PROCEEDINGS

DEVELOPING A RESEARCH AND EDUCATION OUTREACH AGENDA

A Symposium held in conjunction with the
Centennial Conference of the American Society for Horticultural Science
Saturday, October 4, 2003
Providence, RI

INTRODUCTION

The most recent report of the UN Intergovernmental Panel on Climate Change[1] concluded that climate change is already upon us, and that the impacts of this change will not be uniform across regions or species. Almost all horticultural plants are highly sensitive to the direct effects of rising atmospheric carbon dioxide (CO_2) concentrations, as well as temperature and precipitation. Climate change and CO_2 are likely to alter important interactions between horticultural plants and pollinators, insect and disease pests, and weeds. Recent studies[2] have documented that during the past several decades, significant shifts in plant phenology (e.g., earlier first leaf and first bloom dates) and insect migration patterns have occurred for some species in the U.S. and Europe.

This symposium will be the first of its kind to focus on implications of climate change and CO_2 for the important fruit, vegetable, and ornamental horticulture industries. The meeting will bring together climate scientists, horticultural researchers, Extension educators, and representatives from public gardens, environmental and gardening groups, and industry. Invited speakers include leading authorities on climate science, experts on plant and plant pest responses to greenhouse gases and climate, and scientists involved in education outreach and "citizen science" programs. We will review the current state of knowledge, identify research and education priorities, and hear from concerned stakeholders.

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[1] UNIPCC. 2001. *Climate Change Synthesis Report*. Cambridge University Press, Cambridge, UK (also, www.ipcc.ch)

[2] Schwartz MD. 1994. *Internat J Biometeor* 38:18-22; Walther et al. 2002. *Nature* 416:389-396; Fitter and Fitter. 2002. *Science* 296:1689-1691.

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D. Wolfe (chair), A. Markham (co-chair), N. Bassuk, A. DeGaetano, M. Eames-Sheavely, G. Good, A. Lakso, C. Mazza, D. Rakow, F. Rossi, R. Seem

Impacts of Climate Change on Horticulture:
Developing a Research and Education Outreach Agenda

Program

Moderator (morning session): David Wolfe, Professor, Dept. of Horticulture, Cornell University

8:15 **Welcome and Opening Remarks**
Jeffrey Seemann, Dean, College of the Environment and Life Sciences, University of Rhode Island

8:30 **Greenhouse gases and climate change: what we know now**
William Moomaw, Director of the Institute of the Environment, Tufts University

9:00 **Climate change and water resources**
Art DeGaetano, Assoc. Professor, Dept. of Earth and Atmospheric Sci., Cornell University

9:30 **Evidence of climate change in the Northeastern U.S.**
Cameron Wake, Assoc. Professor, Climate Change Research Ctr., University of New Hampshire

10:00 **BREAK**

10:15 **Changes in North American spring as indicated by the lilac phenology network**
Mark Schwartz, Professor and Chair, Dept. of Geography, University of Wisconsin-Milwaukee

Panel: Climate change, invasive species, and pest control

10:45 **Insect pests and population dynamics**
Andrew Gutierrez, Professor, Division of Ecosystem Sci., University of California, Berkeley

11:10 **Plant disease management**
Stella Coakley ,Professor and Head, Dept. of Botany and Plant Pathology, Oregon State University

11:35 **Invasive weeds**
L.H. Ziska, Plant Physiologist, Alternate Crop and Systems Lab, USDA-Beltsville

12:00 **LUNCH**

Moderator (afternoon session) Adam Markham, Executive Director, Clean Air-Cool Planet

1:15 **Yield and quality responses of horticultural crops to CO_2 and temperature**
Mary Peet, Professor, Dept of Horticultural Sci., North Carolina State University

1:45 **Results of the recent "National Assessment" of climate change impacts on agriculture**
John Reilly, Assoc. Research Director, Program on the Sci. and Policy of Global Change, MIT

2:15 **Climate change impacts on public and private gardens and landscapes**
Richard Bisgrove, Senior Lecturer, Centre for Hort. and Landscape,University of Reading, UK

2:45 **Education outreach and data collection through "citizen science" programs**
Robert Stevenson, Assoc. Professor, Dept. of Biology, University of Massachusetts-Boston

3:15 **BREAK**

3:30 **Reaction Panel:** Brief comments by pre-designated representatives of stakeholder groups

- *Harry Chase, Owner of Chase Farms (wholesale nursery and bedding plants), Portsmouth, RI;*
- *Rudolph (Rudi) Hempe, Facilitator with the University of Rhode Island Master Gardener Partnerships;*
- *Donald Rakow, Director, Cornell Plantations, a public garden with 200 landscaped acres and 3400 acres of natural areas;*
- *Vernon Grubinger, Director, Center for Sustainable Agriculture, and Extension Professor (vegetable and berry crop specialist), University of Vermont;*
- *Alan Lakso, Fruit Crop Physiologist, Professor and Chair of the Horticultural Sciences Department, Geneva Experiment Station, Cornell University*
- *John Reilly, Assoc. Research Director, Program on the Science and Policy of Global Change, MIT*

4:30 **Group Discussion: Developing our research and education priorities**

5:30 **ADJOURN**

Summaries of Presentations

A Review of the Potential Impacts of Global Warming on U.S. Water Resources

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Discussions about the influence of CO_2 induced climate change on U.S. water resources are confounded by inconsistencies in model projections concerning changes in precipitation under the scenario of doubled atmospheric CO_2. While virtually all models agree that global (and in many instances regional) temperatures will rise through the next century as CO_2 levels approach twice their pre-industrial level, disagreement on the sign of any change in precipitation amount is generally the rule. In high latitudes (notably across Canada and Siberia), there is a general consensus that both summer and winter precipitation will increase. Across the eastern and western thirds of the United States, winter precipitation is also expected to increase. However, climate models give inconsistent signals for summer rainfall in these regions and precipitation during both seasons in the central U.S. To the south, over the subtropics and particularly across Mexico and Central America there is a more consistent signal toward decreases precipitation (both in summer and winter) under a doubled-$C0_2$ scenario.

Nonetheless, consistent climate model signals of between 1 and 4°C warming during the next century provide some insight as to how the hydrological cycle and hence water resources may be affected. Albritton et al. (2001) summarize model projections of future climate changes related to the hydrologic cycle through the 21st century. Based on agreement between a suite of models it is virtually certain that the water vapor content of the lower atmosphere will increase, presumably due enhanced evaporation under warmer temperatures. Likewise given agreement between a number of models and physically plausible rationale, it is very likely that the precipitation signals noted above, as well as increases in precipitation over tropical oceans, will be seen during the next century. There is less evidence that tropical storm frequency and intensity will increase and much uncertainty regarding non-tropical mid-latitude storm frequency and strength.

Furthermore, modeling studies point to a general drying of mid-continent areas in summer, in terms of soil moisture. (Cubasch et al. 2001). This feature stems from an increase in potential evaporation without a commensurate increase in precipitation. Conversely, modeling studies also point to an increase in the frequency/magnitude of extreme precipitation events (Cubasch et al. 2001). Taken together these two results point to an exaggerated hydrologic cycle where the frequency of both droughts and floods are seen to increase under global warming.

In many ways the observed trends in hydrologic cycle variables across the United States reflect those anticipated by the models. Annual precipitation over the contiguous U.S. has increased modestly (.5 – 1%/ decade) over the last 100 years . Figure 2, produced by the National Climatic Data Center, shows that observed declines in precipitation have been confined to California, Northern New England, and the western High Plains.

