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THE UNIVERSITY OF ARIZONA
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Rising Carbon Dioxide Levels and Forest Management

Climate Change and Variability in the Southwest Ecosystem Series

Background

Recent observations and scientific research indicate that climate change, with its greater extremes in meteorological trends and overall temperature increases, is likely to affect land resources. Natural resource managers need to continually update their knowledge concerning potential impacts of climate to assist decision making and planning. This fact sheet provides a summary of scientific research and climate-related implications for natural resource managers and other concerned stakeholders to consider. The information presented was stimulated from the Workshop on Climate Change & Ecosystem Impacts in Southwest Forests and Woodlands, held February 8-9, 2005, in Sedona, Arizona.

Rising Carbon Dioxide Levels

Carbon dioxide (CO_2) is one of the main greenhouse gases that contributes to global warming. In addition to having an influence on climate, carbon dioxide has a direct, measurable effect on plant growth. Plants tend to grow better under conditions of higher carbon dioxide levels. Scientists have dubbed this effect "CO2 fertilization."

It is well documented that atmospheric carbon dioxide has increased from mid-nineteenth century pre-industrial levels of about 280 parts per million to roughly 380 parts per million in 2005. Levels have been increasing by about 1 to 2 parts per million a year since instrumental measurements began in 1958 (Figure 1). Because of ongoing contributions from human activity, levels are expected to continue rising in the foreseeable future.

The Intergovernmental Panel on Climate Change (2001) estimates that carbon dioxide is responsible for about 60 percent of the current warming. Mean global temperature is projected to rise between 3 and 10 degrees Fahrenheit by end of the century, a rate of up to 1 degree Fahrenheit per decade (IPCC 2001). Land use change, mainly deforestation, accounts for about a quarter of annual carbon dioxide releases from human activities, while the rest comes from fossil fuels emissions—i.e., using gas, oil and coal to power cars and factories and produce electricity.

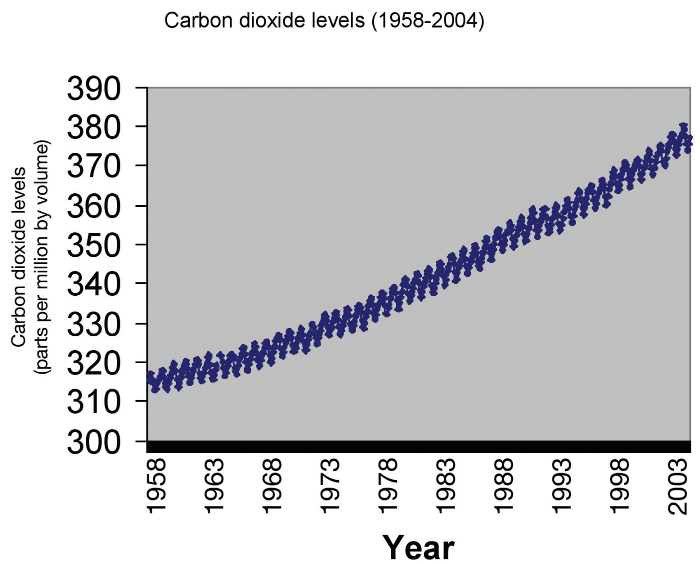

Figure 1. Carbon dioxide levels have been rising since instrumental records began in 1958 at Mauna Loa, Hawaii. Fluctuations within the year occur as northern hemisphere plants take up carbon dioxide in summer, and then release some of it during winter. The data, collected by C.D. Keeling and T.P. Whorf, is available on the web at: http://cdiac.esd.ornl.gov/ftp/trends/co2/maunaloa.co2

Plant Response to Carbon Dioxide

Plant tissue (including wood) is composed of about half carbon, all of which comes from carbon dioxide in the atmosphere. Photosynthesis rates tend to increase as carbon dioxide levels rise, leading to an increase in dry weight, or biomass, of plants grown under elevated carbon dioxide levels.

