Land Plant Evolution: 
Algae to Angiosperms

*The greatest adaptive radiation . . .
. . . a nearly 500 million year story*

- is the largest radiation of plants
- involves series of dramatic adaptations to the problem of living on land and being non-motile
- exhibits successive rounds of speciation and subsequent extinction
- sets the stage for the development of a land-based ecosystem with fungi and animals

Land Plant Evolution: 
Algae to Angiosperms

*The greatest adaptive radiation . . .

- know the basic extant land plant lineages today
- understand the general (not the details) series of events and timing of the rise and fall of extinct land plant lineages
- know some of the adaptations for land plant life that arose from Ordovician to Devonian
- understand the basic arguments on the 4 phylogenetic issues relating to land plant evolution
  - Ancestors of land plants
  - Base of land plants
  - Base of vascular plants
  - Relationships among seed plants

Ancestors of Land Plants

*The Tree of Life*

- land plants are in a larger lineage of green plants within Plantae
- a single endosymbiotic event gave rise to plastids
- land plants are derived from the green algae lineage

. . . for the evolution of Hordeum and Humulus

. . . a nearly 500 million year wait
**Extant Land Plants**

**Bryophyta - bryophytes**
- 16,000 species
- nonvascular plants, primitive land plants
- gametophyte dominant
- comprising 3 main groups (often 3 phyla)

**Lycopsida - lycopsids**
- 1,150 species
- vascular plants, primitive vascular plants
- sporophyte dominant; free sporing
- comprising 3 families

- Liverworts
- Mosses
- Hornworts

**Psilotophyta - whisk ferns**
- 6 species in two genera
- vascular plants, leafless green stemmed, lateral sporangia
- once considered most primitive extant land plant

- Horsetails, scouring rushes
- Club moss
- Quillwort
- Spikemoss
- Psilotum
- Equisetum
Extant Land Plants

Polypodiophyta - ferns
- 11,000 species
- diverse in habit and habitat
- spores produced in specialized sporangia

Extant Land Plants

Pinophyta - gymnosperms
- 870 species
- seed plants but seeds naked or exposed
- often divided into 4 phyla

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**Extant Land Plants**

Pinophyta - gymnosperms
- 870 species
- seed plants but seeds naked or exposed
- often divided into 4 phyla

Magnoliophyta - angiosperms, flowering plants
- 275,000 species
- tremendous adaptive radiation on land
- seed plants with seeds encased in ovary
- flowers a “key innovation”

**Earth Time**

A different perspective before taking a look at the rise and fall of land plant lineages through time . . .

Earth forms at 4.6 bya
= January 1, 12:00 a.m.

Age of the earth = 1 calendar year
4.6 billion years = 365 days

First evidence of life - 3.8 bya
Oldest fossils - 3.5 bya
= late March (1/4 of earth time gone)

Stromatolites - CaCO₃ ppt by cyanobacteria
= photosynthesis!
**Earth Time**

- O<sub>3</sub> accumulates in atmosphere - 2.0 bya
  - = late July (>1/2 of earth time gone)

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{Starch} + \text{O}_2 \\
\text{reducing atmosphere} & \rightarrow \text{oxidizing atmosphere} \\
\text{anaerobe} & \rightarrow \text{aerobe} \\
\text{extinction} & \rightarrow \text{evolution}
\end{align*}
\]

Age of the earth = 1 calendar year
4.6 billion years = 365 days

**Earth Time**

First eukaryotes - 1.5 bya
- = early September (2/3 of earth time gone)

Age of the earth = 1 calendar year
4.6 billion years = 365 days

**Earth Time**

First abundant fossils in Cambrian “explosion” - 560 million years ago
Many phyla of animals
- = early November

Age of the earth = 1 calendar year
4.6 billion years = 365 days

**Earth Time**

First land life in Ordovician - 460 mya (a liverwort?)
- = November 15 (7/8ths of earth time gone!)