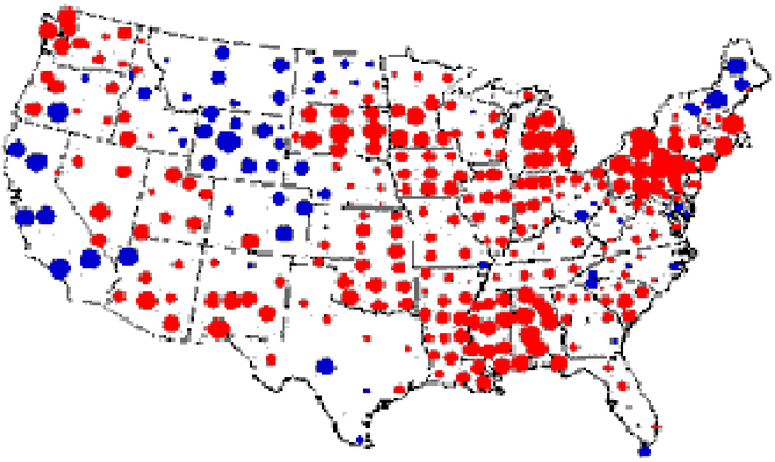

Figure 2. Locations of increasing (gray) and decreasing (black) trends in annual precipitation 1900-1995. The size of each dot represents the magnitude of the trend, with the largest dots indicating 20% change and the intermediate smallest dots showing changes of 10% and 5%, respectively.

Recent studies of primarily mid latitude locations have shown that in many areas, regardless of the observed trend in average precipitation, the frequency of heavy precipitation events (generally those greater than 5 cm) has increased over the last 50 years by approximately 2-4% (Karl and Knight, 1998). The observed record provides little indication of changes in drought frequency, or storm occurrence. However, based on paleoclimatic data (e.g. Cook et al. 1999), there is evidence that the 20th century precipitation record is not representative of the longer term North American drought history. They point to large droughts affecting the much of the Great Basin region of the U.S. for multiple decades during the period from 900 to 1400.

The instrumental record also allows trends in other hydrologically important variables to be assessed (Folland et al. 2001). Snow cover extent across the Northern Hemisphere has decreased on the order of 10% since the mid 1960s. There is strong evidence that this is in response to increases in Northern Hemisphere land temperatures over this period. Likewise, in situ measurements of the duration of lake and river ice have shown a trend toward early thawing over the last 150 years. Trends in evaporation also appear to be related to observed trends in both temperature and precipitation. Potential evaporation (usually inferred from evaporation pan data) has shown consistent decreases across the United States over the last 20 years. However, observations of actual evaporation (particularly in the United States) have trended toward higher values. It is argued that these increases in actual evaporation are related to a greater availability of moisture from enhanced precipitation, despite decreases in the factors responsible for evaporation rates under ample available water.

So collectively what do these observed and projected climatological changes imply for U.S. water resources? It is difficult to view the climate impacts that will affect water resources in isolation. It is likely that stresses on water supplies resulting from population shifts and changes in water rights will be on the same order as those resulting from climate change. Furthermore, arguments can be made for both exacerbation and moderation of these non-climate impacts by the projected 21st century climate changes. With this is in mind, it is likely that the biggest water supply impacts will be felt by the snow-feed systems in the west (Jacobs et al. 1998). In this region, the timing of water supply availability is as important a factor as any change in precipitation amount. These systems are affected by changes in precipitation type as well as the timing of melt. There is general consensus among climate modelers that water systems fed by snowpack will see earlier spring runoff, higher winter flows and lower summer flows as snow cover in middle elevation basins becomes more ephemeral (Fig. 3). In the Pacific Northwest, conflict already exists between irrigators and municipalities (high summer demand) and ecological concerns like protection of salmon habitats. Changes in the overlying climate are likely to intensify this debate. It is also likely that reservoir operating rules will have to be altered to reflect this change in timing. This is also likely to be an issue in the Northeast given the inflexibility of current water supply systems. Water use conflicts across the country will also be fueled by increases in demand for irrigation and hydroelectric power, owing to increased, evapotranspiration and summer energy demand.

Ground water supplies are likely to continue to be taxed as well. However he potential of enhanced rainfall under global warming offers some hope for increasing recharge to these systems. Nonetheless, it is possible that the character of this increase in total precipitation may play a role in determining how much of the surplus rainfall is available for recharge as compared to lost as runoff. Groundwater issues are likely to be particularly problematic across the Great Plains , where 37% of the irrigation withdrawals are from subsurface sources (Jacobs et. al, 2000). Although ground water is less vulnerable to short-term climate anomalies than surface water, long-term trends and increase in drought frequency and extent are cause for concern. Diminished ground water levels may also adversely affect surface water sources through decreased flows on spring-fed streams.

Water quality issues are also a concern under a global warming scenario that produces an exaggerated hydrological cycle (i.e. more floods and droughts). Heavy rainfall events enhance runoff, thus heightening the risk of water supply contamination (Jacobs et. al. 1998). This may be particularly problematic in agricultural and urban areas

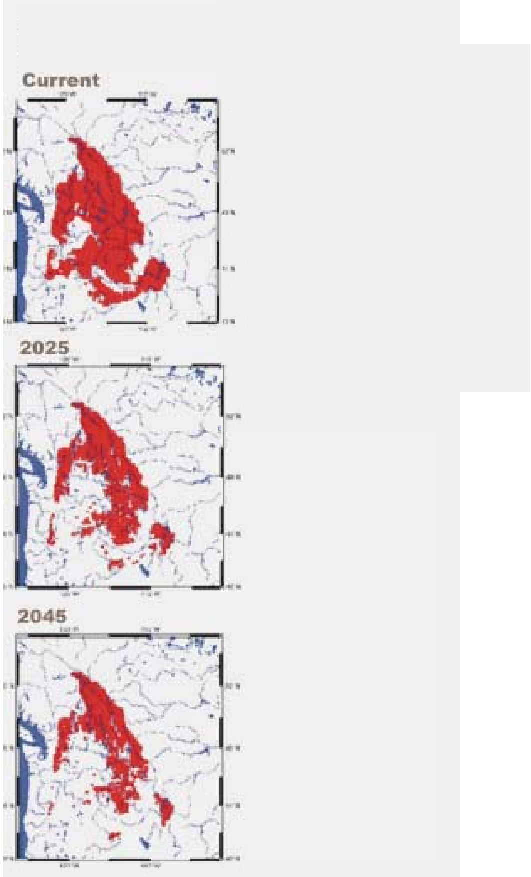

Figure 3 Changes of the extent of snowpack in the Columbia River Basin [from Jacobs et al. 2000].

Some offer a counterargument that this increased risk will be offset by the dilution of organic and inorganic pollutants in the water supplies.

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Evidence of Climate Change in the Northeastern U.S.

