Bioaerosols and Pulmonary Health: The FACES Endotoxin Exposure Assessment

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The Problem

- Assessing the role of bioaerosols in pulmonary health is severely limited by the lack of bioaerosol exposure data
- Bioaerosols are not measured routinely
- Bioaerosols are rarely measured in special studies
- Measurement technologies are not automated and affordable

Objective

- Describe the FACES collection and analysis of endotoxin data as an example of the types of studies needed to facilitate evaluation of bioaerosols and pulmonary health
- Describe the temporal and spatial patterns of endotoxin in Fresno
- Compare spatial variability of endotoxin, conventional pollutants, and other bioaerosols

Why Endotoxin?

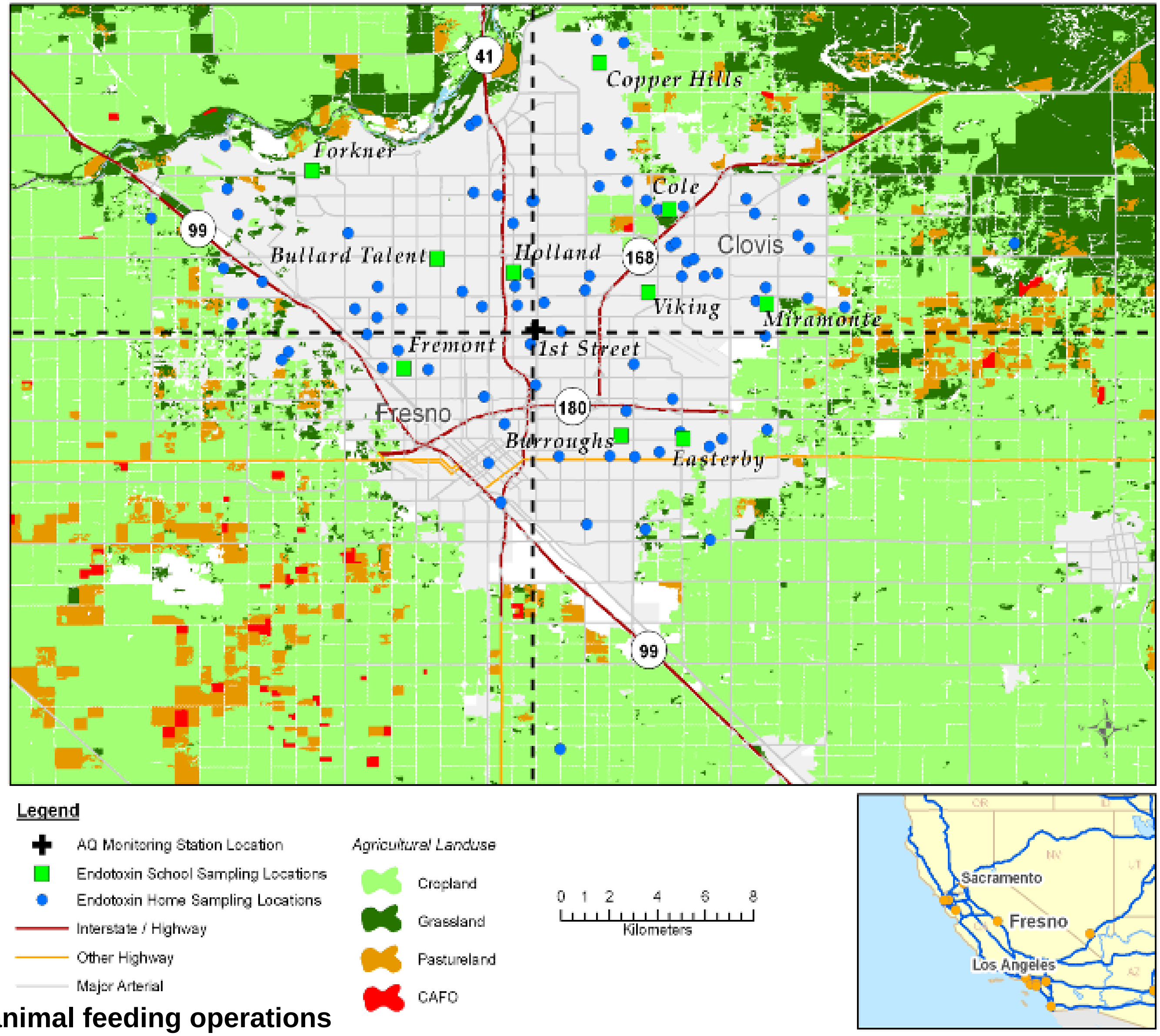
- Endotoxins are lipopolysaccharides (LPS) found in the outer membranes of Gram-negative bacteria that are distributed widely on plants, in soil, water, and the intestines of humans and animals
- Inhalation of endotoxin results in lung inflammation
- It’s known to cause lung disease in high risk occupational settings (cotton textile workers and swine handlers)
- Non-occupational exposures are also a concern for allergic and respiratory disease, especially in infants and children
- Endotoxin exposure may cause or exacerbate symptoms in asthmatics

Background

- Endotoxin primarily occurs in coarse PM (2.5 to 10 µm) and may contribute to coarse PM health effects
- Most studies examined endotoxin in house dust which is not well correlated with ambient endotoxin (r = 0.3). Indoor endotoxin dust is associated with respiratory illness and wheezing in children
- Very few studies of ambient endotoxin exist (e.g., only 4 notable studies in the US: Southern Calif., Palo Alto, New Orleans, and North Carolina)

FACES Study Area

Air Quality Monitoring Locations and Agricultural Land Use



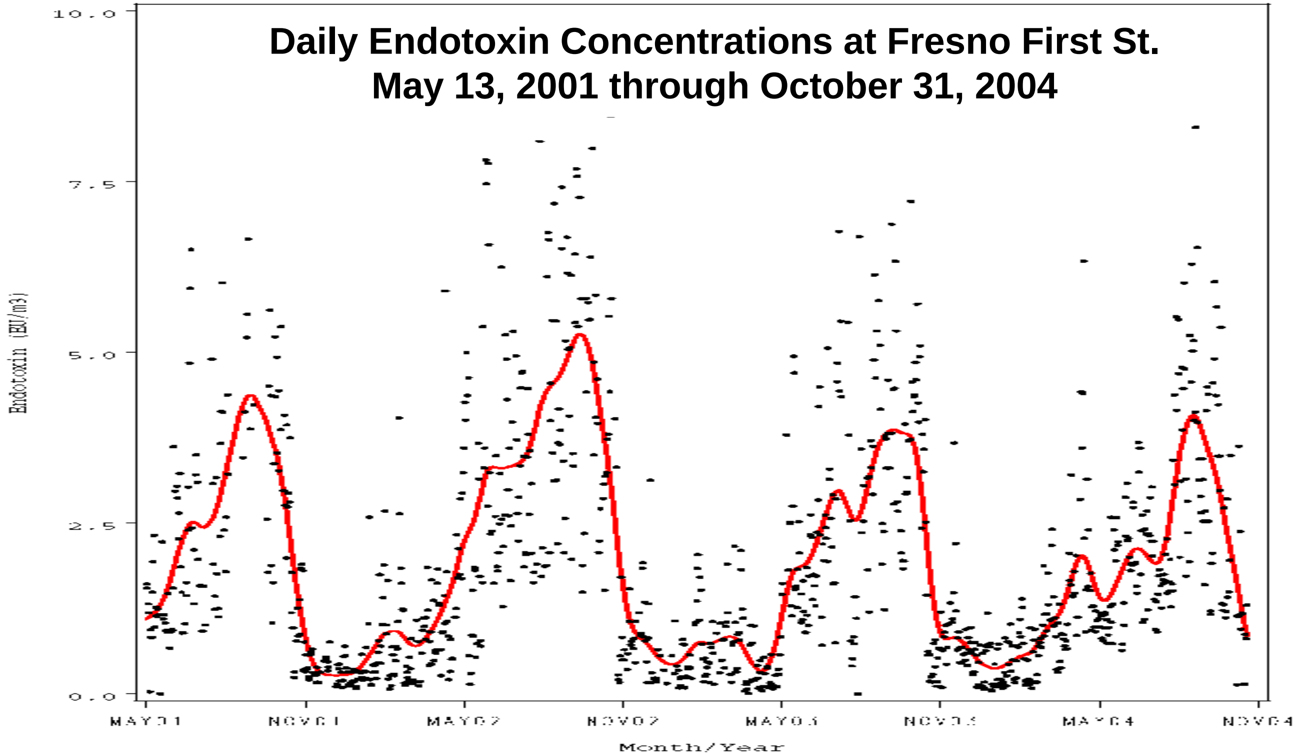
CAFO=confined animal feeding operations

Sampling Methods

- Daily ambient PM10 endotoxin samples were collected on Telfton filters from 2001 to 2004 at the Fresno First St. air monitoring site
  - Additional samples were collected on selected days in 2002-2003 at 10 schools and 83 homes.
  - Typically, 24-hr measurements were collected starting at 8:00 p.m. on the residential sampling days at one central site, two schools, and five homes.
  - Endotoxin was sampled at the homes on five days during a two-week period.
  - Endotoxin samples were analyzed using the Kinetic Limulus Assay with Resistant-parallel-line Estimation (KLARE) Method developed by Milton et al.
- Concurrent, collocated samples were obtained for pollen grains, fungal spores, PM2.5 elemental carbon (EC), PM2.5 mass, and PM10 mass.

Ambient Endotoxin Seasonality

- Distinct seasonal patterns
  - Very low levels from November through March (wet season, geometric mean <0.7 EU/m3)
  - Highest levels in June through October (dry season, geometric mean >2 EU/m3)



Monthly Endotoxin at Fresno 1st St.

MONTH[a]	Geometric Mean	Median	Maximum	75th Percentile	25th Percentile
January	0.28	0.30	2.59	0.57	0.15
February	0.55	0.66	4.04	1.01	0.29
March	0.69	0.83	2.64	1.12	0.37
April	0.68	0.83	6.34	1.5	0.39
May	1.17	1.26	5.00	1.89	0.89
June	1.95	1.94	7.82	2.74	1.31
July	2.49	2.43	6.77	3.53	1.74
August	2.75	3.17	9.29	4.69	1.87
September	3.77	3.87	9.43	5.35	2.68
October	2.6	3.26	8.46	4.42	1.78
November	0.59	0.64	4.03	1.01	0.32
December	0.47	0.54	3.13	0.76	0.32

a) Data (in EU/m^3) for May 1, 2001 thought October 31, 2004.

