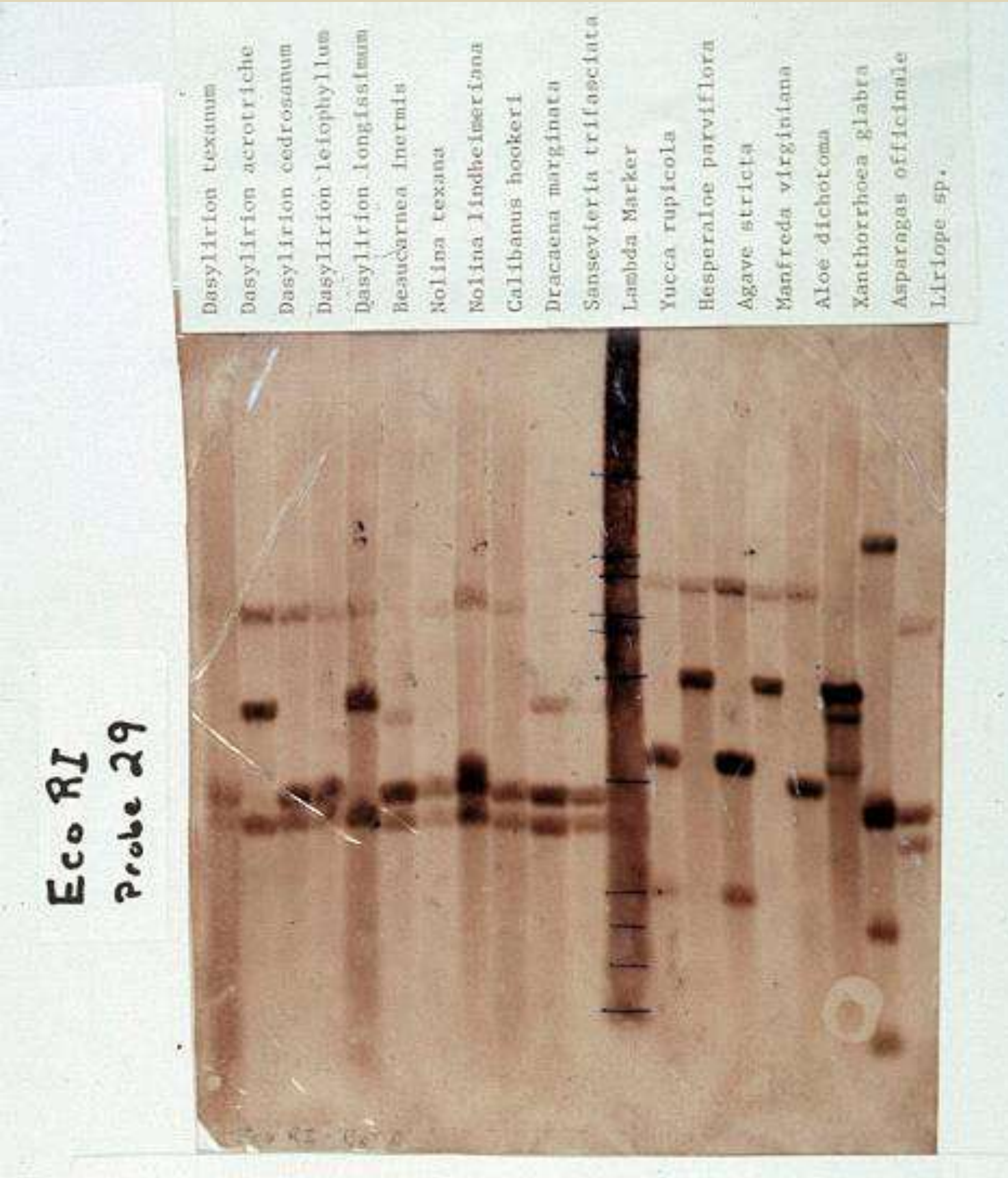
100 Restriction Sites Surveyed

18 Autapomorphies
82 sites Shared by Two or More Taxa

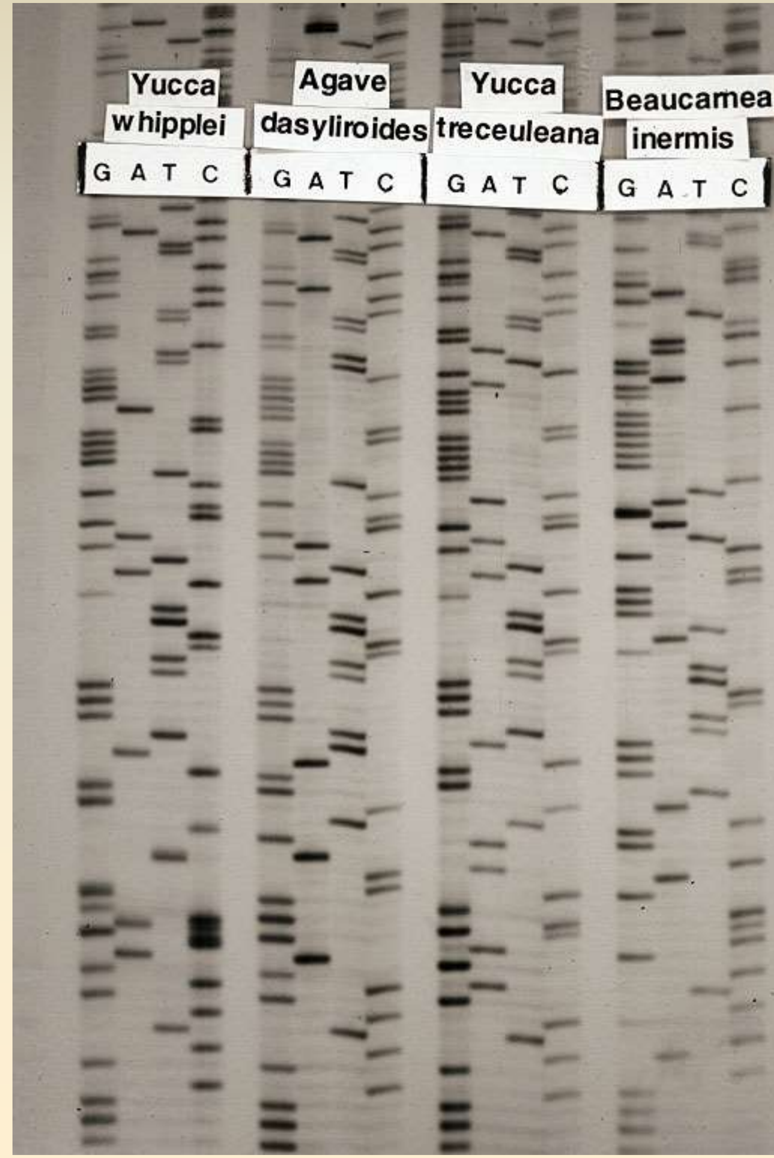




Restriction fragment analysis
Digoxigenin-labeled cpDNA probe

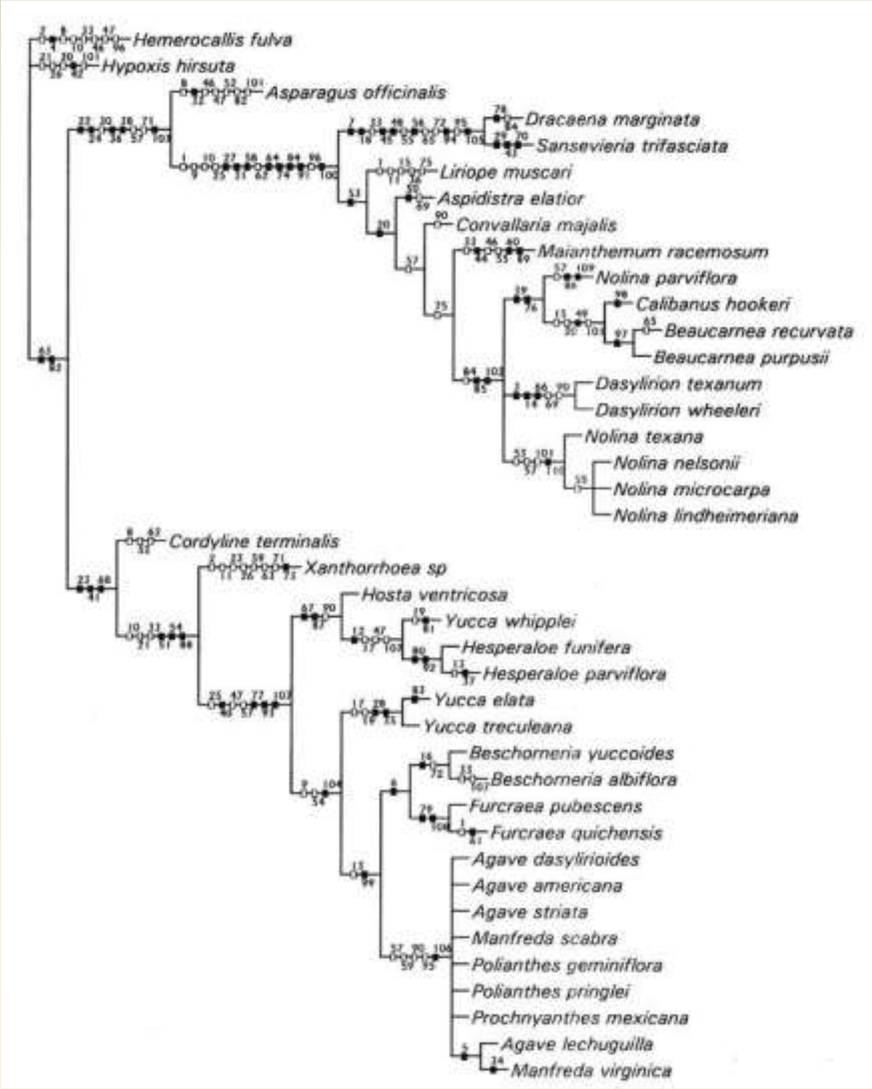


Sanger Sequencing
P32-labeled dNTP
X-ray film



cpDNA Restriction Sites

Bogler and Simpson. 1995. Syst. Bot. 20: 191



Dracaenaceae

Convallariaceae

Nolinaceae

Agavaceae s.s.

