Does Available Scientific Evidence Support the Inclusion of Pollen as a Nationally Consistent Data and Measure Indicator on the Environmental Public Health Tracking Network?

Pollen White Paper from the Pollen Sub-Team, Climate Change Team, Environmental Public Health Tracking (EPHT) Work Group[1, 5]

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Acronyms

AIRS, Aerometric Information Retrieval System

AAAI, American Academy of Allergy, Asthma & Immunology

AAFA, Asthma & Allergy Foundation of American

AVHRR, Advanced Very High Resolution Radiometer

CO_2, Carbon Dioxide

CDC, Centers for Disease Control and Prevention

COPD, Chronic Obstructive Pulmonary Disease

CSTE, Council of State and Territorial Epidemiologists

DPM, Diesel Particulate Matter

ENSO, El Niño Southern Oscillation

EPHT, Environmental Public Health Tracking

ESSENCE, Electronic Surveillance System for the Early Notification of Community-Based Epidemics

EAN, European Aeroallergen Network

ESSENCE, Electronic Surveillance System for the Early Detection of Community-based Epidemics

EU, European Union

GBIF, Global Biodiversity Information Facility

GIS, Geographic Information System

GWS, German Weather Service

IU, International Units

MIF, Macrophase Migration Inhibitory Factor

mL, Milliliter

NAB, National Allergy Bureau

NASA, National Aeronautics and Space Administration

NCDC, National Climatic Data Center

NCDM, Nationally Consistent Data and Measures

NDVI, Normalized Difference Vegetation Index

NEPHTN, National EPHT Network

NOAA, National Oceanic and Atmospheric Administration

NRDF, National Resources Defend Fund

NO_x, Nitrogen oxides

O_3, Ozone

PM, Particulate Matter

$PM_{2.5}$, Fine particulate matter

SEHIC, State Environmental Public Health Indicators Collaborative

SO_2, Sulphur Dioxide

URL, Uniform Resource Locator

US, United States

USDA, US Department of Agriculture

USEPA, US Environmental Protection Agency

USNWS, United National Weather Service

Prologue

This pollen white paper report represents the efforts of the persons identified above. This pollen sub-team was asked to determine if it is possible to develop a pollen National Consistent Data and Measure (NCDM) indicator for Environmental Public Health Tracking (EPHT). I was asked to form the pollen sub-team in spring 2011.

Interest in pollen, as a possible environmental hazard, started to increase because of climate change. My selection to be the lead of the pollen sub-team may have been a result of my prior work in developing a pollen indicator. This earlier pollen indicator effort occurred in collaboration with Dr. Wendy Brunner of the Minnesota EPHT, through the Council of State Territorial Epidemiologists (CSTE) /State Environmental Public Heath Indicators Collaborative (SEHIC) Asthma and Climate Change Work Groups. The completed template and how-to guide for the pollen indicator are now available from the CSTE Internet page, http://www.cste.org/group/ehov. In addition, Dr. Brunner and I made three presentations on the CSTE/SEHIC asthma and climate change pollen indicator at previous held EPHT Workshops held in New Orleans, LA on April 26-29, 2010, New York City (Brooklyn) on April 25-2008, 2011 and Denver on April 30-May 3, 2012.

It has taken a great deal of effort on everyone's part to complete this white paper. Ross Strategic provided the logistical support, conference call and webinar services since mid-2011. Many persons told me informally at the New York City and Denver EPHT Workshops and the EPHT Conference in Atlanta they were interested in participating in the pollen sub-team, but could not because of prior work commitments. Others could only participate in some, but not all, of the conference calls.

The 2011 and 2012 monthly conference calls provided an opportunity for everyone to identify important issues and to arrive at a better understanding of different, although subtle, points of view regarding the minimum standards for an EPHT national pollen surveillance system. For this reason, I wanted to also include the names of persons who freely contributed their ideas, expertise and best assessments on pollen surveillance. Finally, I want to express my gratitude to the pollen sub-team members who wrote sections of the first pollen white paper, reviewed and provided editorial suggestions on earlier versions of this white paper.

John T. Braggio.
January 28, 2013

Executive Summary

The Centers for Disease Control and Prevention's (CDC) Environmental Public Health Tracking (EPHT) decision to evaluate the possible utility of an Nationally Consistent Data and Measure (NCDM) pollen indicator for use by the National EPHT Network (NEPHTN) and by funded state/New York City grantee Tracking partners appears to be, in retrospect, an accurate assessment of the current and future needs of environmental public health and EPHT in the US. This decision was probably in response to the accumulating scientific evidence about the contribution of this new pollen hazard to the occurrence of respiratory-induced illnesses—asthma and rhinitis--as well as the associated health care costs that are occurring now and will surely increase in the future due to climate change.

Scientific evidence is now unequivocal in demonstrating how overall higher total pollen levels and increases in specific pollen taxa that are known to produce more allergic pollen, such as ragweed, adversely impact respiratory conditions. Published scientific studies support the contribution to elevated pollen exposure to increases in asthma and rhinitis visits to health care providers and to emergency departments, asthma inpatient hospitalizations and asthma deaths especially in persons 65 of age or older. Several publications have also demonstrated increased use of over-the-counter medications as an additional method used by pollen-affected persons to personally cope through self-medication with rhinitis and asthma. Other pollen-induced effects include lost school and work days. Some of these pollen effects on different health metrics will be reviewed in this pollen white paper.

The scientific evidence is now unequivocal that climate change effects that include increases in temperature and Carbon Dioxide (CO_2) will result in elevated pollen levels, measured as pollen grains per cubic meter of air. Higher ambient CO_2 have been referred to *fertilizing effects* in stimulating trees and different types of grasses and weeds to produce more pollen. Furthermore, because of a longer pollen season some plant taxa will produce more reactive pollen, such as ragweed, in the United States. The cumulative result is that rates of sensitization and exacerbation of allergies and asthma will increase. Since early exposure to pollen in childhood can result in more persons having asthma.

Climate change increases in pollen levels will produce a hazard and respiratory health loop that will result in incremental increases in the prevalence of asthma and rhinitis. Future cohorts of children who are exposed to higher pollen concentrations could be predisposed to develop asthma at sometime in their lifetime. This suggestion is consistent with the view that increases in asthma prevalence that have occurred in the last two decades have been due to climate change. The doubling of asthma prevalence could be even higher in known risk groups that now include children, blacks, uninsured and persons over 65 years of age. Over decades even a small increase in prevalence can result in possibly the doubling of asthma prevalence in the next 30 years. The content of this pollen white paper will argue that a decision to implement a national pollen surveillance system has to be made as soon as possible because of the complexity and anticipated adverse effects of climate change on respiratory conditions such as asthma.

The pollen sub-team, part of the CDC Tracking (i.e., EPHT) work group within the organizational structure of the climate change team, established a goal of completing its evaluation by August 1, 2012. Initial conference calls involved discussions about the adequacy of currently available pollen monitoring networks. The majority of the pollen sub-team members were of the position that the 82 National Allergy Bureau (NAB) certified pollen counting stations in the US are not enough to satisfy minimum requirements for a national pollen dataset that can then be used to compute an NCDM pollen indicator. The most significant limitations were the absence of at least one pollen counting station in each EPHT state—only 18 of the 24 (75%) programs have at least one monitor—and easy access to actual pollen readings from all of the

82 independent pollen counting stations through a formal data request submitted to the NAB central office. Another limitation was the absence of currently available scientific evidence about what is the functional radius of a pollen counting station. Without this information it is not possible to determine if the existing NAB network of pollen counting stations has sufficient spatial resolution. The minority view was that the NAB pollen count data would be sufficient to develop an NCDM pollen indicator in those EPHT-funded states/New York City programs that had at least one NAB-certified pollen counting station. The pollen sub-team's decision reached in late fall 2011 was to reflect upon what type of optimal pollen Tracking system would complement currently available NCDM indicators as well as other NCDM indicators that were in the process of being developed.

Consensus was reached among all pollen sub-team members to produce a pollen white paper. A small group of volunteers was formed. The smaller pollen working group required approximately three months to write, revise and vet the pollen white paper outline for approval through all other members of the pollen sub-team. Each member also had the opportunity to select writing assignments from the pollen white paper outline. Winter and spring 2012 were devoted to the writing of the pollen white paper outline sections by pollen sub-team members. A first draft was completed by the end of April 2012. The first draft was sent to everyone in the climate change team and was subsequently discussed at the May 2^{nd}, 2012 climate change meeting in Denver, Colorado.

The pollen white paper breaks new ground in the assessment of what pollen tracking resources are currently available in the US and Europe and what will be needed to satisfy the minimum requirements of an environmental-health surveillance system based on currently acceptable and implemented CDC EPHT standards. Additionally, and more importantly, this white paper addresses the urgency of enhancing the available environmental public health response capacity in the US to include the current and future impacts of pollen hazards on selected respiratory health outcomes exacerbated by climate change on respiratory chronic and other related health conditions.

Pollen's adverse effects on respiratory health outcomes will necessarily increase and this hazard-respiratory health relationship will probably change when certain effect modifiers are present. These effect modifiers include: 1) existing co-morbid conditions, such as asthma or rhinitis; 2) increased levels of some criteria air pollutants, such as $PM_{2.5}$ (fine particulate matter) or O_3 (ozone); 3) increased responsiveness to higher pollen levels among sensitized persons, including children, blacks, uninsured and elderly persons 65+ years of age; and, 4) absence of air conditioners in homes located in areas with elevated pollen levels and/or the presence of more allergic pollen grains.

It may be possible in the future to manage pollen hazards through the further development and use of innovative built environment methods to limit what pollen producing plants, trees and grasses are permitted to grow in residential areas where sensitized persons live. Pollen hazards may be mitigated through the increased use of air conditioning, especially in the indoor environments of sensitized and other vulnerable populations. Consideration of the abundance of invasive pollen producing species that will fill ecological niches is also important. For this reason, pollen hazards could be anticipated by using accurate assessments of pollen readings from a satisfactory constructed pollen tracking system with acceptable spatial coverage.

The Pollen Sub-team evaluated the two currently available and major pollen surveillance systems, the NAB in the US and the European Aeroallergen Network (EAN) in Europe. The only pollen surveillance system that includes direct measurements of pollen grains in the US is the NAB. As of March 2012 the NAB included 82 certified pollen counting stations in 35 states. Map 1 shows the number of NAB certified pollen counting stations in the US by state. In the NAB pollen network there are between one and nine pollen counting stations per state. The mean number of pollen counting stations per state is 2.3. As of March 2012 the EAN included 505 pollen counting stations in 36 countries. Map 2 shows the number of EAN pollen counting stations in Europe by country. The Mean number of pollen counting stations in the EAN was 14.0, with minimum-maximum values of 1-99 per country. As expected, the mean pollen counting stations in the EAN was significantly higher than the mean pollen counting stations in the NAB ($p<0.01$).

To facilitate comparison between the states in the NAB pollen network and countries in the EAN pollen network, two equivalent metrics were developed: 1) total persons per monitor; and, 2) total square miles per monitor. The sub team selected the lowest quartile, the bottom 25 percent of states in the NAB and the bottom 25 percent of countries in the EAN, to identify polygons (states or countries) with fewer persons per monitor or fewer square miles per monitor. As seen in Table 4, only the 13 NAB states were significantly different from the 13 EAN countries on persons per monitor but were not significantly different on area per monitor. The mean number of first quartile NAB pollen counting stations was 2.5. But, the mean of first quartile EAN pollen counting stations of 23.5, and was significantly higher. More importantly, these two measures, total persons per monitor and total square miles per monitor, were not significantly correlated. The absence of a significant association between these two metrics suggests that population and area, when expressed as a unit value per available pollen counting stations in a state or country, may represent two independent numeric attributes that describe different attributes of pollen counting stations within states in the US that are part of the NAB pollen counting station network or countries in Europe that are part of the EAN pollen counting station network.

Additional analyses of NAB and EAN pollen counting stations were completed to identify other optimal pollen surveillance system characteristics. One unique feature of the EAN is that the pollen counting stations are maintained by university departments specializing in the study of pollen, including biology and medicine. EAN financial support comes from pharmaceutical companies and universities. The European Union also provides funding for pollen surveillance. The EAN and the participating countries also maintain specialized databases that contain pollen, climate, phenological data, as well as self-reported allergic reaction symptom logs. The EAN pollen-related databases are available to university researchers. These robust databases, with millions of taxa identified pollen and pollen related observations, are used to develop and disseminate local, regional, single and multi country pollen alerts. Pollen advisories are made available through the media and Internet. Pollen reports are also available from smart phones. The language barrier is minimized by making each country's pollen website, as well as the EAN master website, available in several languages, including English. Understanding a country's EAN pollen web page is also facilitated by the use of the Google translation utility. Pollen alerts are developed by using Geographic Information System (GIS) methods. Statistical modeling methods are used to generate pollen surfaces, stratified by pollen taxa sources, for individual countries, regions and all of Europe.

To implement a national EPHT pollen surveillance system in the US several critical and basic questions have to be resolved. We need to know, as stated previously, the functional radius for a *typical* pollen counting station, with regards to persons and square miles per monitor, and possibly other attributes such proportion and type of pollen reactive persons present. What has to be considered is the functional pollen counting station radius for recorded pollen sources as well for different types of pollen. More has to be known about effect modifiers and how they can individually or in combination impact health outcome measures in sensitive and non-sensitive persons. Developing a national pollen surveillance system will require inter-agency collaboration between CDC, the US Environmental Protection Agency (USEPA) and National Aeronautics and Atmospheric Administration (NASA). Still another requirement is to more fully utilize GIS and statistical modeling methods to develop pollen surfaces that can accurately describe current, near-term and future conditions. The reliance on GIS and spatial modeling to understand pollen research questions and to make reliable and accurate pollen single and multi-day forecasts are two activities now being carried out on a regular basis by the EAN. This feature should be utilized in an expanded national pollen surveillance system in the US. Lastly, the remaining major issue to resolve is whether this new NCDM pollen tracking system should be possibly maintained by the National EPHT Network, implemented by each CDC-funded tracking partner or a combination of these two types of possible pollen networks. For example, the entire pollen and pollen attribute database could be maintained by the NEPHTN and used with other federal partner agencies to release national pollen advisories. States/New York City would maintain their own database and release state/county/city pollen advisories. Regional state/New York City EPHT programs could collaborate with other funded or unfunded tracking states to establish a shared regional pollen and pollen attribute database and use the observations to release pollen advisories. The incremental contribution of this proposed national pollen surveillance system is that in addition to pollen and pollen associated observations respiratory chronic disease or other health outcome data should be used to increase the accuracy of the pollen alerts.

