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# Pollen aeroallergens in the Washington, DC, metropolitan area: a 10-year volumetric survey (1998-2007)

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**Background:** Local aeroallergen surveys identify and establish patterns of prevalence for tree, grass, and weed species that enable the clinician to more effectively select allergens for skin testing and therapy.

**Objectives:** To determine peak pollination periods, atmospheric concentrations, and year-to-year variation for identified tree, weed, and grass aeroallergens and examine the influence of selected meteorological parameters.

**Methods:** Atmospheric sampling for pollen aeroallergens was performed using a volumetric rotating-arm impaction sampler. The Spearman correlation coefficient was used to determine the relationship between daily counts and selected meteorological parameters.

**Results:** Previous findings for area trees, conducted at a different location, are corroborated. Predominant pollen types include *Quercus*, Cupressaceae, Pinaceae, *Morus*, Betulaceae, *Acer*, *Platanus*, *Fraxinus*, Poaceae, and *Ambrosia*. Early flowering weeds (*Rumex* and *Typha*) and Poaceae overlap with peak tree season in April. Biphasic seasons are noted for Poaceae and *Ulmus*. Tree pollen accounts for 91.2%, weeds 3.8%, and grasses 3.2% of total annual pollen yield. Variation in overall pollen production is evident from year to year. High production years for some species are low for others. Cyclic pollinating patterns for *Alnus*, Betulaceae, and *Fagus* were observed. Grass and weed pollen correlated positively with maximum temperature and dew point; however, the results for individual tree species were variable.

**Conclusion:** The Washington, DC, metropolitan area is host to a variety of tree, weed, and grass species that produce copious amounts of pollen. Further investigation into year-to-year variation with respect to inherent cycling and meteorological influences is warranted.

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## INTRODUCTION

The aerial dispersion of copious amounts of pollen, as part of a complex reproductive strategy in wind pollinated plants, results in adverse health-related consequences for millions of individuals annually. Elevated atmospheric concentrations of allergenic pollen have been correlated to the onset of hay fever symptoms and asthma, increasingly constituting a major public health concern.<sup>1–3</sup> Allergic rhinitis affects an estimated 20% to 30% of the general population in the United States.<sup>4–7</sup> Asthma morbidity remains a major cause of missed days from school and work, emergency department visits, and hospitalizations.<sup>8</sup> Local aeroallergen surveys identify and establish patterns of prevalence for allergenic tree, grass, and weed species that enable the clinician to more effectively select allergens for skin testing and therapy. Increasing the

public's knowledge of major area aeroallergens will facilitate the practice of more effective avoidance measures for the sensitized patient.

The metropolitan Washington, DC, area is located within the expansive Eastern Deciduous Forest, a tree region dominated by a great diversity of tree species that drop their leaves in the winter. The region extends from northern New England to southern Florida and westward to the prairie grasslands.<sup>9</sup> Washington, DC, lies at the western edge of the Atlantic Coastal Plain, generally wet with marshland, rivers, and swamp areas. A rockier, hilly Piedmont plateau region stretches west of the city to the Blue Ridge Mountains. The “fall line” marking the convergence of the 2 geographic provinces runs close to the sampling location, just east of Rock Creek Park, one of the largest natural urban parks in the US national park system.<sup>10</sup>

The region features a continental climate with hot, humid summers and cold, damp winters. Precipitation tends to be uniformly distributed throughout the year. Annual rainfall amount averages close to 40 in. The average date of the last freezing temperature in the spring is April 1, and the average date for the first freezing temperature in the fall is November 10.<sup>11</sup>

A variety of botanic field guides, aeroallergen surveys, and maps provide insight into the distribution of predominant tree, grass, and weed species in the Washington, DC,

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Table 1. Common Tree, Grass, and Weed Species for Pollen Observed in the Washington, DC, Area

| Family         | Genus and species              | Common name              |
|----------------|--------------------------------|--------------------------|
| Trees          |                                |                          |
| Betulaceae     | <i>Alnus glutinosa</i>         | European black alder     |
|                | <i>Alnus serrulata</i>         | Common or hazel alder    |
|                | <i>Betula alleghaniensis</i>   | Yellow birch             |
|                | <i>Betula lenta</i>            | Cherry or sweet birch    |
|                | <i>Betula nigra</i>            | River birch              |
|                | <i>Betula papyrifera</i>       | White or paper birch     |
|                | <i>Betula populifolia</i>      | Gray birch               |
|                | <i>Carpinus caroliniana</i>    | American hornbeam        |
|                | <i>Corylus americana</i>       | American hazelnut        |
| Cupressaceae   | <i>Ostrya virginiana</i>       | Hop hornbeam or ironwood |
|                | <i>Chamaecyparis pisifera</i>  | Sawara cypress           |
|                | <i>Juniperus communis</i>      | Common juniper           |
|                | <i>Juniperus virginiana</i>    | Eastern red cedar        |
|                | <i>Thuja occidentalis</i>      | Eastern white cedar      |
| Fagaceae       | <i>Thuja orientalis</i>        | Oriental arborvitae      |
|                | <i>Fagus grandifolia</i>       | American beech           |
|                | <i>Fagus sylvatica</i>         | European beech           |
|                | <i>Quercus acutissima</i>      | Saw tooth oak            |
|                | <i>Quercus alba</i>            | White oak                |
|                | <i>Quercus bicolor</i>         | Swamp white oak          |
|                | <i>Quercus coccinea</i>        | Scarlet oak              |
|                | <i>Quercus falcata</i>         | Southern red oak         |
|                | <i>Quercus ilicifolia</i>      | Bear oak                 |
|                | <i>Quercus imbricaria</i>      | Shingle oak              |
|                | <i>Quercus lyrata</i>          | Overcup oak              |
|                | <i>Quercus macrocarpa</i>      | Bur oak                  |
|                | <i>Quercus marilandica</i>     | Blackjack oak            |
|                | <i>Quercus nigra</i>           | Water oak                |
|                | <i>Quercus palustris</i>       | Pin oak                  |
|                | <i>Quercus phellos</i>         | Willow oak               |
|                | <i>Quercus prinus</i>          | Chestnut oak             |
|                | <i>Quercus rubra</i>           | Northern red oak         |
|                | <i>Quercus stellata</i>        | Post oak                 |
|                | <i>Quercus velutina</i>        | Black oak                |
|                | <i>Quercus virginiana</i>      | Live oak                 |
| Hamamelidaceae | <i>Liquidambar styraciflua</i> | Sweetgum                 |
| Juglandaceae   | <i>Carya cordiformis</i>       | Bitternut hickory        |
|                | <i>Carya glabra</i>            | Pignut hickory           |
|                | <i>Carya laciniosa</i>         | Shellbark hickory        |
|                | <i>Carya ovalis</i>            | Red hickory              |
|                | <i>Carya ovata</i>             | Shagbark hickory         |
|                | <i>Carya tomentosa</i>         | Mockernut hickory        |
|                | <i>Juglans cinerea</i>         | Butternut                |
|                | <i>Juglans nigra</i>           | Black walnut             |
| Moraceae       | <i>Broussonetia papyrifera</i> | Paper mulberry           |
|                | <i>Morus alba</i>              | White mulberry           |
|                | <i>Morus rubra</i>             | Red mulberry             |
| Oleaceae       | <i>Fraxinus americana</i>      | White ash                |
|                | <i>Fraxinus nigra</i>          | Black ash                |
|                | <i>Fraxinus pennsylvanica</i>  | Red/Green ash            |
| Pinaceae       | <i>Abies balsamea</i>          | Balsam fir               |
|                | <i>Picea abies</i>             | Norway spruce            |
|                | <i>Picea glauca</i>            | White spruce             |
|                | <i>Picea pungens</i>           | Blue spruce              |
|                | <i>Picea rubens</i>            | Red spruce               |

Table 1. (Continued) Common Tree, Grass, and Weed Species for Pollen Observed in the Washington, DC, Area

