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Resident cleanup activities, characteristics of flood-damaged homes and airborne microbial concentrations in New Orleans, Louisiana, October 2005

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Abstract

Background: Flooding in the greater New Orleans (GNO) area after the hurricanes caused extensive mold growth in homes resulting in public health concerns.
Objectives: We conducted an environmental assessment of homes to determine the extent and type of microbial growth.
Methods: We randomly selected 112 homes, stratified by water damage, and then visually assessed mold growth. Air samples from a subset of 20 homes were analyzed for culturable fungi, fungal spores, and markers of mold ((1→3, 1→6)-β-D-glucans) and bacteria (endotoxin).
Results: Visible mold growth occurred in 49 (44%) homes; 18 (16%) homes had >50% mold coverage. Flood levels were >6 ft at 20 (19%), 3–6 ft at 20 (19%), and <3 ft at 28 (26%) homes out of 107; no flooding at 39 (36%) homes. The residents spent an average of 18 h (range: 1–84) doing heavy cleaning and of those, 22 (38%) reported using an N-95 or other respirator. Visible mold growth was significantly associated with flood height ⩾3 ft and the predominant fungi indoors were *Aspergillus* and *Penicillium* species, which were in higher concentrations in homes with a flood level ⩾3 ft. Geometric mean (GM) levels of endotoxin were as high as 40.2 EU/m^3, while GM glucan levels were as high as 3.5 μg/m^3 even when flooding was ⩽3 ft.
Conclusions: Based on our observations of visible mold, we estimated that elevated mold growth was present in 194,000 (44%) homes in the GNO area and 70,000 (16%) homes had heavy mold growth. Concentrations of endotoxin and glucans exceeded those previously associated with health effects. With such high levels of microbial growth following flooding, potentially harmful inhalation exposures can be present for persons entering or cleaning affected homes. Persons exposed to water-damaged homes should follow the CDC recommendations developed following the 2005 hurricanes for appropriate respiratory precautions.
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Keywords: Mold; Hurricane; Flooding; Glucan; Endotoxin

1. Introduction

Hurricane Katrina made landfall on August 29, 2005, as a category 3 hurricane with the center of the eye hitting Plaquemines Parish, Louisiana (Fig. 1). Within 4 weeks, on September 24, 2005, Hurricane Rita made landfall near the

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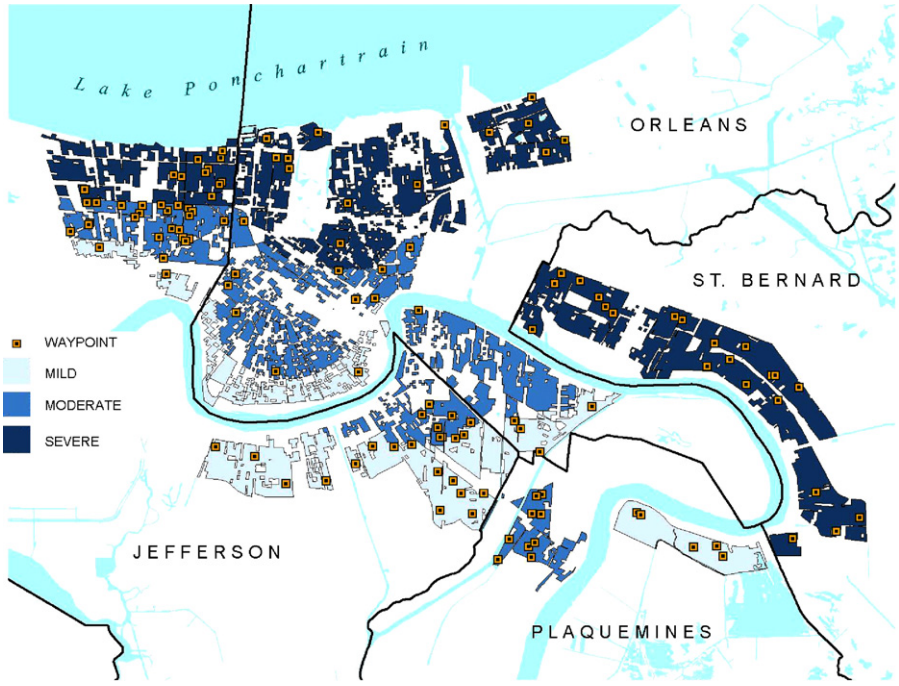

Fig. 1. Map of four parish area with randomly generated waypoints (orange) used as starting points to identify participants by damage strata—greater New Orleans area, Louisiana, October 2005. [a]Census blocks were classified into three damage strata (mild—light blue, moderate—medium blue, and severe—dark blue) on the basis of Federal Emergency Management Agency flood and damage assessment maps.