While there are challenges ahead, especially in these times of limited federal support for environmental health projects, the adverse impact of pollen on American citizens and the healthcare system will only get worse in the future. This *urgent* temporal time frame is driven by the climate change time line which now includes three general reference points: 2030, 2050 and 2100. For these and other reasons described in this white paper, the pollen sub-team's recommendation is to consider what type of pollen tracking system could be realistically implemented within EPHT, and if an NCDM pollen indicator can be developed by using pollen surveillance system observations. The secondary purpose of this white paper is to promote the importance of pollen as a *peer* EPHT environmental hazard. By doing so, we can start now to develop a more complete understanding of the environmental risk factors behind the high rates of asthma and allergies in the United States. The working hypothesis embraced by the pollen sub-team is that climate change is partly responsible for the observed increases in asthma prevalence that has occurred in the US between the early 1990's and today. While pollen was not an environmental hazard that was included in the Pew Commission reports that preceded the start of EPHT at CDC, all currently available evidence supports the conclusion that pollen is an important health hazard, and based on this type of direct and supporting evidence pollen should now be included as an equivalent EPHT hazard, and placed with criteria air pollutants, especially $PM_{2.5}$ and O_3.

The architecture of the proposed national pollen tracking system will use the best features that are now in some of the US states that have multiple NAB pollen counting stations, as well as, but more importantly, European countries in the EAN that have even more pollen counting stations, as shown in Figure 4. These combined optimal pollen surveillance system attributes from either the NAB or the EAN state/country polygons were identified by combining the NAB first quartile monitors with EAN first quartile monitors, as shown in Figure 5. Based on these attributes for population, area and pollen counting stations, a continuous surface was produced, and is shown in Figure 6. This last figure shows the number of pollen counting stations that would be required given the log square miles and log population for a polygon, in this case a US state.

While this approach is presented *only* for illustration purposes, it does demonstrate in a tangible manner that a stylized statistical modeling approach may be used to produce possible scenarios of the minimum pollen counting stations that will be required in a US state to establish a national pollen tracking system. The statistical properties of a more realistic model that should be used to produce this type of smooth surface will require collaboration with researchers from Universities and federal partners such as the USEPA and/or NOAA, and possible others with specialized technical expertise, e.g., National Aeronautics Space Administration (NASA).

The proposed national pollen tracking system could be established by including a stand-alone automated unit to count and classify pollen grains into taxa, as well as produce total pollen grain counts. Figure 7 shows the automated pollen grain classification and counting system that has been implemented by the German Weather Service (GWS) since 2009.

The sub-team's analysis identified similarities between fine particulate matter and pollen grains. These common features could include their aerodynamic properties and that the adverse influence of pollen on the occurrence of a respiratory disease such as asthma is also influenced by the prior exposure to fine particulate matter. Mechanistically, both pollen grains and fine particulate matter may possess some aerodynamic properties analogous to the trajectory of golf balls. That is, how far a golf ball will travel will depend on several variables that include the force of the swing of the golf club and the weight, composition and surface of the golf ball. Figure 3 demonstrates different pollen grain as viewed under an electron microscope. The appearance of ragweed is shown in Figure 2. This is one reason to include automated pollen counting units with existing on the ground criteria air pollutant monitors. The logical choice, then, would be to include an automated pollen counting station where there is a fine particulate matter ground monitor.

All 82 NAB pollen counting stations that continue to use the microscope to classify and count pollen grains should be included with the proposed US EPA pollen-fine particulate matter network (E. Leventin, personal communication). This two-pronged approach to the proposed national pollen surveillance system will result in increased spatial coverage for pollen surveillance and decrease the total number of automated pollen counting units that have to be purchased. Overlapping spatial coverage between the automated pollen counting units and NAB pollen counting stations will provide data that can be used to evaluate the equivalence of these two methods to classify and count pollen grains. A similar approach should be taken by including overlapping spatial converge if some US NWS stations will be selected because they may be closer spatially to existing NAB pollen counting station or to an automated pollen counting unit that could be added to a location that has an on the ground fine particulate matter or ozone recording unit.

Financial support for such a national pollen surveillance system could come from a variety of sources; these can include the voluntary allocation of fines imposed by the USEPA on polluters who have the option to direct the use of the paid fines to support a new national pollen surveillance system. This is an arrangement that is now in place in the State of Maine. Additional funding for a national pollen surveillance system could come from pharmaceutical companies, universities that utilize the pollen data, and federal or state sources. Given that the climate change literature has identified pollen as an important air hazard, and proposals for different pollen indicators, it is conceivable that future increases in climate change funding could be used to establish and maintain the proposed national pollen surveillance system.

The sections below will provide additional support for the recommendation that the tracking network should develop a national pollen surveillance system and then use pollen and respiratory measures, especially asthma, to develop an NCDM pollen indicator. Other uses of the NCDM formatted pollen-health datasets could be to make available reliable and accurate pollen forecasts. Sufficient scientific evidence will be included below to argue for the immediate necessity of starting an enhanced national pollen surveillance system in the next three years because of the anticipated effects of climate change on substantially increasing pollen grain density and selective increases in pollen grain allergenicity.

Narrative

I. Background

A. Public health significance of pollen exposure: Over the past century, the overall global surface temperature has increased by 0.7–1.4°F[1]. Atmospheric variables altered by climate change have and will to continue to have, impacts on aeroallergens such as pollen[2-3]. Allergic disease related to aeroallergens is currently a significant public health issue in many countries, and the increased adverse impact that will result from climate change is of great concern[4-11].

In the United States alone, allergic rhinitis affects up to 10-30% of adults as and 40% of children[12]. The cost associated with this for one single year is approximately11.2 billion dollars[13-14]. Three studies reported that exposure to aeroallergens exacerbates asthma symptoms as well[15-17]. Asthma currently affects approximately 24.6 million people in the United States, and it is estimated that this number may grow by more than 100 million by 2025[18]. The cost in medical expenses, missed work or school days, and premature mortality, has been estimated to be about 3,300 dollars per person[19]. It is important that public health and allergy practitioners understand the currently documented impacts that will result over the next several decades and to 2100 because of climate change, how it will affect pollen production, and how increased levels of pollen in turn will impact adversely human health.

B. *What is pollen?* Pollen is the microscopic male gametophyte produced as part of reproduction by seed plants. These include gymnosperms and angiosperms. Pollen must be distributed and reach a female reproductive structure in order for germination to occur[20]. Figure 1 is a photograph of common ragweed. Figure 2 is a scanning electron microscope photomicrograph of common ragweed pollen grain.

1. *Pollen sources (species) and pollen grains:* Pollen grains consist of about 1-3 cells, some vegetative and one reproductive, and have an inner and outer shell. The inner shell is composed of cellulose, while the outer shell is composed of sporopollenin, a chemically stable material that offers protection from degradation. The outer wall, also known as the exine, often has characteristics like spines, furrows, or warts that are visible under a microscope and can be used to help identify the genus or species of the pollen. Size, shape, and color of pollen grains can also be used to help identify the genus or species. Size may vary from about 10-100 micrometers. Pollen grains can be of different shapes: round, ovular, or disc-shaped, sometimes with filaments. Color of pollen grains may range from white to yellow or orange[20-22]. Figure 3 is an electron microscope image of different pollen grains from a variety of common pollen producing sources.

The generally recognized pollen categories include weeds, grasses, and trees. Common weeds in the US that produce allergies include ragweed, curly dock, lambs quarters, pigweed, plantain, sheep sorrel and sagebrush[20, 23-24]. The most common grasses in North America that cause allergies are Bermuda grass, Johnson grass, Kentucky bluegrass, Orchard grass, Sweet Vernal grass, and Timothy grass[20, 23-24]. Fewer than 100 types of trees have been shown to cause allergies[23]. The most common allergies related to trees occur in response to ash, box elder, catalpa, cottonwood, date palm, elm, hickory, maples, olive, pecan, phoenix palm, poplar, sycamore, walnut and willow. Some people have allergic responses, thought to be due to cross-reactivity of multiple pollen sources, especially in relation to pollen from alder, beech, birch, cedar, juniper, and oak as wel[23]. Other trees, like pines, have heavy pollens that fall to the ground quickly[24].

Which pollen will cause the worst respiratory health effects will depend largely on the individual experiencing symptoms and past exposures to allergens. One of the most common exposures is to plants belonging to the genus *Ambrosia*, which is ragweed. It is also a monoecious plant, since it produces separate male and female flower heads on the same plant[20, 24]. There are 41 species worldwide of ragweed[22]. A ragweed plant can produce up to one billion grains of pollen each season, and the grains are so light in weight that they have been found up to 400 miles out to sea, and two miles high into the atmosphere[20]. Therefore, while ragweed plants are most common in the East and Midwest United States, their pollen can be found virtually anywhere in the country, and the world[20].

2. *Pollination methods:* Pollination is the process of transferring pollen during the reproductive cycle of plants, which allows for fertilization. There are two main ways seed producing plants can achieve pollination[20].

i. *Entomophilous:* Entomophilous plants produce heavy, sticky, protein rich pollens. These pollen types are carried by insects to the female gametes, and are not normally inhaled. These pollen types are typically from flowering plants.

ii. *Anemophilous:* Anemophilous plants produce large quantities of lightweight pollen grains that are transferred by the wind. These are typically large quantities of lightweight pollen grains transferred by the wind. These are typically non-flowering plants, or plants with inconspicuous flowers. Pollen from anemophilous plants can be easily inhaled and thus have adverse effects on human health, especially because of their allergic conditions. Ragweed is also a wind pollinated plant[20, 24].

3. Implications for pollen levels: Because anemophilous plants have a less direct method of pollination than entomophilous plants, they produce larger quantities of pollen. Typically, anemophilous plants release the most pollen shortly after sunrise, but that pollen travels best on mid-day winds. Therefore, between 10 am-4 pm is when the highest pollen counts can be expected to occur[20, 25].

C. Ecological influences: Today, we do know that pollen levels and prevalent pollen types are influenced by multiple factors[20, 26-36]. These factors can result in bi-directional changes in pollen levels. In turn, pollen levels can either increase or decrease under predictable circumstances, at least under ideal conditions and for a known set of predictors. In the next sub-section there will be a selective review of these factors on pollen levels.

1. Effects of increasing carbon dioxide levels and other Greenhouse Gases (GHG): The abundance of available pollen is expected to increase with higher levels of carbon dioxide, CO_2. One consequence of climate change during the past century has been the excessive release of carbon dioxide in the air. Carbon dioxide levels have increased because energy stores on and below the earth's surface have been used as fuels. Through the burning of coal and other fossil fuels, CO_2 is released. The presence of more CO_2 in and of itself can result in trees, plants, grasses, and weeds producing more pollen. Studies have shown plants in elevated CO_2 conditions produced more pollen[27, 30-31, 33-34, 37-40]. Another study demonstrated that ragweed thrives with elevated CO_2 levels as well[27, 38]. An additional and significant result of increased CO_2 in the atmosphere is the rise in Earth's average temperature, resulting in longer growing seasons and as a result more pollen. These altered climatic conditions also cause higher pollen levels to shift to colder climates, resulting in longer pollen seasons in northern locations and increased pollen production by plants[33, 41]. The climatic characteristics that could affect pollen production and distribution include higher temperatures, humidity, wet seasons, and stormy days, and colder winter temperatures[20, 26-32, 39-43]. The relationship between these variables and increased pollen production is not simply linear in one direction, positive or negative. To the extent that these variables contribute to greater pant growth and a longer pollen season, such increasing temperature and more precipitation, it is expected that pollen production will increase. But, colder temperatures will have the opposite effect on plant growth and shorten the pollen season, thereby result in lower pollen levels. As climate change continues to occur, several studies have noted the potential for expansion of the existing habitats of allergy producing plants, or their seasons. For example, in the Northern Hemisphere, birch and olive trees are expected to expand further north, and areas of perennial ragweed are expected to extend and become more persistent[6, 26, 35]. Geographically, mountainous regions, or areas in proximity to the ocean may be of lower risk, as least this was the case in the past. But, with increasing temperatures and more CO_2 ragweed pollen has started to appear at higher elevations and in deserts because of human activities that have included soil perturbations, irrigation and gardening[39, 43].

2. *Rainfall/humidity:* Climate change will make precipitation patterns more variable and unpredictable. Generally, areas that have plenty of rain will become wetter and dry areas will become drier (see below)[1]. The effects of rainfall and humidity can result in separate contributors to increased pollen prevalence and pollen movement[20]. Rainfall should contribute to increased pollen production by promoting plant growth. When pollen is present in ambient air, rainfall can both decrease total pollen grains and increase pollen allergenicity when the pollen casings are disrupted by thunderstorms[44]. Rainfall can make pollen grains heavier and travel shorter distances when wind speed is kept constant. Humidity also contributes to pollen production during the pollen season. Yet, it also adds weight to pollen grains, and, as a result, should limit how far pollen grains will be transported by the wind[20].

3. *Climate change induced droughts:* Drought effects on pollen can occur at different times and different levels, with the outcome being reduced pollen levels in the air. Rainfall is required for plants to grow and produce pollen. Droughts will lower pollen levels by decreasing the percentage of plants that can continue to live under conditions of severe limitations in rainfall. For hardy plants, however, a dryer climate will make pollen grains lighter and increase the distance that the lighter pollen grains will be carried by the wind.

4. Phenological reference: Phenology is the study of when plants and trees produce pollen. Some pollen season start dates may differ based on the presence of flowering plants[45]. This outcome could mean that the presence of pollen can be recorded in areas where pollen producing plants, trees, shrubs or grasses indigenous to the index area have not yet started to release pollen, leading to the conclusion that a national pollen tracking system should also include a phenological reference component. Under this scenario pollen can be transported by the wind, thus explaining why pollen can be recorded when that type of pollen is not available in a given location because that type of pollen producing plant has not yet started to produce pollen.