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Changes in North American Spring As Indicated by the Lilac Phenology Network

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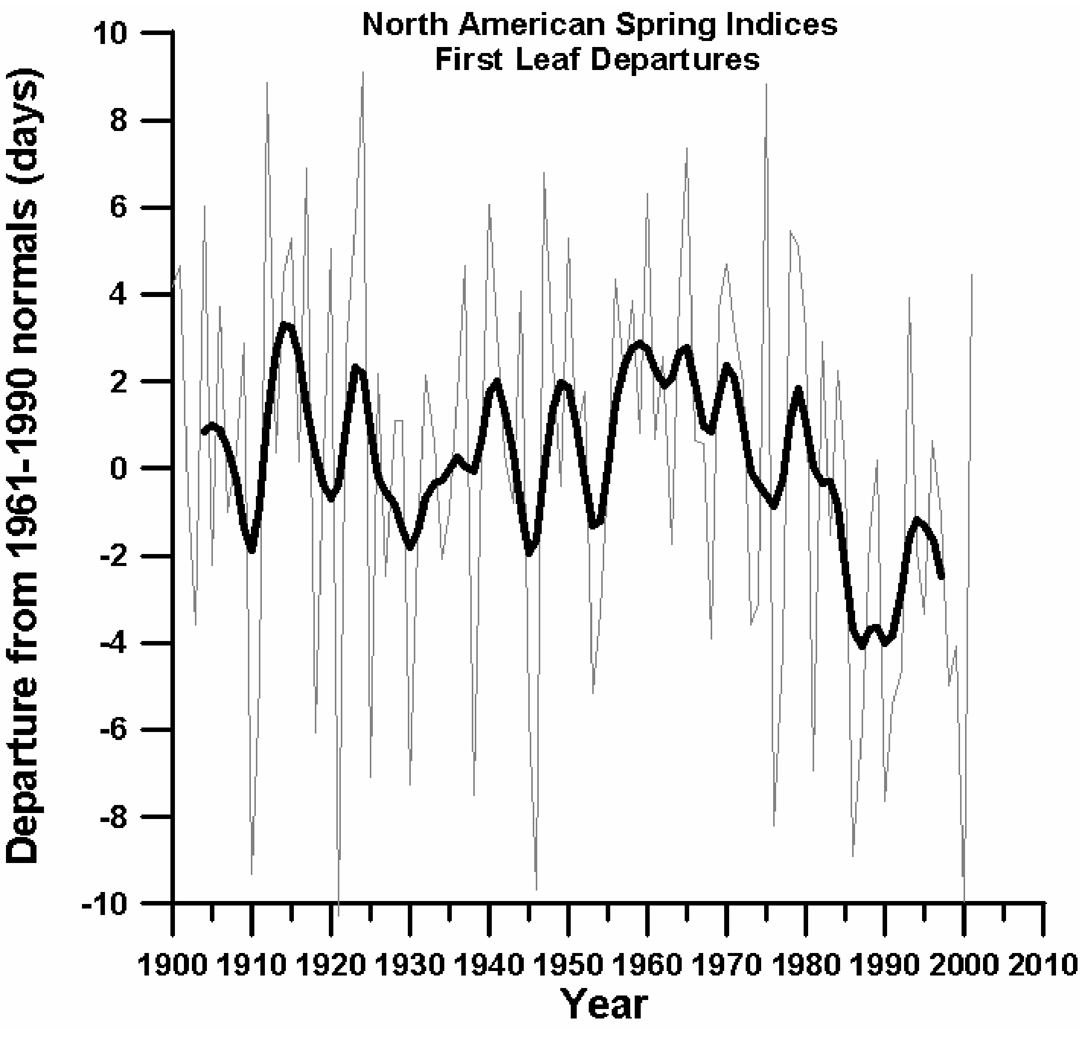
Understanding atmosphere-biosphere interactions is a crucial part of efforts to improve global change simulation models, monitor variations in the growing season, and calculate the carbon budget. Satellite-derived information has a role to play in the development of global biospheric databases, but no comprehensive surface phenology network exists to calibrate these data. One type of phenological measure, the first appearance of Spring foliage (commonly called the "green wave," "start of season," or "onset of Spring"), is particularly important because it is crucial for accurate assessment of many processes, and is among the most sensitive plant-response measures of climate change.

Since satellite data are available for only several decades, and may not provide the details needed for many studies, and a global phenology network is not yet functional, alternatives must be employed to measure changes in the onset of Spring at the global spatial-scale and century timescale. The Spring Indices phenology models have been developed to simulate the Spring phenology of cloned understory shrubs (lilac *Syringa chinensis* 'Red Rothomagenisis' and honeysuckles *Lonicera tatarica* 'Arnold Red' and *L. korolkowii* 'Zabeli'), based on data collected in the Eastern North American Phenology Network (ENAM) from 1961-1994. These models use only daily maximum-minimum temperature data as input. They have been rigorously tested in a variety of regions and continents. While not capable of reproducing all the detailed information that would be obtained from multi-species phenology data, they can process weather data into a form where it can be applied as a baseline assessment of some aspects of a location's phenological response over time.

In North America, cloned lilac phenology data from ENAM is extensive (over 2000 observations), covering the 1961 through 2003 period, however only a few stations (about 50) have records of 20 years or more. Most of these stations (about 35) are in the Northeast USA.

Using the actual lilac and Spring Indices (modeled) phenology data, a clear and consistent pattern of change is evident. The onset of Spring is getting earlier across much of the continent since the late 1950s (Figure 1), with geographic clusters of greater-than-typical change in the Northeast and Western USA, and some indication of change toward later dates in the central USA.

Figure 1.



Panel: Climate Change, Invasive Species, and Pest Control

Effects on Pest Dynamics

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From an anthropocentric perspective, pests are organisms of any taxa (species of arthropods, fungi, plants, vertebrates, etc) that cause annoyance, disease, discomfort, or economic loss to humans. In an ecological context, pests are merely filling evolved roles in ecosystems that have been simplified, or disrupted through domestication, inputs of nutrients and toxic substances, or by human mismanagement. Climate change may disrupt not only pest dynamics in agriculture but also the dynamics of herbivores in natural ecosystems where regulation of their numbers largely goes unnoticed.

To examine the impact of climate change on agricultural and natural systems, we know how species respond to weather, and to do this we must take a holistic tritrophic view, using realistic models that can be field-tested. Some of the questions that need examination are: how will climate change affect pest survival and regulation by natural enemies, the geographic range, pest phenology, pest numbers and damage, and what measures will be needed to control them. Unfortunately, the literature on these topics is sparse.

Three physiologically based modeling approaches are reviewed: (1.) Physiologically based growth indices for climate matching, (2.) physiologically based population dynamics models for examining site specific dynamics, and (3.) physiologically based models embedded in geographic information systems (GIS) for use in regional analyses. All of these approaches are deeply steeped in field data and analysis.

1. Physiologically Based Growth Indices

The use of growth indices to characterize the growth rates of temperate and tropical pastures in Australia was proposed by Fitzpatrick and Nix (1968). The effects of temperature (T), light (L) and soil factors such as water (W) and nitrogen (N) and other factors on plant growth were formulated as normalized convex index functions. The optimum level of the factors occurs at the maximum of the function (index equal unity). The product of these indices predicts the combined effect of all factors on the growth (index *GI (t)*) at time *t* at location coordinates *ij*.

$$GI_{ij}(t) = TI_{ij}(t)xLI_{ij}xNI_{ij}(t)xWI_{ij}(t)....$$

One may view each of the terms a survivorship probability, where their product reflects the individual effects on *GI (t)*. A factor is completely limiting when its value is zero. Gutierrez *et al.* (1974) modified this approach and used mean soil moisture and temperature indices to explain the phenology and abundance of several species of aphids common in Australian pastures. Plots of mean indices for several species produced characteristic distribution on the MI x TI plane that described their ecological niche. Weather played a major role in the phenology and abundance of cowpea aphid while natural enemies played a minor role across S.E. Australia.

