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# Pesticides in Urban Multiunit Dwellings: Hazard Identification Using Classification and Regression Tree (CART) Analysis

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## ABSTRACT

Many units in public housing or other low-income urban dwellings may have elevated pesticide residues, given recurring infestation, but it would be logistically and economically infeasible to sample a large number of units to identify highly exposed households to design interventions. Within this study, our aim was to devise a low-cost approach to identify homes in public housing with high levels of pesticide residues, using information that would allow the housing authority and residents to determine optimal strategies to reduce household exposures. As part of the Healthy Public Housing Initiative, we collected environmental samples from 42 public housing apartments in Boston, MA, in 2002 and 2003 and gathered housing characteristics; for example, household demographics and self-reported pesticide use information, considering information available with and without a home visit. Focusing on five organophosphate and pyrethroid pesticides, we used classification and regression tree analysis (CART) to disaggregate the pesticide concentration data into homogenous subsamples according to housing characteristics, which allowed us to identify households and associated networks impacted by the mismanagement of pesticides. The CART analysis demonstrated reasonable sensitivity and specificity given more extensive household information but generally poor performance using only information available without a home visit. Apartments with high concentrations of cyfluthrin, a pyrethroid of interest given that it is a restricted use pesticide, were more likely to be associated with Hispanic residents who resided in their current apartment for more than 5 yr, consistent with documented pesticide usage patterns. We conclude that using CART as an exploratory technique to better understand the home characteristics associated with elevated pesticide levels may be a viable approach for risk management in large multiunit housing developments.

### IMPLICATIONS

Pesticide exposures in public housing and other low-income dwellings can be elevated because of frequent use for pest management, but measurements of residue levels are expensive and often impractical. Screening approaches based on demographics, questionnaire information, and home visits are therefore necessary to identify highly exposed households and design interventions. The results of our CART analysis demonstrate that highly exposed households can be detected with reasonable sensitivity and specificity given appropriate information gathering. The results of these analyses may provide insight about approaches to reduce pesticide exposure by identifying networks and routes of exposure.

## INTRODUCTION

The use of chemical pesticides to control cockroach and rodent infestation in inner-city households, particularly in older, poorly maintained housing stock, is a public health concern, especially given that occupants spend most of their time indoors.[1,2] Residents living in large multiunit dwellings (e.g., public housing developments) are especially vulnerable because they are not only exposed to pesticides from personal/household use but from use by maintenance staff or professional pesticide applicators (contracted by property managers). Pesticide burdens may be elevated in these homes because of inadequate and improper professional pest control services, use of banned or restricted-use pesticides, and resource limitations that may include unavailability of vacuum cleaners.

Various sampling and modeling methodologies have been developed to characterize the sources and pathways of pesticide exposure indoors.[3] However, technical, social, and economic challenges and constraints make these methods impractical or prohibitive for routine assessments within inner-city low-income households. In particular, although collecting a representative random sample of pesticide residues can reasonably characterize the central tendency of exposure, this approach will not serve to identify the subset of households with sufficiently elevated exposures that would require interventions. Thus, alternative classification schemes to quickly identify high-risk homes are needed.

In this study, our aim was to identify households with the highest burden of pesticide residues for selected pesticides. Classification and regression tree (CART) analysis is one approach that can provide this identification. CART is a nonparametric procedure[4,5] that has been applied in several disciplines including environmental health studies to build predictive models.[6] CART works by disaggregating data into homogeneous subsamples and is applicable in settings with small sample sizes and multivariate comparisons as well as multiple interactions between variables. CART analysis provides a qualitative classification, a potential limitation of the method in some settings. However, from a risk management perspective, we are more concerned with identifying high-risk households than with capturing the quantitative relationships among variables. Given the high cost of pesticide sampling, which limits sample size, and the numerous factors potentially associated with pesticide levels in urban low-income housing, CART is a potentially informative approach.

In this study, we used the CART method with household information obtained from a review of existing files and databases and data collected during home visits to allow us to identify households and associated networks in a way that would allow for interventions to be developed and applied. We focused on five organophosphate and pyrethroid pesticides, which may have different sources, environmental fate and transport, and associated predictors. We separately considered information available from file reviews and from home visits to determine if homes can be adequately classified without more expensive and labor-intensive home visits. We conclude by determining whether the insights gained from CART analysis are in agreement with field observations for a pesticide with clearly identified subpopulations of users.

## EXPERIMENTAL METHODS

The Healthy Public Housing Initiative (HPHI) was a longitudinal intervention study targeting apartments of pediatric asthmatics (between 4 and 17 yr of age) living in three housing developments in Boston, MA. The ethnic make-up of the households participating in this study was 64% Hispanic and 36% Black, with similar composition across developments.[7] As a component of this asthma intervention study, which is described elsewhere,[7,8] we collected environmental and household-specific information during 2002 and 2003 from the following three developments: West Broadway ($n$ = 17), Washington Beech ($n$ = 6), and Franklin Hill ($n$ = 19). Vacuum dust in living room and floor wipe samples in the kitchen and living room were collected from each apartment and served as the dependent data in the CART analysis. On the basis of Spearman correlations that showed modest but significant correlations between the two sampling methods,[9] only the kitchen floor wipe samples will be discussed in this article.