D. Spatial-temporal distribution: Given that pollen dispersion is influenced by a variety of factors, some of which include characteristics of the pollen grains, such as weight and physical structure, wind direction and speed, climatic conditions such as precipitation, and possibly temperature, pollen types found in any one location may represent a mixture of pollen from that location and other pollen grains transported to a given location from other places of origin[20]. For this reason, a broad perspective has to be taken to fully understand the origins of different pollen types. By only knowing the local pollen sources by an analysis of tree taxa, speciation of other pollen producers such as grasses and weeds can, at best, only produce an incomplete inventory[22]. One possible approach to resolving this problem of pollen movement and origin would be to collect pollen samples on a regular basis and then to examine pollen grains by using a light microscope. Developing a catalog of the identified pollen types and knowledge of all of the pollen sources in the area and more distant locations should assure consistency of pollen counts and the pollen sources[22, 24]. The remaining pollen types could be cataloged and actual point of origin approximated by knowing the distribution of pollen produces around the given location as well up to 400 miles in all directions[20]. Use of GIS methodology is one way to capture the spatial-temporal properties of different pollen grains and then also include on the GIS map information about the source of each pollen type.

1. *Geographical distribution*. Pollen is ubiquitous because of its function in the reproduction cycle of plants[20, 24]. Pollen sources are many and because the way pollen is transported from one location to another, it can be found in urban and rural areas alike[20]. Within densely populated cities, the use of available land that can have trees, grasses, and weeds could

be less than in less densely populated areas. But, ragweed can thrive in cities because of heat island effects that result in higher temperatures and elevated CO_2 levels from trucks and vehicles[27]. Natural and man-made barriers can also influence pollen movement as well as the preponderance of certain types of pollens. As will be discussed in more detail below, the use of GIS is one way to document the movement of pollen across diverse landscapes that include densely populated cities, towns with fewer residents, in different states, U.S. regions, and nationwide[20].

E. *Built Environment.* The built environment approach represents an opportunity to proactively evaluate environmental needs and then go about to modify what is present in a preselected location. This field is a hybrid discipline that includes expertise and methods from other specialty areas such biology, botany, architecture, etc. The built environment principles have been applied to the mitigation of climate change effects and to the reduction of selected chronic diseases, such as obesity. With regards to obesity, the approach has been to require persons to expand more energy, consequently burn more calories. The premise of this approach is that a major contributor to obesity is lack of exercise. A review of the scientific literature using the combined key words *built environment* and *pollen* or *pollination* or *ecology* did not yield any published articles that described the use of built environment principles and related methods to decrease pollen levels or types in an area. But, in fall 2012 there was a conference presentation on this topic[46].

As a way to mitigate the effects of climate change variables on increasing the abundance of pollen, one approach involves the use of available vegetation management practices[46]. This approach is a version of what is done when new communities are built. What varieties of grasses and trees are planted, up to now, have been decisions that have been made based on enhancing esthetic aspects of residential communities and to acquiesce to the wishes of the persons who own and live in the homes. A version of vegetation management involves selectively planting trees and grasses that emit less pollen or less allergic pollen. The limit of this approach is that it can only modify local pollen sources, not pollen coming to a location from other points of origin[20]. No doubt individual persons or families or even developers of new housing developments or single homes use some version of built environment principles to determine what trees, shrubs, plants and grasses are used in landscaping. A related approach would be to also eliminate weeds that emit highly allergic pollen. The way that the term built environment is used in this context is to suggest that pollen levels and types can be changed by using built environment principles.

F. *Health effects:* Allergic rhinitis is the most common health concern resulting directly from pollen exposure[12, 38-50]. It is, in fact, the most common chronic condition[38]. It presents as an itchy nose, throat or roof of mouth, itchy or tearing eyes with dark circles, a stuffy or runny nose, or sneezing, irritability and fatigue[5, 39]. Allergic conjunctivitis may also accompany rhinitis, or occur separately. Symptoms of allergic conjunctivitis include watery, puffy, red eyes, a feeling of grittiness in the eyes, and sensitivity to light. Asthma exacerbation, oral allergy syndrome, atopic dermatitis, or other sinus or ear infections may also occur as a result of pollen exposure[51].

1. *Epidemiology:* Prevalence of allergic rhinitis appe*ars* to be increasing, and already affects up to 40 percent of children and 10-30 percent of adults in the US[52]. It occurs less in children under the age of five, and is even less rare in those under two, because at least two seasons of pollen exposure are needed before allergic rhinitis can develop[53]. After that, the prevalence rises to peak in school age children, decreases during adolescence, and peaks again in young adults[54]. Young adults may experience missed work, sleep disturbance, and an impaired quality of life. As age advances past young adulthood, symptoms have a tendency to improve[54]. Despite the declining prevalence with age, allergic rhinitis is still an important concern in older adults, and it may be possible to acquire an allergy or develop asthma at any age[55-57].

2. *Pathophysiological (inflammation):* Pollen grains can produce an allergic reaction when inhaled, because the body interprets them as unwelcomed foreign bodies. Pollen can bind to IgE on the surface of basophils and mast cells, causing the release of histamines and other chemical mediators that cause symptoms, such as inflammation. Once the body is exposed to pollen grain(s), the antibodies remain and can respond faster and stronger when next exposure occurs to the same antigen. Therefore, symptoms may worsen later in the pollen season due to a priming effect[58]. During an allergic reaction, inflammatory cells such as mast cells, eosinophils, and

lymphocytes migrate to the site toward locally produced chemical factors. Macrophage migration inhibitory factor (MIF) is one chemical mediator that works to block anti-inflammatory effects of glucocorticoids. It has been found that people with allergic rhinitis have higher levels of MIF in their blood than healthy control groups, and that there is a correlation between the severity of symptoms and MIF level[59]. Co-morbid diseases such as asthma and atopic dermatitis are also thought to occur from both a genetic predisposition and environmental exposure. This type of synergistic effect between the differential contribution of environmental exposure to pollen and pollen's heightened effects due to a family history of allerginity will be described below.

3. *High-risk groups:* Risks that have been associated with developing allergic rhinitis in the literature include: 1) a family history of allergy; 2) being the first born child; 3) having early exposure to formula and food; 4) exposure to maternal smoking as an infant; 5) having early use of antibiotics; 6) being male; 7) having a serum IgE over 100 international units/milliliter (IU/mL) before 6 years of age; and, 8) exposure to indoor allergens[49, 60-61]. Those migrating to or living in urban areas or close to roadways may also be at an increased risk, since exposure to diesel fuel fumes has been shown to produce increased irritation of the respiratory system and can subsequently trigger allergic rhinitis [17, 28, 62-63].

The main factors that could determine high risk areas for respiratory allergic diseases are the types and concentrations of trees, grasses, and weeds present[20]. Other factors that identify high risk areas include air pollution, climactic and geographic factors. Air pollution affects both the health effects due to pollen and pollen production itself. It can increase inflammation in the lungs, elevating the response to pollen exposure. Urban surroundings, especially being near heavily traveled roadways, are likely places that are at high risk for air pollution exposure. Now there are studies underway that it is anticipated will produce results that will increase our understanding of the risk factors for asthma and allergy associated with migrant and urbanizing populations[64].

4. *Co-morbid conditions:* When airways become inflamed, bacterial infection of the sinuses is more likely, and sinusitis may occur. Sinusitis can be differentiated from rhinitis because the

discharge is thicker and often has a yellow-green color. There also may be facial or maxillary tooth pain. In one study, 55 percent of the patients with sinusitis also had a history of allergic rhinitis rhinitis[65]. Because the tissues involved in sinusitis and rhinitis are adjacent anatomically, it is rare to see a case of sinusitis that does not involve rhinitis as well[66]. Asthma, which is characterized by coughing, wheezing, shortness of breath or chest tightness, is also correlated with allergic rhinitis. It is extremely rare to see an asthma patient without allergic rhinitis[67]. In the "one airway hypothesis" asthma and allergic rhinitis are actually considered one disease manifested on one clinical continuum [68-69]. Other conditions associated with allergic rhinitis include allergic conjunctivitis, atopic allergic conditions such as atopic dermatitis (eczema) or oral allergy syndrome (pollen-food allergy syndrome), and eustachian tube dysfunction[48].

5. *Genetics:* Aside from the environment, genetic influences have also been demonstrated to play a large role in development of allergic rhinitis. Twin studies have estimated inheritability of up to 0.75[70]. It is currently thought that a series of individual genes, with and without interactions, influence the final health outcome[71], and the pattern of inheritance may not be a standard Mendelian one.

6. *Dose response characteristics:* Previous reviews of the contribution of exposure to pollen and its contribution to adverse respiratory outcomes, especially asthma and rhinitis, have supported the conclusion that pollen is a peer EPHT hazard, with evidentiary support presented in this pollen white paper. To summarize, pollen effects in the general population appear to have, in some instances, the appearance of an ordinal dose-response relationship. As pollen levels, defined as total pollen grains per cubic meter of air, increase, the total number of persons who will report symptoms of rhinitis or an asthma attack also can be expected to rise. It has not been definitively established, however, in the scientific literature if this is a linear relationship or simply ordinal. The latter type of relationship is supported by the fact that at two points in time, lower pollen levels and fewer respiratory adverse health reactions precede some later point in time when increased pollen levels are associated with more respiratory adverse health events.

Another well-documented observation in the pollen and health outcome literature is that some persons demonstrate a greater sensitivity to specific pollen taxa. It is also expected that some pre-existing conditions can increase the severity of the pollen induced adverse health outcome; they can include Chronic Obstructive Pulmonary Disease (COPD) or a history of asthma. Children and the elderly persons would be considered to represent high risk groups in terms of increased responsiveness to the presence of pollen in outdoor air. Residential factors such as the absence of air conditioning can also contribute to the effects of increased pollen levels on the occurrence of adverse health effects. Persons who are under-nourished could also show greater responsiveness to increased pollen levels in ambient air. Lastly, criteria air pollutants such as $PM_{2.5}$ along with increased pollen levels can increase the combined effects of both air hazards on the occurrence of adverse respiratory outcomes. These pollen induced adverse respiratory health outcomes will become worse when the longer-term effects of climate change become established.

G. *Epidemiologic studies can help to define public health burden of respiratory illnesses impacted by pollen allergens:* How can the findings from published studies be used to more precisely define the public health burden that is produced by pollen induced allergic reactions? One limitation is that each published study, more than likely, utilized methodologies that are different from other studies. A meta-analysis of this literature is one way to come up with a more precise relationship between pollen effects and other factors that can mediate the allergic reaction responsible for the adverse respiratory health outcomes. Undertaking a meta-analysis of any literature is a labor-intensive process. It is also an activity that is beyond the scope of this pollen white paper.

Alternatives to carrying out a meta-analysis would be to determine if such an analysis has been completed, and if the results are available in print. At the time this white paper was written, in January 2013, the authors did not find a meta-analysis publication on pollen and health effects. Still another approach could be to select a subset of articles in one of several areas, and then attempt to summarize what are the consistent findings. The last option could be to speak with experts in the field, to survey their opinions on how and to what extent pollen can affect adverse respiratory outcomes[72-74]. These approaches argue for developing a local knowledge base on how pollen levels affect respiratory health in general, as well as identifying what pollen taxa are most allergenic in each location and what groups of persons are most susceptible. These are the questions now considered by an *ad hoc* pollen working group, composed of experts from diverse disciplines, that has been formed under the direction of the Maine EPHT program manager and an author of this pollen white paper (NA).

H. Timely public and provider alerts based on data-based pollen forecasts: Through knowing what adverse respiratory health outcomes result from exposure to increased pollen levels or the abundance of highly allergenic pollen types that are known to produce a greater allergic response in susceptible persons, it may be possible to predict what health provider resources will be needed. Such a relationship suggests that some form of regression analysis could be applied to available parameters, health care utilization outcome measures and predictors being pollen levels and pollen species. Effect modifiers would have to be included, such as climate variables, and personal characteristics, such as gender and age. A prerequisite of making pollen observations a basis for pollen forecasts to the public and to health care providers is the soundness of the factual data—pollen readings—on which these next day and future predictions are made. Credibility of sources that make the forecasts can be at stake if the predictions are inaccurate. For this reason, it is imperative that a robust national pollen surveillance system should be implemented. Once it is operational it will be able to produce accurate and timely pollen results.

I. *Tracking ambient pollen over time within one area, as an indicator of climate, land use, etc.*: Pollen effects on health outcomes and the resulting need for health care resources for persons who develop allergic reactions or increased asthma attacks will occur over time and in selected areas. This two-dimensional relationship can be characterized over space and time by the use of GIS and spatial modeling methods. The former can be used to show the spatial properties of this cascade of pollen induced events that first impact the occurrence of adverse respiratory outcomes and then result in the necessity of having available health care resources for impacted persons. Mathematical modeling can assist in interpolating between unavailable and recorded temporal and spatial data points. This is precisely what is currently being done on a large scale by the EAN and European and some non-European countries that have active pollen counting stations.

To improve upon the current American approach of not specifying the data sources that are used as inputs to mathematical models, the proposed EPHT national pollen surveillance system should begin with the recording of pollen levels by type in a pre-planned system of pollen counting stations. This new national pollen surveillance system will require knowledge of the effective range for each counting station. To our knowledge, which is based on a completed review of the literature and online searches, there is no credible factual documentation of the effective radius for a pollen counting station. This is one of several research questions that is best answered by academic researchers affiliated with the NEPHTN.

There are other challenges in the implementation of a national pollen surveillance system that satisfies EPHT's requirements for a national pollen data source that could be used to develop a NCDM pollen indicator. If the optimal national pollen surveillance system cannot be implemented because it is cost prohibitive, another less expensive national pollen surveillance system may be designed and implemented as replacement of the ideal EPHT national pollen surveillance system. However, with each compromise in what is in fact needed to have available good pollen tracking data, there are also accompanying degradations in pollen tracking data quality and utility. The real question that needs to be addressed is, what is the minimum gold standard that can be implemented and also assure that the pollen readings are representative at different spatial hierarchies, i.e., communities, states, Nation?

J. *Other mitigation strategies (and effect modifiers) can include air conditioning, behavioral compensation, treatment compliance, etc.*: Mitigation approaches can be implemented to fine-tune intervention of the effects of pollen in producing adverse respiratory outcomes. One known intervention involves having persons to spend less time outdoors when pollen levels are high. Another complementary method is to have a susceptible person in a room with air conditioning. An air conditioner filters out some of the pollen grains from the air before a person breathes the air. The filtered and colder air contains fewer pollen grains per cubic meter of air. Other approaches can include closing windows in automobiles and turning on the air conditioner, changing clothes and taking showers. These two methods will also remove some of the pollen grains from the air. For persons who do not have air conditioners in their residences, cooling centers can be established and used by pollen susceptible persons. In theory this is a solution to pollen induced asthma attacks or the occurrence of rhinitis. But with this additional demand on the availability of cooling centers due to increased pollen effects, it is not known if dedicated resources will be sufficient to support the increased demand. Use of malls and other air conditioned public places can be effective alternatives. Implementable solutions will depend on a careful assessment of each local area and available financial resources as well as community commitment to such novel efforts. This assessment will have to include knowledge of disperse pollen taxa, who are the susceptible persons and what health care resources are available in the community.

