Anthropogenic climate change and allergen exposure: The role of plant biology

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Accumulation of anthropogenic gases, particularly CO_2, is likely to have 2 fundamental effects on plant biology. The first is an indirect effect through Earth's increasing average surface temperatures, with subsequent effects on other aspects of climate, such as rainfall and extreme weather events. The second is a direct effect caused by CO_2-induced stimulation of photosynthesis and plant growth. Both effects are likely to alter a number of fundamental aspects of plant biology and human health, including aerobiology and allergic diseases, respectively. This review highlights the current and projected effect of increasing CO_2 and climate change in the context of plants and allergen exposure, emphasizing direct effects on plant physiologic parameters (eg, pollen production) and indirect effects (eg, fungal sporulation) related to diverse biotic and abiotic interactions. Overall, the review assumes that future global mitigation efforts will be limited and suggests a number of key research areas that will assist in adapting to the ongoing challenges to public health associated with increased allergen exposure. (J Allergy Clin Immunol 2012;129:27-32.)

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That certain gaseous molecules (eg, CO_2, methane, and H_2O) absorb in the infrared portion of the electromagnetic spectrum and contribute to Earth's surface temperatures has been recognized for approximately 200 years.[1] That human activities, principally fossil fuel use and deforestation, continue to add significant amounts of these gases to the atmosphere, with concurrent effects on climate stability, is recognized by the scientific community at large.[2,3] Indeed, as population increases in conjunction with land and energy use, projected concentrations of CO_2 by 2100 are likely to increase to 2$\times$ to 4$\times$ greater than preindustrial levels of the 18th century.[2]

To date, the most comprehensive review and assessment of the science of climate change rests with the Intergovernmental Panel on Climate Change (IPCC).[3] Beginning in 1990, the IPCC has done a methodical and extensive analysis of current peer-reviewed studies, direct observations, historical records, and the paleoclimatologic evidence. On the basis of these evaluations, the IPCC has devised a systematic, weight-of-evidence approach regarding future climate projections that has resulted in an international scientific consensus as to the confidence of anthropogenic climate change. It is clear that climate change is unequivocal, largely anthropogenic, and, given the lack of effective global mitigation, very likely to continue throughout the 21st century. The goal of the current review is not to restate the IPCC findings but rather to provide a relevant context of those findings to plant biology and subsequent effects on allergen exposure and public health.

Within the rubric of anthropogenic climate change, there are 2 global factors that are of particular significance with respect to allergens and the aerobiology of plants. The first is related to differential spatial increases in global surface temperatures. Such increases are a function of the relative proportion of the different greenhouse gases.[3] For example, at the equator, where it is warm and humid, water vapor is the dominant greenhouse gas, and increasing CO_2 concentrations has a smaller relative effect than adding CO_2 to regions with less water vapor (eg, poles and deserts); a similar case can be made temporally because winters in northern latitudes are colder (and hence drier) and would be expected to warm faster than summers.[3,4] This differential increase in surface temperatures, a likely driver of extreme weather events, will certainly have global significance to plant lifecycles. A second factor is that almost all aspects of plant biology are likely to be directly affected by increasing CO_2 concentrations because CO_2 is the sole supplier of carbon for photosynthesis and growth. How both factors affect the production, distribution, dispersion, and allergenic potential of pollen and plant species is the focus of the current review.

Abbreviations used
IPCC: Intergovernmental Panel on Climate Change
PM: Particulate matter

INCREASING CO_2 CONCENTRATIONS AND TEMPERATURE: POLLEN PRODUCTION, SEASON, AND DISTRIBUTION

Recent estimates suggest that approximately 34 million Americans have been given a diagnosis of asthma.[5] Results from the International Study of Asthma and Allergies in Childhood indicate that the global (and North American) burden of asthma is continuing to increase.[6] A range of possible mechanisms for the increased prevalence of allergic disease have been postulated.

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At present, the role of changes in plant aeroallergen exposure times and concentrations associated with increasing CO_2 concentrations, climate change, or both as a potential contributor to the observed increase in asthma is still being elucidated.[7,8] However, it is recognized that there are 3 distinct plant-based contributions to allergenic pollen likely to be affected by anthropogenic change: trees in the spring, grasses and weeds in the summer, and ragweed (*Ambrosia* species) in the fall (autumn).

