12 Impacts of Elevated Atmospheric $[\text{CO}_2]$ and $[\text{O}_3]$ on Northern Temperate Forest Ecosystems: Results from the Aspen FACE Experiment

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12.1 Introduction

Globally, mean atmospheric carbon dioxide $[\text{CO}_2]$ and tropospheric ozone $[\text{O}_3]$ have risen 30–36% since pre-industrial times (IPCC 2001). These increases in $[\text{CO}_2]$ are largely due to increased emissions from fossil fuel burning (Beedlow et al. 2004), while the increases in $[\text{O}_3]$ are primarily related to increasing emissions of oxidized nitrogen ($\text{NO}_x$) and volatile organic emissions from fossil fuel combustion (Felzer et al. 2004). Nearly 25% of the Earth’s forests are currently at risk from $[\text{O}_3]$ where peak concentrations exceed 60 ppb (Fowler et al. 1999). Those authors predict that half of the Earth’s forests will be subjected to peak concentrations exceeding 60 ppb by the year 2100. Little is known about how forest ecosystems will respond to these co-occurring pollutants (Gower 2003).

The Aspen FACE (free air $\text{CO}_2$ enrichment) experiment was established in 1997 in northern Wisconsin to examine the impacts of elevated tropospheric $\text{O}_3$ ($e[\text{O}_3]$), alone and in combination with elevated atmospheric $\text{CO}_2$ ($e[\text{CO}_2]$), on the structure and functioning of a northern forest ecosystem dominated by the rapid-growing, pioneer species trembling aspen ($\text{Populus tremuloides}$ Michx.) but including also another rapid-growing, pioneer species paper birch ($\text{Betula papyrifera}$ Marsh) and the slower-growing, later-successional species sugar maple ($\text{Acer saccharum}$ Marsh). Trembling aspen is the most widely distributed tree species in North America. Aspen forest types make up over $8.8 \times 10^6$ ha in the United States and $17.8 \times 10^6$ ha in Canada. In Wisconsin alone, where this experiment is located, aspen, birch and maple stands comprise over 50% of the State’s vast forest resource. Aspen and birch make up some 70% of the pulpwood harvested in the Lake States (Piva 1996).
The main objective of the Aspen FACE has been to examine how \(e[CO_2]\) and \(e[O_3]\) affect carbon and nitrogen cycles and the ecological interactions of forests (Dickson et al. 2000). Specifically, we are studying the impacts of these co-occurring greenhouse gases on aggrading northern forests in terms of physiological processes, growth and productivity, carbon sequestration, competitive interactions and stand dynamics, interactions with pests and ecosystem processes, such as foliar decomposition, mineral weathering and nutrient cycling (Karnosky et al. 2003, 2005). Furthermore, we have been interested in how temporal changes in ecosystem structure and functioning occur from establishment phase through to crown closure and beyond. We hypothesized that the ecosystem-level responses to \(e[CO_2]\) and \(e[O_3]\) would be driven by the responsiveness of the keystone tree species and that ecophysiological responses of the keystone species would cascade through the ecosystems in a predictable manner.

12.2 Site Description

The Aspen FACE project was established in 1997 with 4- to 6-month-old aspen rooted cuttings of five genotypes and 4- to 6-month-old sugar maple and paper birch seedlings planted on a sandy loam soil on a relatively flat-terrain, old-field site at 490 m elevation on a U.S. Forest Service site which had previously been used for poplar genetic trials (Dickson et al. 2000). This experiment consists of 12 30-m diameter rings (Fig. 12.1), assigned to factorial treatments of \([CO_2]\) (current and elevated) and \([O_3]\) (current and elevated) during daylight hours throughout the growing season. Treatments are arranged in a randomized complete block design (\(n=3\)). In one half of each ring, we planted five trembling aspen genotypes of differing \(CO_2\) and \(O_3\) responsiveness. The other half of each ring is further divided into two quarters; one is planted with aspen and sugar maple and the other is planted with aspen and paper birch; and each FACE ring was planted at \(1 \times 1\) m spacing. Approximately 20 000 hybrid poplar unrooted cuttings were planted around the 12 rings to improve uniformity of fetch into each ring. Trees were irrigated for the first growing season and weeds were controlled through a combination of hand hoeing and herbicides for the first two growing seasons. No supplemental fertilization was conducted and pest control practices were only conducted in the establishment phase of this experiment when pests were deemed to be threatening survival of the experiment.

The site is located in a continental climate with a frost-free growing season of approximately 120 days. Summer temperatures average 16.1 °C, reaching highs of about 32 °C; and winter temperatures average –6.7 °C, but reach –20 °C. Details of the Aspen FACE micrometeorology can be found at http://www.ncrs.fs.fed.us/4401/focus/face/ meteorology/.