An aerial photograph of a lush, green landscape. In the foreground, a small, dark pond is visible, surrounded by dense forest. The middle ground is filled with rolling hills covered in thick green trees. In the background, a flat expanse of land stretches towards the horizon under a clear sky. The overall scene is a natural, undisturbed environment.

# Long Term Ecological Research at Cedar Creek Minnesota, USA

Dr. Sarah Hobbie

Department of Ecology, Evolution and Behavior  
University of Minnesota  
St. Paul, Minnesota, USA



A photograph of a dirt path leading through a lush green forest. The path is made of brown earth and is flanked by tall grass and various green plants. The trees are mostly deciduous with vibrant green leaves, creating a dense canopy overhead. The lighting is soft, suggesting a slightly overcast day. The path leads from the foreground into the distance, disappearing into the woods.

# Outline

- Natural history of Cedar Creek Ecosystem Science Reserve
- Overview of Cedar Creek Long Term Ecological Research (LTER) program
- Focus on global change research
- Long-term research during a pandemic



# Minnesota, USA





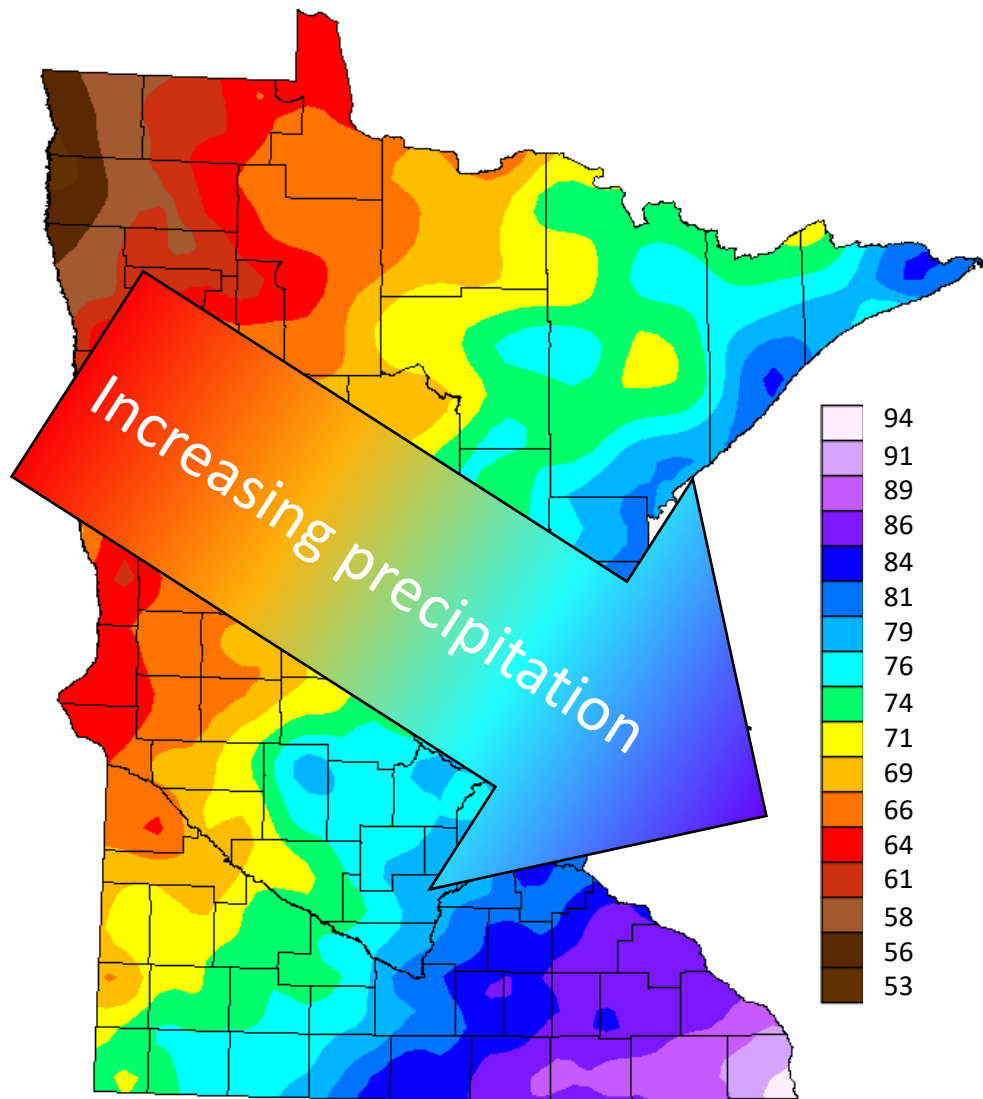
An aerial photograph of the Cedar Creek Ecosystem Science Reserve. The image shows a large, light blue lake in the upper portion, surrounded by dense green forests. Below the lake, there is a large, irregularly shaped green field with scattered trees and a small, dark blue pond. The foreground is dominated by a dense forest of green trees. The text "Cedar Creek Ecosystem Science Reserve" is overlaid in white on a semi-transparent dark band across the middle of the image.

# Cedar Creek Ecosystem Science Reserve

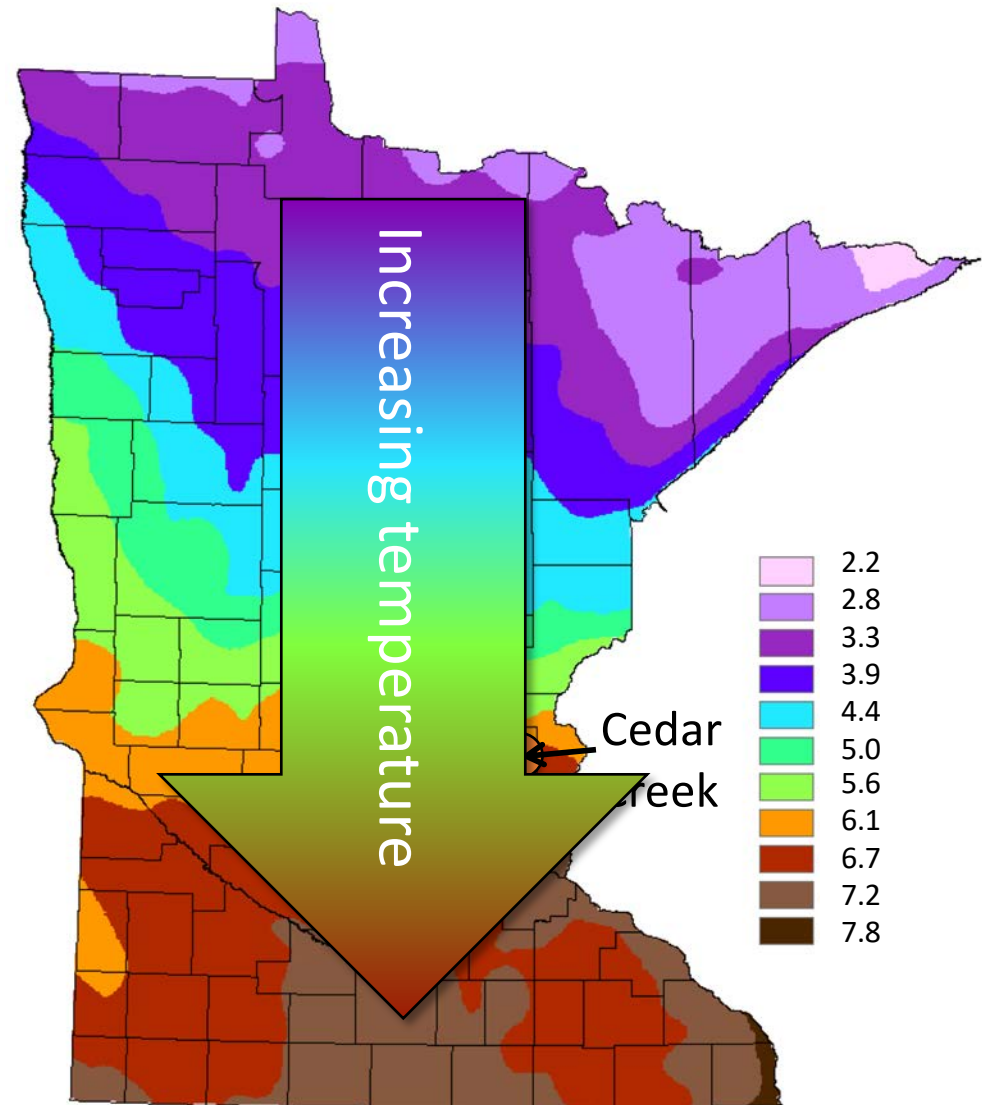
- Established in 1942
- 2100 hectares
- 50 km north of Minneapolis-St. Paul, Minnesota



# Minnesota climate (1981-2010)



Mean annual precipitation (cm)



Mean annual temperature (°C)



# Minnesota biomes





# Plants of Cedar Creek



Boreal conifer forest



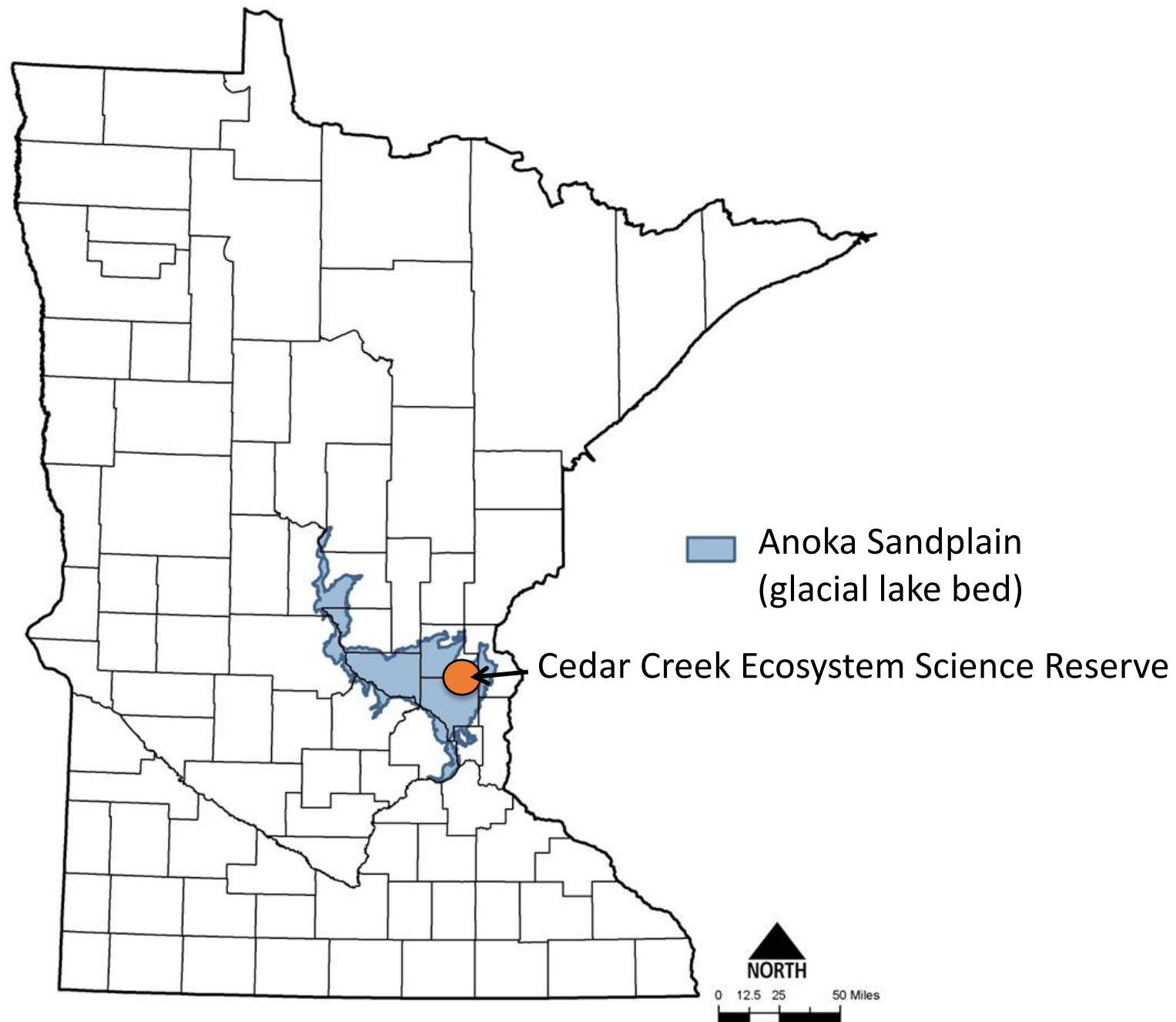
Temperate prairie grassland



Temperate deciduous forest



# Cedar Creek geology



Source: Minnesota Department of Natural Resources





## Cedar Creek soils

- extremely sandy ( $\approx 90\%$ )
- low in organic matter
- well drained
- low in nitrogen
- shallow water table



# Upland habitats of Cedar Creek

Jacob Miller



*Quercus* savanna and sand prairie



Dry *Quercus* forest

Jacob Miller



Mesic *Acer-Tilia* forest

Jacob Miller



Abandoned agricultural “old” fields



# Wetland habitats of Cedar Creek



Open wetlands



Wooded swamps



The background of the slide is a photograph of a dirt path that leads into a lush, green forest. The path is made of light-colored soil and is flanked by dense vegetation and tall trees with vibrant green leaves. The scene is captured from a low angle, looking down the path towards the distance. A semi-transparent dark green rectangular box is overlaid on the upper half of the image, serving as a background for the text.