Texas–Louisiana border. The storm surge, rainfall, and high winds associated with these hurricanes caused extensive damage to Orleans, Jefferson, Plaquemines, and St. Bernard Parishes, Louisiana. Over 80% of New Orleans was flooded for more than 2 weeks after the levee system throughout the city was breached (Knabb et al., 2005). The duration and extent of flooding as well as the number of structures flooded and warm temperatures led to massive mold growth throughout the area after flood waters receded (Centers for Disease Control and Prevention (CDC), 2006a).

The health consequences of residential exposure to high concentrations of fungal and bacterial agents or specific fungal genera after floods are not well characterized. However, the Institute of Medicine (IOM) report entitled *Damp Indoor Spaces and Health* concluded that exposures to mold are associated with respiratory illnesses and that immunocompromised persons are at risk for fungal colonization and opportunistic infections (IOM, 2004). Recent parallels to the degree of flooding seen in post-hurricane New Orleans occurred in 1997 in Grand Forks, North Dakota, and in 1999 in North Carolina after Hurricane Floyd (National Institute for Occupational Safety and Health (NIOSH), 1999). In North Carolina, there was a reported increase in persons presenting with asthma symptoms and this was postulated to be due to storm-related mold exposure (National Institute for Occupational Safety and Health (NIOSH), 1999). Flooding and subsequent mold growth on the Turtle Mountain reservation in North Dakota was associated with self-reported rhinitis, rash, headaches, and asthma exacerbation (Stock et al., 2005).

Physical evidence (e.g., visual and olfactory) of mold and water-damage in buildings has been associated with an increased risk of respiratory health outcomes among occupants (Bornehag et al., 2001). Air-sampling also is widely used for fungal exposure assessment; however, interpretation of results is difficult as no health-based standards exist. Environmental testing may not be possible when flood damage is wide spread and cleanup needs to begin without the benefit of such information. Some non-specific sampling methods allow estimation of fungal and bacterial biomass by measurement of cell wall or membrane components through biological assays. Two of these components, glucans and endotoxins, have been shown to induce inflammatory responses and are specific microbial agents that may allow accurate determination of exposures in relation to health effects (Martinez et al., 2004).

After the massive flooding in the greater New Orleans (GNO) area, the CDC, Louisiana health officials, and the general public were concerned about possible health effects for residents returning to mold-contaminated buildings (CDC, 2006a). The conditions in the GNO area, reoccupation, and cleanup practices presented opportunities for the residents to be exposed to mold and other particulate matter. Because of these concerns, we conducted an investigation to assess mold exposure in flood-damaged homes. This cross-sectional survey combined subjective assessments of mold contamination (resident questionnaire and visual inspection of homes) with airborne fungal and

endotoxin sampling to evaluate flood damage in residential areas of New Orleans. The objectives were to characterize the type and extent of mold growth in homes, identify predictors of mold growth, describe resident activity in homes, and determine the types of respiratory protection used during cleanup activities.

2. Methods

2.1. Study population

The GNO population for this cross-sectional survey included 440,269 households in four parishes based on 2000 US Census data. Sampling was restricted to blocks with more than 20 housing units yielding 239,949 potential households. Blocks were classified into three strata (mild, moderate, and severe water and wind damage) on the basis of Federal Emergency Management Agency (FEMA) flood and damage maps (Fig. 1). Geographic information system (GIS) mapping software (ArcGIS Version 9.1, ESRI, Redlands, CA, USA) was used to randomly select a specified number of waypoints (defined by latitude and longitude) proportionate for each stratum. A sample size of 88 homes was required to obtain estimates with $\pm 10\%$ precision, an alpha error of 0.05 and an anticipated design effect of 1.0 (loss of power based on stratified sampling design) assuming a prevalence of 65% for flood- or water-damaged homes based on FEMA map estimates. One hundred twenty-six waypoints were randomly selected to include a 30% oversampling for demolished or abandoned homes, which could not be inspected. Global positioning system (GPS) units were used to locate each waypoint as a random starting position to identify the nearest home with someone present that was at or north of the waypoint. Only one household per waypoint was selected.