2. Physiologically based models

Physiologically based population dynamics models may be examine how weather drives physiological processes and this affects the population dynamics of species. The basic premise of the physiological approach is that all organisms are consumers and have similar problems of resource acquisition (input) and allocation (output). Such models include the effects of weather on behavior and physiology and hence the species' ability to function and compete in a changing environment. Intraspecific competition for resources (bottom-up effects), predation from higher trophic levels (top-down effects), and lateral effects from interspecific competition for resources affect the dynamics of interacting species. All of these responses may be affected by climate change.

Weather may affect patterns of diapause induction and overwinter survival, and a well-worked example is the diapause induction in pink bollworm in response to temperature and photoperiod. Across its range, a wide variety of outcomes are possible producing unique site-specific patterns of diapause induction and population dynamics in responses to prevailing weather. This punctuates the need to understand the factors that determine the yearlong phenology of a species before the effects of different climate change scenarios on pest dynamics can be estimated (e.g., the effect of potential climate change scenarios on pink bollworm phenology and distribution in California).

There are good examples of the effects of climate on the establishment and efficacy of biological control agents (cassava mealybug in Africa, spotted alfalfa aphid, walnut aphid in California, cottony cushion scale in California). The effects of climate change on biological control must be examined in a tritrophic setting, as climatic disruption may occur at any trophic level. The lower down the trophic chain disruption occurs, the greater will be the number of species in food webs likely to be affected (so-called *keystone species*). A well worked out example is the food web analysis of the pea aphid - blue alfalfa system in California alfalfa where weather operating through a fungal pathogen (*Pandora neoaphidis*) determines dominance between the two species of aphid. Pea aphid normally out-competes blue aphid during hot dry periods, but during wet periods the fungal pathogen severely attacks pea aphid but not blue aphid. If as predicted, winter rainfall increases in California, a strong shift in species dominance from pea aphid to blue aphid would likely occur. How many other systems would be similarly affected in this and other ways is unknown.

3. GIS based tritrophic modeling

Analyses of the effects of climate change on regional pest dynamics require the use of weather driven tri-trophic physiologically-based models that are embedded in a GIS system. Two case studies are examined here: the failed biological control of yellow starthistle and the change in the geographic distribution of pink bollworm. If winter rains and temperature in California increase, yellow starthistle would become a even more serious pest, and the range of the destructive pink bollworm might increase into the vast cotton growing regions of the Great Central Valley. Both of these outcomes would be catastrophic. Systems model currently embedded in a GIS include alfalfa, cotton, cassava, coffee, grape, olive, rice and yellow starthistle. The model and GIS are general and hence have wide scale application.

Panel: Climate Change, Invasive Species, and Pest Control

Plant Disease Management

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Plant disease management under a changing climate will pose many of the same challenges that managing diseases under today's climate does. The unpredictability of the direction, magnitude, and speed of change in a given region makes it unlikely that one can accurately estimate the immediate or cumulative impact on disease occurrence for a particular host or ecosystem. There is concern that a changing climate will be accompanied by an increase in the frequency of extreme weather events and that such may result in subsequent increases in disease (Rosenzweig et al. 2001). With a rapidly changing climate, horticultural crops, especially those grown on a perennial basis, are more apt to be growing under conditions of stress and therefore may be more subject to attack by pathogens and insect vectors of pathogens than plants grown under optimal conditions. Although in unmanaged ecosystems, plants and their associated pathogens display the ability to migrate over time in response to natural climatic variation, the speed at which this can happen has little application to managed horticultural crops. It is a given that with any changing climate regime that the severity of some pathogen outbreaks will decrease, others will increase, and some will not change. While one can estimate which diseases will fall into which category based on a knowledge of what diseases are currently present and how they normally fluctuate with meteorological conditions, it is difficult to guess at what new diseases may be introduced into an area and subsequently find a favorable environment. Quantifying the relationship between meteorological variables and disease occurrence has allowed the development of useful prediction systems that allow disease control on high value crops but such systems are available for only a limited number of host-pathogen combinations.

Although the specific topic of this panel focuses primarily on climatic change, it is important to consider a broader context because invasive species are both a cause and a consequence of global change (Scherm and Coakley, 2003). The upsurge in global trade and travel over the last 25 years has resulted in a substantial increase in the number of invasive species and approximate 20% of the losses are due to non-indigenous plant pathogens and their associated control costs (Pimentel et al. 2000). "Predicting invasions of nonindigenous plants and plant pests" is the subject of a a National Research Council report (2002) and serves as an important reference for how future invasions may be anticipated or prevented. New developments in biotechnology will offer an increasing number of tools both for detection and elimination of pathogens on propagation or other plant material and it is important that an emphasis be placed on prevention of plant disease since inspection and quarantine rules may prevent the movement of infected material. As is currently the case, horticulturists will need to utilize all available methods to manage plant diseases under a changing climate.

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Panel: Climate Change, Invasive Species, and Pest Control

Elevated CO_2 and Invasive Weeds

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Invasive plants are generally recognized as those species, usually non-native for a given system, whose introduction, commonly by human transport, results in economic or environmental harm. Obviously, understanding those environmental factors which determine the introduction and reproductive success of such species is of paramount importance. Here we begin to examine one environmental aspect that is rapidly changing both with respect to background concentration and as a result of urbanization--the amount of carbon dioxide (CO2) in the atmosphere.

Initial studies of 6 of the top 15 agronomic invasive species to CO_2 concentrations that existed at the beginning of the 20th century, the current [CO_2], and the future [CO_2] projected for the end of the 21st century were conducted over an 18 month period using growth chambers. The average stimulation of plant biomass among invasive species from current to future [CO_2] averaged 46%, with the largest response (+72%) observed for Canada thistle (the number one rated agricultural invasive). However, the growth response among these species to the recent [CO_2] increase during the 20th century was significantly higher, averaging 110%, with Canada thistle again (+180%) showing the largest response. Overall, the CO_2-induced stimulation of growth for these species during the 20th century (285-382 μmol mol^{-1}) was about 3x greater than for any species examined previously.

In addition to species associated with agronomic conditions we also examined a rangeland invasive, cheatgrass (*Bromus tectorum*) associated with livestock damage and the outbreak of fires in the Western U.S. Overall, we are examining lignin content, combustibiilty and growth of this species over a smaller range of CO2 concentrations, from 270 to 420 ppm. Although data are still being analyzed, the growth data to date are also consitent with strong growth response to recent increases in carbon dioxide.

But won't the CO_2 response be limited by nutrients? We examined the N by CO_2 interaction for Canada thistle (*Cirsium arvense* L. Scop.) at ambient and pre-ambient concentrations of atmospheric carbon dioxide [CO_2] (373 and 287 ppm, respectively) at three levels of supplemental nitrogen (N), (3, 6 and 14.5 mM) from seeding until flowering (77 days after sowing, DAS). Leaf photosynthesis increased both as a function of growth [CO_2] and N supply through 46 DAS. Although by 46 DAS photosynthetic acclimation was observed relative to a common measurement CO_2 concentration, there was no interaction with N supply. Overall, N supply did not effect the relative response to [CO_2] for any measured vegetative parameter through 77 DAS. Due to the relative stimulation of shoot biomass, total above ground N increased at elevated [CO_2] for all levels of supplemental N, but nitrogen use efficiency (NUE) did not differ as a function of [CO_2]. Overall, these data suggest that any potential response to increased atmospheric [CO_2] in recent decades for this noxious weedy species was probably not limited by nitrogen supply.