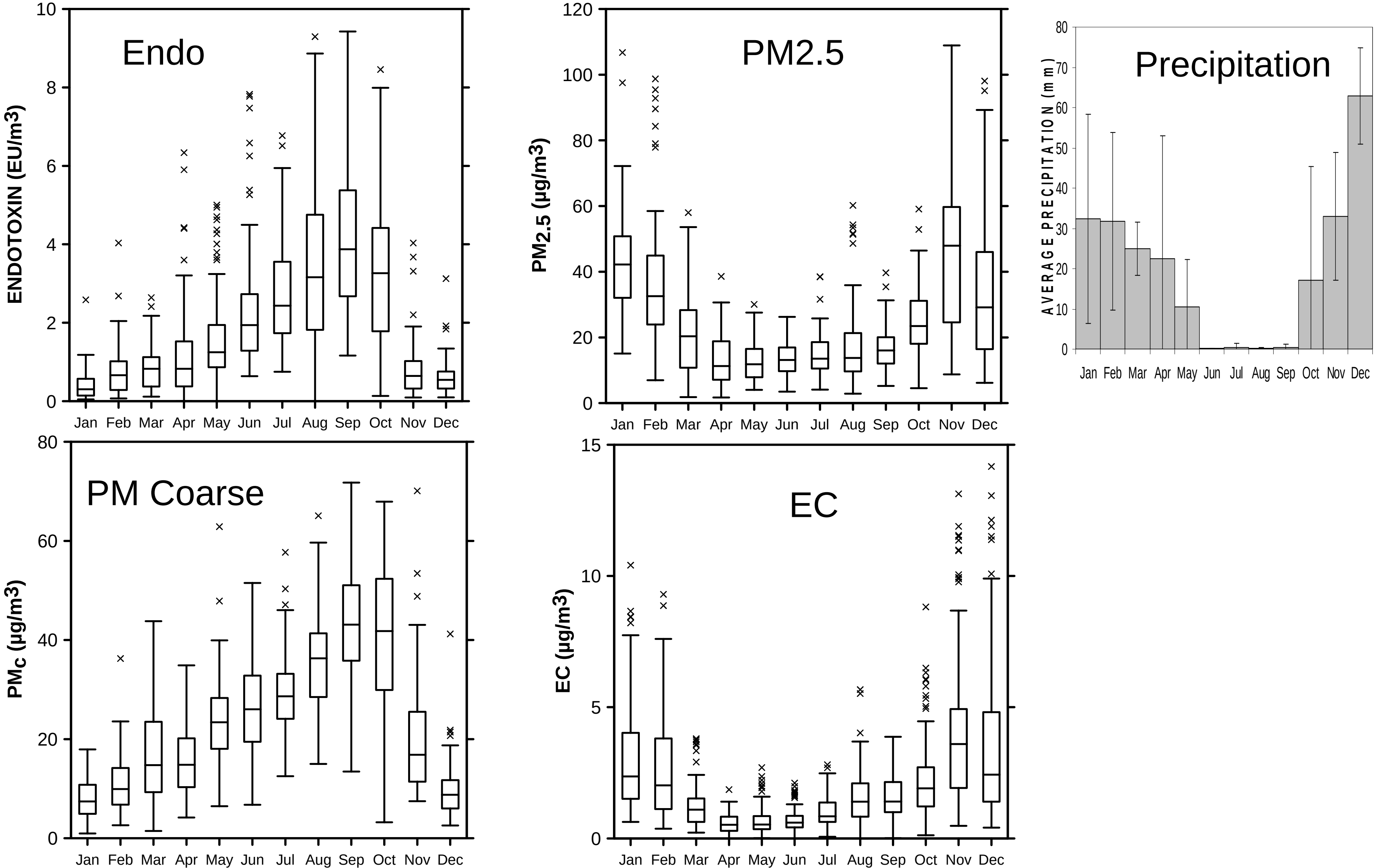
Endotoxin by Year at Fresno 1st St.

Year	Geometric Mean	Median	Maximum	75th Percentile	25th Percentile	Minimum
2001	1.3	1.49	6.66	3.03	0.7	<LOD
2002	1.38	1.72	9.43	3.6	0.6	0.07
2003	0.98	1.05	7.21	2.53	0.47	<LOD
2004	1.24	1.33	8.29	2.41	0.81	<LOD

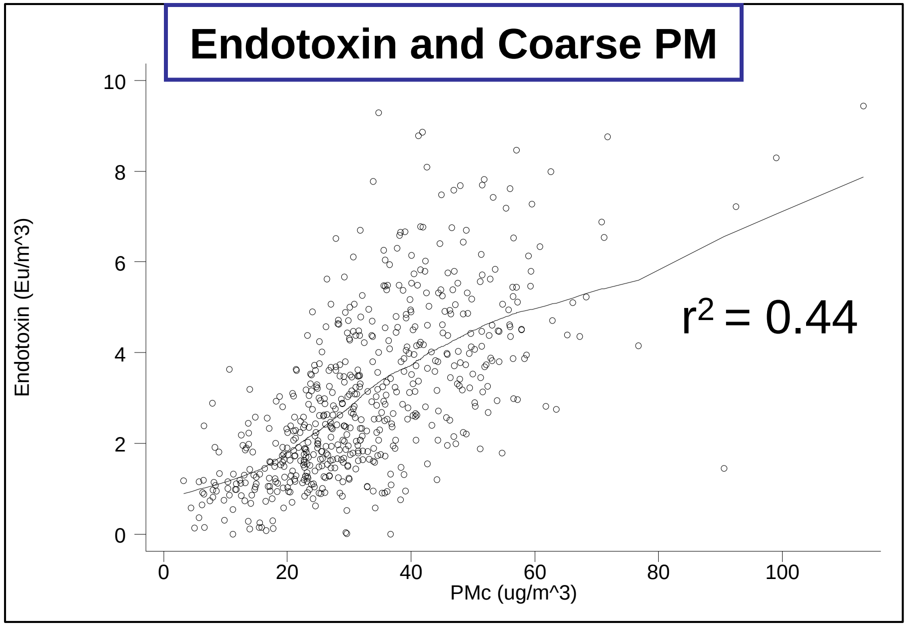
a) Data for May 1, 2001 thought October 31, 2004.

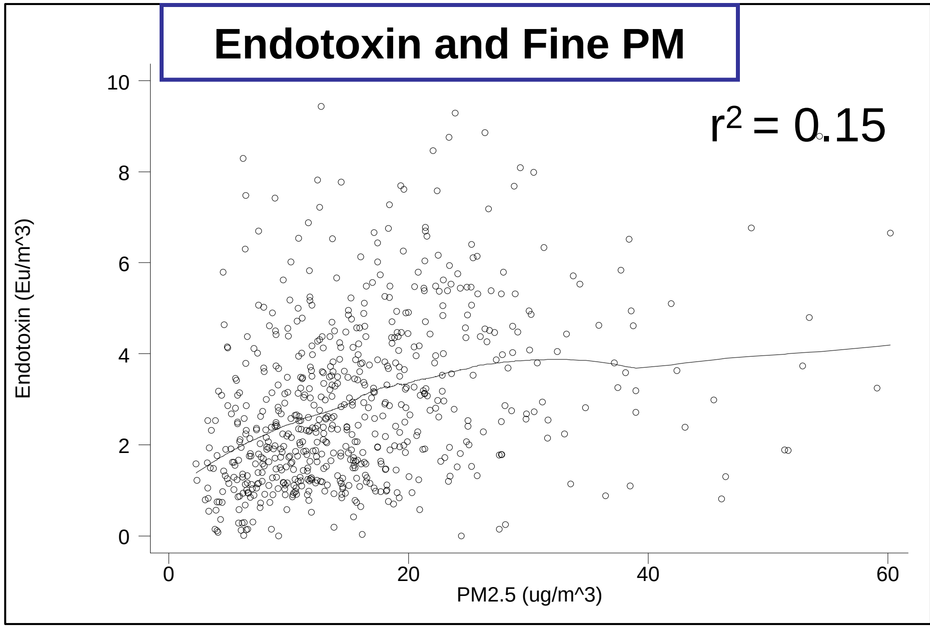
b) LOD = ~0.05 EU/m^3

Seasonality Endotoxin, $PM_{2.5}$, PMc, and EC concentrations



Nonlinear Relationships between Endotoxin and coarse and fine PM mass





Dry Season Only

Most of the variability in daily endotoxin is not explain by PM mass measurements!

Temporal Model Development

- A temporal model was developed to describe physical factors (other than emissions) influencing the daily variations in endotoxin concentrations at the First St. site for the dry seasons of May to October, 2001-2004.
- Wind speed, wind direction, temperature, relative humidity, recirculation factors, month, and the previous day’s endotoxin level were considered in linear models.
- The Deletion, Substitution, Addition (DSA) machine-learning, model-fitting algorithm was used to verify the fit of the final model.

The Temporal Model

- Physical Factors that explain daily endotoxin in Fresno in order of importance:
  1. The prior day’s endotoxin level
  2. An index of meteorological recirculation
  3. Mean relative humidity during the sampling interval
  4. Wind speed at the beginning of the sampling interval
- Including the single day lag endotoxin removed all autocorrelation and captured all lag associations
- Days with high recirculation, usually associated with summertime inversions, were associated with higher endotoxin levels.
- These factors explained 55% and 52% of the variance at Fresno First St. and Fremont School. They factors are probably predictive of endotoxin in the greater Fresno region.

Temporal Models of Daily Endotoxin at First St. and Fremont School in the Dry Season

Variable	Parameter Estimates (SE)	
	First Street (N = 615, r2 = 0.55)	Fremont School (N=120, r2 = 0.52)
Intercept	2.822	4.4652
Previous Day [Endotoxin] (EU/m_3)[a]	0.6901 (0.0368)	0.3500 (0.1076)
Previous Day [Endotoxin] Cubed	-0.0084 (0.0012)	-0.0072 (0.0039
Same Day Mean Relative Humidity(%)	-0.0122 (0.0058)	-0.0506 (0.0250)
Same Day Mean RH Squared	-0.0010 (0.0003)	0.0003 (0.0015)
12-hr Recirculation Index[b]	1.4705 (0.4067)	4.9971 (1.2541)
Same Day 8 pm Wind speed[c]	-0.1618 (0.0330)	-0.0856 (0.1167)
Wind Speed Squared	-0.0211 (0.0100)	-0.0372 (0.0297)

a) 24-hr average concentration starting on the previous day
b) The average recirculation in six 12 hour trajectories arriving at First St. 4, 8, 12, 16, 20, and 24 hours into the sampling period. Recirculation index is one with prefect recirculation and zero with no recirculation.
c) Average wind speed during the first hour of the 24-hr sampling period.

