Overview of Lecture: Some things about Plants
see the schedule for reading and watching assignments

The following PREVIEW has been approved for all audiences

Bullet Points:
• land plant abundance, phylogeny & diversity
• photosynthesis - chloroplasts
• Rubisco and world food production
• up in the air: light spectral sensitivity
• shade avoidance
• down in the soil: water, nitrogen-fixing rhizobia mutualists
• games plants and rhizobia play
• alternation of generations: multicellular gametophyte (n)
  multicellular sporophyte (2n)
• Whole Genome Duplication, KNOX and reduction of the gametophyte
• meristems and grasses
• grasses, grazers and human food
• fruit, seed dispersal and propagation
• chemical defenses, pharmaceuticals and spices
Learning Goals:

1. Be able to compare and contrast chloroplasts (plastids) and rhizobia with regard to their: location, function in plant nutrition and level of integration with their plant host/partners. Explain how a plant-rhizobium mutualism might be susceptible to cheating and describe at least one of the important mechanisms plants use to suppress cheating by rhizobia.

2. Be able to use examples from lecture text and/or the video Your Salad Is Trying To Kill You to explain why it was not entirely silly to title the video “Your Salad Is Trying To Kill You”.

3. Be able to explain why/how it is that a major portion of the human food supply is derived from triploid (endosperm) tissues.

4. Be able to explain why many fruits (and some vegetables) have evolved to wrap their precious babies in sugary, carbohydrate-rich packaging. If you bite into a delicious apple and would like to grow more trees that produce that variety, can you just plant the seeds to get the same delicious fruit? Explain.
Billions of years ago, life crossed a threshold. Single cells started to band together, and a world of formless, unicellular life was on course to evolve into the riot of shapes and functions of multicellular life, from ants to pear trees to people.

It's a transition as momentous as any in the history of life …

A single cell's existence is simple and limited. Like hermits, microbes need only be concerned with feeding themselves; neither coordination nor cooperation with others is necessary, though some microbes occasionally join forces. [quorum sensing]

Multicellularity brings new capabilities. Animals gain mobility for seeking better habitat, eluding predators, and chasing prey. Plants can probe deep into the soil for water and nutrients; they can also grow toward sunny spots to maximize photosynthesis. [How can plants be two places at once? – by growing into both places.]
Most of the biomass on earth is plants and most of them live on land:

The biomass distribution on Earth
Yinon M. Bar-On, Rob Phillips, and Ron Milo PNAS May 21, 2018. 201711842
http://www.pnas.org/content/early/2018/05/15/1711842115
An excellent, simple overview:
https://www.youtube.com/watch?v=X4L3r_XJW0I

Also
Watch: Do Plants Think?
Watch: Nitrogen Fixation
Watch: Your Salad Is Trying To Kill You
Optional: Which Came First - Flowers or Bees?
**Plant Diversity:** Land plants evolved from freshwater green algae with many shared, derived traits - adaptations to life on land in air and soil.

The Land Plants are a sister clade of the chara pond weed clade.

Evolutionary innovations for

The Land Plants are a sister clade of the chara pond weed clade.
Photosynthesis (ch 8): Life is powered by sunshine. Every molecular $O_2$ that we breath was once part of two $H_2O$ molecules, liberated by photosynthesis. The captured energy is released from our food and fuel.

Photosynthesis occurs in many bacteria [cyanobacteria] and in chloroplasts [aka plastids] of algae, as well as most plants; chloroplasts are ‘remains’ of ancestral prokaryotic endosymbionts.

**Photosynthesis** uses **light energy** to

2 stages: light rxns + Calvin cycle
1a capturing energy from light (ch 8) w/ photopigment molecules: chlorophylls & carotenoids
1b using the energy to make reducing (electron accepting) NADPH energy-storing ATP
2 the Calvin cycle (ch 8): using ATP & NADPH to synthesize complex organic molecules: sugars: glucose $C_6H_{12}O_6$ → starch, wood, etc.

Rubisco – limiting enzymatic step
Redesigning photosynthesis to sustainably meet global food and bioenergy demand

Population growth … will all require increased agricultural productivity, … [putting us] on a collision course with environmental and sustainability goals.

If agricultural production is to double by 2050, it will require at least a doubling of productivity per hectare …

Alas, growth in productivity of the world’s major crops is stagnating …

[Rubisco is the enzyme that incorporates CO$_2$ into plants during photosynthesis. … is probably the most abundant protein on earth and a major sink for plant nitrogen. … is the ultimate rate-limiting step in photosynthetic carbon fixation.

There is much effort going toward increasing the efficiency of photosynthesis.]

