German Cockroach Allergen Levels in North Carolina Schools: Comparison of Integrated Pest Management and Conventional Cockroach Control

Authors: Godfrey Nalyanya, J. Chad Gore, H. Michael Linker, and Coby Schal

Source: Journal of Medical Entomology, 46(3) : 420-427

Published By: Entomological Society of America

URL: https://doi.org/10.1603/033.046.0302

FORUM

German Cockroach Allergen Levels in North Carolina Schools: Comparison of Integrated Pest Management and Conventional Cockroach Control

GODFREY NALYANYA, J. CHAD GORE,[1] H. MICHAEL LINKER, AND COBY SCHAL[2]

Department of Entomology, Box 7613, North Carolina State University, Raleigh, NC 27695-7613

J. Med. Entomol. 46(3): 420–427 (2009)

ABSTRACT Cockroach suppression is fundamental to cockroach allergen mitigation in infested homes. The effects of various cockroach control strategies on cockroach populations and allergen concentration have not been examined in schools. This study was conducted to compare the effectiveness of integrated pest management (IPM) and conventional pest control in controlling German cockroach (*Blattella germanica* L.) infestations and concentrations of the cockroach allergen Bla g 1 in public school buildings. Two school districts included six schools that used conventional pest control and one district included seven schools that used IPM to control pests. Cockroach traps were deployed to assess the level of infestation, settled dust samples were collected in food service areas, classrooms, and other school areas, and the Bla g 1 allergen was quantified by ELISA. Both cockroach counts and Bla g 1 concentrations were dependent on the pest control approach, with highly significant differences between IPM-treated schools and conventionally treated schools in both the cockroach mean trap counts (0 versus 82.6 ± 17.3 cockroaches/trap/wk, respectively) and in the amount of Bla g 1 in dust samples (2.8 ± 0.3 versus 30.6 ± 3.4 U/g dust). Cockroaches and Bla g 1 were primarily associated with food preparation and food service areas and much less with classrooms and offices. Our data extend recent findings from studies in homes, showing that cockroach allergens can be reduced by cockroach elimination alone or by integrating several tactics including education, cleaning, and pest control. IPM is not only effective at controlling cockroaches but also can lead to long-term reductions in cockroach allergen concentrations, resulting in a healthier environment for students and school personnel.

KEY WORDS cockroaches, cockroach allergen, Bla g 1, integrated pest management, schools

The prevalence of asthma has increased dramatically over the last 40 yr, ostensibly as a result of changes in structural design and more time spent indoors, which have consequently prolonged exposure to perennial allergens (Platts-Mills et al. 1998, Krieger et al. 2000, Mannino et al. 2002). In the United States, asthma affects ≈30 million people, 9 million of whom are under the age of 18 yr (Dey and Bloom 2005), and it is one of the most costly diseases, with an estimated annual cost of $12.7 billion (Weiss and Sullivan 2001). According to the Third National Health and Nutrition Examination Survey (NHANES; CDC 1988–1994), ≈43% of the U.S. population, 6–59 yr of age, is allergic to at least one common indoor allergen, and 26% exhibit allergic sensitization to the German cockroach (Arbes et al. 2005a). Sensitization and exposure to German cockroach allergens are associated with the development and exacerbation of acute asthma morbidity and increased medical utilizations, especially among inner city children (Call et al. 1992, Gelber et al. 1993, Rosenstreich et al. 1997).

Most allergic disease and asthma result from sensitization and perennial exposure to allergens. It follows that the central tenet of asthma intervention should be to minimize exposure through environmental allergen reduction (IOM 2000). The two obvious components of a strategy for minimizing exposure to German cockroach allergens are (1) eradication of cockroach populations and (2) removal of cockroach allergens from homes, schools, and other areas where children spend time.

There are two main approaches to suppression of cockroach populations. The first approach, conventional cockroach control, entails prophylactic or scheduled applications of pesticides to a structure (Miller and Meek 2004, Williams et al. 2005) whether or not the structure is infested with cockroaches. The other approach, integrated pest management (IPM), combines various actions or tactics to mitigate cockroach infestations (Schal and Hamilton 1990, Miller and Meek 2004, Williams et al. 2005) and to prevent future infestations. In IPM, the infested structure is

[1] Present address: JC Ehrlich, 29 Noblestown Rd., Suite 200, Carnegie, PA 15106.

[2] Corresponding author, e-mail: coby_schal@ncsu.edu.

inspected and monitored (usually with sticky traps) to locate cockroach infestations and to determine availability of conditions that are conducive to cockroach infestations. Based on this information, a decision is made on the necessary action(s) to control the current infestation and to prevent recurrence. Insecticides can be applied as needed in IPM, but the choice of active ingredients and formulations considers "reduced-risk" products that can be targeted at cockroach aggregations and harborages to minimize exposure to people.