II. *Existing pollen data sources and monitoring networks:* The proliferation of ambient and, at times, indoor air with pollen grains continues to be an environmental hazard. Each warm season, trees, weeds, grasses, and flowers emit pollen. Pollen grains are ubiquitous, and their presence can be seen by everyone with an amplification device, such as a light microscope. In many regions in the United States, pollen grains accumulate on outdoor surfaces and form a colorful layer on automobiles and other surfaces. Personal experiences with pollen include increased allergic reactions to elevated levels of pollen grains or pollen-specific allergic reactions to certain types of pollen. This is an abbreviated list of known pollen induced health effects: 1) rhinitis; 2) increased asthma attacks; 3) increased use of over the counter medications or doctor issued prescriptions; 4) more visits to healthcare providers, emergency departments, or inpatient hospitalizations; 5) missed school days; 6) missed work days; and, 7) lower quality of life because of the consequence of major adjustments persons will have to make to having running noses, headaches, malaise, difficulty concentrating, or temporary loss of speech at home, school or work.

Scientific literature has documented all of these pollen induced adverse health effects, as well as increased access to health care services, and greater volume of purchases of over-the-counter medications for pollen induced respiratory conditions. Even with all of these sources of experiential evidence and scientific findings, pollen-induced adverse health effects remain an under-recognized environmental health hazard. Within the current context of climate change effects that will surely result in increases in the earth's temperature and available CO_2 in the atmosphere, it is now possible to use statistical models to predict future increases in ambient pollen concentration. The use of statistical models to estimate pollen levels relies on the availability of spatially representative pollen readings. Unfortunately, currently available pollen readings in the US are inadequate to thoroughly address the near- and long-term effects of pollen on adverse health effects as well as the increased occurrence of asthma mortality in persons 65 years old and older[55-57].

An initial review of available information of pollen surveillance systems completed in March 2012 only found two systems: one in the United States (NAB) and the other in Europe (EAN). Map 1 shows the spatial distribution of the 82 pollen counting stations in 35 US states. Map 2 displays the spatial distribution of the 505 pollen counting stations in 36 countries in Europe. The characteristics of these two pollen surveillance systems have been quantified for this pollen white paper. The purpose of these descriptive statistical analyses was to know where we are right now in our capacity to evaluate pollen as an EPHT hazard measure, and to use the results of this analysis to describe the attributes that should be included in the proposed national pollen surveillance system. Based on the results on these two currently available pollen surveillance systems, the NAB in the US and the EAN in Europe, we expect that they will demonstrate that, at this time, there are not enough pollen monitors either in either the United State or Europe. This conclusion is based on the analyses of two new descriptive statistical metrics that were developed to compare total persons per monitor and total square miles per monitor in US states (NAB) with European countries (EAN).

Another difference between the European and American approaches to pollen surveillance system, maintenance and sustainability is that the former—the EAN—is more diversified and includes multiple partners. In Europe nearly all pollen counting stations are maintained by university affiliated personnel. For this reason in the EAN member countries, the level of pollen scholarly expertise is also cutting edge. The bulk of the funding for the European pollen surveillance system also comes from drug companies, and secondarily from universities. Government funding for pollen surveillance is available through grants awarded to university faculty who maintain the pollen counting stations. Government financial support for EAN pollen surveillance comes from the European Union (EU) and individual countries. Still another important attribute of the European model of pollen surveillance is the broad and extensive scientific knowledge base on pollen as a hazard, pollen effects on health, and the availability of pollen alerts through the Internet, smart phones and the media. Upon reflection, one wonders why the pollen surveillance system now in the US, as a complete environmental public health entity, has not been more influenced by the activities that are now going on in Europe.

A. *USA:* In the United States, for all practical purposes, there is only one pollen surveillance system, the National Allergy Bureau (NAB). The NAB is part of a private professional organization of physician immunologists and others with interests and expertise in pollen and the effects of pollen on health, the American Academy of Allergy, Asthma & Immunology (AAAAI).

There are also isolated efforts on the part of university-affiliated researchers to develop pollen surveillance resources and to build scientific expertise on pollen and its effects on health. One such effort in New England is described below. Because there is little or no sustained federal support for pollen activities in the United States, it is an uphill battle for universities to sustain a viable pollen program or carry out ongoing pollen surveillance. Previous and current university efforts have not contributed to providing a direct observation based approach to the release of reliable pollen alerts as has been done by the NAB. Medical practices that include immunologists maintain pollen surveillance as part of their patient clinical activities. Pollen surveillance is used by medical practices to alert patients when pollen levels are high. Because pollen taxa are also identified by trained technicians who use a light microscope to analyze pollen samples on glass slides, it is also possible to track specific pollen sources that produce in susceptible persons debilitating pollen induced rhinitis, asthma attacks, other allergic reactions that require the use of interventions from health care providers, visits to the emergency room or, in some instances, inpatient hospitalizations.

1. *NAB:* A quantitative analysis of NAB pollen counting stations was undertaken. Descriptive statistical summaries were computed on the NAB state aggregated data included in Table 1, Appendix A. There are states in the continental United States that have one or more active pollen counting stations. As seen in Map 1, Texas is the state with the highest number of pollen counting stations, 9 in all. In descending order, other states with higher number of pollen counting stations are California (7), New York (6) and Pennsylvania, Oklahoma, Colorado, each with 4.

2. *USA National Phenology Network*: In the United States, there is also the USA National Phenology Network, a volunteer organization that maintains its activities based on financial support from mostly private sources, including individuals and foundations, with little or no support from government sources. Volunteers record personal observations when specific pollen sources are active. The reported information includes the date of the observation, when the event occurred, the pollen source, and other descriptive information. Pollen phenology can be used to determine the start and end of the pollen season in each area and what are the prevalent pollen sources in that area. Unfortunately, this type ecological pollen observation system makes it impossible to verify the reliability or validity of entered observations. Another limitation is that because of its reliance on voluntary reporting, the accuracy of the observations is not always uniform.

3. *NOAA National Climatic Data Center (NCDC).* Phenology data are also available from NOAA[45]. Remote sensing readings are used to derive the Normalized Difference Vegetation Index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRA). The AVHRA provides 8 hour km^2 spatial coverage with a 15-day composting period. These phenological readings are available from 1981 to the present. Starting in 2000, MODIS phenological readings are used. MODIS can provide higher spatial resolution of surface vegetation than was available from AVHRA. Higher resolution permits the quantification of spatial heterogeneity[75-76].

4. *NASA remote sensing*: A cutting edge but not yet standardized method—off the shelf technology—of pollen surveillance utilizes remote sensing. Remote sensing involves the use of pollen related information from orbiting NASA satellites. Initial efforts seem encouraging. So far, remote sensing measurements have been used to classify on the ground vegetation types. This is accomplished by pixel classification based on a limited number of discernible groups. Pollen remote sensing efforts have included the use of a known pollen source on the ground and its correspondence to a remote sensing measured pixel type. This method has made it possible to use the satellite derived pollen pixel proxy for juniper pollen sources. NASA researchers have collaborated with the New Mexico EPHT to develop tracking remote sensing pollen identification and health applications. As a result of multi-year efforts, it has been possible to demonstrate a convincing proof of concept that includes the use of remote sensing results to identity pollen sources on the ground and then to utilize this information as a way to develop health care provider alerts. The objective of this effort is to inform physicians in private practices and hospitals, including emergency departments, when demands for health care services will increase, by how much and where. At this time the use of remote sensing technology is still in development, and is not used to make pollen forecasts for the medical community or impacted persons.

There are four limitations on the use of remote sensing pollen surveillance: First, it cannot be used as easily as a pollen trap. Second, it is expensive to maintain, and requires expertise that is only available in selected university settings or federal laboratories that specialize in this type of activity. Third, these remote sensing pollen surveillance projects are limited to a few readily discernible pollen species, such as juniper. Fourth, remote sensing pollen surveillance efforts have been carried out, up to now, only in the southwestern United States—Arizona, Oklahoma and New Mexico. No National remote sensing pollen surveillance system is now available for use by EPHT programs.

5. *Pollen.com*. Because of paid advertising and this type of name recognition, many persons associate this company with pollen surveillance. Pollen forecasts are made daily and appear in many places that include the Internet. Yet, the pollen sources for these pollen alerts are reported inaccurately and rely on historical pollen readings and other unidentified sources. For example, the footnote for the Baltimore Pollen.com counting station is identified as being located at the Johns Hopkins University medical campus in East Baltimore. But, an Internet search of this pollen counting station could not confirm its existence. Another report also described problems with the absence of accurate pollen readings used by www.pollen.com and www.theweathernetwork.com[84]. It is possible that these commercial sites that provide pollen forecasts rely upon historical pollen counts and meteorological readings and not actual pollen counts are reported by the NAB[85]. Pollen.com releases pollen forecasts at the zip code level. Predictions at a smaller geographic scale such is the case with zip codes should make the pollen estimates less accurate than pollen counts for the day that the pollen report is based[86].

B. European Aeroallergen Network: The EAN included 505 pollen counting stations in 36 countries as of March 2012. This is the Uniform Resource Locator (URL) to the EAN public portal, Polleningo.org. Map 2 shows the EAN pollen counting stations by European countries. Italy had the most pollen counting stations, 99. In descending order, other countries with higher number of pollen counting stations are Germany (82), France (65), Spain (60), Great Britain (28), Hungary (21), Switzerland (20), Poland (16), Sweden (16), and 12 each for Austria and Serbia.

C. Evaluation of NAB and EAN: The two derived metrics were used to compare NAB states to EAN countries on total persons per pollen monitor and total square miles per pollen monitor. Table 1 includes these summary measures for the NAB (left side) and EAN (right side). Comparisons are made with regards to population, square miles, pollen counting stations, and the two derived measures of persons/monitor and area/monitor. The NAB was significantly different from the EAN on two measures, population and pollen counting stations. Mean population per country in the EAN was significantly higher than mean population per state in the NAB ($p<0.05$). Also, the mean number of pollen counting stations in the EAN was significantly higher than the mean pollen counting stations in the NAB ($p<0.01$). Several of the measures had higher values for the mean than the median. This was the case for population, for both the NAB and EAN, and stations for the EAN. As seen in Table 1, there were no significant differences between the NAB and EAN in persons/monitor and area/monitor ($p>0.05$ for each comparison). The two derived measures, persons/monitor and area/monitor, were not significantly correlated ($p>0.05$). These results suggest that on the two derived metrics of persons/monitor and area/monitor the EAN is not qualitatively different than the NAB and that there is variability between the spatial aggregation of pollen counting stations in EAN member countries and, to some extent, NAB member states. These two conclusions do not imply that the factors that contribute to the documented differences in population and pollen counting stations and variability within the EAN and NAB are necessarily the same. Figure 4 is a three-dimensional display of total pollen counting stations in the NAB and EAN as a function of log square miles (X axis) and log population (Z axis). Total pollen counting stations per US state or country in Europe is also displayed (Y axis). Because of the magnitude of the last two measures, log values were used for square miles and population. This graph demonstrates that concentration of EAN and NAB pollen counting stations within the middle quadrant, between 3.5 and 5.1 log square miles, and 5.9 and 7.0 log population. The other observation is that there were more pollen counting stations in EAN countries than NAB states.

Regression analyses were used to better understand the relationship between the two computed measures, persons/monitor and area/monitor represented as square miles per monitor. The results for all 35 NAB states are presented in Table 2. The left hand side includes regression results for the persons/monitor outcome measure. The right hand side contains results for area/monitor. Stations and population, but not square miles, were significant predictors of persons/monitor ($p<0.0001$ for the first two predictors, and the third predictor of square miles was not significant, $p>0.05$). For area/monitor the two significant predictors were stations and square miles ($p<0.0001$ for both). But, population was not a significant predictor ($p>0.05$). The adjusted R^2 was 70% for the first regression model and 84% for the second. As mentioned previously persons/monitor and area/monitor appear to be independent of each other because the correlation between both was not significant, $p>0.05$.

Similar regression analyses that were carried out for the NAB states' pollen counting stations were undertaken for the 36 EAN countries' pollen counting stations. The results are summarized in Table 3. As seen in the left hand side of Table 3, the three predictors of stations, population and square miles were significant for the outcome measure of persons/monitor ($p<0.0001$ for the first two and $p<0.05$ for the third). The right hand side of Table 3 includes the results for area/monitor. For this regression analysis only square miles was a significant predictor ($p<0.001$). R^2 for the first regression analysis was 45% and for the second it was 62%.

To better understand the importance of the variability in EAN countries and NAB states with regards to pollen counting stations, group differences were evaluated for first quartile for countries and the first quartile for states. For an NAB state to be included in the first quartile group it had to have a value for the total persons/monitor that was below the first quartile value for persons/monitor for all NAB states or it had to have a value for total square miles/monitor that was below the first quartile value for square miles/monitor for all NAB states. When this algorithm was applied to the NAB states there were 13 NAB states that were selected. The same algorithm was used to select the EAN countries that had values for total persons/monitor or total square miles/monitor that were below the first quartile value for each metric. The use of this selection rule to the 36 EAN countries resulted in the identification of 13 EAN countries that became part of the first quartile group. As expected, some of the NAB states were below the first quartile values for both total persons/monitor and total square miles/monitor. Likewise, for the EAN countries, there were some that were below the first quartile values for both total persons/monitor and total square miles/monitor. Because there were only 13 NAB states in the first quartile and 13 EAN countries in the first quartile, this latter difference was not analyzed further. The results for the first quartile groups are summarized in Table 4. The results for the

NAB states are in the left side of Table 4, the results for the EAN countries are in the right side of Table 4. Again, the EAN was significantly different from the NAB in having more pollen counting stations than the NAB ($p<0.05$). The mean pollen counting stations in the EAN was 23.5 per country and the mean pollen counting stations in the NAB was 2.5 per state. The EAN was also significantly different from the NAB in persons/monitor ($p<0.05$). For the EAN the mean for persons/monitor was 653,693.6. For the NAB the mean for persons/monitor was much higher, 2,276,537.8. Figure 5 displays the three-dimensional relationship between pollen counting stations as a function of log square miles and log population only for EAN countries and NAB states in the first quartile. This time the EAN countries appear to be located at the intersection of log 3.2 to 5.9 square miles and log 5.8 and 6.9 log population values. Inspection of this figure suggests that there are more pollen counting stations in EAN countries that have higher population, but not more square miles. No such relationship between more pollen counting stations and higher population is evident for the first quartile NAB states. To better visualize the relationship between pollen counting stations as a function of log square miles and log population, the 13 NAB observations and the 13 EAN observations were used to generate a smooth surface, as seen in Figure 6. Red values, which can be seen at the top right in the three dimensional graph but below the plotted smooth surface, represent values for the EAN. The blue values, which can be seen on the top of the smooth surface, represent the 13 NAB observations. This three-dimensional display shows, for illustration purposes only, that the number of pollen counting stations in either EAN or NAB polygons (countries and states, respectively) increases from about 120+ to about 305+ as a function of increasing area (in square miles) and population. While this three dimensional display was generated without consideration of the many other variables identified as important in understanding the pathophysiological relationship between the effects of pollen grain counts and allergenicity on adversely impacted respiratory conditions such as rhinitis and asthma in the population overall and in sensitized sub-groups such as children and persons 65+ years old, the suggestion is that a pollen surveillance system should consider, as a starting point, both population and area in determining the spatial distribution of pollen counting stations.

