Diversity in the Plant Kingdom

I. Introduction

All modern terrestrial plants are the descendants of algae that adapted to a terrestrial habitat roughly 500 million years ago. Compared to water, land is an erratic habitat where temperature and moisture availability may change abruptly and dramatically.

What were the adaptations that these primitive plants needed to survive on land?

- Surrounded by air, the land plant is in constant threat of desiccation and must have **waterproofing**, usually in the form of a waxy **cuticle** layer.
- While algae could obtain nutrients from the surrounding water, land plants needed to extract minerals (and now, even water!) from the soil; and **roots** adapted to take on this task.
- Evolution of rigid **structural support** allowed plants to grow to new heights, and better compete for sunlight.
- Yet, height must have coevolved with **vascular (transport) tissue**, the internal plumbing system needed to transport water and nutrients from the roots skyward.
- **Reproduction** now became problematic as well, as sperm could no longer swim through open water to a joyous meeting with the egg. Thus evolved sperm cells protected within **pollen grains** that could instead use wind, and later, unwitting animals to be carried to the egg.
- And what to do with the next generation? Conditions on land are much less predictable than in water, possibly unfavorably dry or hot after fertilization occurs. Packaging the immature (and dormant) plant in a **seed**, allowed it to survive until favorable growth conditions (or the correct season) arrived.

These were the traits that appeared during the evolution of plants, and they can be traced through a study of the different groups of plants that exist on earth today. Although you may be casually familiar with many of these plants, you may not appreciate their evolutionary significance or relationships.

**The objectives of this lab exercise are that you understand the:**

- Particular evolutionary innovations associated with the major groups of plants, and learn to identify these plants.
- Evolutionary relationships between these plant groups.
- The distinctive characteristics of plant reproduction.
What are the major groups of plants and when did they evolve?

There are four major groups that evolved in the following sequence:
1. **Bryophytes**, which include the mosses
2. **Seedless vascular plants**, which include the ferns
3. **Gymnosperms**, many of which are also called conifers
4. **Angiosperms**, the ‘flowering’ plants, which now predominate

The approximate ages during geologic time when these groups evolved are shown in the figure. Ancestral algae began to invade the land early in the Paleozoic, and plants that closely resemble modern bryophytes appeared shortly (say… 100 million years!) thereafter. Plants with advanced vascular systems appeared in the mid Paleozoic and quickly became the dominant plant form on earth. The gymnosperms reached predominance in the Mesozoic (triceratops was probably eating conifers) to be later replaced by the much more reproductively successful angiosperms.

What are the sporophyte and gametophyte?

While mating behaviors among humans may seem inexplicable on occasion, sexual reproduction among plants is actually more complicated. In animals, the adult (male or female) has specialized organs that produce reproductive cells called **gametes** (sperm or egg cells). Upon fertilization, the egg and the sperm combine to produce a zygote that can grow into another male or female adult.

Unlike animals, plants have two alternating life stages. The figure shows the ‘alternation of generations’ as it occurs in a moss.
1. One stage – the **sporophyte** – produces spores;
2. the spores develop into a **gametophyte** stage plant, which may be male or female;
3. gametophytes produce either sperm or egg gametes;
4. egg and sperm cells unite and grow into another sporophyte.

**Notice:** spores develop into a whole plant; gametes must first unite then develop. **Animals do not produce spores.**
How did the life stages of plants change during evolution?
1. Initially, the gametophyte was the larger, more apparent stage; as in a moss.
2. Later, the sporophyte stage became more dominant and elaborate.
3. Eventually, the gametophyte stage became reduced to being only microscopic.

II. Characteristics of the major groups of plants

A. Bryophytes (nonvascular)
These are considered to be the most primitive of the plants. They are typically only found where water is readily available, and never grow more than a few inches tall for lack of a vascular system.

What are the distinguishing characteristics of the Bryophytes?

- Bryophytes disperse through spores, not seeds.
- Bryophytes lack a vascular system. There are no tree-size bryophytes because water could never travel adequately from the rootlets to the very top.
- The gametophyte stage is dominant. Bryophytes are the only group of plants where the gametophyte stage is larger than the sporophyte stage.

There are three divisions of bryophytes, two of which are on display.

