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Climate Change, Aerobiology, and Public Health in the Northeast United States

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Lewis H. Ziska, Paul R Epstein, Christine A Rogers.

ABSTRACT

The epidemiological implications with respect to climate change and public health (e.g., shifts in disease vectors) are beginning to be acknowledged. Less recognized however, are the potential links between climate, plant biology and public health. In addition to being affected by climate (e.g., temperature determines plant range), carbon dioxide (CO_2) represents the raw material needed for photosynthesis and its rapid increase in the atmosphere is expected to stimulate plant growth. While there are a number of means by which plant biology intersects with human health (e.g., plant nutrition), one of the most widely recognized is aerobiology; specifically, the ability of plants to both produce pollen and to serve as a substrate for molds/fungi (e.g., sporulation). The current review represents an initial attempt to coalesce what is known regarding the likely impacts of climate / CO_2 on plant pollen / fungal spores and associated allergic disease that are, or could be, specific to the Northeast United States. Although the current results indicate a number of potentially unfavorable effects, we wish to stress that the current data are based on a small number of experiments. Additional data are crucial to both reduce epidemiological uncertainty and to derive a robust set of mitigation / adaptation strategies.

KEY WORDS

Allergies, Asthma, Carbon dioxide, Hay fever, Ragweed, Urbanization.

1. Introduction

Allergic diseases are the sixth leading cause of chronic illness in the U.S., affecting approximately 17% of the population (AAAAI 2000). The Centers for Disease Control and Prevention (CDC) estimate asthma prevalence in the U.S. at about 25 million (9 million children, 16 million adults) (CDC 2002). Self-reporting of asthma onset increased 75% from 1980-1994, with the largest increase (+160%) occurring in pre-school aged children (Mannino et al. 1998).

The epidemiology of allergic diseases is complex, depending on such factors as genetic pre-disposition, exposure to air pollution, and access to health care. However, exposure to allergens from pollen grains or fungal spores is unequivocally associated with symptomology and exacerbation of human respiratory disease (Frenz 2001). Consequently, changes in atmospheric chemistry and climate that enhance the presence of airborne pollen and/or fungi contribute to a heightened risk of allergic rhinitis and related asthma (Beggs 2004).

In addition to carbon dioxide (CO_2) induced changes in climate that could contribute indirectly to an increased plant or fungal risk of allergic rhinitis and asthma, the direct effect of CO_2 on plant growth and fungal decomposition also has serious implications for public health. Such direct impacts would, of course, be compounded by on-going changes in temperature and precipitation, altered timing of seasons, connections with other by-products of fossil fuel combustion, and to synergies among all these elements. Overall, for many opportunistic species (e.g. microbes, insects, rodents and weeds), multiple environmental disturbances are likely to provide distinct and unseen opportunities with unexpected impacts for human health.

2. Climate Change and Plant Based Allergens

Plant induced increases in allergic rhinitis (i.e., hayfever) and asthma are associated with three distinct seasonal sources of plant pollen; trees (spring), grasses (summer), and ragweed (fall). Nearly 40 million people in the U.S. suffer from hay fever, with an estimated four million lost days of work and school (AAAAI 2000).

Quantity and seasonality of pollen depend in large part on plant responses to climatic and meteorological variables. However, changes in such variables are likely as a result of anthropogenic influences on levels of atmospheric CO_2, and enhancement of the greenhouse effect, with subsequent impacts on plant growth and pollen production.

For example, In Europe, a 35 year record for birch (*Betula* spp.), a known source of allergenic tree pollen, indicated earlier spring floral initiation and pollen release in response to warming trends (Emberlin et al. 2002). For Western ragweed (*Ambrosia psilostachya*), simulated increases in summer temperatures (+4°C) have also found increased growth, and re-growth, following cutting with an 85% increase in overall pollen production (Wan et al. 2002). Overall, it seems likely that climatic changes in temperature and precipitation are likely to alter the growth and distribution of a number of weed species, with subsequent effects on pollen production (e.g., Ziska and George 2004).

Recent research on loblolly pine (*Pinus taeda*) at the Duke University forest Free-Air CO_2 Enrichment (FACE) site indicated that elevated CO_2 concentrations resulted in early pollen production from younger trees and greater seasonal pollen production (LaDeau and Clark 2006). Experimental chamber studies have also shown significant effects on pollen production in common ragweed (*Ambrosia artemisiifolia*) with increased future CO_2 concentrations (Wayne et al. 2002; Ziska and Caulfield 2000). Moreover, similar studies have shown that ragweed pollen is likely to have responded both quantitatively and qualitatively to increases in CO_2 concentration that have occurred during the 20th century (Singer et al.

