**How does increasing atmospheric carbon dioxide disrupt ecological systems?**

* Context: Communities of organisms in ecological systems may change as the abiotic environment changes.
* Major themes: (1) Biological systems utilize feedback mechanisms to regulate and maintain optimal conditions, (2) time-dependent processes regulate biological systems, and (3) a biological system’s size and environment influences how it addresses physical and chemical challenges.
* Take Home Message: Increasing atmospheric carbon dioxide is leading to changes in ecological systems.

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| **Biology Learning Objectives**   * Explain how ecological system homeostasis is maintained during global climate change. * Understand and explain how increasing atmospheric carbon dioxide and global climate change are disrupting ecological system homeostasis. |  |

You learned in [lecture](http://trunity.org/textbooks/174401/topics/4367162/article/5a1dd547c96b402792b423b3) that mean global temperatures are rising, due in part to human activities that have led to increases in levels of CO2 and other greenhouse gases. CO2 concentrations can be altered by photosynthesis. Plants have, to some extent, an ability to remove and store atmospheric carbon via photosynthesis. Thus, there is a link between plant metabolism, how carbon moves around the Earth (global carbon cycle) and global climate change.

Trees photosynthesizing in Brazil’s tropical rainforests may affect glaciers of Greenland through their effects on atmospheric CO2 concentrations. A rainforest actively photosynthesizing acts as a **carbon sink** (absorbs carbon)**,** whereas one that is cut down by humans could be a **carbon source** (emits carbon)**.** Other carbon sources are also related to human activities. Besides deforestation, forest ecological systems may be affected by changing environmental factors, including rising CO2 and temperatures, and changes in precipitation patterns associated with global climate change. Richard Norby and colleagues from several research institutions compiled data from experiments on the effects of elevated CO2 on growth and productivity of forests (*Your fearless teacher worked on several of these experiments*!).

The scientists involved in the study below worked at several sites in forests in the US and Europe where Free-Air Carbon Dioxide Enrichment (FACE) experiments have been set up. FACE experiments are made up of tall vertical pipes placed in a circle around an experimental plot, which are up to 30 meters in diameter (Figure 1). The pipes emit CO2-enriched air toward the interior of the plot to maintain a higher concentration of CO2 than normal. Sensors in the plots provide feedback to computers, which monitor and adjust the output from the pipes. Comparable control plots pump ambient air into the plot. Various responses of the plants, including growth rates and productivity, inside the plots are measured over long periods of time.

FACE experiments are critical because measuring the effects of elevated CO2 in ecological systems can better estimate how plant growth and forest communities will change as CO2 concentrations rise. FACE experiments also allow the effect of elevated CO2 on tall, long-lived plants (such as, trees) to be measured. Norby and his colleagues analyzed net primary production (NPP, ‘total annual biomass growth’) data from four long-term FACE experiments, in Wisconsin, North Carolina, Tennessee, and Italy. The goal was to assess how increased levels of CO2 over long periods of time affect forest ecological systems and through that determine how the global carbon cycle might be affected, as forests dominate global NPP. The FACE approach permits the study of processes under elevated CO2 that was previously impossible or intractable in forest ecological systems.

These FACE experiments are all conducted in temperate zone forests, yet the forests represent a broad range of productivity, climatic conditions, and diversity of tree species (Table 1; Figure 2). For the experiments, the average atmospheric carbon dioxide concentration ([CO2]) in the ambient CO2 plots across all of the years assessed was 376 ppm, whereas the elevated CO2 FACE plots had an average [CO2], across all experiments and sites, of 550 ppm, which is a level chosen based on projections of atmospheric [CO2] anticipated for 2050. *In 2020, the atmospheric [CO2] is ~407ppm.*

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| http://www.trunity.net/files/315301_315400/315314/icb-30.07.jpg |
| **Figure 1**The FACE experimental site at the Duke University Forest. FACE plots are located in a primarily loblolly pine forest, including many deciduous trees. FACE plot consists of an array of vertical pipes surrounding the plot and CO2 sensors inside of the plot. From <https://www.bnl.gov/bnlweb/pubaf/pr/1999/bnlpr051399.html> |