Spatial Analysis

- Spatial analysis was conducted for the 2002-2003 period when school and home data were available
  - The relationships between concentrations at schools and the central site were described using regression equations and coefficients of divergence (COD)
- Daily spatial variability across Fresno was evaluated using 22 days in the dry season of 2002 when 6 to 8 samples per day were available.
  - Daily coefficients of spatial variations (CV)
  - Daily maps and 22-day average maps
- Land-use regression was used to assess the contribution of potential sources to the observed spatial patterns. Sources considered were:
    - Urban parks and Schools
    - Cropland, grasslands, forests, and pastureland
    - Confined animal feeding operations (CAFO)

Spatial Analysis

- Spatial correlations between daily endotoxin concentrations at First St. and schools in Fresno were quite variable:
  - In the dry season, r^2 ranged from 0.26 at Easterby School (SE) to 0.74 at Cole School (NE).
  - In the cool season, spatial correlations tended to be higher because levels were low and more uniform
  - Year-round data from the longest operating school site, Fremont, were higher and reasonably corrected with those at Fresno First Street

$$\text{Endo}_{\text{Fremont}} = 1.03 * \text{Endo}_{\text{First St}}. + 0.48 \quad (r^2 = 0.75)$$

Spatial Analysis

- The coefficient of divergence (COD) for daily endotoxin for site pairs which involve First Street range from 0.14 to 0.40
  - These are low values and indicate fairly large spatial differences (33% to 133% on average).
- Endotoxin levels at the individual homes were higher and weakly associated with the First Street levels
  - $r^2 = 0.36$ in the dry season; $r^2 = 0.24$ in the cool season.
  - $Endo_{Residences} = 0.77 * Endo_{First\ St}. + 1.97$ (dry season)
- Home endotoxin levels were associated more strongly with levels at most schools, including their neighborhood school, than those at First Street.

Relationships Between Daily Endotoxin at Fresno 1st St., Schools, & Residences

Independent	Dependent Site	Season	Slope	Intercept	N	R^2	COD
First Street	Bullard Talent	Dry	0.86**	0.50	35	0.45	0.19
	Burroughs	All	0.92**	0.44	36	0.80	0.15
		Cool/rainy	0.91**	0.09	11	0.94	0.14
		Dry	0.74**	1.39	25	0.55	0.15
	Cole	All	1.31**	0.13	29	0.43	0.39
		Cool/rainy	0.91*	0.17	18	0.38	0.38
		Dry	2.42*	-0.08	11	0.74	0.40
	Copper Hills	Cool/rainy	0.59**	0.2	27	0.56	0.31
	Easterby	Dry	0.44*	1.8	28	0.28	0.36
	Forkner	Cool/rainy	0.67**	0.07	31	0.67	0.28
	Fremont	All	1.03**	0.48	264	0.75	0.27
		Cool/rainy	1.14**	0.14	129	0.62	0.31
		Dry	0.87**	1.34	135	0.57	0.23
	Holland	Cool/rainy	0.57*	0.39	31	0.26	0.26
	Miramonte	Dry	0.90**	0.39	37	0.56	0.18
	Viking	Dry	0.69**	1.35	57	0.51	0.17
	Individual Residences	All	0.98*	0.72	320	0.55	#
		Cool/rainy	0.79*	0.52	166	0.24	#
		Dry	0.77*	1.97	154	0.36	#

* p <0.05

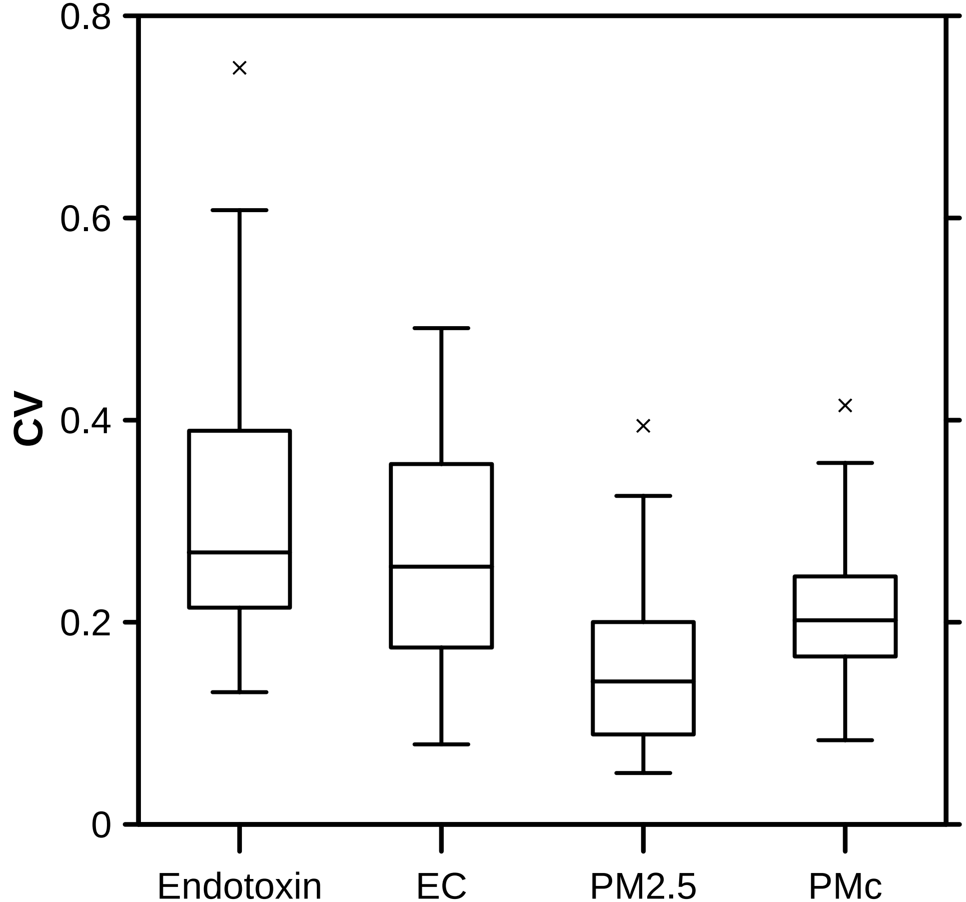
** P<0.01

insufficient data

Spatial correlation (r) between daily endotoxin, PMc, EC, and PM2.5 concentrations at First Street central site and those at Fresno schools based on year-round data

School	Endotoxin	PM_c Mass	EC	$PM_{2.5}$ Mass
Bullard Talent	0.67	0.76	0.98	0.92
Burroughs	0.89	0.95	0.94	0.99
Cole	0.66	0.57	0.97	0.89
Copper Hills	0.75	0.90	0.84	0.87
Easterby	0.53	0.88	0.66	0.93
Forkner	0.82	0.73	0.72	0.84
Fremont	0.87	0.79	0.97	0.97
Holland	0.51	0.98	0.94	0.98
Miramonte	0.75	0.81	0.90	0.84
Viking	0.71	0.92	0.92	0.99
Average	0.72	0.73	0.88	0.92

Daily Spatial Coefficients of Variation (CV) of Endotoxin and Other Pollutants

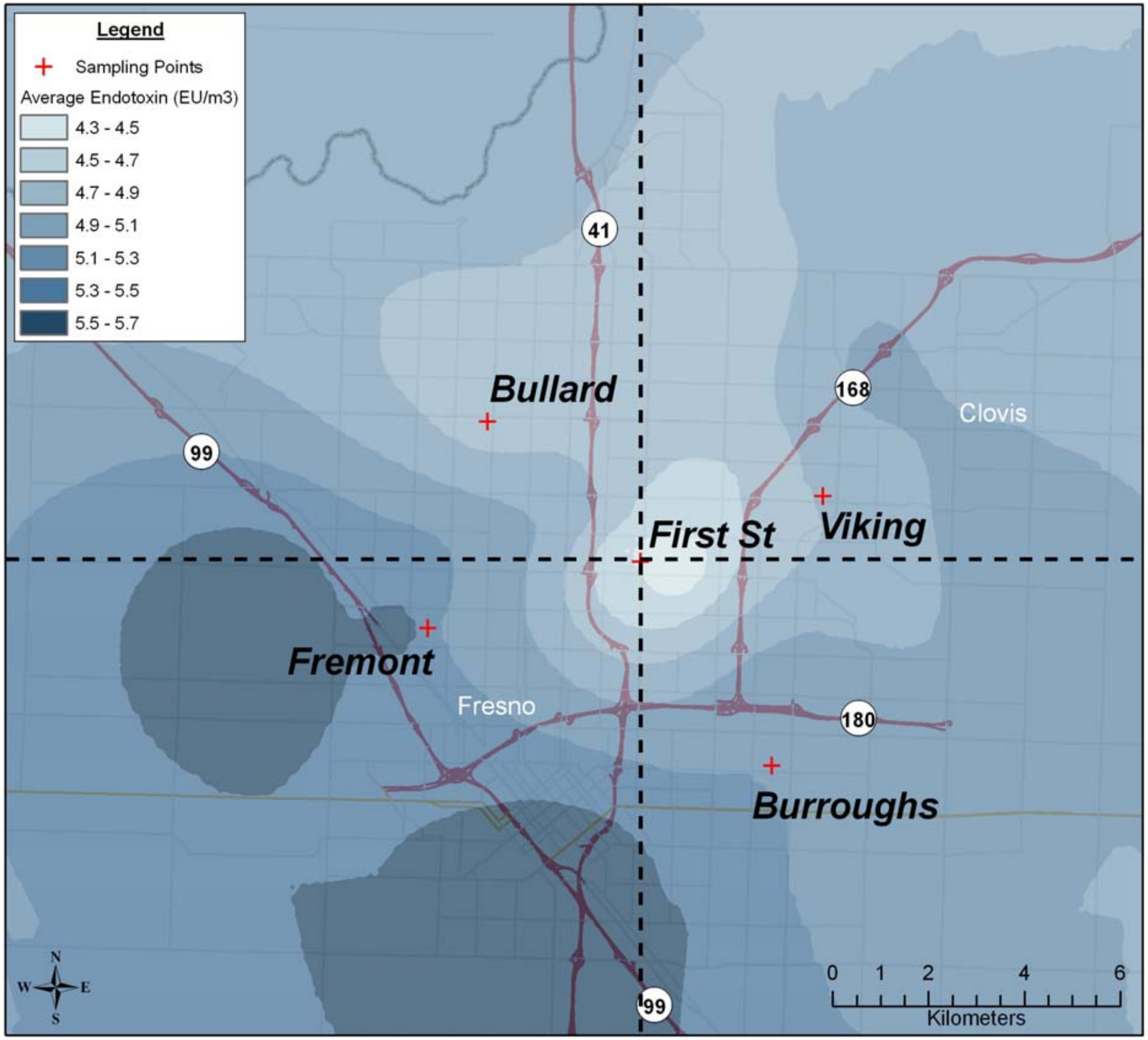


Data show that Endotoxin is the most spatially heterogeneous of the group

Box-whisker plots of the daily spatial coefficients of variation (CV) for endotoxin, elemental carbon (EC), PMc, and $PM_{2.5}$ on the 22 dry season days 6 endotoxin measurement **locations**