Allergen removal is accomplished through vacuuming to remove contaminated dust, dead cockroaches, and their feces from structures and cleaning to remove allergen from floors, bedding, and other surfaces within homes (Gore and Schal 2007). Cleaning alone, without suppressing the cockroach population, does not afford long-term allergen reduction; therefore, most cockroach allergen mitigations have used a mix of intervention strategies, most commonly pest control coupled with cleaning (Gore and Schal 2007). Until recently, however, there has been sparse evidence that cockroach control alone could attain long-term, clinically relevant reductions in cockroach allergens in infested structures. Sarpong et al. (1996) and Sever et al. (2007) clearly showed that cockroach control alone significantly reduced cockroach allergen levels in homes. The effect of cockroach control has not been shown in school settings, even though many schools—in both urban and rural districts—are prone to cockroach infestations and have clinically relevant cockroach allergen levels (Sarpong et al. 1997, Abramson et al. 2006, Perry et al. 2008). Our study was conducted to compare the effectiveness of IPM and conventional pest control in controlling German cockroach (*Blattella germanica* L.) infestations and in reducing concentrations of the German cockroach allergen Bla g 1 in public school buildings.

Table 1. Insecticides applied to control German cockroaches in IPM- and conventionally treated schools

Conventional[a] (two school districts; $N = 6$ schools)	IPM (one school district; $N = 7$ schools)
Guilford County schools	Wake County schools
Orthene Concentrate (acephate)	Maxforce FC roach bait gel (fipronil)
PT Cy-Kick aerosol (cyfluthrin)	Maxforce FC roach bait stations (fipronil)
Maxforce roach bait gel (hydramethylnon)	CB Invader HPX-15 residual (propoxur)
Maxforce roach bait stations (hydramethylnon)	
East North Carolina County schools	
Suspend SC (deltamethrin)	
Cynoff WP (cypermethrin)	
Gentrol IGR Concentrate (hydroprene)	
Avert cockroach bait gel (abamectin)	
Boric acid powder	
Maxforce roach bait gel (hydramethylnon)	
Maxforce roach bait stations (hydramethylnon)	

[a] Since this study was completed, the Guilford County School District and the East North Carolina County Schools have changed their practices, and the conditions reported in this study are no longer prevalent (data not shown). Personnel from the School IPM Program of North Carolina State University (Department of Entomology) helped to control the cockroach infestations at the end of the study. In addition, recommendations for removing cockroach-conducive conditions and IPM programs were implemented.

Materials and Methods

Selection of Schools. Maintenance directors of school districts in central and eastern North Carolina were contacted to recruit schools into this study. Three school districts agreed to participate in the study (Guilford County Schools, Wake County Public Schools, and a third school district in eastern North Carolina that preferred to remain anonymous—we refer to this school district as "East NC County"): two districts (Guilford County and East NC County) used conventional pest control (six schools used in this study) and one district (Wake County) used IPM to control pests (seven schools used in this study).

Pest Control Procedures in Schools. All schools had ongoing standard pest management programs and they continued with their procedures during this study without any supervision or direction from study personnel. The Wake County Public School System (IPM) had an in-house pest management program operated entirely by pest control technicians employed by the Environmental Health and Safety Department of the school district. The technicians were responsible for controlling indoor pests in all the schools. They were scheduled to visit each school monthly, during which they reviewed the pest sightings log, inspected school buildings and grounds and talked to school employees on site about pest control concerns. The technicians documented conditions that might be conducive to pests and reported them to the relevant department for remediation. They usually deployed sticky traps in the kitchens, teachers' lounges, and employee lavatories to monitor pests between service visits. In case of pest sightings, the technicians determined whether it was necessary to treat, and they used mainly baits and occasionally aerosol formulations of residual insecticides directed into cracks and crevices (Table 1).

The Guilford County School District (conventional) contracted a pest management professional (PMP) to provide pest control services. Interviews with the cafeteria managers indicated that schools were serviced monthly, but the technicians did not inspect or monitor for pests. During service visits, the technicians applied water-based organophosphate sprays or pyrethroid aerosol sprays to baseboards, and occasionally used baits in cracks and crevices (Table 1).

Pest control in the East NC County Schools (conventional) was primarily done in-house by school custodial and cafeteria staff and by a contracted PMP on

Fig. 1. German cockroaches and cockroach feces in conventionally treated schools. (A) German cockroaches infesting a floor drain. (B) Heavy German cockroach infestation and fecal smears behind a poster in the kitchen. (C) German cockroaches infesting a wall plate beneath the kitchen sink. (Online figure in color.)

an "as needed" basis. The PMP applied a mixture of pyrethroids and an insect growth regulator (IGR) to the baseboards and to cracks and crevices, whereas the school staff used boric acid along baseboards and bait gels and bait stations in other areas (Table 1).