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| http://www.trunity.net/files/315301_315400/315315/icb-t30.04.jpg |
| **Table 1** Characteristics of the four FACE experiments. Growing season is the length of time that leaves or stems are actively growing. NC, North Carolina; WI, Wisconsin; TN, Tennessee; IT, Italy; FACE, Free-Air Carbon dioxide Enrichment. From Norby et al., 2005, Table 1, copyright 2005, National Academy of Sciences, U.S.A. |

***Comparing annual biomass production (NPP) in FACE plots***

The scientists made annual estimates of biomass increases of stem wood and large woody roots using periodic measurements of the diameter of trees. The scientists estimated growth increases of small root biomass from experiments where growth of small roots was monitored over time. Leaf tissues were harvested, and leaf litter fall was captured in baskets to estimate biomass production of leaves. The scientists used these estimates of stems, leaves, and roots to estimate biomass increases for entire plots. *Combined,* *these estimates of annual increases in biomass of plant tissues are an estimate of NPP.*

NPP was expressed as grams of carbon fixed per square meter of land per year (g C × m-2 × yr-1).

* NPP = annual carbon increases in wood, leaf, and root tissue (combined).
* Biomass estimates were converted to carbon units via known carbon content of different tissues (~40-50%).
* Thus, the scientists were able to measure how much carbon dioxide was fixed in organic carbon biomass
  + Remember, some plots had air [CO2] around 550ppm (*predicted* *future elevated CO2*)

Norby and his colleagues analyzed NPP based on all years and plots for which they had data and for which the tree canopy was fully developed (see Figure 2A); in other words, they excluded years and plots with younger, rapidly growing trees. *They compared NPP in plots with elevated CO2 to that in plots with current CO2 for each tree species or tree species combination.* The scientists wanted to understand the response of forests with fully developed canopies, which they reasoned would be informative of global forest responses.

* If elevated CO2 plots created more NPP in the current CO2plots, then a best-fit line for all plots would be greater than a 1:1 relationship line.