2005; Ziska and Caulfield 2000). Simulation of earlier seed germination in common ragweed due to increasing CO_2 levels and warming also resulted in greater growth and increased inflorescences in common ragweed grown in climate-controlled glasshouses (Rogers et al. 2006). Concurrent increases in CO_2 and temperature related to urbanization were also used to demonstrate *in situ* differences in growth and pollen production of common ragweed monocultures along an urban-rural transect (See Case Study; Ziska et al. 2003). Urban levels of CO_2 and air temperature can be substantially higher than surrounding rural areas with subsequent effects on pollen production (Ziska et al. 2003). Such findings, compounded by the synergistic attachment of aeroallergens to diesel particles (and irritation of immune cells in the respiratory tract by the nitrates within the particles), which are concentrated along bus and truck routes, have implications for the health of children and adults in inner cities (see Knox et al. 1997; Ormstad et al. 1998).

Case Study: Urbanization and Ragweed.

Approximately 53 million people live in the Northeastern United States, and it is recognized as one of the most urbanized areas in the country. Because cities constitute a "heat-island", and produce many of the gases (e.g., carbon dioxide, ozone) that are responsible for environmental change at regional and planetary levels, it has been suggested that cities may provide analogs for studying ecological responses to global change (Carreiro and Tripler 2005).

Using an existing CO_2/temperature gradient between rural and urban areas of Baltimore and the Maryland countryside, we utilized this analog approach to examine the quantitative aspects of ragweed growth and pollen production in 2000 and 2001 (See Figure). Overall, ragweed monocultures demonstrated significantly earlier flowering and greater pollen production in urban areas, relative to rural or semi-rural areas.

While it is not clear that urbanization would result in similar responses either spatially (i.e., other cities), or temporally (multi-year stimulation), when compared to projected climatic change, these data do suggest that the higher carbon dioxide concentrations and increased air temperatures associated with urbanization may be a harbinger of what could be expected with respect to pollen production and allergic rhinitis / asthma with global climate change.

In addition to ragweed, recent research has also indicated that allergenicity associated with contact dermatitis from poison ivy (*Rhus radicans)* may also increase as a function of rising atmospheric CO_2 (Mohan et al. 2006). Specifically, the growth and toxicity of the allergenic chemical – urushiol – was increased in poison ivy under elevated CO_2 levels.

Overall, there is sufficient evidence to suggest a probable link between rising temperatures and/or CO_2, and increasing levels or temporal shifts in plant based aero-allergen production and allergenicity.

Finally, it is worth noting that the etiology of allergic rhinitis and related asthma is complex. There are numerous sociological factors (e.g., access to health care) and synergistic environmental effects (e.g., diesel fumes or ground level ozone) that may interact with climate change induced allergic rhinitis and/or asthma (Beggs and Bambrick 2005). Understanding these links at the national and regional level remains a high priority among both scientists and health care providers since a quantitative assessment of such links is needed in order to assess future health impacts and current adaptive measures.