| Family                | Genus and species             | Common name             |
|-----------------------|-------------------------------|-------------------------|
| Pinaceae              |                               |                         |
| (Continued)           | <i>Pinus echinata</i>         | Shortleaf pine          |
|                       | <i>Pinus nigra</i>            | Austrian pine           |
|                       | <i>Pinus pungens</i>          | Table mountain pine     |
|                       | <i>Pinus resinosa</i>         | Norway/Red pine         |
|                       | <i>Pinus rigida</i>           | Pitch pine              |
|                       | <i>Pinus strobus</i>          | Eastern white pine      |
|                       | <i>Pinus sylvestris</i>       | Scots pine              |
|                       | <i>Pinus taeda</i>            | Loblolly pine           |
|                       | <i>Pinus virginiana</i>       | Virginia/Scrub pine     |
|                       | <i>Tsuga canadensis</i>       | Eastern Hemlock         |
| Platanaceae           | <i>Platanus hybrida</i>       | London plane tree       |
| Salicaceae            | <i>Platanus occidentalis</i>  | American sycamore       |
|                       | <i>Populus alba</i>           | White poplar            |
|                       | <i>Populus deltoides</i>      | Eastern cottonwood      |
|                       | <i>Populus grandidentata</i>  | Big tooth aspen         |
|                       | <i>Populus nigra</i>          | Lombardy poplar         |
|                       | <i>Populus tremuloides</i>    | Quaking aspen           |
|                       | <i>Salix babylonica</i>       | Weeping willow          |
|                       | <i>Salix nigra</i>            | Black willow            |
|                       | <i>Salix sericea</i>          | Silky willow            |
|                       | <i>Acer negundo</i>           | Box elder               |
| Sapindaceae           | <i>Acer palmatum</i>          | Japanese maple          |
|                       | <i>Acer pensylvanicum</i>     | Striped maple           |
|                       | <i>Acer platanoides</i>       | Norway maple            |
|                       | <i>Acer pseudoplatanus</i>    | Sycamore maple          |
|                       | <i>Acer rubrum</i>            | Red maple               |
|                       | <i>Acer saccharinum</i>       | Silver/Soft maple       |
|                       | <i>Acer saccharum</i>         | Sugar maple             |
|                       | <i>Tilia americana</i>        | American basswood       |
|                       | <i>Celtis occidentalis</i>    | Hackberry               |
|                       | <i>Ulmus alata</i>            | Winged Elm              |
| Tiliaceae             | <i>Ulmus americana</i>        | American/White elm      |
|                       | <i>Ulmus parvifolia</i>       | Chinese elm             |
|                       | <i>Ulmus procera</i>          | English elm             |
|                       | <i>Ulmus pumila</i>           | Siberian elm            |
|                       | <i>Ulmus rubra</i>            | Slippery or red Elm     |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
| Ulmaceae              | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
|                       | <i>Ulmus</i>                  |                         |
| Grasses and grasslike |                               |                         |
| Poaceae               | <i>Agrostis species</i>       | Bent                    |
|                       | <i>Anthoxanthum odoratum</i>  | Sweet vernal            |
|                       | <i>Bouteloua curtipendula</i> | Grama                   |
|                       | <i>Bromus species</i>         | Brome                   |
|                       | <i>Cynodon dactylon</i>       | Bermuda                 |
|                       | <i>Dactylis glomerata</i>     | Orchard                 |
|                       | <i>Digitaria species</i>      | Crab grass              |
|                       | <i>Festuca species</i>        | Fescue                  |
|                       | <i>Holcus lanatus</i>         | Velvet                  |
|                       | <i>Lolium species</i>         | Rye                     |
| Cyperaceae            | <i>Phleum pratense</i>        | Timothy                 |
|                       | <i>Poa species</i>            | June grass or bluegrass |
|                       | <i>Sorghum halepense</i>      | Johnson                 |
|                       | <i>Carex species</i>          | Sedge                   |
| Typhaceae             | <i>Typha angustifolia</i>     | Narrowleaf cattail      |
|                       | <i>Typha domingensis</i>      | Southern cattail        |
|                       | <i>Typha latifolia</i>        | Broadleaf cattail       |

Table 1. (Continued) Common Tree, Grass, and Weed Species for Pollen Observed in the Washington, DC, Area

| Family         | Genus and species              | Common name                     |
|----------------|--------------------------------|---------------------------------|
| <b>Weeds</b>   |                                |                                 |
| Amaranthaceae  | <i>Amaranthus albus</i>        | Prostrate pigweed               |
|                | <i>Amaranthus blitoides</i>    | Mat amaranth                    |
|                | <i>Amaranthus cannabinus</i>   | Tidmarsh amaranth               |
|                | <i>Amaranthus hybridus</i>     | Green or slim amaranth          |
|                | <i>Amaranthus palmerii</i>     | Careless weed                   |
| Asteraceae     | <i>Amaranthus retroflexus</i>  | Rough or redroot pigweed        |
|                | <i>Amaranthus spinosus</i>     | Spiny pigweed                   |
|                | <i>Daucus carota</i>           | Queen Anne's lace               |
|                | <i>Ambrosia artemisiifolia</i> | Short or annual ragweed         |
|                | <i>Ambrosia bidentata</i>      | Lanceleaf ragweed               |
|                | <i>Ambrosia trifida</i>        | Giant or great ragweed          |
|                | <i>Artemisia annua</i>         | Sweet sagewort                  |
|                | <i>Artemisia biennis</i>       | Biennial wormwood               |
|                | <i>Artemisia campestris</i>    | Field sagewort                  |
|                | <i>Artemisia ludoviciana</i>   | White sagebrush                 |
|                | <i>Artemisia vulgaris</i>      | Common wormwood                 |
|                | <i>Iva annua</i>               | Rough or annual marshelder      |
|                | <i>Iva frutescens</i>          | Jesuit's bark                   |
|                | <i>Xanthium spinosum</i>       | Spiny cocklebur                 |
|                | <i>Xanthium strumarium</i>     | Rough or Canada cocklebur       |
| Chenopodiaceae | <i>Atriplex patula</i>         | Spear saltbush                  |
|                | <i>Bassia scoparia</i>         | Burning bush                    |
|                | <i>Chenopodium abrosioides</i> | Mexican tea                     |
|                | <i>Chenopodium album</i>       | Lambs quarters                  |
|                | <i>Chenopodium botrys</i>      | Jerusalem oak or goosefoot      |
|                | <i>Chenopodium glaucum</i>     | Oakleaf goosefoot               |
|                | <i>Salsola kali</i>            | Russian thistle                 |
|                | <i>Salsola tragus</i>          | Prickly Russian thistle         |
|                | <i>Plantago aristata</i>       | Largebracted plantain           |
|                | <i>Plantago cordata</i>        | Heartleaf plantain              |
| Plantaginaceae | <i>Plantago heterophylla</i>   | Slender plantain                |
|                | <i>Plantago lanceolata</i>     | Narrowleaf or buckhorn plantain |
|                | <i>Plantago major</i>          | Broadleaf or common plantain    |
|                | <i>Plantago maritima</i>       | Goose tongue                    |
|                | <i>Plantago pusilla</i>        | Dwarf plantain                  |
|                | <i>Plantago rugelii</i>        | Blackseed plantain              |
|                | <i>Plantago virginica</i>      | Virginia plantain               |
|                | <i>Rumex acetosella</i>        | Common or sheep sorrel          |
|                | <i>Rumex altissimus</i>        | Pale dock                       |
|                | <i>Rumex crispus</i>           | Curly dock                      |
| Polygonaceae   | <i>Rumex obtusifolius</i>      | Bitter dock                     |
|                | <i>Rumex verticillatus</i>     | Swamp dock                      |
|                | <i>Boehmeria cylindrica</i>    | False nettle                    |
|                | <i>Laportea canadensis</i>     | Wood nettle                     |
|                | <i>Parietaria pensylvanica</i> | Wild or Pennsylvania pellitory  |
| Urticaceae     | <i>Pilea pumila</i>            | Clearweed                       |
|                | <i>Urtica dioica</i>           | Stinging nettle                 |

area.<sup>12-17</sup> Table 1 presents predominant families and common area species for major pollen types identified in our atmospheric survey. Regional tree and herbaceous species are capable of generating considerable amounts of pollen. Representative tree families include Betulaceae, Cupressaceae, Fagaceae, Hamamelidaceae, Juglandaceae, Moraceae, Oleaceae, Pinaceae, Platanaceae, Salicaceae, Sapindaceae, Tiliaceae, and Ulmaceae.

Predominant regional allergenic weed families include Amaranthaceae, Asteraceae, Chenopodiaceae, Plantaginaceae, Polygonaceae, and Urticaceae. Although a large number of native and cultivated grass species are found in the region, important allergenic species include Bermuda (*Cynodon*), brome (*Bromus*), fescue (*Festuca*), grama (*Bouteloua*), Johnson (*Sorghum*), June (*Poa*), orchard (*Dactylis*), red top (*Agrostis*), rye (*Lolium*), sweet vernal (*Anthoxanthum*), timothy (*Phleum*), and velvet (*Holcus*).<sup>13,18</sup>

Previous aeroallergen surveys for the region were performed using exposed gravity slides, making it difficult to assess data in a quantitative fashion.<sup>19-21</sup> The last significant volumetric survey for the Washington, DC, area was conducted more than a decade ago for predominant tree pollen.<sup>22</sup> Our 10-year atmospheric sampling survey will identify pollination periods, peak concentration levels, and the percentage of annual pollen production for major area tree, grass, and weed species. Year-to-year variation and the influence of selected meteorological variables on atmospheric pollen concentrations will be examined.

## METHODS

Atmospheric sampling for pollen aeroallergens was performed using a volumetric rotating-arm impaction sampler (model 40 Rotorod; SDI Company, Plymouth Meeting, Pennsylvania) according to National Allergy Bureau, American Academy of Allergy, Asthma and Immunology guidelines. The sampler is situated on the roof of a 2-story building at an elevation of 25 ft above ground. Sampling exposure time was set for a 10% sampling period (ie, 60-second exposure time each 10-minute period). Two polystyrene "I" rods (1.52-mm wide), coated with silicone grease, sampled the air at 2,400 rpm. After a 24-hour collection period, the rods are removed, mounted on a grooved stage adapter slide, and stained with Calberla's solution, a fuchsin pollen stain (glycerol 16.0% vol/vol, ethyl alcohol 33.0% vol/vol, and basic fuchsin 0.02% vol/vol). A National Allergy Bureau-certified counter examined the rods microscopically for pollens at ×400 magnification.

Raw pollen counts were converted to the average number of pollen grains per cubic meter of air for each 24-hour sampling period. Weekly mean concentrations were obtained by dividing the total volumetric count for each week by the number of days sampled. The pollen season for specific pollen types was determined using 1%/99% criteria. The start was the day in which the cumulative total reaches 1% of the total annual pollen sum. The end was signified by the day in

which 99% of the total annual sum was reached. A tighter season determined by using 5%/95% criteria is also depicted.

Local climatological data were obtained from the National Climatic Data Center (Asheville, North Carolina), National Oceanic and Atmospheric Administration, for Ronald Reagan–Washington National Airport, Washington, DC.

The Spearman rank-order correlation coefficient ( $r_s$ ) was used to determine the relationship between daily pollen counts for specific species and selected meteorological parameters.

