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Publisher: Taylor & Francis

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## Grana

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/sgra20>

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Available online: 17 Dec 2007

To cite this article: Michael S. Zavada, Stephanie M. McGraw & Melissa A. Miller (2007): The role of clothing fabrics as passive pollen collectors in the north-eastern United States, *Grana*, 46:4, 285-291

To link to this article: <http://dx.doi.org/10.1080/00173130701780104>

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## The role of clothing fabrics as passive pollen collectors in the north-eastern United States

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### Abstract

The purpose of this investigation is to determine if clothing fabrics act as passive pollen collectors, and to determine if different fabrics vary with regard to the abundance and type of pollen trapped. Five of the most common fabrics in the United States (cotton, wool, polyester, silk and linen) were used to trap pollen. The pollen collecting apparatus was constructed of a 30 cm diameter circular needlepoint hoop, which vertically rotated freely, and was mounted on a dowel that was driven into the soil to chest height. Five pollen collectors, each with one of the five fabrics were placed at a collection site in rural, suburban, and urban habitats in Rhode Island for a 24 h period at weekly or biweekly intervals throughout 2002–2003. Pollen was washed from each of the fabrics and acetolysed. Total pollen per cm<sup>2</sup> removed from each of the fabric types was estimated using a haemocytometer. The pollen types were identified, and 200 grains were counted to determine the relative abundance of the various pollen types recovered from the fabrics. Clothing fabrics act as passive pollen collectors and the flora recovered from the fabric represent the qualitative and quantitative components of the pollen rain for that specific day. There are quantitative differences among the relative abundance of pollen types from the three habitats (urban, suburban, and rural). Washing with water and a detergent eliminates a majority of the pollen from the fabrics.

**Keywords:** *Fabrics, pollen, allergies, forensic palynology, indoor contamination*

Many people suffer from allergies and the occurrence of allergies is considered one of the major medical problems in the world (Rachele, 1980; Stock et al., 2005; Eder et al., 2006; Russell, 2006). The daily reports of outdoor airborne pollen and spores are used as an indicator of the threat of exposure to a variety of allergens for people at high risk (Frenz, 2000a; Frenz et al., 1998; Giberson et al., 1997).

Indoor allergens have also been identified as a contributing to chronic allergy symptoms (Ledford, 1994; Ormstad, 2001), and the source of these allergens are believed to be derived from indoor dust, pet dander (Holmquist & Vesterberg, 1999; Fahlbusch et al., 2001, and references therein), and outdoor allergens introduced into the indoor environment by ventilation systems. Strategies to reduce the numbers and kinds of indoor allergens include

indoor air purification (Chafee, 1985; D'Amato et al., 1996; Sterling & Lewis, 1998; Sabbah, 2000) and shutting down of the avenues of ingress for the outdoor allergens. Yli-Panula & Rantio-Lehtimäki (1995), however, observed that footwear and clothing transport allergens indoors. Two months after the peak pollen period, these allergens were still evident. These findings suggest that while allergy sufferers are advised to remain inside during peak pollen periods, they are exposed to allergens carried into the home and work environment via a variety of avenues.

Pollen recovered from clothes may also have applications in forensic palynology (Horrocks, 2004). Pollen recovered from clothes may qualitatively suggest proximity to unique species or habitats, and may mirror quantitative and qualitative seasonal variation that will establish the exposure of

the clothing to a particular seasonal airborne pollen profile, and possibly place the collection of the sample in a specific time frame and/or a specific location.

The purpose of this investigation is to determine if clothing fabrics are effective passive pollen collectors that reflect qualitative and quantitative outdoor allergen loads, and to determine if different fabrics vary with regard to the abundance and type of pollen trapped. This investigation also assesses the role of pollen trapped on clothing and what contribution it may make to increasing the indoor allergen load, and does the indoor allergen load proportionally vary with the outdoor allergen loads as determined by conventional collection techniques (e.g. Burkard or Rotorod samplers) at established reporting stations in New England, USA.