2.2. Investigation of homes

Between October 22 and 27, 2005 (7 weeks after Hurricane Katrina), a questionnaire on demographics, home occupancy, indoor and outdoor flood levels, roof damage, participation in remediation activities, and respirator use was interviewer-administered to one consenting adult from a home at which someone was present. During the interview, respondents were asked to identify the respiratory protection they had used during cleanup. They were shown a display containing dust and surgical masks as well as respirators used in the GNO area at the time of our survey. Henceforth, dust or surgical mask will be referred to as dust mask. We also conducted a visual inspection of the homes for flood damage and mold growth, selecting rooms based on current occupancy. For homes without overnight residents, both the least and most mold-affected rooms were evaluated. For currently occupied homes, the room where residents slept was also evaluated. Inspectors examined each home using a standard assessment instrument designed for this study to collect information on flood level, mold coverage, estimates of mold confluency on the walls, building type, and building materials.

2.3. Environmental sampling and analysis

The detailed environmental sampling and analysis methodology are presented elsewhere (Rao et al., 2007). During the dates of home investigation (October 22–27, 2005), air samples were collected indoors at a non-random subset of 20 participating homes and outdoors at 11 of those homes. Indoor samples were collected in the "moldiest" room of the residence, as determined by the inspector, using 0.4 μm pore size, 37 mm closed-faced filter pyrogen-free, polycarbonate filters housed in three-piece cassettes (SKC, Eighty-four, PA, USA), sampling at a rate of 3 l/min. Filters were extracted in 5 ml pyrogen-free water with 0.05% Tween 20 in endotoxin-free borosilicate glass tubes. Samples were analyzed for culturable fungi identified to genus (by serial culture dilutions on malt extract agar and incubation at room temperature), fungal spores identified to taxon (by microscopy), endotoxins (by Limulus amebocyte lysate assay; Thorne 2000), and (1→3, 1→6)-β-D-glucans (by immunoassay; Metwali et al., 2005).

2.4. Statistical analyses

Frequencies and means were calculated for the demographic information, resident activities, use of respiratory protection, and damage assessment. Questionnaire and visual assessment items were dichotomized to evaluate determinants of mold coverage. The laboratory measurements were continuous variables that were found to be right skewed so a logarithmic transformation was done. In the case of zero counts, one was added to all values of the variables before log-transforming. For samples in which total culturable fungi were too numerous to count (TNTC), values were imputed equal to the largest observed value in the data sample plus one. Geometric means (GM) and geometric standard deviations (GSD) were calculated for air concentrations of endotoxin and glucans as well as culturable fungi and spore counts. To compare continuous variables with respect to dichotomized variables, non-parametric tests (Kruskall–Wallis) were performed. Finally, all variables were dichotomized and univariate analyses were conducted with Fisher's exact p-values reported due to the small numbers of counts. All statistical analyses were done using the SAS (version 9.12) software package (SAS, 2004).

3. Results

3.1. Participation rates

We approached 146 homes at which someone was present. At 113 of these homes, an adult agreed to participate, yielding an overall participation rate of 77%. We were unable to complete one survey because of safety hazards in the home. Surveys were completed for the remaining 112 households.

3.2. Demographics

The median age of the 112 respondents was 52 (range: 18–85) years. There were 59 (53%) males and of the 109 persons who chose to identify their race, 76 (70%) were white, 25 (23%) were black, and 8 (7%) were another race; 7 (6%) of all respondents identified themselves as Hispanic. The median age of homes inspected was 40 (range: <1–185) years. Ninety-five (86%) homes were single-family houses, 15 (14%) were apartments, condos or townhouses, and 1 (1%) was a trailer. Of the homes inspected, there was a median of 6 (range: 1–16) rooms, and 77 (69%) homes had one story, 32 (29%) homes had two stories and 3 (3%) homes had three stories. The median elevation of homes above ground was 2 (range: 0–20) ft. Electricity was on in 74 (70%) out of 106 homes.

3.3. Damage assessment

Of the 107 homes for which outdoor flood level was recorded (Table 1), the level was high (>6 ft), medium (3–6 ft), and low (<3 ft) in 20 (19%), 20 (19%), and 28 (26%) homes, respectively; there was no flooding in 39 (36%) homes. Seventy-six (70%) of 108 homes had roof

Table 1
Frequency of exterior flooding and roof damage

	No.[a] ($N = 107$)	%
Flood level		
None	39	36
Low (<3 ft)	28	26
Medium (3–6 ft)	20	19
High (>6 ft)	20	19
	($N = 108$)	%
Roof damage with water leakage	76	70

[a]There were 112 respondents; 5 missing values for flood level; 4 for roof damage.