Monitoring Cockroach Populations. All monitoring of German cockroach populations was conducted by us from November 2003 through May of 2004, as schools became available for the study, without interfering with the standard pest control procedures of each school. We conducted visual inspections of the kitchens to discover infested areas or for evidence of infestation before placing cockroach traps (Victor Roach Pheromone Traps; Woodstream, Lititz, PA) near visible signs of cockroaches (Fig. 1). A variable number of traps ranging from 6 to 18 per school were placed in kitchens, cafeterias, and other areas (teachers' lounges, lavatories) of the schools. Traps were not placed in classrooms because we saw little evidence of infestation and it was difficult to obtain consistent access to classrooms. Traps were generally retrieved after 1 or 2 d, but in some instances we could not retrieve traps for up to 12 d. Therefore, trap catch was standardized "per trap per week." The average (±SEM) time that traps were deployed was 3.71 ± 1.43 d. All trapped cockroaches were counted in the laboratory.

Settled Dust Collection and Assay. Dust samples were collected from November 2003 to May 2004, as schools became available for sampling. Settled dust samples were collected in food service areas, classrooms, and other school areas using a modified Eureka Mighty-Mite 9.0-ampere vacuum cleaner (Eureka, Bloomington, IL). A 19 by 90-mm cellulose extraction thimble (Whatman International, Kent, United Kingdom) was placed in the distal end of the extension tube, sealed with a rubber O-ring around the thimble, and covered with a clean crevice tool. A 2-m^2 area of the floor was vacuumed for 1 min. Thimbles containing the collected dust were placed into individual 50-ml centrifuge tubes (Fisher, Pittsburgh, PA) and transported at ambient temperature to the laboratory. Samples were stored at −20°C until processing.

Dust was collected from floor surfaces in food service areas where cockroach infestations had been ascertained by traps or visual inspection and from areas most likely to harbor cockroaches. Because no trapping was done in classrooms, the classrooms were selected for dust collection based on reports by teachers that cockroaches had been sighted and by our observations of signs of previous cockroach presence or infestation. Nine to 12 dust samples were collected per school in the IPM schools and 7–8 samples were collected in conventionally treated schools. The number of samples collected in each school depended on size of the room and availability of relevant space to vacuum (space that is used by children and staff on a daily basis)—we vacuumed only floor space that was exposed and often used by children during class or playtime, but did not move stored items, equipment, or heavy furniture. Similarly, we vacuumed kitchen areas and areas adjacent to teachers' desks, and administrative secretary desks and chairs.

Vacuumed dust samples were sieved through a 425-μm pore grating to remove large particles, weighed, and separated into 50-mg aliquots of dust. Aliquots were extracted in phosphate-buffered saline (PBS) overnight and centrifuged at 12,000 rpm for 10 min. Supernatants were decanted and stored at −20°C until assay. Bla g 1 (*Blattella germanica* allergen 1) concentration in samples was measured using a monoclonal capture and polyclonal detector ELISA (Indoor Biotechnologies, Charlottesville, VA) as described by Pollart et al. (1991). Allergen concentration is reported as units of Bla g 1 per gram of dust (U/g), and the lower limit of detection was 0.1 U/g of vacuumed dust.

Data Analyses. This study was laid out in a split plot design with schools as the whole plot factor and treatment as the subplot factor. Trap data were analyzed by treatment and by location within schools using PROC GLM (analysis of variance [ANOVA]; SAS Institute 2001). Bla g 1 allergen samples, like trap data, were analyzed by school, location (classroom, food service/eating area, or faculty area), and treatment (IPM or conventional pest control). The allergen data were log transformed (Bla g 1 level + 0.5) and subjected to PROC GLM (ANOVA; SAS Institute 2001). For calculations of geometric means, a value of one half the limit of detection (0.05) was used for each zero value, so that the information contained in these data were not lost.