## Material and methods

### Sample localities and pollen collection

Five of the leading selling fabrics with the most common thread counts (cotton,  $48 \times 48/\text{cm}^2$ ; wool felt; polyester,  $40 \times 64/\text{cm}^2$ ; silk,  $64 \times 56/\text{cm}^2$ , and linen,  $60 \times 60/\text{cm}^2$ ) in the USA, were used to trap pollen at three habitats, i.e., rural (UTM 19 T 0285807 4636764), urban (UTM 19 T 0302305 4638962), and suburban (UTM 19 T 0297641 4635136) habitats from October 2002 to October 2003 in Rhode Island, USA (Figure 1).

All three localities fall within an oak-hickory dominated forest type. Dominant trees include white (*Quercus alba* L.), scarlet (*Q. coccinea* Münchh.), black (*Q. velutina* Lam.), and red (*Q. rubra* L.) oak. In lower density but still a dominant element in this forest type are pignut hickory [*Carya glabra* (P. Mill) Sweet], shagbark hickory [*C. ovata* (P. Mill) K. Koch], and mockernut hickory [*C. tomentosa* (Lam.) Nutt ex Ell.]. Other trees include white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), and white pine (*Pinus strobus* L.) may be associated with the canopy trees. An understory is typically present and include, witch hazel (*Hamamelis virginiana* L.) and dogwood (*Cornus florida* L.). The forest floor is dominated by blueberries (*Vaccinium pallidum* Ait. and *V. angustifolium* Ait.), black huckleberry [*Gaylussacia baccata* (Wangenh.) K. Koch], and laurel (*Kalmia angustifolia* L.) and wild sarsaparilla (*Aralia nudicaulis*), false Solomon's seal [*Smilacina racemosa* (L.) Desf.], and a sedge (*Carex pensylvanica* Lam.) comprise the herb layer. The American chestnut [*Castanea dentata* (Marsh.) Borkh.] was a co-dominant canopy tree species; however, the infestation of chestnut blight has relegated this tree to the shrubby under story as adventitious shouts

that after 2–5 years become infested and suppresses sexual reproduction (Department of Environmental Management, State of Rhode Island [website], 2000; Butler & Wharten, 1998). American chestnut no longer contributes significant quantities of pollen to the airborne pollen profile. The major difference among the three localities is the degree of urbanization, forest fragmentation, and the introduction of cultivated exotic species.

The pollen collecting apparatus was constructed of a circular needle point hoop 30 cm in diameter (a total area of  $706.9 \text{ cm}^2$ ) that vertically rotated freely and was mounted on a  $2 \text{ m} \times 3 \text{ cm}$  dowel that was driven into the ground to chest height (1–1.25 m above ground level), (Figure 2). The pollen collectors were placed at the collection sites for a 24 h period at weekly or biweekly intervals.

### Pollen recovery, preparation and quantitative analysis

At the end of the 24 h period, the fabrics were collected from each of the sites and kept in sterile plastic bags. The pollen was then washed from the fabrics using 300 ml of distilled water, and 2–4 ml of Tween 80, centrifuged, and the sample was then acetolyzed (Erdtman, 1969). Samples were maintained in 30 ml of water with a crystal of phenol added to retard bacterial and fungal growth. Each week, the total pollen removed from each of the fifteen fabrics was estimated using a haemocytometer following the method Stein-Taylor et al. (1973–1985). Another wet mount was prepared and two hundred pollen grains were counted and the species identified to the lowest taxonomic level in each sample. All statistical analyses were done using AXUM 7 for Windows, MathSoft Engineering & Education, Inc., Cambridge, Massachusetts.

To determine the efficiency with which pollen is recovered using the above method, 10 g of pollen from *Betula papyrifera* Marsh. was collected in the spring of 2003. One gram of pollen was suspended in 50 ml of water. Using a haemocytometer and following the method of Stein-Taylor et al. (1973–1985) the 50 ml solution was estimated to have 2 880 000 pollen grains. A 7 ml aliquot was removed from the 50 ml solution and was estimated to have 806 000 pollen grains using a haemocytometer. This aliquot was brought up to 50 ml. Samples of each of the fabrics were suspended in a chamber and the 50 ml containing approximately 806 000 pollen grains was sprayed into the chamber using an Aerosol spray bottle. All of the surfaces in the container were covered with the solution. The fabrics were removed and washed as above, and the number of pollen grains recovered from the fabric was estimated using a haemocytometer (Stein-Taylor et al.,