Table 2
Frequency of mold growth on interior walls

	No. ($N = 111$[a])	%
Homes with any visible mold growth	49	44
Light mold growth[b]	31	28
Heavy mold growth[c]	18	16
Indoor flood level in homes with heavy mold growth		
Low flood level (<3 ft)	2	11
Medium flood level (3–6 ft)	7	39
High flood level (>6 ft)	9	50

[a]There was one missing value for mold growth.
[b]Defined as ⩽50% mold coverage on interior wall of "moldiest" room.
[c]Defined as >50% mold coverage on interior wall of "moldiest" room.

damage with water leakage. Visible mold growth occurred in 49 (44%) homes and 18 (16%) had heavy mold coverage (>50% coverage on an interior wall of the "moldiest" room; Table 2). Of the 18 homes with heavy mold growth, nine, seven, and two homes had high, medium, and low flooding indoors, respectively. By randomly sampling from a population of 440,269 homes in the GNO area, we were able to extrapolate from the sample to estimate that approximately 282,000 (64%; 95% CI: 242,000–321,000) homes had flooding, 308,000 (70%; 95% CI: 269,000–348,000) homes had roof damage with water leakage, that visible mold was present in approximately 194,000 (44%; 95% CI: 154,000–233,000) homes and that 70,000 (16%; 95% CI: 40,000–101,000) homes had heavy mold growth.

3.4. Resident activities

Since the hurricanes, participants reported having spent a mean of 18 h (range: 1–84) doing heavy cleaning such as power washing, removing drywall or carpeting, and moving furniture, 18 h (range: 1–90) doing light cleaning such as mopping or wiping down surfaces, 16 h (range: 1–56) getting personal things and 34 h (range: 1–224) viewing damage in their home as well as those of friends and neighbors. Sixty-six (60%) participants reported inhabiting their homes a median of 21 (range: 3–60) nights since the hurricanes. Forty-four (40%) respondents were in their homes only during the day to clean or gather belongings.

3.5. Respiratory protective equipment usage

Fifty-six (51%) of the residents reported using a dust mask or respirator. Of those, 35 (63%) reported using an N-95 filtering face piece respirator or a respirator that provided greater protection while the remaining 21 (38%) used only a dust mask. The frequency of mask or respirator use during specific cleanup activities is shown in Table 3. Twenty-two (38%) of the 58 residents who performed heavy cleanup wore an N-95 or other respirator, and 14 (18%) of 78 residents who performed light cleanup wore this level of respiratory protection. However, over half of the persons who participated in cleanup activities wore no respiratory protection or only a dust mask (53% and 70%, respectively, for heavy and light cleanup).

3.6. Visible mold growth

The amount of mold growth by conditions of the residence and building material used is shown in Table 4. Visible mold growth on interior walls was significantly associated with indoor and outdoor flood height ⩾3 ft ($p < 0.001$). Homes with roof damage were significantly more likely to have mold growth ($p = 0.01$); however, some homes with roof damage had no mold growth (Table 4). No difference in mold coverage was seen for drywall or wood as compared with plaster or tile walls, nor did homes with tile or concrete floors differ from those with carpeting or wood floors. However, there was significantly less mold growth on the walls of homes with a wet/muddy floor than homes in which the floor was dry ($p < 0.001$).

Table 3
Frequency of respirator and mask use among residents while cleaning

	Respiratory protection (n (%))			
	None	Dust mask	N-95 or other respirator	Unknown
Heavy cleaning[a] ($N = 58$[b])	19 (33)	12 (21)	22 (38)	4 (7)
Light cleaning[c] ($N = 78$[b])	47 (60)	8 (10)	14 (18)	2 (3)

Only the 58 and 78 respondents who participated in heavy or light cleaning, respectively, are included in this assessment. Cleaning categories are not mutually exclusive.
[a]Heavy cleaning is defined as power washing, removing drywall or carpeting, or moving furniture.
[b]Among those who were cleaning, there were seven missing values for respiratory protection while light cleaning; one while heavy cleaning.
[c]Light cleaning is defined as mopping or wiping down surfaces.