ITS1 and ITS2

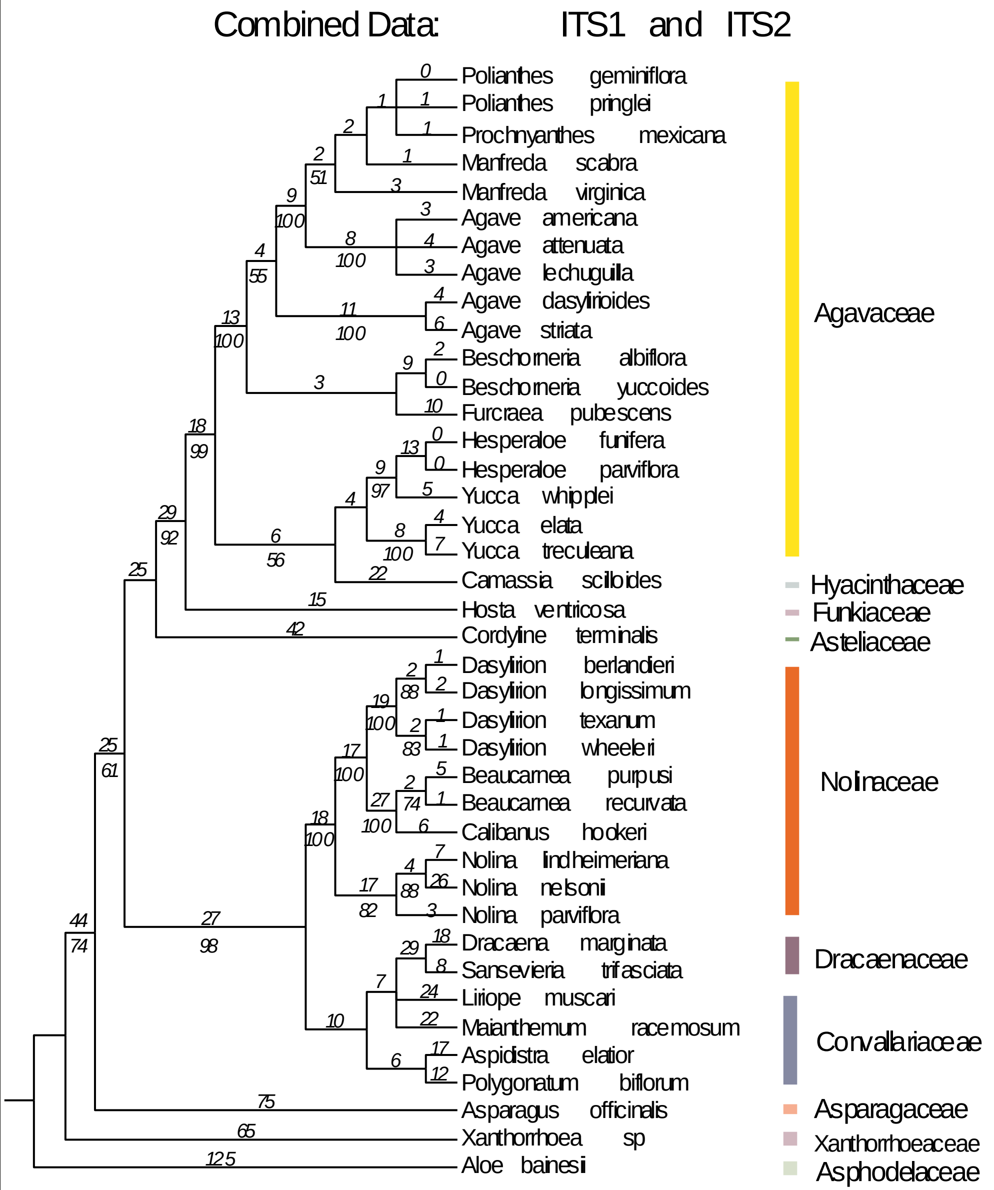
Strict Consensus

4 Trees

979 Steps

CI = 0.659

RI = 0.815

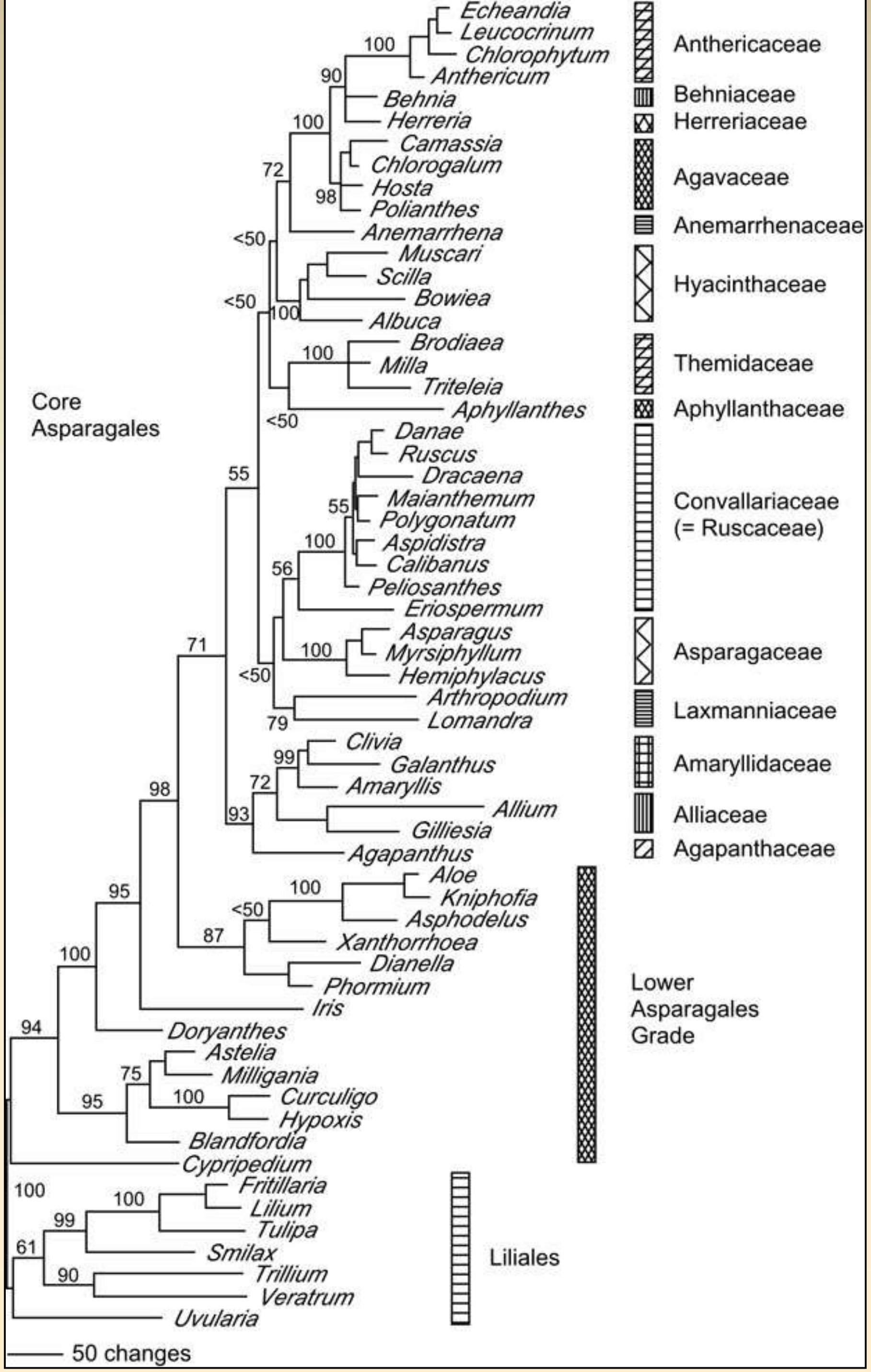


Bogler and Simpson. 1996. AJB 83: 1225-1235.