# Outline

- Natural history of Cedar Creek Ecosystem Science Reserve
- Overview of Cedar Creek Long Term Ecological Research (LTER) program
- Focus on global change research
- Long-term research in a pandemic



## U.S. LTER Sites 2017



## US Long-Term Ecological Research (LTER) Program

- Funded by the National Science Foundation
- 28 sites in network
- 6-year funding cycle for individual sites
- Cedar Creek LTER funded since 1982





# Cedar Creek LTER Investigators



Sarah Hobbie, co-lead   Eric Seabloom, co-lead



Elizabeth Borer   Jeannine Cavender-Bares   Forest Isbell   Peter Kennedy   Linda Kinkel



Rebecca Montgomery   Caitlin Potter   Peter Reich   David Tilman



An aerial photograph of a vast, green landscape. A winding road cuts through the terrain, which is covered in dense vegetation and patches of open land. In the distance, rolling hills and a clear sky are visible.

# Cedar Creek Long-Term Ecological Research (LTER) Program

*Overarching research question:*  
How do multiple environmental changes interact to affect ecological systems across biological, spatial, and temporal scales?



# Theory, experiments, and observations





An aerial photograph of a lush green landscape. The terrain is covered in dense grass and scattered trees, some of which are tall and dark green. A thin, light-colored line, possibly a fence or a path, runs diagonally across the middle of the image. The overall scene is bright and vibrant, suggesting a healthy ecosystem.

# Research Theme: Nutrient Enrichment

## Example Research Questions:

- How do nutrients structure ecosystems?
- How do communities and ecosystems recover from nutrient enrichment?
- How do effects of nutrients compare to effects of consumers (“bottom-up” vs. “top-down” effects)?



# Research Theme: Biodiversity

## Example Research Questions:

- How does biodiversity influence
  - the stability of communities?
  - ecosystem processes?
  - ecosystem response to global change?





# Research Theme: Interactions between Disturbance & Consumers

## Example Research Questions:

- How does fire frequency alter communities and ecosystems?
- How does grazing by bison affect plant community response to fire?



An aerial photograph of a rural landscape. In the foreground, there's a dirt road curving through green fields. A small pond is visible in the middle ground. The background is filled with dense green trees under a clear blue sky.

# Research Theme: Interactions among Multiple Environmental Change Drivers

## Example Research Questions:

- How do different global change drivers interact to influence communities and ecosystems?



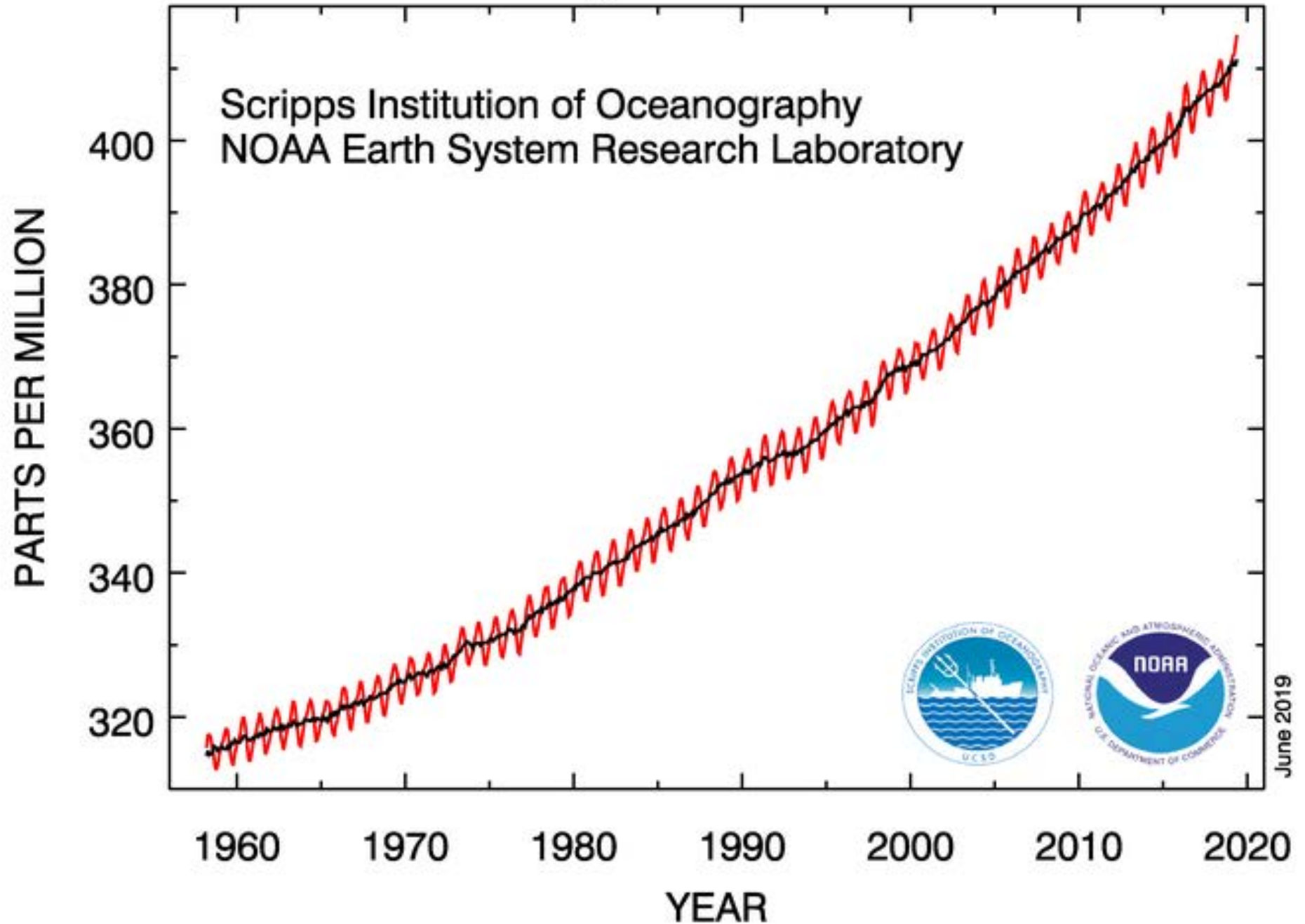
A photograph of a dirt path leading through a lush green forest. The path is made of brown earth and is flanked by tall grass and various green plants. The trees are mostly deciduous with vibrant green leaves, creating a dense canopy overhead. The lighting is soft, suggesting a slightly overcast day. The overall scene is peaceful and natural.

# Outline

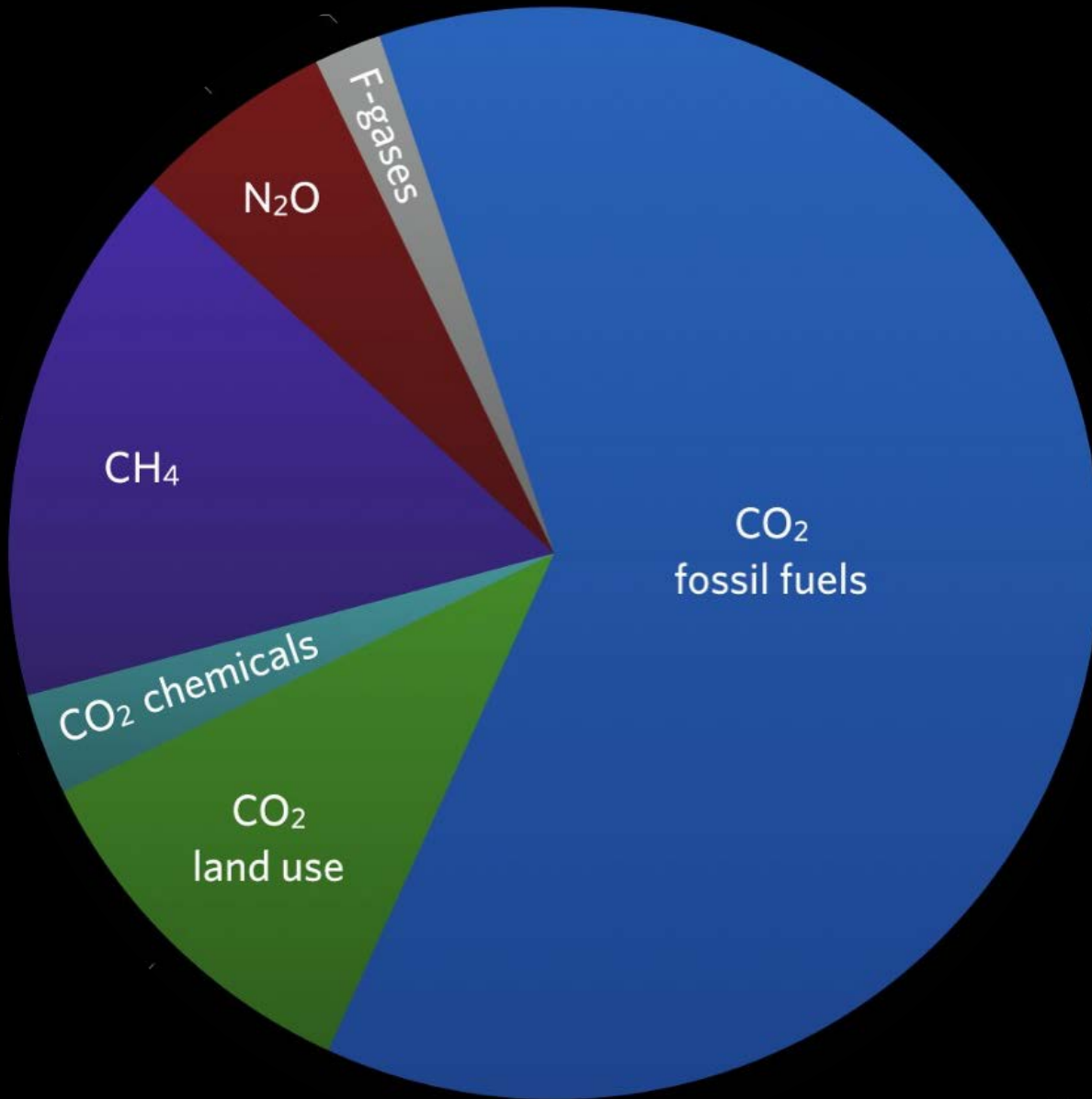
- Natural history of Cedar Creek Ecosystem Science Reserve
- Overview of Cedar Creek Long Term Ecological Research (LTER) program
- Focus on global change research
- Long-term research in a pandemic



# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory







# Greenhouse Gas Emissions

by major gas

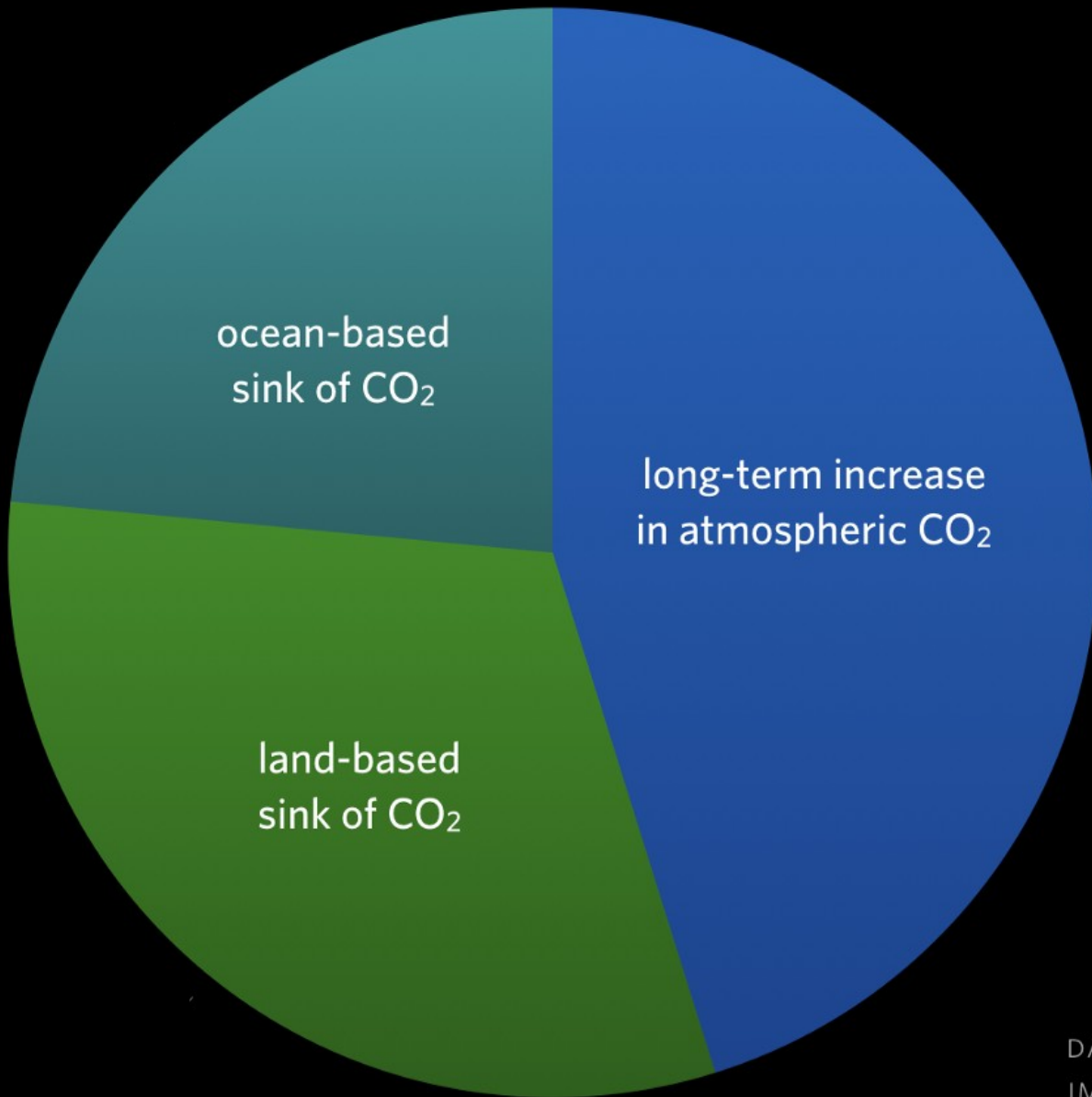
(non-CO<sub>2</sub> gases converted with their equivalent "global warming potential")

DATA FROM EPA

IMAGE BY J. FOLEY, PROJECT DRAWDOWN

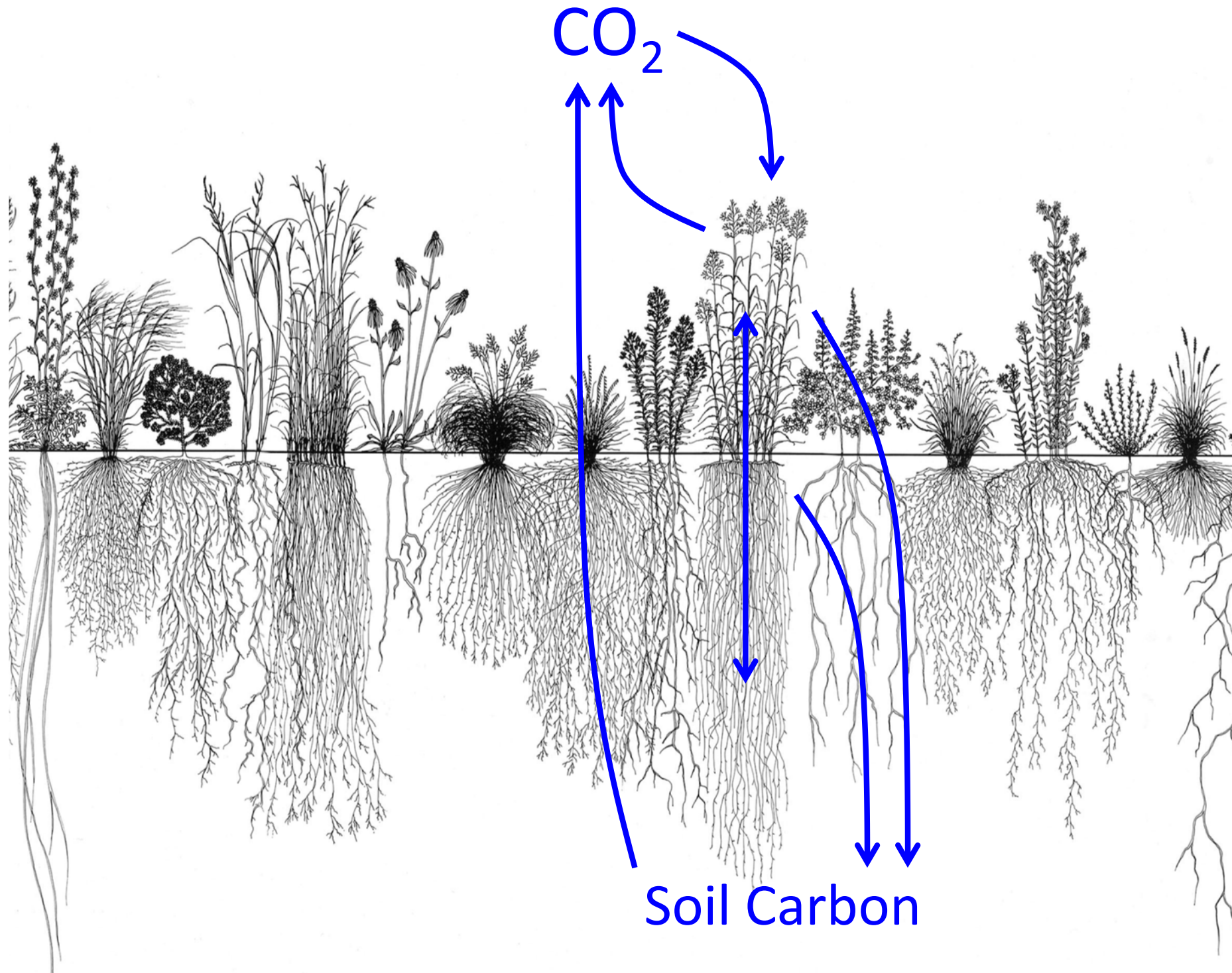


# Fate of Carbon Dioxide Emissions

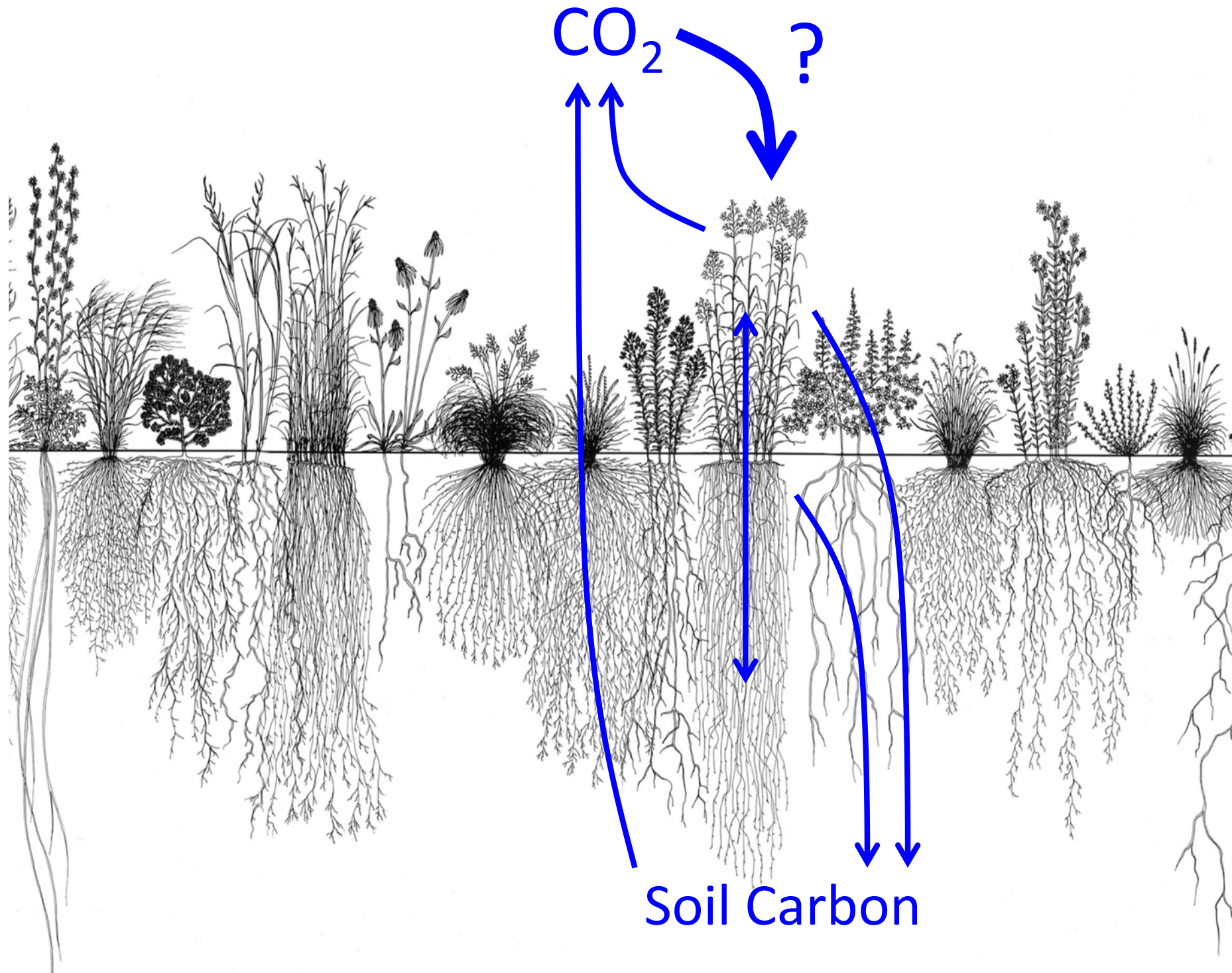


DATA FROM [GLOBALCARBONPROJECT.ORG](https://globalcarbonproject.org)  
IMAGE BY J. FOLEY, PROJECT DRAWDOWN