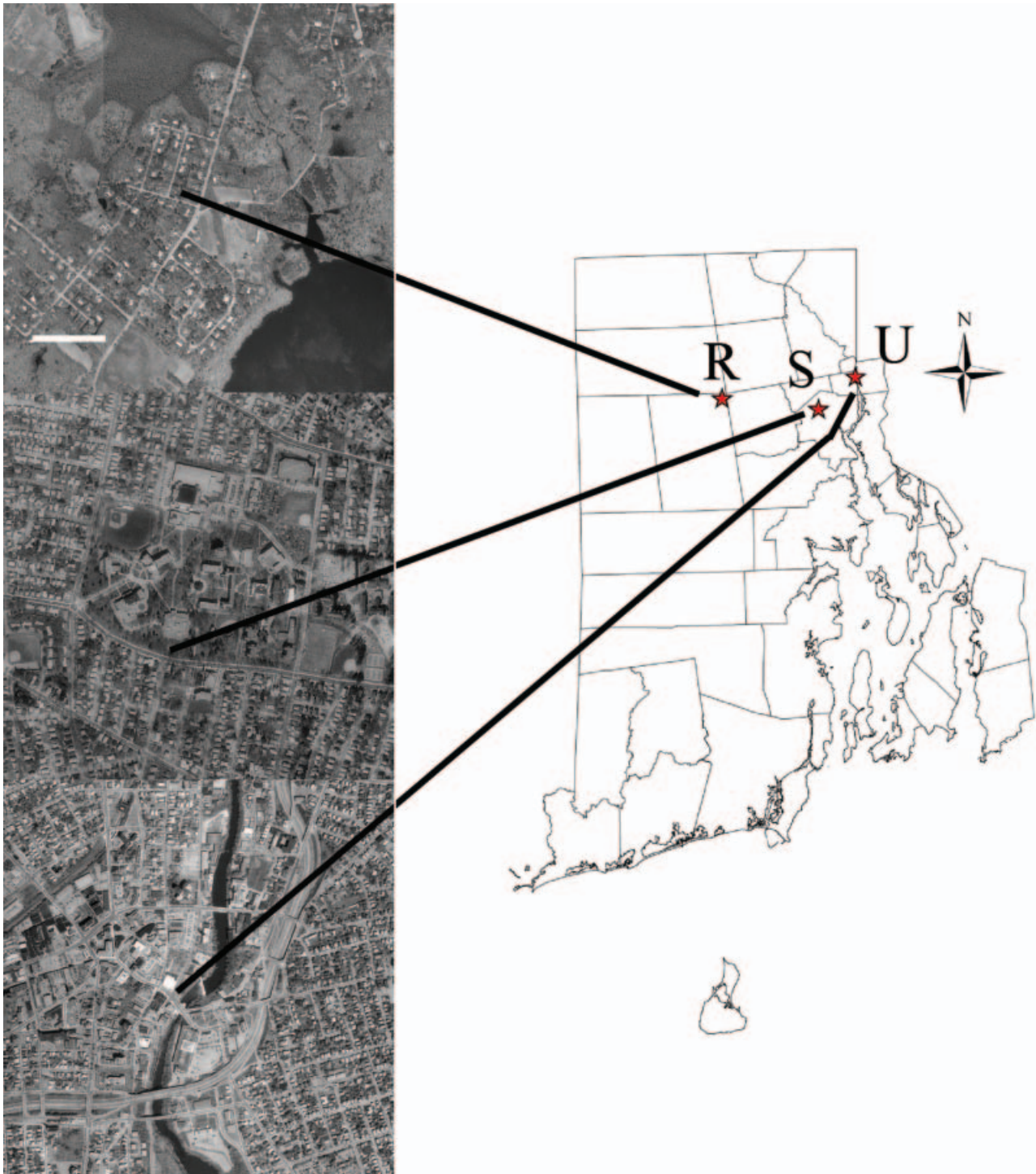


Figure 1. Aerial photographic of the Rural collection site (R), Suburban collection site (S), and Urban collection site (U) showing there location in Rhode Island, USA. Scale bar – 200 m.

1973–1985). The fabrics were washed a second and third time, each time estimating the number of pollen grains using a haemocytometer. The washing was terminated when no recordable pollen was recovered from the fabrics. On the third washing, in both replications of the procedure, no recordable pollen was recovered. The first washing removed greater than

99.9% of the pollen. The pollen recovered from the second wash was undetectable or less than 0.01% of the total introduced, indicating that this method recovered 99.9% of the pollen trapped by the fabrics after the first washing.