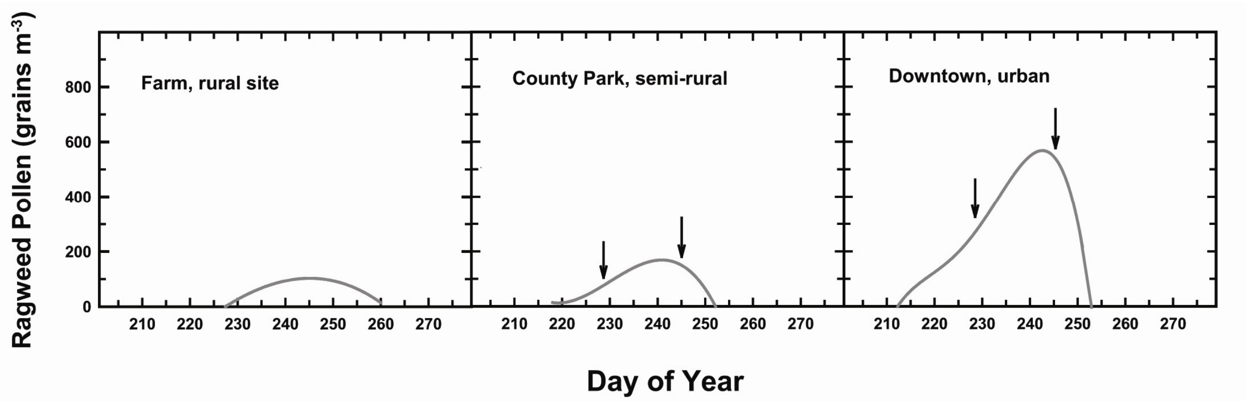

Figure. Time course for ragweed pollen production for 3 sites along an urban-rural transect in 2001 as a function of day of year. Lines are best fit regression for pollen counts determined through roto-rod sampling. The rural site was an organic farm in Western Maryland, the semi-rural site was The Carrie Murray Nature Center (at the extreme western edge of Baltimore City), and the urban site was the Science Center near the Inner Harbor in downtown Baltimore. The arrows shown for the semi-rural and urban sites indicate the dates for the onset and maximum production of pollen in comparison to the rural site. Note the changes in total pollen production and accelerated flowering as a function of urbanization. Initial meteorological data suggest that urbanization may act as a surrogate for climate change (See Ziska et al. 2003 for additional details).

3. Climate Change and fungal spore allergens.

Evidence for CO_2 and climate change effects on fungal growth and reproduction is less well documented than for pollen, although the implications for allergic disease are just as important. As it is for pollen, exposure to fungal spores is unequivocally associated with exacerbations of allergy and asthma (IOM 2000; IOM 2004).

While there are known direct effects of CO_2 on some soil fungal processes such as sporophore development (Webster 1980) and morphotype switching in human pathogenic fungi (Bahn et al. 2005; Klengel et al. 2005), predicted levels of atmospheric CO_2 change will not directly impact fungal processes in the environment. However, other climate change parameters that result from elevated CO_2, such as increased temperatures or changed precipitation regimes, may have pronounced effects on fungal abundance and/or activity.

Because of their intimate relations with plants (as pathogens, saprobes, and mutualists), there may also be large indirect effects of CO_2 on fungi as a result of enhanced plant growth under elevated CO_2. Therefore, plausible arguments can be made for the likelihood of increased fungal biomass which would: 1) result from increased photosynthate being channeled below ground, 2) be needed to facilitate nutrient uptake to support CO_2 driven increases in plant biomass, and 3) be needed to degrade the increased plant biomass that will likely result under climate change scenarios.

Little information exists on the response of saprobic fungi to climate change but activity patterns can be inferred from studies on soil respiration. Soil respiration appears to be positively linked to soil moisture content and temperature (Borken et al. 2003), which may be higher under elevated CO_2 scenarios. Increased amounts of plant biomass generated as a result of increased CO_2 will provide added resources for saprobic microbes and some studies show increases in fungal biomass as a result (Lipson et al. 2005).

However, critical studies are needed to establish whether increased organic matter and fungal activity will translate into greater fungal biomass across a range of ecosystems.

Another important question is whether these expected changes in fungal abundance and activity will translate into greater quantities of released spores. Where studied, increased fungal abundance has led to increased sporulation (e.g., Chakraborty & Datta 2003), but much more research is needed. In addition, very few long term spore monitoring sites exist in order to make these evaluations. At one site, Corden et al. (2003) found increasing numbers of *Alternaria* spores over 26 years of record, although this is partly attributable to increases in cereal production. Greater fungal exposure has important implications to allergic disease since, increasingly, studies show that exposure to fungal spores in outdoor air is associated with exacerbations of asthma (Dales et al. 2004).

To the detriment of human health and productivity, the same circumstances that benefit fungi in natural settings also promote fungal growth in man-made settings. Because of increased temperatures, reliance on air conditioning will increase. Frequently, improper installation and management of air-conditioning systems, or mismanagement of building ventilation, leads to inappropriate moisture conditions in buildings which can lead to fungal growth. In addition, changes in precipitation regimes are anticipated, with heavier downpours creating local flooding as was experienced in the Northeast in May 2006. Increased flooding in coastal areas is also projected with increases in sea level. All of these scenarios indicate a higher likelihood of wet interior surfaces that are prone to fungal growth and subsequent human exposure to released spores. This will increase problems for those with allergies and asthma as several studies have shown that home dampness is a significant predictor of respiratory symptoms (Dales et al. 1991; Bornehag et al. 2001; IOM 2004). Any change in the severity of storms and subsequent changes in indoor molds may exacerbate the problem (CDC 2006).