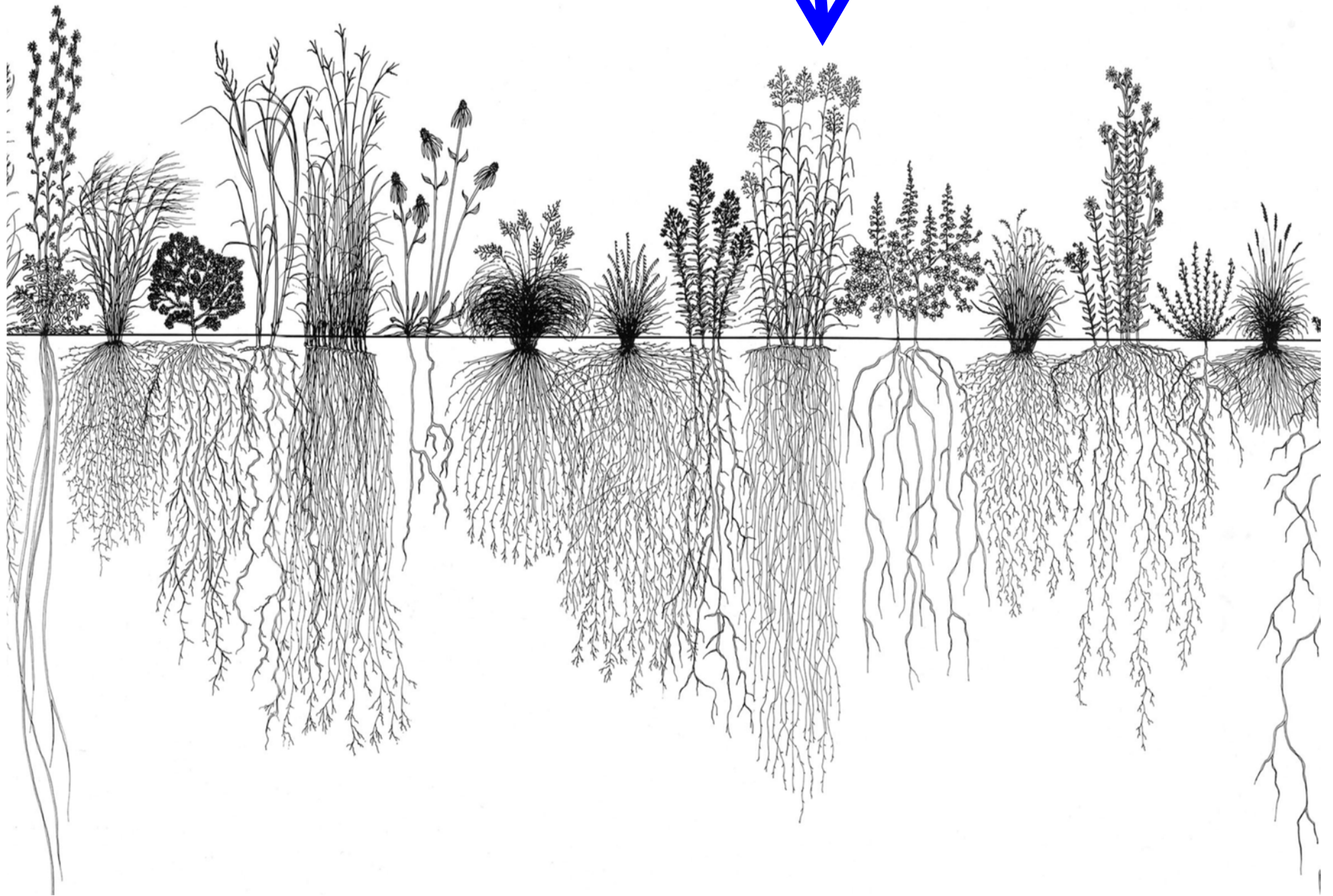








$\text{CO}_2$  ?





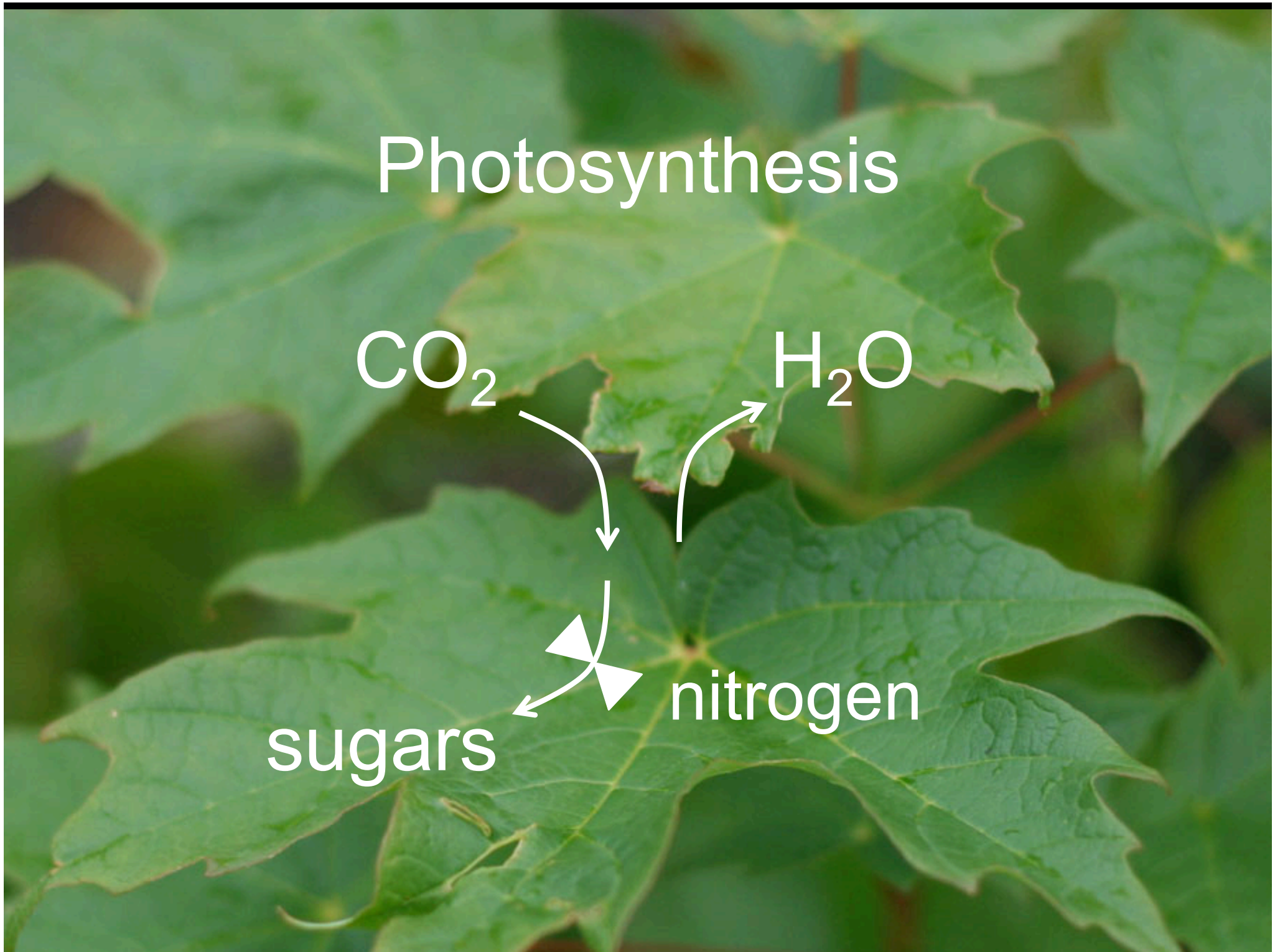
# Photosynthesis

$\text{CO}_2$

$\text{H}_2\text{O}$

sugars

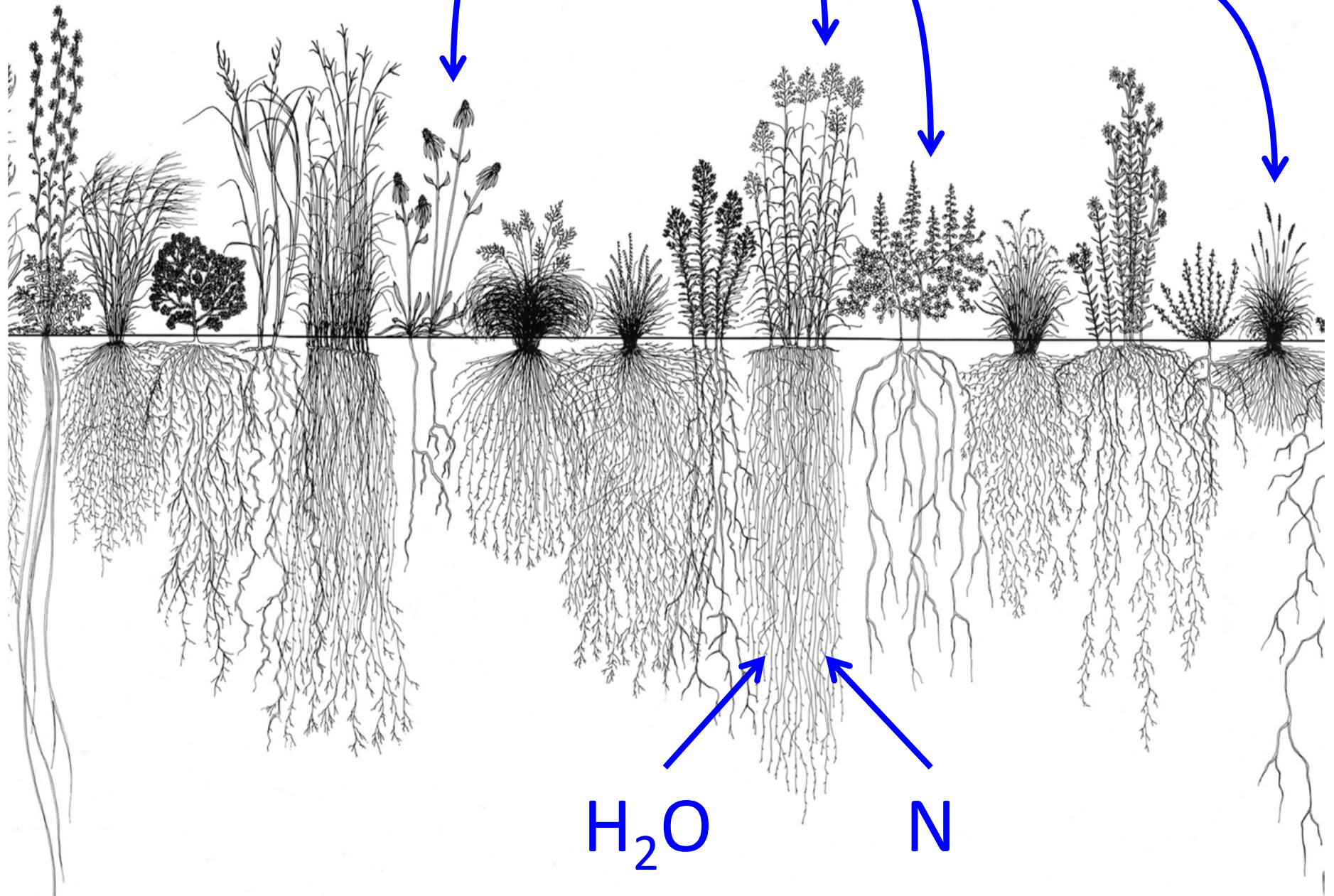
nitrogen





Warming

$\text{CO}_2$



$\text{H}_2\text{O}$

$\text{N}$



# Motivating Questions:

- How does plant response to elevated CO<sub>2</sub> depend on:
  - belowground resource supply?
  - plant species composition and diversity?
  - climate warming?



Peter Reich



Melissa Pastore



Tali Lee



Kally Worm



# BioCON

## Biodiversity, CO<sub>2</sub>, Nitrogen

- Planted in 1997
- 296 2x2 m plots





# Biodiversity

- 0, 1, 4, 9, 16 perennial plant species
- Four plant “functional groups”





# BioCON Functional Groups



legume

*Amorpha canescens*  
*Lespedeza capitata*  
*Lupinus perennis*  
*Petalostemum purpureum*



forb

*Achillea millefolium*  
*Asclepias tuberosa*  
*Anemone cylindrica*  
*Solidago rigida*



C<sub>3</sub> grass

*Agropyron repens*  
*Bromus inermis*  
*Koeleria cristata*  
*Poa pratensis*



C<sub>4</sub> grass

*Andropogon gerardii*  
*Boutelous gracilis*  
*Shizachyrium scoparium*  
*Sorghastrum nutans*



CO<sub>2</sub>

- FACE (Free Air CO<sub>2</sub> Enrichment) technology
- 6 20-m diameter FACE rings
- 3 ambient rings, 3 +180 ppm rings
- Growing season only









# Nitrogen

- Ambient, +4 g m<sup>-2</sup> y<sup>-1</sup> as ammonium nitrate





# TeRaCON

## Temperature, Rainfall, CO<sub>2</sub>, Nitrogen

- Established in 2007 (rainfall) and 2012 (temperature)
- 48 plots, all planted with 9 species





# Temperature

- Infra-red heat lamps, soil heating rods
- Ambient temperature, +2.6°C surface + soil warming
- Growing season only





# Rainfall reduction

- Temporary rainout shelters
- Ambient rainfall, -40% rainfall events
- Growing season only