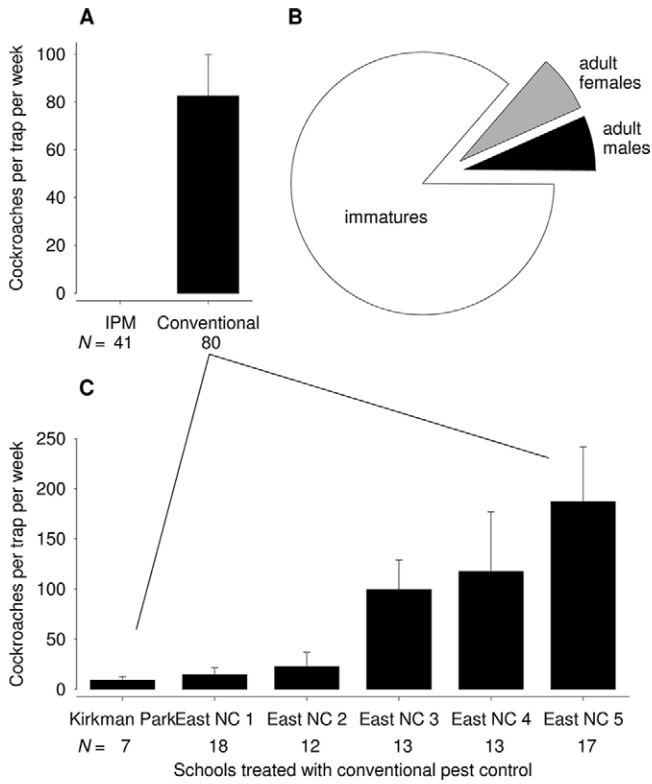

Fig. 2. (A) German cockroach trap counts from IPM- and conventionally treated schools. (B) Proportions of adult males, females, and nymphs in traps. (C) German cockroach trap counts from the six conventionally treated schools. Mean trap catches are reported per trap per week (±SEM) because variable numbers of traps were deployed in each school for varying durations. Sample sizes are shown under the *x*-axis.

Results

German Cockroach Trap Counts. There were highly significant differences in the number of German cockroaches trapped in IPM- and conventionally treated schools (t = 3.402; df = 119; $P < 0.001$). We recovered a total of 41 traps from the seven IPM schools; no cockroaches were trapped in any of these traps, whereas 80 traps recovered from conventionally treated schools averaged 82.6 ± 17.3 (SEM) cockroaches per trap per week (Fig. 2A). Considering all 80 traps, nymphs represented 86.2 ± 3.3% of the trapped insects, with adult males and females represented approximately equally at <7% each (Fig. 2B).

Trap catch was highly variable in the six conventionally treated schools, ranging from 9.2 ± 3.4 cockroaches per each of 7 traps per week in Kirkman Park Elementary School to 187.2 ± 54.4 cockroaches per week in each of 17 traps in East NC 5 (Fig. 2C). Trap catch also varied greatly by location within the school; although sticky traps in the cafeterias and kitchens trapped far more cockroaches than did traps in offices, differences were not statistically significant (t = 1.991; df = 77; P = 0.157) because we deployed few traps outside of food preparation and service areas (Fig. 3A). The number of cockroaches trapped per week also varied by location within the kitchen and cafeteria (F = 3.923; df = 2,55; P = 0.026), with most cockroaches trapped under the kitchen sink, under other kitchen counters, and in and around equipment such as refrigerators, freezers, and dishwashers (Fig. 3B). We also routinely trapped cockroaches in cafeterias of conventionally treated schools, mainly around vending machines and the food service lines.

Allergen Concentrations. There were highly significant differences in the mean concentration of Bla g 1 between IPM- and conventionally treated schools. Bla g 1 concentrations were significantly lower in IPM-treated schools than in schools treated with conventional approaches (F = 31.57; df = 1; $P < 0.0001$; Fig. 4). Nevertheless, it is important to note that Bla g 1 was undetectable (<0.1 U/g dust) in many settled dust samples, resulting in medians of 0 U/g dust in both sets of schools. The geometric mean in conventionally treated schools was 0.53 (N = 80) compared with 0.08 (N = 72) in IPM-treated schools (with zero values replaced by 0.05—a value of one half the limit of detection).

There were highly significant differences (F = 11.85; df = 2; $P < 0.0002$) in mean Bla g 1 concentrations among areas where dust was collected in schools, with significantly more allergen collected in the food service areas compared with the classrooms and faculty areas in the conventionally treated schools. Although we found higher concentrations of Bla g 1 in

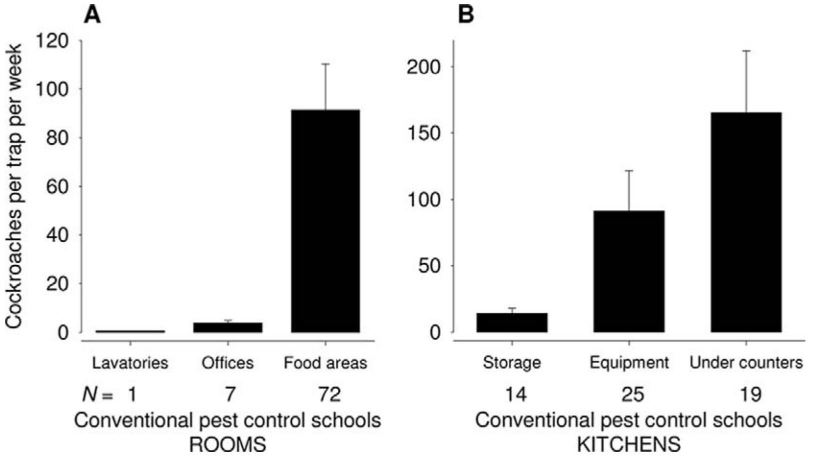

Fig. 3. (A) German cockroach trap counts from various rooms within conventionally treated schools. (B) Trap counts from various areas within food service areas of conventionally treated schools, namely storage areas, around equipment, and under kitchen counters. Mean trap catches are reported per trap per week (±SEM) because variable numbers of traps were deployed for varying durations in each school, room, and areas within rooms. Sample sizes are shown under the *x*-axis.