1. Mosses

Note: Not everything called a “moss” is a bryophyte; Spanish moss is a flowering plant, Irish moss is a marine Red Alga, Reindeer moss is a lichen, and Club mosses are a primitive vascular plant called a Lycopod.
Mosses lack a vascular system. The leaves contain many photosynthetic cells and a structural midrib. Stems can conduct water only short distances.

Sphagnum moss has small scale-like leaves that are adapted for water retention. Under the microscope one can see large (dead) water holding cells reinforced by ribs. The photosynthetic cells occur in strands extending around these huge cells.

2. Liverworts

There are several groups of liverworts. For one group, the thallus-forming liverworts, the gametophyte looks like a flat, branching green ribbon. Gametes are produced beneath the umbrella-shaped structures and the fertilized eggs develop into the sporophytes. The sporophyte generation is small and not easily visible -- it occurs only as tiny bag-like structures underneath the little umbrella-shaped structures growing out of the thallus.

“Gemma cups” produce small clusters of cells called ‘gemmae’ capable of asexual reproduction. After being splashed out of their ‘cups’, the gemmae can develop into another thallus.
B. The seedless vascular plants

The vascular plants are believed to have evolved from moss-like plants 300-400 million years ago. They were the first plants to grow to large size and away from open water. These capabilities were made possible by the presence of a vascular system which allowed these plants to form the first forests on earth. The vascular system extends from the roots, through the stem and branches, and into the leaves, allowing efficient transport of water and nutrients throughout the plant. While the bryophyte’s life cycle has the gametophyte as the dominant stage, all vascular plants have the sporophyte generation as the dominant stage.

This group of plants is distinguished by:
- the presence of a vascular system
- a dominant sporophyte stage
- dispersal through spores

On display are representatives of three Divisions of seedless vascular plants:

1. Ferns (Division Pterophyta)
   Ferns produce leaf-like fronds and spore-producing structures called sori on the bottom side of fronds.

Fern Life Cycle

The fern "plants" with which you are familiar are the dominant sporophyte stage which, like the small sporophyte of moss, produces spores. Ferns also have a gametophyte stage which develops from the germinating spores, but the fern gametophyte is very small, about the size of a child’s fingernail.

The fern frond (leaf) may have on its underside some small brownish spots called sori (singular: sorus), which consist of clusters of lollipop-shaped sporangia that produce spores. Each sporangium has thick-walled cells on one side of the sporangium; upon drying, these thick-walled cells contract, causing the sporangium to tear open and then violently fling the spores away from the plant, catapult-style.
2. Lycopods (Division Lycophyta)
   -- produce small leaves around the stem

3. Horsetails (Division Sphenophyta)
   -- appear almost like 'naked' stems, with occasional whorls of scale-like leaves.

   For both, the spores are typically produced in small cone-like structures at the shoot tips.

   The fossil record indicates that these plants were dominant during the Carboniferous period (300 mya) and grew to the size of trees. The partially decomposed bodies of these plants along with tree ferns eventually created the coal deposits that we now use as an energy source. Because of their long evolutionary lineage, the lycopods and horsetails are often called "living fossils."

III. The seed-producing plants: Gymnosperms and Angiosperms

Why have seed-producing plants been so successful?
1) The plant can remain dormant as a seed until conditions favorable to growth occur; this may be the following spring, or for some desert plants, years later.
2) Seed plants also broke the dependence on external water in reproduction; the sperm do not swim through external water but rather are within the pollen grains that travel through the air.
3) Both pollen and seeds can be dispersed more efficiently than spores, and can withstand harsher conditions. The seed is a rugged package for dispersal; within the tough seed coat is a dormant plant embryo as well as stored food for the embryo to use in resuming growth and getting established.

The gametophyte is reduced to two microscopic structures:
- a pollen grain – a tiny male gametophyte containing sperm.
- a small portion inside an ovule – a tiny female gametophyte containing an egg cell. After pollination, an ovule develops into a seed.

Gymnosperms (the naked-seed plants): Conifers, Cycads, Ginkgo

What are the distinguishing characteristics of gymnosperms?
- The pollen grains and ovules are produced in cones.
- They produce seeds, although the seeds are not encased by an outer layer (which is called a fruit in angiosperms). The name gymnosperm means ‘naked seed’.

Some examples of Gymnosperms include:
  - Conifers (Division Coniferophyta)
  - Cycads (Division Cycadophyta)
  - Ginkgos (Division Ginkgophyta)
A. Conifers

Conifers produce cones in the spring—male cones and female cones. The small non-woody male cones produce pollen grains. A pollen grain is a microscopic male gametophyte that contains only 3 cells, one of which is a sperm.