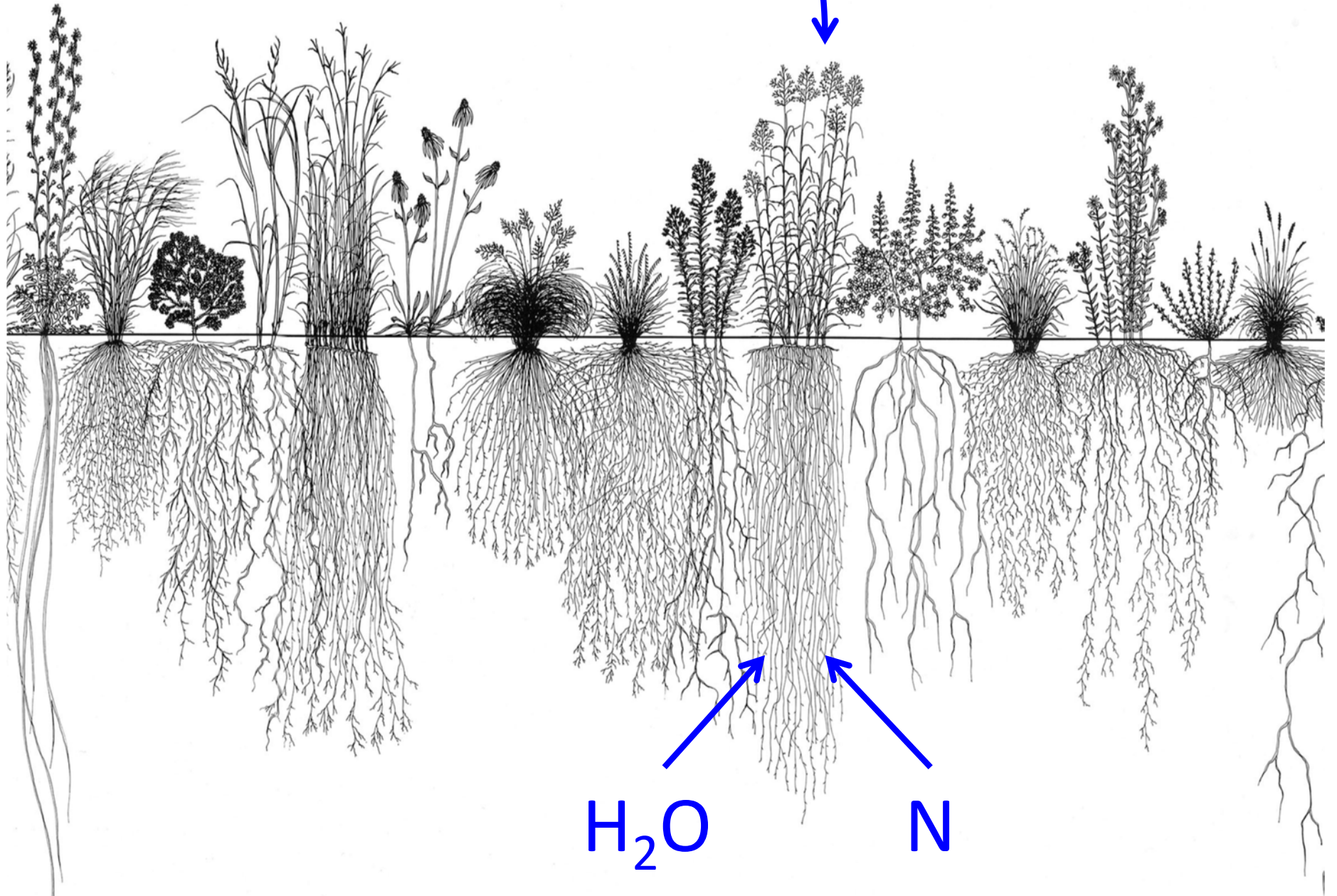
# Motivating Questions:

- How does plant response to elevated CO<sub>2</sub> depend on:
  - belowground resource supply?
  - plant species composition and diversity?
  - climate warming?





$\text{CO}_2$



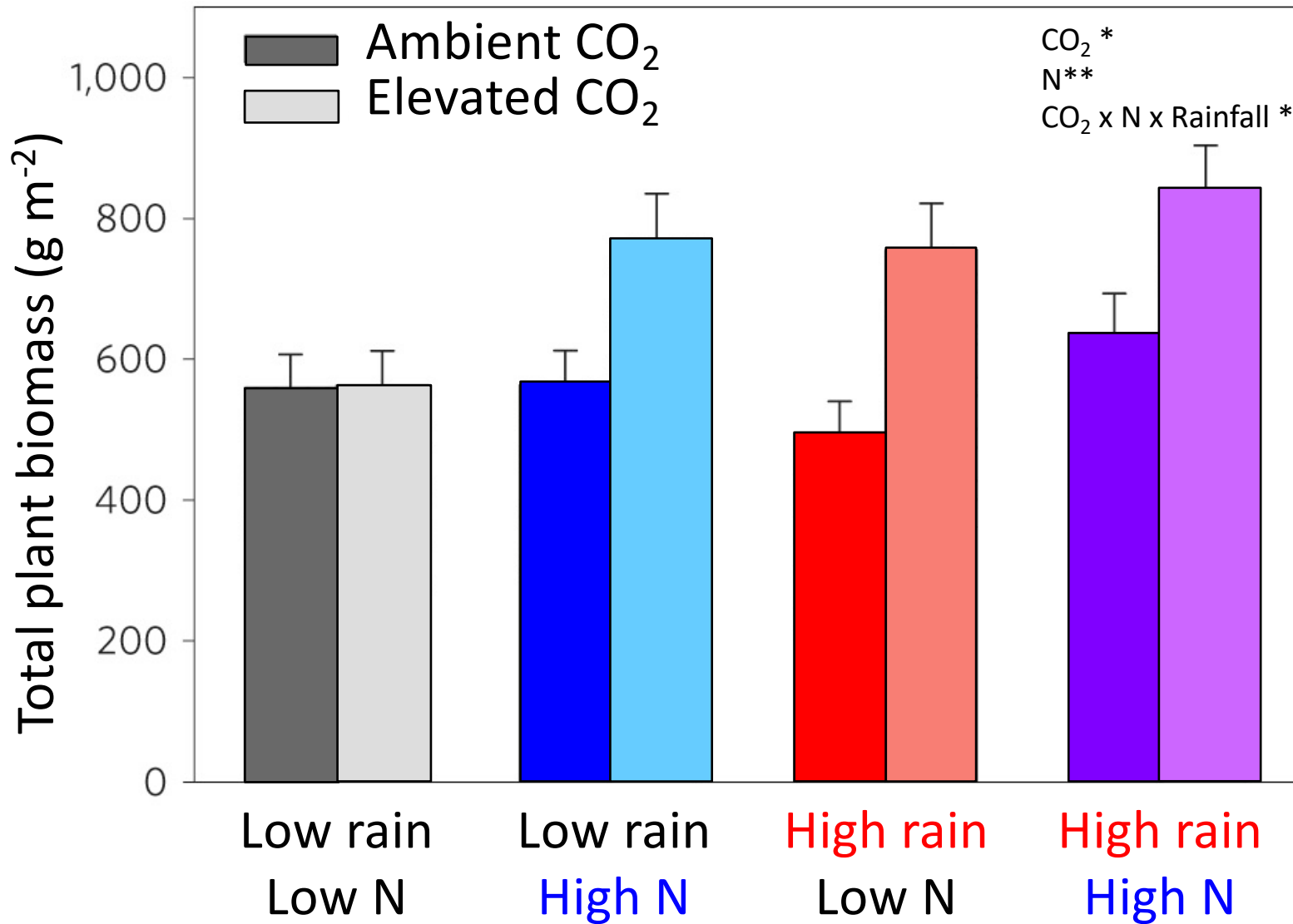
$\text{H}_2\text{O}$

N





# N and H<sub>2</sub>O constrain how plant growth respond to elevated CO<sub>2</sub>





# Motivating Questions:

- How does plant response to elevated CO<sub>2</sub> depend on:
  - belowground resource supply?
  - plant species composition and diversity?
  - climate warming?





# Comparison of monoculture and 4-species plots containing single functional groups



legume

*Amorpha canescens*  
*Lespedeza capitata*  
*Lupinus perennis*  
*Petalostemum purpureum*



forb

*Achillea millefolium*  
*Asclepias tuberosa*  
*Anemone cylindrica*  
*Solidago rigida*



C<sub>3</sub> grass

*Agropyron repens*  
*Bromus inermis*  
*Koeleria cristata*  
*Poa pratensis*



C<sub>4</sub> grass

*Andropogon gerardii*  
*Boutelous gracilis*  
*Shizachyrium scoparium*  
*Sorghastrum nutans*