RESULTS

*Pollen calendar for trees.* Figure 1 illustrates flowering

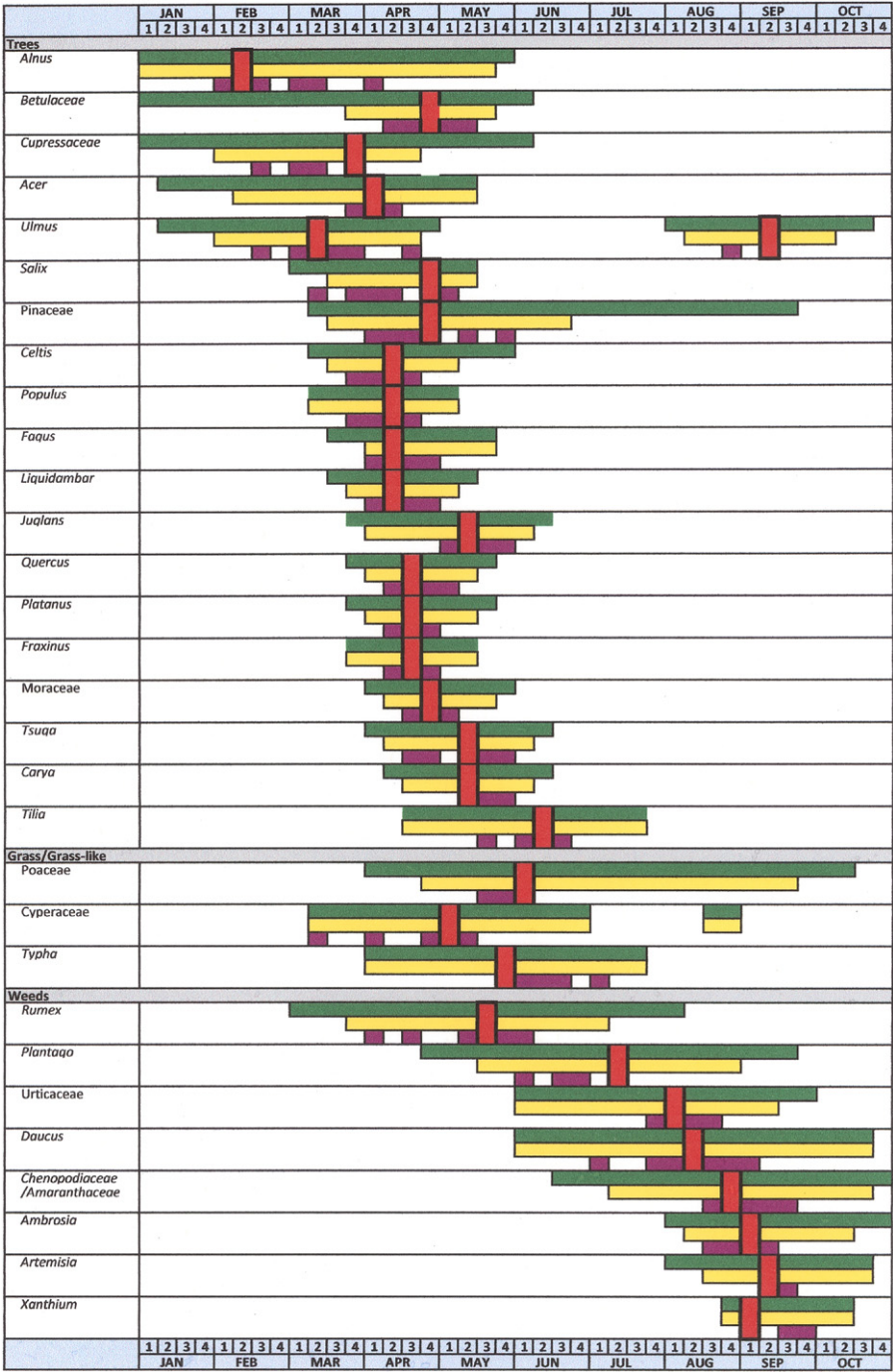


Figure 1. Pollen calendar for major tree, grass, and weed pollen in the Washington, DC, area.

Table 2. Maximum Weekly Average Observed for Total Tree Count (January through September)

| Month | Total tree counts, grains/m <sup>3</sup> |        |       |        |        |        |        |        |        |        |
|-------|------------------------------------------|--------|-------|--------|--------|--------|--------|--------|--------|--------|
|       | 1998                                     | 1999   | 2000  | 2001   | 2002   | 2003   | 2004   | 2005   | 2006   | 2007   |
| Jan   | 3.8                                      | 3.4    | 6.4   | 1.3    | 4.0    | 0.1    | 0.1    | 1.0    | 3.2    | 1.0    |
| Feb   | 81.4                                     | 109.5  | 57.4  | 35.7   | 520.8  | 6.9    | 5.4    | 61.7   | 66.5   | 3.1    |
| Mar   | 187.6                                    | 198.0  | 408.9 | 181.8  | 241.0  | 415.2  | 122.9  | 526.4  | 463.0  | 376.7  |
| Apr   | 1431.2                                   | 1081.2 | 612.2 | 1252.0 | 1194.8 | 1836.9 | 1595.6 | 1105.5 | 1484.3 | 1557.8 |
| May   | 191.7                                    | 750.2  | 706.6 | 467.7  | 198.0  | 348.7  | 218.7  | 695.3  | 489.5  | 466.2  |
| Jun   | 6.5                                      | 28.8   | 5.1   | 15.6   | 37.3   | 102.8  | 2.6    | 41.7   | 6.5    | 16.0   |
| Jul   | 0.4                                      | 0.3    | 0.9   | 0.7    | 1.0    | 1.1    | 0.9    | 0.7    | 0.4    | 1.4    |
| Aug   | 2.2                                      | 1.5    | 2.5   | 0.2    | 0.4    | 1.6    | 1.2    | 0.6    | 0.2    | 11.3   |
| Sep   | 18.1                                     | 2.3    | 2.2   | 6.1    | 4.7    | 4.5    | 5.6    | 8.2    | 24.3   | 1.7    |

periods for specific area tree, grass, and weed pollens. In January and February, pollen of the Betulaceae, Cupressaceae, Sapindaceae, and early pollinating Ulmaceae is observed. Maximum weekly mean concentrations can be highly variable from year to year (Table 2). In February, for example, the highest weekly average for tree pollen was recorded in 2002, at 520.8 grains/m<sup>3</sup>. In 2007, however, the maximum weekly average reached only 3.1 grains/m<sup>3</sup>.

In March, more than 1% of the total annual sum is observed for most area trees. April is the most prolific month for tree species, with highest weekly averages generally noted the second and third weeks. Maximum weekly average concentrations for April range from 612 grains/m<sup>3</sup> in 2000 to 1,837 grains/m<sup>3</sup> in 2003. By May, peak periods for heavy pollinators, such as *Quercus*, *Morus*, and Pinaceae, have ended. March through May accounts for 95.5% of the total annual tree pollen produced. March accounts for 11.97%, April 63.66%, and May 19.87%.

Juglandaceae and *Tsuga* continue to pollinate through June. *Tilia* is observed into the month of July. Cupressaceae

and Pinaceae pollen are sporadically observed in very low concentrations throughout the rest of the year.

In August through the middle of October, pollen from later flowering *Ulmus*, to include the widely planted Chinese elm (*Ulmus parvifolia*), is recorded. Two distinct pollinating periods for species of *Ulmus* have been previously documented.<sup>13,22</sup> The highest weekly average for early flowering elm was 90.9 grains/m<sup>3</sup> in March 2000. The highest weekly average for later flowering elm was recorded in September 2006 at 24.17 grains/m<sup>3</sup> (Figure 2).

**Pollen calendar for grasses and weeds.** In late March, pollen of early flowering *Rumex* is observed. In April and May, Poaceae, *Plantago*, and small amounts of *Typha* overlap with area tree species. Chenopodiaceae-Amaranthaceae, *Daucus*, and Urticaceae begin to pollinate in June, with peak weekly averages observed in August. *Ambrosia*, *Artemisia*, and *Xanthium* at 1% of the total annual sum are not observed until August. Highest weekly averages for *Ambrosia* occur the third week in August to the second week in September.

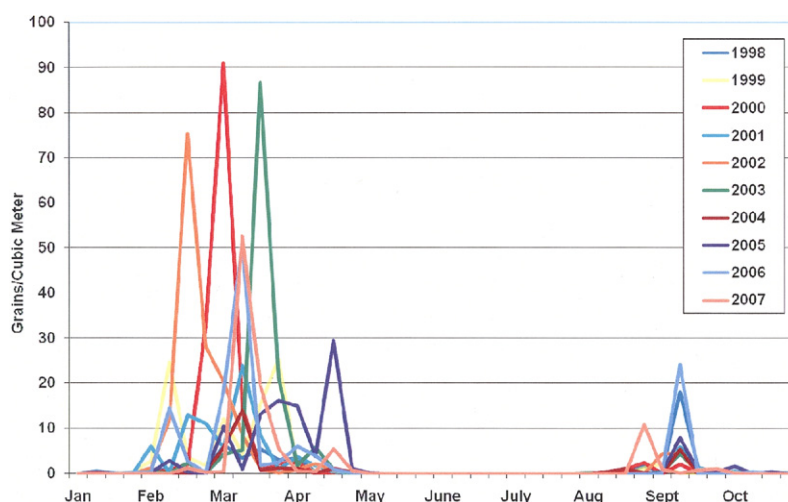


Figure 2. Biphasic annual elm pollen profile. Weekly mean values for elm pollen (1998-2007) reported in grains per cubic meter. The highest weekly average for early flowering elm species is 91 grains/m<sup>3</sup>. In contrast, for late flowering elm, the highest recorded weekly average is 24 grains/m<sup>3</sup>.