III. *Summary of Justification for a National Pollen Surveillance System in the US*: There are many reasons why a national pollen surveillance system should be established in the US. These reasons were mentioned in several places in this pollen white paper. These reasons will be summarized in Table 5. Pollen is another type of environmental hazard that has both independent effects as well as synergistic adverse effects with fine particulate matter on asthma. The pollen-$PM_{2.5}$ burden on health care services, missed school and work days will surely increase because of climate change effects. One way to intervene will be to have available accurate and easily accessible pollen readings from pollen counting stations that take into account the aerodynamics of different types of pollen grains and their concentration in air as well as impacted persons, especially those who are especially sensitive to the impact of pollen on the respiratory system. As scientific evidence for climate change effects continues to increase and the recognition as well as acceptance of climate change as a real and serious ambient air hazard, in the last few years there has been an increased awareness by the scientific community and federal and state agencies have started to see the need for pollen indicator data. Pollen indicators have been developed by several organizations that have included the CSTE/SEHIC asthma and climate change work groups, the World Health Organization and the USEPA. The major limitation, however, is the absence of pollen data to accurately describe the entire US. In response to this need, the next section will describe what attributes should be included in a national pollen surveillance system

IV. *Long-term vision for an EPHT Pollen surveillance system to support health alerts and other preventive measures, including university-based research source:*

A. *Conceptualization of a National optimal pollen network:*

1. *Public health basis:* The establishment of an optimal pollen network should start first with the recognition of pollen's current and projected importance in contributing to the public health burden.

Primary drivers for a national pollen network are the significant public health and welfare burdens associated with asthma and related allergic disorders and today's pressing need to anticipate future burdens resulting from climate change. These include:

- Asthma and allergies affect approximately 20 percent of the population;
- Many persons with asthma and allergies include persons sensitive to pollen exposure;
- At risk groups include children, blacks, persons without health insurance and those who are 65+ years old;
- Asthma and allergies are known to include a significant percentage of school and work absenteeism, poorer work performance, results of surveys reporting poor life satisfaction, poor health status, more psychological stress and reduced activity days.

Furthermore, when viewed within the context of climate change, public health impacts may become even further magnified, with increasing temperatures and CO_2 levels having a fertilizing effect on pollen production. Alternatively, as evidence of severe climate impacts on drought and desertification becomes more apparent in the United States and around the globe, pollen monitoring may provide an indicator of these processes as well, reflecting dramatic changes in vegetation.

Pollen monitoring also intersects with other important phenological concerns relative to climate change. One is the fact that climate influenced seasonal changes are not restricted to just pollen, but also are important to other pressing health concerns, such as the ecology of pollinators, invasive species, and vector borne diseases. In addition, the paleo-ecological pollen record could give us clues regarding past climate transformations such as the one we are experiencing now.

2. *Comparisons to current criteria pollutants:* As a starting point, the optimal national pollen surveillance system could resemble the USEPA's current ambient air quality monitoring network for the two Criteria air pollutants, i.e., ozone and fine particulate matter. These points support this conclusion:

- Pollen may be considered to be a subset of PM_{10} and total suspended particulates. Further, just as PM can be subdivided into various subcategories (e.g., $PM_{2.5}$, PM_{10}, diesel particulate matter (DPM)), pollen can also be subdivided into various categories (e.g., trees, grasses, weeds, ragweed, and other fine-grain groupings into pollen taxa).

- Pollen and PM also share aerodynamic properties. They can be considered as spheres that are light enough to be transported by wind. To our knowledge, this shared aerodynamic property between pollen and PM has not been described in the scientific literature.
- Like the USEPA's criteria air pollutants, pollen levels vary spatially and temporally, and are of concern because of their acute effects.
  - Pollen may interact toxicologically with ozone and fine particulates, increasing health risks:
    - The pathophysiology of PM and pollen has been explored in the scientific literature. Prior PM exposure contributes to the increased responsiveness to pollen.
    - Like the criteria air pollutants, airborne pollen problems can be both local and regional in nature.
    - Criteria pollutants are of concern because of the widespread presence of emission sources (mostly related to energy and transportation); pollen sources can be widespread, but are also associated with vegetation versus industrial sources.
    - Because of the acute nature of their health hazards, public health responses to both criteria air pollutants and pollen hazards require a health alert system.
    - Pollen hazards also share certain seasonal similarities with air pollutants, such as the timing of pollen and ozone seasons. But, it also known that emergency department asthma visits can occur because of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) elevations in winter, and tree pollen increases in spring contributes more emergency department asthma visits[17].

At the same time, there are significant differences. Notably, criteria air pollutants are air hazards that are managed through engineering controls placed on emission sources. Pollen sources can be controlled, to a limited extent, through urban planning and landscaping practices, but are largely beyond the scope of societal intervention as reviewed in this pollen white paper[46]. In addition, future airborne pollen hazards are likely to be significantly influenced by a changing climate. Increasing temperatures and CO_2 levels have a fertilizing effect on pollen release and allergenicity. Furthermore, over time, climate can lead to the introduction of new vegetation that both increase novel allergen risks and reduce familiar ones (such as through changes in the boreal forests).

3. *Options for a pollen monitoring network:* Climate can also influence air pollution levels, but in different ways. Most notably, increasing summer time temperatures can enhance photochemical reactions leading to the formation of ozone and secondary particulates.

4. *NAB Ambient pollen monitoring:* One logical starting point for the national pollen monitoring network is to build on the network of the 82 NAB pollen monitoring stations. These stations are maintained by a group of trained volunteers, mostly from hospitals, medical practices, and universities throughout the country. But, the actual cost for purchasing the pollen monitoring equipment and paying the salaries of the trained technicians are covered by the pollen counting stations, and not the NAB. Another interesting observation is that the NAB pollen counting stations are concentrated in urban areas.

According to the information on the NAB website, in order to be a pollen counter, an applicant: *…must accurately identify and count pollen on an actual pollen slide. To be a mold counter, an applicant must accurately identify and count mold grains on an actual mold slide.*

Once certified: *…a station must collect samples, a minimum of three days per week, using a Burkard volumetric grain trap, a Kramer-Collins sampler or a Rotorod sampler. The sampler must be situated on an unobstructed rooftop at least one story above ground with no local pollen and/or mold grain sources.*

This network of pollen counting stations may prove adequate for many, if not most, of EPHT purposes. For states that only have one pollen counting station or no pollen counting station, what can be done is to encourage private medical practices that specialize in respiratory-allergic conditions to consider starting an NAB certified pollen counting station. What has to be determined is: What is the minimum number of pollen counting stations that will satisfy the needs of persons susceptible to the adverse respiratory health effects brought on by elevated pollen levels or certain types of pollen sources and can be the basis for environmental health surveillance?

To envision an ideal network, however, the following considerations need to be taken into account:

a. *Public availability*: The NAB data are currently not publicly available, though CDC's National Center for Environmental Health is now developing a proposal which could make these pollen data available from the National EPHT portal.

b. *Speciation:* there may be a need to further subdivide pollen counts based on pollen species (such as various tree species). This is not currently being done through the NAB. However, some pollen counting stations in the NAB report pollen counts by taxa. In addition, some NAB affiliated pollen counting stations do not record daily pollen levels based on pollen taxa.

c. *Spatial variability*: Further analysis is needed in order to determine the geographical extent to which pollen monitoring characterizes exposure to the surrounding population. This is particularly important given the relative absence of pollen monitoring in rural environments. These data needs could be addressed through pilot studies, including approaches that integrate monitoring and modeling tools similar to those used in estimating pollutant concentrations and heat impacts. The studies could also incorporate the input of climatologists, to ensure coverage of different climate zones within a state or region.

d. *Pollen grain composition*: Changing temperatures and CO_2 levels may affect the biochemical composition of pollen grains, making them either more or less allergenic on a per grain basis.

B. *Aerometric Information Retrieval System (AIRS) Monitoring Sites*

The proposed national pollen surveillance system should also include the current USEPA system for monitoring criteria air pollutants. This system has several advantages, as a starting point:

- It is operated by state and federal environmental agencies, thereby making the data publicly available and not contingent on volunteer support;
- Monitoring sites are selected to ensure geographical representativeness;

- Monitoring stations also include meteorological instruments (e.g., wind speed and direction);
- Monitoring schedules could be synchronized to avoid extra trips to monitoring stations;
- Pollen monitoring equipment is relatively inexpensive and fairly easy to maintain; and,
- Co-location of pollen and air pollutant monitors could provide a more complete hazard assessment of air quality risks. Recently several different approaches have been developed to automate the classification of pollen and to count pollen grains[77-78]. A stand-alone pollen speciation and grain counting unit has been developed in Germany, and it is now part of the German Weather Service (GWS)[79]. The German weather service has added 15 of these units to their network of weather stations. Figure 7 shows what the computerized pollen classification and grain counting unit looks like. The included publication describes how this automated pollen taxa identification and pollen grains counting unit functions[80]. The English abstract states that the pollen recognition software attained recognition rates that exceeded 90%. The next publication describes how a pollen forecast system was developed for Europe[81]. This type of stand-alone pollen unit could be included with selected on-the-ground fine particulate matter monitoring stations with the USEPA AIRS national network. Map 3 shows a US map with ozone and ragweed. This map was produced by the National Resources Defense Fund (NRDF) using USEPA ozone readings and ragweed data from a variety of sources that included the US Department of Agriculture (USDA), Global Biodiversity Information Facility (GBIF), and Asthma and Allergy Foundation of America (AAFA), Asthma Capitals. This map is used to illustrate what the results from the joint display of pollen and a criteria air pollutant, in this case ozone, would appear if a national pollen and health tracking system were implemented.

There are several significant barriers to including automated pollen counting and classification units with the USEPA AIRS network:

- Pollen monitoring is not currently supported by AIRS, and is not likely to be in the future, given the regulatory mandate of state and federal environmental agencies; and, a system for air quality alerts would have to be developed separately by the US National Weather Service (NWS);
- Another possibility is to use the German Weather Service (GWS) as a model to include automated pollen counting and classification units to selected NWS Stations in the US. The advantage of taking this approach is there is already a history of its effectiveness in Germany.

The relationship between pollen and heat has been documented previously. This would be the rationale for this suggestion. The other advantage is that pollen forecasts could be included with existing weather forecasts, as is now done in Germany.

C. New/Innovative or Hybrid Approaches

In the absence of a specific regulatory mandate to establish a pollen monitoring network, EPHT is free to consider a variety of approaches to meet tracking objectives. Also, because pollen monitoring involves more a commitment of human resources than capital equipment, it may be fairly adaptable to a variety of tracking approaches.

One possibility is to combine knowledge to the extent that we can by using both the NAB and the ambient air quality monitoring. Additionally, it is possible to explore the tracking information available through remote sensing activities. While each of these approaches alone may not be sufficient to constitute a comprehensive national tracking strategy for pollen, collectively they may provide a path forward, and much useful data.

An alternative approach to building from medical and environmental data projects is to expand on the growing interest in volunteer scientist Phenological projects, as exemplified in the National Phenology Network (http://www.usanpn.org/), and what is available from NOAA. While focused more on observing the timing of seasonal cycles among plants, animals, and the physical environment, it is possible that activities could be expanded to more of a health oriented focus among those citizen scientists particularly interested in the relationships between climate and health. For this change in the way the National Phenology Network operates, it will be necessary to include this organization as an EPHT collaborator and develop a data sharing agreement. Similar agreements have to be developed with NOAA to obtain remote sensing phenological data.

D. *Health data:* Health data sources that can be used to document the effects of pollen effects include emergency department visits, inpatient hospitalizations and essentially real time reporting of asthma and possibly other respiratory conditions such as rhinitis through Early Notification of Community-based Epidemics (ESSENCE). These two data sources are now part of the National and state/New York City tracking networks. What would be required will be to select patients with ICD-9-CM codes that also include respiratory conditions impacted by pollen, besides asthma. Another health data source could be the real-real time reporting of asthma, rhinitis and possibly other respiratory emergency department visits available from ESSENCE. ESSENCE emergency department patient reports are now available to some state health departments. An additional data source could be prescribed medications and/or over the counter medications that are associated with pollen induced adverse health effects. These last two health outcome measures are not currently available from the National or CDC tracking partner web sites.

Another data source relevant to detection of pollen effects on health is to obtain health records available from health maintenance organizations. This type of data source has been used in analytical studies that have been published in the literature. But, to our knowledge, health maintenance organization records are not currently available from the 24 states/New York City tracking portals and/or from the NEPHTN.

Still another data source for pollen effects is to obtain patient records from health care providers in the areas covered by pollen counting stations. Here again, these private provider records have not been used by EPHT programs or the national tracking program.

At this time there is the transition to the future use of the electronic medical record. So far, there have not been discussions among EPHT programs and CDC tracking about the use of the electronic medical record. The advantage of the electronic medical records is that health events can be recorded in almost real time. It is then possible to look at temporal and spatial relationships between pollen events and pollen related health outcome events.