Asparagales

Combined
rbcL and ndhF
Sequence data

Bogler et al. 2006.
Aliso 22: 313–328

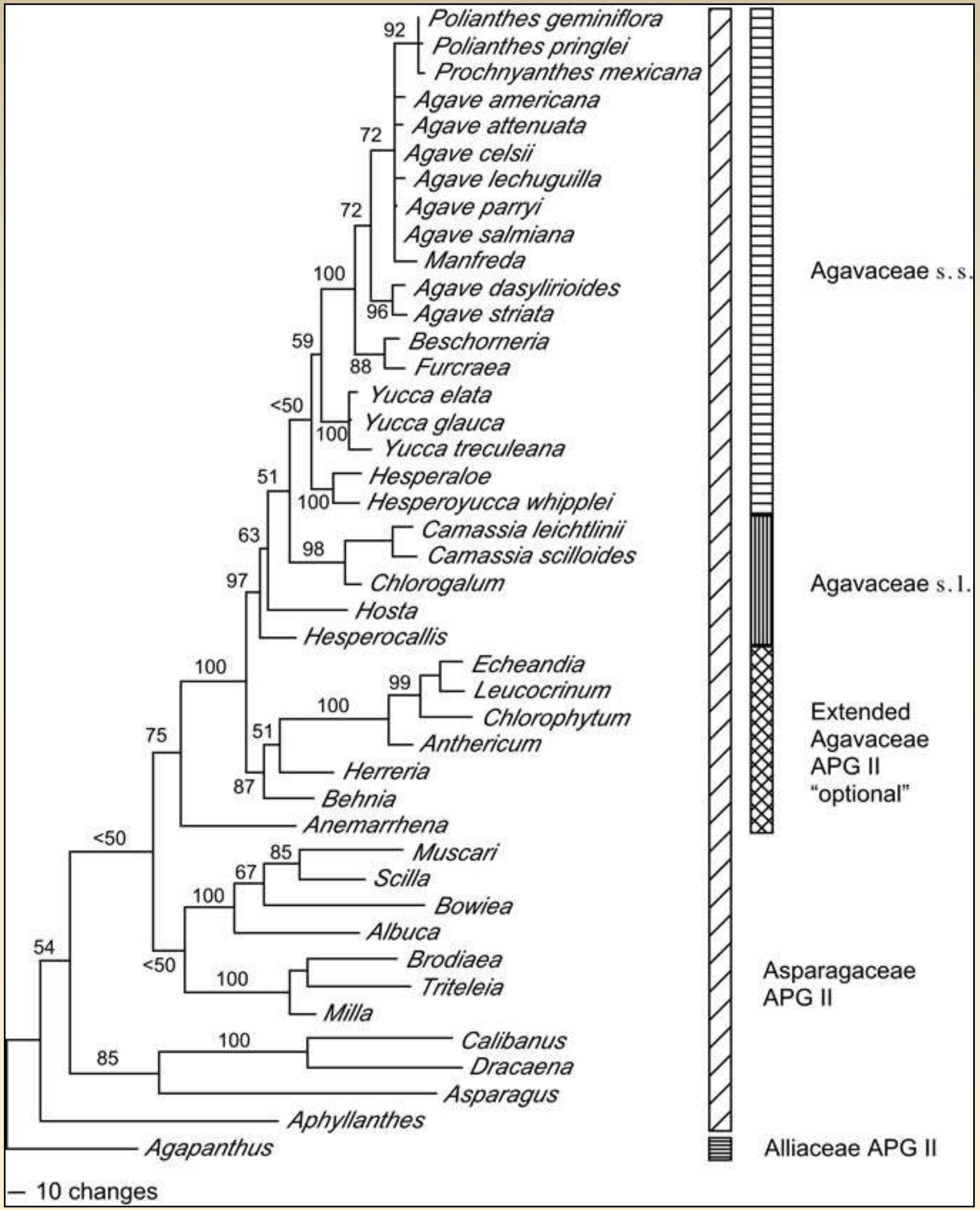


Agave

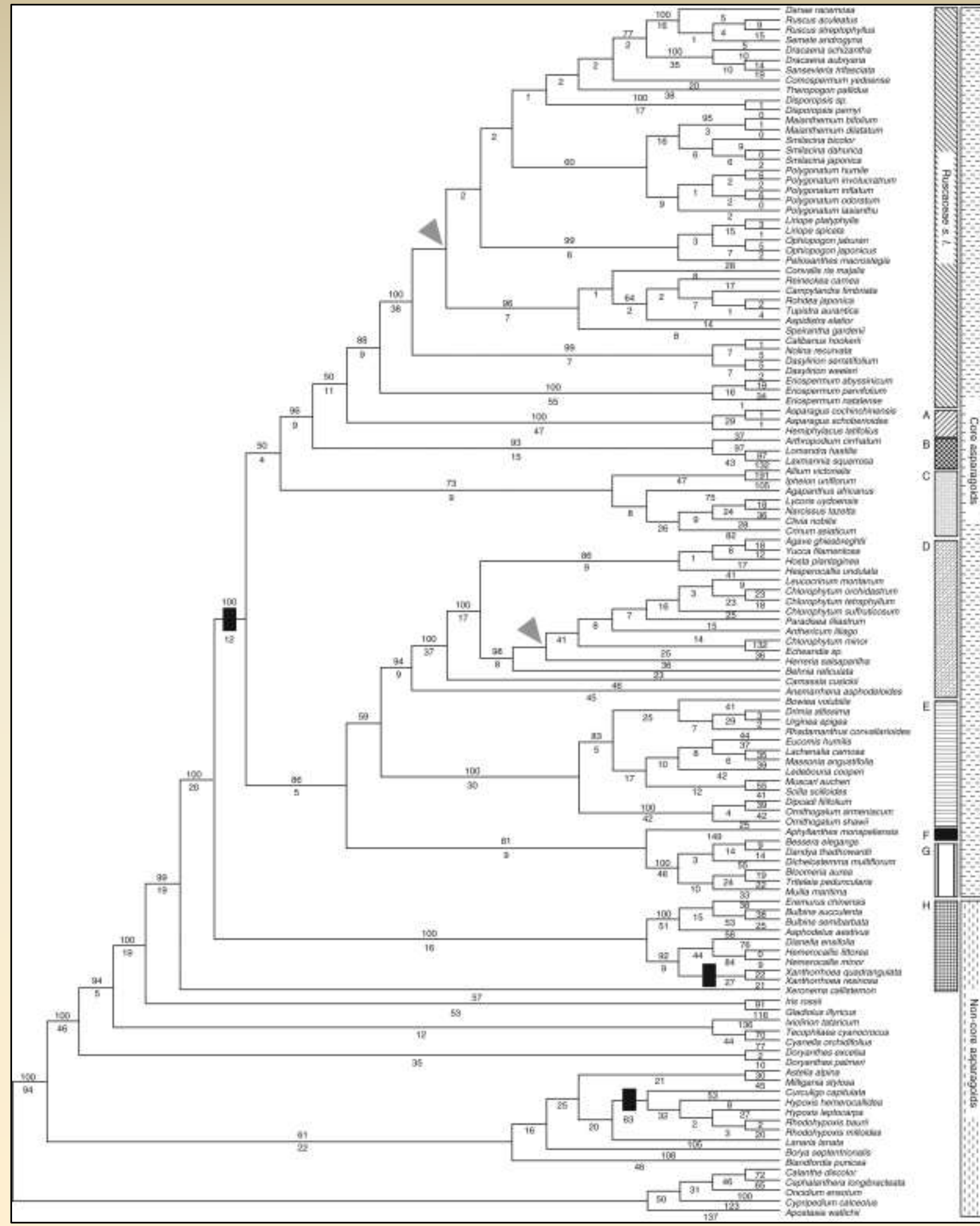
Dasylirion

Combined rbcL, ndhF, and ITS sequence data

Bogler et al. 2006
Aliso **22**: 313–328

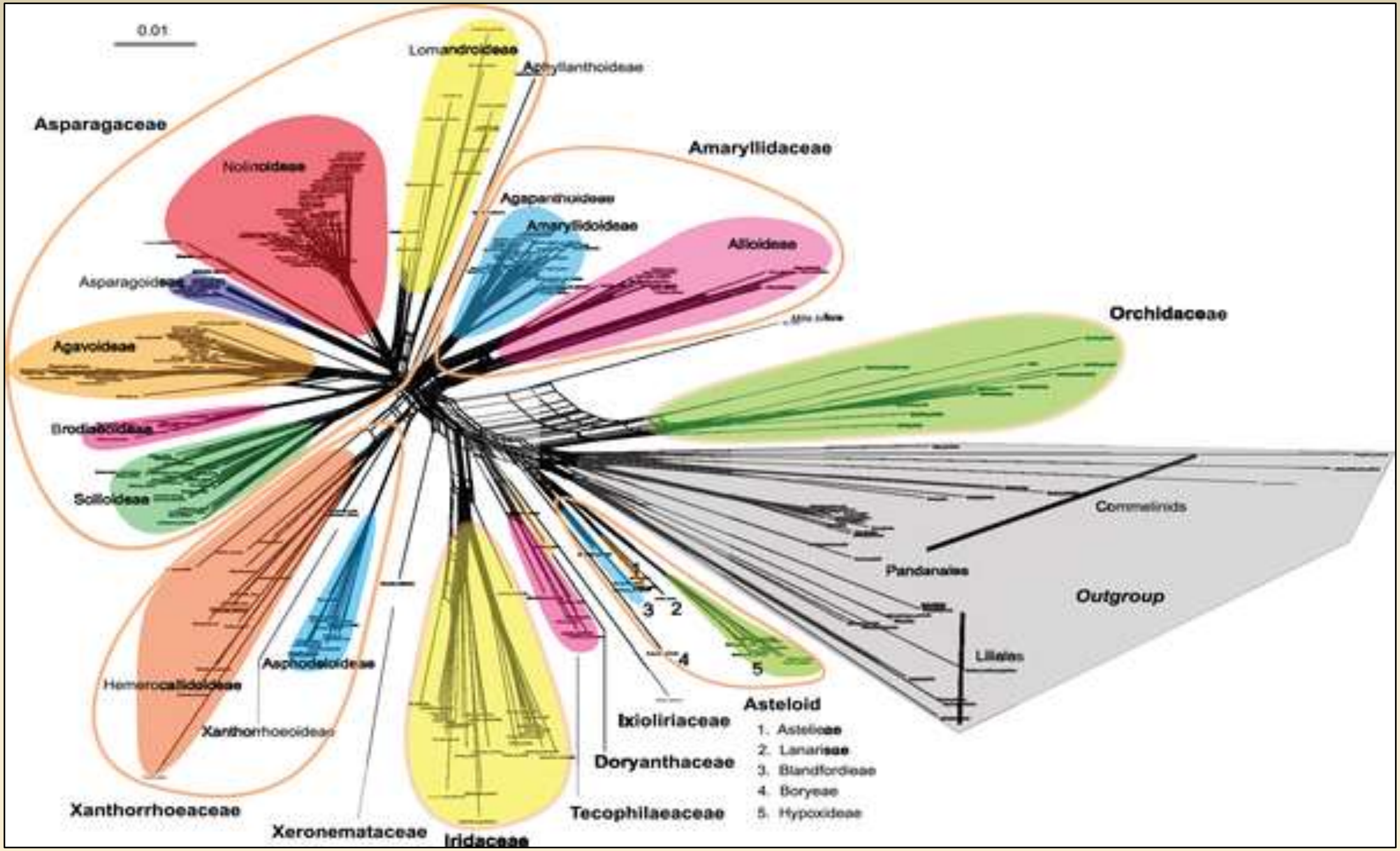


121 Taxa Asparagales three nuclear and plastid DNA coding genes, 18S rDNA (1796 bp), *rbcL* (1338 bp) and *matK* (1668 bp), approx. 4·8 kb



Kim, Joo-Hwan et al. “Molecular Phylogenetics of Ruscaceae *sensu Lato* and Related Families (Asparagales) Based on Plastid and Nuclear DNA Sequences.” *Annals of Botany* 106.5 (2010): 775–790. *PMC*. Web. 29 June 2015.

Figure 1. Neighbour net for Asparagales and outgroups.

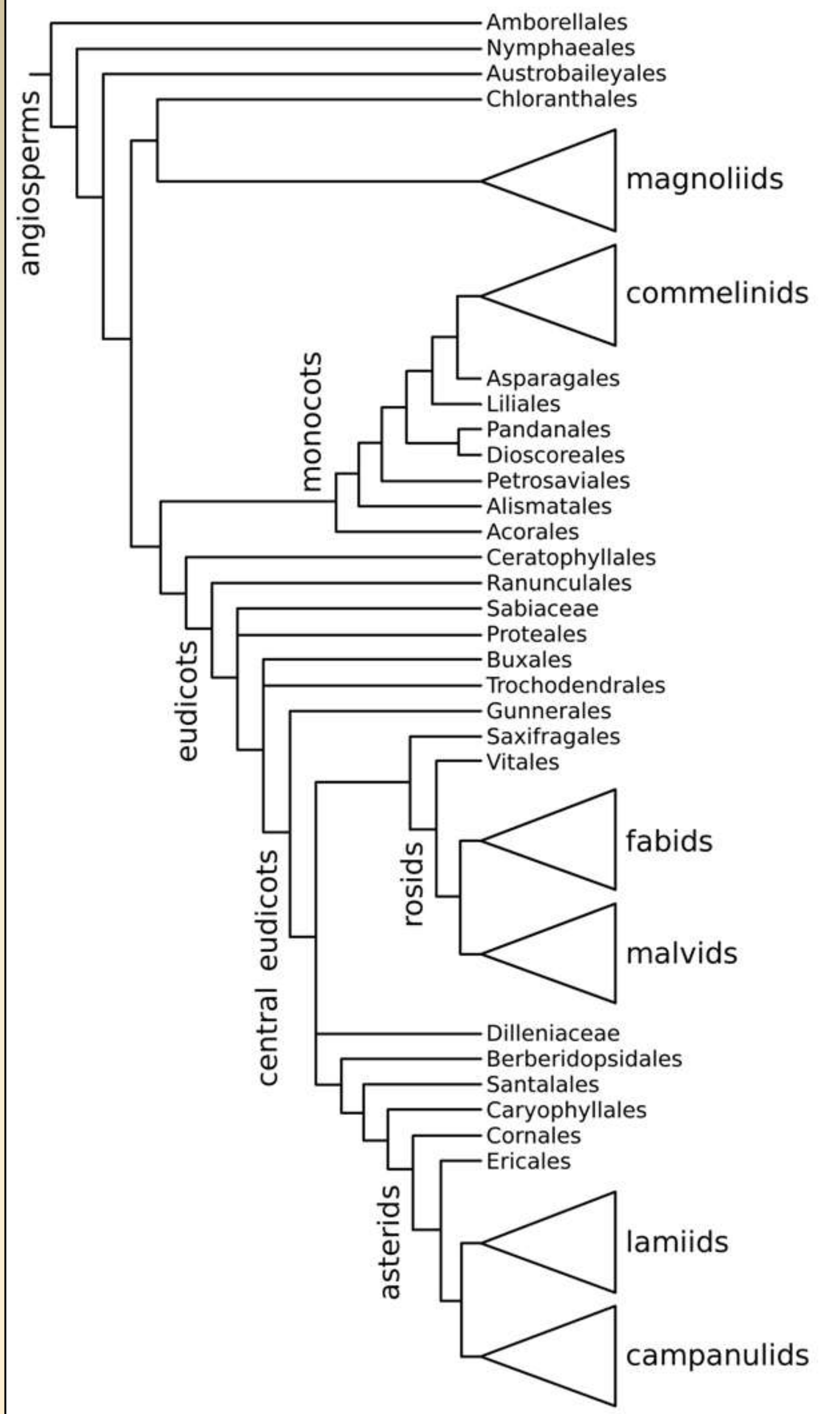


Chen S, Kim DK, Chase MW, Kim JH (2013) Networks in a Large-Scale Phylogenetic Analysis: Reconstructing Evolutionary History of Asparagales (Lilianae) Based on Four Plastid Genes. PLoS ONE 8(3): e59472. doi:10.1371/journal.pone.0059472
http://127.0.0.1:8081/plosone/article?id=info:doi/10.1371/journal.pone.0059472

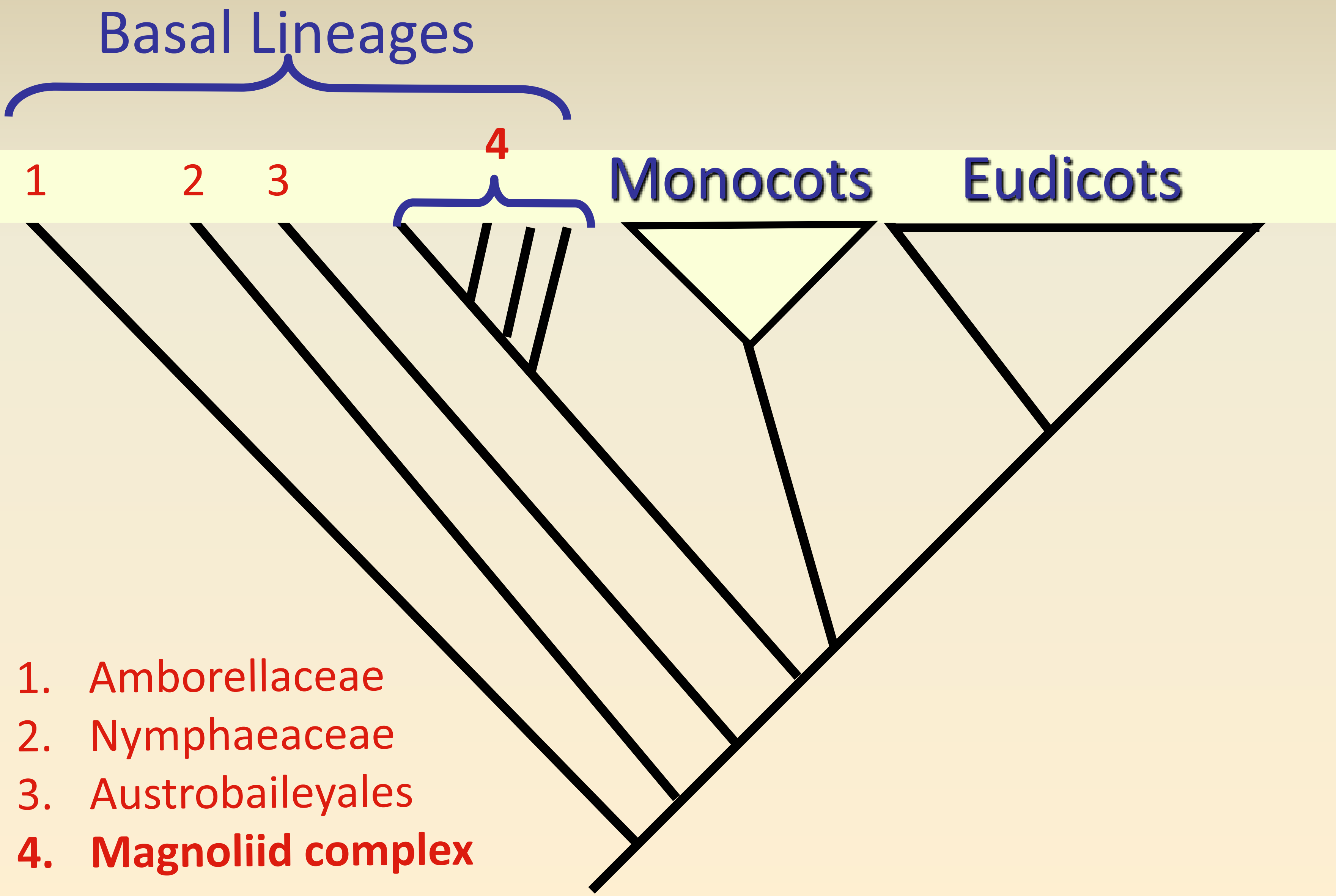
Angiosperm Phylogeny Group
APG I1(998, 2003, 2009