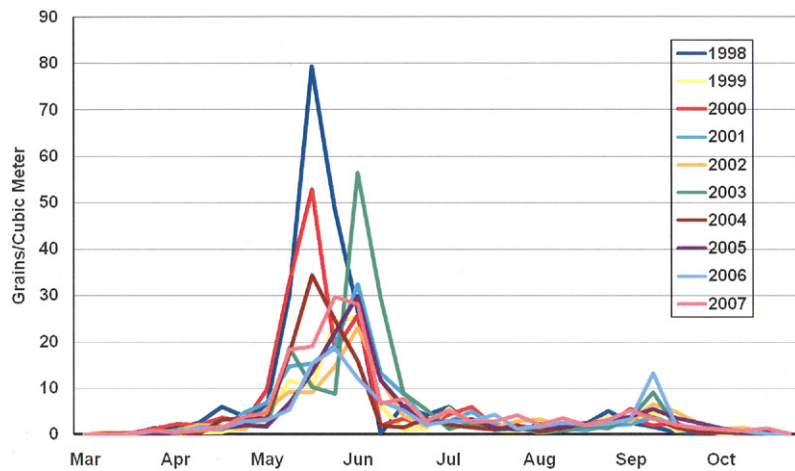


Figure 3. Biphasic annual grass pollen profile. Weekly mean values for grass pollen (1998-2007) reported in grains per cubic meter. Peak weekly averages for grass pollen are noted for the third week in May through the first week in June. A smaller peak period is noted in September, when highest weekly averages may reach 13 grains/m<sup>3</sup>.

Table 3. Pollen Recorded and Percentage of Total Annual Pollen Production in Order of Overall Percentage Rank (1998-2007) for Individual Species

| Species                | 1998                          |                             | 1999                          |                             | 2000                          |                             | 2001                          |                             | 2002                          |                             |
|------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|
|                        | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % |
| Trees                  |                               |                             |                               |                             |                               |                             |                               |                             |                               |                             |
| <i>Quercus</i>         | 9,727                         | 53.06                       | 8,873                         | 44.83                       | 5,499                         | 29.97                       | 7,793                         | 41.52                       | 8,811                         | 40.45                       |
| Cupressaceae           | 780                           | 4.26                        | 1,246                         | 6.29                        | 2,008                         | 10.94                       | 1,263                         | 6.73                        | 3,380                         | 15.52                       |
| Pinaceae               | 2,162                         | 11.80                       | 1,267                         | 6.40                        | 1,029                         | 5.61                        | 2,523                         | 13.44                       | 1,707                         | 7.83                        |
| Moraceae               | 595                           | 3.25                        | 2,330                         | 11.77                       | 875                           | 4.77                        | 1,898                         | 10.11                       | 798                           | 3.66                        |
| Betulaceae             | 491                           | 2.68                        | 290                           | 1.47                        | 2,769                         | 15.09                       | 225                           | 1.20                        | 724                           | 3.33                        |
| <i>Acer</i>            | 360                           | 1.96                        | 888                           | 4.49                        | 1,165                         | 6.35                        | 615                           | 3.28                        | 872                           | 4.00                        |
| <i>Platanus</i>        | 338                           | 1.84                        | 503                           | 2.54                        | 314                           | 1.71                        | 709                           | 3.78                        | 1,151                         | 5.28                        |
| <i>Fraxinus</i>        | 247                           | 1.35                        | 1,089                         | 5.50                        | 353                           | 1.92                        | 596                           | 3.18                        | 229                           | 1.05                        |
| <i>Ulmus</i>           | 205                           | 1.12                        | 380                           | 1.92                        | 590                           | 3.21                        | 284                           | 1.52                        | 665                           | 3.05                        |
| <i>Carya</i>           | 297                           | 1.62                        | 286                           | 1.45                        | 305                           | 1.66                        | 424                           | 2.26                        | 198                           | 0.91                        |
| <i>Populus</i>         | 124                           | 0.68                        | 231                           | 1.17                        | 402                           | 2.19                        | 134                           | 0.71                        | 196                           | 0.90                        |
| <i>Juglans</i>         | 189                           | 1.03                        | 144                           | 0.73                        | 374                           | 2.04                        | 230                           | 1.22                        | 176                           | 0.81                        |
| <i>Liquidambar</i>     | 255                           | 1.39                        | 120                           | 0.61                        | 188                           | 1.02                        | 58                            | 0.31                        | 403                           | 1.85                        |
| <i>Fagus</i>           | 209                           | 1.14                        | 14                            | 0.07                        | 448                           | 2.44                        | 9                             | 0.05                        | 201                           | 0.92                        |
| <i>Alnus</i>           | 35                            | 0.19                        | 92                            | 0.47                        | 102                           | 0.55                        | 22                            | 0.12                        | 86                            | 0.39                        |
| <i>Celtis</i>          | 15                            | 0.08                        | 12                            | 0.06                        | 18                            | 0.10                        | 23                            | 0.12                        | 28                            | 0.13                        |
| <i>Salix</i>           | 40                            | 0.22                        | 62                            | 0.31                        | 25                            | 0.14                        | 24                            | 0.13                        | 13                            | 0.06                        |
| <i>Tsuga</i>           | 76                            | 0.41                        | 12                            | 0.06                        | 54                            | 0.29                        | 27                            | 0.14                        | 50                            | 0.23                        |
| <i>Tilia</i>           | 5                             | 0.03                        | 6                             | 0.03                        | 9                             | 0.05                        | 1                             | 0.00                        | 6                             | 0.03                        |
| Poaceae                | 959                           | 5.23                        | 614                           | 3.10                        | 896                           | 4.88                        | 711                           | 3.79                        | 608                           | 2.79                        |
| Sedge ( <i>Carex</i> ) | 3                             | 0.02                        | 2                             | 0.01                        | 0                             | 0.00                        | 2                             | 0.01                        | 2                             | 0.01                        |
| Weeds                  |                               |                             |                               |                             |                               |                             |                               |                             |                               |                             |
| <i>Ambrosia</i>        | 869                           | 4.74                        | 642                           | 3.24                        | 514                           | 2.80                        | 586                           | 3.12                        | 791                           | 3.63                        |
| <i>Plantago</i>        | 72                            | 0.39                        | 117                           | 0.59                        | 156                           | 0.85                        | 111                           | 0.59                        | 165                           | 0.76                        |
| Urticaceae             | 75                            | 0.41                        | 37                            | 0.19                        | 52                            | 0.28                        | 54                            | 0.29                        | 60                            | 0.28                        |
| <i>Rumex</i>           | 53                            | 0.29                        | 27                            | 0.13                        | 55                            | 0.30                        | 31                            | 0.17                        | 17                            | 0.08                        |
| Chenopodiaceae-        | 30                            | 0.17                        | 34                            | 0.17                        | 24                            | 0.13                        | 23                            | 0.12                        | 41                            | 0.19                        |
| Amaranthaceae          |                               |                             |                               |                             |                               |                             |                               |                             |                               |                             |
| <i>Artemisia</i>       | 18                            | 0.10                        | 15                            | 0.07                        | 30                            | 0.16                        | 33                            | 0.18                        | 27                            | 0.13                        |
| <i>Typha</i>           | 2                             | 0.01                        | 8                             | 0.04                        | 13                            | 0.07                        | 2                             | 0.01                        | 15                            | 0.07                        |
| <i>Daucus</i>          | 1                             | 0.01                        | 6                             | 0.03                        | 2                             | 0.01                        | 6                             | 0.03                        | 3                             | 0.01                        |
| <i>Xanthium</i>        | 4                             | 0.02                        | 2                             | 0.01                        | 2                             | 0.01                        | 2                             | 0.01                        | 2                             | 0.01                        |
| Other                  | 99                            | 0.54                        | 443                           | 2.24                        | 75                            | 0.41                        | 349                           | 1.86                        | 355                           | 1.63                        |
| <b>Total</b>           | <b>18,335</b>                 |                             | <b>19,794</b>                 |                             | <b>18,345</b>                 |                             | <b>18,768</b>                 |                             | <b>21,781</b>                 |                             |

Overall, the highest weekly average for total annual weed pollen is the first week in September.

A biphasic grass season in the United States is well documented<sup>13,22,23</sup> (Figure 3). The highest overall weekly average for grass pollen is noted the first week in June. The highest weekly averages for grass pollen ranged from 18.66 grains/m<sup>3</sup> in May 2006 to 79.3 grains/m<sup>3</sup> in May 1998.

The pollination periods for grass and weed pollen overlap. Grass pollen is primarily observed in May (45.2%) and June (28.9%); however, close to 20% is observed in the months of July (6.8%), August (5.3%), and September (7.9%). Most of the total annual weed pollen is recorded in August (33.7%) through September (44.1%).

*Percentage of total annual pollen production.* Table 3 gives the total annual amount of pollen recorded, the percentage of the total annual sum, and the 10-year average. Trees and weeds are listed in rank order according to percentage

contribution to total annual yield in 1998 to 2007. Tree pollen comprised 91.2%, weeds 3.8%, grasses 3.2%, and other unidentified pollen 1.8% of the annual pollen yield.

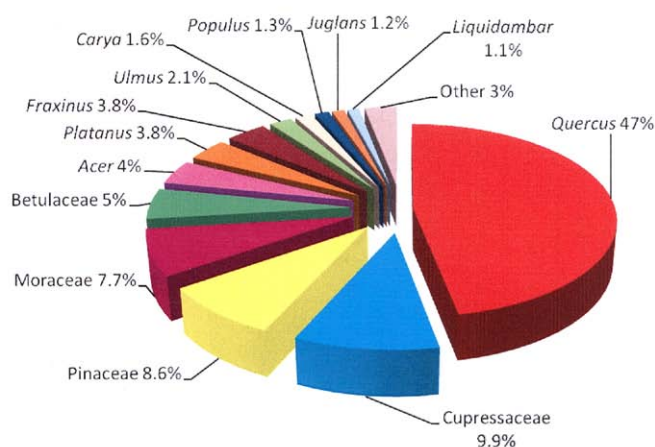
The 10 predominant pollen types were *Quercus* (43.4%), Cupressaceae (9.1%), Pinaceae (7.9%), *Morus* (7.1%), Betulaceae (4.7%), *Acer* (3.7%), *Plantanus* (3.5%), *Fraxinus* (3.5%), Poaceae (3.2%), and *Ambrosia* (2.5%).