What about control measures? Won't we still be able to control chemically where and when invasive weeds become established? Canada thistle was grown in the field in each of two years at ambient and elevated carbon dioxide [CO_2] (ambient and 350 μmol mol^{-1} above ambient, respectively) in order to assess how rising [CO_2] alters growth, biomass allocation and efficacy of chemical control. Elevated CO_2 resulted in significant increases in below ground biomass (2-2.5x) but no consistent effect on above-ground (shoot) biomass compared to the ambient CO_2 control for both years. Post-emergent herbicides, glyphosate (Roundup^{TM}) and glufosinate (Liberty^{TM}), were applied at commercially recommended rates (2.24 and 0.376 kg active ingredient (ai) ha^{-1}) in 2000 and 2001, respectively. Following a six-week regrowth period, significant reductions in above ground (shoot) and below-ground (root) biomass relative to unsprayed plots were observed under ambient CO_2. Reductions in root, and shoot and root biomass, were also observed in 2000 and 2001, respectively for Canada thistle under elevated CO_2

conditions following herbicide application. However, the decrease in the ratio of sprayed to unsprayed biomass was significantly less at elevated relative to ambient [CO_2]conditions for shoot and roots in both years; and no difference in shoot biomass was observed between sprayed and unsprayed plots for Canada thistle grown at elevated [CO_2] in 2000. CO_2-induced increases in herbicide tolerance were probably not related to differential herbicide absorbence, and similar results for changes in tolerance for herbicides with divergent modes of action also argues against elevated [CO_2]-induced physiological repair. Alternately, tolerance may be simply a dilution effect, related to the consistently large stimulation of root relative to shoot biomass at elevated [CO_2] in Canada thistle. These data indicate that rising atmospheric CO_2 could increase the below-ground biomass and herbicide tolerance of Canada thistle, a widely recognized noxious weed species; and could exacerbate chemical control efforts of other perennial species which demonstrate a CO_2-induced increase in below-ground organs.

These data, while limited, suggest that invasive weeds can, and do, show a strong growth response to recent and projected changes in atmospheric CO2. At least for Canada thistle, this response does not appear to be N dependent, and the efficacy of chemical control for Canada thistle is also altered with increasing CO2. Obviously additional field experiments are crucial to examining key ecological aspects including, competition and seed bank dynamics and establishment. Overall, understanding the role of carbon dioxide, particularly the sudden and dramatic rise in atmospheric carbon dioxide within recent decades, as a possible factor in the biology of invasive species deserves additional consideration. Knowledge obtained in this manner may be crucial in assessing the response and potential threat posed by invasive weeds as atmospheric [CO_2] continues to increase.

Articles:

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Suggested websites:

University of Florida, Center for aquatic and invasive plants. **http://plants.ifs.ufl.edu**

Yield and Quality Responses of Horticultural Crops to CO_2 and Temperature

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Other speakers in this Symposium will be discussing evidence for climate change, implications for weed, insect and disease control, effects on agriculture in general, and effects on gardens. I would like to take this opportunity to present examples of potential temperature and CO_2 effects on vegetable and fruit crops in the hope that each of you will ask the same type of questions about the crops and locations you work with. Perhaps in this way we can prepare ourselves and our growers for climate change in the coming decades.

The examples I have chosen are: interaction of CO_2 and elevated temperature on yield in tomatoes and potatoes, grapes and apples (grape and apple data provided by Alan Lakso, Cornell University, Geneva, NY). Interaction effects on carrot, onion, and cauliflower are discussed briefly. Even less data is available on quality, but some examples from studies on tomatoes and Japanese pear are cited. CO_2 enrichment data only or CO_2 and drought/nutrient stress data on lettuce, bean, cauliflower, leek, onion, kohlrabi, sweetpotato, carrot, pepper, citrus, and radish is also summarized.

There is considerable uncertainty about the agronomic implications of climate change, and even more about the implications for horticultural crops. Days to market should decrease in most crops with temperature increases, but in some cases, yield and/or fruit quality also decreases. There are also exceptions to the effect of higher temperatures on maturity. In cauliflower in England, for example, curd initiation was delayed for up to 49 days and 36 more leaves were produced. Potentially, higher CO2 and temperature could increase yields, but in tomatoes and potatoes, CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperatures on yield.

It is hard to generalize over the wide variety of both crops and growing locations that are important in horticultural production, and even harder to generalize in moving beyond strictly production responses into markets, timing of production, and availability of inputs such as labor, water and energy. Presumably in areas where current temperatures are below optimal for specific crops, there will be a benefit, while in areas where plants are near the top of their optimal range, yields will decrease. In crops where low winter temperatures are required for vernalization, to meet chilling requirements, or to regulate sap flow in sugar maples, effects of milder winters are hard to predict. Since many crops with chilling requirements are tree species, moving production areas is difficult. Thus in replanting orchards and plantations over the next decade, selection of lower-chill types may be advisable.

Potentially, with global warming production areas for specific crops and/or timing of planting could be changed, but for many horticultural crops, market windows and infrastructure, such as availability of local packing and distribution facilities are critical components of the production system. Locations of important production areas are often defined as much by available land, markets and infrastructure as by climatic conditions *per se*. Thus as horticulturalists we have to ask ourselves and our clientele whether it is realistic to move production areas in response to climate change, or whether there are other production practices that can be adjusted to compensate.

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Climate Variability and Change: The US National Assessment

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The US National Assessment of Climate Variability and Change examined the impacts on U.S. agriculture of transient climate change as simulated by 2 global general circulation models focusing on the decades of the 2030's and 2090's. It also examined historical shifts in the location of crops and trends in the variability of U.S. average crop yields, finding that non-climatic forces have likely dominated the north and westward movement of crops and the trend toward declining yield variability. For the simulated future climates we considered impacts on crops, grazing and pasture, livestock, pesticide use, irrigation water supply and demand, and the sensitivity to international trade assumptions, finding that the aggregate of these effects were positive for the U.S. consumer but negative, due to declining crop prices, for producers. The analysis, in addition to grain and forage, considered potato, tomato, citrus, and cotton crop, thus extending beyond many previous studies that have not considered horticultural crops. It also examined the effects of potential changes in El Niño/Southern Oscillaton (ENSO) and impacts on yield variability of changes in mean climate conditions. Increased losses occurred with ENSO intensity and frequency increases that could not be completely offset even with perfect forecasts of the events. Effects on yield variability of changes in mean temperatures were mixed. Case study interactions of climate, agriculture, and the environment focused on climate effects on nutrient loading to the Chesapeake Bay and groundwater depletion of the Edward's Aquifer that provides water for municipalities and agriculture to the San Antonio, Texas area. While only case studies, these results suggest environmental targets such as pumping limits and changes in farm practices to limit nutrient run-off would need to be tightened if current environmental goals were to be achieved under the climate scenarios we examined.

Climate Change Impacts on Public and Private Gardens in the UK

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Introduction:

Our report *Gardening in the Global Greenhouse* (Bisgrove and Hadley 2002) was published under the auspices of the UK Climate Impacts Programme. The National Trust and the Royal Horticultural Society were the two main organisations funding the study together with six other sponsors.

The terms of reference for the study required the authors to examine the potential impacts on gardens of climate change scenarios produced in April 2002 for the United Kingdom Climate Impacts Programme, in the *UKCIP02 Scientific Report* (Hulme et al. 2002). We felt it important, though, to emphasise two other important sets of potential impacts on gardens: extreme weather events not necessarily related to climate change and what might loosely be called "urbanisation".