The larger female cones produce ovules, each containing a microscopic female gametophyte containing an egg; the ovule will develop into a seed after pollination. Maturation of the female cones for some species, such as pines, may require two years.

Conifers rely upon wind to disperse the pollen grains and bring them to the female cones, and to carry away the seeds. Conifer seeds are usually winged -- having a papery extension of the seed coat to aid in wind dispersal.

Conifer leaves (needles)

Most conifers are “evergreen” and do not drop their leaves in the winter when it is cold and a lot of the water is tied up in snow and ice. The surface area of conifer leaves is much smaller than that of broadleaf trees and has a thick waxy covering. These are adaptations to surviving cold winters when very little water can be transported up from the ground. They are well adapted to colder northern latitudes and higher mountain elevations; in these habitats, retaining their leaves also helps conifers get a “quick start” and make the most of the short growing season.

B. Ginkgo and Cycad

The GINKGO tree is the sole surviving member of an evolutionary line that extends back to the Paleozoic; it also was a dominant tree during the Carboniferous period. Known from fossils, it was thought extinct until western explorers discovered it in the 1800s growing in temple gardens in the mountains of China. The shape of the leaf and the branching pattern of the veins are considered to be primitive traits.

The CYCADS are non-flowering seed plants that look like very short-stemmed palms. Some cycads have the common name of “Sago Palm” which is a misnomer; it’s not a palm; palms are flowering seed plants; these plants produce ‘naked’ seeds on a large central cone, a more primitive trait.
Angiosperms (the flowering plants)

What are the distinguishing characteristics of angiosperms?
- The pollen grains and ovules are produced in flowers.
- They produce seeds that are encased by an outer layer called a fruit.

Through their color, smell and edible nectar, flowers attract insects and animals that unwittingly carry pollen between flowers to achieve pollination; this is much more efficient than merely releasing pollen into the wind. Likewise, fruits may also help recruit animals, this time to help disperse the seeds.

Reproduction in flowering plants will be examined in more detail in a separate lab exercise.

Wood Structure

Woody trees are found in the gymnosperms and in the angiosperms. Most commonly, the bulk of a tree trunk is made up of a central region of xylem tissue; the functional phloem tissue consists only of the inner bark. Each ring of the wood represents the xylem growth that occurred during one growing season (thus the name “annual ring”). During each growing season, the cells initially produced are large-bored and thin-walled (“early wood”), but later in the season the cells become small-bored and thick-walled (“late wood”).

Some trees are said to have hard wood and others soft wood. Hard wood trees are prized for their strength, beauty of the ring structure, and also as firewood since they burn more slowly and give off more heat. The difference lies in the formation by some trees of special cells in the xylem – the tough, very thick-walled fibers and the “vessels”. Vessel cells are much bigger in diameter that the normal “tracheid” cells of the xylem, and have highly reinforced cell walls. Abundance of thick, hard cell walls is what makes the wood much harder. “Softwood” trees are conifers, while “hardwood” trees are flowering plants.
Lab Activities

A. Mosses

1. **Examine the moss** on display. Compare it to the description provided above. **To the right**, draw a diagram of the plant **labeling** the leaves, gametophyte, sporophyte and capsule.

2. **Make a wet mount** of a sphagnum leaf on a microscope slide, and examine the leaf through the compound microscope. In the **diagram to the left**, **label** a water-holding cell, location of photosynthetic cells and a reinforcing rib.

3. The ________________ stage of the life cycle is dominant. The gametes produced by this stage fuse to form the ________________ stage; the spores produced by this stage develop into another ________________ stage.

4. How can mosses survive without vascular tissue?

Liverworts

1. **Examine the examples** of thallus liverworts provided in the lab and compare to the description provided above.

2. In the diagram to the right, **label** the thallus, gemma cups and ‘umbrella-shaped’ structures. Where are the gametes and spores produced?

3. **Complete this table about Bryophytes (check the features bryophytes possess)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ferns

1. **Draw a fern leaflet** of two different fern species, showing precisely the arrangement of sori on the under side of each leaflet.
   **What are the sori?**

2. **Examine** a sorus under a dissecting microscope. Notice the cluster of rounded "sporangia". The spores are produced inside the sporangia, and some of these should be visible.