Figure 4 illustrates the average annual percentage of total pollen production for predominant area tree and weeds. *Quercus* accounts for 47% of the total annual tree pollen produced. *Ambrosia* accounts for 66.2% of total annual weed pollen production.

*Variation in annual pollen production.* Considerable variation in overall pollen production is observed from year to year. Annual pollen totals ranged from 18,335 grains/m<sup>3</sup> in 1998 to 30,952 grains/m<sup>3</sup> in 2003. Five of the top 10 tree pollen producers, including Pinaceae, *Morus*, *Acer*, *Fraxinus*, and *Carya*, had

| 2003                          |                             | 2004                          |                             | 2005                          |                             | 2006                          |                             | 2007                          |                             | Total pollen, grains/m <sup>3</sup> | Average annual pollen production, % |
|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------------|-------------------------------------|
| Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % | Pollen, grains/m <sup>3</sup> | Annual pollen production, % |                                     |                                     |
| 11,786                        | 38.08                       | 11,524                        | 56.13                       | 10,764                        | 38.63                       | 12,177                        | 38.63                       | 10,395                        | 48.43                       | 97,350                              | 43.34                               |
| 2,569                         | 8.30                        | 909                           | 4.43                        | 3,863                         | 13.86                       | 2,652                         | 13.86                       | 1,775                         | 8.27                        | 20,444                              | 9.10                                |
| 2,598                         | 8.40                        | 2,056                         | 10.01                       | 1,904                         | 6.83                        | 1,138                         | 6.83                        | 1,396                         | 6.51                        | 17,782                              | 7.92                                |
| 2,506                         | 8.10                        | 1,492                         | 7.27                        | 1,950                         | 7.00                        | 2,397                         | 7.00                        | 1,155                         | 5.38                        | 15,997                              | 7.12                                |
| 2,013                         | 6.50                        | 242                           | 1.18                        | 1,804                         | 6.47                        | 1,556                         | 6.47                        | 419                           | 1.95                        | 10,534                              | 4.69                                |
| 1,308                         | 4.23                        | 680                           | 3.31                        | 674                           | 2.42                        | 1,092                         | 2.42                        | 699                           | 3.26                        | 8,353                               | 3.72                                |
| 1,002                         | 3.24                        | 530                           | 2.58                        | 1,400                         | 5.02                        | 1,165                         | 5.02                        | 723                           | 3.37                        | 7,834                               | 3.49                                |
| 2,074                         | 6.70                        | 624                           | 3.04                        | 922                           | 3.31                        | 621                           | 3.31                        | 1,029                         | 4.79                        | 7,784                               | 3.47                                |
| 633                           | 2.04                        | 168                           | 0.82                        | 516                           | 1.85                        | 618                           | 1.85                        | 399                           | 1.86                        | 4,457                               | 1.98                                |
| 717                           | 2.32                        | 114                           | 0.56                        | 413                           | 1.48                        | 203                           | 1.48                        | 284                           | 1.32                        | 3,242                               | 1.44                                |
| 461                           | 1.49                        | 184                           | 0.90                        | 316                           | 1.13                        | 408                           | 1.13                        | 253                           | 1.18                        | 2,708                               | 1.21                                |
| 386                           | 1.25                        | 51                            | 0.25                        | 326                           | 1.17                        | 257                           | 1.17                        | 249                           | 1.16                        | 2,381                               | 1.06                                |
| 361                           | 1.17                        | 101                           | 0.49                        | 228                           | 0.82                        | 346                           | 0.82                        | 227                           | 1.06                        | 2,287                               | 1.02                                |
| 393                           | 1.27                        | 21                            | 0.10                        | 201                           | 0.72                        | 126                           | 0.72                        | 129                           | 0.60                        | 1,750                               | 0.78                                |
| 64                            | 0.21                        | 11                            | 0.05                        | 94                            | 0.34                        | 81                            | 0.34                        | 12                            | 0.05                        | 598                                 | 0.27                                |
| 79                            | 0.25                        | 29                            | 0.14                        | 107                           | 0.38                        | 66                            | 0.38                        | 98                            | 0.46                        | 474                                 | 0.21                                |
| 27                            | 0.09                        | 28                            | 0.14                        | 49                            | 0.18                        | 75                            | 0.18                        | 39                            | 0.18                        | 382                                 | 0.17                                |
| 35                            | 0.11                        | 13                            | 0.06                        | 32                            | 0.11                        | 43                            | 0.11                        | 34                            | 0.16                        | 376                                 | 0.17                                |
| 8                             | 0.02                        | 2                             | 0.01                        | 26                            | 0.09                        | 2                             | 0.09                        | 22                            | 0.10                        | 86                                  | 0.04                                |
| 723                           | 2.34                        | 685                           | 3.34                        | 657                           | 2.36                        | 587                           | 2.36                        | 828                           | 3.86                        | 7,268                               | 3.24                                |
| 2                             | 0.01                        | 4                             | 0.02                        | 8                             | 0.03                        | 6                             | 0.02                        | 8                             | 0.04                        | 37                                  | 0.02                                |
| 388                           | 1.25                        | 355                           | 1.73                        | 646                           | 2.32                        | 381                           | 2.32                        | 469                           | 2.18                        | 5,639                               | 2.51                                |
| 73                            | 0.24                        | 71                            | 0.34                        | 112                           | 0.40                        | 62                            | 0.40                        | 122                           | 0.57                        | 1,061                               | 0.47                                |
| 40                            | 0.13                        | 93                            | 0.45                        | 130                           | 0.47                        | 88                            | 0.47                        | 70                            | 0.32                        | 698                                 | 0.31                                |
| 43                            | 0.14                        | 38                            | 0.19                        | 37                            | 0.13                        | 17                            | 0.13                        | 30                            | 0.14                        | 348                                 | 0.15                                |
| 26                            | 0.08                        | 35                            | 0.17                        | 43                            | 0.16                        | 34                            | 0.16                        | 43                            | 0.20                        | 334                                 | 0.15                                |
| 29                            | 0.10                        | 44                            | 0.21                        | 43                            | 0.15                        | 31                            | 0.15                        | 42                            | 0.19                        | 311                                 | 0.14                                |
| 1                             | 0.00                        | 2                             | 0.01                        | 9                             | 0.03                        | 10                            | 0.03                        | 20                            | 0.10                        | 82                                  | 0.04                                |
| 1                             | 0.00                        | 2                             | 0.01                        | 4                             | 0.01                        | 4                             | 0.01                        | 1                             | 0.00                        | 31                                  | 0.01                                |
| 1                             | 0.00                        | 0                             | 0.00                        | 1                             | 0.00                        | 1                             | 0.00                        | 1                             | 0.00                        | 17                                  | 0.01                                |
| 607                           | 1.96                        | 427                           | 2.08                        | 596                           | 2.14                        | 523                           | 2.14                        | 493                           | 2.30                        | 3,967                               | 1.77                                |
| 30,952                        |                             | 20,534                        |                             | 27,875                        |                             | 26,766                        |                             | 21,462                        |                             | 224,611                             |                                     |

## A Tree Pollen



## B Weed Pollen

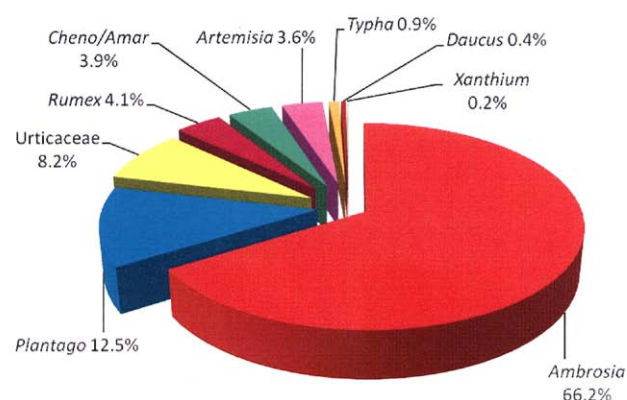
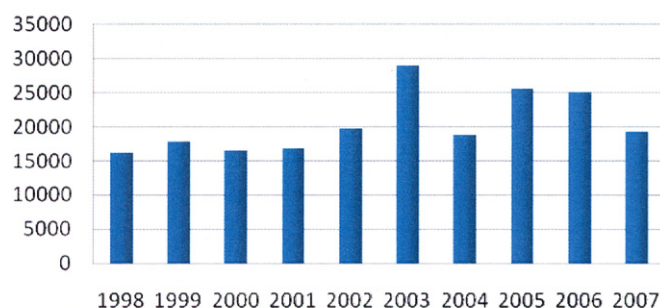


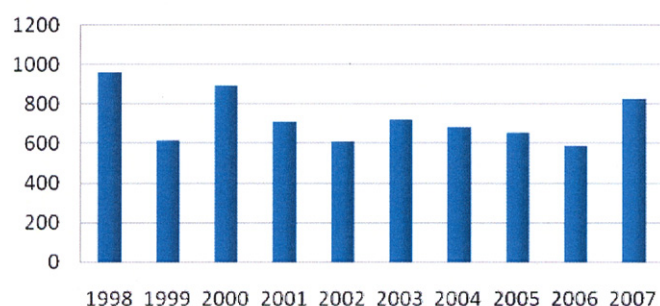
Figure 4. Average percentage of total annual pollen production 1998–2007. A, Area tree pollen production is predominated by *Quercus*. “Other” tree species include unknown tree pollen and those species for which the average of annual tree pollen production recorded was less than 1% of the total (*Fagus*, *Alnus*, *Celtis*, *Salix*, *Tsuga*, and *Tilia*). B, Area weed pollen production is predominated by *Ambrosia*.