Compared to plants grown at existing carbon dioxide levels, plants "fertilized" by elevated levels of atmospheric carbon dioxide increase their photosynthesis rates (Norby et al. 1999, Kimball et al. 2002, Nowak et al. 2004). In addition, carbon dioxide-fertilized plants respond with increased biomass (dry weight), improved water use efficiency, and an increased tolerance of low light levels. Free-Air Carbon Dioxide Enrichment (FACE) research and other studies have focused on plant response to carbon dioxide levels of 550 parts per million or more, but it seems likely that plants in range and wildland environments are "fertilized" by modern levels (which are about one-third higher than pre-industrial levels of 280 parts per million). FACE experiments involve exposing plants in the field to elevated carbon dioxide levels.

An important consideration in relation to climate change is that carbon dioxide fertilization raises the optimum temperature for photosynthesis (e.g., Norby et al., 2002). It also increases water use efficiency of plants. However, other factors, such as deficient nitrogen or absence of moisture, can limit plant response to increases in carbon dioxide.

Various plant species and genotypes express differences in their degree of responses to carbon dioxide fertilization. Although most experiments have considered the effect of carbon dioxide fertilization on individual species and not interactions among species, woody species such as trees and shrubs appear to be more responsive to carbon dioxide fertilization than some grasses and crops. For instance, forest ecosystems tend to have a more pronounced response to carbon dioxide fertilization than grassland ecosystems, based on a comparison of 18 FACE experiments compared by Nowak and colleagues (2004).

Woody plant biomass in southwestern forests and grasslands has increased in the past century, primarily due to fire suppression. Arguably, one should consider that carbon dioxide fertilization in recent decades could be contributing to the biomass increase. Response to carbon dioxide fertilization may influence competition between species, including woody species versus grasses and native grasses versus invasive species (Smith et al. 2000). Plants using the C4 photosynthetic pathway already boost their internal concentration of carbon dioxide, so they tend to be less affected by external increases than C3 plants. Therefore, C3 plants, which include all trees and shrubs as well as some cool-season invasive grasses like bromes and cheatgrass, may be more responsive to carbon dioxide fertilization than C4 plants, which include most warm-season grasses and invasives like lovegrass and buffelgrass.

Meanwhile, desert ecosystems exhibited a greater response than both forests and grasslands in these FACE experiments after adjustments for differences in precipitation. Carbon dioxide fertilization increases plant water use efficiency, which may help explain why the desert ecosystems responded more dramatically than other ecosystems. In comparing all the ecosystems, Nowak and colleagues (2004) found that net primary productivity rose by an average of 12 percent in ecosystems exposed to elevated levels of carbon dioxide compared to controls (typically 550 parts per million compared to ambient levels of 380 parts per million or below, depending on the year of the experiment).

There is some evidence that plants grown under conditions of carbon dioxide fertilization may increase the production of chemical compounds (phenols) that make them more resistant to some insects. On the other hand, it has been hypothesized that the increased growth will also promote herbivory, in part because the concentration of nitrogen in leaves tends to drop. However, declines observed among potted seedling are not always apparent in field-grown trees (Norby et al., 1999).

Researchers continue to test whether the increased photosynthesis is a short-lived response or an ongoing one. Most experiments last only one or two years, so this is difficult to assess. There is no clear evidence that the response is short-lived for trees except when root containers (pots) limit their potential for root expansion (Curtis and Wang, 1998). In a 15-year experiment in Maricopa, Arizona, the wood of sour orange trees exposed to carbon dioxide levels about 300 parts per million higher than ambient levels initially yielded nearly three times as much biomass as control trees, with the rate slowing to less than double after a few years (Figure 2).