Main Features:

- Anonymous, with contributions from many people
- No subclasses, only informal higher groups
- 40 orders
- 462 families
- Based largely on molecular phylogenies
- Taxa are monophyletic



Modern angiosperm relationships



1. Amborellaceae
2. Nymphaeaceae
3. Austrobaileyales
4. **Magnoliid complex**

“Agavaceae”
APG3 Asparagaceae – Agavoideae

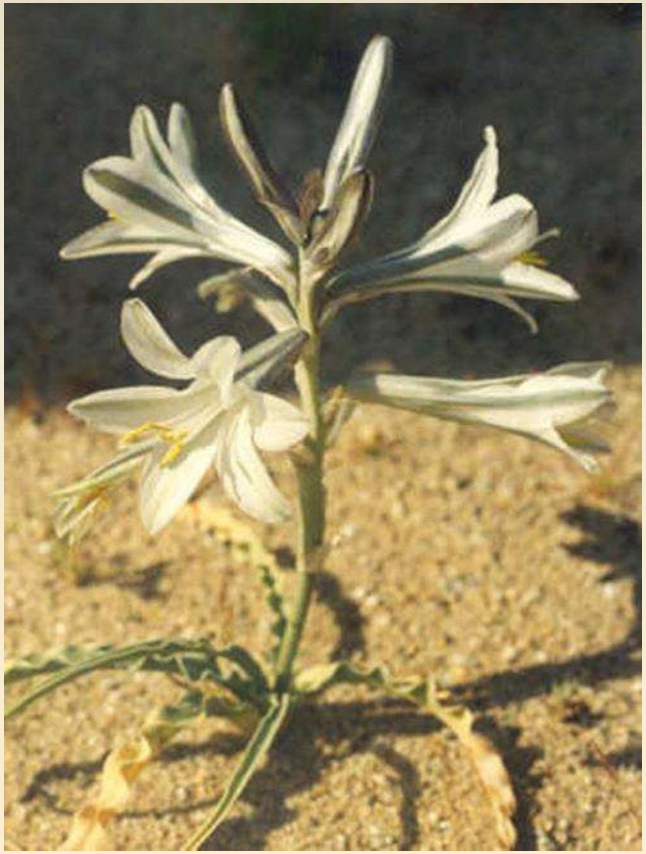
Agave salmiana

<u>Core Genera:</u>
Yucca
Hesperoyucca
Hesperaloe
Beschorneria
Furcraea
Agave
Manfreda
Polianthes
Prochnyanthes

<u>Basal Genera:</u>
Hosta
Camassia
Chlorogalum
Hesperocallis

Basal Genera in Agavoideae

Hesperocallis



H. undulata
SW U.S., Mex.
n = 24, bimodal

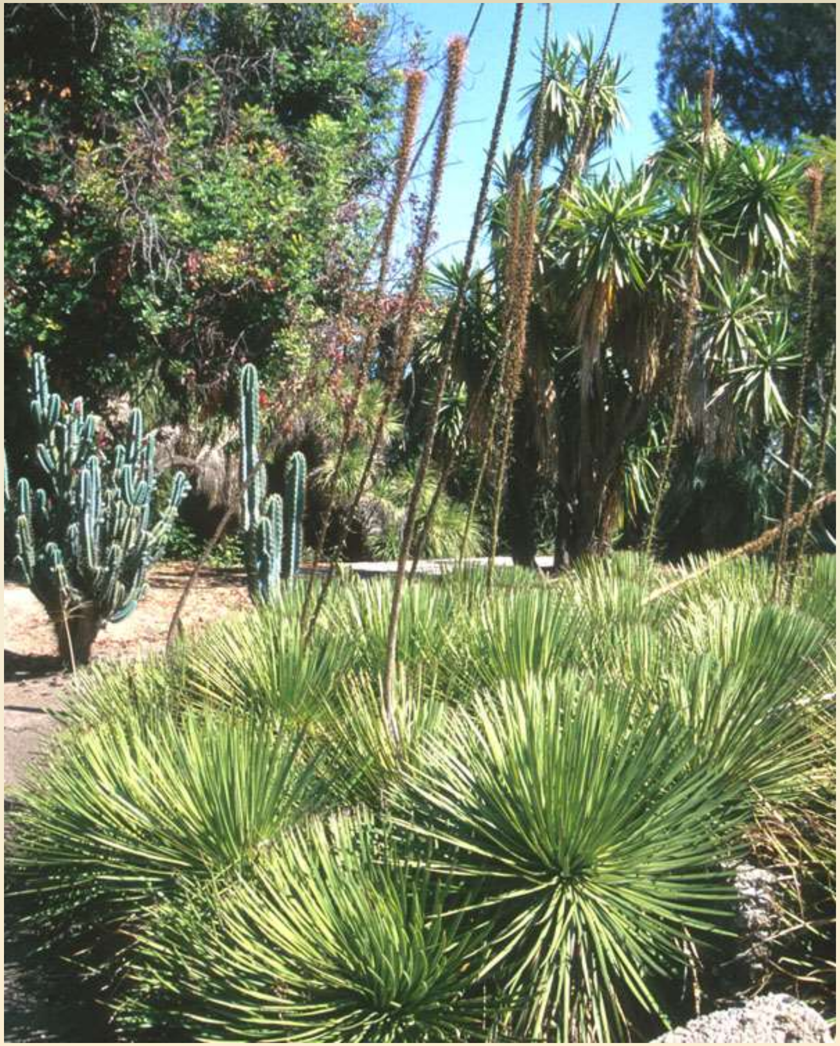
Camassia

Camassia 5 spp. n= 30. bimodal
Chlorogalum - 5 spp. n =15, 30
Schoenolirion - 3 spp.
Hastingsia - 5 spp.

Hosta

Hosta
25-many spp., Korea, China
n = 30, bimodal

Genus *Agave* - Group Striatae



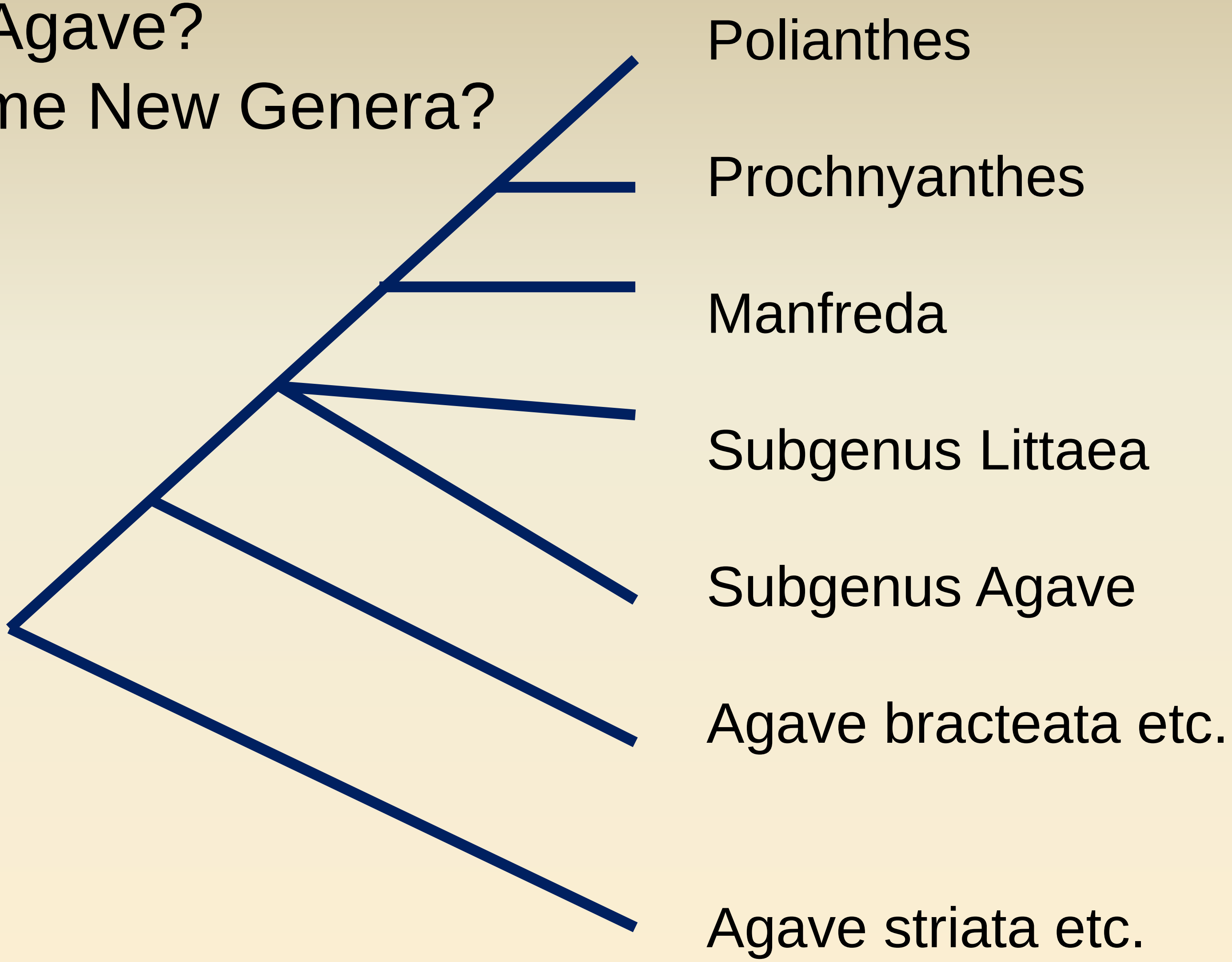
Agave striata

Characters thought by
Gentry (1982)
to be ancestral

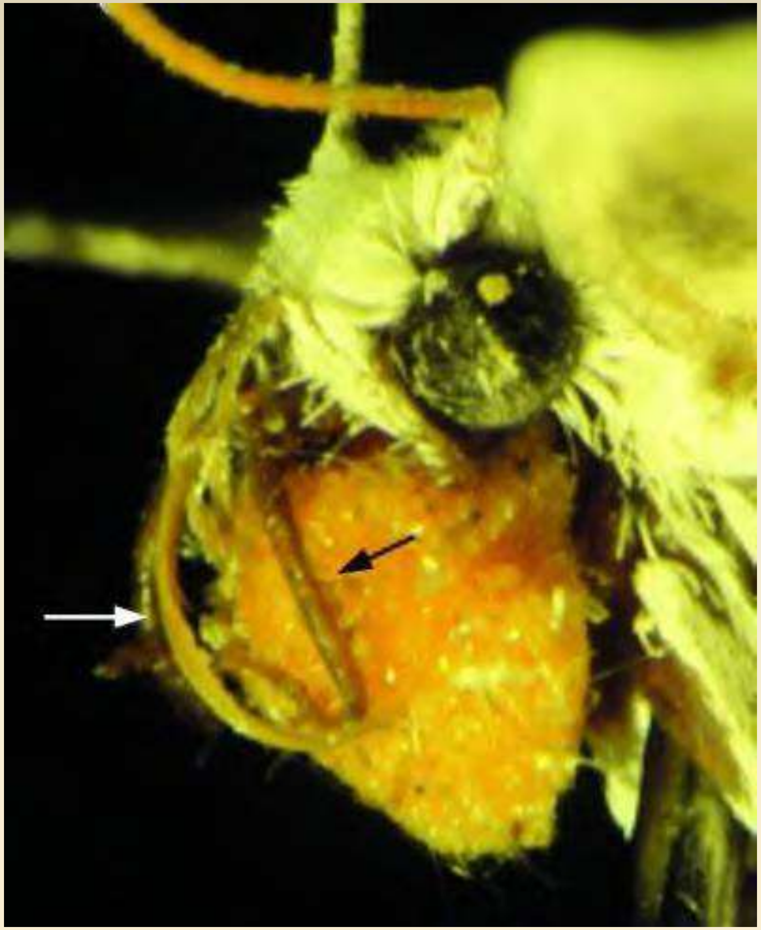
- Perennial habit
- Hard, serrulate leaves
- Simple spikes
- Flowers geminate
- Non-dimorphic tepals
- Ovary incompletely inferior
- Reproduce only by seed

All Agave?

Name New Genera?



