Teacher Background: Grassland Evolution

What distinguishes grasses from other plants?

(1) Modern plants use one of 3 photosynthetic pathways: C4, C3 and CAM to capture carbon.

C3	Trees, shrubs, some grasses	Adapted to higher CO2, cooler temps, wetter climate Prefer precipitation during cold season.
C4	Over 50% of all modern grasses.	Can tolerate lower CO2, higher temps, less moisture Prefer precipitation during warm season.
CAM	Succulents, cacti	CAM pathway seen in highly drought resistant plants.

(2) Many grasses today use the C4 pathway to capture carbon.

About 20 million years ago**, plants living in hotter, drier climates evolved a new method of capturing energy from the sun: C4 photosynthesis**. Because C4 plants obtain carbon in a different way, they record a different carbon isotopic signature and thus leave a record in the fossil record.

C4 photosynthesis evolved at least 12-20 different times in separate plant lineages.

Grasses today comprise 40% of the Earth's vegetative surface cover.

(3) Grasses are more difficult for herbivores to eat than other plants. Grasses have a higher abundance of silica phytoliths in their plant tissues and cells than other plants, which cause abrasive wear on teeth.

C4 grasses account for over 50% of the world's present-day species of grass.

C4 grasses have considerably higher amounts of silica protoliths than C3 grasses.

When and why do grasslands first evolve?

Large-scale climactic drying and cooling occurred on both global and regional scales in the Oligocene (20-30 million years ago). **Increased aridity, as well as changes in precipitation caused plants to evolve to take advantage of new climates**. Fragmenting forests enabled the spread of open savannas and grasslands.

Why did the C4 pathway evolve?

At the same time we see rise in C4 plants in the fossil record, we see a decline in the abundance of water-loving species like palms.

C4 plants can better tolerate cooler, drier climates.

Why did C4 grasses become dominant?

Today, **74% of grass communities in the North American Great Plains contain greater than fifty-percent C4 grasses**. That percentage is even higher (40-80%) in Kansas and Nebraska.

C4 grasses first appear in the fossil record 20 million years ago. Not until over 15 million years later do C4 grasses become dominant (comprising over 50% of grassland composition).

Note: **The first grasslands were dominated by C3 grasses.** Climate changes favored the expansion of C4 grasses *after* grasslands had developed and spread 15 million years earlier. At their rise to dominance 3 million years ago, it is believed that C4 grasses mainly replaced C3 grasses in existing grasslands.

Environmental change is a major driver in ecosystem composition. The paleontological record records the expansion and eventual ecological dominance of C4 grasses in the Great Plains of North America.

Teacher Background: Climate and Ecosystem Change

Paleoclimatology: The study of how Earth's climate has changed in the past. Scientists study a variety of fossil evidence to give clues to the past climate: changes in fossil plankton preserved in seafloor sediments, fossil pollen records in lakes, the chemistry of oxygen and carbon isotopes in ice cores.

The **terrestrial fossil record** preserves information about the behavior and adaptations of now extinct animals in Earth's past. Oftentimes, contextual information derived from the **geologic rock record** is as important in providing information as classifying and describing fossilized specimens. **Modern paleontology** relies heavily on tracing the chemistry of elements such as carbon and oxygen preserved in fossil bones, teeth and sediments.

Paleontologists study the fossil record to understand the diversity of life that existed on our planet in the past, and how that diversity has changed over time due to changing climates and environments.

Timeline of Climate and Ecosystem Changes (30 Million Years to Present)

> *Teacher Note: The following list of information was compiled directly from primary scientific literature, to give a sense of the types of evidence used by paleontologists to make hypotheses about the past.*

32-30 Ma (early Oligocene): C4 pathway first developed (originating at least 12- 20 different times in various plant families), perhaps as a result of fluctuations in atmospheric CO_2. (Christin et al. 2008, Edwards and Smith 2010)

23 Ma (late Oligocene): Grasslands dominated by C3 grasses spread. C4 grasses comprised ~10-20% of grassland composition. (Evidence of carbon isotopes measured in soil carbonates, Fox and Koch 2003, 2004)

19 Ma (early Miocene): C4 grasses present in early grasslands in the Great Plains. (Evidence from diagnostic phytolith morphology, Stromberg 2005)

15-5 Ma (mid-late Miocene): Plant fossil record shows habitats in North America varied in openness. (Stromberg 2011)

10 Ma: Hoofed mammals (ungulates) show tooth morphology specific to grazing adaptations. (Gordon, Prins 2007).

7 million years ago: grasslands shifted from being dominated by C3 to C4 grasses (McFadden 2005)

8-2 Ma (Late Miocene/early Pliocene): The ecological dominance of grasslands and savannas (>50% ? of habitats) in Great Plains of North America. Habitats became more uniformly open (grasslands/savannas). Stromberg et al. argues that this C4 expansion comes at the expense of C3 *grasses* not necessarily trees and shrubs. Evidence from phytoliths records a shift in the *type* of grasses present but not necessarily the relative size of *grassland habitat.* (Carbon isotopes phytoliths from NE and KA, Stromberg 2011)

3 Ma (Pliocene): Carbon isotopes in fossil soil carbonates record the abundance of C4 plants greater than 40%. (Fox and Koch 2003, 2004)

0 Ma (Present day): 74% of grasslands are dominated by greater than 50% C4 grasses, with higher percentage (40-80%) in the prairies of NE and KA. (Gibson 2009)