To determine if the one type of fabric (cotton, wool, polyester, silk, and linen) consistently trapped

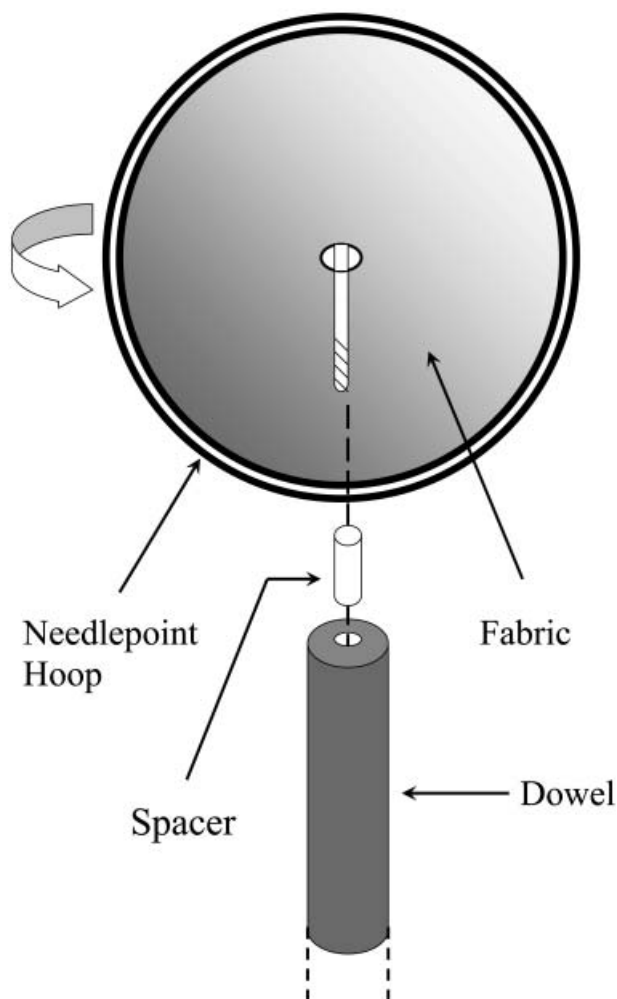


Figure 2. The collecting apparatus showing the vertically mounted needlepoint hoop, and the dowel that was driven into the ground to a height of about 1.5 meters.

pollen at a different rate in comparison to the other fabric types at each locality, the number of particles/square centimeter were averaged for each fabric type at each locality, a standard deviation was calculated and an analysis of variance was done to determine if there were any significant differences among the fabric types at each sample locality at the 0.05 and 0.01 confidence level. An alternative analysis was done where each fabric at each sample locality on a given sample day was rated between one (1) to five (5), one being the highest number of trapped pollen for that particular fabric type for that particular sample day, and five being the lowest. The rating for each of the fabrics for each of the sample days were then averaged to determine if any of the fabrics exhibited a trend to trap pollen in higher or lower quantities compared to the other fabric types.

To determine if all the fabric types at each locality (urban, suburban or rural) trapped pollen at a different rate in comparison to the other localities, an average of the total number of particles/square

centimeter by the five fabrics was calculated for each locality on each sample day. The average number of particles/square centimeter for each sample day was then averaged, a standard deviation calculated and an analysis of variance done to determine if there were any significant differences among the localities (urban, suburban or rural) at the 0.05 and 0.01 confidence levels. An alternative analysis was done where the average number of particles of all the fabrics at a locality were rated between one (1) and (3), one (1) being the locality at which the most pollen was trapped, two (2) being the next highest and three (3) being the lowest. The average rating for each locality were calculated, and then compared to the other localities to determine if a particular locality exhibited a trend to trap fewer or more particles than the other localities.

The pollen recovered from the fabrics was compared to the regional pollen data collected from volumetric collectors located on top of the medical buildings at the Waterbury Connecticut Counting Station, 1389 West Main Street, Waterbury, CT 06708, the Clemsford, MA counting station, 9 Village Square, Chelmsford, MA 01824, and in the Washington DC at Walter Reed Army Medical Ctr., Washington, DC 20307-5001. Data from the Waterbury CT, and Clemsford MA counting stations were pooled due to their regional proximity.