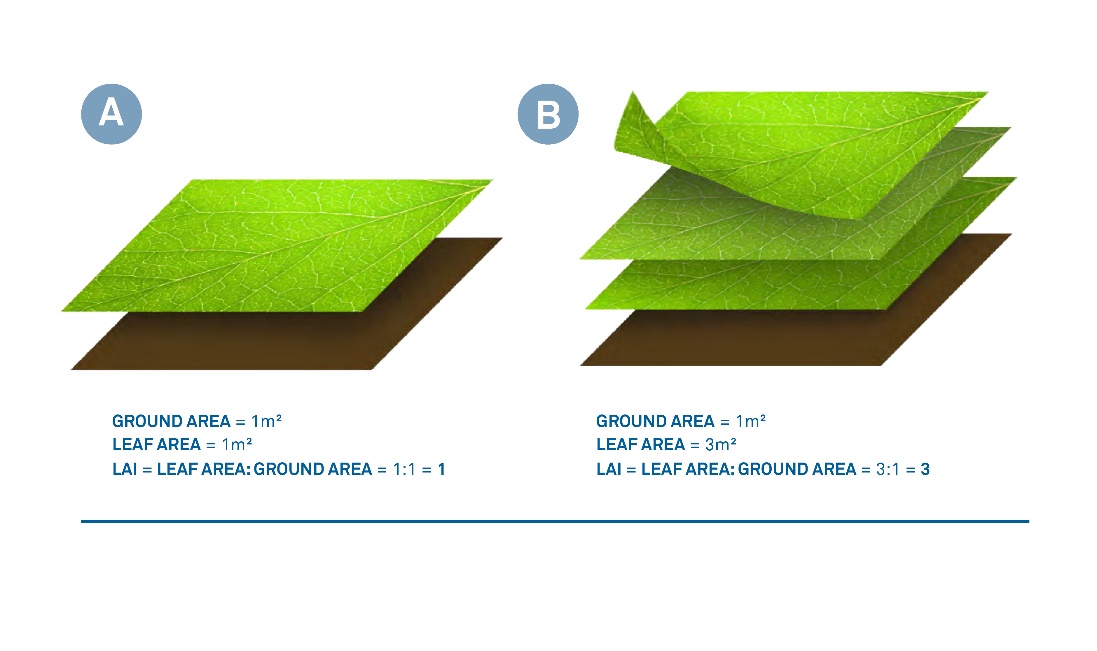
***The importance of light***

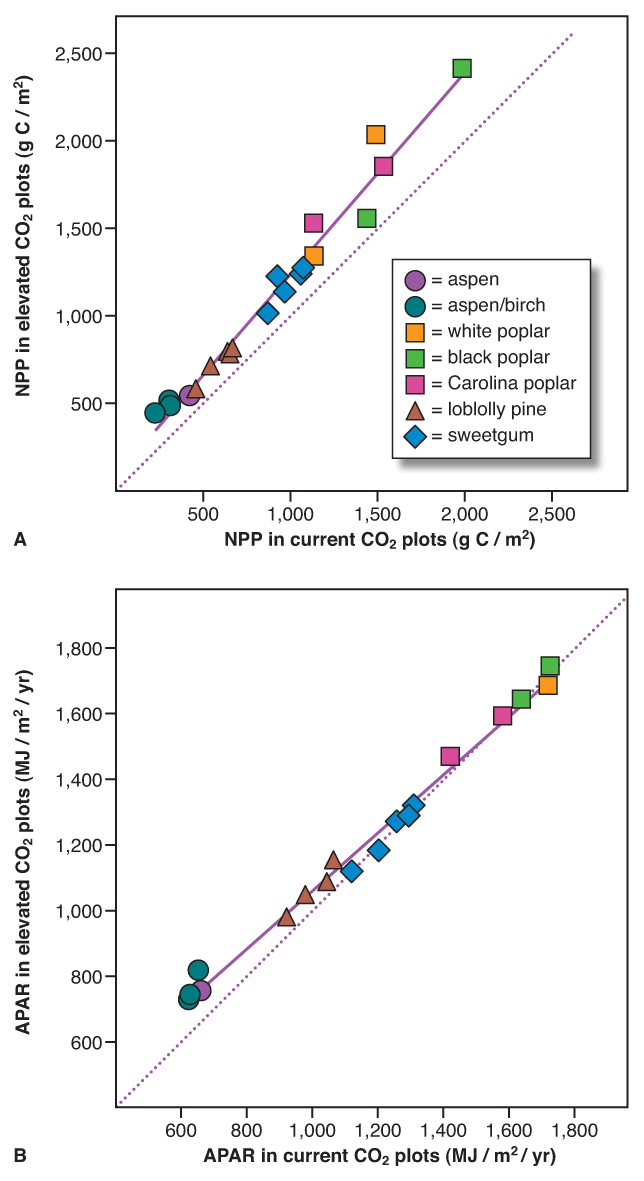
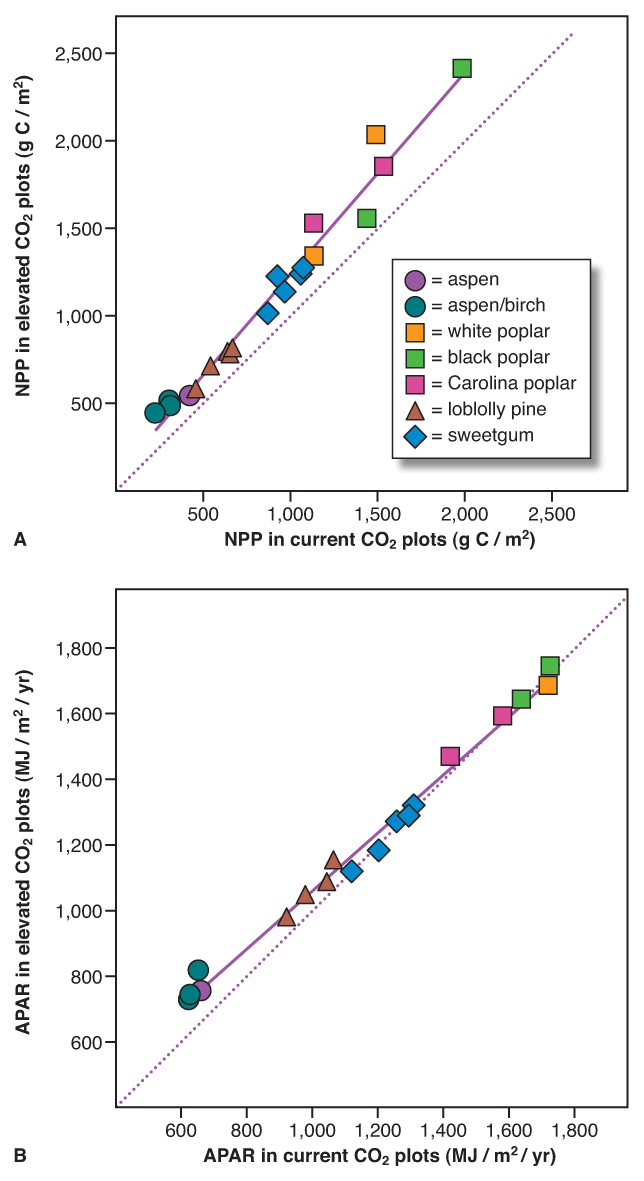
Norby and his colleagues also measured the light energy absorbed by the canopy (APAR) by taking the difference of the amount of light energy at the top of the canopy and that striking the forest floor. These values were then integrated over the entire growing season to yield the total light energy absorbed per unit area per year in each plot for each tree species combination. The scientist then compared APAR in plots with elevated CO2 to APAR in plots with current CO2 *for each tree species or tree species combination* (see Figure 2B).