Table 4
Mold coverage on interior walls by condition of the home and building materials used

	Mold coverage on walls (*n* (%))			
	None	<50%	≥50%	*p*-Value
Outdoor flood height ($N = 107$[a])				
<3 ft[b]	47 (71)	17 (26)	2 (3)	<0.001
≥3 ft	10 (25)	14 (35)	16 (40)	
Indoor flood height ($N = 110$[a])				
<3 ft[b]	59 (69)	23 (27)	4 (5)	<0.001
≥3 ft	3 (13)	7 (29)	14 (58)	
Roof damage ($N = 107$[a])				
No	24 (75)	3 (9)	5 (16)	0.01
Yes	37 (49)	26 (35)	12 (16)	
Wall material ($N = 110$[a])				
Plaster/tile	18 (60)	8 (27)	4 (13)	0.9
Drywall/wood	43 (54)	23 (29)	14 (18)	
Floor material ($N = 108$[a])				
Tile/linoleum	21 (54)	9 (23)	9 (23)	0.3
Carpet/wood	38 (55)	22 (32)	9 (13)	
Floor condition[c] ($N = 111$[a])				
Dry	3 (17)	9 (50)	6 (33)	<0.001
Wet/muddy	59 (63)	22 (24)	12 (13)	

[a]There were missing values for either mold growth, condition of the home or building materials used.
[b]Includes homes with no flooding.
[c]The appearance of the floor at the time of the survey; dry floors may have been once flooded and were covered with dried mud or silt at the time of the survey.

3.7. Environmental sampling

A complete description of bioaerosol concentrations and fungal species detected in the indoor and outdoor air is discussed elsewhere (Rao et al., 2007). In summary, when comparing the 20 homes where indoor samples were taken with results from the 11 outdoor samples, the geometric mean of all microbiological measurements were higher indoors than outdoors (Rao et al., 2007). Five fungal genera were identified by culture along with two less-specific groups (*Aspergillus*, *Penicillium*, *Paecilomyces*, *Cladosporium*, *Trichoderma*, Zygomycetes, and Yeasts), with *Aspergillus* and *Penicillium* being the most frequently recovered. As shown in Table 5, air concentrations of culturable *Aspergillus* (indoor flood level) and *Penicillium* (outdoor flood level) species were higher in homes with high flood levels ($p < 0.1$ and $p < 0.05$, respectively). The air concentration of culturable *Aspergillus* species also was higher in homes with heavy mold growth and porous wall material ($p < 0.05$). This trend was the same for *Penicillium* species although not statistically significant.

Spores from 19 fungal taxa were identified with *Aspergillus*/*Penicillium* species, *Trichoderma* species, and Zygomycetes being most frequently recovered. Following identification, the spore counts for the following 12 taxa were grouped into three categories: (1) Asp/Pen (i.e., *Aspergillus* and *Penicillium* species); (2) hydrophilic taxa (i.e., *Chaetomium* species, *Epicoccum* species, *Memnoniella* species, or *Stachybotrys* species); and (3) outdoor taxa/spores generally considered to be found indoors as a result of outdoor air infiltration (i.e., *Alternaria* species, ascospores, basidiospores, *Cladosporium* species, rust, or smut). The other species such as *Trichoderma* and Zygomycetes, although prevalent could not be grouped into any of the above categories and were not analyzed individually. In homes without roof damage, concentrations of total, Asp/Pen, outdoor, and hydrophilic spores were higher than in homes with damaged roofs; these results were marginally significant only for hydrophilic spores ($p < 0.1$) (Table 5). Results for outdoor taxa are not presented as there were no statistically significant differences in the concentration of outdoor taxa by home conditions or building materials.

In contrast with measurements of culturable fungi and fungal spores, concentrations of endotoxin and glucans were higher in homes with low flooding, although not statistically significant. Concentrations of all microbiological measurements tended to be higher in homes with drywall vs. plaster and smooth floors, such as tile or concrete, vs. carpet (Table 5).

4. Discussion

Hurricanes Katrina and Rita resulted in devastating floods causing extensive mold growth in homes throughout the GNO area. Our assessment demonstrated that substantial concentrations of mold and microbial products existed in a large number of GNO area homes. Therefore, as will be discussed later, post-flood conditions and cleanup practices provided exposures that may have put residents at risk for potentially developing respiratory symptoms and fungal infections.