4. Focus/relevance to NE

Specific assessments of quantitative or qualitative changes in pollen and/or fungal spores have not been made with respect to the Northeastern United States. However, while trees or ragweed have not been examined in the Northeast per se, milder winters and continued warming trends since 1965 have been linked to earlier flowering and leaf initiation for three woody perennials in this region (grape, apple and lilac) (Wolfe et al. 2007, this issue). These later data suggest that earlier flowering of known allergenic species in the Northeast is also likely. In general it is expected that warming trends and milder winters would shift the timing and distribution of pollen, with subsequent effects on allergic rhinitis. For spores, changes in weather patterns related to precipitation as well as sea level rise, in combination with rising temperatures, are likely to increase favorable environments for spore growth. High urbanization locales in the Northeast could, potentially, act as a surrogate for climatic change, with subsequent effects on pollen production of allergenic species (See Ziska et al. 2003, case study).

5. Uncertainties/Points for further research

While climate change is likely to alter exposure to aero-allergens, there are a number of uncertainties that need to be addressed before the range of health impacts and possible management strategies can be ascertained at either a regional or national scale. These uncertainties include: (a) how other atmospheric changes, particularly ozone and nitrogen deposition, will interact with rising temperature and/or CO_2 levels to alter the growth or fecundity of pollen producers or the biological success of fungi; (b) how stimulation of trees, ragweed, and agricultural weeds by CO_2 would alter pesticide use (and subsequent health effects related to food consumption and water contamination); (c) quantification of the pollen response of summer grasses to climate change; (d) qualitative changes in pollen that might affect allergenicity (see Hjelmroos et al. 1995; Singer et al. 2005); (e) potential interaction between stimulation of plant growth by CO_2 and/or temperature and rates of fungal decomposition and sporulation that could result; (f) over-wintering of insects that could destroy forests (e.g., pine-bark beetle), and the subsequent increase in fires and smoke; etc.

Unfortunately, the extent of climatic change and the specific issues related to aerobiology are occurring at a time when research funds to examine such questions are diminishing. Yet it is also clear that the cost, both economic and environmental, of not understanding the impact of climate change on human respiratory disease via plant and fungal stimulation, and any appropriate control measures, may be substantial. Clearly, effective adaptation and mitigation require a strong scientific consensus that accurately describes and predicts how climate change will contribute to human health. As this information is presently incomplete, current decisions may exacerbate future problems. Yet, public awareness of the problem may spur “grass-roots” efforts that also may be beneficial. Such efforts may include monitoring ragweed growth within urban areas, or fungus and mold education and outreach. In addition, tracking of new, potentially harmful plant or mold species within the Northeast that could arrive as a result of climatic shifts could provide a “heads-up” to policy makers and environmental groups.

Overall, it is hoped that this initial assessment will serve as a guide for interested researchers and policymakers in the Northeastern U.S. and elsewhere to begin a systematic evaluation of fossil fuel combustion and climate on allergic disease, highlighting key areas where additional information is needed.

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References:

American Academy of Allergy, Asthma and Immunology (AAAAI) (2000) The Allergy Report. American Academy of Allergy, Asthma and Immunology, Milwaukee, WI 130 pages.

Bahn Y-S, Cox GM, Perfect JR, et al. (2005) Carbonic Anhydrase and CO_2 Sensing during Cryptococcus neoformans Growth, Differentiation, and Virulence. Current Biology 15, 2013–2020.

Beggs PJ (2004) Impacts of climate change on aeroallergens: past and future. Clinical and Experimental Allergy 34: 1507-1513.

Beggs PJ and HJ Bambrick (2005) Is the global rise of asthma and early impact of anthropogenic climate change? Environmental Health Perspectives 113:915-919.

Borken W, Davidson EA, Savage K, et al. (2003) Drying and wetting effects on carbon dioxide release from organic horizons. Soil Science Society of America Journal 67:1888–1896.

Bornehag C-G, Blomquist G, Gyntelberg F, et al. (2001) Dampness in buildings and health. Indoor Air. 11:72-86.

Carreiro MM and CE Tripler (2005) Forest remnants along urban-rural gradients: Examining their potential for global change research. Ecosystems 8:568-582.

CDC (2002) Asthma prevalence and control characteristics by race/ethnicity – United States. Morbidity and Mortality Weekly Report 53: 145-148.

CDC (2006) Health concerns associated with mold in water-damaged homes after Hurricanes Katrina and Rita—New Orleans area, Louisiana 2005. Morbidity and Mortality Weekly Report 55:41-44.