* If elevated CO2 plots were absorbing more light than in the current CO2plots, then a best-fit line for all plots would be greater than a 1:1 relationship line.

***Biomass production (NPP) vs light absorption***

Norby and his colleagues compared the NPP response to any potential change in the light energy absorbed by the plants to determine whether changes in NPP were related to changes in APAR. They standardized the NPP and APAR values to the maximum values observed for each plot. The scientists then calculated the ratio of the change in APAR between elevated and current CO2 plots to the change in NPP between elevated and current CO2 (ΔAPAR/ΔNPP). They plotted this against the maximum leaf area index (LAI) for each year (Figure 3). LAI is the ratio of total leaf surface area divided by land surface area. LAI accounts for all the entire leaf produced across the many vertical layers of a tree (see diagram below).





**Figure 2**Responses of NPP and APAR to elevated [CO2] in FACE experiments in forests. **A,** NPP in elevated CO2 plots as a function of NPP in current CO2 plots. **B,** Absorbed photosynthetically active radiation (APAR) in elevated versus current [CO2]. Each point represents one tree species/tree combination in 1 year, but only from years after the canopy was no longer increasing. Solid lines represent best-fit lines and dotted lines represent the 1:1 relationship. From Norby et al., 2005, Figure 1, copyright 2005, National Academy of Sciences, U.S.A.

**Figure 30.8**Responses of NPP and APAR to elevated [CO2] in FACE experiments in forests. **A,** NPP in elevated CO2 plots as a function of NPP in current CO2 plots. **B,** Absorbed photosynthetically active radiation (APAR) in elevated versus current [CO2]. Each point represents one tree species/tree combination in 1 year, but only from years after the canopy was no longer increasing. Solid lines represent best-fit lines and dotted lines represent the 1:1 relationship. From Norby et al., 2005, Figure 1, copyright 2005, National Academy of Sciences, U.S.A.