classrooms (4.4 U/g) than in food service areas (mean = 0.23 U/g) and teachers' areas (0.26 U/g) in IPM schools, only 4 of 14 classroom samples had detectable Bla g 1, and one sample collected near the teacher's desk (190.4 U/g) accounted for the high mean (Fig. 5). The median Bla g 1 concentrations in food service and teachers' areas were 26.8 and 2.4 U/g, respectively, in conventionally treated schools compared with 0.0 in both areas in IPM-treated schools. The treatment × room type interaction was statistically significant ($F = 11.15$; df = 2; $P < 0.0003$), indicating that lower Bla g 1 concentrations were generally found in various room types (kitchen, cafeteria, teachers' lounges, offices) in schools under IPM contracts. The school × treatment interaction was not significant ($F = 0.66$; df = 13; $P > 0.05$), suggesting that similar Bla g 1 levels were found in schools within each of the two treatments.

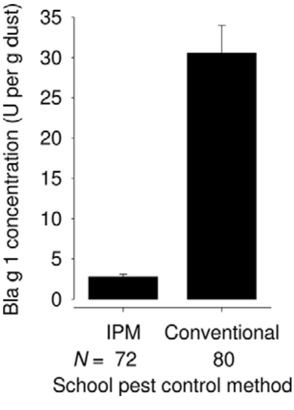

Fig. 4. Concentration of German cockroach Bla g 1 allergen in dust samples collected from IPM- and conventionally treated schools. Mean Bla g 1 (U/g of sieved dust) is reported (±SEM). Sample sizes are shown under the *x*-axis.

Since this study was completed, the Guilford County schools and the East NC County schools have modified their pest control practices, and the conditions reported in this study are no longer prevalent (data not shown).

Discussion

Several studies have documented the ubiquitous presence of cockroach allergens in schools and preschool centers across the country (Custovic et al. 1996, Sarpong et al. 1997, Fernandez-Caldas et al. 2001, Chew et al. 2005, Tranter 2005, Perry et al. 2008). However, most have concentrated on urban, inner city schools (Amr et al. 2003, Chew et al. 2005, Perry et al. 2008), and none have documented either the presence of active cockroach infestations in the schools (for review, see Gore and Schal 2007) or a relationship between the prevailing pest control services in the school and the combined environmental prevalence of cockroaches and cockroach aeroallergens. This study is the first to evaluate the effectiveness of conventional cockroach control (routine, calendar-based insecticide applications) and IPM in controlling German cockroach infestations and reducing cockroach allergen levels in schools. Schools using the IPM approach had no detectable cockroach infestations and we found significantly lower concentrations of Bla g 1 than in conventionally treated schools, which had high cockroach trap counts and concomitantly much higher Bla g 1 allergen levels.

Fourteen percent of the dust samples from IPM-treated schools and 44% of the samples from conventionally treated schools had detectable Bla g 1 (i.e., > 0.1 U/g dust). However, only 1.4% (1 of 72) of the dust samples from IPM schools had >2 or 8 Bla g 1 U/g dust, the proposed sensitization and morbidity thresholds, respectively, for this allergen (Rosenstreich et al. 1997,

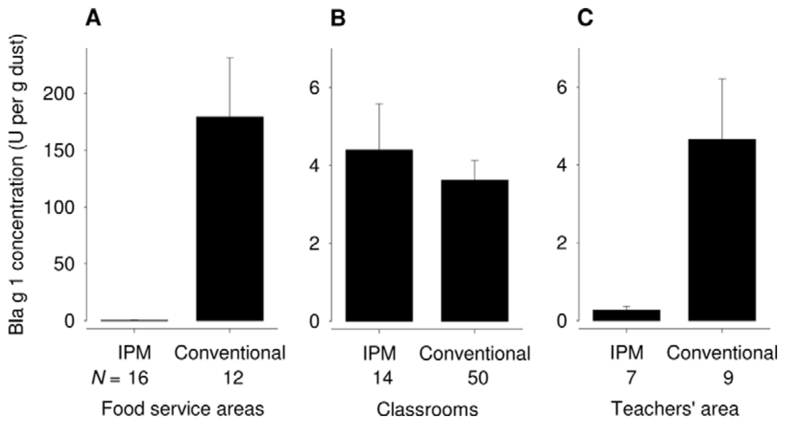

Fig. 5. Concentration of German cockroach Bla g 1 allergen in dust samples collected from (A) food service areas, (B) classrooms, and (C) faculty areas of IPM- and conventionally treated schools. Mean Bla g 1 (U/g of sieved dust) is reported (±SEM). Sample sizes are shown under the *x*-axis. Note different *y*-axis scales.