Yucca and the Yucca Moth



Tegiticula – Yucca moth larvae inside fruits

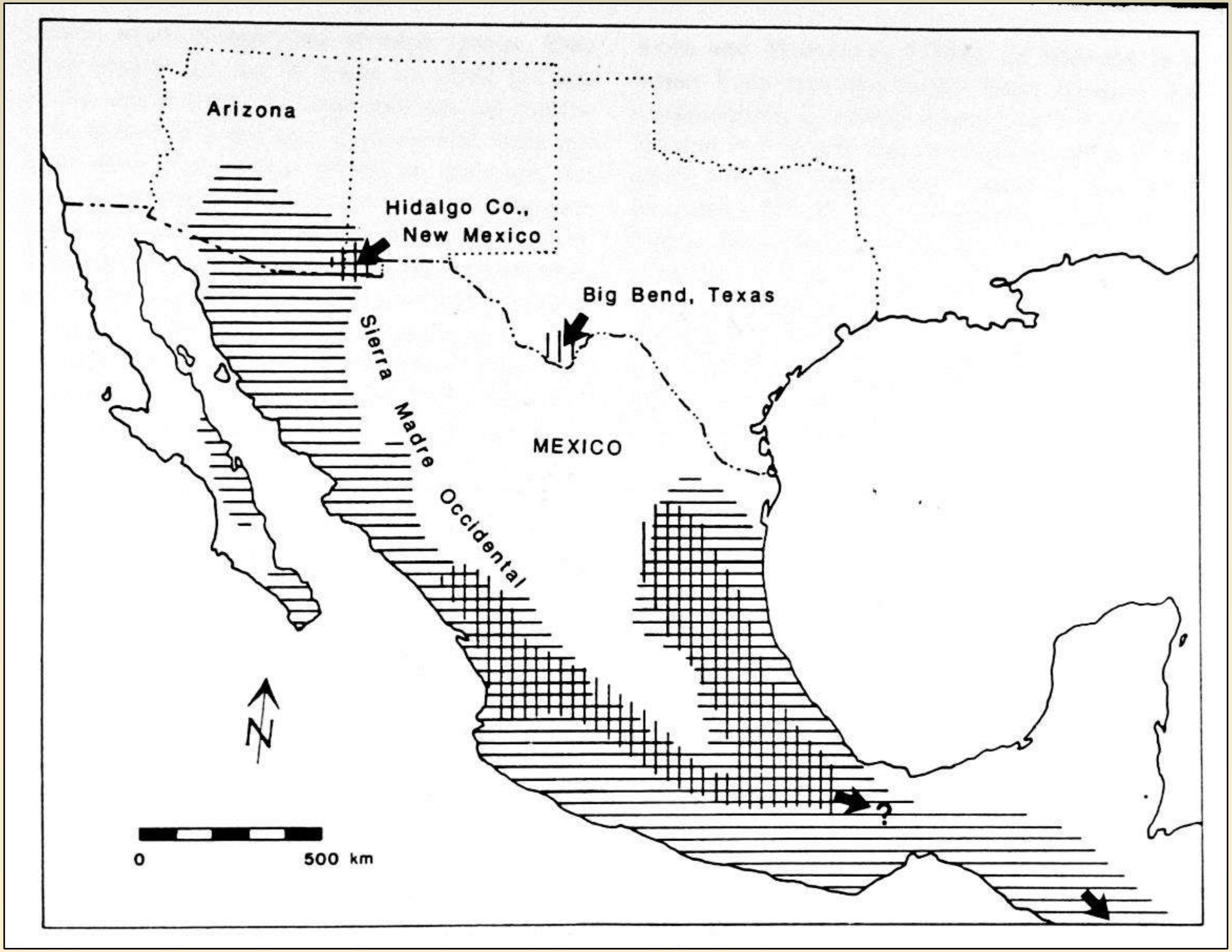
Hesperoyucca whipplei

Monocarpic
Capitate Stigma
Pollinated by *Tegiticula* moths

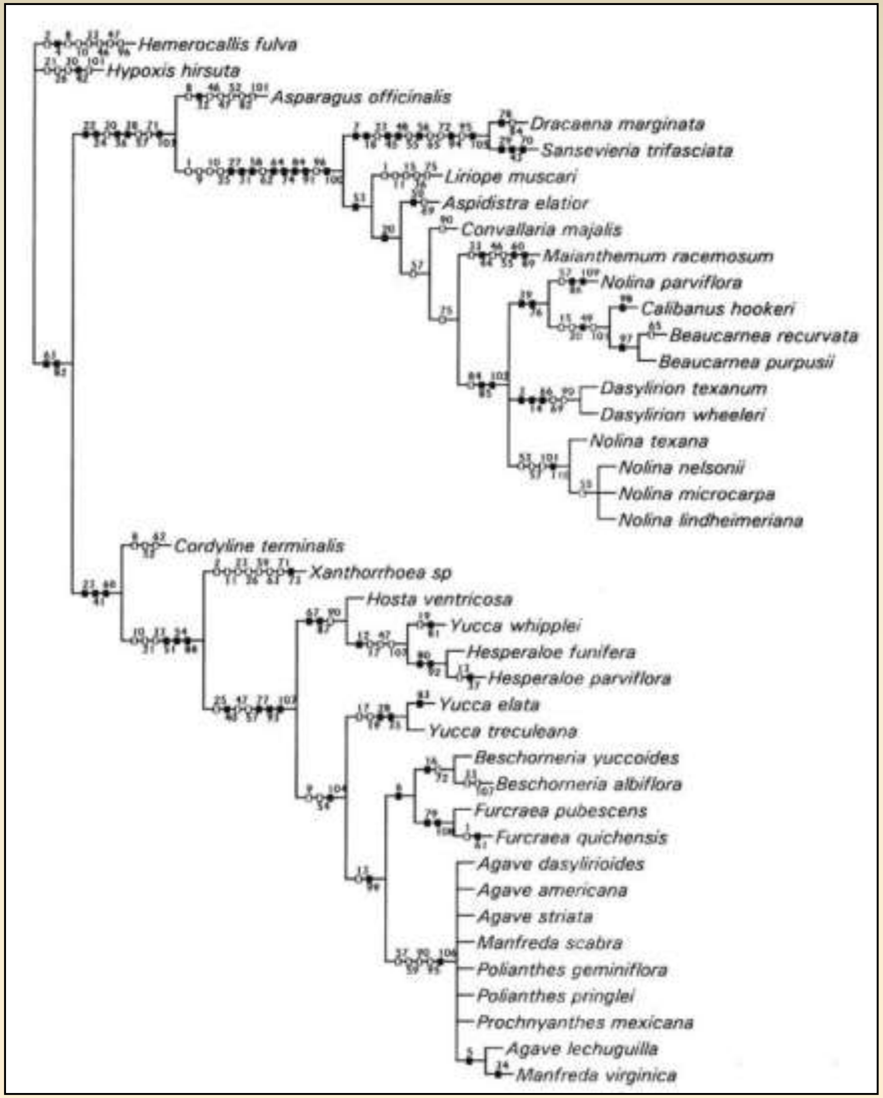

Hesperaloe funifera

Leptonycteris

Nectar-Feeding Bat Range and Migration

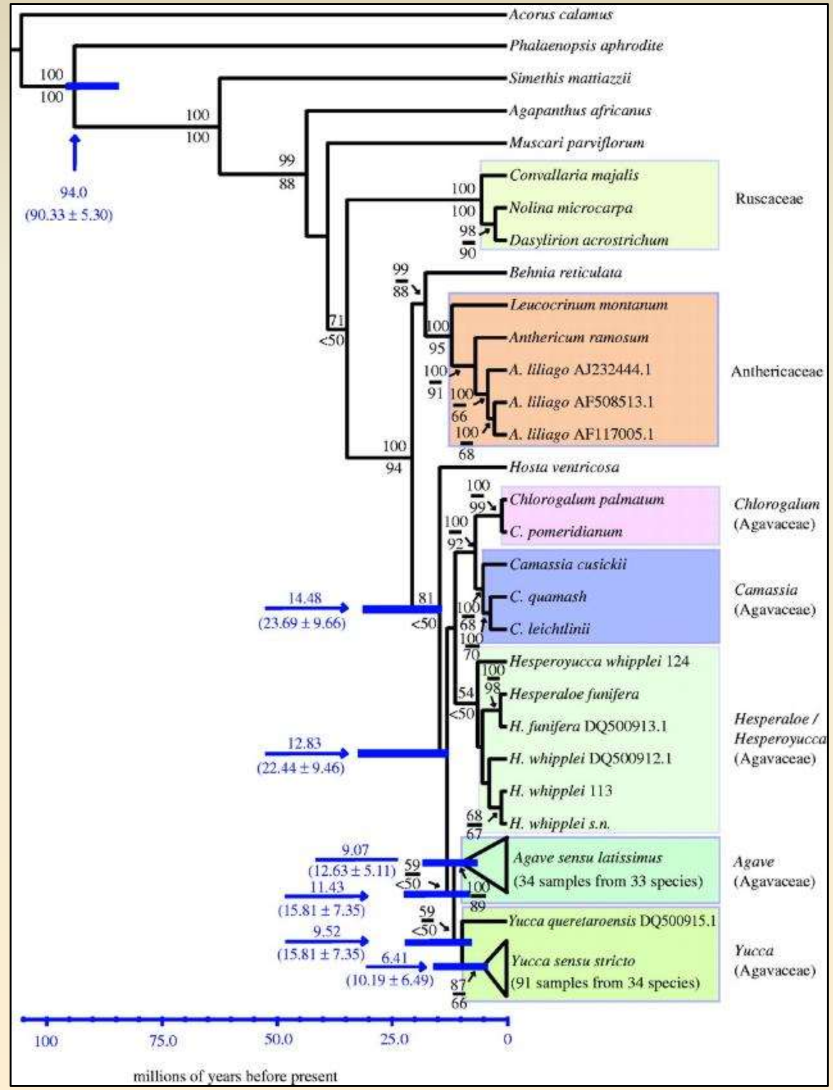



Phylogram of Agavaceae based on cpDNA Restriction Sites



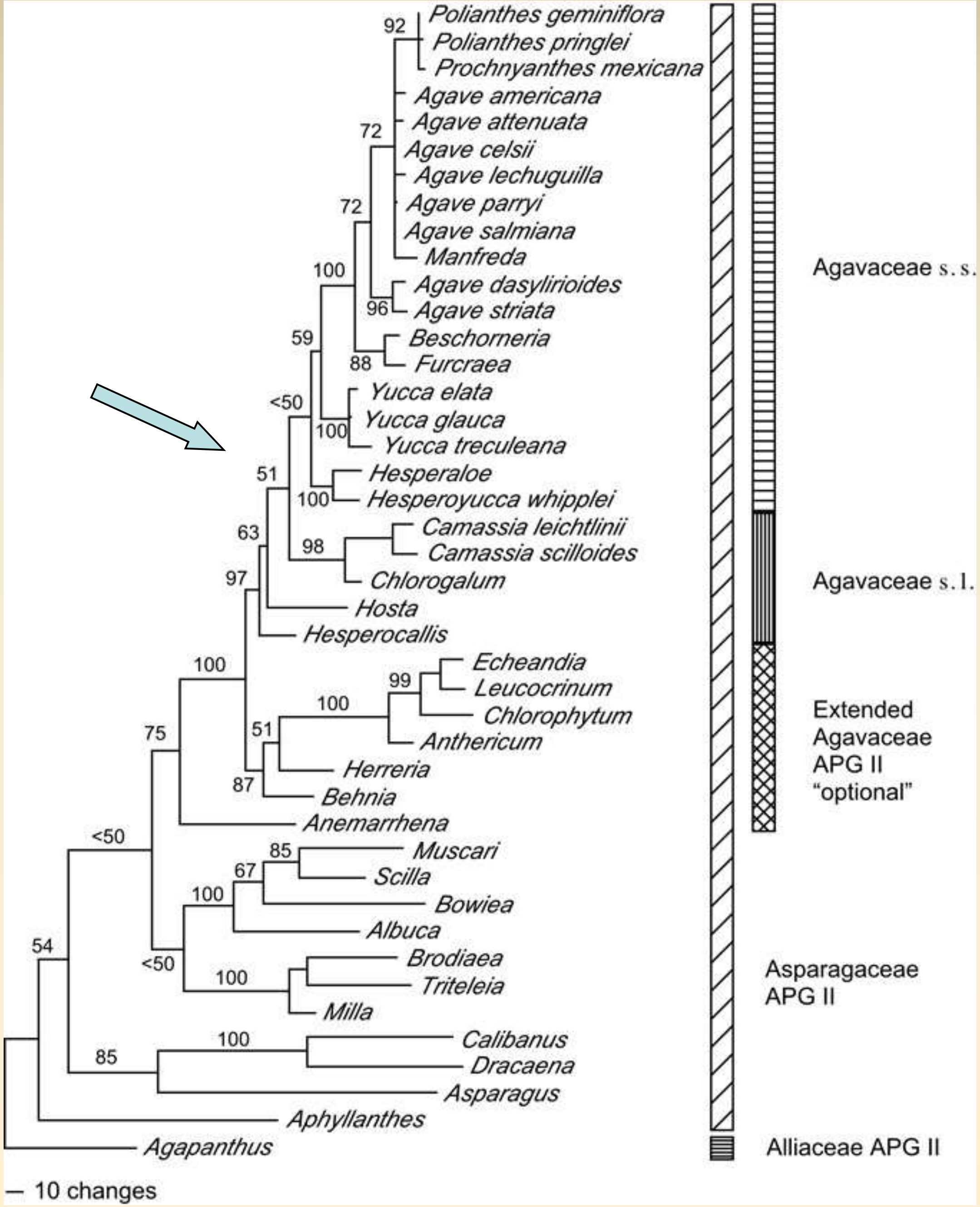
Bogler and Simpson. 1995. Syst. Bot. 20: 191

Chronogram of the Agavaceae based on cpDNA intergenic spacer sequences.