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| http://www.trunity.net/files/315301_315400/315317/icb-30.09.jpg |
| **Figure 3**Fraction of the gain in NPP caused by a gain in APAR plotted against peak seasonal LAI. The changes in NPP and APAR were normalized to the maximum values observed, using a z-score. From Norby et al., 2005, Figure 2, copyright 2005, National Academy of Sciences, U.S.A. |

**Results from 10+ years of FACE experiments**

Norby and his colleagues found a strong linear relationship between NPP in elevated CO2 and that in current CO2 plots that rose at a rate significantly greater than a slope of 1 (Figure 2A). The conclusion of the scientists was that there was a significant effect of elevated CO2 on NPP, and an estimated 23% increase in forest NPP would result from atmospheric CO2 increases to 550 ppm over the next few decades. However, APAR in elevated CO2 plots was not different from APAR in current CO2 plots. When all FACE plots were graphed, the slope of the best-fit line was not significantly different from one (Figure 2B). Thus, the light energy absorbed by the canopy did not increase faster in elevated CO2 plots relative to current CO2 plots, as NPP did.

* The scientists, and you, might have predicted that APAR would be higher in elevated CO2, because higher NPP should lead to more leaves to absorb more light energy.

Because this did not occur, Norby and his colleagues hypothesized that leaves in elevated CO2 became more efficient at using light (instead of using more light). If the ratio (elevated CO2/control) of the change in APAR to the change in NPP is equal to one (Figure 3) the increase in NPP is due to an increase in APAR.

* However, if the ratio is close to zero, then increases in NPP are due to higher light-use efficiency.

Norby and his colleagues found that the change in APAR from current to elevated CO2 in *dense canopy forests* is close to zero. In forests with dense canopies, very little of the gain in NPP was associated with increased absorbed light energy. Whereas in the forest stands with lower LAI, the gain in NPP with CO2 fertilization was associated with increased absorbed light energy.

* The forests were already full of leaves, so they could not increase light absorption!

***TAKE HOME*:** When the canopy is sparse in leaves and CO2 is elevated, plants can respond by absorbing more light energy whereas when the canopy is dense, the plants in elevated CO2 are more efficient with light energy.

**SUMMARY:** Norby and his colleagues presented evidence that suggests a feedback between the biosphere and atmosphere that involves the carbon cycle. This is an example of ecological system homeostasis, although the change in the environmental conditions (increased CO2) may actually cause the ecological system to move to a new state. A sustained or large change in an environmental condition could push an ecological system to a new “set point,” which is the condition at which a biological system attempts to maintain itself through feedback mechanisms. Coincident to the sustained change in CO2 concentrations that are occurring globally is the increased global mean temperature that has been documented. Scientists predict that by 2100, the Earth’s mean global temperature could be 1.5o to 5.8o C warmer than it is now, although the distribution of temperature changes varies globally. Far northern latitudes have already experienced a change of between 0.6o to 1.0o C over the last 100 years, which is a change that is greater in magnitude than for the entire northern hemisphere.

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| **Review Questions**   1. What are the ways in which organisms have responded to increasing atmospheric carbon dioxide and global climate change? 2. Have increasing atmospheric carbon dioxide and global climate change disrupted ecological system homeostasis? Provide evidence for or against. |  |

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| **Explore More on Global Climate Change and Global Pollution**  The Intergovernmental Panel on Climate Change most recent report suggests a small window of time to change our pattern of emissions: <https://archive.ipcc.ch/report/sr15/index_background.shtml>. |  |

**Bibliography**

Norby RJ, DeLucia EH, Gielen B, et al: [Forest response to elevated CO2 is conserved across a broad range of productivity](http://www.pnas.org/content/102/50/18052.full.pdf+html), *Proc Nat Acad Sci* 102(50):18052-18056, 2005.