Age of the earth = 1 calendar year
4.6 billion years = 365 days

**Burgess Shale**

Spore Tetrad
Earth Time

First angiosperm Jurassic/Cretaceous
- 135 mya
= December 21!

Age of the earth = 1 calendar year
4.6 billion years = 365 days

Earth Time

First human civilization (centered on beer production?) & formation of Great Lakes flora/vegetation
= December 31, 11:59pm.

Age of the earth = 1 calendar year
4.6 billion years = 365 days

Barley harvest, Mesopotamia 7000ya

Extinct Land Plants - the Fossil Record

Ordovician Period (505 - 440 mya)
- First evidence of land life at 460 mya

Microfossils of spores with sporopollenin (degradation resistant material like lignin) and similar to modern day bryophytes such as liverworts

Found worldwide in shales that were deposited at the marine-terrestrial interface

Extinct Land Plants - the Fossil Record

Ordovician Period (505 - 440 mya)
- Other evidence of land life

Glomales fungi seen in 460 my Wisconsin rock. Glomales today form important arbuscular mycorrhizal associations with some liverworts and hornworts and many vascular plants. Symbiosis!
Extinct Land Plants - the Fossil Record

Ordovician Period (505 - 440 mya)
- Other evidence of land life

- Manitoba patula thallus from Canada - an aquatic charophyte algae

Extinct Land Plants - the Fossil Record

Silurian Period (440 - 410 mya)

- Cooksonia fossils are seen in the mid Silurian growing close to water

- Very simple, stick-like, leafless plants but sporophyte dominant
- No roots are seen
- Terminal sporangia (spore producing structures)
- Possibly non-vascular

Extinct Land Plants - the Fossil Record

Silurian Period (440 - 410 mya)

- Late Silurian is also the first occurrence of land animals - arachnids, centipedes
- These are predators and thus indicate that there were unknown herbivores - community of plants, herbivores and carnivores!
Rhynia seen in the early Devonian (Rhynie Chert fossil) is more complex than Cooksonia (part of Ryniophytes)
20 cm tall, no roots, no leaves, primitive vascular tissue
Rhynia and other Rhynie Chert plants were infected with the fungus, Paleomyces, indicating extensive mycorrhizal relationships

Zosterophyllum seen in the early Devonian is a lycopsid
Clonal plant with reticulating stems, and lateral sporangia as in the shining club moss

Huuperzia lucidula - shining club moss

The Early Devonian lasted some 30 million years after the first appearance in mid-Silurian of simple land plants
During this interval the critical characteristics of land plant survival evolved:
### Extinct Land Plants - the Fossil Record

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- underground axis (root) and above ground photosynthetic stem
- rhizoids (water uptake)
- primitive leaves
- internal transport - vascular tissue

![Rhynia](image1)

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- internal transport - vascular tissue
- epidermis, cuticle, stomates

![Rhynia](image2)
Extinct Land Plants - the Fossil Record

Early Devonian Period (410 - 390 mya)

The Early Devonian lasted some 30 million years after the first appearance in mid-Silurian of simple land plants. During this interval the critical characteristics of land plant survival evolved:

- underground axis (root) and above ground photosynthetic stem
- rhizoids (water uptake)
- primitive leaves
- internal transport - vascular tissue
- epidermis, cuticle, stomates
- support tissue - lignin
- shift to sporophyte dominant rather than gametophyte dominant
- sporopollenin to cover spores for protection

Extinct Land Plants - the Fossil Record

Later Devonian Period (390 - 360 mya)

First "progymnosperms" [Archaeopteris] - free sporing like ferns and relatives but trees like gymnosperms with complex leaves - megaphylls

Extinct Land Plants - the Fossil Record

Late Devonian Period (390 - 360 mya)

First "seeds" - "seed ferns" [Archaeosperma]

Plants fern-like with dissected compound leaves, but produce naked seeds (embryo within protective coverings)
The tropical equatorial coal swamps were dominated by a diversity of lycopsids (Lycopsidophyta) and sphenopsids (Equisetophyta).