Eggleston et al. 1998). However, 35% (28 of 80) of the dust samples from conventionally treated schools had >2 U Bla g 1/g dust, and 20% (16 of 80) had >8 U/g of dust. This relatively high level of antigen detected in school dust is of concern because it may constitute an important occupational risk to students, teachers, and other school personnel (Sarpong et al. 1997). It is important to note, however, that the highest cockroach allergen concentrations were in the kitchen and cafeteria of conventionally treated schools, suggesting that other personnel in these schools may be at greater risk than students and teachers.

We detected high numbers of cockroaches and high concentrations of Bla g 1 in kitchens and other food service areas of conventionally treated schools and much lower levels in classrooms and offices (Figs. 3A and 5). In fact, samples of settled dust from classrooms showed no differences in Bla g 1 concentrations between IPM-treated and conventionally treated schools (Fig. 5B), consistent with the observations that most cockroach sightings, cockroach infestations, and cockroach control efforts were directed at food service areas and not at classrooms. Although the median Bla g 1 levels in both sets of classrooms were zero, the mean levels were higher than the proposed sensitization threshold for this allergen, indicating that levels of exposure and risk would be high in some classrooms. These results underscore the need for effective pest control and allergen mitigation in food service areas and also in classrooms, where food is also available and where elementary school children spend most of their time, often in close contact with settled dust on carpeted floors.

The Bla g 1 aeroallergen concentrations we measured in conventionally treated schools were similar to measurements that we have made in North Carolina homes (Arbes et al. 2003, 2004; Sever et al. 2007) and to levels measured in North Carolina daycare facilities (Arbes et al. 2005b). It is important to recognize that, although children may encounter cockroach and other allergens in various settings, they spend most of their time in the school and home environments, where sensitization and exposure risks are highest. It is not surprising, therefore, that a positive correlation was found between asthma prevalence and cockroach allergen exposure in inner city elementary schools (Amr et al. 2003). Our environmental sampling further indicates that suburban, non–inner city schools may be subject to the same levels of cockroach infestations and allergens as inner city schools and homes. Fortunately, IPM programs have now been shown to be highly effective in both home and school settings and in both inner city and non-urban settings.

Schools treated with conventional pest control had higher German cockroach trap counts than IPM-treated schools, indicating that conventional pest control is less effective than IPM in controlling German cockroaches. This difference between IPM and conventional pest control has been shown in other urban settings (Arbes et al. 2003, Miller and Meek 2004, Gore and Schal 2007, Peters et al. 2007). IPM uses inspections and monitoring to identify and remedy conditions that are conducive to cockroach infestations (food, water, appropriate shelters such as cracks and crevices), detect infestations early, and pinpoint cockroach aggregations and infestations. Whenever insecticides are needed, reduced-risk formulations, such as baits, are preferred, and they are targeted precisely at the cockroach aggregations and shelters that have been identified during inspections, thus increasing the bioavailability of the insecticide treatments to cockroaches while minimizing exposure of building occupants. On the contrary, conventional pest control tends to rely on residual insecticides that are sprayed onto baseboards and other surfaces without regard to whether cockroaches are present; that is, monitoring or inspection are not used to determine the presence and distribution of cockroaches. Sever et al. (2007) reported that PMPs were less able to effectively control cockroaches in homes even though some used bait stations and gel baits. The authors attributed lower effectiveness to lack of monitoring of cockroach populations, resulting in poor targeting of insecticide treatments and consequently poor control.

Higher cockroach trap catches correlate with higher Bla g 1 levels, as seen in conventionally treated schools (see also Wang et al. 2008). The food service areas of conventionally treated schools had higher Bla g 1 levels than the classroom and faculty areas of the schools. This is probably because conditions that are conducive to cockroach infestations (e.g., food, water, warmer temperatures, and cracks and crevices) were more readily available in food service areas than in other areas of the schools. In the IPM schools, a significantly higher Bla g 1 level was seen in classrooms than food service areas. This is probably because food is allowed in kindergarten and lower elementary school classrooms. However, this observation was attributed to one dust sample that had a much higher Bla g 1 content than the rest of the dust samples from that school and the entire school district.