## Results

The five fabric types that were placed at each of three localities trapped a variety of airborne pollen and re-suspended debris (e.g. pollen, fungi, algae, insect parts, mites, nematodes, trichomes, protozoans). The pooled data for the five different fabrics at the three locations (15 samples in all) ranged between 0–1 485 pollen grains per square centimeter. The pooled data for all sites and samples have a pollen profile that indicated two major pollen producing intervals (spring and fall) punctuated by a low frequency of airborne pollen from late November to the end of January (Figures 3, 4). The primary airborne particles during this time interval were of fungal origin (Figure 5). The second dip in overall airborne pollen is in late July (Figures 3, 4); however, particles recovered during this time interval are of both pollen and of fungal origin.

There are quantitative differences among the five fabrics from the three localities on any given day; however, there are no significant differences among the fabric types with regard to their ability to trap particles at a higher or lower rate in comparison to the other fabric types. In addition, all of the rating sums for the individual fabrics averaged a rating of 3

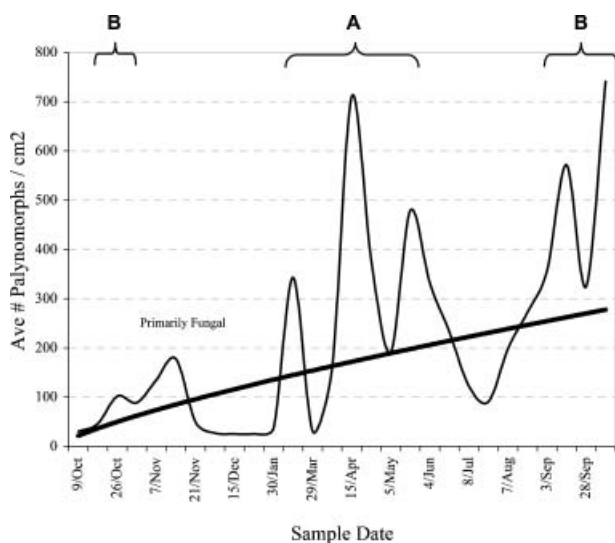


Figure 3. The pollen profile of the pooled data (3 localities, rural, suburban and urban, 5 different fabrics (cotton, wool, polyester, silk, and linen) from each locality from beginning October 9, 2002 to October 9, 2003 showing spring (A) and fall (B) pollen spikes. Note that the airborne palynomorphs recovered from the winter months are primarily of fungal origin.

on the 1–5 scale plus or minus one, thus none of the fabrics exhibited a trend to consistently trap pollen at a higher or lower rate than the other fabric types. The pollen trapped by the fabrics exhibit seasonal fluctuations that are comparable to the seasonal trends of pollen trapped using standard collection devices, e.g. Burkard or rotorod collectors (Figure 6). In this study the quantity is expressed in palynomorphs per square centimeter ( $\text{cm}^2$ ) vs. the

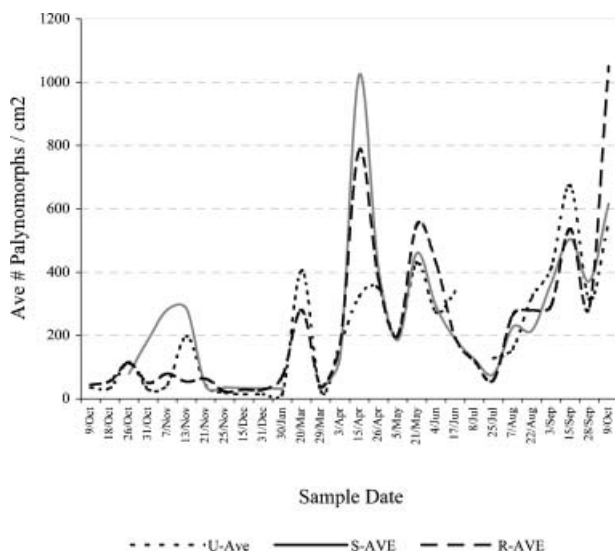


Figure 4. The pollen profile for each individual habitat (rural, suburban, urban) for the same time interval in Figure 6, showing the parody among the pollen profiles from the three sites. There are no consistent statistical differences among the data from the three localities.