The kitchen floor wipe samples were collected using a method adapted from the National Human Exposure Assessment Survey in Arizona (NEXHAS-AZ)[10] and were collected from vinyl flooring in standardized locations adjacent to the stove. The sampling involved wiping a 1-ft$^2$ area (0.0929 m$^2$) with a 3-in$^2$ (58 cm$^2$) sterile gauze, wetted with 5 mL of a 99% isopropyl alcohol solution. The samples were collected and placed in 60-mL amber glass jars and stored in a freezer at −22 °C. Chemical analyses of samples were conducted using gas chromatography–mass spectrometry. Additional information on sampling methods can be found elsewhere.[9]

We focused on the following five organophosphate and pyrethroid pesticides on the basis of the detection of these pesticides in more than 70% of the homes: chlorpyrifos (100%), permethrin (100%), diazinon (98%), cypermethrin (90%), and cyfluthrin (71%) (Table 1). To apply the CART analysis, we needed to determine a breakpoint that would separate highly exposed from less exposed households. We classified homes as being at high risk of exposure to a particular analyte if the residues were at or above the 75th percentile. This threshold was chosen for two reasons: (1) higher thresholds were not feasible because of the relatively small sample size, and (2) lower thresholds may not provide adequate discrimination for responsible authorities with limited budgets (e.g., public housing authorities).

To obtain a CART model that selects a set of predictors that correctly depicts highly exposed households without "overfit," we used a combination of cross-validation techniques and an adapted version of the "dependent:independent" ratio of 10:1.[11] Applying this guideline, all models were limited to a maximum of three independent variables. Information on household characteristics was categorized into two tiers and is summarized in Table 2.

The tiers represent differences in the level of difficulty required to obtain the information on households. Tier 1 information can be readily obtained through a review of existing files by a building manager (e.g., housing authority) and does not require a home visit. It includes tenant ethnicity, the number of years the tenant has lived in the current apartment, and the renovation status of the development (e.g., energy- and water-saving upgrades such as installation of exhaust fans and roof, wall, and piping repairs). Collection of Tier 2 information is more labor intensive and requires a home visit, which includes a visual inspection of the home and interviews with the residents. Collected information included an assessment of the severity of a

**Table 1.** Summary statistics for pesticide prevalence (percent above limit of detection [LOD]) and pesticide loadings in kitchen (μg/m$^2$).

| Analyte | Mean LOD | %>LOD | Minimum | Median | 75th Percentile | Maximum |
|---|---|---|---|---|---|---|
| Chlorpyrifos | 0.05 | 100 | 0.03 | 0.3 | 1.3 | 19.5 |
| Permethrin | 0.01 | 100 | 0.21 | 6.8 | 33 | 226.5 |
| Diazinon | 0.02 | 98 | <LOD | 0.4 | 2.6 | 556.2 |
| Cypermethrin | 0.08 | 90 | <LOD | 3.7 | 16.2 | 330.7 |
| Cyfluthrin | 0.12 | 71 | <LOD | 1.1 | 16.4 | 567.1 |

**Table 2.** Resident information used in CART analysis.

| Variable | Potential Response |
|---|---|
| Tier 1 | |
| Years in current apartment | >5 yr, ≤5 yr |
| Ethnicity | Hispanic, African-American |
| Renovated development | Yes, no |
| Number of work order requests | None, ≥1 |
| Tier 2 | |
| Report of housekeeping practices | Good, poor |
| Consultant's report of roach problem | Mild, severe |
| Residents' self-report of roach problem | Mild, severe |
| Use of sprays | Yes, no |
| Use of traps | Yes, no |
| Use of gels | Yes, no |
| Use of smoke bombs | Yes, no |

roach problem (by a contractor and the resident), the type of pesticide used or found in the home (and frequency of its use), and other household attributes pertaining to pest control activities such as housekeeping practices.

CART was first applied to the pesticide data using Tier 1 variables, but then it was rerun with both Tier 1 and 2 variables. Because the CART method we used required complete information for each of the variables, the number of households available for the two CART applications varied. When Tier 1 variables were used, 33 households had complete data, but the sample size was reduced to 28 when both tiers were used in the analysis. To interpret the results of the CART analysis, we computed the values for specificity (percent correctly assigned to low exposure group) and sensitivity (percent correctly assigned to high exposure group) for Tier 1 and Tiers 1 and 2 combined for each respective pesticide. To perform the CART analysis we used S-PLUS for Windows (Seattle, WA: Insightful Corp.)[12] functions to create classification trees. Our independent variables included various home and resident characteristics and our dependent variable was the categorization of pesticide concentrations from wipes into either greater or less than the 75th percentile. After growing the full tree (i.e., where the algorithm continued to search for distinguishing characteristics until each home had its own terminal node), we used 10-fold crossvalidation to aid in determining the optimal tree that balanced accurate classification and overfitting of the data to the tree. The crossvalidation method randomly split the data into 10 subsets and used 90% for training the data and creating the tree, and 10% to test the created tree and obtain a misclassification rate. This procedure was repeated 10 times, in which each of the 10 subsets were used as the training data. Thus 10 misclassification rates were obtained. The optimal tree was then the one that had the minimum misclassification rate. Where more than one tree yielded the same misclassification rate, best judgment was used to choose the optimal tree. The tree was then pruned to reflect the number of nodes and/splits in the optimal tree.