The results of this study support the latest findings that cockroach allergen concentrations can be reduced by integrating several tactics including education, cleaning, and pest control (Arbes et al. 2003, Peters et al. 2007) or by cockroach elimination alone (Arbes et al. 2004, Sever et al. 2007). School districts that are hesitant to adopt IPM methods because of skepticism about the effectiveness of this pest control approach can be encouraged to implement IPM programs because both prospective and retrospective studies show that IPM is more effective than conventional pest control, and it can lead to long-term reductions in cockroach allergens, resulting in a healthier school environment for students and teachers. Our study did not consider the effects of exposure to cockroach allergens on asthma and other health outcomes in children and school workers. Nevertheless, the well-documented relationship between exposure to cockroach allergens and childhood morbidity in inner city homes (Rosenstreich et al. 1997) provides strong support for similar associations in other indoor environments, including schools. Therefore, both the home and school environments should be the principal sites for primary and secondary efforts to prevent allergic disease.

Acknowledgments

We thank Wake County and Guilford County Schools and personnel in the East NC County Schools for excellent cooperation, Drs. C. Brownie and J. Osborne for statistical consulting, and Woodstream (Lititz, PA) for a donation of Victor cockroach traps. Supported in part by the National Research Initiative of USDA Cooperative State Research, Education and Extension Service Grant 2004-35302-14880, USDA–Risk Avoidance and Mitigation Program Grant 2005-51101-02388, the NC Department of Agriculture and Consumer Services Pesticide Environment Trust Fund (1998-1449), and the Blanton J. Whitmire endowment at North Carolina State University.

References Cited

Abramson, S. L., A. Turner-Henson, L. Anderson, M. P. Hemstreet, L. K. Bartholomew, C.L.M. Joseph, S. H. Tang, S. Tyrrell, N. M. Clark, and D. Ownby. 2006. Allergens in school settings: results of environmental assessments in 3 city school systems. J. School Health. 76: 246–249.

Amr, S., M. E. Bollinger, M. Myers, R. G. Hamilton, S. R. Weiss, M. Rossman, L. Osborne, S. Timmins, D. S. Kimes, E. R. Levine, and C. J. Blaisdell. 2003. Environmental allergens and asthma in urban elementary schools. Ann. Allergy Asthma. Immunol. 90: 34–40.

Arbes, S. J., P. J. Gergen, L. Elliott, and D. C. Zeldin. 2005a. Prevalences of positive skin test responses to 10 common allergens in the US population: results from the Third National Health and Nutrition Examination Survey. J. Allergy Clin. Immunol. 116: 377–383.

Arbes, S. J., M. Sever, J. Mehta, N. Collette, B. Thomas, and D. C. Zeldin. 2005b. Exposure to indoor allergens in day-care facilities: results from 2 North Carolina counties. J. Allergy Clin. Immunol. 116: 133–139.

Arbes, S. J., M. Sever, J. Mehta, J. C. Gore, C. Schal, B. Vaughn, H. Mitchell, and D. C. Zeldin. 2004. Abatement of cockroach allergens (Bla g 1 and Bla g 2) in low-income, urban housing: month 12 continuation results. J. Allergy Clin. Immunol. 113: 109–114.

Arbes, S. J., M. Sever, J. Archer, E. H. Long, J. C. Gore, C. Schal, M. Walter, B. Nuebler, B. Vaughn, H. Mitchell, E. Liu, N. Collette, P. Adler, M. Sandel, and D. C. Zeldin. 2003. Abatement of cockroach allergen (Bla g 1) in low-income, urban housing: a randomized controlled trial. J. Allergy Clin. Immunol. 112: 339–345.

Call, R. S., T. F. Smith, E. Morris, M. D. Chapman, and T.A.E. Plattsmills. 1992. Risk factors for asthma in inner city children. J. Pediatr. 121: 862–866.

Chew, G. L., J. Correa, and M. Perzanowski. 2005. Mouse and cockroach allergens in the dust and air in northeastern United States inner-city public schools. Indoor Air 15: 228–234.

Custovic, A., R. Green, S.C.O. Taggart, A. Smith, C.A.C. Pickering, M. D. Chapman, and A. Woodcock. 1996. Domestic allergens in public places. 2. Dog (Can f 1) and cockroach (Bla g 2) allergens in dust and mite, cat, dog and cockroach allergens in the air in public buildings. Clin. Exp. Allergy 26: 1246–1252.

Dey, A. N., and B. Bloom. 2005. Summary health Statistics for U.S. Children: National Health Interview Survey 2003. Vital Health Stat. 10. 223: 1–87.

Eggleston, P. A., D. Rosenstreich, M. Lynn, P. Gergen, D. Baker, M. Kattan, K. M. Mortimer, H. Mitchell, D. Ownby, R. Slavin, and F. Malveaux. 1998. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. J. Allergy Clin. Immunol. 102: 563–570.