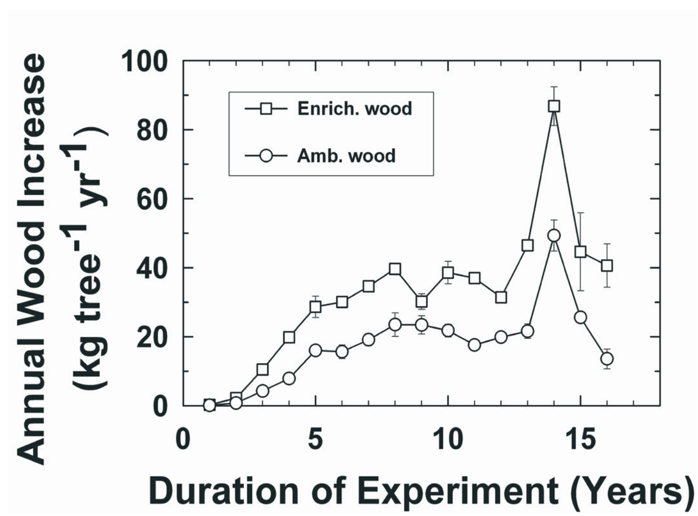

Figure 2. Annual increments of sour orange wood versus duration of exposure to CO2 enrichment. The wood data are based on monthly trunk circumference measurements converted to bio-volume using an allometric relationship established during years 2 and 3 of the experiment (Kimball and Idso, 2005). Volume was converted to biomass using density measurements from pruned branches.

Increased CO2 fertilization	→ Increased photosynthetic production rate → Increased biomass (plant dry weight) → Increased water use efficiency → Increased tolerance for low light levels → Increased optimum temperature for photosynthesis

Ecosystem Changes and Land Management Implications

The issue of carbon dioxide fertilization applies most immediately and understandably to managing forests and woodlands to reduce fire risk. In addition, carbon dioxide fertilization may have an effect on plant competition that contributes to shifts in species distribution, including post-fire recovery. This factor complicates projections about how southwestern forest and woodlands will be impacted by global warming.

Experiments testing the effects of carbon dioxide fertilization indicate rising atmospheric levels will result in an increase in herbaceous production (Nowak et al 2004). This increase will translate into more fine fuels that can carry fire in forests and woodlands. Meanwhile, the improved growth of trees exposed to carbon dioxide fertilization indicates that rising levels of this greenhouse gas may exacerbate the tendency toward increasingly dense southwestern forests. Plants in lower light levels (i.e., understory plants) survive better in conditions of elevated carbon dioxide. The reintroduction of a surface fire regime can help counteract this tendency toward increased density.

Forest protection and reforestation are widely acknowledged means for sequestering carbon from the atmosphere and storing it in plants, at least until a stand-replacing fire occurs. Not only does a stand-replacing fire release carbon dioxide into the atmosphere as it burns plants and wood, it arguably may cause a reduction in the disturbed stand's ability to sequester carbon until a full tree canopy is reestablished. Carbon dioxide fertilization may improve seedling survival rates after a large-scale disturbance, but this has not been tested in the field.

Reducing the risk of large-scale crown fires by treatments such as thinning understory trees could be seen as a means of keeping carbon sequestered in southwestern forests. Forestry practices such as thinning treatments, intermediate, shelter-wood and seed-tree harvest cuts, as opposed to clear-cuts, also leave many mature trees standing. Carbon dioxide continues to be taken up by the remaining trees, which can grow better with the reduction of competition for limited resources. Meanwhile, carbon is also sequestered in the harvested lumber for decades or more. When small-diameter wood is used as biomass for heat or energy production, it displaces the need for using fossil fuels for this purpose.

Land managers may want to incorporate some of the information on carbon dioxide fertilization effects, including the value of intact forests for carbon sequestration, into their educational materials about the need to treat stands to reduce fire risk. They may also be interested in the scientific literature that contains many reports of carbon dioxide fertilization experiments involving different wildland species.

