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Differences in detection frequency as a bioaerosol data criterion for evaluating suspect fungal contamination

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ABSTRACT

With no health based numerical standards for evaluating airborne fungal spore data, sampling for environmental fungal spores is conducted by a variety of non-standardized methods to test the hypothesis of similarity between indoor and outdoor airborne fungal populations. Numerically based criteria, to include fixed fungal spore levels and various ratios, have been utilized to assist in interpreting data, but the lack of standards also precludes verification relative to a "true" airborne concentration. However, using the bootstrap version of Monte Carlo analysis (BMC), the false negative and false positive error rates of criteria can be approximated by the frequency indoor and outdoor fungal data sets are correctly or incorrectly determined to be similar. An alternative criterion for airborne fungal data analysis, using differences in frequency of detection (Δf_d) greater than the combined median, treats individually detected fungal types as separate contaminants; the mathematical description of differences between indoor and outdoor fungal populations is the calculated probability that Δf_d greater than actually observed could randomly occur. Culturable and spore trap sampling data at various sites from 2004 to 2008 provided a source of data by which to test the performance of Δf_d. Probability values estimated via BMC were close approximations to direct calculations based on Δf_d, and strongly support Δf_d as a criterion. As a building performance indicator, analysis via BMC demonstrates the appropriate measure for differences in "mold levels" is defined by the frequency with which a particular type of mold is detected relative to the combined median.

1. Introduction

While the proliferation of fungi (mold) in an indoor environment is generally recognized as an important public health issue, the environmental, public health, insurance, legal, and building industries struggle with the lack of health based numerical "levels" of fungal spores (in air or dust) by which a building can be assessed. Part of the evaluation of suspect contamination in a building often results in monitoring/testing for environmental fungal spores as intuitively, the acceptability of an environment is gauged by measured levels of contaminants. (Other parameters for fungal contamination such as mycotoxins may also be relevant as indicators of a problematic building. However, the discussion herein is restricted to the more common practice of sampling and evaluation of airborne fungal spores.) This approach is primarily driven by the traditional industrial hygiene/public and environmental health model, in which it is assumed contaminants are able to be identified and measured in a consistent way, and levels considered to pose various levels of risk can be derived. However, there are important differences in how environmental fungal data is derived relative to more traditionally encountered contaminants. There is no standardization in the sampling and analysis for environmental fungi and there is no general agreement on whether the appropriate target "contaminant" consists of total fungal spores or spores of individual (or select) species. Similarly, as reflected in a variety of studies and industry references, the appropriate metric for evaluating data is total spores, individual fungal types, or any one of a number of ratios or indices relating groups of fungi or individual fungal types to others is not consistent [1–15]. With no agreement as to the precise identity, characterization, or quantification of the "contaminant" in question, the requisite studies to establish meaningful numerical exposure levels for airborne fungi with any scientific basis are lacking.

In the absence of health based numerical standards, a relative standard is widely utilized, in which it is assumed that an acceptable indoor environment should exhibit similarity to airborne fungi in the local outdoor (or a suitable reference) environment. Conversely, a difference between indoor and outdoor fungal

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Table 1
Calculating significance.

		Is 5/8 indoors and 2/9 outdoors “significant”?								
Frequency		0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8
	Probability	0.0143	0.0802	0.1967	0.2754	0.2409	0.1349	0.0472	0.0094	0.0008
0/9	0.0084	0.0001	0.0007	0.0017	0.0023	***0.0020***	***0.0011***	***0.0004***	***0.0001***	***0.0000***
1/9	0.0531	0.0008	0.0043	0.0104	0.0146	0.0128	***0.0072***	***0.0025***	***0.0005***	***0.0000***
2/9	0.1489	0.0021	0.0119	0.0293	0.0410	0.0359	0.0201	***0.0070***	***0.0014***	***0.0001***
3/9	0.2430	0.0035	0.0195	0.0478	0.0669	0.0585	0.0328	***0.0115***	***0.0023***	***0.0002***
4/9	0.2551	0.0036	0.0205	0.0502	0.0703	0.0615	0.0344	0.0120	***0.0024***	***0.0002***
5/9	0.1776	0.0025	0.0142	0.0349	0.0489	0.0428	0.0240	0.0084	0.0017	***0.0001***
6/9	0.0833	0.0012	0.0067	0.0164	0.0229	0.0201	0.0112	0.0039	0.0008	0.0001
7/9	0.0250	0.0004	0.0020	0.0049	0.0069	0.0060	0.0034	0.0012	0.0002	0.0000
8/9	0.0044	0.0001	0.0004	0.0009	0.0012	0.0011	0.0006	0.0002	0.0000	0.0000
9/9	0.0003	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000

For 5/8: $p = ({}_nC_x)(P^x)(Q^{n-}x) = (8!/5!3!)(0.412)^5(0.588)^3 = 0.1349$
For 2/9: $p = ({}_nC_x)(P^x)(Q^{n-}x) = (9!/2!7!)(0.412)^2(0.588)^7 = 0.1489$

Total probability of cells with Δf_d greater than $0.403 = 0.0392$ (bolded and italicized cells) = Fisher's ASL. Probability that “levels” indoors greater than outdoors $= 1 - 0.0392 \sim 0.96$.

populations is an indicator of a building promoting fungal growth. As a result, prominent industry guidance publications recommend environmental fungal sampling for building investigations, when appropriate, be conducted as a hypothesis test [16–19]. Under the “comparative standard” model, data is collected and analyzed to determine consistency with the a priori assumption of similarity of the indoor (test zone) and outdoor (or similar reference zone) fungal populations. However, hypothesis testing as an analytical tool inherently incorporates the concepts of error rate and significance, which creates a definitional problem as a result of the industrial hygiene/public and environmental health model from which the majority of published studies emerge. “Error rate” as

Table 2
Outdoor fungal spores (Site C).

Fungal type (genus/species)	AM							PM								
Acremonium													9			
Acrodontium					18								36		9	
A. alternate		9	9		9					9			9	9		
A. aranearum										27					71	
A. fumigatus	27	18	9	9	27	9										
A. japonicus					9											
A. niger	18	18		9	9											
A. ochraceus				9												
A. sydowii													9			
A. versicolor				9												
Basidiomycetes	36		45				18									
B. bassiana			9													
Botrytis											9					
C. cladosporioides	125	161	134	205	205		27		18	63	18		18	18	18	9
E. nigrum				9									9			
E. jeanselmei									9							
Fusarium					18											
F. solani				9												
P. brevicompactum		18	9	9												
P. chrysogenum		9														
P. citrinum			9		9									9		
P. commune					18											
P. decumbens	9	36	9	9	27											
P. glabrum					18											
P. lividum		9	9													
P. mineoluteum	18	18	9	18	9											
P. oxalicum		18	27		9					9						9
P. sclerotiorum					9											
P. spinulosum		9														
P. variable	9		9	27												
P. chartarum	9	9	9													
R. stolonifer				9												
Rhinocladella										9	9					
R. mucilaginosa			36									9				
S. constrictum											9					
Sterile fungi	18	63	36		36	54	18	54	45	18	71	45	54	27	18	27
Thysanophora							9									
Yeasts						9	9			9	27	18			9	18
Total CFU/m^3	269	395	368	331	430	72	81	54	72	144	143	72	144	63	125	63
TIME	09:10	09:20	09:42	09:53	10:50	11:15	11:41	01:09	01:27	01:46	02:02	02:18	02:32	02:46	03:00	03:13