A faster Rubisco with potential to increase photosynthesis in crops

… attempts to replace Rubisco … in plants with the enzymes from cyanobacteria and red algae have not been successful.

We report two tobacco lines with functional Rubisco from cyanobacterium …

Both transformed lines … had higher rates of CO$_2$ fixation per unit of enzyme …

These … lines represent an important step towards improved photosynthesis in plants … [but still far from application]
What is in sunlight that plants can use?

Light is electromagnetic energy, ‘conveniently thought of as’ a wave.
Shorter wavelengths carry greater energy.

Cyanobacteria, green algae & plants use **chlorophyll a** as main photopigment & chlorophyll b and carotenoids as an accessory pigments.

**Fig 8.7** Englemann’s brilliant 1882 experiment w/ aerobic bacteria distributing themselves along spyrogyra algae behind a prism.

Note: carotenoids do not absorb yellow-red.

Leaves look green because chlorophyll does NOT absorb green— it absorbs red and violet.

Light visible to human retinal pigments is a small portion of the solar spectrum.

{birds & insects see down into UV}
Plants have sensory systems and “behavioral” responses: to crowding

Note low ratio of **red/far-red** left in light that has passed through leaves (shade).

Manipulative approaches to testing **adaptive plasticity**: Phytochrome-mediated shade-avoidance responses in plants. Schmitt et al. 1999. AM NAT 154:S43-S54.

Because chlorophyll selectively absorbs red wavelengths, the **ratio of red (R) to far-red (FR) wavelengths** is an accurate signal of vegetation shade ...

Many plants respond to **low R:FR [shade]** with a suite

**Watch:** Do Plants Think?

**bolt - race up high to compete for scarce sunlight vs**

**branch - spread out wide to collect abundant light**
The growth of all organisms depends on the availability of mineral nutrients, and none is more important than nitrogen, which is required in large amounts as an essential component of proteins, nucleic acids, etc.

The earth's atmosphere nearly 79% N₂ gas.

Some bacteria [rhizobia] can “fix” N₂ into ammonia. Other bacteria bring about transformations of ammonia to nitrate. Some of them live independently of other organisms [in soil or water]. Others live in intimate symbiotic associations with plants [in root nodules – legumes and a few other plants] or with other organisms. [in lichens, termite guts etc.] Watch: Nitrogen Fixation

The biochemical mechanism of N₂ fixation can be written in simplified form as follows:

\[
\text{N}_2(a) + \text{ATP} + \text{H}^+ \rightarrow \text{NH}_3 \rightarrow \text{amino acids} \rightarrow \text{proteins} \]

From photosynthesis – up in the sky

Down in the soil/roots - anaerobic
Symbiosis is an ecological interaction in which two or more species exchange mutual benefits ... promotes the fitness of both species. [see: Comparative Advantage and the Benefits of Trade http://www.econlib.org/library/Topics/College/comparativeadvantage.html]

However, symbiotic systems are vulnerable to emerging selfish cheaters that extract benefits from the system without paying costs.
Mutualistic interactions are widespread and obligatory for many organisms, yet their evolutionary persistence in the face of cheating is theoretically puzzling.

Partner-choice \([selectively \text{ interacting with cooperators}]\) is a mechanism for dealing with \([selectively \text{ avoiding}]\) cheaters, and can theoretically allow mutualisms to persist despite cheaters.

Legume roots secrete a variety of (iso)flavonoid \([chemical \text{ signals}]\) which induce genes in bacteria \([to \text{ transcribe-translate chemical responses}]\).
All plants undergo mitosis {cell multiplication} after meiosis {formation of haploid spores}

The multicellular **diploid sporophyte** produces haploid spores, not gametes, by meiosis.

{if you were a plant, would you be a sporophyte, gametophyte or both?}
The closest living relatives of land plants, green algae lack an alternation of generations. Their only organismic \textit{multicellular} generation is a \textit{haploid} gametophyte; \textit{[like moss]} after fertilization and the formation of a diploid zygote, meiosis creates haploid propagules that reestablish new gametophytes. The \textit{multicellular sporophyte} as we know it (such as a leafy fern, pine tree, water lily, and buttercup) is a developmental innovation of land plants. \textit{[alternation of generations w/ multicellular diploid stage is a shared derived trait in plants]} The KNOX2 gene plays a critical role in the development of a \textit{multicellular diploid sporophyte} in land plants.

Gene duplication as a driver of plant morphogenetic evolution
The ancestral algal KNOX gene was duplicated in the lineage leading to land plants. While the resulting \textit{KNOX1} subfamily \textit{regulates} \textit{[diploid]} sporophytic growth, the \textit{[paralogous]} KNOX2 genes evolved to \textit{repress} the haploid-specific \textit{[gametophyte]} body plan …
In terrestrial habitats, the resources that a photosynthetic organism needs are found in two very different places. **Light and carbon dioxide** are mainly aboveground; **water and mineral nutrients** are mainly in the soil. Though plants cannot move from place to place, the elongation and branching of their **shoots** and **roots** allows them to ‘forage’ for resources. *be two places at once*

“I’m trying to decide between water and sunlight.”