3. Using forceps, carefully remove some of the sporangia and mount them in a drop of water on a microscope slide with a cover slide. **Draw a sporangium** as it appears under the 10x objective of a compound microscope.

4. **Explain** how the sporangium is designed to disperse the spores into the wind:

Examine the lycopod and horsetail specimens on display.
5. Why are these plants able to grow taller and live further away from open water than mosses?

6. **Complete this table about ferns**

|----------------|------------------|-----------------|----------------------|------------------|----------------|------------------|
Gymnosperms

Examine the assortment of cones and seeds on display in the lab.

1. ________________ are produced in the male cones of conifers, whereas in the female cones the ________________ occur, which develop into ________________ after fertilization.

**Explain** how to distinguish male and female cones:

2. **Explain** why female cones are so well reinforced and often armed with ferocious looking spikes.

Examine the conifer branches provided in the lab.

3. What are two adaptations that help conifer needles survive the winter season?

   1.
   
   2.

4. What are **three reasons** why seed bearing plants have come to dominate the landscapes of earth?

   1.
   
   2.
   
   3.

5. In gymnosperms, **where is the**:

   Male gametophyte?
   
   Female gametophyte?

6. **Complete this table about Gymnosperms**

Pollen grains

1. Examine pollen grains from 2 species. For each, place a drop of water on a microscope slide, and then add pollen or swirl an anther in the droplet to release some pollen. Add a cover slip and examine the pollen using the high power (40X) objective of a microscope. Make a drawing of typical grains in the space to the right.

2. A pollen grain represents which life stage?

Angiosperms

1. What are two ways in which Angiosperms differ from Gymnosperms?

2. Complete this table about Angiosperms

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Write in the names of the four groups of plants in the order of their evolution.

<table>
<thead>
<tr>
<th>1: First</th>
<th>2</th>
<th>3</th>
<th>4: Last</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Wood structure

In a previous lab exercise you learned about xylem and phloem cells of plant vascular tissue.

1. What is the function of phloem cells?

2. What is the function of xylem cells?

3. Which one of these transport functions is served by the bulk of a tree trunk?

4. Examine wood sections (prepared slides) for two species under a compound microscope, and identify the characteristics of the wood type for each.

<table>
<thead>
<tr>
<th>Species Name:</th>
<th>have prominent ‘vessel’ type cells</th>
<th>would be classified as a Hard or Soft wood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Draw a diagram of an annual ring as it appears through the microscope from the hardwood species, and label the late wood and early wood.
Other interesting tidbits:

The remarkable sphagnum moss . . .

Sphagnum moss is known for its ability to absorb and hold large amounts of water--four times as much water as cotton can hold. (That’s why natives used Sphagnum in diapers, and why bogs are good natural flood-control areas.) There is something special about the leaf structure (Figure 2) that enables Sphagnum to hold so much water: the photosynthetic cells are restricted to narrow strands surrounding giant clear-looking empty dead cells that have openings that admit water. The walls of the large empty dead cells have reinforcing “ribs” that keep the cells from collapsing.

Peat moss, or "peat," is often added to garden soils to increase the organic content. Peat consists of partially decomposed Sphagnum moss, which accumulates to great depths in wetlands known as bogs from which the peat is "mined." Sphagnum itself is ecologically interesting in the way that it contributes to the bog habitat. The moss secretes acids that lower the pH of the bog water. The acidity decreases the rate of decomposition – some bogs accumulate partially decomposed peat to a thickness of many meters – and reduces the availability of nitrogen. While most plants cannot grow in such a nutrient poor habitat, carnivorous plants (which are angiosperms) occurring in bogs have evolved an interesting way to get additional nitrogen.

Desert Mosses?

Contrary to expectations, some mosses actually grow in the desert, and can survive long periods of time completely devoid of free water. These small mosses form part of the “cryptogamic crust” that forms a brittle layer over desert soils. During the long dry desert summers, these plants (and other microorganisms in the ‘crust’) become almost completely dry, and metabolically dormant. They will reactivate and turn green within minutes of rainfall; taking advantage of the water as quickly as possible.

Not Evergreens?

Those gymnosperms with which you are most familiar are probably the common evergreen conifers of the northern coniferous forests and mixed temperate forests—the pines, firs, spruces, hemlocks, etc. There are also several “deciduous” conifers which drop all their needles in the autumn—the bald cypress of the southeast and larches of the northern woods.