their highest production year in 2003. As noted previously, in any particular year, some species may have a high pollen yield, whereas others have low recorded levels.<sup>22–24</sup> For example, in 2000, *Quercus*, Pinaceae, and *Platanus* yielded their lowest pollen production, whereas Betulaceae, *Fagus*, and *Alnus* had their highest production year. Figure 5 depicts annual variation in total tree, weed, and grass pollen counts. For annual tree pollen, there was an increase over time ( $r_s = 0.71$ ,  $P = .02$ ). Although a cyclic pattern for annual tree and herbaceous pollen production was difficult to discern, for certain individual tree species, a cycle seemed more apparent. In Figure 6, fluctuating high and very low pollen levels, every 2 to 3 years, seemed evident for *Alnus*, Betulaceae, and *Fagus*. Annual pollen production for Betulaceae ranged from 2,769 grains/m<sup>3</sup> in 2000 to 225 grains/m<sup>3</sup> in 2001. Likewise for *Fagus*, annual pollen production reached a high of 448

## Total Annual Tree Pollen



## Total Annual Grass Pollen



## Total Annual Weed Pollen

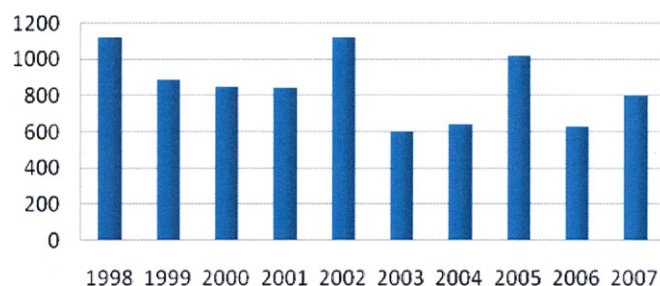


Figure 5. Annual variation in total recorded tree, grass, and weed pollen production (1998–2007). Cyclic patterns for overall annual tree, grass, and weed pollen are not readily discernable.

grains/m<sup>3</sup> in 2000 and decreased to 9 grains/m<sup>3</sup> in 2001. A 2- to 3-year cycle for Betulaceae has been described.<sup>24,25</sup> Cyclic variations in the annual pollen sums for our grass and weed species were not evident.

**Peak weekly average concentrations.** Table 4 gives the highest weekly averages and week of occurrence. For trees, the timing of peak weekly average concentrations varied from a 3- to 4-week window for most trees (*Fraxinus*, *Fagus*, *Populus*, *Celtis*, *Carya*, *Acer*, *Morus*, *Quercus*, *Liquidambar*, *Platanus*, and *Juglans*) to more than a month for others. Pollen concentrations for *Quercus* far exceeded those for any other tree species. Highest weekly averages for *Quercus* varied more than 3-fold from 331 grains/m<sup>3</sup> in May 2000 to 1,147 grains/m<sup>3</sup> in April 2004 (Figure 7A).

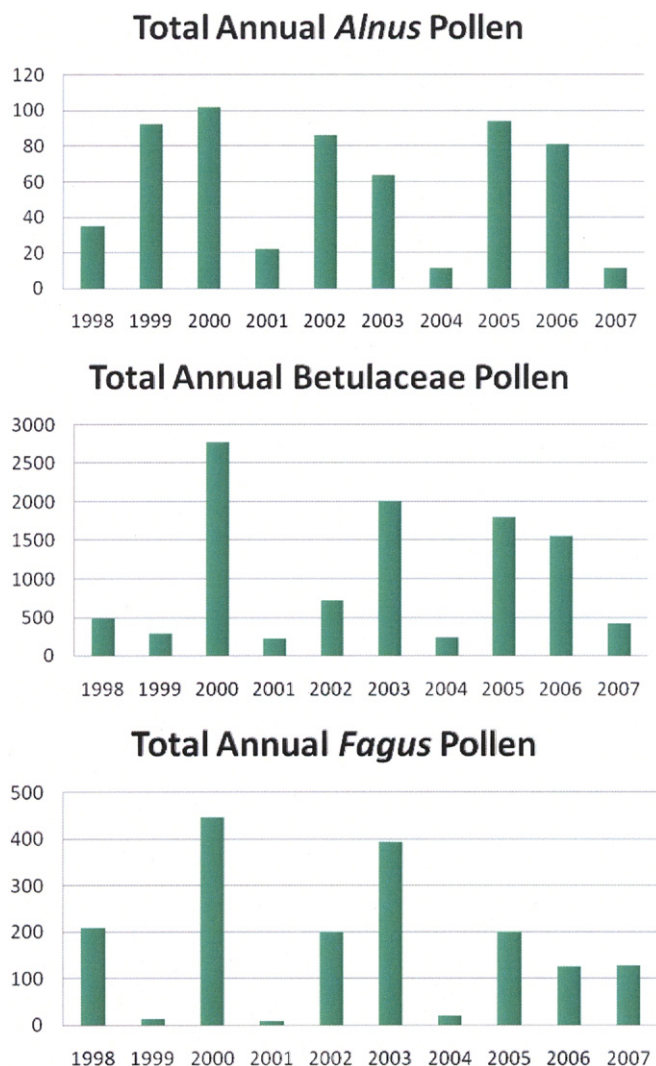


Figure 6. Annual variation in total pollen production recorded for *Alnus*, Betulaceae, and *Fagus* (1998-2007). A 2- to 3-year cyclic pattern with high production years followed by very low production years is evident.

Peak weekly concentrations for Poaceae ranged from 19 grains/m<sup>3</sup> in May 2006 to a high of 79 grains/m<sup>3</sup> in May 1998. Although grass pollen is recorded from early April to October, peak concentrations are noted the third week in May to the first week in June.

*Ambrosia* demonstrated the highest weekly averages for weed pollen, ranging from 20 grains/m<sup>3</sup> in September 2006 to 57 grains/m<sup>3</sup> in August 1998. Peak concentrations for *Ambrosia* are observed from the third week in August to the second week in September (Figure 7B). Peak concentrations for *Artemisia* occur within a tight 2-week window from the second week to third week in September.

**Meteorological influences.** Table 5 gives the Spearman correlation coefficients between daily counts for predominant pollen types observed and same-day meteorological vari-

ables. Grass pollen was positively and strongly correlated with maximum temperature ( $r_s = 0.679$ ,  $P < .001$ ) and dew point ( $r_s = 0.594$ ,  $P < .001$ ) and was weakly and inversely correlated with average daily wind speed ( $r_s = -0.052$ ,  $P < .05$ ). The 5 major weed species were all positively and significantly correlated with maximum temperature and dew point. The strongest positive correlations with maximum temperature were noted for *Plantago* ( $r_s = 0.645$ ,  $P < .001$ ) and Urticaceae ( $r_s = 0.578$ ,  $P < .001$ ). Weak inversely significant correlations were noted for most weed species with precipitation (*Ambrosia*, Urticaceae, and Chenopodiaceae-Amaranthaceae) and average daily wind speed (*Ambrosia*, *Plantago*, Urticaceae, and Chenopodiaceae-Amaranthaceae). Results for tree species were more variable. Weak inverse correlations were noted for Cupressaceae and Betulaceae with maximum temperature, whereas weak positive correlations were noted for Pinaceae and Moraceae. Only Pinaceae daily counts correlated with precipitation ( $r_s = 0.051$ ,  $P < .05$ ). Weak positive correlations were observed for all tree species with average daily wind speed, whereas weak inverse correlations were noted for most trees, except Pinaceae ( $r_s = 0.073$ ,  $P < .01$ ) with dew point.

## DISCUSSION

**Seasonal calendar.** The golden dust that accumulates on cars and outdoor surfaces from April to May primarily reflects weekly averages for tree pollen that can exceed more than 1,800 grains/m<sup>3</sup> of air. Early pollinating *Rumex* species is observed in March and Poaceae by the beginning of April. Although more than 1% of total annual tree pollen is recorded as early as January for *Acer*, *Alnus*, Betulaceae, Cupressaceae, and *Ulmus*, the season for most tree species begins by the end of March and lasts through the middle of June. Peak weekly averages for most tree species are noted from April to May with considerable overlapping of flowering periods. Cupressaceae and Pinaceae pollen may pollinate at low levels through September owing to the diverse number of species in the region and the large number of introduced species planted for landscape and garden purposes. Prolific area tree pollen producers, including *Quercus*, Cupressaceae, Moraceae, and Betulaceae, have been implicated in severe pollinosis and respiratory allergy and demonstrate moderate to severe clinical reactivity.<sup>13,25-31</sup>

In August to late October, late flowering *Ulmus*, with weekly averages exceeding 20 grains/m<sup>3</sup>, coincides with the flowering of numerous area weed species. Skin tests performed in Southern California with autumn elm extracts showed many patients to be severely allergic.<sup>13</sup> Skin testing for *Ulmus* may also be warranted for patients with symptoms during weed season.