Fernandez-Caldas, E., R. Codina, D. K. Ledford, W. L. Trudeau, and R. F. Lockey. 2001. House dust mite, cat, and cockroach allergen concentrations in daycare centers in Tampa, Florida. Ann. Allergy Asthma Immunol. 87: 196–200.

Gelber, L. E., L. H. Seltzer, J. K. Bouzoukis, S. M. Pollart, M. D. Chapman, and T.A.E. Platts-Mills. 1993. Sensitization and exposure to indoor allergens as risk factors for asthma among patients presenting to hospital. Am. Rev. Respir. Dis. 147: 573–578.

Gore, J. C., and C. Schal. 2007. Cockroach allergen biology and mitigation in the indoor environment. Annu. Rev. Entomol. 52: 439–463.

[IOM] Institute of Medicine. 2000. Clearing the air: asthma and indoor air exposures. National Academy Press, Washington, DC.

Krieger, J., L. Song, T. Takaro, and J. Stout. 2000. Asthma and the home environment of low-income urban children: preliminary findings from the Seattle-King County Healthy Homes Project. J. Urban Health Bull. N.Y. Acad. Med. 77: 50–67.

Mannino, D., D. Homa, L. Akinbami, J. Moorman, C. Gwynn, and S. Reed. 2002. Surveillance for asthma-United States, 1980–1999. Surveillance Summaries MMWR 51: 1–14.

Miller, D., and F. Meek. 2004. Cost and efficacy comparison of integrated pest management strategies with monthly spray insecticide applications for German cockroach (Dictyoptera: Blattellidae) control in public housing. J. Econ. Entomol. 97: 559–569.

Perry, T. T., P. A. Vargas, J. Bufford, C. Feild, M. Flick, P. A. Simpson, R. G. Hamilton, and S. M. Jones. 2008. Classroom aeroallergen exposure in Arkansas head start centers. Ann. Allergy Asthma Immunol. 100: 358–363.

Peters, J. L., J. I. Levy, M. L. Muilenberg, B. A. Coull, and J. D. Spengler. 2007. Efficacy of integrated pest management in reducing cockroach allergen concentrations in urban public housing. J. Asthma 44: 455–460.

Platts-Mills, T.A.E., L. M. Wheatley, and R. C. Aalberse. 1998. Indoor versus outdoor allergens in allergic respiratory disease. Curr. Opin. Immunol. 10: 634–639.

Pollart, S., D. Mullins, L. Vailes, M. Hayden, T. Platts-Mills, W. Sutherland, and M. Chapman. 1991. Identification, quantitation, and purification of cockroach allergens using monoclonal antibodies. J. Allergy Clin. Immunol. 87: 511–521.

Rosenstreich, D., P. Eggleston, M. Kattan, D. Baker, R. Slavin, P. Gergen, H. Mitchell, K. McNiff-Mortimer, H. Lynn, D. Ownloy, and F. Malveaux. 1997. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N. Engl. J. Med. 336: 1356–1363.

Sarpong, S., R. Wood, and P. Eggleston. 1996. Short-term effects of extermination and cleaning on cockroach allergen Bla g 2 in settled dust. Ann. Allergy Asthma Immunol. 76: 257–260.

Sarpong, S., R. Wood, T. Karrison, and P. Eggleston. 1997. Cockroach allergen (Bla g 1) in school dust. J. Allergy Clin. Immunol. 99: 486–492.

SAS Institute. 2001. SAS/STAT user's guide. SAS Institute, Cary, NC.

Schal, C., and R. Hamilton. 1990. Integrated suppression of synanthropic cockroaches. Annu. Rev. Entomol. 35: 521–551.

Sever, M. L., S. J. Arbes, J. C. Gore, R. G. Santangelo, B. Vaughn, H. Mitchell, C. Schal, and D. C. Zeldin. 2007. Cockroach allergen reduction by cockroach control alone in low-income urban homes: a randomized control trial. J. Allergy Clin. Immunol. 120: 849–855.

Tranter, D. 2005. Indoor allergens in settled school dust: a review of findings and significant factors. Clin. Exp. Allergy 35: 126–136.

Wang, C. L., M. M. Abou El-Nour, and G. W. Bennett. 2008. Survey of pest infestation, asthma, and allergy in low-income housing. J. Community Health 33: 31–39.

Weiss, K., and S. Sullivan. 2001. The health economics of asthma and rhinitis. I. Assessing the economic impact. J. Allergy Clin. Immunol. 107: 3–8.

Williams, G. M., H. M. Linker, M. G. Waldvogel, R. B. Leidy, and C. Schal. 2005. Comparison of conventional and integrated pest management programs in public schools. J. Econ. Entomol. 98: 1275–1283.

Received 1 October 2008; accepted 26 January 2009.