# Hypothesized functional group responses to elevated CO<sub>2</sub>

Relative biomass or photosynthetic response



legume



forb



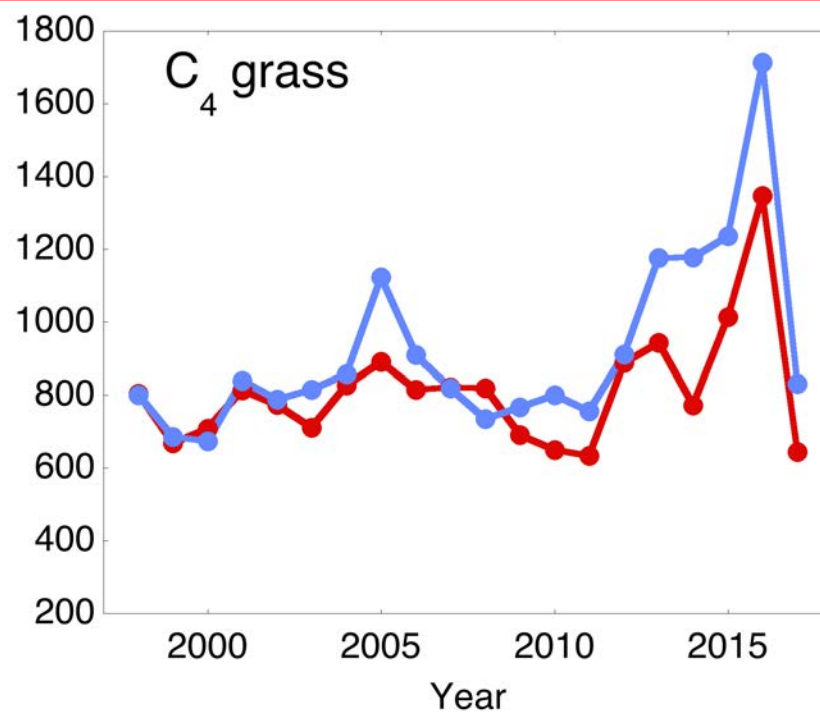
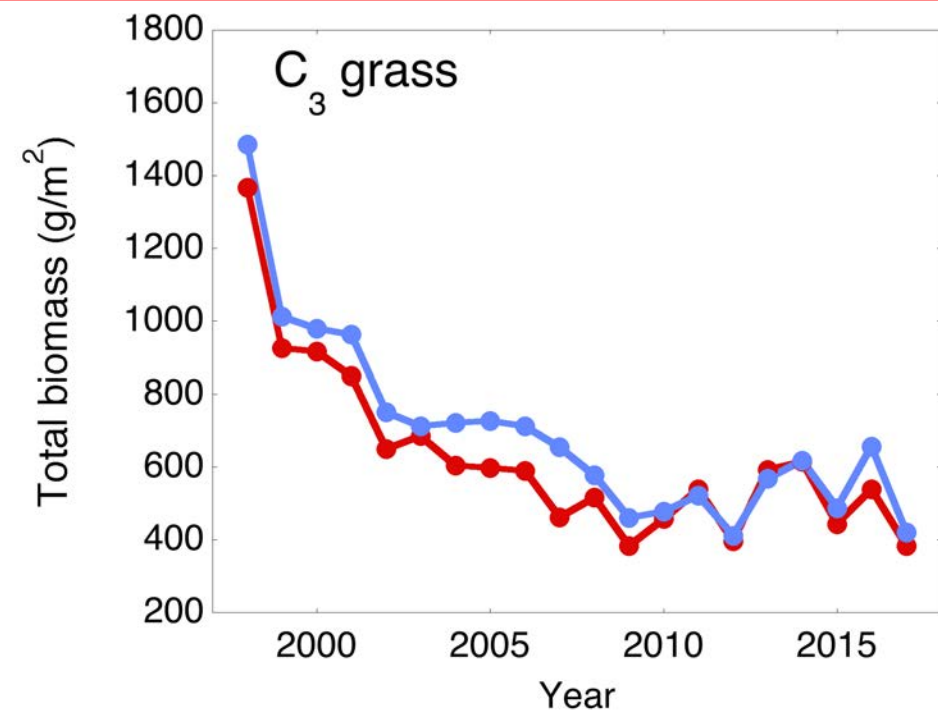
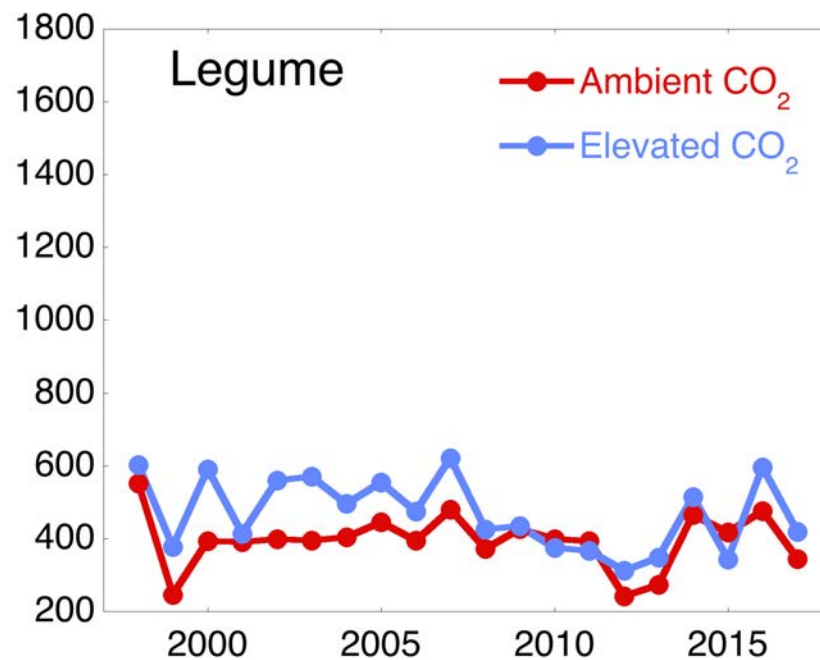
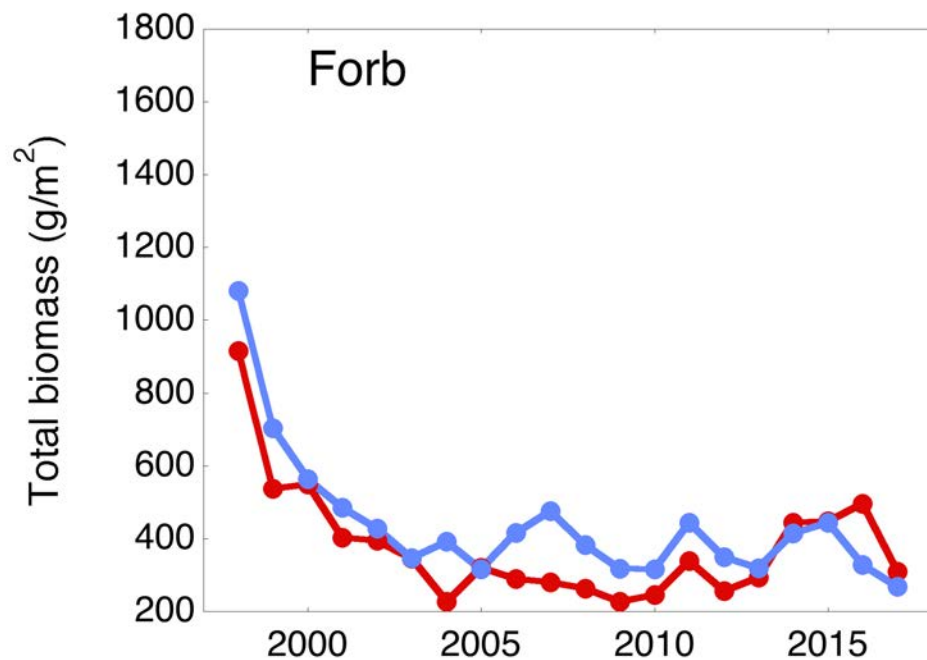
C<sub>3</sub> grass



C<sub>4</sub> grass

Functional group







# Theoretical predictions based on physiology



$C_3$  grass

Photosynthesis  
should increase  
with rising  $CO_2$

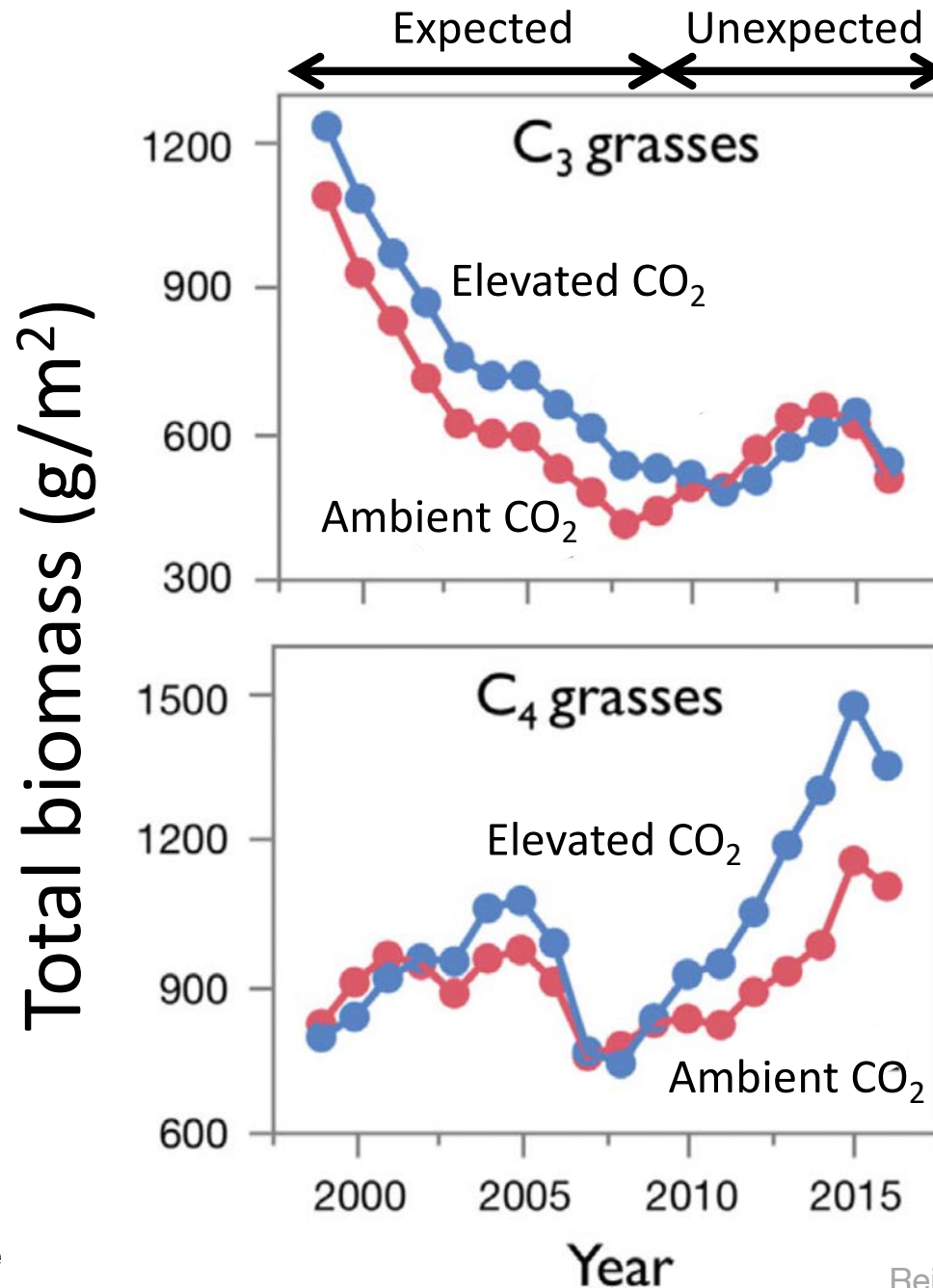


$C_4$  grass

Photosynthesis  
saturated at  
current  $CO_2$



# Unexpected reversal of CO<sub>2</sub> effects on C<sub>3</sub> and C<sub>4</sub> grasses over time



3-year running average

Reich, Hobbie, Lee, and Pastore 2018 *Science*



# Why the shift over time in CO<sub>2</sub> effects on C<sub>3</sub> and C<sub>4</sub> grasses?



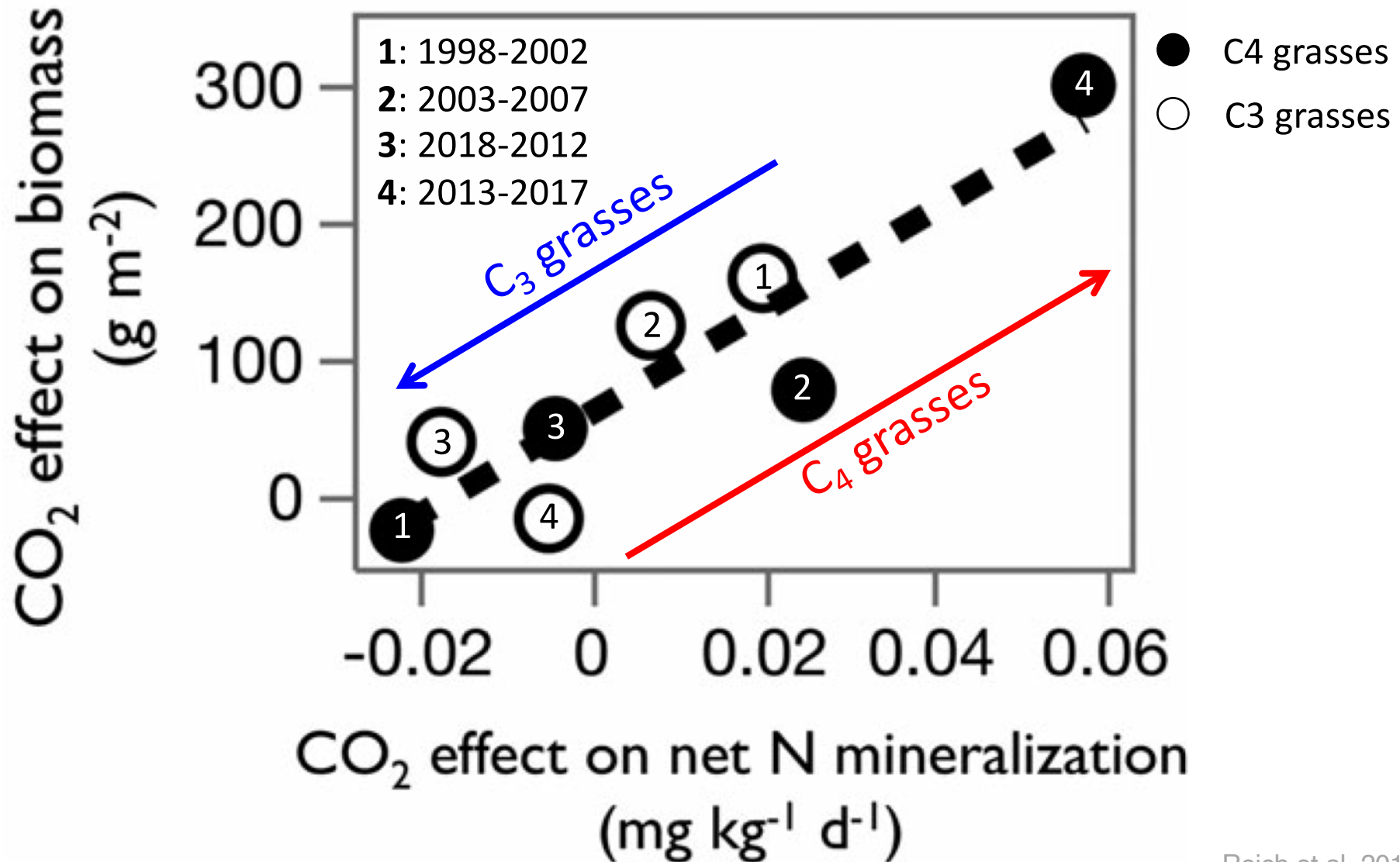
C<sub>3</sub> grass



C<sub>4</sub> grass



CO<sub>2</sub> effects on biomass are related to CO<sub>2</sub> effects on N supply