*Lepidodendron* (lycopsid) was 30 m tall with 1 meter long “microphyll” leaves.

*Calamites* was one of the dominant large tree-like horsetails (sphenopsid).

Permian Period (286 - 245 mya)

Pangaea begins to coalesce.

South of the tropical flora dominated by lycopsids, sphenopsids, and seed ferns existed the Glossopterid Flora.

- Big trees with net-veined leaves
- Seed bearing (derived from female gametophyte) and pollen forming (from male gametophyte)

Permian Period (360 - 286 mya)

The tropical equatorial coal swamps were dominated by a diversity of lycopsids (Lycopsidophyta) and sphenopsids (Equisetophyta).

*Calamites* was one of the dominant large tree-like horsetails (sphenopsid).
Triassic Period (245 - 208 mya)

The Triassic (and Jurassic) is known as the “Age of Cycads” as this gymnosperm group rapidly diversified after initially appearing earlier in the Permian.

Modern cycad - *Dioon*

Jurassic Period (208 - 146 mya)

"Age of Dinosaurs" (and Cycads)

The Jurassic saw an increase not only in gymnosperm groups such as the cycads and ginkgos, but also extinct lineages Bennettitales and relatives like *Pentoxylon*. These plants produced leaves that superficially resembled cycad leaves.

*Williamsonia*

Jurassic Period (208 - 146 mya)

"Modern" genera are first seen for Ginkgo…

- The big trees of the Triassic were primitive lineages of conifers and ginkgos.
- The gymnosperms replaced lycopsids and sphenopsids which were reduced in size and diversity.
- The Petrified Forest National Park originated during the late Triassic.
Extinct Land Plants - the Fossil Record

Jurassic Period (208 - 146 mya)

“Modern” genera are first seen for Ginkgo and Equisetum (horsetail)

Modern genera are first seen for Ginkgo and Equisetum (horsetail)

Extinct Land Plants - the Fossil Record

Cretaceous Period (146 - 65 mya)

Near the Jurassic/Cretaceous border, the first Angiosperms are seen

Archaefructus

Extinct Land Plants - the Fossil Record

Cretaceous Period (146 - 65 mya)

Although not a strict co-evolution, as insects group had already diverged by the Cretaceous, the relationship between insects and flowering plants for pollination purposes and herbivore interactions spurred speciation in both groups

Molecular Phylogeny of Land Plants

1. Ancestors of land plants?
   - land plants are most closely related to the Charales within the Charophytes (Karol et al. 2001 - Science)
Molecular Phylogeny of Land Plants

2. Base of land plants?

- Hornworts are closest to vascular plants (Qi et al., in press)
- Photosynthetic sporophyte is shared derived character

- Bryophyta - bryophytes
  - hornworts
  - mosses

- Liverworts

Molecular Phylogeny of Land Plants

3. Base of vascular plants?

- Lycopsids are sister to rest of vascular plants
- Whisk ferns and horsetails are just strange primitive ferns?

Molecular Phylogeny of Land Plants

4. Gymnosperms paraphyletic?

- Gnepiphytes are not related to angiosperms
- Gnepiphytes may be related to Pinaceae!

Fig. 5. Four major hypotheses of relationships among gymnosperms and other land plants. AF = angiopterids, CV = cycads, GE = ginkgos, GN = gnetophytes, PS = Pinaceae, CO = coniferous conifers.
Concluding thoughts . . .

The field of plant systematics epitomizes the work of all other branches of biology centered on the organism itself, and brings the varied factual information from them to bear on the problems of interrelationships, classification, and evolution.
Thus, systematics is at once the alpha and omega of biology.

Reed Rollins 1957

Concluding thoughts . . .

Plant systematics has not outlived its usefulness; it is just getting under way on an attractively infinite task.

Lincoln Constance, 1957

. . . and thanks for being a great class!