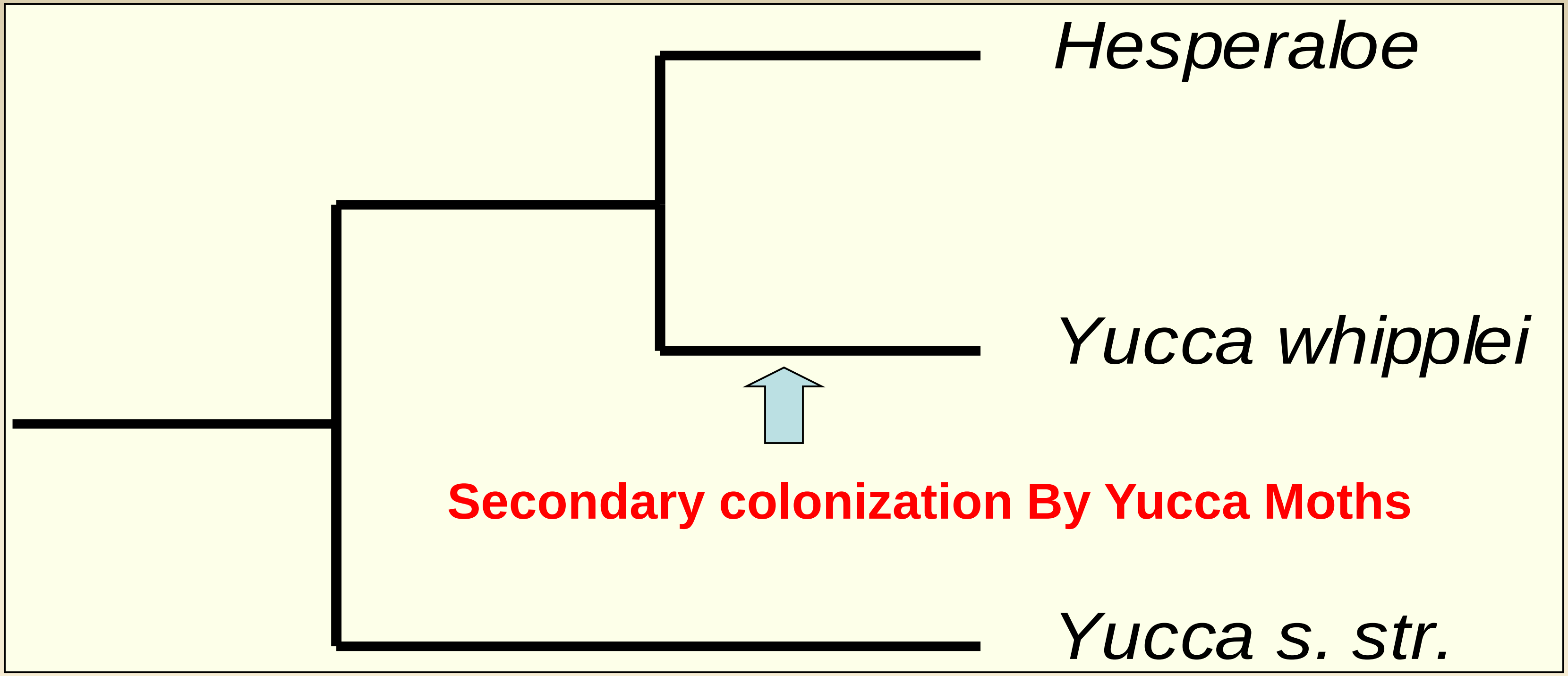
Smith C I et al. Proc. R. Soc. B 2008;275:249-258

Combined rbcL, ndhF, and ITS sequence data



Bogler et al. 2006
Aliso **22**: 313–328

Bogler et al. 1995. PNAS 92:6864-6867



“Groups” of *Agave* (Gentry, 1982)

Howard Scott Gentry

Subgenus Littaea:

- **Group Amolae**
- **Group Chloripetalae**
- **Group Filiferae**
- **Group Marginatae**
- **Group Parviflorae**
- **Group Polycepahalae**
- **Group Striatae**
- **Group Urceolatae**

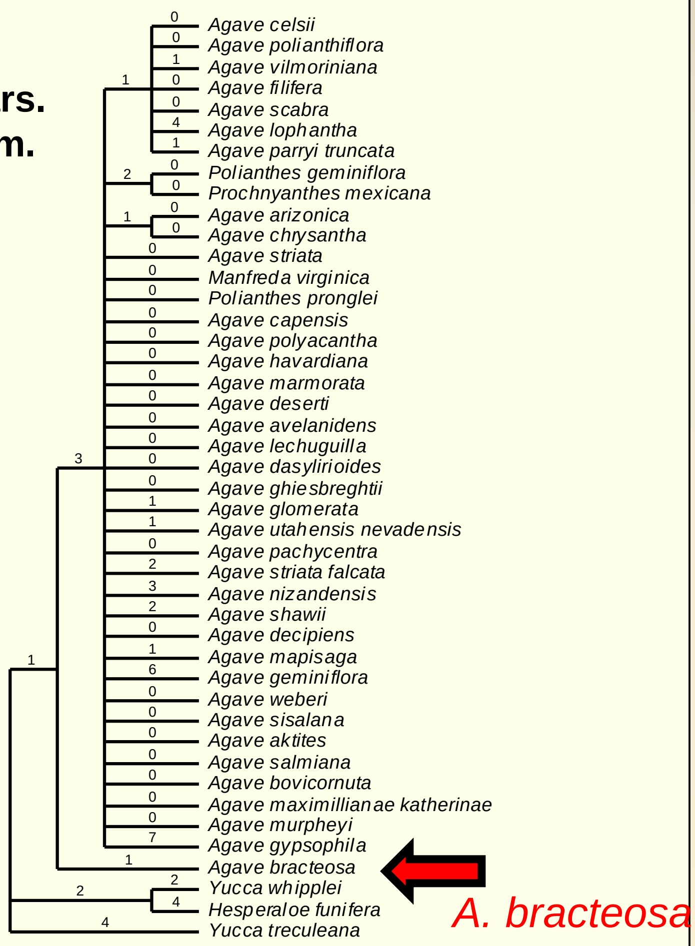
Subgenus Agave:

- **Group Americanae**
- **Group Campaniflorae**
- **Group Crenatae**
- **Group Deserticolae**
- **Group Ditepalae**
- **Group Hiemeflorae**
- **Group Marmoratae**
- **Group Parryanae**
- **Group Rigidae**
- **Group Salmianae**
- **Group Sisalanae**
- **Group Umbelliflorae**

Chloroplast Gene Spacers in *Agave*

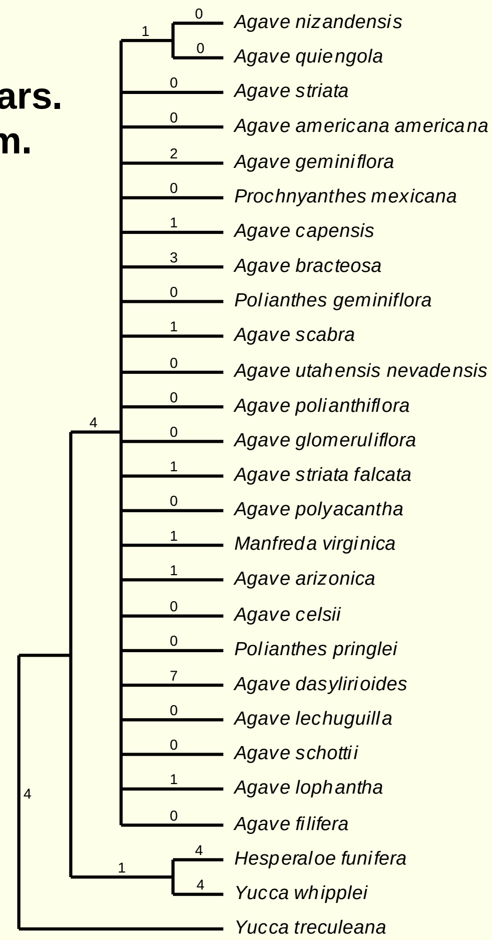
atpB - rbcL spacer

820 Chars.
12 inform.



rpl20 - rps12 spacer

734 Chars.
7 inform.



What to do?

Agave bahamense – Andros Island

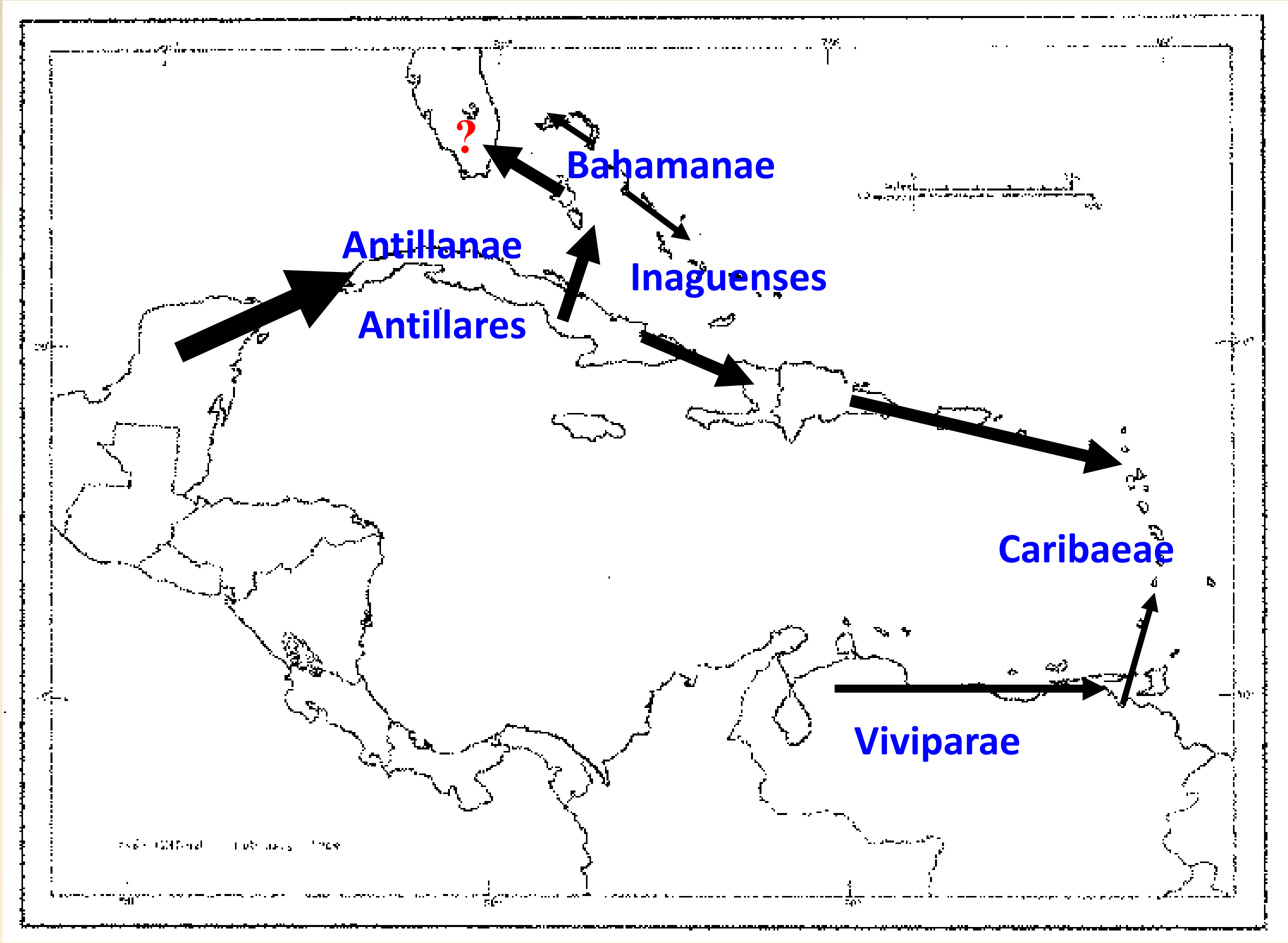
Agave sp. Whale Point, Eleuthera, Bahamas

Agave in the West Indies and Florida

Agaves of the West Indies (mostly from Trelease, 1913)
Group Bahamanae - 6 spp.
Group Inaguenses - 2 spp.
Group Antilllanae - 13 spp.
Group Antillares - 5 spp.
Group Caribaeae - 15 spp
Group Viviparae - 6 spp.