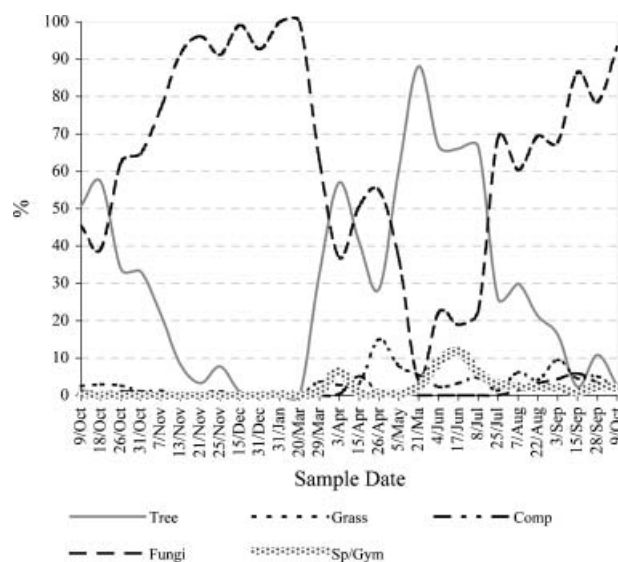


Figure 5. The pollen profile of the pooled data (3 localities, rural, suburban and urban, 5 different fabrics (cotton, wool, polyester, silk, and linen) of the Arboreal, Poaceae, Asteraceae, fungi, and the pteridophyte spores and gymnosperm pollen (Sp/Gym).

volumetric measures used with, e.g., a Burkard collector.

When the data for the five fabrics was averaged for a particular locality and then compared to the other localities there are no significant differences among the three localities at the 0.05 or 0.01 confidence levels. Our alternative analysis, however, exhibited a

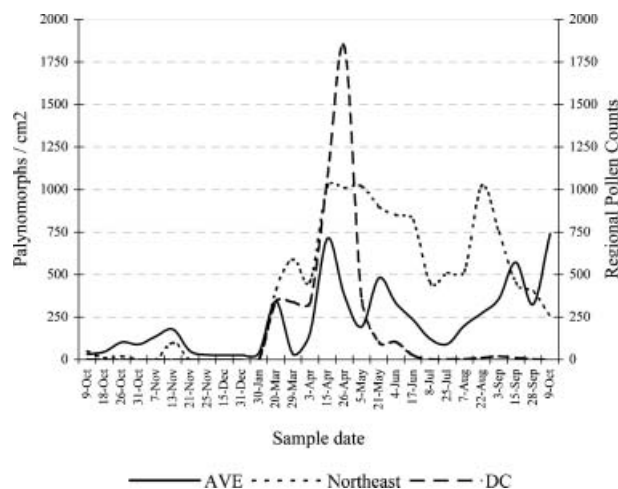


Figure 6. Pollen profiles of the pooled data in this study expressed as average number of palynomorphs per square centimeter plotted with pollen data from the northeast United States (Data from the Waterbury, CT Counting Station, 1389 West Main Street, Ste. 205, Waterbury, CT 06708, and the **Clemsford, MA Counting station**, 9 Village Square, Chelmsford, MA 01824 were pooled to derive this curve) and the Washington, DC area (Walter Reed Army Medical Ctr., Washington, DC 20307-5001), showing the overall similarity in the pollen profiles despite the different collection methods and data values. The data from the three collecting stations has been standardized to reflect the overall pollen profile.

trend among the three localities, i.e., on average the urban locality had the lowest number of pollen trapped on any given sample day (1.7 on a 3 point scale). The suburban locality had the next highest number of pollen trapped on any given sample day (1.9 on a 3 point scale), and the rural locality exhibited the highest number of trapped pollen (2.2 on a 3 point scale). This trend may be related to the difference in vegetation cover in the three localities due to urbanization and forest fragmentation (Figure 1).