Endotoxin Spatial Pattern

Warm Season Average



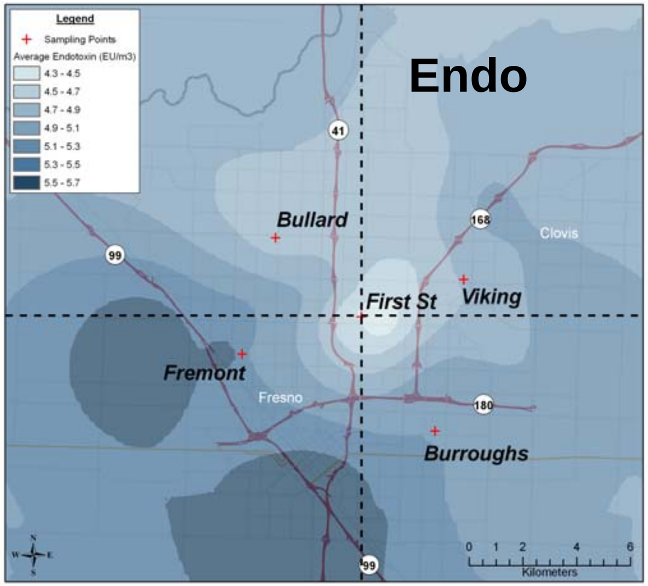
Spatial Pattern

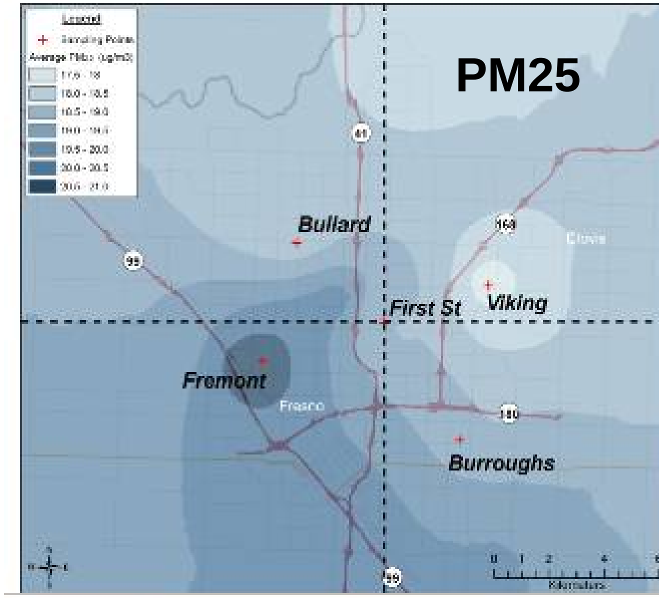
- The spatial pattern for endotoxin indicates:
  - Low concentrations at the First St. (4.3 EU/m^3)
  - Somewhat low concentrations in the urban core north of the First Street site.
  - The average levels are high (5.3 to 5.7 EU/m3) in the areas west and south of Fremont and Burroughs School.
- The high endotoxin area is mostly west of Highway 99, where the land use is primarily agricultural and includes CAFO.
  - Given the predominant northwesterly wind flow in the region, this pattern suggests that agricultural sources, located to the west and southwest of Highway 99 generate the highest ambient levels in the region.

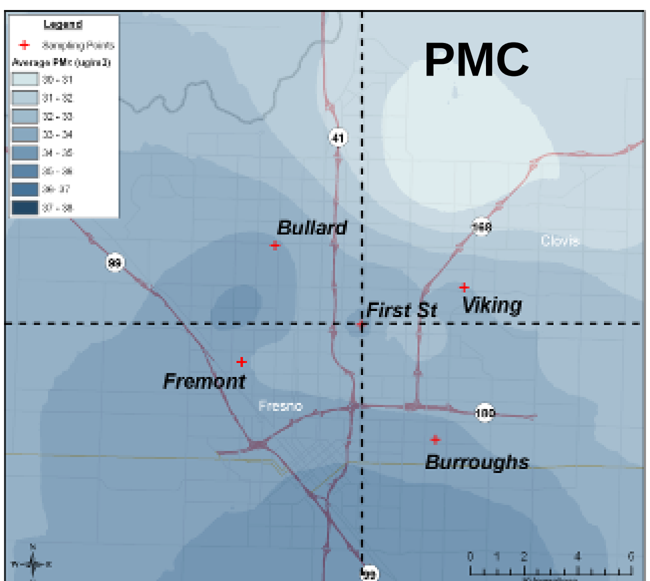
Potential Sources

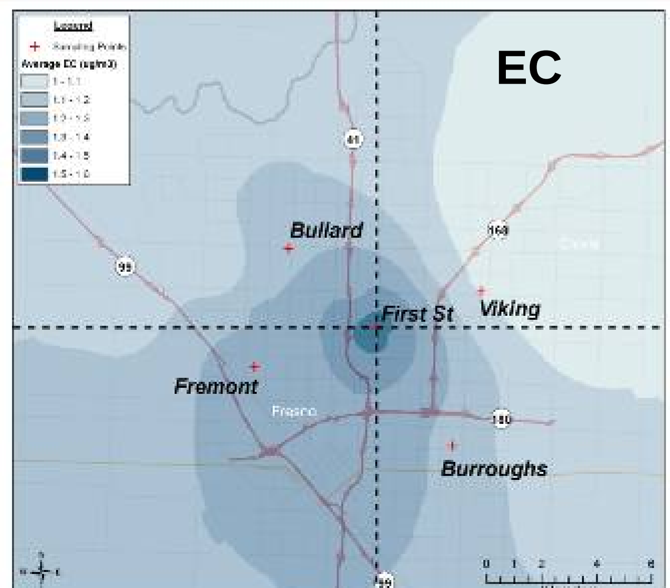
- There is no emissions inventory for endotoxin
- Land-use regression analysis indicated:
  - CAFOs, pastureland, and cropland within 20 km radius buffers of monitored locations explained 41%, 41%, and 36% of the variance in average dry season endotoxin concentrations, respectively.
  - Forest, grassland, urban parks, and school land cover were not associated with endotoxin
  - These results corroborate the suspected association with agricultural land use and CAFOs.