Introduced
Group Rigidae
A. angustifolia group
Group Sisalanae
A. sisalana group

Agaves in Florida
A. decipiens
A. desmettiana
A. neglecta



Pleistocene Sea Level Fluctuations?

Agave eggersiana

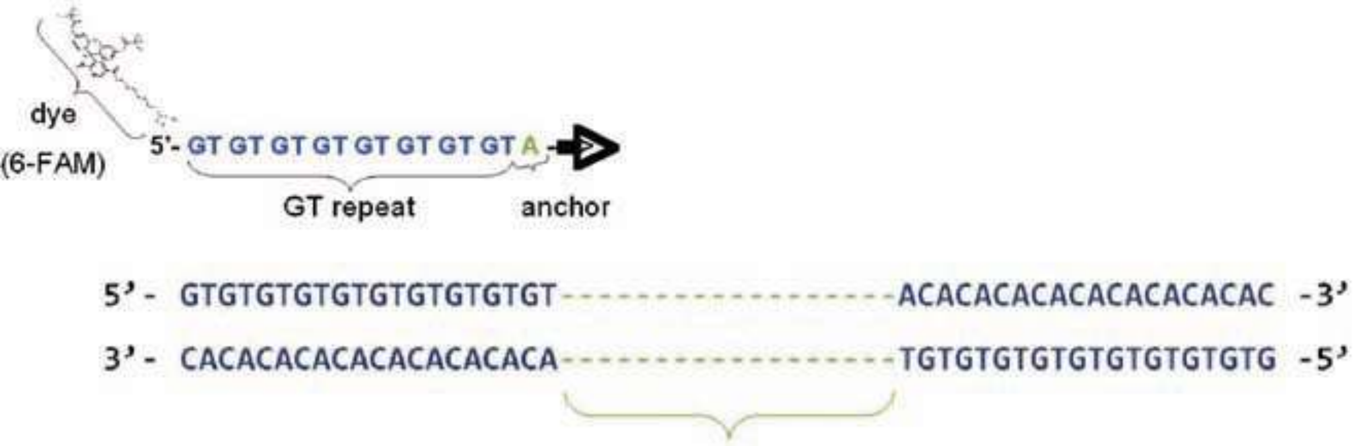
St. Croix, U.S. Virgin Islands

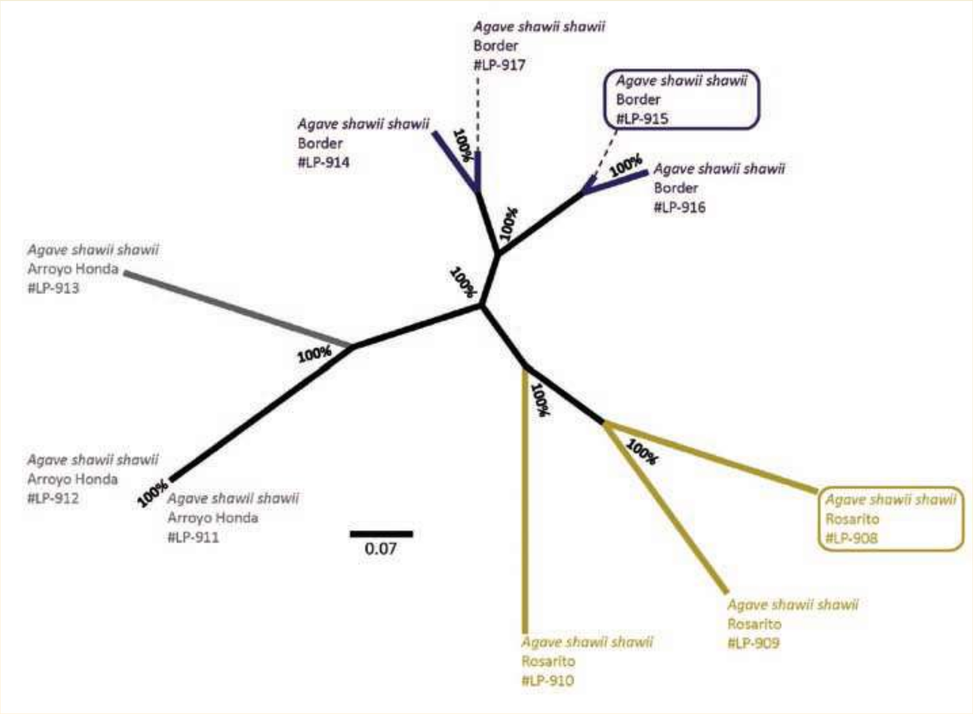
~200 individuals left

Agave shawii - Shaw's Century Plant

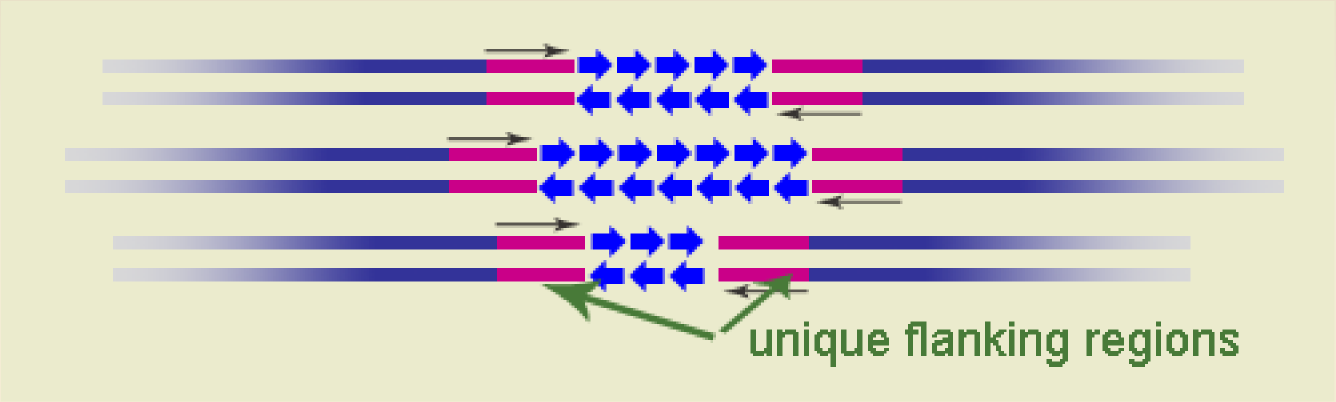
Inter-Simple-Sequence-Repeats - ISSRs

Linda Prince
Agave shawii





SSRs - Simple Sequence Repeats (= Microsatellites)
Short repeating sequences scattered throughout the genome,
e.g..GTGTGTGTGTGT, or CATCATCATCATCAT
The number of SSRs is highly variable among individuals



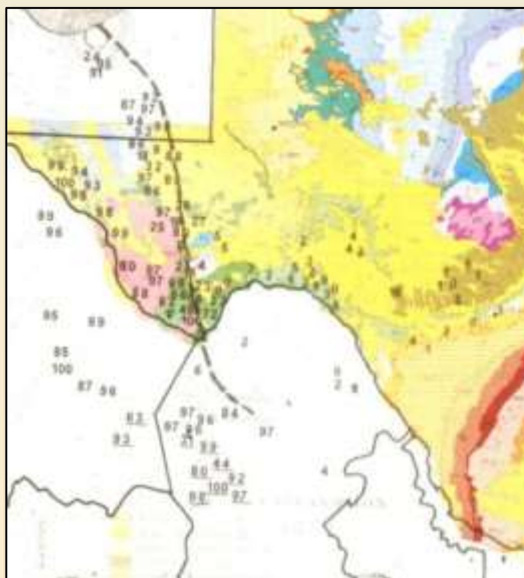
Two Kinds of Markers Use SSRs

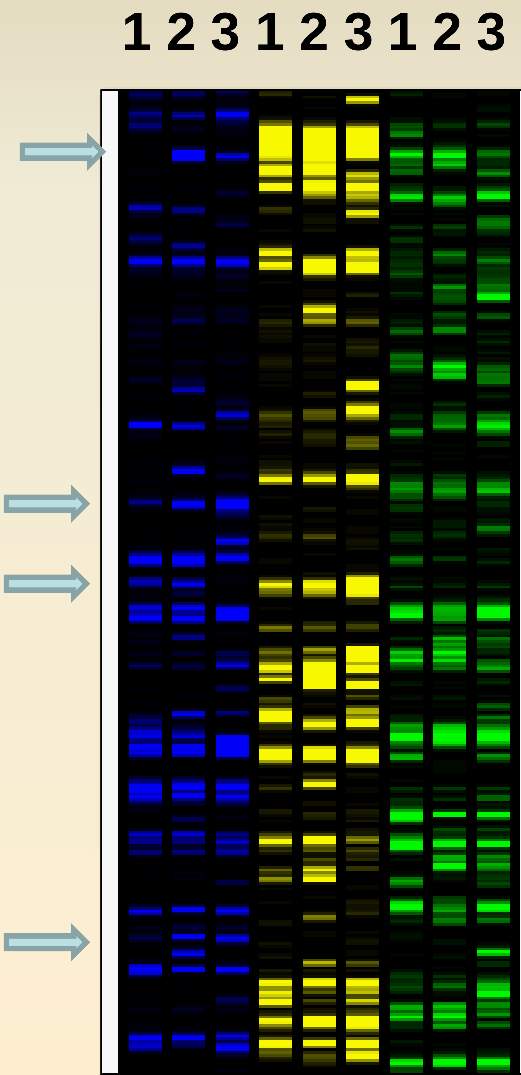
ISSRs – Inter-Simple-Sequence-Repeats
Repeating unit used as a primer to amplify region in between SSRs

Microsatellites
Flanking regions used to amplify SSR repeating units

Hybrids between *Dasylirion wheeleri* and *D. leiophyllum* in west Texas?

1. *D. wheeleri* - Organ Mtns.
2. *D. wheeleri/leio.* - Hueco Tanks
   Putative hybrid
3. *D. leiophyllum* - Chinati Mtns.