There are differences among the species association from the urban/suburban vs. the rural localities particular among the arboreal species. There are different species associations from the three localities among the Poaceae, Asteraceae, fungal spores, and gymnosperm pollen; however, these could not be determined based solely on morphology of the trapped pollen. Pollen related to the Poaceae, and Asteraceae can not be differentiated to the species level, likewise particles of fungal origin can include spores, conidia, and mycelia some of which can not be reliably identified by visual examination to genus or species. Bryophyte and pteridophyte, monolete and trilete spores, and bisaccate gymnosperm pollen are also difficult to determine to species. The arboreal pollen, however, is often distinguishable and represents a variety of taxa from the three localities. Arboreal pollen from the urban and suburban habitat are comprised of cultivated and introduced arboreal species, e.g. exotic maples, *Tilia*, and ornamental cherry. The rural habitat has a number of native species represented in the arboreal pollen flora, e.g. *Acer*, *Betula*, *Fagus*, *Ilex*, *Ulmus*, *Liquidambar*, *Lindera*, *Sassafras*, *Quercus*, and *Carya*.

The arboreal and nonarboreal pollen of the Poaceae, and Asteraceae showed a strong bimodal distribution which correspond to the spring and fall flowering seasons in New England (Figures 5, 6), however, some species of arboreal pollen and pollen from the Poaceae is present in low frequency through most of the year. Pollen of the Asteraceae, spores and gymnosperm pollen are predominantly seasonal, and are absent from the pollen profiles during the winter months (December, January, February). Fungal spores and mycelia fragments are present throughout the year and due to the lack of pollen during this time, are the dominant airborne particles present during the winter months (December, January, February; Figures 5, 6). Pteridophyte spores and gymnosperm pollen (bisaccate pollen) showed a marked increase during May, June and early July, but remained low to absent for the rest of the year (Figure 6).

## Discussion

All of the fabrics regardless of fiber type, weave, and color showed no statistical differences among the rates at which the five fabrics trap pollen. Although quantitative differences are known to occur among collection methods (Dechamp, 1993; Frenz & Lince, 1997; Frenz, 1999; Trigo et al., 2000; Portnoy et al., 2000) and may be influenced by meteorological conditions (Failey & Batchelder, 1986; Frenz, 2000b; Freye et al., 2001; Glassheim et al., 1995; McDonald & O'Driscoll, 1980; Valencia-Barrera et al., 2001), the quantitative pattern exhibited by the pollen passively collected on the fabrics exhibits similar regional and seasonal trends to pollen profiles that characterize the north-east United States (Figure 6). Another feature of clothing acting as a passive pollen collector is the unexpected high numbers of pollen and airborne particles trapped by clothing fabrics during the spring and fall pollen spikes (Figure 4). The number of pollen and other particles per square centimeter can exceed 1 400 per sq centimeter. This suggests that clothing is acting as a cumulative collector throughout the 24 h time period. On peak pollen producing days a large T-shirt (assumed to have a surface area of 5 000 cm<sup>2</sup>) can trap approximately 7 000 000 pollen grains. The high numbers of pollen and airborne particles trapped on fabrics may act as a primary source for indoor allergens particularly public indoor areas, e.g. the work environment where large numbers of people come in from the out doors wearing the same clothes throughout the day (Yli-Panula & Rantio-Lehtimäki, 1995). For severe allergy sufferers a frequent changing or washing of clothes will reduce the number of allergens on clothing. We found that washing the fabrics with water and a foaming wetting agent (Tween 80) removed 99.9% of the pollen in the first washing.

Clothing acts as a quantitative and qualitative collector, and produces a pollen profile that exhibit regional seasonal trends similar to patterns generated using volumetric collectors. Qualitative and quantitative aspects of a pollen profile are representative of local and regional habitats and seasonal variations. This may aid forensic palynologists in determining a person's location to specific habitats, and the time of year the person was present at a specific location based on the qualitative and quantitative analysis of pollen recovered from clothing that is associated with an individual (Horrocks & Walsh, 1998; Horrocks, 2004; Mildenhall, 2004), however, the interpretation of pollen findings from clothes may be difficult if the individual visited a variety of different locations during the same day.

Clothing fabrics are efficient quantifiable collectors of airborne particles, and re-suspended particles as a result of disturbance of surface deposited pollen, fungal spores, hyphal fragments and other animals and biological derived debris. The longer clothes are worn, the more cumulative the sample becomes. The allergen load for clothes can be high, exceeding 1 400 palynomorphs per square centimeter. Clothing may be a primary avenue of ingress that contributes to the contamination of indoor air quality at the workplace and the home.

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