A majority of the homes in our assessment experienced flooding with nearly half containing visible mold growth. As would be expected, homes subjected to higher flood levels were found to have increased mold. Mold coverage was greatest in homes with >3 ft of indoor flooding; however, roof damage with water intrusion also provided conditions for mold growth. We estimate that approximately 194,000 residences had elevated mold growth with approximately 70,000 homes in the GNO area having heavy mold growth.

Although not statistically significant in our study, qualitative observations by survey teams indicated that drywall or wood wall paneling appeared more likely to have visible mold growth compared to plaster or tile walls. This phenomenon has been described in the past in both observational and experimental studies in which certain building materials have been found to be more vulnerable to mold growth (Gravesen et al., 1999; Karunasena et al., 2001). The use of alternative building materials, such as those made of inorganic compounds, could be beneficial

Table 5
Results of indoor microbiological air samples by condition of the home and building material types

	GM[a] (GSD[b])							
	Endotoxin (EU/m^3)	Glucans ($\mu g/m^3$)	Total culturable fungi (CFU/m^3)	Culturable *Aspergillus* (CFU/m^3)	Culturable *Penicillium* (CFU/m)	Total spores ($spores/m^3$)	Asp/Pen[c] spores ($spores/m^3$)	Hydrophilic[d] taxa spores ($spores/m^3$)
Roof damage								
No ($N = 4$)	27.8 (12.8)	3.6 (8.4)	1.3×10^4 (31.4)	6.2×10^3 (17.6)	3.0×10^3 (6.9)	4.7×10^4 (24.2)	9.4×10^3 (34.9)	34.1* (18.1)
Yes ($N = 14$)	16.7 (4.2)	1.1 (3.3)	5.6×10^4 (9.7)	5.5×10^3 (7.1)	1.4×10^4 (8.6)	3.4×10^4 (9.1)	2.6×10^3 (17.0)	7.8 (1.2)
Flood level outdoors								
$\leqslant 3$ ft ($N = 7$)	40.2 (7.8)	3.5 (6.2)	1.4×10^4 (26.4)	5.1×10^3 (25.7)	$4.5 \times 10^{3**}$ (8.4)	4.5×10^4 (17.5)	2.0×10^3 (46.0)	17.3 (9.2)
> 3 ft ($N = 13$)	17.4 (4.5)	1.1 (3.1)	1.0×10^5 (6.5)	9.6×10^3 (4.7)	2.5×10^4 (9.0)	6.2×10^4 (13.4)	9.8×10^3 (17.7)	14.2 (7.1)
Flood level indoors								
< 3 ft ($N = 11$)	1.1 (6.3)	2.0 (5.5)	3.3×10^4 (20.6)	$4.8 \times 10^{3*}$ (12.4)	9.6×10^3 (12.5)	4.3×10^4 (17.9)	5.7×10^3 (28.9)	13.7 (5.8)
$\geqslant 3$ ft ($N = 9$)	16.4 (4.9)	1.2 (3.3)	9.0×10^4 (6.2)	1.4×10^4 (5.8)	2.1×10^4 (7.5)	7.6×10^4 (1.1×10)	5.4×10^3 (26.4)	17.3 (10.6)
Mold coverage on wall								
$< 50\%$ ($N = 12$)	20.5 (5.0)	1.3 (3.8)	3.4×10^4 (18.2)	$4.1 \times 10^{3**}$ (9.4)	1.4×10^4 (12.3)	3.2×10^4 (12.8)	3.3×10^3 (22.1)	8.0 (1.2)
$\geqslant 50\%$ ($N = 8$)	28.4 (7.1)	2.1 (5.7)	9.8×10^4 (6.7)	2.0×10^4 (7.0)	1.3×10^4 (7.9)	1.3×10^5 (14.1)	1.2×10^4 (33.9)	39.7 (20.2)
Wall material								
Plaster ($N = 4$)	10.4 (1.8)	0.7 (2.6)	1.4×10^4 (18.4)	$2.4 \times 10^{3**}$ (5.8)	1.1×10^4 (18.0)	1.2×10^4 (6.2)	2.6×10^3 (7.5)	7.5 (1.1)
Drywall ($N = 16$)	29.5 (6.4)	2.0 (4.6)	7.2×10^4 (11.4)	1.0×10^4 (9.7)	1.5×10^4 (9.2)	8.1×10^4 (14.8)	6.7×10^3 (33.1)	18.1 (9.1)
Floor material								
Carpet ($N = 14$)	22.5 (6.9)	1.4 (5.1)	3.8×10^4 (16.6)	5.3×10^3 (10.0)	8.0×10^3 (9.5)	3.7×10^4 (14.8)	4.3×10^3 (25.3)	12.4 (4.7)
Tile ($N = 6$)	25.5 (3.3)	2.3 (3.0)	1.1×10^5 (6.1)	1.9×10^4 (6.5)	4.9×10^4 (7.1)	1.4×10^5 (10.7)	9.7×10^3 (32.3)	24.3 (18.6)