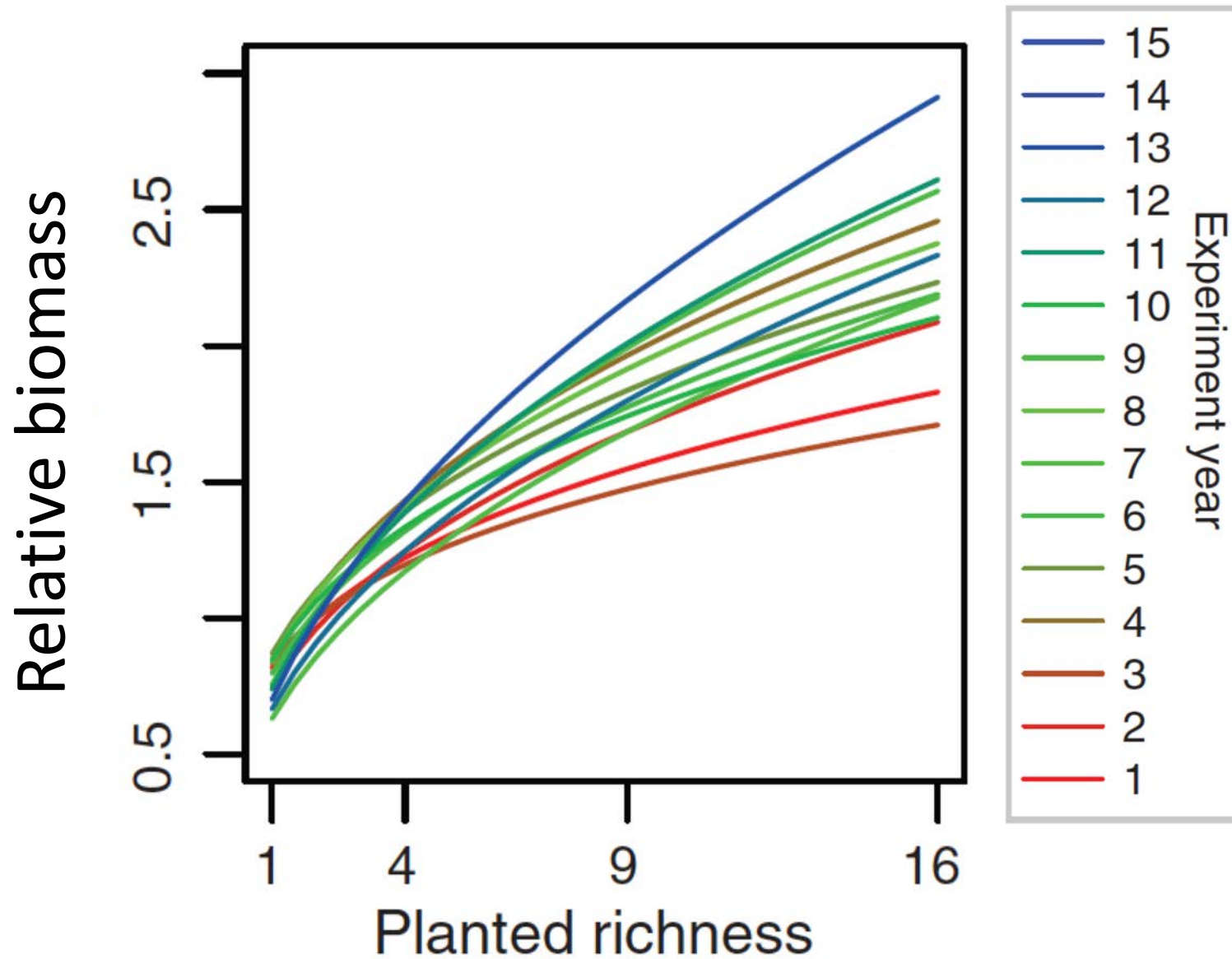
# Biodiversity

- 1, 4, 9, 16 perennial plant species



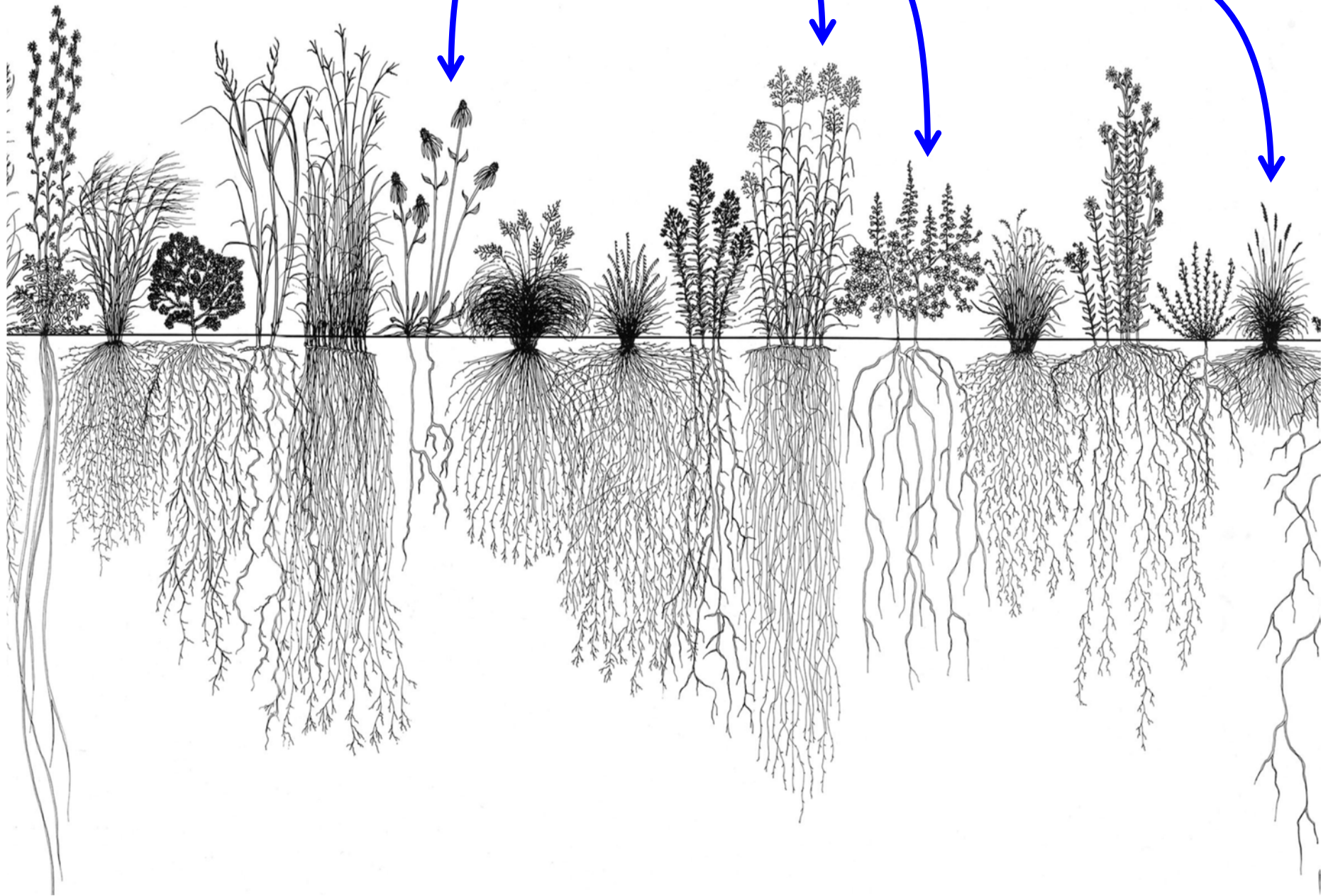


Diversity effects on biomass have increased over time



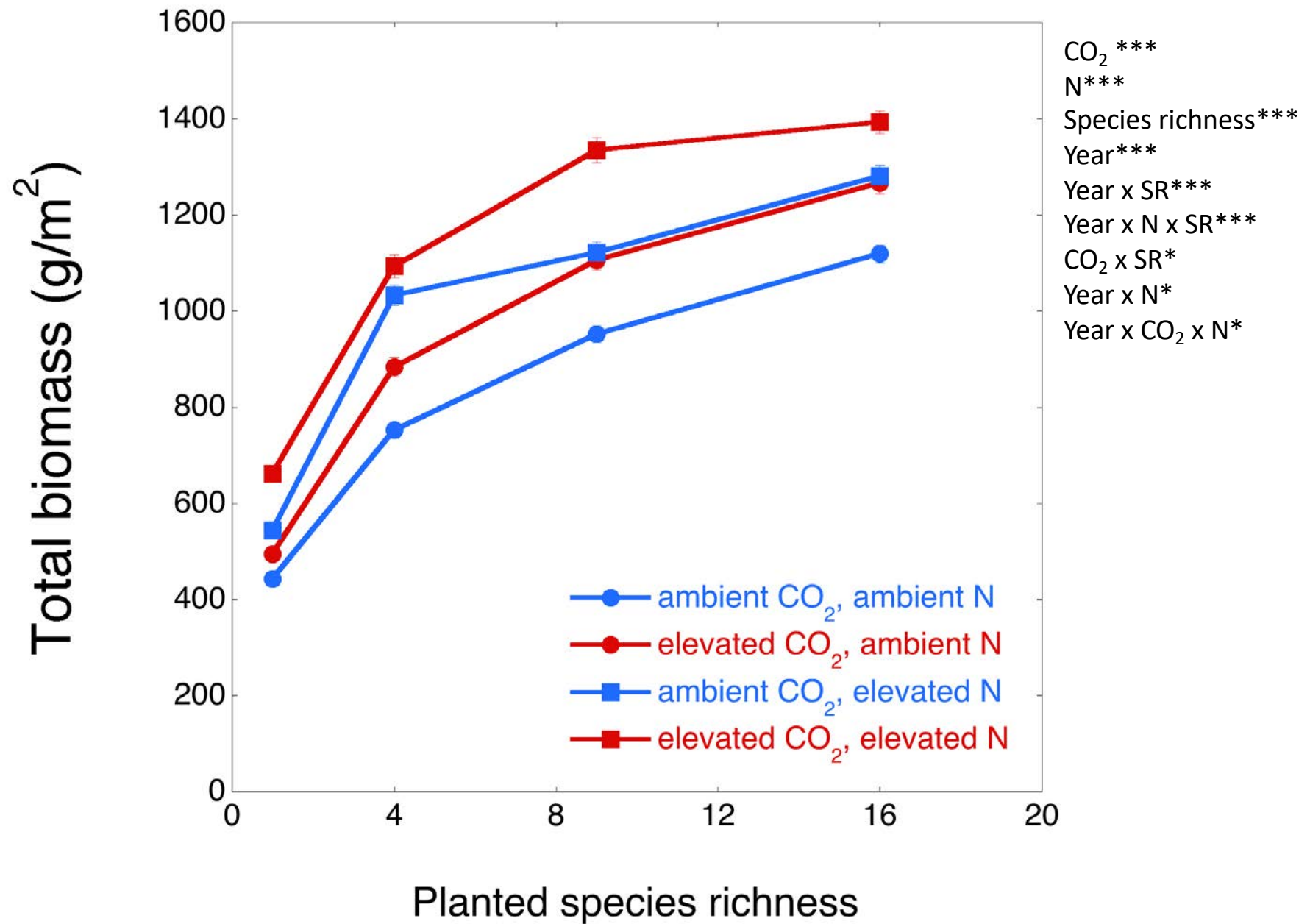


CO<sub>2</sub>





# Elevated CO<sub>2</sub> effects on biomass are larger in more diverse plots





# Motivating Questions:

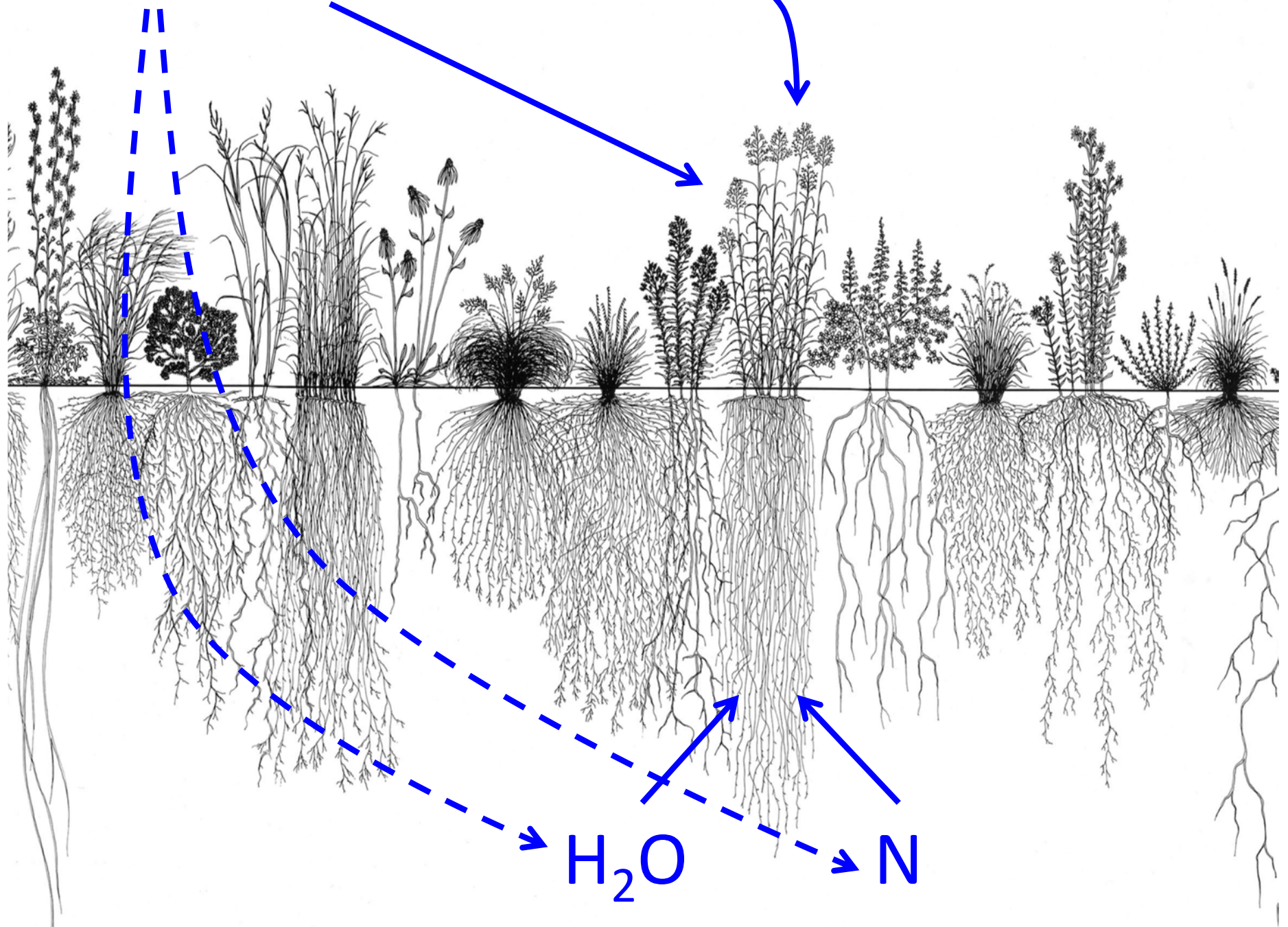
- How does plant response to elevated CO<sub>2</sub> depend on:
  - belowground resource supply?
  - plant species composition and diversity?
  - climate warming?





Warming

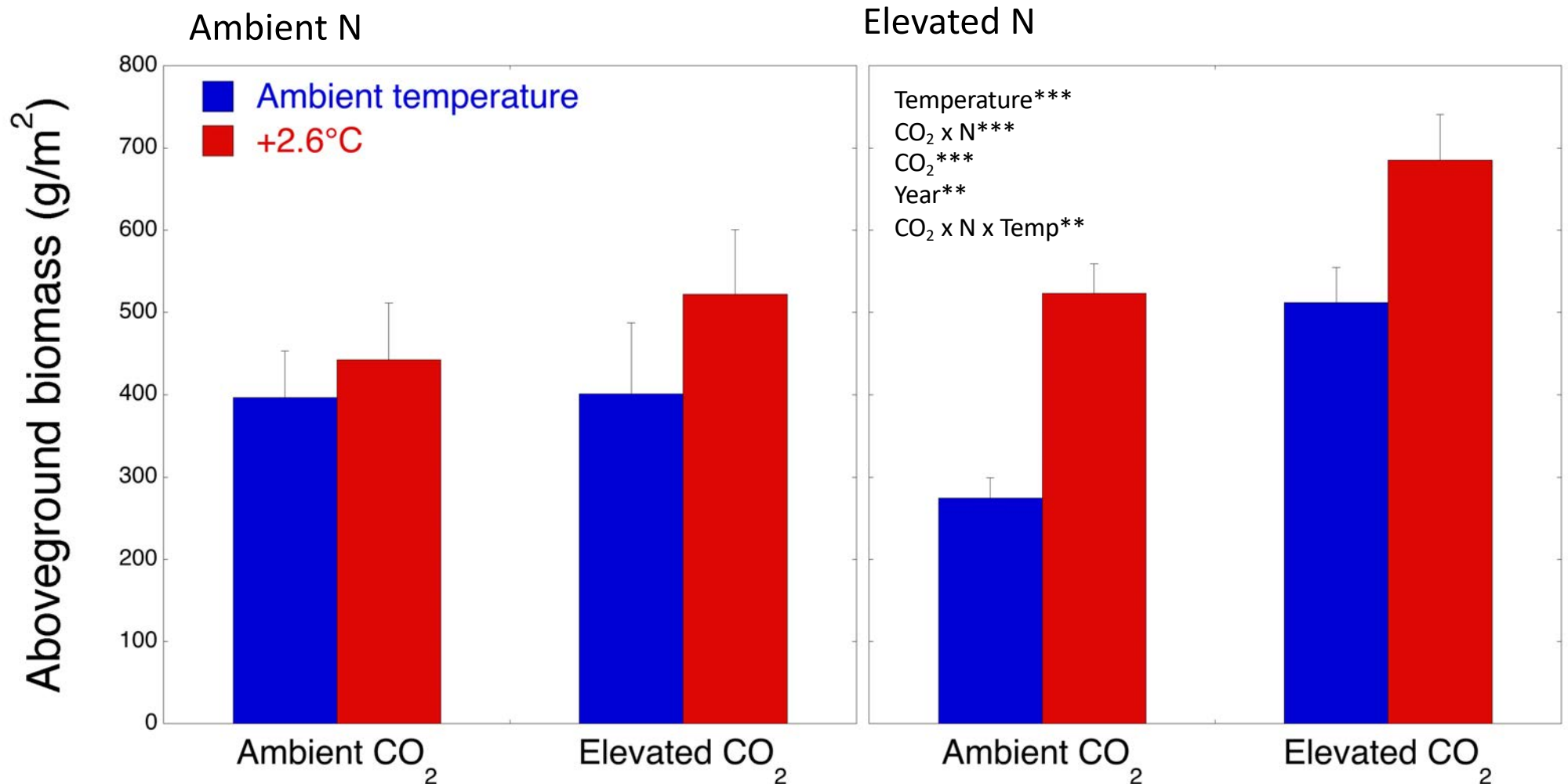
$\text{CO}_2$





# Warming, CO<sub>2</sub>, and N all increased aboveground biomass

## Complex interactions



2012-2018 average



# Theoretical predictions based on physiology



$C_3$  grass

Negative effects of  
temperature offset  
by elevated  $CO_2$

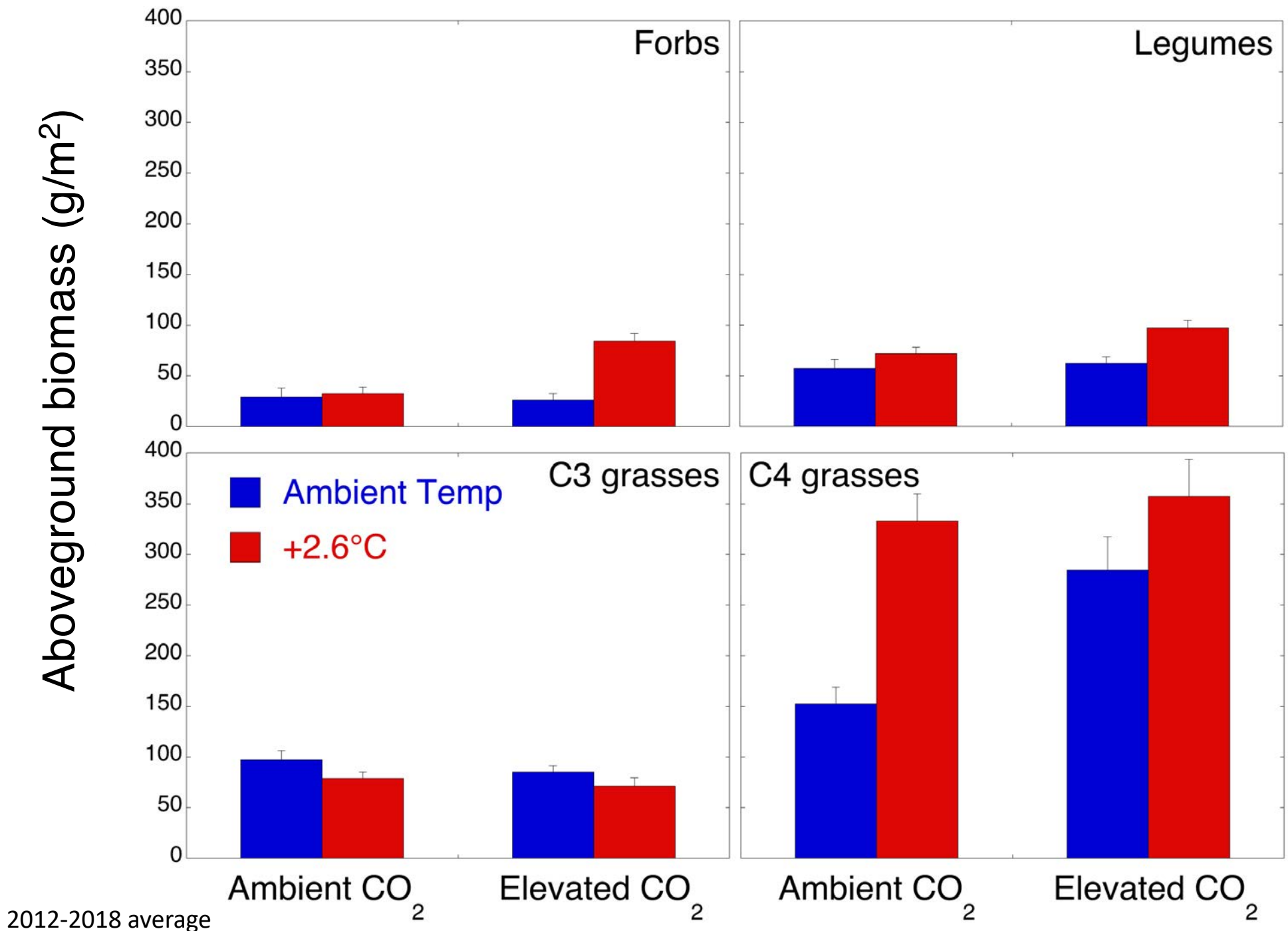


$C_4$  grass

Positive effects of  
temperature



# Warming decreased C<sub>3</sub> grasses and increased other groups





# Summary

- Elevated CO<sub>2</sub>:
  - Increased biomass when belowground resource supply was relatively high
  - Increased C<sub>3</sub> grasses initially, but C<sub>4</sub> grasses over time
  - Increased biomass more in more diverse plots
- Warming:
  - Increased total biomass because of increased C<sub>4</sub> grass biomass
  - Effects were as large as CO<sub>2</sub> and N effects



A photograph of a dirt path leading through a lush green forest. The path is made of brown earth and is flanked by tall grass and various green plants. The trees are mostly deciduous with vibrant green leaves, creating a dense canopy overhead. The lighting is soft, suggesting a slightly overcast day. The path leads from the foreground into the distance, disappearing into the woods.

# Outline

- Natural history of Cedar Creek Ecosystem Science Reserve
- Overview of Cedar Creek Long Term Ecological Research (LTER) program
- Focus on global change research
- Long-term research during a pandemic



# Implications

- Experiments
- Long-term datasets
- Professional development and mentoring



## U.S. LTER Sites 2017



## US Long-Term Ecological Research (LTER) Program

- Funded by the National Science Foundation
- 28 sites in network
- 6-year funding cycle for individual sites
- Cedar Creek LTER funded since 1982