The *UKCIP02 Scientific Report* uses four scenarios of carbon dioxide emissions and from them develops four scenarios of climate change for three 30-year periods centred on the 2020s, 2050s and 2080s for over a hundred 50x50km grid squares covering the UK. In order to cope briefly with this mass of data, the following discussion focuses on the medium-high scenario and the 2080s, and uses broad geographical regions.

Scenarios and impacts:

Carbon dioxide concentrations will increase by 45-125% over current levels. In most climate change sector studies, this is important only in that it is the driver for climate change. In horticulture and garden management carbon dioxide levels have a direct significance in affecting photosynthesis. In the short term, a doubling of carbon dioxide concentration may increase plant growth by 40-50%. Plants will be sturdier and may show greater freedom of flowering and greater resistance to pest attack. If maintenance involves removing excess growth (as in mowing), there will be more material to remove. In the long term, plants may adapt to increased carbon dioxide levels by reducing the number of stomata, thereby increasing efficiency of water use.

Temperatures will rise by 2.5-5°C in summer and by 2-3°C in winter. This will result in earlier springs, later autumns (falls) and a longer growing season. A 1°C rise in temperature is roughly equivalent to a 3-week increase in growing season in the south; ten days in the north of the UK. A year-round growing season will therefore be experienced in many years in the south before the 2080s.

There will be more hot and very hot days (10 year maximum increases from 37°C to 42°C in central England) and much less frost and snow. Warmer winters will result in reduced winter chilling, affecting flowering (and therefore fruiting) in important fruit crops.

Generally higher temperatures will have important indirect effects in accelerating loss of organic matter in soils and increasing evaporation. They will also favour the spread of overwintering pests and the survival of pests introduced or migrating from warmer climates. These indirect effects will have more dramatic effects on the cultivation of plants than will the temperature rise itself: a 3°C rise is roughly equivalent to half a USDA climate zone and most plants *in cultivation* will be able to adapt to that change. (The situation in the natural environment will be much more dramatic.)

Summer rainfall will decrease by 30-50% and an increasing proportion of the precipitation which does occur will be lost by evaporation because of higher temperatures. There will be more frequent, more severe and more prolonged droughts. Hotter and drier conditions will favour pests such as red spider mite and many aphids. Fine lawns, large trees and pampered perennials will be most at risk from drought, though the last group will be manageable with higher inputs. Lawn management, in particular, may need to be modified dramatically as higher winter temperatures and lower summer rainfall shift the mowing season from April-October to September-June. Water bodies (ponds and lakes) will also be under serious threat from a combination of reduced water supply, higher temperatures (reducing dissolved oxygen levels) and higher nitrate levels from the accelerating breakdown of soil organic matter.

Autumn and spring rainfall will decrease but by small amounts. Conditions for garden visiting will improve and demand for earlier and later opening of gardens may increase. Late autumn plants (especially grasses) may be more effective and autumn foliage colour may be more pronounced *if* leaves do not fall prematurely as a result of drought. We could see a return to autumn as the main planting season, and nurseries might stimulate this to foster a second season of sales in response to the end of summer drought.

Winter precipitation will increase *but* evaporation also increases at higher temperatures. The result will be a net *reduction* of soil moisture reserves except in the north-west of Scotland. Snow will become a rare event in the south, and may be reduced by 60-80% even in the north. There will be increasing scope for “Mediterranean” and “sub-tropical” gardening, although this will be hampered by short days and low light levels characteristic of the UK climate.

Winter rainfall will be increasingly concentrated into shorter downpours. Flood risks will increase and water conservation will become of crucial importance, especially given the loss of soil structure and serious reduction of precipitation anticipated in the scenarios. High temperatures will increase the susceptibility of tree roots to flooding, and the combination of higher temperatures and flooding will increase the incidence of root-fungi such as Phytophthora.

Wind speeds may increase slightly (4-10%) in winter but could have significant impacts if larger and leafier trees are exposed to higher winds in wetter soils.

Sea level rise will be negligible in the north west (where the land is rebounding from the effects of the last ice age) and will vary from 15-85cm in the south-east. Storm surges may be 80-140cm higher in the south-east.

Overall outcomes:

In the short term, climate change will present increased opportunities for adventurous gardening in private gardens and public parks where change is acceptable or welcome. It presents serious challenges for the conservation of historically important gardens and plant collections.

Overall message:

Climate change is here, and here to stay. The adverse effects of climate change will be exacerbated by intensification of land use ("urbanisation").

In gardens we can develop considerable resilience to climate change by good gardening although greater inputs will be needed to conserve historically important gardens. In the next half-century, at least, general cultural changes (including fashions relating to the conservation of historic gardens) will be at least as important as climate change in determining the future of gardens.

However, unchecked climate change at currently predicted rates will lead to major disasters in many parts of the world, in comparison with which worries over brown lawns in UK gardens become trivial or obscene.

Gardens have an important part to play in the UK psyche. Gardening techniques have an important part to play in reversing the adverse effects (physical and psychological) of urbanisation. By using the garden as a symbol or model of the wider environment, and by extending the principles of good gardening to the UK landscape as a whole, we may retain the reality and perception of the UK as a green and pleasant land, and perhaps save the human race.

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The Dandelion Project, Climate Change and a Framework for Citizen Science

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Abstract

Scientific data indicate that Earth's climate is warming, which has the potential for multiple, large impacts on human societies. Yet societies are reacting slowly. The Dandelion Project was conceived of as a way for school children to get direct experience with climate change issues by monitoring dandelion phenology at large spatial scales using web technologies. I described the anticipated educational and scientific results, relate two years of experience with a pilot project and discuss a framework for doing citizen science projects.

Challenges of Climate Change

Today we face a great number of environmental alterations – loss of natural habitats, accelerated extraction of natural resources, increased loads of toxic substances, loss of biodiversity and multiple threats from invasive species (Lubchenco et al.1991, Lubchenco 1998). Climate change is acknowledged as one of the most important of these changes (Lubchenco 1998, EPA, 2002) and is clearly connected to other alterations such a biodiversity loss (WWF 1996, Burns 1999)

A host of globally coordinated studies have documented that our climate is changing (see publications at the Intergovernmental Panel on Climate Change (IPCC) website). Scientists working within the IPCC framework have made predictions about the climate trajectory and called attention to the detrimental impacts for human societies. However, because of the remoteness of these changes to people (there are large fluctuations in weather from year to year so climate changes are difficult to experience, Bradley 1999), a lack of understanding of the climate change mechanisms (Nancy Cole, Union of Concerned Scientists, personal communication), politics and basic resistance to change (Gelspan 1998, Godrej and Godrej 2001, Essex and McKitrick. 2003), societies are taking few actions (i.e. Kyoto Treaty experience).

There are growing efforts to incorporate scientific findings into policy decisions through such strategies as adaptive management and applications of the precautionary principle. However, great chasms remain between scientific knowledge and governmental actions. Science educators and the AAAS are aware of the basic scientific literacy issue. Through such efforts as Project 2061 and publication of National Science Standards (see below) they are providing new approaches to education known to improve scientific literacy. The Dandelion Project was conceived in light of the hands-on, inquired-based approaches that are being advocated in science curriculum reform efforts.