Questions for Further Research

Land managers are gaining appreciation of the importance of rising atmospheric carbon dioxide levels and their future impacts on wild vegetation. It is a topic that could greatly benefit from additional research. Participants at the 2005 Workshop on Climate Change & Ecosystem Impacts in Southwest Forests and Woodlands were asked what information would help them. The following questions were generated:

- What is the response of invasive species to carbon dioxide fertilization compared to native plants? More research needs to be conducted to determine how variable carbon dioxide responses among genotypes and species might influence competition among species, including invasive plants.
- Will increased growth caused by carbon dioxide fertilization cause nutrient depletion and affect plant performance and/or herbivory? Will another limiting factor regulate or slow growth?
- Is carbon dioxide fertilization contributing to the increasing densification of southwestern Ponderosa pine forests? Is it contributing to the woody encroachment of grasslands? These questions need to be considered in order for managers to make reasonable projections about how this observed "woodification" might play out in the future.
- How will the increased temperatures that come with global warming affect the responses of plants to elevated carbon dioxide?
- How much will the improvement in plant water-use efficiency temper the projected increase in evapotranspiration rates as temperature goes up?
- Does the response of plants to carbon dioxide fertilization occur on a predictable linear scale, or is there a non-linear relationship between carbon dioxide, temperature variation and plant response?

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This bulletin includes scientific jargon which some readers may not find familiar. For those and other readers that may appreciate a little reminder, a list of key scientific words or other terms is provided below:

Ambient – Existing on all sides of a surrounding or encircling atmosphere.

Carbon dioxide (CO_2) – A heavy colorless inert gas that is formed in animal respiration and in the combustion and decomposition of organic substances. It is a greenhouse gas that contributes to global warming.

CO_2 fertilization – Refers to the fertilizing effect carbon dioxide has on plants.

Crown fire – A wildfire that spreads from tree canopy to tree canopy, usually considered the most destructive of wildfire behavior.

Forestry practices – those actions or activities used in Forest Management.

- **Intermediate thinning/harvest –** a mid-term harvest of some of the merchantable trees to create less competition and to release the growth of the remaining trees for later harvest.
- **Shelter-wood tree harvest –** a full-term harvest technique used for shade-tolerant species of trees such as Douglas-fir to allow sufficient shade for seedlings to germinate.
- **Seed-tree harvest –** a full-term harvest technique used for sun loving species of trees such as Ponderosa pine to allow sufficient sunlight for seedlings to germinate.
- **Thinning-from-below –** cutting of understory trees and other crowded trees to create less competition and to release the growth of the remaining trees.

Genotype – the genetic makeup or constitution of an organism or group.

Global warming – An increase in the average temperature of the earth's atmosphere. In common usage, it refers to the climate change stemming from society's release of greenhouse gases.

Greenhouse gas – any of the atmospheric gases, such as carbon dioxide, that contribute to the greenhouse effect. The greenhouse effect is the warming of a planet's atmosphere that occurs when the sun's radiation passes through the atmosphere, is absorbed by the planet, and is reradiated as infrared (i.e., heat) that can be absorbed by atmospheric gases.

Herbivory – The act of feeding directly on plants.

Meteorology – A science that deals with the atmosphere and its phenomena and especially with weather forecasting.

Phenol – any of a class of weakly acidic organic compounds whose molecule contains one or more hydroxyl groups.

Photosynthesis – The process by which chlorophyll-containing plants use light energy to make carbohydrates from water and carbon dioxide. Oxygen is released as a by-product.

- **C3 –** A common metabolic pathway for carbon fixation in photosynthesis. Plants that use C3 fixation (C3 plants) mostly thrive in areas where sunlight intensity and temperature are moderate, and moisture is readily available.
- **C4 –** A less common metabolic pathway for carbon fixation in photosynthesis. C4 plants use water more efficiently and therefore have a competitive advantage over C3 plants under conditions of drought, high temperatures and limited nitrogen or carbon.

Forest Stand – A contiguous group of trees sufficiently uniform in species composition, arrangement of age classes and condition to be a distinguishable unit.

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