[a]GM: geometric mean.
[b]GSD: geometric standard deviation.
[c]Asp/Pen: Aspergillus, Penicillium.
[d]Hydrophilic: *Chaetomium*, *Epicoccum*, *Memnoniella*, and *Stachybotrys*.
*p-Value < 0.1 as assessed by Kruskal–Wallis Test.
**p-Value $\leqslant 0.05$ as assessed by Kruskal–Wallis Test.

for structures in areas at risk of disaster events such as floods.

Heavy mold growth on walls was found more frequently in homes with a dry floor. One likely explanation is that higher flooding and more recent exposure to flood water (signified by a muddy rather than dry floor) delayed growth of meso- and xerophilic molds while the home was under water. In contrast, mold growth may have been more rapid in homes with dry floors because the flood water had receded more quickly allowing a longer growth period prior to assessment. Floor material did not appear to make a difference in the amount of mold growth on the walls. However, carpet is more likely to retain water and, therefore, may partly explain why some homes remained wet after flood waters receded.

Many of the surveyed residents were at their homes to remediate and clean, and while over 90% of the residents described some level of cleanup participation, fewer than half of them had worn respiratory protection considered appropriate by the CDC (CDC, 2006a). The average time spent cleaning inside mold-contaminated buildings compounded by the lack of proper respiratory protection suggests that a substantial number of residents were exposed to high concentrations of mold and other particles. In a separate study of GNO residents, discomfort was the most common reason for not wearing respiratory protection (Cummings et al., 2007). In addition, the crippling of New Orleans' infrastructure led to an inability to obtain proper respiratory protection. Lack of education about appropriate safety precautions, the unavailability of respiratory protection and the discomfort of wearing it in hot, humid conditions all contributed to lack of appropriate respiratory protection use by many residents while participating in cleanup (Cummings et al., 2007).

Although some atypical molds were found in the GNO area in the aftermath of the hurricanes (Rao et al., 2007), we primarily found molds typical of indoor and outdoor air in all regions of the US, predominantly *Aspergillus* and *Penicillium* species (Shelton et al., 2002). We found that flood level was associated with airborne concentrations of culturable *Aspergillus* and *Penicillium* species as was mold coverage and type of wall material. Greater spore growth of water-loving fungi was associated with roof damage. Overall, airborne mold concentrations were very high and exceeded those associated with wheeze and persistent cough in a study of infants at risk for asthma development (Gent et al., 2002).

There were several limitations to this study. First, the sample may have been under-representative of the GNO population, as only residents with access or ability to return home participated in the study. Therefore, the amount of mold growth may have been underestimated since the most damaged homes were less likely to have someone present, residents had not yet returned to the worst damaged areas at the time of our assessment. For example, the Ninth Ward, a heavily damaged area, was excluded from our survey because residents were not permitted to return to their homes. Qualitative, non-systematic observations by the field teams suggested that more severely damaged and unoccupied homes had heavy mold growth further supporting the assertion that our estimates are conservative. Secondly, a small convenience sample of homes was used for air-sampling because of the limited availability of equipment and time constraints. Six of the 20 homes had been fully remediated before the air-sampling which could have weakened the association between level of flooding and airborne microbial concentrations. In addition, the sample size was calculated to detect differences in the extent of visual mold growth compared to objective measures of flooding and, therefore, the sample may not have been large enough to detect statistical significance in observed differences for the types of building materials and damage conditions that were examined. Furthermore, the comparison criteria (e.g., 3 ft for flood height and 50% wall coverage for extent of fungal growth) may not have been optimal. However, the visual assessment of mold generally correlated with objective measures of mold and microbial growth. This is in agreement with what was reported in a study of 110 Canadian homes in which glucans were highly correlated to the extent of visible mold damage in the houses (Foto et al., 2005).