The Dandelion Project Vision

The specific goal of the Dandelion Project is to engage people, especially elementary school children but also including other groups (scouts, 4-H, garden clubs, etc.) and individuals (birders, naturalists, interested citizens), in monitoring the growth and development of the Common Dandelion (*Taraxacum officinale*) over a wide geographic area each year. The Common Dandelion was chosen because it is widely distributed in North America (found in every state) and because it grows in habitats where people live and work.

The longer term goals are to answer the questions about how the climate is changing. The timing of plant development depends on many variables such as sunshine, temperature, moisture and snowmelt. We expect that during a wet, warm spring, green-up and flowering will occur earlier in the year than when compared with a cold, dry spring. If data are kept for longer periods of time, we will be able to see if changes in dandelion phenology are indicating climate change. The data are not likely to be critical for the scientific community to understand how the climate is changing. Much more dramatic events such as high altitude glaciers and polar ice melting (Thompson et. al. 2002, De Angelis and Skvarca 2003, Mueller et al. 2003) will offer more dramatic evidence. However, the intimate contact people get in collecting data will provide a deeper understanding of the analysis and results that climatologists are reporting. Our notion is that the Dandelion Project will lead to a better informed public.

Environmental Education

The Dandelion Project's education goals and activities are designed to help teachers implement a variety of standards including: the *National Science Standards* (http://books.nap.edu/html/nses/html/), *Project 2061* (http://www.project2061.org/tools/benchol/bolframe.htm), and in Massachusetts the *Science, Technology, and Engineering Frameworks* http://www.doe.mass.edu/frameworks/current.html , and the *Benchmarks for Environmental Literacy* (http://www.state.ma.us/envir/Elbhome.htm.) The heart of this project addresses the sections in these documents that are requiring students to participate in science investigations through inquiry. By "doing science" students bring meaning and reason to their observations, and their conceptual understand of biology, phenology and climate change are being developed. Participants are gathering and interpreting data, formulating explanations, communicating their investigations, and using simple tools to aid them with their observations. Over time participants will be able to see how scientific evidence and explanations are developed. The life science strands that are embedded in this project include characteristics of organisms, life cycles, diversity and adaptations of organisms, populations and ecosystems, form and function, and the transfer of energy. Most importantly, this project provides the foundation to build upon the participant's "habits of mind", and to instill curiosity, enthusiasm, and an innate sense of wonder for an extraordinary plant growing outside our back doors!

Our more general goals are to encourage people to take an interest in their local environment, become more careful observers of plants and animals and to encourage everyone's curiosity about the natural world.

Two years experience with the Dandelion Project

Workshops in person and over the web were conducted with environmental educators and teachers. Initial contact was made at the Massachusetts Environmental Educators Society annual meeting which generated interest among teachers. Information about the overall goals, teaching philosophy, ways to participate, equipment needs, specific instructions for the data forms, websites, contacts and detail instructions for picking a site and recording dandelion phenological data were available via the website (www.dandelionbiology.org), on CD or in a booklet form. The recommended study procedure was described and modeled at the workshops. Sample data sheets and a journal format were provided. First participants were asked to define a study site, and then monitor the phenology of a population or a group of individually marked dandelions during the spring. Data to gather included bud formation, leaf and stalk growth, flowering, seed head opening and seed dispersal through the spring green up. Data were submitted via the website.

Participants have many different kinds of constraints. Students and others cannot samples as often as a scientists would prefer. More feedback from the project during the spring monitoring and of a summary form at the end of the season would improve the project

Teachers are looking for this kind of activity because of its hands on and interdisciplinary nature. Feedback has been very positive from the project as an education experience. Young children know and really love dandelions. First and second grade students become very focused on following their own plants. The project can be integrated with other learning areas including math, art and literature. Teachers had difficulty submitting data because the students were not old enough to do it by themselves.

Designing Citizen Science Projects

The term “Citizen Science” comes for the Laboratory of Ornithology at the Cornell University (http://birds.cornell.edu/). A group of enthusiastic scientists have developed a handful of internet based projects that depend on teaming up with educators, computer programmers, students and citizens in conjunction with other environmental institutions. The Laboratory of Ornithology projects, such as the Christmas Bird Count, Feeder Watch and e-Bird, gather and process information about birds on regional and continental scales (http://www.birds.cornell.edu/programs/citSci/). The Christmas Bird Watch is over a hundred years old so data were initially collected by mail and analyzed by hand. In the early 1990's scan forms were used to automate the input of data for the Feeder Watch program and then in 1999 the laboratory of Ornithology started a project that was entirely web-based call the Great Backyard Bird Count. In 2003 48,446 total checklists were submitted, in which people in the US and Canada observed 512 species of bird and counted over 4.2 million individuals. Now all the projects have web based data input and data sharing.

There are many other kinds of citizen science programs including projects on astronomy, weather, water quality, and biology (Adirondack Science Online 2003, Ecowatch Network 2003, Pathfinder Science 2003, NatureWatch 2003, Society for Amateur Scientists 2003, Stevenson et al. 2003) with several devoted to plant phenology (see Phenology and Phenological Related Web Sites 2003, Phenology Networks Home, PlantWatch 2003, Lilac Phenology Network 2003). In Canadian, the government has taken an active role in citizen science projects through their NatureWatch section of the National Ecological Monitoring and Assessment Network. Citizens study frogs, ice, plants and worms (NatureWatch 2003).

With such a diversity of projects it is hard to make generalizations without more systematic data gathering and analysis (but see The Concord Consortium and TERC. 1996, Ledley et al. 2003). However, based on experience with the Dandelion Project and several other citizen science projects, I can offer the following points.

1. Citizen science projects require a variety of perspectives and careful integration to make them successful. Usually the projects are undertaken by teams and the roles are filled by different people. Scientists generate questions, develop a focus, set protocols, analyze data and publish results. Environmental educators design the materials that citizens and school children can use. Project coordinators interact with schools and the public to provide them the materials in workshops and other formats, answer questions and write press releases. Software engineers do the programming to communicate effectively over the web.

2. Getting feedback to the volunteers is important but people participant for many reasons. There will always be turn over in the participants from year to year.

3. Citizen science represents a chance for scientists to answer questions that were heretofore unanswerable but requires them to work effectively in teams. Among ecologists there is little culture training about how to work in teams effectively during graduate school.

4. There are few standards from a scientific perspective to evaluate Citizen Science projects. For instance it would be possible to have a more structured review of the scientific hypotheses and methods such as with Quality Assurance / Quality Control analysis or Quality Assurance Project Plan used in water quality studies. These process has the possibility for a Citizen Science Project to get endorsement by a scientific society which would then help promote the projects with NGO's and educators. Imagine if AAAS, AIBS, ESA, BSA and ASHS all certified specific phenological projects as being scientifically sound for helping to understand climate change.

5. Many Citizen Science projects seem to be driven by specific people and initiated with grant money rather than having an institutional basis with a sustainable economic plan to

maintain the projects. Since these projects grow in scientific value with time, it is important to plan for a sustainable approach.

6. Education assessment has been limited but for environmental projects the The North American Association for Environmental Education (NAAEE) http://naaee.org/ has a very good process to evaluate educational materials.

7. Citizen projects have not been incorporated into state education plans.

8. Citizen Science activities are better if they include opportunities for students to share ideas, pose their own questions and develop their own studies.

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Speakers and Reaction Panel Participants

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Dr. Coakley is a Fellow of the American Association for the Advancement of Science, and a member of the scientific steering committee for the UN Global Change and Terrestrial Ecosystems Program (with particular responsibility for global change impacts on pests, pathogens, and weeds). Her research focus is quantifying the impacts of climate change on plant disease; she has published several reviews on this topic.