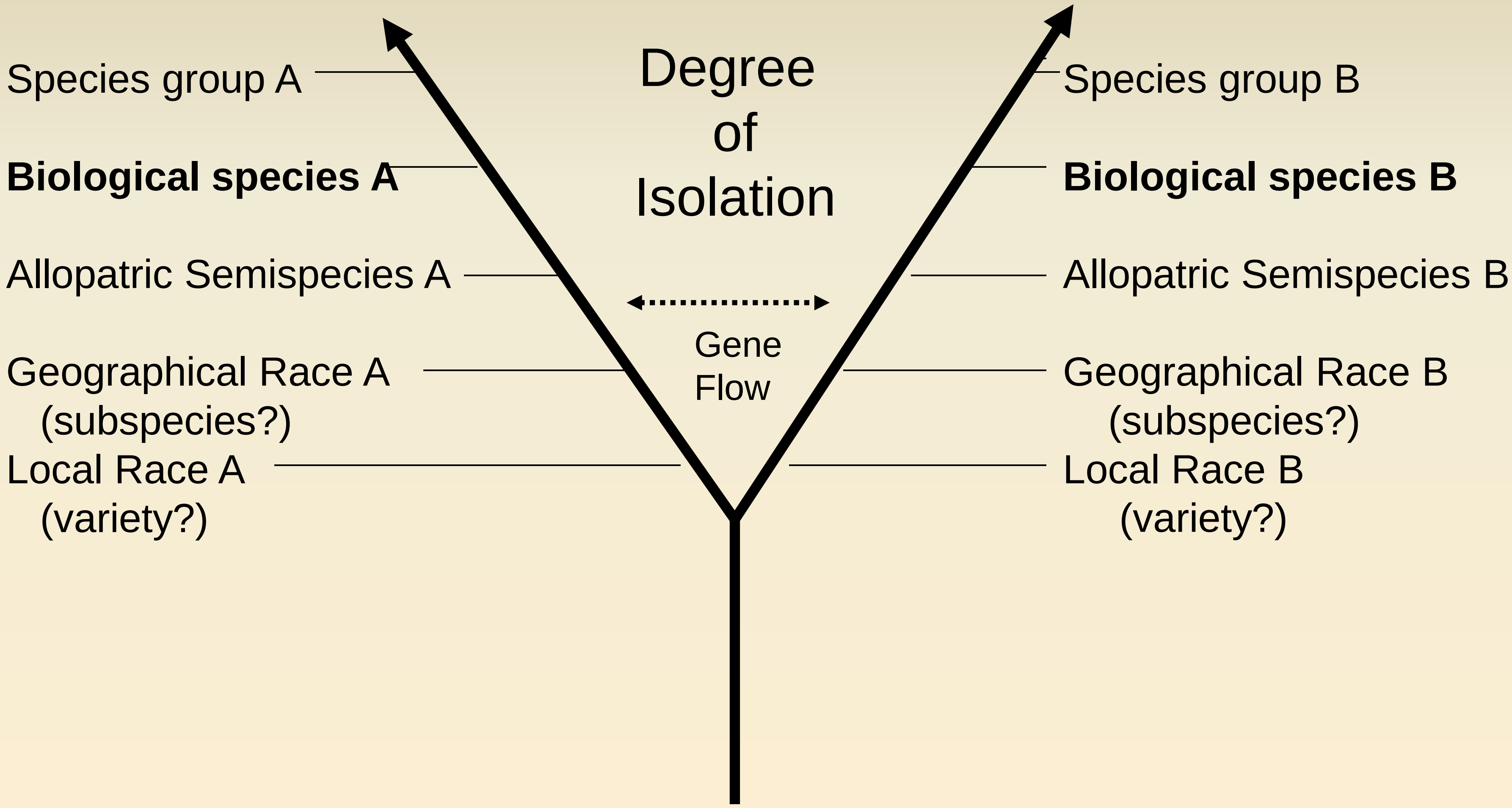




Need to look at larger sample size

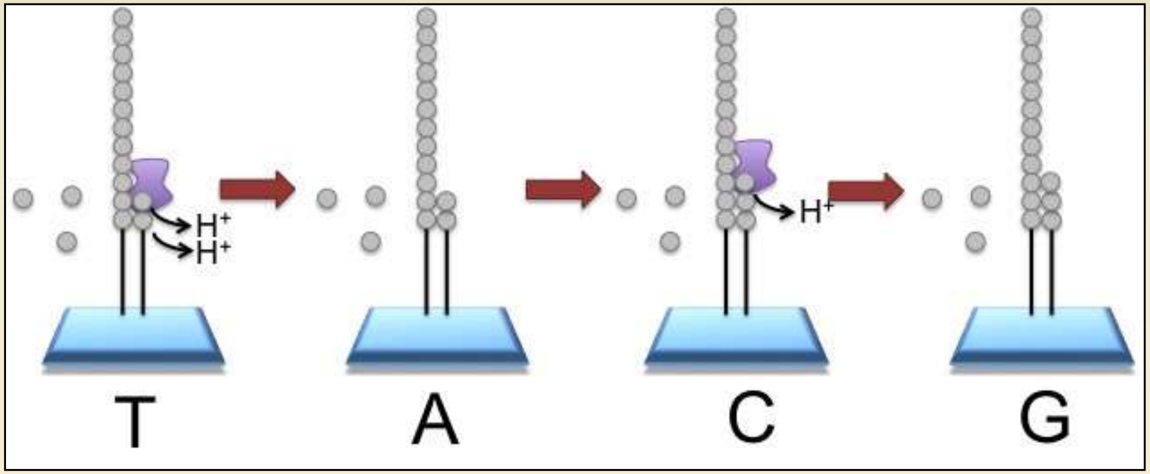
Stages in Divergence Leading to Biological Species

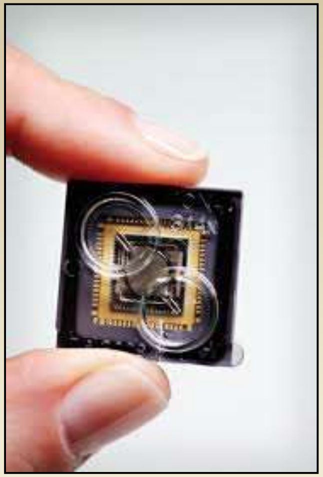
from V. Grant, 1981



NGS in a Nutshell

DNA is fragmented.
Adapters are added.
One molecule is placed on a bead.
Each bead is placed in a single well on a slide





Semiconductor Chip

Molecules are amplified on the bead by emulsion PCR
Slide is flooded with a single species of dNTP, along with buffers and polymerase, one NTP at a time.
The pH is detected in each of the wells, as each H^+ ion released will decrease the pH.
The changes in pH allow us to determine if that base, and how many thereof, was added to the sequence read. Computer keeps track.
The dNTPs are washed away, and the process is repeated cycling through the different dNTP species.

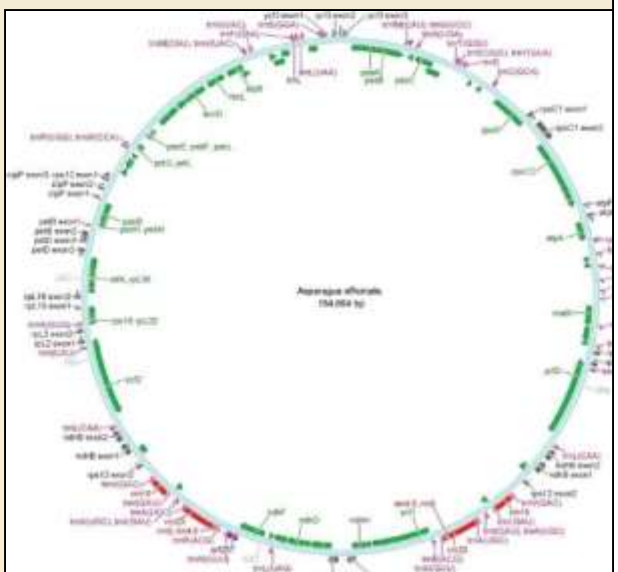
Sequence fragments are assembled into fragments by software

Sequence fragments can also be screened for microsatellite regions
New NGS population techniques on horizon - RADSeq

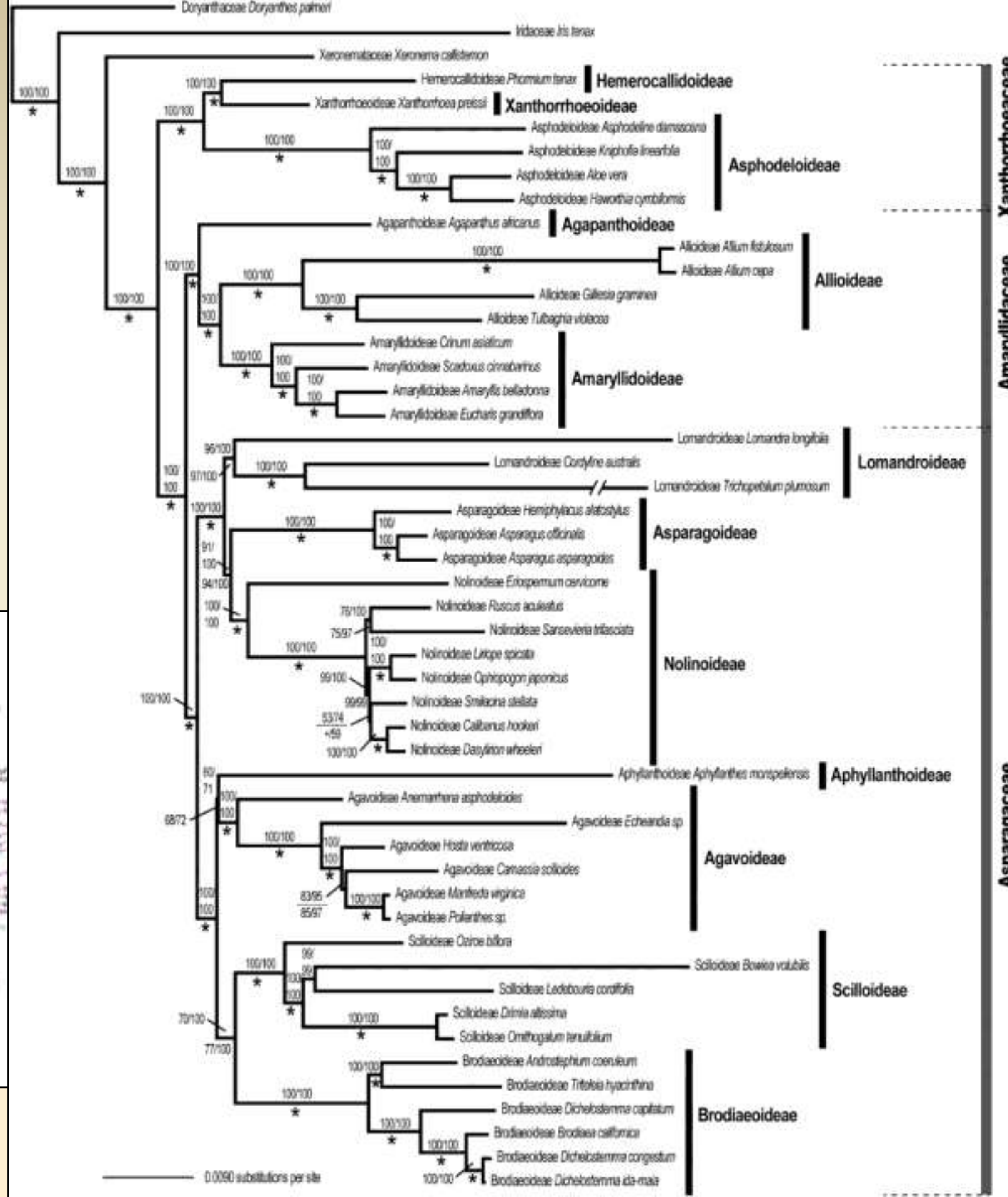
Whole Genome Sequencing

Steele et al. 2012
Am. J. Bot. 99:330-348

79 gene markers + other data sets
ML tree



Asparagus cp genome



Interactive Key to Agavaceae of the United States - Windows Internet Explorer provided by MBG

http://davidbogler.com/MonocotsUS/Agavaceae.html

Matching Taxa | Best | Describe Remaining Taxa | Restart | Filter by Genus | Lookup | Help | About SLIKS

Interactive Key to Agavaceae of the U.S.

David Bogler, Missouri Botanical Garden, USDA-NRCS

- ☐ *1. Acaulescent*
- ☐ *2. Caulescent*
- ☐ *3. Mature plants arborescent*
- ☐ *4. Rosettes freely suckering*
- ☐ *5. Rosettes or bulbs solitary*
- ☐ *6. Rosettes or bulbs cespitose, clustered, several to numerous*
- ☐ *7. Roots tuberous*
- ☐ *8. Rhizomes present*
- ☐ *9. Rhizomes erect or ascending, corm-like or with corm-like shoots*
- ☐ *10. Stolons present*
- ☐ *11. Bulbs present*
- ☐ *12. Bulb tunicate, with fibrous coat*
- ☐ *13. Stems woody*
- ☐ *14. Stems erect or ascending*
- ☐ *15. Stems geniculate, decumbent, or lax, sometimes rooting at nodes*
- ☐ *16. Stems branched*
- ☐ *17. Leaves rigid, erect*
- ☐ *18. Leaves flexible, recurved*

All Taxa:

- D *Agave ajoensis*
- D *Agave americana*
- D *Agave arizonica*
- D *Agave asperrima*
- D *Agave chrysantha*
- D *Agave decipiens*
- D *Agave delamateri*
- D *Agave deserti*
- D *Agave desmettiana*
- D *Agave eggersiana*
- D *Agave glomeruliflora*
- D *Agave gracilipes*
- D *Agave havardiana*
- D *Agave lechuguilla*
- D *Agave missionum*
- D *Agave murpheyi*

Internet | 100%

Acknowledgements

University of Texas at Austin

Fairchild Tropical Garden

Florida International University

Huntington Botanical Garden

Desert Botanical Garden

Missouri Botanical Garden

Jardin Botanico UNAM

End