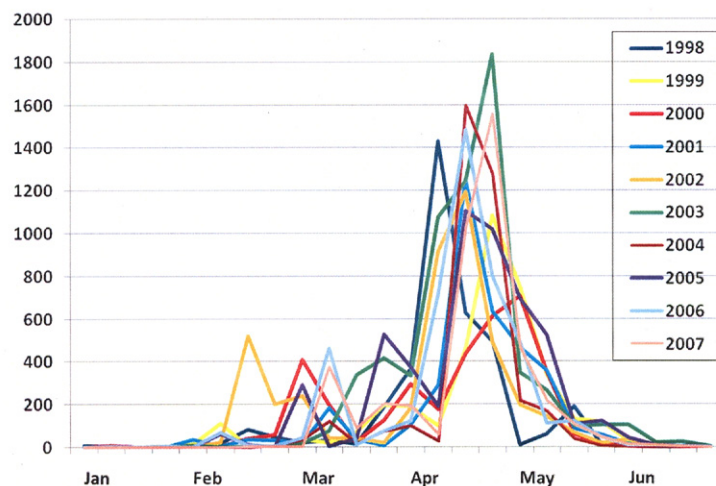
The greatest percentage of Poaceae pollen is observed in May (45.2%), with the overall peak weekly average the first week in June. Poaceae is observed through the month of October, with a lesser secondary peak noted in September. In each month, April to October, more than 1% of total annual Poaceae pollen may be observed. Although making up a

Table 4. Highest Weekly Average Concentration Recorded and the Week of Occurrence (1998-2007)<sup>a</sup>

| Species                | Highest weekly average concentration, grains/m <sup>3</sup> |             |             |             |               |               |               |             |               |               |
|------------------------|-------------------------------------------------------------|-------------|-------------|-------------|---------------|---------------|---------------|-------------|---------------|---------------|
|                        | 1998                                                        | 1999        | 2000        | 2001        | 2002          | 2003          | 2004          | 2005        | 2006          | 2007          |
| <b>Trees</b>           |                                                             |             |             |             |               |               |               |             |               |               |
| <i>Quercus</i>         | 1,003 (Apr 2)                                               | 700 (Apr 4) | 331 (May 1) | 839 (Apr 3) | 807 (Apr 3)   | 843 (Apr 4)   | 1,147 (Apr 3) | 706 (Apr 3) | 1,014 (Apr 3) | 1,109 (Apr 4) |
| Cupressaceae           | 63 (Feb 3)                                                  | 144 (Mar 4) | 288 (Mar 1) | 144 (Mar 2) | 417 (Feb 3)   | 248 (Mar 4)   | 96 (Mar 2)    | 472 (Mar 4) | 352 (Mar 2)   | 292 (Mar 2)   |
| Pinaceae               | 242 (Apr 2)                                                 | 77 (May 4)  | 64 (May 2)  | 123 (May 2) | 88 (Apr 3)    | 149 (Apr 4)   | 121 (Apr 4)   | 116 (Apr 1) | 51 (Apr 2)    | 62 (May 2)    |
| Moraceae               | 74 (Apr 3)                                                  | 175 (Apr 4) | 80 (May 1)  | 125 (Apr 4) | 96 (Apr 3)    | 383 (Apr 4)   | 130 (Apr 3)   | 136 (Apr 4) | 229 (Apr 3)   | 94 (Apr 4)    |
| Betulaceae             | 32 (Apr 4)                                                  | 21 (May 1)  | 250 (Apr 4) | 30 (Apr 2)  | 44 (Apr 2)    | 264 (Apr 4)   | 35 (Apr 3)    | 88 (May 2)  | 117 (May 1)   | 32 (Apr 4)    |
| <i>Acer</i>            | 37 (Mar 4)                                                  | 128 (Apr 1) | 76 (Mar 4)  | 95 (Apr 2)  | 88 (Apr 1)    | 150 (Apr 1)   | 53 (Apr 1)    | 48 (Apr 1)  | 80 (Apr 1)    | 92 (Apr 1)    |
| <i>Platanus</i>        | 46 (Apr 2)                                                  | 30 (Apr 4)  | 27 (Apr 3)  | 78 (Apr 3)  | 133 (Apr 3)   | 72 (Apr 2)    | 56 (Apr 4)    | 119 (Apr 4) | 97 (Apr 3)    | 85 (Apr 4)    |
| <i>Fraxinus</i>        | 27 (Apr 2)                                                  | 115 (Apr 4) | 28 (Apr 3)  | 61 (Apr 3)  | 27 (Apr 3)    | 144 (Apr 3)   | 74 (Apr 3)    | 110 (Apr 3) | 43 (Apr 3)    | 105 (Apr 4)   |
| <i>Ulmus</i>           | 6 (Mar 1)                                                   | 25 (Mar 4)  | 91 (Mar 1)  | 24 (Mar 2)  | 75 (Feb 3)    | 87 (Mar 3)    | 14 (Mar 2)    | 30 (Apr 3)  | 51 (Mar 2)    | 53 (Mar 2)    |
| <i>Carya</i>           | 39 (May 3)                                                  | 17 (May 4)  | 25 (May 2)  | 33 (May 2)  | 16 (May 2)    | 79 (May 2)    | 12 (May 2)    | 29 (May 2)  | 16 (May 3)    | 18 (May 2)    |
| <i>Populus</i>         | 25 (Mar 4)                                                  | 25 (Apr 1)  | 37 (Apr 1)  | 35 (Apr 2)  | 26 (Apr 2)    | 45 (Mar 4)    | 13 (Apr 1)    | 26 (Apr 2)  | 46 (Apr 2)    | 18 (Apr 3)    |
| <i>Juglans</i>         | 22 (May 3)                                                  | 9 (May 3)   | 34 (May 2)  | 18 (May 2)  | 13 (May 2)    | 39 (May 2)    | 6 (May 2)     | 20 (May 4)  | 11 (May 1)    | 20 (May 2)    |
| <i>Liquidambar</i>     | 30 (Apr 2)                                                  | 9 (Apr 4)   | 20 (Apr 1)  | 6 (Apr 3)   | 56 (Apr 2)    | 33 (Apr 3)    | 16 (Apr 3)    | 27 (Apr 1)  | 49 (Apr 2)    | 37 (Apr 4)    |
| <i>Fagus</i>           | 20 (Apr 2)                                                  | 1 (Apr 4)   | 57 (Apr 1)  | 1 (Apr 3)   | 29 (Apr 2)    | 41 (Apr 2)    | 3 (Apr 3)     | 27 (Apr 3)  | 12 (Apr 2)    | 17 (Apr 3)    |
| <i>Alnus</i>           | 2 (Feb 2)                                                   | 13 (Feb 2)  | 8 (Feb 3)   | 2 (Feb 1)   | 12 (Feb 3)    | 9 (Mar 2)     | 1 (Mar 1)     | 10 (Apr 1)  | 8 (Feb 2)     | 2 (Mar 2)     |
| <i>Celtis</i>          | 2 (Apr 1)                                                   | 2 (Apr 1)   | 2 (Apr 1)   | 3 (Apr 2)   | 3 (Apr 2)     | 9 (Apr 2)     | 5 (Apr 3)     | 12 (Apr 3)  | 3 (Apr 2)     | 8 (Mar 4)     |
| <i>Salix</i>           | 6 (Apr 2)                                                   | 6 (May 1)   | 2 (Mar 2)   | 3 (Apr 4)   | 1 (Apr 4)     | 2 (Apr 1)     | 3 (Apr 4)     | 3 (May 1)   | 5 (Mar 4)     | 2 (Mar 4)     |
| <i>Tsuga</i>           | 9 (May 3)                                                   | 1 (May 4)   | 4 (May 2)   | 2 (Apr 3)   | 4 (May 2)     | 2 (Apr 4)     | 1 (May 2)     | 3 (Apr 4)   | 3 (May 3)     | 3 (May 4)     |
| <i>Tilia</i>           | 0.4 (Jun 1)                                                 | 0.8 (Jun 2) | 0.9 (Jun 1) | 0.1 (Jun 3) | 0.6 (Jun 1)   | 0.9 (Jun 2)   | 0.2 (Jun 1)   | 3 (Jun 2)   | 0.2 (May 3)   | 2 (Jun 1)     |
| Poaceae                | 79 (May 3)                                                  | 26 (Jun 1)  | 53 (May 3)  | 32 (Jun 1)  | 23 (Jun 1)    | 56 (Jun 1)    | 34 (May 3)    | 30 (Jun 1)  | 19 (May 4)    | 30 (May 4)    |
| Sedge ( <i>Carex</i> ) | 0.1 (Apr 4)                                                 | 0.2 (May 1) | 0.2 (Mar 2) | 0.3 (Apr 4) | 0.2 (Apr 1)   | 0.2 (Apr 1)   | 0.3 (May 1)   | 0.3 (May 1) | 0.3 (Apr 4)   | 0.4 (May 2)   |
| <b>Weeds</b>           |                                                             |             |             |             |               |               |               |             |               |               |
| <i>Ambrosia</i>        | 57 (Aug 4)                                                  | 47 (Aug 4)  | 30 (Sep 1)  | 37 (Sep 1)  | 52 (Sep 1)    | 21 (Aug 4)    | 22 (Sep 1)    | 34 (Aug 3)  | 20 (Sep 2)    | 22 (Aug 4)    |
| <i>Plantago</i>        | 3 (Jun 3)                                                   | 5 (Jun 1)   | 6 (Jul 2)   | 3 (Jun 3)   | 6 (Jun 1)     | 3 (Jul 2)     | 2 (Jul 2)     | 4 (Jun 4)   | 2 (Jun 3)     | 4 (Jun 4)     |
| Urticaceae             | 3 (Jul 4)                                                   | 2 (Aug 3)   | 4 (Aug 2)   | 3 (Aug 1)   | 2 (Jul 4)     | 2 (Aug 3)     | 5 (Aug 2)     | 5 (Aug 2)   | 3 (Aug 3)     | 4 (Aug 1)     |
| <i>Rumex</i>           | 3 (May 3)                                                   | 1 (May 3)   | 3 (May 2)   | 1 (May 4)   | 1 (May 4)     | 2 (Jun 1)     | 2 (Apr 3)     | 1 (Apr 1)   | 0.5 (May 4)   | 1 (May 2)     |
| Chenopodiaceae-        | 2 (Aug 4)                                                   | 3 (Aug 4)   | 2 (Sep 3)   | 1 (Aug 4)   | 2 (Sep 2)     | 2 (Aug 4)     | 1 (Aug 3)     | 1 (Aug 3)   | 1 (Aug 4)     | 2 (Sep 1)     |
| Amaranthaceae          |                                                             |             |             |             |               |               |               |             |               |               |
| <i>Artemisia</i>       | 2 (Sep 2)                                                   | 2 (Sep 2)   | 3 (Sep 2)   | 4 (Sep 2)   | 4 (Sep 3)     | 2 (Sep 3)     | 6 (Sep 2)     | 5 (Sep 3)   | 4 (Sep 3)     | 3 (Sep 2)     |
| <i>Typha</i>           | 0.2 (Jun 3)                                                 | 0.7 (Jun 1) | 2 (May 4)   | 0.3 (Jul 1) | 1 (May 4)     | 0.2 (Jun 2)   | 0.2 (Jun 2)   | 0.6 (Jun 2) | 1 (May 4)     | 1 (Jul 1)     |
| <i>Daucus</i>          | 0.2 (Aug 2)                                                 | 0.4 (Jul 1) | 0.2 (Sep 1) | 0.3 (Aug 1) | 0.1 (Aug 1,3) | 0.2 (Jul 4)   | 0.1 (Aug 2,4) | 0.2 (Jul 1) | 0.1 (Aug 1)   | 0.1 (Aug 2)   |
| <i>Xanthium</i>        | 0.4 (Sep 1)                                                 | 0.2 (Sep 3) | 0.2 (Sep 3) | 0.2 (Sep 1) | 0.2 (Sep 1)   | 0.1 (Sep 3-4) | 0             | 0.1 (Sep 1) | 0.2 (Sep 1)   | 0.2 (Sep 1)   |