One of the strengths of this study was the early assessment of water damage and mold growth, which was conducted within 1 month of the second hurricane. There also was a high participation rate despite the austere conditions and the stress this disaster placed on the residents. Another strength was the use of multiple methods to assess mold and microbial exposure, i.e., air-samples provided objective measurements of home conditions for comparison with subjective visual assessments. Although it may have been an underestimation, the random sampling plan identified the approximate number of homes with flooding and elevated mold concentrations.

The health effects from exposures to molds and microorganism constituents in these flooded environments are undetermined. There are no exposure standards relating health effects to specific concentrations of airborne molds or markers of mold (e.g., glucans; Rao et al., 1996). Although, β-glucans have been shown to have potent pulmonary effects in animal experimental models, the evidence of adverse health effects in epidemiological investigations is sparse (Rylander et al., 1998; Thorn and Rylander, 1998). Airborne (1→3)-β-glucans in various occupational settings have ranged from 0.40 to 92.5 $\mu g/m^3$ using polyclonal antibody immunoassays (Douwes et al., 1996, 2000). We used a more specific monoclonal antibody immunoassay and found lower concentrations of (1→3, 1→6)-β-D-glucans. Since, (1→3)-β-D-glucans are also found in plants and some bacteria (Douwes et al., 1996), this may explain the higher concentrations found in the agricultural and occupational studies. Although the results from different analytical methods may not be directly comparable, the concentrations of the more specific (1→3,

1→6)-β-D-glucans that we detected indoors were higher than concentrations reported in previous indoor studies of (1→3)-β-D-glucans (range reported from 0.02 to 0.03 μg/m^3 using a Limulus Amebocyte Lysate assay) that were associated with markers of airway inflammation and sick building syndrome symptoms (Rylander et al., 1998; Thorn and Rylander, 1998; Wan and Li, 1999).

On the other hand, sufficient evidence of health effects exists for endotoxins, a bacterial cell membrane constituent. Exposure limits (i.e., 50–200 EU/m^3) and relative limit values (10 times background levels) for endotoxins have been proposed based on concentrations of airborne endotoxin in occupational settings (Milton, 1999; Martinez et al., 2004). Concentrations of airborne endotoxin in occupational and agricultural settings often exceed 45 EU/m^3, while indoor environment levels (e.g., residential, schools, office buildings) tend to be much lower (usually less than 2 EU/m^3) and similar to outdoor levels (Hines et al., 2000; Jacobs, 1997; Olenchock et al., 1990; Reynolds et al., 2001; Wan and Li, 1999). In our investigation, the geometric mean of endotoxin levels was higher indoors than outdoors with concentrations more than 20 times higher than in previously observed indoor environments. In fact, endotoxin levels in five of our sampled residences exceeded 45 EU/m^3.

The assessment of exposures to airborne particles is difficult because air concentrations may vary with resident activity. Ambient exposure may be low when particles previously airborne have settled but high when room activity re-suspends them (Lehtonen and Reponen, 1993). The relevance of the observed microbial concentrations to the health of GNO residents is difficult to determine, but the avoidance of such extremely "moldy" conditions or the use of appropriate respiratory protection if avoidance is not possible are the most practical ways to reduce the risk of adverse health effects.

5. Recommendations

The findings of this investigation support the CDC recommendations for mold prevention strategies to reduce possible health effects in the aftermath of major floods (CDC, 2006b). These precautions include avoidance of unnecessary exposure to mold-contaminated areas, particularly for immunocompromised persons and those with allergy-related illnesses. Public health officials should promote public awareness of appropriate respiratory protection and remediation practices for persons who will be exposed to mold-contaminated buildings particularly among workers and employers of those workers. These persons should use particle filtering respirators at least as protective as a disposable N-95 respirator, but respirator selection should be guided by the nature of the task. Public health officials should be aware of reports of illnesses that may represent sentinel cases for mold-related respiratory disease and, where appropriate, should investigate these cases to identify any associations.

This study also supports the CDC recommendation that following a major hurricane or flood, visible mold growth itself and estimation of the extent of that growth from a thorough visual inspection is sufficient to categorize a building as "moldy" (CDC, 2006b). In such cases, cleanup based on established guidelines (United States Environmental Protection Agency (EPA), 2001; D'Andrea, 2001) including the use of appropriate personal protective equipment (CDC, 2006b), can be initiated without collection of environmental samples for individual homes.

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