E. *Summary of National Pollen Surveillance System for the US:* Table 6 includes the key attributes that should be included in a national pollen surveillance system. Some of these features were discussed above. The last item in this table deals with sustaining ability. The first topic concerns relevance of a pollen surveillance system in contributing to reduced heath burdens on US citizens. Evidence in support of this conclusion has provided in this pollen white paper. More accurately and timely pollen alerts to health care providers and impacted persons should result in less need to obtain medical services, decreased medical costs and fewer missed school and work days. A related sustainability issue involves payment for the additional cost of establishing and maintaining a national pollen surveillance system. Costs savings can come from decreased medical costs, financial support from fees paid for pollen alerts, data use fees, funds from pharmaceutical companies and federal or state support.

V. *Additional system attributes needed to track climate-change impacts on phenology and pollen number/allergenicity:* Atmospheric conditions can affect timing in the release of pollen, total pollen count, and allergenicity[27, 29, 31, 40]. For example, ragweed was found to release more pollen, grow faster, and flower earlier, in areas with greater CO_2 concentrations (i.e. urban centers) as compared to rural regions[27] . Therefore, the monitoring of CO_2 concentrations at or near pollen counting stations can provide valuable information to any analysis that aims to investigate the effects of CO_2 concentrations on pollen production in other allergenic species, or to determine the significance of CO_2 concentrations on the burden of allergic disease (i.e. allergic rhinitis or asthma).

Specific weather conditions such as thunderstorms have been associated with increased asthma hospitalizations, due to a sudden and increased dispersion of pollen into the lower atmosphere[44]. The incorporation of data specifying the daily occurrence of weather types to be used to assess geographically the relationship between thunderstorms and allergic related hospitalizations throughout the United States.

Shorter term climate variations (i.e. El Niño Southern Oscillation, ENSO) have been implicated as a cause for increased allergic illness[30]. With consideration that the El Niño/La Nina episodes affect regionally weather patterns differently, and thus the production of pollen in allergenic plants[83], the inclusion of an ENSO measure into a predictive model could improve a pollen health alert system, but more research is needed. Additionally, long term trends in temperature and precipitation should be considered in the development of any system to report pollen related health alerts. Long term climatic trends could either mask or magnify the relationship between climate and pollen, which for certain allergenic plants have also shown an increasing pollen count trend[31]. Long term trends in temperature and precipitation can be easily calculated using weather observation data over an extended period of time (i.e., 20 years).

VI. *Resource needs and next steps*

A. *Identify funding and other support for pilot projects, research and analyses necessary to recommendations:* Interests in pollen monitoring cut across various interests and administrative structures, including health, environment, and climate. It might therefore be possible to put together collaborative proposals that interest funders with multiple health and environmental funding objectives. It might also be possible for different programs to collaborate around a shared funding project (e.g., between USEPA, NOAA and CDC EPHT).

One outcome of this pollen white paper could be to have a pre-established project team consisting of federal, state, and academic public health entities that could implement proposals to further the goals of the pollen white paper when relevant funding opportunities arise. This team would be organized under the auspices of the EPHT program.

The Maine EPHT has formed an *ad hoc* group consisting of allergists, climatologists, laboratorians, air quality monitoring, and environmental health. This group will outline current monitoring activities in the State. These activities will include: 1) provide initial input regarding needs and opportunities for pollen alerts; 2) outline possible project proposals to develop an adequate pollen monitoring system at the state level. This group will also work in collaboratively with the EPHT pollen sub-team toward a shared objective of developing a robust state-national partnership around pollen monitoring. If successful, the *ad hoc* Maine pollen specialty committee might also serve as a model for other state/local initiatives.

VI. *Final summary:* There is an advantage to EPHT to take an active role in facilitating discussions that will be required to establish a national pollen surveillance system. Because of what is already known about pollen effects on a variety of health endpoints, pollen does satisfy the basic definition of an EPHT ambient air hazard. Some of the health measures that have been shown to be adversely impacted by pollen are already available on the national and state/New York City tracking web sites. These include emergency department visits and inpatient hospitalizations for asthma. Since emergency department visits and inpatient hospitalizations are already included as part of the core EPHT datasets, it would not be difficult to develop other NCDM indicators for other respiratory conditions impacted by pollen; these could include rhinitis. Up to now only retrospectively collected data have been included as EPHT datasets. Discussions are now ongoing by some CDC supported tracking grantees to utilize ESSENCE data as part of the EPHT data. Some of these discussions have occurred because of climate change. An additional benefit for a pollen surveillance system would be that pollen readings could be obtained and made available prospectively to EPHT programs.

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Table 1: All National Allergy Bureau (NAB) pollen counting stations in US states an all European Aeroallergen Network (EAN) pollen counting stations in countries in Europe

VARIABLES	NAB[1]		EAN[2]		*P*
	Mean	Median	Mean	Median	
Population	7635841.4	5303925.0	22089475.5	8914944.5	<0.05
Square miles	64032.3	54157.8	315644.4	41296.5	>0.05
Stations	2.3	2.0	14.0	3.5	<0.01
Persons/Monitor	3885577.9	2793951.2	4883822.8	1256886.7	>0.05
Area/Monitor	38490.8	25910.5	90092.8	8205.5	>0.05

[1]In March 2012 there were 82 pollen counting stations in 35 US states. Pearson correlation between persons/monitor and area/monitor were not significant, $r\ (33) = 0.066$, $p > 0.05$.

[2]Also, in March 2012 there were 505 pollen counting stations in 36 countries in Europe. Pearson correlation between persons/monitor and area/monitor was not significant, $r\ (34) = 0.296$, $p > 0.05$.

Table 2: Regression analyses for National Allergy Bureau (NAB) pollen counting station monitors, population and square miles as predictors for the two outcome measures of persons/monitor and area/monitor

PREDICTORS	PERSONS/MONITOR[1]			AREA/MONITOR[2]		
	PE[3]	SE[3]	*P*[4]	PE[3]	SE[3]	*P*[4]
Intercept	4598514	522549	<0.0001	36191	4060.7764	<0.0001
Stations	-1806913	248054	<0.0001	-17778	1927.6466	<0.0001
Population	0.49111	0.0568	<0.0001	0.0000	0.0004	>0.05
Square miles	-3.58633	7.3331	>0.05	0.6853	0.0570	<0.0001

[1]Model F value for persons/monitor was significant, F (3, 31) =27.34, p<0.0001. Adjusted R^2 was 0.699.

[2]Area/monitor F value for area/monitor was significant, F (3, 31) =61.24, p<0.0001. Adjusted R^2 was 0.842.

[3]Abbreviations used to evaluate regression model results were: PE=Parameter Estimate and SE=Standard Error.

[3]*T*-test was used to evaluate significance of predictors in each regression model. DF was 1 for all predictors and intercept.

Table 3: Regression analyses for European Aeroallergen Network (EAN) pollen counting station monitors, population and square miles as predictors for the two outcome measures of persons/monitor and area/monitor

PREDICTORS	PERSONS/MONITOR[1]			AREA/MONITOR[2]		
	PE[3]	SE[3]	*P*[4]	PE[3]	SE[3]	*P*[4]
Intercept	3250637	1395076	<0.05	71968	29782	<0.05
Stations	-308652	67259	<0.0001	223.9382	1435.8125	>0.05
Population	0.3261	0.0683	<0.0001	-0.0022	0.0015	>0.05
Square miles	-3.9278	1.6625	<0.05	0.2034	0.0355	<0.001

[1]Model F value for persons/monitor was significant, $F(3, 32) = 10.48$, $p<0.0001$. Adjusted R^2 was 0.4482.

[2]Area/monitor F value for area/monitor was significant, $F(3, 32) = 20.06$, $p<0.0001$. Adjusted R^2 was 0.6204.

[3]Abbreviations used to evaluate regression model results were: PE=Parameter Estimate and SE=Standard Error.

[3]*T*-test was used to evaluate significance of predictors in each regression model. DF was 1 for all predictors and intercept.

Table 4: First quartile National Allergy Bureau (NAB) pollen counting stations in US states and first quartile European Aeroallergen Network (EAN) pollen counting stations in countries in Europe

VARIABLES	NAB[1]		EAN[2]		*P*
	Mean	Median	Mean	Median	
Population	5236091.0	3751351.0	19509722.2	7866500.0	>0.05
Square miles	48053.5	44742.7	126948.9	39770.0	>0.05
Stations	2.5	2.0	23.5	2.0	<0.05
Persons/monitor	2276537.8	1257299.0	653693.6	593388.8	<0.05
Area/monitor	26047.5	11185.7	69005.6	2698.1	>0.05

[1]Selection criteria were US states with first quartile value of <15030.35 or square miles/monitor of <1457959.0. There were 33 NAB pollen counting stations in 13 US states. For NAB, Pearson correlation between persons/monitor and area/monitor was not significant, r (11) =-0.269, p>0.05.

[2]Selection criteria were European countries with first quartile value of <648170.46 persons/monitor or first quartile value of <3212.76 square miles/per monitor. There were 306 EAN pollen counting stations in 13 European counties. For EAN, Pearson correlation between persons/monitor and area/monitor was not significant, r (11) =-0.363, p>0.05.

Table 5: Justification for a national pollen surveillance system in the US

1. Contribution of pollen to respiratory chronic diseases
    a. Missed school or work days
    b. Over-the-counter medication sales
    c. Doctor visits, emergency department visits and inpatient hospitalizations
    d. Preventable health care costs
    e. Unnecessary asthma deaths in persons 65+ years old
2. Climate change effects
    a. Increased pollen due to higher temperature and more carbon dioxide
    b. Increased ragweed pollen
    c. Heat island effect in urban areas will further increase ambient temperature and available carbon dioxide

Table 6: Proposed National Pollen Surveillance System for the US

1. Establish a national pollen surveillance system that will include, at a minimum, the spatial coverage of the first quartile of pollen counting stations in the European Aeroallergen Network.
    a. These minimum population and area criteria should be implemented within each state in the US.
    b. Spatial coverage should consider the presence of allergenic pollen sources, especially in urban centers and where there are more pollen-sensitive persons.
2. Each pollen counting station should collect pollen samples each day and use established technician training and testing criteria now implemented by the NAB in the US.
    a. Other pollen-related observations should include phenology (catalog of pollen producing sources, start, end and duration of the pollen season for all pollen and by taxa).
        i. Include direct observations and remote sensing measurements
    b. Reported respiratory symptoms database
        i. Pollen impacted persons should be able to report manifested pollen symptoms by using personal computers and sophisticated telephone devices. Each report should include date when symptom occurred, location in longitude/latitude, age category, gender, race, ethnicity, and symptom(s).
    c. Real time reporting of persons admitted to the emergency department for respiratory conditions resulting from pollen exposure.
3. Basis for pollen advisories
    a. Emphasis on use of direct pollen readings, current and historical values
    b. Use of statistical modeling to create prediction surfaces
    c. Geographic Information System tools used to display spatial attributes
4. Pollen advisories to:
    a. Health care providers
    b. Impacted persons
    c. Next day, and multiple days in the future
5. Easy access to all pollen data and related measures
    a. Data summaries in the form of tables, graphs and maps and simple to understand interpretations made available to everyone
    b. Actual observations also available to researchers, university faculty and graduate students and others with demonstrated data analysis skills
    c. Encourage use of pollen data through data analysis workshops
6. Sustainability
    a. Pollen counting stations supported though medical cost savings
    b. Fees paid for pollen alerts
    c. Data use fees

Figure 1: Picture of common ragweed, *Ambrosia artemisiifolia*.

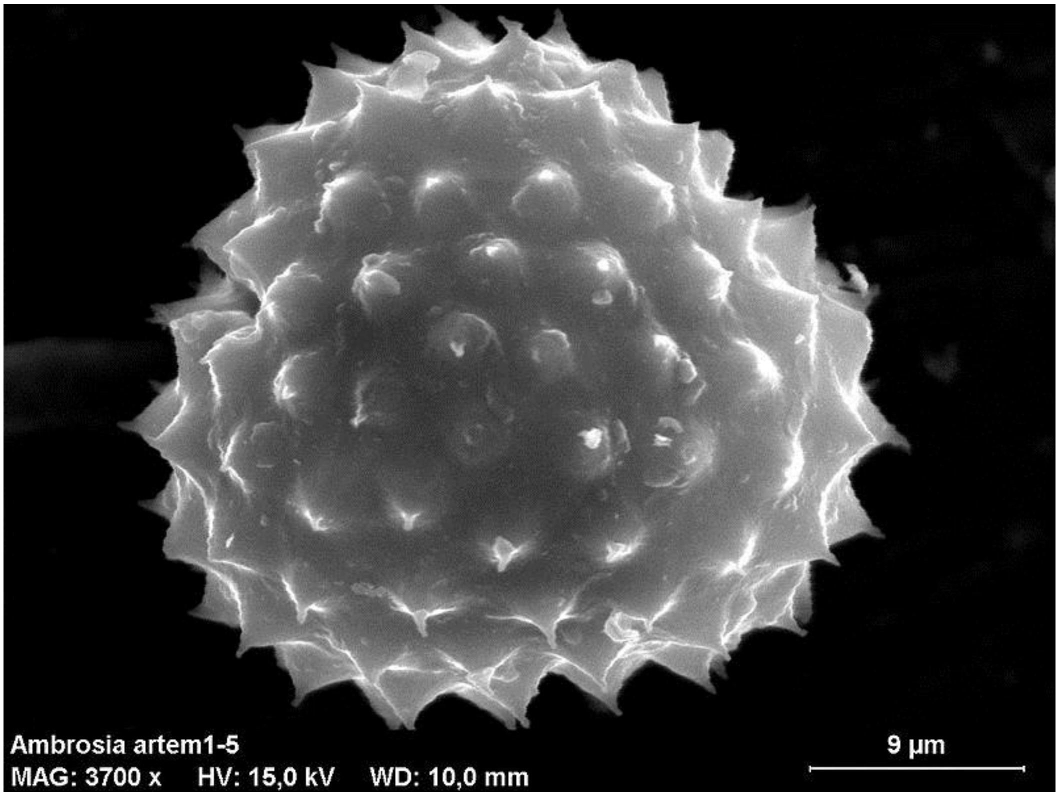


Figure 2: Scanning electron microscope image of common ragweed pollen core. *Ambrosia artem*.