Average Endotoxin, PM2.5, PMc, and EC Concentrations During The Warm Season



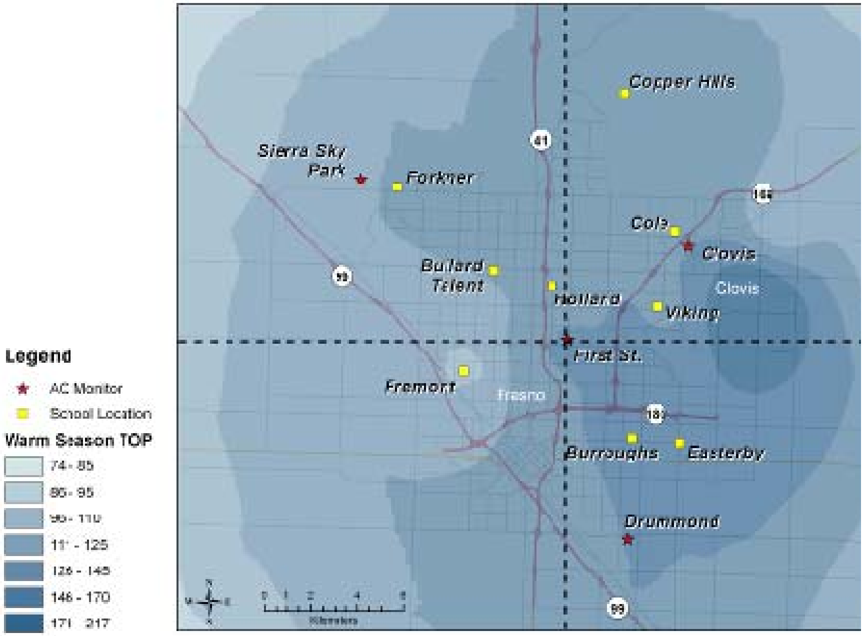






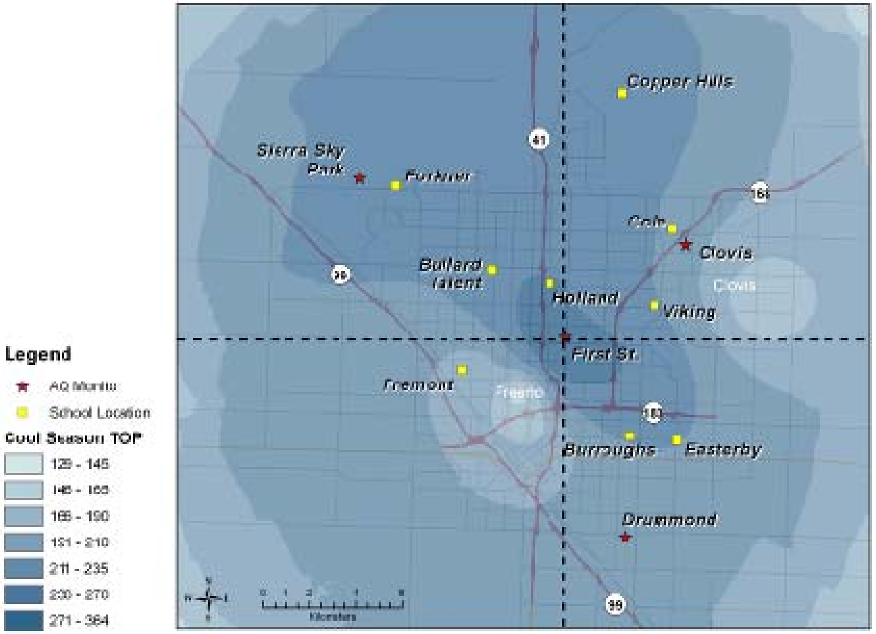
Total Pollens

Warm Season Average



Range: 74 to 217 grains/m3

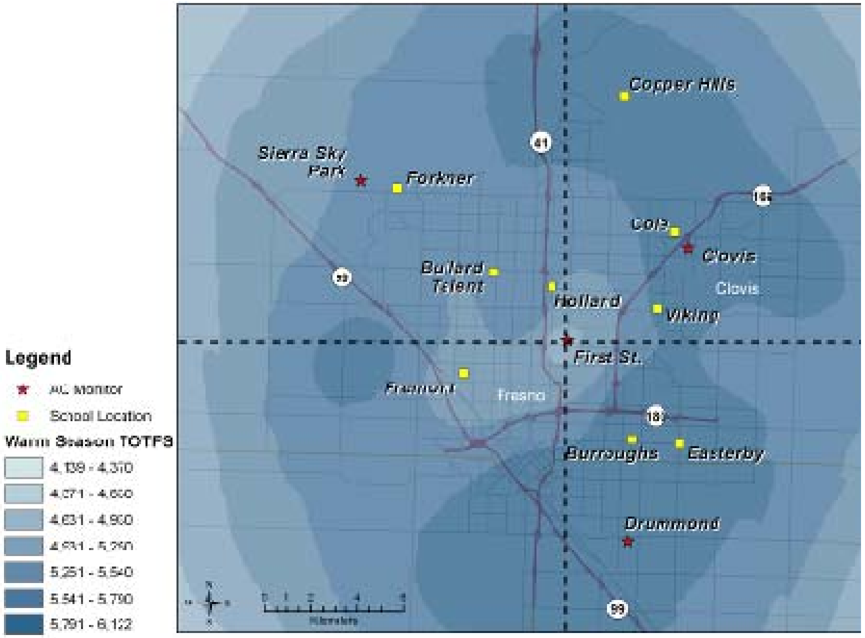
Cool Season Average



Range: 129 to 364 grains/m3

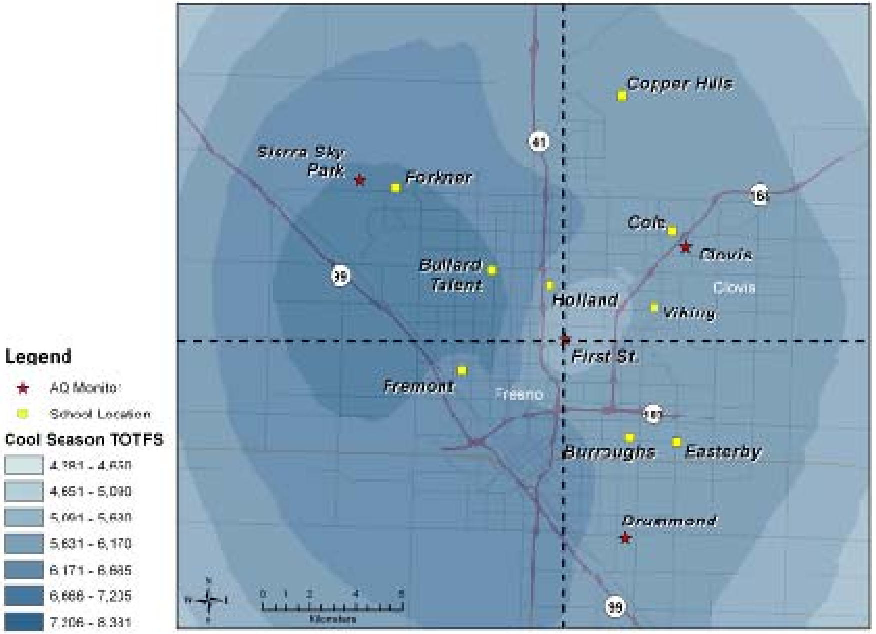
Total Fungal Spores

Warm Season Average



Range: 4,139 to 6,122 spores/m3

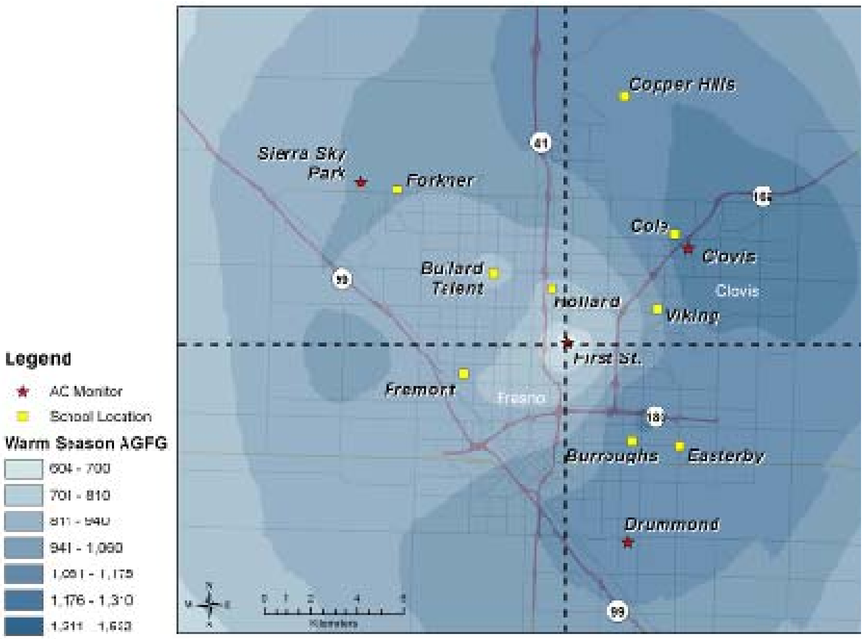
Cool Season Average



Range: 4,281 to 8,331 spores/m3

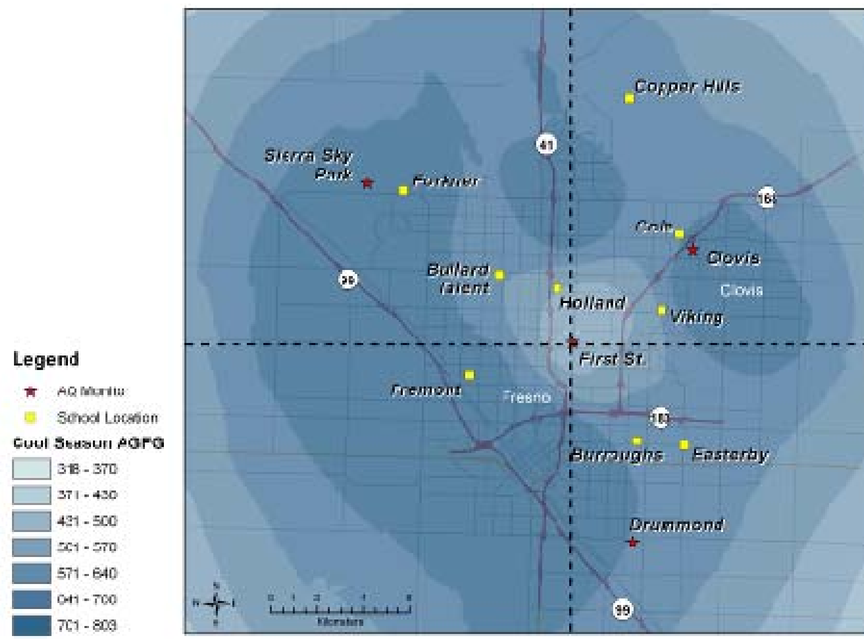
Agricultural Fungal Spores

Warm Season Average



Range: 604 to 1,532 spores/m3

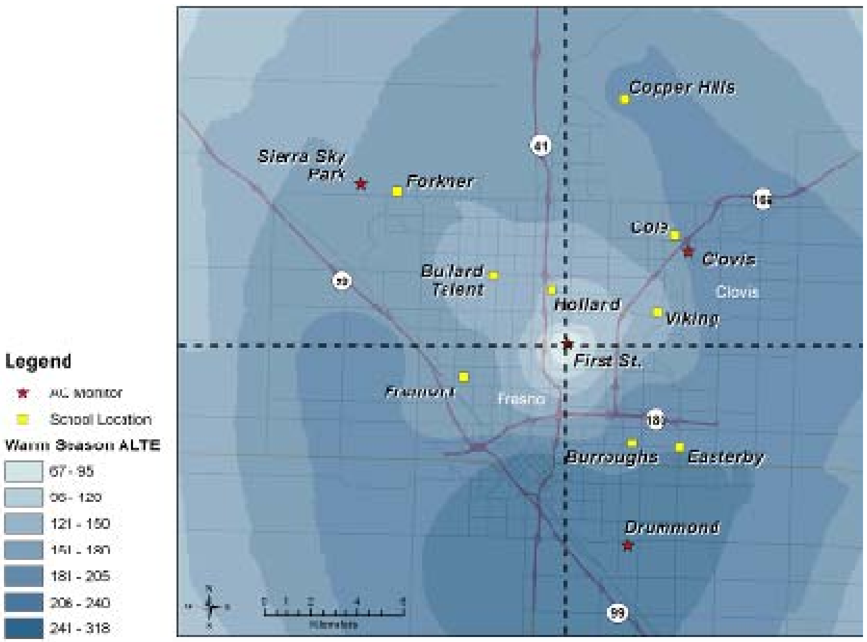
Cool Season Average



Range: 318 to 803 spores/m3

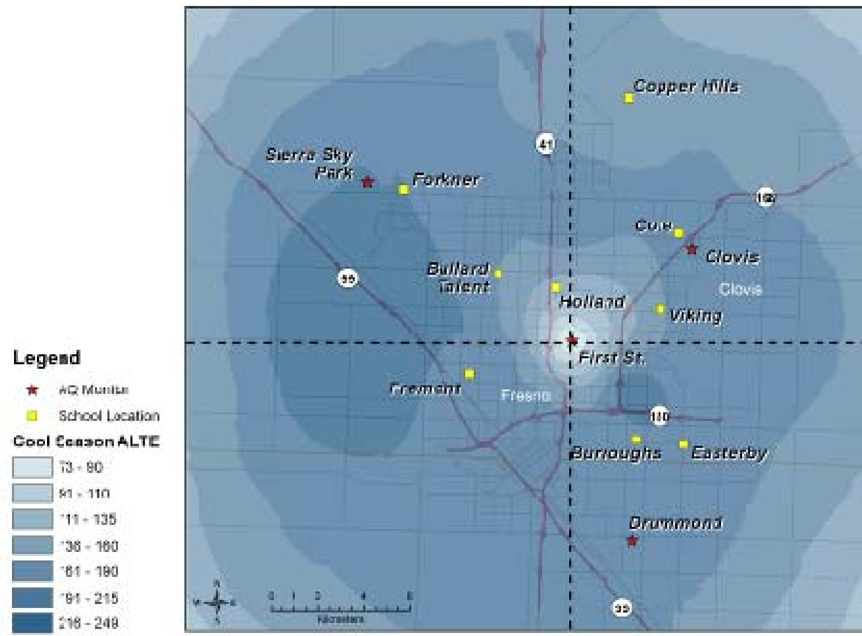
Alternaria

Warm Season Average



Range: 67 to 318 spores/m3

Cool Season Average

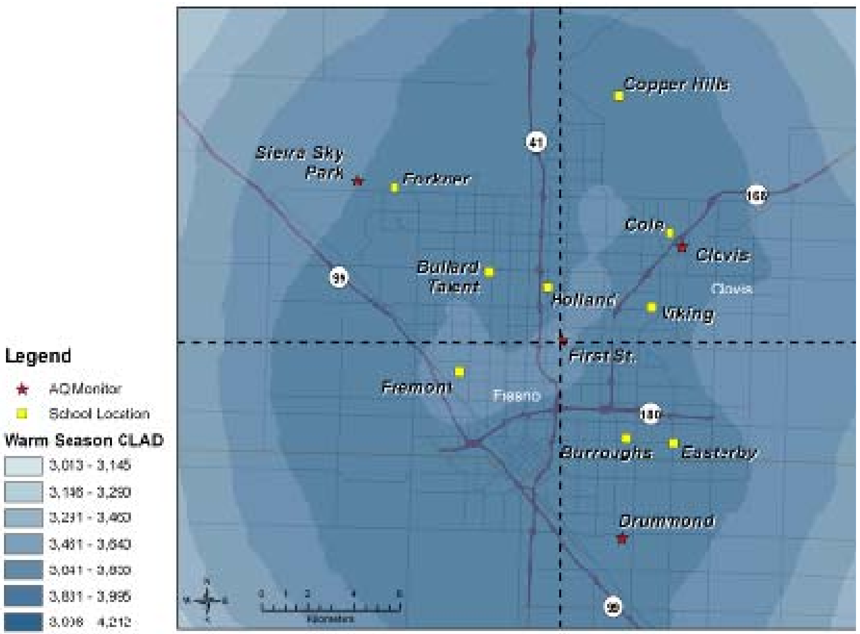


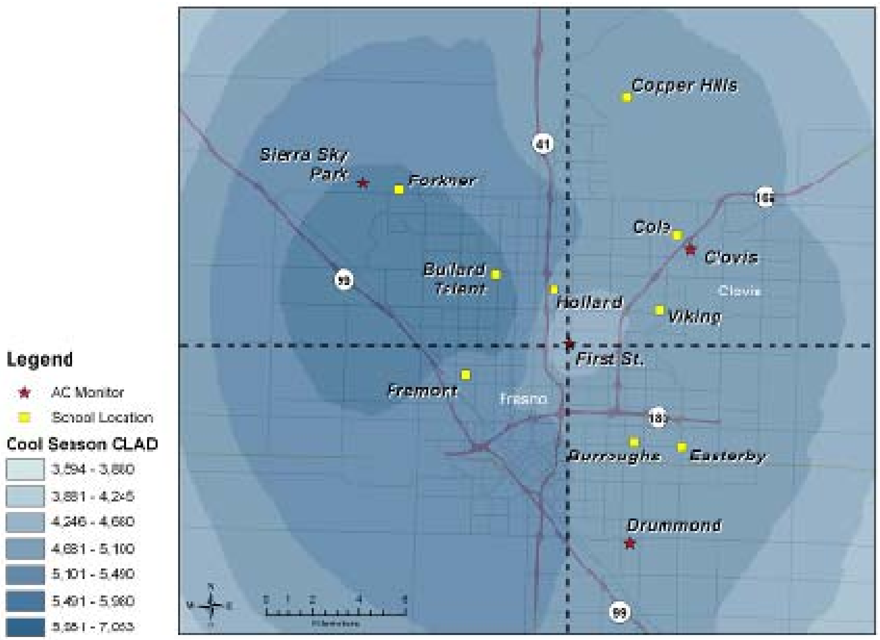
Range: 73 to 249 spores/m3

Cladosporium

Warm Season Average

Cool Season Average



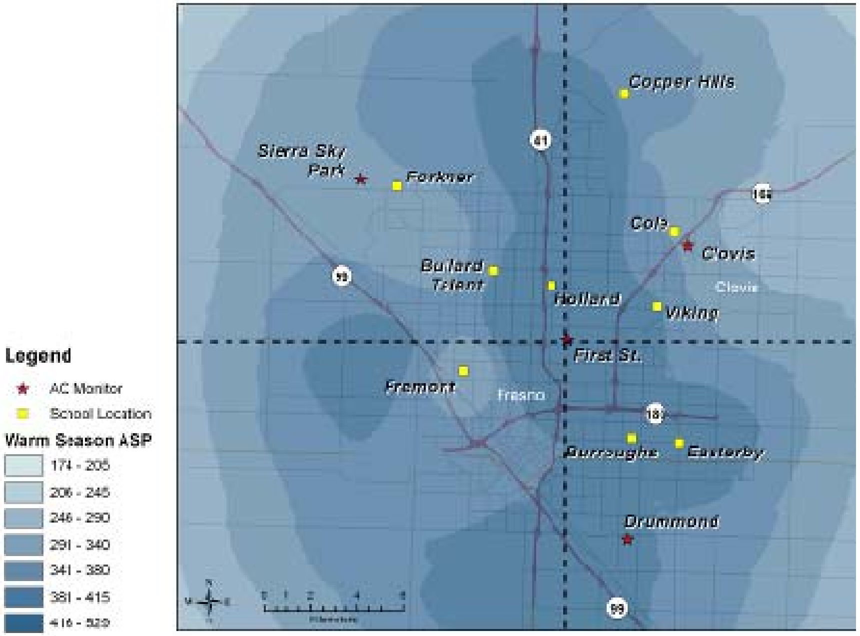