“growth isn’t disrupted by grazing or mowing”
Grasses are modern, specialized (derived) flowering plants. Grasses are vascular, flowering seed plants but, most grasses are pollinated by wind, so that their flowers are highly reduced ... All the world's cereal crops are grasses. The top 3 food crops are grasses: corn, wheat, rice.

Grass plants and grazing mammals appeared in the fossil record at the same time in the lower Miocene Epoch about 20 million years ago. {recent!} and have evolved together. [having the apical meristem at the base makes grasses more tolerant of grazing.]

Grasses are well adapted for use in lawns, because their basal meristems (growing points) are not lost with mowing. {or grazing, or burning - used in prairie restoration}
Double fertilization:

1. of 1n egg: to form diploid 2n zygote — "germ"

2. of 2n double haploid cell: triploid 3n endosperm

Endosperm (3n) is the bulk of cereal grains (grasses: corn, wheat, rice, barley) which directly or indirectly (meat, beer) provide most human nutrition. [meant to feed embryo]

Beans have converted 3n endosperm into 2n embryo.

How much triploid endosperm have you eaten today?

Vascular Flowering Seed Plants – Angiosperms ~90% of all land plants

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**Fruits** are mature ovaries that contain seeds (Fig 30.20)

If you find a tastee new mutant variety of apple, can you plant the seeds to propagate the variety? How do we propagate new varieties, like honeycrisp?

**Pomes** - include: apples, pears & quinces. The core is the ovary (maternal) with seeds (partly recombinant w/ dad genes), and the rest (the tastee part) is overgrowth of receptacle (maternal only).
Plant Manipulation
Many plants have ripe, fleshy, coloured fruit in order to attract animals that will eat them and then disperse their seeds in droppings. However, the chilli plant has developed another way of ensuring its seeds are spread far and wide.

What raises the roof of your mouth when you eat a chilli is a substance called capsaicin. This stimulates the areas of the skin and tongue that normally sense intense heat and pain, falsely telling the brain that the area affected is burning.

New research has discovered that this characteristic peppery taste repels certain animals – which are no good at dispersing the seeds.

Seed dispersal – Directed deterrence by capsaicin in chillies.
Tewksbury & Nabhan 2001 Nature 412:403-404

Digestion And Dispersal
... scientists observed ... animals living around a group of wild-growing chillies in Arizona. ... desert mice and rats avoided spicy chillies, but birds fed almost exclusively on the plants.

... seeds pass through a birds’ digestive systems very quickly and come out unharmed, whereas in mice, rats and other mammals, the seeds don’t make it out in one piece ...

The researchers suggest that chilli plants have evolved to produce capsaicin as a repellent for animals – whilst still allowing birds to eat their seeds.

Molecular basis for species-specific sensitivity to "hot" chili peppers.
{the vanilloid receptor subtype 1 (VR1)}
Ch 39: Plants have evolved a variety of **defensive mechanisms** to reduce damage from attack by viruses, bacteria, fungi, animals and other plants.

Plants have (or induce) **toxins** to poison herbivores, *Watch: Your Salad Is Trying To Kill You*

Herbal & folk medicines exploit these, including for disease control: ex: quinine & taxol

**Ethnobotany/ethnopharmacology** and mass bioprospecting:
Issues on intellectual property and benefit-sharing
Soejarto et al. 2005
*J. Ethnopharm* 100:15-22

**Spices – tickle tongue & kill pathogens!**

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### Table 39-1  Secondary Metabolites

<table>
<thead>
<tr>
<th>Compound</th>
<th>Source</th>
<th>Structure</th>
<th>Effect on humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphine</td>
<td>Opium poppy</td>
<td></td>
<td>Narcotic pain killer</td>
</tr>
<tr>
<td>Quinine</td>
<td>Quinine bark</td>
<td></td>
<td>Antimalarial drug</td>
</tr>
<tr>
<td>Taxol</td>
<td>Pacific Yew</td>
<td></td>
<td>Anticancer drug</td>
</tr>
<tr>
<td>Genistein</td>
<td>Soybean</td>
<td></td>
<td>Estrogen mimic</td>
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<tr>
<td>Manihotin</td>
<td>Cassava</td>
<td></td>
<td>Metabolized to release lethal cyanide</td>
</tr>
</tbody>
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Watch: Your Salad Is Trying To Kill You