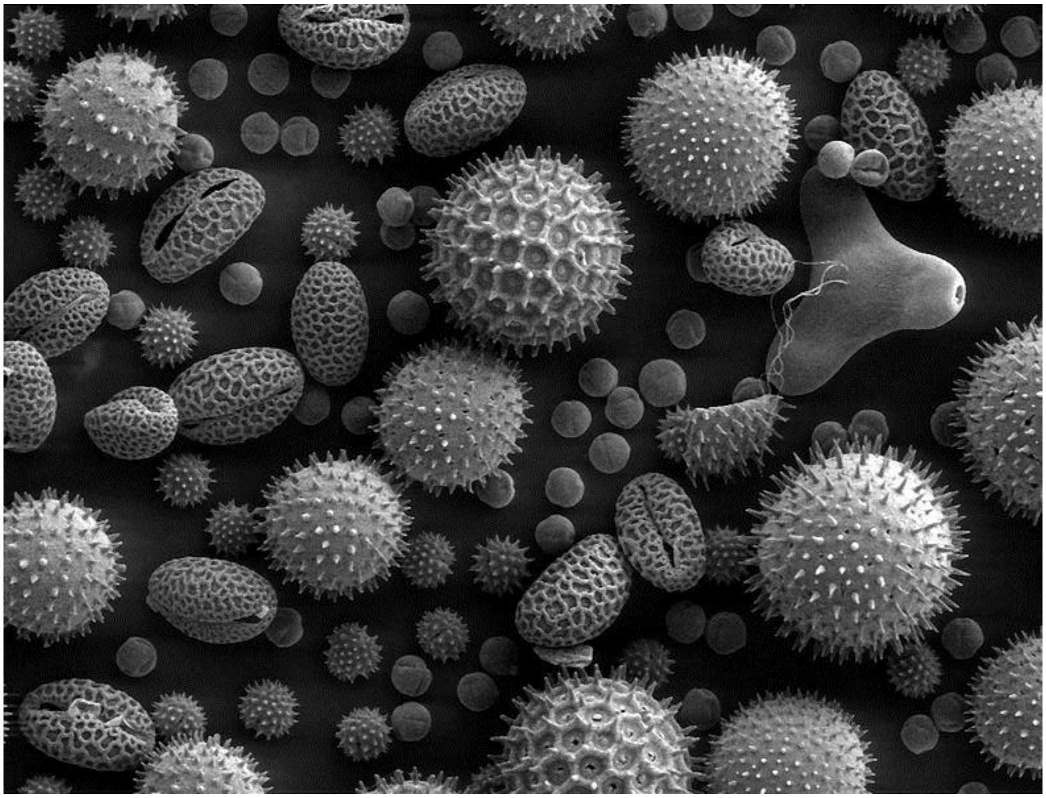


Figure 3: Scanning electron microscope image of pollen grains from a variety of plants: sunflower (*Helianthus annuus*), morning glory (*Ipomoea purpurea*), prairie hollyhock (*Sidalcea malviflora*), oriental lilly (*Lilium auratum*), evening primrose (*Oenothera fruticosa*), and castor bean (*Ricinus communis*).

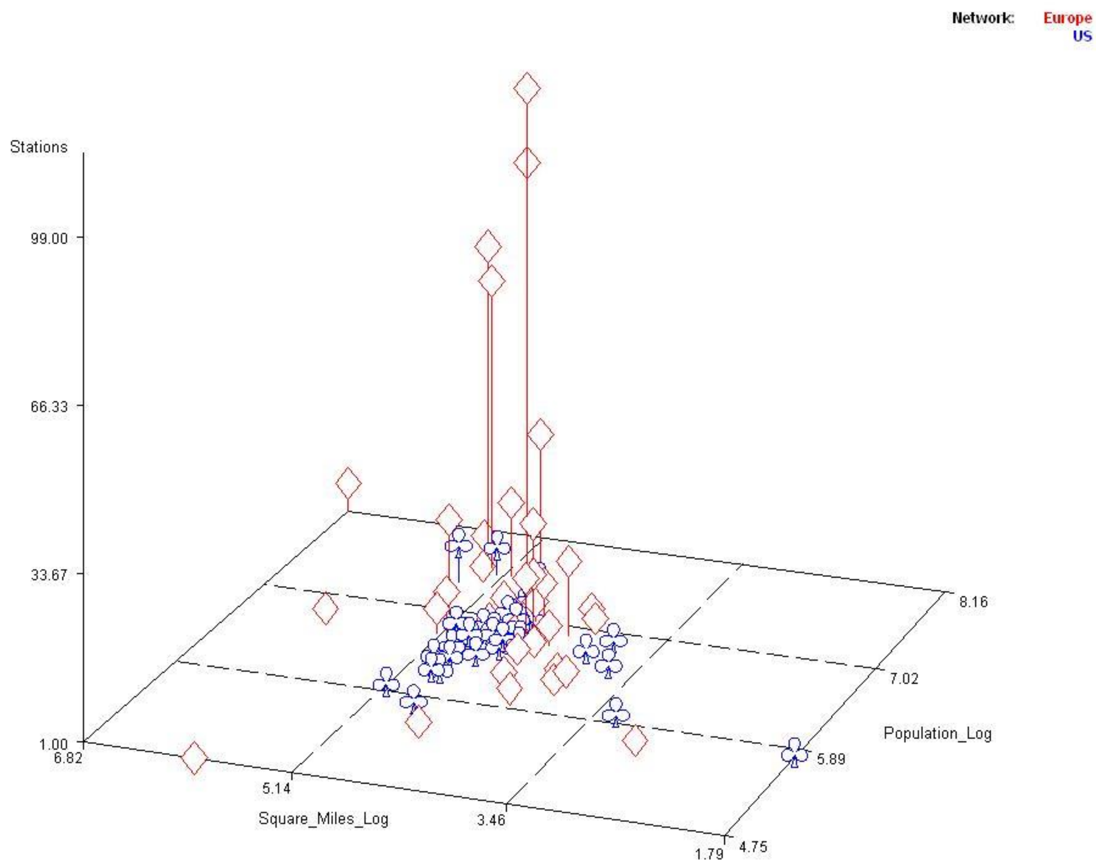


Figure 4: Log population, log area in square miles and pollen counting stations in the NAB (US) and EAN (Europe).

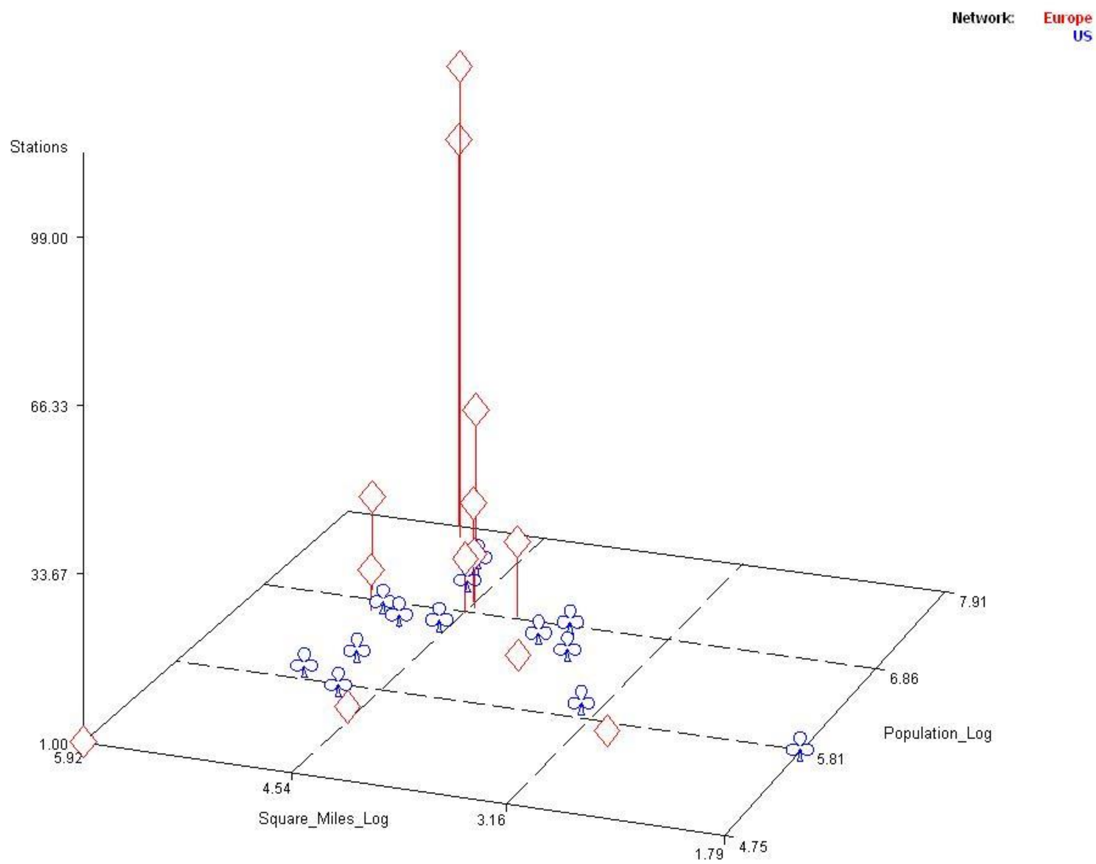


Figure 5: Log population, log area in square miles and pollen counting stations in the NAB (US) and EAN (Europe). First quartile NAB states or EAN countries.

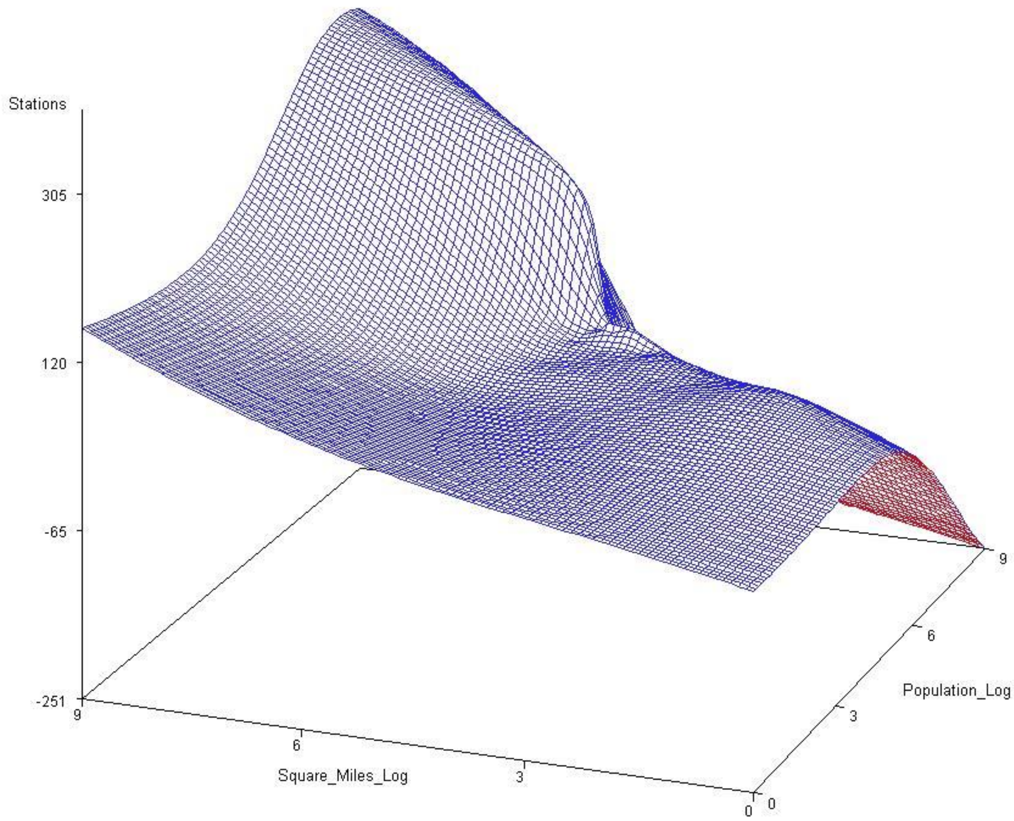
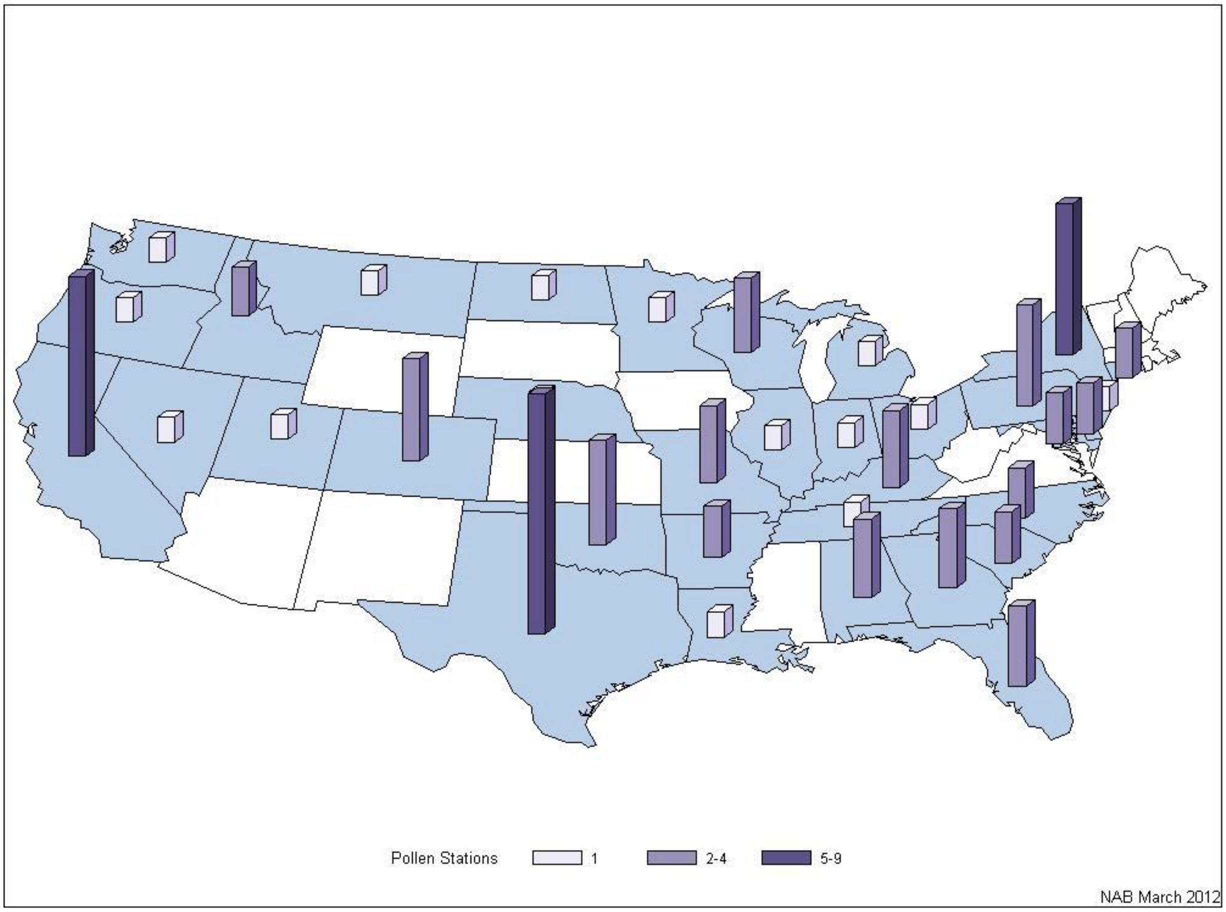
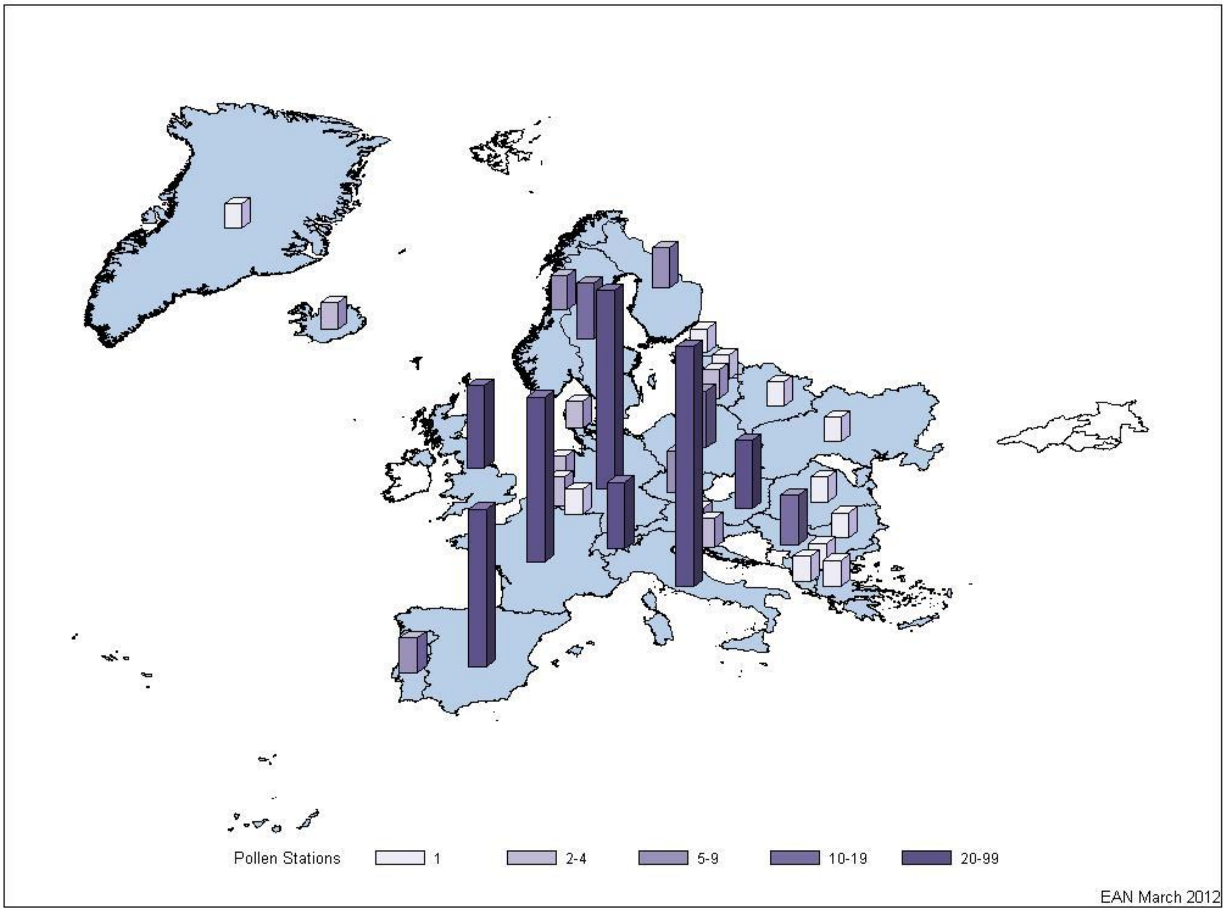