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In addition to research interests focused on observed climate variations over the last 100 years, Dr. DeGaetano is Director of the federally-funded Northeast Regional Climate Center, which has as its mission the enhanced dissemination and use of climate information to a wide variety of sectors in the Northeast. He received an interdisciplinary Ph.D. in Climatology and Horticulture from Rutgers University in 1989.

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Dr. Gutierrez is well-known internationally for his pioneering work on the modeling of insect population dynamics and crop growth for use in Integrated Pest Management. His multitrophic systems models for alfalfa, apple, bean, cassava, coffee, cotton, grape, tomato and other crops have yielded considerable economic benefit world-wide. He has authored or co-authored many research articles, and several books and book chapters, including a recent review of potential climate change impacts on insect pests.

Adam Markham (symposium co-organizer and moderator; amarkham@cleanair-coolplanet)
Executive Director, Clean Air-Cool Planet
Adam is author of *A Brief History of Pollution and Potential Impacts of Climate Change on Tropical Forest Ecosystems*, was a contributing author to the forest impacts chapter of the 1995 UN Intergovernmental Panel on Climate Change (IPCC) Report, and has published in *Bioscience*, *Climate Research*, and other journals. As Director of CA-CP, he frequently collaborates on research and education projects with university faculty and administrators, policy makers, and various stakeholder groups.

William R. Moomaw (william.moomaw@tufts.edu)
Professor of International Environmental Policy at the Fletcher School, and Senior Director of the Institute of the Environment, Tufts University
Dr. Moomaw's research interests are frequently focused on energy, technology, and policy implications of climate change. He was a Convening Lead Author for both the 1995 and 2000 UN IPCC Reports, and has served on numerous national and international committees evaluating environmental issues. In addition to many academic articles, he was co-editor of the recent book, *People and Their Planet: Searching for Balance* (Palgave, 1999).

Mary M. Peet (mary_peet@ncsu.edu)
Professor, Department of Horticulture, North Carolina State University
Dr. Peet is a leading authority on environmental physiology of horticultural crops, particularly effects of heat stress and CO_2 enrichment on tomatoes. She also directs an Extension program on greenhouse vegetable production. She has published 2 books, many peer-reviewed research articles, and 8 book chapters, including co-authoring a recent review of vegetable crop responses to climate change, published in *Climate Change and Global Crop Productivity* (CABI, 2000).

John Reilly (jreilly@mit.edu)
Assoc. Research Director, Program on the Science and Policy of Global Change, MIT
Much of Dr. Reilly's research career has focused on the economics of climate change, including modeling economic impacts on agriculture, and evaluation of agriculture and forestry as carbon sinks. He was a principal author for the UN IPCC Second Assessment, and the agriculture section of *Climate Change Impacts on the U.S.* (Cambridge Univ. Press, 2000). His most recent book (editor) is: *Agriculture: The Potential Consequences of Climate Variability and Change* (Cambridge Univ. Press, 2002).

Mark D. Schwartz (mds@csd.uwm.edu)
Professor and Chair, Department of Geography, University of Wisconsin-Milwaukee
Dr. Schwartz's research interests include plant phenology-climate interactions during the onset of spring in mid-latitudes, detecting climate change, and assessing vegetation condition with remote-sensing imagery. He has published numerous peer-reviewed research articles, and is editor of a new book to be released this fall entitled, *Phenology: An Integrative Environmental Science* (Kluwer Academic, 2003).

Jeffrey R. Seemann (jseemann@uri.edu)
Dean, College of the Environment and Life Sciences, University of Rhode Island
In addition to his current administrative responsibilities, Dr. Seemann is an internationally recognized authority on photosynthesis and plant physiological responses to elevated CO_2. He has served on the Editorial Board of *Plant Physiology* and numerous reviewer panels for NSF and USDA/NRI. Prior to coming to URI, he was Chair of the Biochemistry Department at the University of Nevada, Reno, and a lead organizer of the multi-institutional Nevada Global Environmental Change Program.

Robert D. Stevenson (Robert.Stevenson@umb.edu)
Assoc. Professor, Department of Biology, University of Massachusetts, Boston
Dr. Stevenson has a background in engineering and biology, and interdisciplinary Ph.D. in Biophysical Ecology from the University of Washington. With computer scientist Robert A. Morris at UMass Boston, he is currently working in the area of environmental informatics on a project called the Electronic Field Guide (see www.cs.umb.edu/efg/). His interests also include frameworks for involving students and citizens in science, such as a recent phenology monitoring project with elementary school children.

Cameron Wake (cameron.wake@unh.edu)
Assoc. Professor, Climate Change Research Center, University of New Hampshire
In addition to developing new records of climate change from ice cores collected from around the globe, Dr. Wake is co-PI of a NOAA-funded AIRMAP (Atmospheric Investigation, Regional Modeling, and Prediction) project for the Northeast region. AIRMAP seeks to improve our understanding of changing climate and air quality through the investigation of physical and chemical aspects of the atmosphere.

David W. Wolfe (symposium co-organizer and moderator; dww5@cornell.edu)
Professor, Department of Horticulture, Cornell University
Much of Dr. Wolfe's research program is focused on the effects of climate change and CO_2 on plants and soils. He has numerous articles and reviews on this topic in the scientific literature, and recently published a soil ecology book, *Tales From the Underground: A Natural History of Subterranean Life* (Perseus, 2001). In 1997 he co-authored the agriculture and natural resources sector reports for the White House-sponsored New England Regional Climate Change Impacts Workshop.

Lewis H. Ziska (lewis.ziska@usda.gov)
Plant Physiologist, USDA-ARS Alternate Crop and Systems Laboratory, Beltseville, MD
Dr. Ziska's research goals are to promote a greater understanding regarding the role of rising CO_2 and temperature on: (a) the spread of invasive weeds; (b) weed-crop interactions; (c) efficacy of herbicide applications; and (d) weeds and public health. He received his Ph.D. from the University of Calfornia at Davis in 1988.

Reaction Panel Members

Harry Chase

Owner of Chase Farms, a greenhouse wholesale producer of bedding and landscape plants in Portsmouth, RI.

Rudolph (Rudi) Hempe

Facilitator of the University of Rhode Island Master Gardener Partnerships, Director of the Southern RI Conservation District, and a coordinator of the East Farm Agricultural Experiment Station Plant Evaluation Team.

Donald Rakow

Director, Cornell Plantations, and Assoc. Professor, Department of Horticulture, Cornell University
Director of Cornell's botanic gardens, which includes 200 landscaped acres and 3400 acres of natural areas. Interested in the role of public gardens in education and research relevant to climate change issues.

Vernon Grubinger

Director, Center for Sustainable Agriculture, and Extension Professor, University of Vermont.
Vegetable and berry crop specialist with close ties to the industry, and applied research and Extension program focused on sustainability of farming in the Northeast region.

Alan Lakso

Professor and Chair of the Horticultural Sciences Department, Geneva Experiment Station, Cornell University
Fruit crop physiologist, with considerable experience collaborating with apple, grape and wine producers in New York State

John Reilly

Assoc. Research Director, Program on the Science and Policy of Global Change, MIT
As lead author of a "national assessment" of climate change impacts on agriculture, Dr. Reilly is familiar with knowledge gaps regarding crop responses, economic impacts, and modeling tools. Also, with close ties to USDA, knowledgeable about national policy and funding priorities.