Trees

A number of peer-reviewed studies indicate a clear association between anthropogenic climate change and significant advances in spring flowering times with subsequent shifts in plant phenology and anthesis.[9,10] Long-term records have indicated earlier initiation of flowering for oak (*Quercus* species)[11] and birch (*Betula* species)[12] consistent with earlier and warmer spring temperatures. In addition, European pollen data have shown increases in hazel and birch counts in Switzerland and Denmark.[13-16] Studies have also projected an advance of pollen initiation of 1 to 3 weeks for olive *(Olea europaea)*[17] and up to 4 weeks for *Quercus* species (and up to 50% more pollen) with projected warming.[11] Research on loblolly pine *(Pinus taeda)* at the Duke University Free-Air CO_2 Enrichment site showed that increased CO_2 concentrations *per se* could also induce earlier and greater seasonal pollen production.[18]

However, the interactive role of warming temperatures and increasing CO_2 concentrations on pollen production in tree species is complex. Often, tree species, unlike other aeroallergen plants (eg, weeds), require temporal exposures to minimum winter temperatures to break dormancy (ie, vernalization), followed by warmer spring temperatures to speed anthesis. Consequently, projecting pollen release from some tree species, such as birch, is complicated by differential responses among *Betula* species to low winter temperatures,[19] as well as the difficulty of distinguishing pollen among different species of birch. Overall, although trees do release aeroallergens in the spring, warmer winters might result in earlier flowering or flowering delays or even decreased floral numbers, depending on the tree species' specific needs for vernalization. Hence there can be both earlier and later allergen exposures from trees, depending on species and location. Overall, changes in pollen season length, allergenicity, and amounts have not been well quantified, particularly for hardwood trees with respect to increasing CO_2 concentrations or CO_2 concentrations and temperature.

Changes in tree spatial distribution have been both observed and are projected to continue. There are now observations of northward shifts in plant hardiness zones in the United States.[20] Therefore, as minimal winter temperatures increase, allergenic species are also likely to migrate poleward, with subsequent effects on their distribution (eg, *Betula* species).[21,22] Levetin and Van de Water[23] have also recently discussed the expansion of *Juniperus* species in the United States over the past several decades, including potential links with both climate change and increasing CO_2 concentrations.

Weeds and grasses

A number of weed and grass species are known allergenic pollen producers during the summer. In general, an earlier start of the pollen season associated with warmer temperatures has been shown for mugwort (*Artemisia* species),[24] nettle,[25] and some grasses.[26,27] Similarly, the total airborne pollen load has progressively increased for some important weed species, such as *Parietaria* species, over recent decades in association with increasing temperatures.[28] As with trees, however, quantification of combined temperature and CO_2 concentration effects on pollen seasonality, allergenicity, and pollen load has not been determined.

There is now considerable evidence that weed distribution might also be affected by anthropogenic climate change.[29-31] At present, it is unclear whether such expansion will shift the species distribution northward *in toto* or increase the entire range, and further study is needed to determine the potential consequences of altered distribution in regard to aerobiology. However, we would emphasize that, in general, many of the anticipated anthropogenic climatic changes, such as increasing CO_2 concentrations or greater occurrence of abiotic extremes, are associated with environmental conditions that are likely to favor physiologic characteristics associated with weed biology and fecundity.[31] Weeds are, in fact, inherently adapted to disturbance and transition and benefit irrespective of whether such a disturbance is anthropogenic or natural in origin.

Ragweed

Among allergenic species, perhaps the most studied has been ragweed (*Ambrosia* species), the principle fall allergen (Table I).[32-40] This might reflect the pernicious and ubiquitous nature of ragweed pollen. For example, results from the US National Health and Nutrition Examination Survey show that 26.2% of the US population has a positive skin test response to ragweed.[41] The current National Health and Nutrition Examination Survey 2005-2006 survey shows that among those who reported any allergy-related symptoms in the past 12 months, ragweed allergen–specific IgE sensitization rates ranged from 23.0% to 32.8%.[42] The American Academy of Allergy, Asthma & Immunology estimates that about 36 million persons in the United States have seasonal ragweed allergies.[43]

In a prairie experiment, simulation of warming *per se* (1°C-2°C) significantly increased western ragweed pollen production and pollen diameter.[32] Projected increases in atmospheric CO_2 concentrations also stimulated the growth and pollen production of common ragweed by 60% to 90% in indoor studies.[33,34] Manipulation of both temperature and CO_2 concentration in a glasshouse study to simulate the effects of climate change resulted in earlier flowering, greater floral numbers, and greater pollen production in common ragweed.[35]

Because the relevance of experimental results produced in indoor studies to larger regional areas is uncertain, attempts have been made to determine the response of common ragweed to increasing CO_2 concentrations and temperatures at greater spatial and temporal scales. Microclimatic affects of urbanization, most notably a CO_2 concentration and temperature increase, were used as an analog for near-term climate change projections to quantify the growth and pollen production of common ragweed over an urban-rural gradient in Baltimore, Maryland.[36] These data indicated that ragweed plants grew faster, flowered earlier, and produced significantly greater aboveground biomass and pollen at urban relative to rural locations.[37] Microclimatic effects of urbanization have also been linked to longer pollen season and earlier floral initiation for Polish cities.[44]