Figure 6: Surface plot for pollen counting stations. Interporalted log values for log square miles and log population. First quartile NAB states (US) or EAN countries (Europe).

Figure 7: Automatic pollen taxa classification counting station. Source is Fraunhofer-Gesellschaft, Automatic Measuring Stations for Pollen will Improve Forecasts, *ScienceDaily*, Feburuary 12, 2009, http://www.sciencedaily.com/releases/2009/02/090203081615.htm. Last accessed January 28, 2013



Map 1: Nunber of National Allergy Bureau (NAB) pollen counting stations per US state as of March 2012.



Map 2: Number of European Allergy Network (EAN) pollen counting stations per country in Europe as of March 2012. Some EAN countries not in the European contient are not shown on this map, eg., Russia and Turkey.

Appendices

Appendix A: Pollen Monitors per Population and Land Area that are Part of the National Allergy Bureau, United States

States[1]	Pollen Stations	Population	Area in Sq. Miles	Persons/ Monitor	Sq. Miles/ Monitor
Alabama	3	4,779,736	50,645	1,593,245.3	16,881.8
Arkansas	2	2,915,918	52,035	1,457,959.0	26,017.6
California	7	37,253,956	155,779	5,321,993.7	22,254.2
Colorado	4	5,029,196	103,642	1,257,299.0	25,910.5
Connecticut	2	3,574,097	4,842	1,787,048.5	2,421.2
Delaware	2	897,934	1,949	448,967.0	974.3
District of Columbia	2	601,723	61	300,861.5	30.5
Florida	3	18,801,310	53,625	6,267,103.3	17,874.9
Georgia	3	9,687,653	57,513	3,229,217.7	19,171.2
Idaho	2	1,567,582	82,643	783,791.0	41,321.6
Illinois	1	12,830,632	55,519	12,830,632.0	55,518.9
Indiana	1	6,483,802	35,826	6,483,802.0	35,826.1
Kentucky	3	4,339,367	39,486	1,446,455.7	13,162.1
Louisiana	1	4,533,372	43,204	4,533,372.0	43,203.9
Maryland	1	5,773,552	9,707	5,773,552.0	9,707.2
Michigan	1	9,883,640	56,539	9,883,640.0	56,538.9
Minnesota	1	5,303,925	79,627	5,303,925.0	79,626.7
Missouri	3	5,988,927	68,742	1,996,309.0	22,913.8
Montana	1	989,415	145,546	989,415.0	145,545.8
Nebraska	1	1,826,341	76,824	1,826,341.0	76,824.2
Nevada	1	2,700,551	109,781	2,700,551.0	109,781.2
New Jersey	1	8,791,894	7,354	8,791,894.0	7,354.2
New York	6	19,378,102	47,126	3,229,683.7	7,854.4
North Carolina	2	9,535,483	48,618	4,767,741.5	24,309.0
North Dakota	1	672,591	69,001	672,591.0	69,000.8
Ohio	1	11,536,504	40,861	11,536,504.0	40,860.7
Oklahoma	4	3,751,351	68,595	937,837.8	17,148.7
Oregon	1	3,831,074	95,988	3,831,074.0	95,988.0
Pennsylvania	4	12,702,379	44,743	3,175,594.8	11,185.7

South Carolina	2	4,625,364	30,061	2,312,682.0	15,030.4
Tennessee	1	6,346,105	41,235	6,346,105.0	41,234.9
Texas	9	25,145,561	261,232	2,793,951.2	29,025.7
Utah	1	2,763,885	82,170	2,763,885.0	82,169.6
Washington	1	6,724,540	66,456	6,724,540.0	66,455.5
Wisconsin	3	5,686,986	54,158	1,895,662.0	18,052.6
Total	*82*	*267,254,448*	*2,241,132*	*135,995,226.6*	*1,347,176.8*
N	*35*	*35*	*35*	*35*	*35*
Mean	*2.3*	*7,635,841.4*	*64,032.3*	*3,885,577.9*	*38,490.8*
Median	*2*	*5,303,925.0*	*54,157.8*	*2,793,951.2*	*25,910.5*
Minimum	*1*	*601,723*	*61.1*	300,861.5	30.5
Maximum	9	37,253,956	261,231.7	12,830,632.0	145,545.8

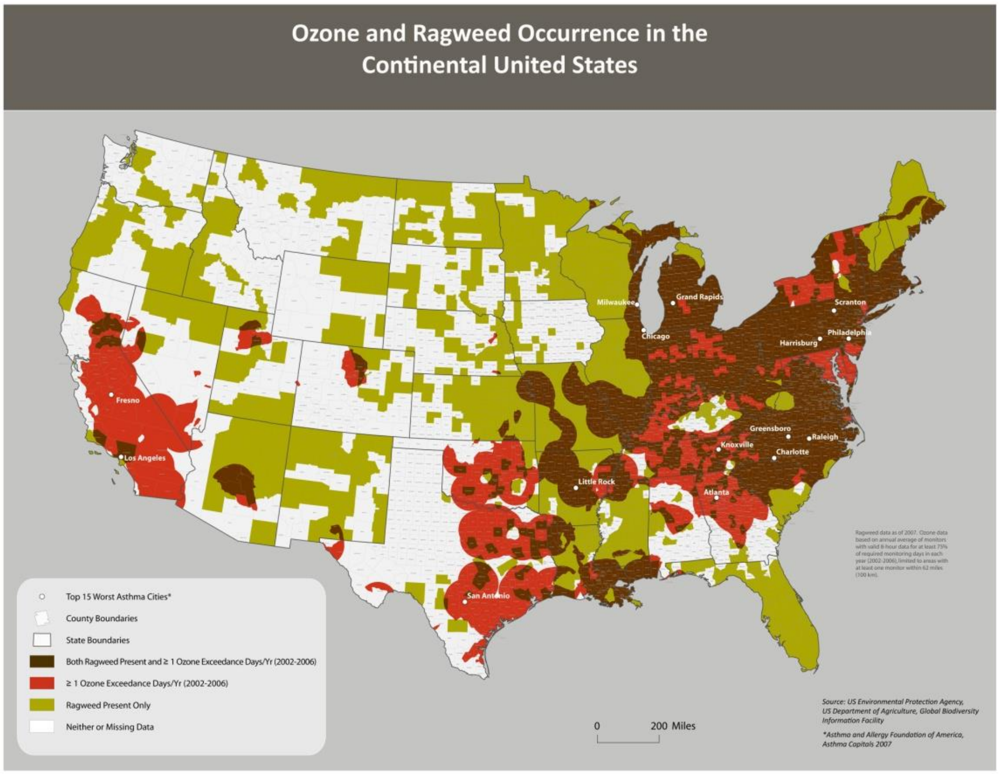
[1]States in blue hue are in the lower group; they have more desirable pollen surveillance features.

Appendix B: Pollen Monitors per Population and Land Area that are Part of the European Aeroallergen Pollen Network in Europe.

Country[1]	Pollen Stations	Population	Area in Sq. Miles	Persons/ Monitor	Sq. Miles/ Monitor
Albania	1	2,831,741	11,100	2,831,741.0	11,100.0
Austria	12	8,414,638	32,377	701,219.8	2,698.1
Belarus	1	9,503,807	80,155	9,503,807.0	80,155.0
Belgium	3	11,007,020	11,787	3,669,006.7	3,929.0
Bulgaria	1	7,364,570	42,823	7,364,570.0	42,823.0
Croatia	3	4,290,612	21,851	1,430,204.0	7,283.7
Czech Republic	9	10,562,214	30,450	1,173,579.3	3,383.3
Denmark	2	5,671,050	1,370,000	2,835,525.0	685,000.0
Estonia	1	1,340,194	17,413	1,340,194.0	17,413.0
Finland	9	5,404,956	130,596	600,550.7	14,510.7
France	65	65,350,000	260,558	1,005,384.6	4,008.6
Germany	82	81,799,600	137,847	997,556.1	1,681.1
Great Britain	28	60,003,000	88,745	2,142,964.3	3,169.5
Greece	1	11,305,118	50,944	11,305,118.0	50,944.0
Greenland	1	56,615	836,109	56,615.0	836,109.0
Hungary	21	9,982,000	35,919	475,333.3	1,710.4
Iceland	2	319,575	39,770	159,787.5	19,885.0
Italy	99	60,681,514	116,346	612,944.6	1,175.2
Latvia	1	2,067,887	24,938	2,067,887.0	24,938.0
Lithuania	3	3,190,070	25,174	1,063,356.7	8,391.3
Luxembourg	1	511,840	999	511,840.0	998.6
Macedonia	1	2,055,004	9,779	2,055,004.0	9,779.0
Netherlands	2	16,847,007	16,039	8,423,503.5	8,019.5
Norway	6	4,985,870	148,746	830,978.3	24,791.0
Poland	16	38,501,000	120,696	2,406,312.5	7,543.5
Portugal	5	10,561,614	35,646	2,112,322.8	7,129.2
Romania	1	19,042,936	92,043	19,042,936.0	92,043.0
Russia	7	143,030,106	6,592,800	20,432,872.3	941,828.6
Serbia	12	7,120,666	34,116	593,388.8	2,843.0
Slovak Republic	5	5,445,324	18,932	1,089,064.8	3,786.4

Slovenia	3	2,050,189	7,827	683,396.3	2,609.0
Spain	60	46,030,109	195,364	767,168.5	3,256.1
Sweden	16	7,866,500	15,940	491,656.3	996.3
Switzerland	20	9,415,295	173,745	470,764.8	8,687.3
Turkey	4	74,724,269	302,535	18,681,067.3	75,633.8
Ukraine	1	45,888,000	233,090	45,888,000.0	233,090.0
Total	*505*	*795,221,910*	*11,363,198.8*	*175,817,620.7*	*3,243,341.9*
N	*36*	*36*	*36*	*36*	*36*
Mean	*14*	*22,089,497.5*	*315,644.4*	*4,883,822.8*	*90,092.8*
Median	*4*	*8,914,966.5*	*41,296.5*	*1,256,886.7*	*8,205.4*
Minimum	*1*	*56,615*	*998.6*	*56,615.0*	*996.3*
Maximum	99	143,030,106	6,592,800.0	45,888,000.0	941,828.6

[1]Countries in blue hue are in the lower group.



Map 3: Ozone and ragweed occurrence in the Continental United States.