Range: 3,013 to 4,212 spores/m3

Range: 3,594 to 7,053 spores/m3

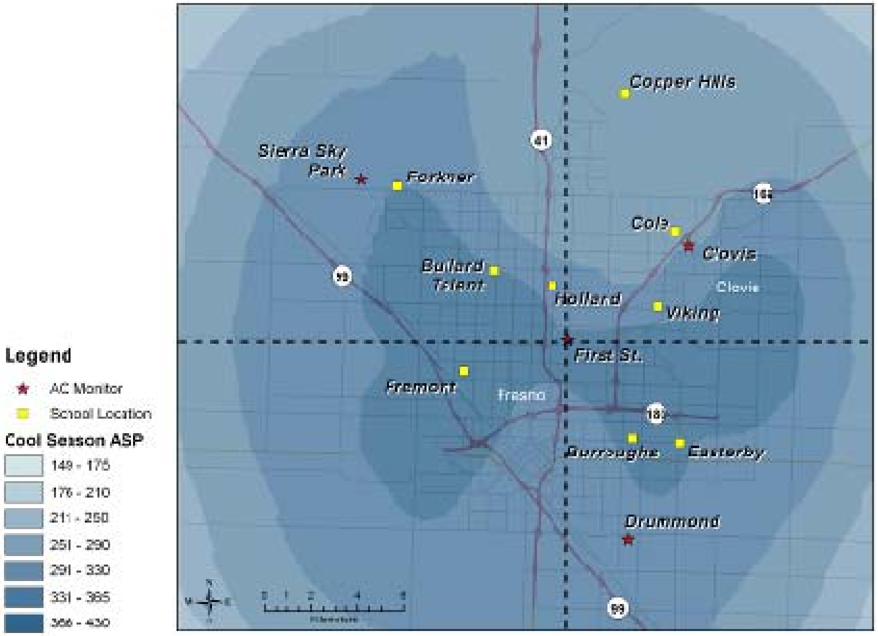
Aspergillus & Penicillium

Warm Season Average



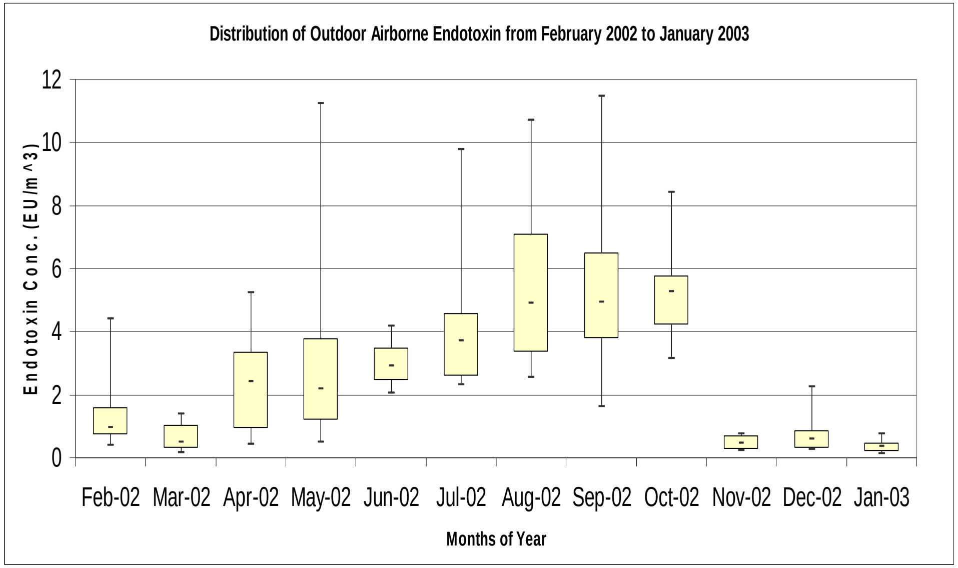
Range: 174 to 529 spores/m3

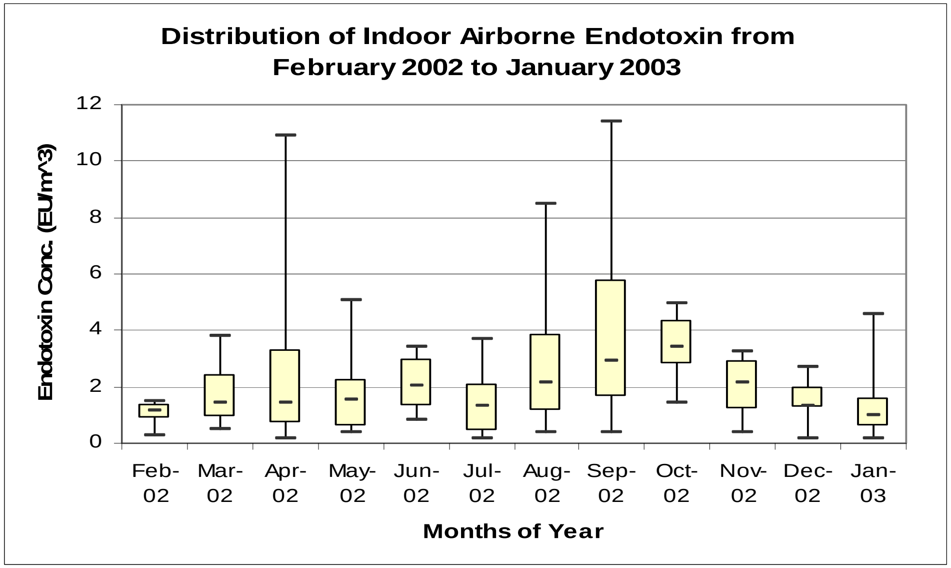
Cool Season Average

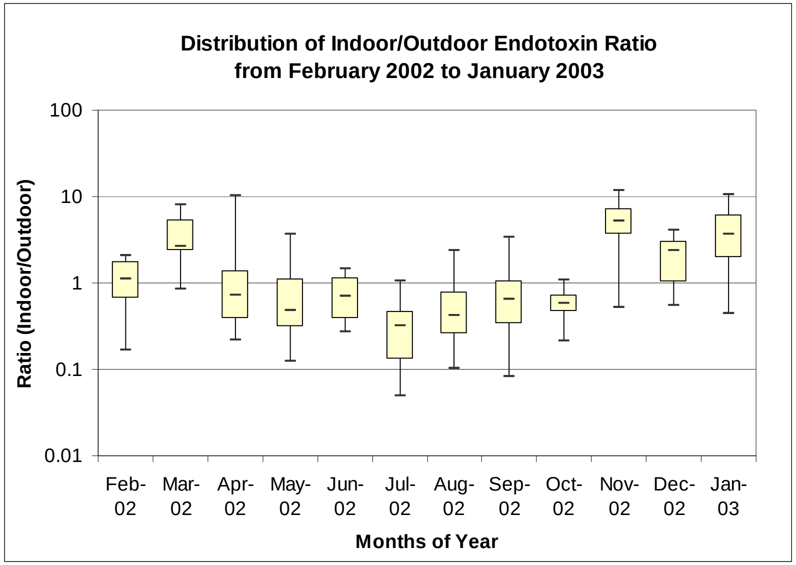


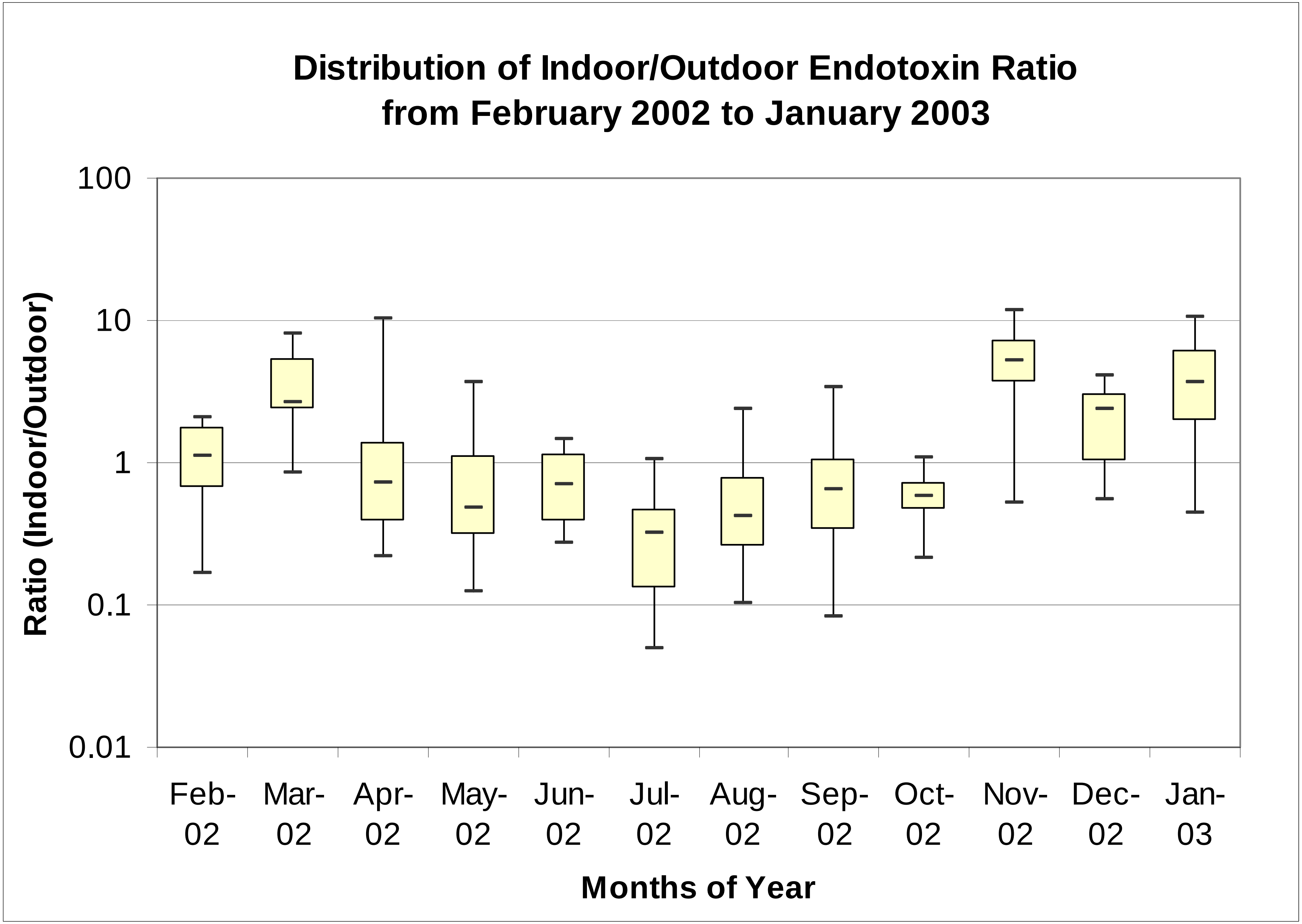
Range: 149 to 430 spores/m3

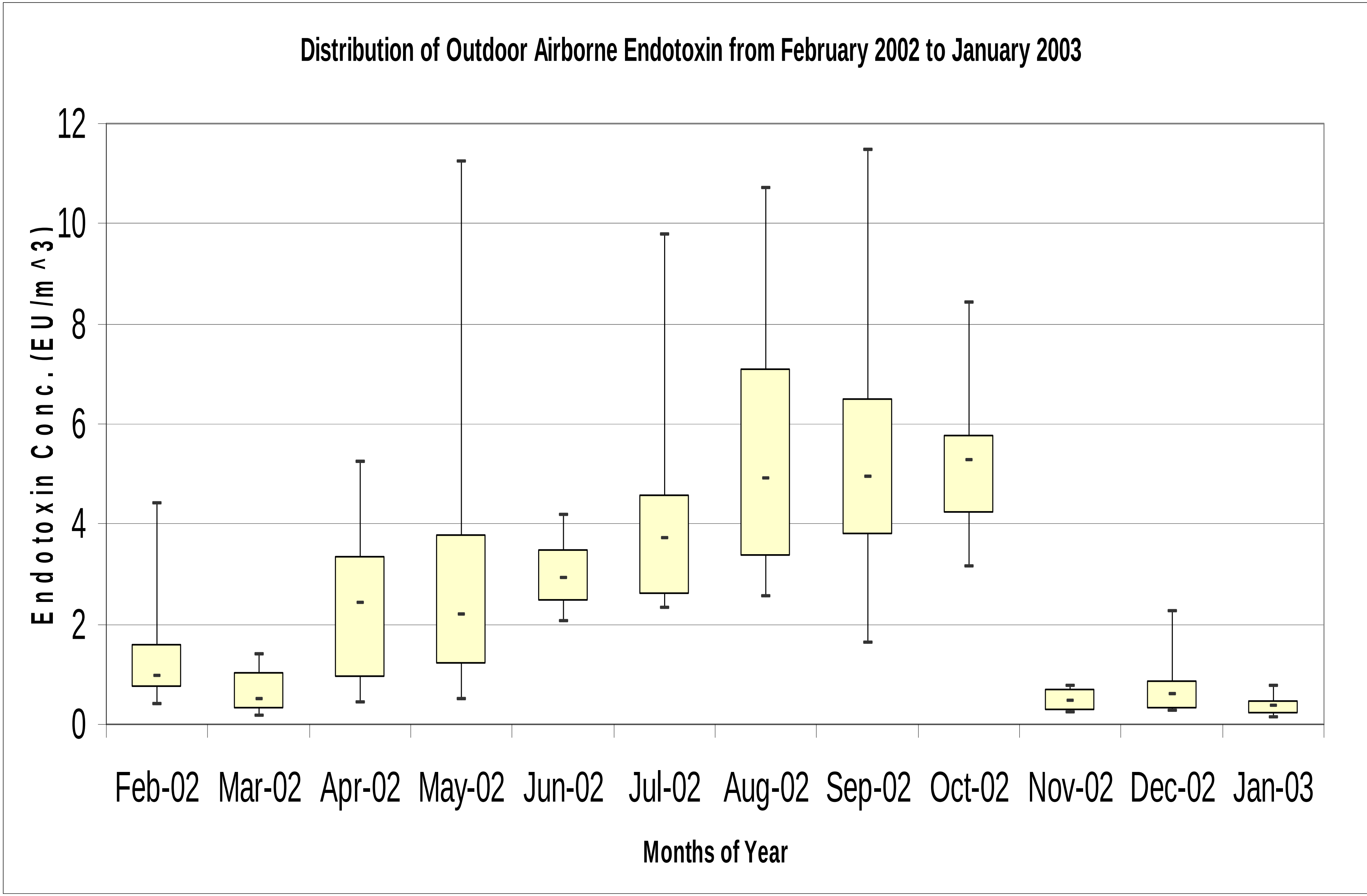
Indoor Endotoxin

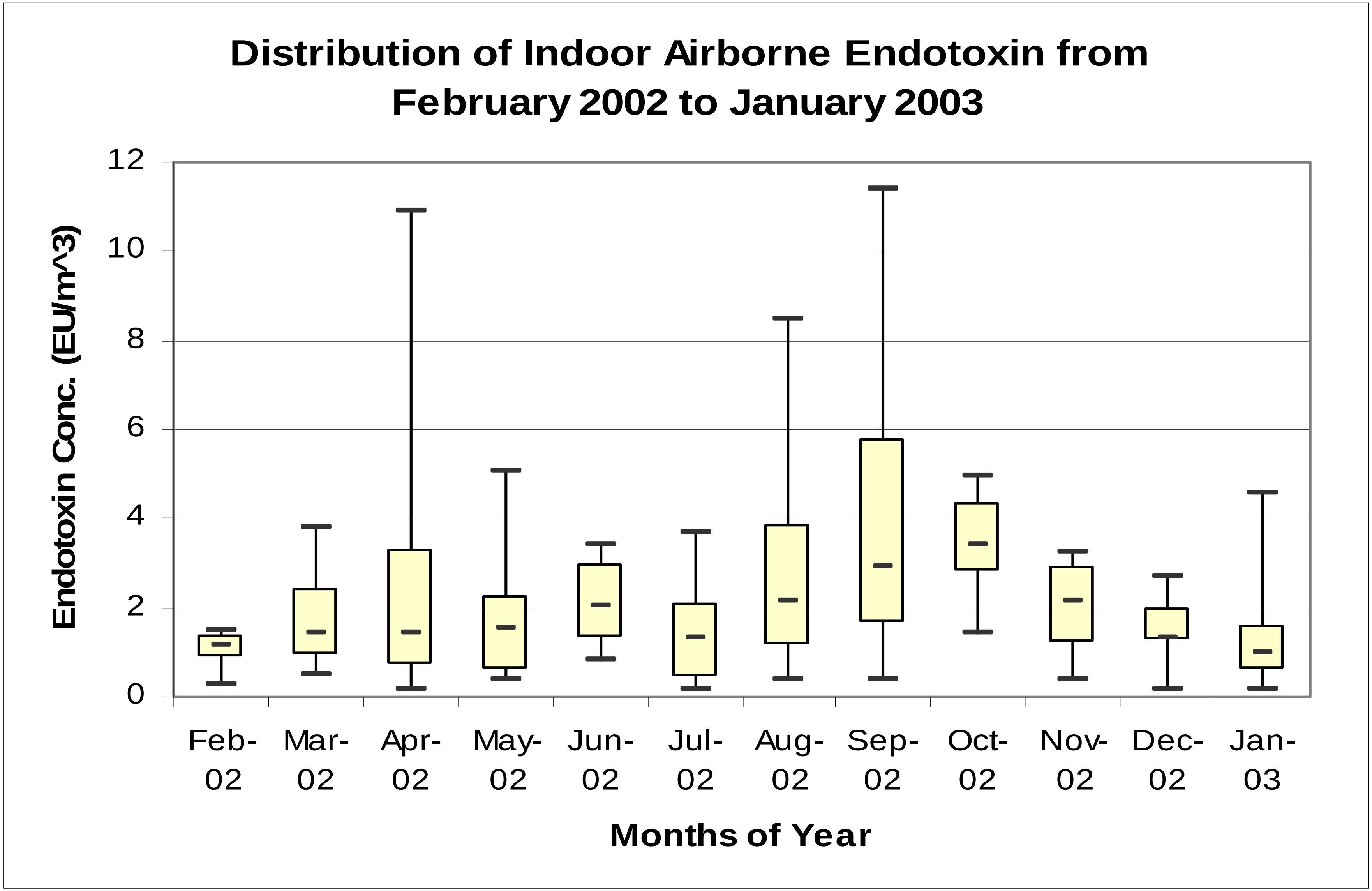







Distribution of Indoor/Outdoor Endotoxin Ratio
from February 2002 to January 2003
100
10
1
0.1
0.01
Ratio (Indoor/Outdoor)
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Months of Year


Distribution of Outdoor Airborne Endotoxin from February 2002 to January 2003
Endotoxin Conc. (EU/m^3)
0
2
4
6
8
10
12
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Months of Year



Distribution of Indoor Airborne Endotoxin from February 2002 to January 2003
Endotoxin Conc. (EU/m^3)
0
2
4
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Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Months of Year