Chakraborty S and S Datta (2003) How will plant pathogens adapt to host plant resistance at elevated CO_2 under a changing climate? New Phytologist 159: 733–742

Corden J, Millington WM, and J Mullins (2003) Long-term trends and regional variation in the aeroallergen Alternaria in Cardiff and Derby UK – are differences in climate and cereal production having an effect? Aerobiologia 19:191-199.

Dales RE, Burnett R, and H Zwanenburg (1991) Adverse health effects in adults exposed to home dampness and molds. Am Rev Respir Dis. 143:505.

Dales RE, Cakmak S, Judek S et al (2004) Influence of outdoor aeroallergens on hospitalization for asthma in Canada. Journal of Allergy and Clinical Immunology 113:303-306.

Emberlin J, Detandt M, Gehrig R, et al. (2002) Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe. International Journal of Biometeorology. 47:113-115.

Frenz DA (2001) Interpreting atmospheric pollen counts for use in clinical allergy: allergic symptomology. Annals of Allergy, Asthma and Immunology 86:150-158.

Hjelmroos M, Schumacher MJ, and M Van Hage-Hamsten (1995) Heterogeneity of pollen proteins within individual *Betula pendula* trees. International Archives of Allergy and Immunology, 108:368-376.

Institute of Medicine (2000). Clearing the air: Asthma and indoor air exposures. Washington, D.C.: National Academy Press.

Institute of Medicine (IOM) (2004) Damp Indoor Spaces and Health. Washington, D.C.: National Academy Press.

Klengel T, Liang W-J, Chaloupka J, et al (2005) Fungal adenylyl cyclase integrates CO_2 sensing with cAMP signaling and virulence. Current Biology, 15: 2021–2026.

Knox RBC, Suphioglu P, Taylor R, et al. (1997) Major grass pollen allergen Lol p 1 binds to diesel exhaust particles: implications for asthma and air pollution. Clinical andExperimental Allergy, 27:246-251.

LaDeau SL and JS Clark (2006) Pollen production by *Pinus taeda* growing in elevated atmospheric CO_2. Functional Ecology 10:1365-1371.

Lipson DA, Wilson RF, and WC Oechel (2005) Effects of elevated atmospheric CO_2 on soil microbial biomass, activity, and diversity in a chaparral ecosystem. Applied and Environmental Microbiology 71(12): 8573-8580.

Mannino, DM, Homa DM, Pertowski CA., et al. (1998) Survellance for asthma prevalence- United States, 1960-1995. Morbidity and Mortality Weekly Report 47 (SS-1), 1-28.

Mohan JE, Ziska LH, Schlesinger WH, et al. (2006) Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO_2. Proceedings National Academy of Sciences 103: 9086-9089.

Ormstad H, BV Johansen and PI Gaarder (1998) Airborne house dust particles and diesel exhaust particles as allergen carriers. Clinical and Experimental Allergy, 28: 702-708.

Rogers CA, Wayne PM, Macklin EA, et al. (2006) Interaction of the onset of spring and elevated atmospheric CO_2 on ragweed (*Ambrosia artemisiifolia* L.) pollen production. Environmental Health Perspectives 114:865-869.

Singer BD, Ziska LH, Frenz DA, et al. (2005) Increasing Amb a 1 content in common ragweed (*Ambrosia artemisiifolia*) pollen as a function of rising atmospheric CO_2 concentration. Functional Plant Biology 32:667-670.

Wan S, Yuan T, Bowdish S, Wallace L, Russell SD, and Y Luo (2002) Response of an allergenic species *Ambrosia psilostachya* (Asteraceae), to experimental warming and clipping: implications for public health. American Journal of Botany 89:1843-1846.

Wayne P, Foster S, Connolly J, Bazzaz F, and P Epstein (2002) Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO_2-enriched atmospheres. Annals of Allergy, Asthma and Immunology 88*:*279-282.

Webster J (1980) Introduction to Fungi. 2nd edition, Cambridge University Press, New York 669pp.

Wolfe DW, Ziska, LH, Petzoldt C, et al. (2007) Projected Change in Climate Thresholds in the Northeastern U.S.: Implications for Crops, Pests, Livestock, and Farmers. (This issue).

Ziska LH and FA Caulfield (2000) Rising carbon dioxide and pollen production of common ragweed, a known allergy-inducing species: Implications for public health. *Australian* Journal of Plant Physiology 27:893-898.

Ziska LH and George K (2004) Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. World Resource Rev. 16: 427-447.

Ziska LH, Gebhard DE, Frenz DA, et al. (2003) Cities as harbingers of climate change: Common ragweed, urbanization, and public health. Journal Allergy and Clinical Immunol. 111:290-295.