<sup>a</sup> In parentheses is the month and week that the species peaked. For example, April 1 means the first week in April.

### A *Quercus* Pollen Profile



### B *Ambrosia* Pollen Profile

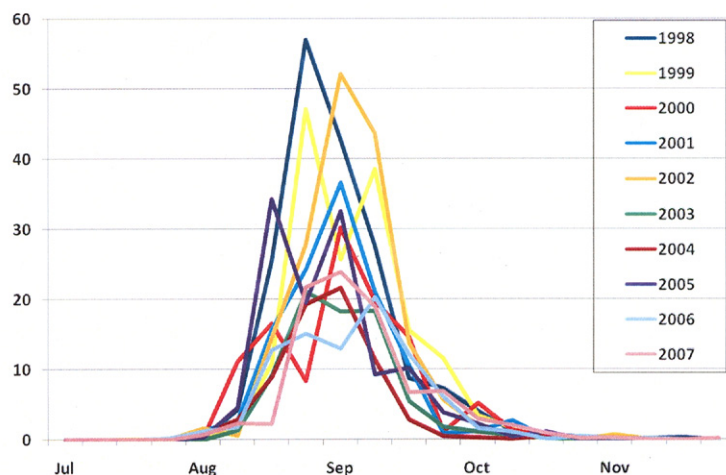


Figure 7. *Quercus* pollen profile (A) and *Ambrosia* pollen profile (B). Mean weekly values for *Quercus* pollen January through June and *Ambrosia* pollen July through November (1998–2007) recorded in grains per cubic meter.

significantly smaller portion of the total annual pollen yield (3.2%), grasses play a prominent role as a potent cause of allergic asthma and hay fever worldwide.<sup>32–35</sup>

In April and May, early flowering *Rumex*, *Plantago*, and small amounts of *Typha* overlap with Poaceae and peak tree season. *Plantago* and *Rumex* are observed for a long span of time, with at least 1% of their total annual sum observed for a period of 20 to 21 weeks. A lengthy pollination season for *Plantago* has been previously documented.<sup>32</sup> In August to September, 77.8% of total annual weed pollen is recorded. *Ambrosia* produces the greatest percentage of total annual weed pollen produced (66.2%). *Ambrosia trifida* and *Ambrosia artemisiifolia* are the area's 2 predominant ragweed species. Throughout the world, the abundant pollen produced by ragweed plants is considered to be one of the most significant

sources of allergenic proteins. Although not as well studied, other herbaceous species, including *Artemisia*, *Plantago*, *Rumex*, *Xanthium*, and pollen from the Chenopodiaceae, Amaranthaceae, and Urticaceae families, are also implicated as causes of hay fever and allergic asthma.<sup>33–37</sup>

The seasonal calendar depicted is consistent with previous survey results reported for the Washington, DC, area, and the neighboring Philadelphia, Pennsylvania, and Cherry Hill, New Jersey, region and the Newark, New Jersey, and New York, New York, region.<sup>22,23,38</sup>

**Annual variation.** Variation is observed for the timing of peak weekly mean values and the total annual sum for individual pollen types. Variation in the annual timing of the highest weekly concentrations is noted, from a tight 2-week window for *Artemisia* to more than 6 weeks for other tree and

Table 5. Spearman Rank Correlation Values for Daily Pollen Counts for Predominant Tree, Weed and Grass Pollen Types and Meteorological Parameters 1998-2007

|                       | Maximum Temperature |         | Precipitation  |         | Average Wind Speed |         | Dew Point      |         |
|-----------------------|---------------------|---------|----------------|---------|--------------------|---------|----------------|---------|
|                       | r <sub>s</sub>      | P value | r <sub>s</sub> | P value | r <sub>s</sub>     | P value | r <sub>s</sub> | P value |
| <b>Poaceae</b>        | 0.679               | < .001  | -0.022         | .341    | -0.052             | .022    | 0.594          | < .001  |
| <b>Betulaceae</b>     | -0.061              | .008    | -0.004         | .871    | 0.149              | < .001  | -0.162         | < .001  |
| <b>Cupressaceae</b>   | -0.155              | < .001  | -0.033         | .150    | 0.139              | < .001  | -0.256         | < .001  |
| <b>Moraceae</b>       | 0.058               | .010    | -0.012         | .601    | 0.058              | .010    | -0.019         | .396    |
| <b>Pinaceae</b>       | 0.181               | < .001  | 0.051          | .024    | 0.124              | < .001  | 0.073          | =.001   |
| <b>Quercus</b>        | 0.022               | .339    | 0.016          | .484    | 0.110              | < .001  | -0.068         | .003    |
| <b>Ambrosia</b>       | 0.340               | < .001  | -0.076         | =.001   | -0.128             | < .001  | 0.363          | < .001  |
| <b>Cheno/Amaranth</b> | 0.399               | < .001  | -0.088         | <.001   | -0.096             | < .001  | 0.381          | < .001  |
| <b>Plantago</b>       | 0.645               | < .001  | 0.067          | .003    | -0.074             | =.001   | 0.607          | < .001  |
| <b>Rumex</b>          | 0.168               | < .001  | 0.005          | .819    | 0.059              | .009    | 0.106          | < .001  |
| <b>Urticaceae</b>     | 0.578               | < .001  | -0.051         | .025    | -0.125             | < .001  | 0.549          | < .001  |

herbaceous pollen. Annual fluctuations in seasonal peaks, pollen production, and the start of the season for plant species have been attributed to meteorological factors during pollen production and flowering,<sup>39-42</sup> inherent plant biorhythms or cycles,<sup>24,25,31,32,43</sup> and changes in land use practices and reforestation measures.<sup>44-46</sup> Although cyclic patterns were not clearly evident for the overall annual pollen sum for tree and herbaceous species (Figure 5), several tree species, including Betulaceae, *Alnus*, and *Fagus* (Figure 6), demonstrated high pollen years followed by very low production years.

Total annual pollen production ranged from 30,952 grains/m<sup>3</sup> in 2003 to 18,335 grains/m<sup>3</sup> in 1998, reflecting primarily the highest and lowest production years for trees. Interestingly, the top 3 highest pollen production years were observed in the last 5 years of the survey (2003, 2005, and 2006). An increasing trend over time was noted for annual tree pollen production. Rising temperatures associated with global warming and increased carbon dioxide production in urban areas has been linked to elevated aeroallergen levels and enhanced allergenicity.<sup>47,48</sup> Further studies with individual tree, weed, and grass species in relation to these concerns are warranted. Complex meteorological interactions and weather trends, combined with the inherent biorhythm and cyclic pollinating patterns of individual plant species, undoubtedly play a role in the variation of pollen counts from year to year.

**Meteorological influences.** Although moderate to strong positive correlations were noted for grass and weed pollen with daily maximum temperature and dew point, the results for individual tree species were more variable. The negative influence of rainfall on pollen levels is well known. Most weed species were weakly and negatively correlated with precipitation; however, for grass and most tree species the results were not significant. Tree species were positively correlated with average daily wind speed, whereas the converse was true for grasses and predominant weed species. Differences in the affect that specific meteorological variables have on individual species has been previously docu-

mented.<sup>23,42,49</sup> It has also been shown that for a particular species, *Plantago*, the correlation with maximum temperature could be both inverse or positive in different years.<sup>50</sup>

A more complete examination of the relationship among meteorological parameters, significant weather events, and year-to-year variation in daily pollen levels was well beyond the scope of this investigation. Further studies are needed to better elucidate the complexities of this relationship and facilitate the development of a predictive model that might enable the forecasting of daily pollen levels. The knowledge gained would be invaluable for both the allergy practitioner and the atopic patient in the Washington, DC, area.

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