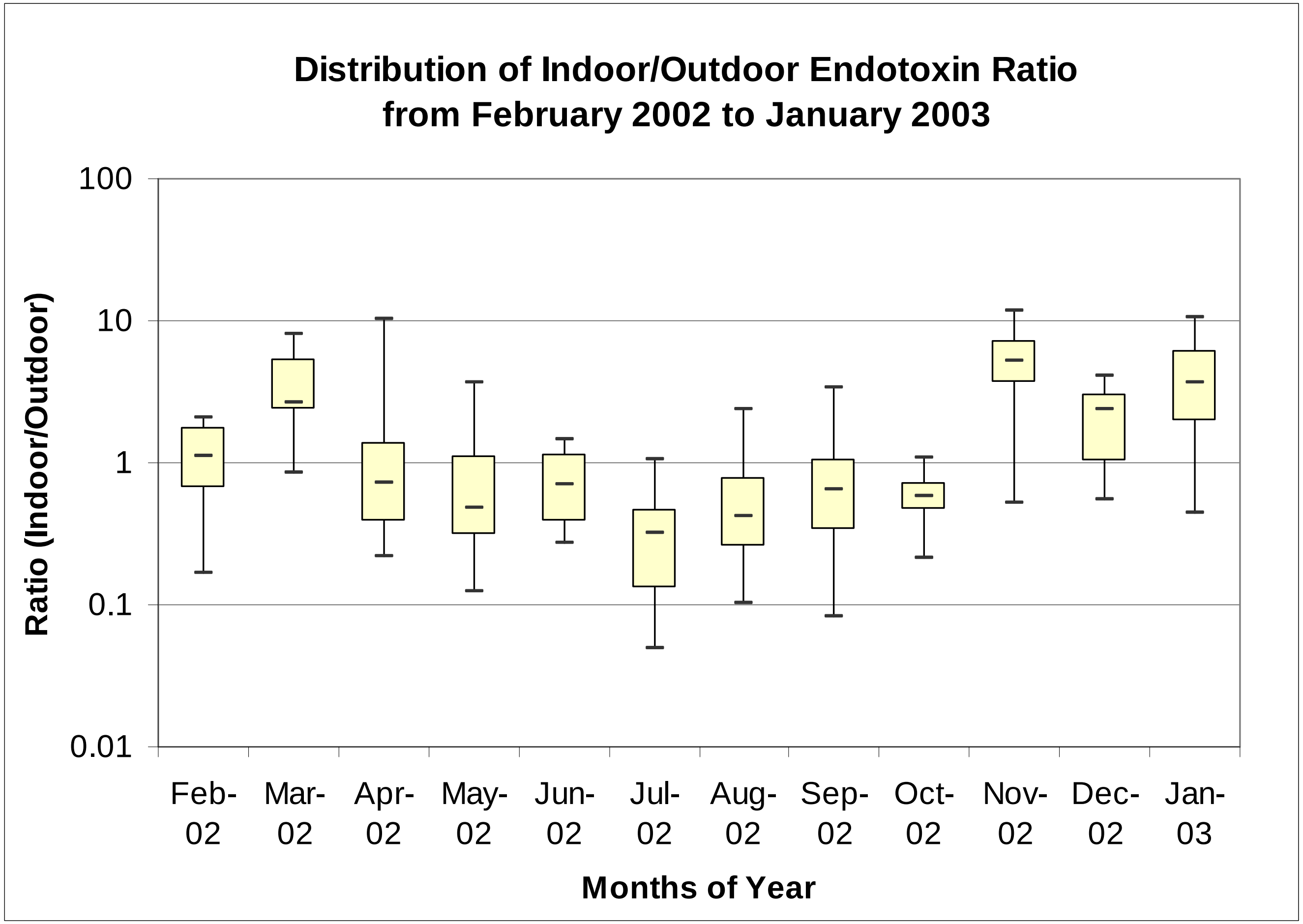
Conclusions - Endotoxin

- Like most air pollutants, daily ambient concentrations of endotoxin are influenced heavily by meteorology in addition to sources.
- In Fresno, which is surrounded on three sides by agricultural land, endotoxin has a spatial distribution that is associated with proximity to CAFOs, pastureland and cropland, and differs from $PM_{2.5}$ (a regional pollutant) and EC (marker of traffic in our study area) but is somewhat similar to PMc with which it is moderately correlated.
- These data support the need to evaluate the spatial and temporal variability of endotoxin concentrations, rather than relying on a few measurements made at one location in studies in which health effects associated with PM and its components are being evaluated.

Take Away Message

- Bioaerosols are different from conventional pollutants
- Bioaerosols have there own temporal and spatial patterns
- Not all bioaerosols are alike: Endotoxin, pollen, and fungal spores have their own seasonal and spatial patterns.
- Future studies should include ambient bioaersol measurements and assessment of bioaerosol emissions to support evaluation of their health impacts

Indoor/Outdoor Ratios



FACES

- The Fresno Asthmatic Children's Environment Study (FACES) was designed to assess the effects of ambient air pollution on the natural history of children with asthma.
- As part of FACES, the temporal and spatial distributions of ambient endotoxin over several years in Fresno, CA were characterized.
  - This analysis examines the influence of meteorology on daily concentrations and of potential sources on its spatial distribution.

Measures of Spatial Variations

- **Coefficient of Divergence (COD) for Comparison of Two Locations**

$$\overline{COD_{ab}} = \sqrt{\frac{1}{ndays}\sum_{i=1}^{ndays}\left(\frac{C_{ia}-C_{ib}}{C_{ia}+C_{ib}}\right)^2}$$

where C_{ia} and C_{ib} are the concentrations at stations “a” and “b” on the ith day, respectively.

- **Coefficient of Variation for Comparison of All Locations**

$$\overline{CV} = \frac{1}{ndays}\sum_{i=1}^{ndays} CV_i$$

where CV_i is the coefficient of variation of the concentrations measured at all locations on the ith day.