## RESULTS AND DISCUSSION

To utilize and interpret the CART analysis fully, it is important to understand the magnitude and distribution of the individual analytes across our study homes. These data are summarized in Table 1 and have been presented in detail elsewhere.[9] Briefly, the cumulative frequency distributions of pesticide loadings revealed loadings of target pyrethroids (permethrin, cyfluthrin, and cypermethrin) exceeding that of target organophosphates (diazinon and chlorpyrifos) by several orders of magnitude, with the distribution of cyfluthrin somewhat broader and more skewed than the distributions for the other pyrethroids.

Using Tier 1 information commonly available to managers of public housing developments, such as the ethnicity of the household and the length of time that a family had been living in their current apartment, the CART analysis failed to identify factors related to high concentrations of the two organophosphates pesticides (chlorpyrifos and diazinon) and one pyrethroid (permethrin) with all households categorized in the low exposure grouping (Table 3). Sensitivity was low for cypermethrin as well (11%), but moderate for cyfluthrin (56%). However, Tier 2 data provided by residents, such as self reports on the severity of the roach problem in their apartment, greatly improved the ability to classify households, with sensitivity increasing to 100% for diazinon, 78% for chlorpyrifos, 80% for permethrin, and relatively high specificity as well. Performance for cypermethrin improved with Tier 2 data but remained inadequately sensitive, and cyfluthrin was reasonably well captured with Tier 1 data and improved slightly with the addition of Tier 2 data (Table 3).

**Table 3.** Comparison of the ability of Tier 1 ($n = 33$) or both Tier 1 and Tier 2 ($n = 28$) covariates to identify households at or above the 75th percentile in pesticide concentrations.

| Tiers | Measure | Diazinon (%) | Chlorpyrifos (%) | Permethrin (%) | Cypermethrin (%) | Cyfluthrin (%) |
|---|---|---|---|---|---|---|
| 1 | Sensitivity | 0 | 0 | 0 | 11 | 56 |
| | Specificity | 100 | 100 | 100 | 100 | 92 |
| 1 and 2 | Sensitivity | 100 | 78 | 80 | 44 | 67 |
| | Specificity | 63 | 74 | 96 | 100 | 95 |

**Table 4.** Predictors for identifying households at or above the 75th percentile in pesticide concentrations.

| Pesticide | Tier 1 | Tiers 1 and 2 |
|---|---|---|
| Diazinon | [a] | Currently living in unrenovated housing |
| Chlorpyrifos | [a] | Do not use smoke bombs<br>House keeping practices was assessed as poor during site visit |
| Permethrin | [a] | Residents' self-report of severe roach problem in the home |
| Cyfluthrin | Living in current apartment for more than 5 yr,<br>Being Hispanic | Being Hispanic<br>Living in current apartment for more than 5 yr<br>Residents' self-report of severe roach problem in the home |
| Cypermethrin | Having no work order requests at start of the study,<br>Being Hispanic | Consultant's assessment of mild roach problem in the home<br>Residents' self-report of severe roach problem in the home |

*Notes:* [a]No predictors of target households were observed.

Focusing on the two pyrethroids (cypermethrin and cyfluthrin) with non-zero sensitivity in Tier 1 analyses, we can examine if predictors are interpretable. For cyfluthrin, elevated exposures were found among Hispanic households living in the current apartment for 5 yr or more (Table 4). Cypermethrin was similarly predicted by Hispanic status, along with the number of work order requests made by the household at the start of the study (with fewer work order requests indicating higher exposures). The reason for the association between elevated cypermethrin levels and fewer work orders is unclear. However, it was not uncommon to learn about families who refused to submit work orders to address the roach problem and/or conditions in the homes conducive to pest problems; for example, leaky faucets and holes in the walls. The apathy towards this form of redress was based on the general perception that these problems would not be corrected in a very expeditious manner, which could lead households to conduct their own pest management without addressing structural issues.

Looking at the addition of Tier 2 data for the organophosphate pesticides (chlorpyrifos and diazinon), the levels were best predicted by whether the development had been renovated (with higher exposures in unrenovated developments) and poor housekeeping (Table 4). The latter could be an indication of more substantial dust reservoirs, which may have greater reserves of these pesticides. House dust can potentially act as a reservoir for pesticides applied indoors when compared with pesticides applied outdoors, because the house dust matrix protects the pesticide from photodegradation and microbial activity.[13,14] Moreover, because these two organophosphates are no longer registered for home use by the U.S. Environmental Protection Agency,[15,16] detection in the homes could be a function of persistence and not current use.

In the case of the pyrethroids (permethrin, cyfluthrin, and cypermethrin), the resident's self report of a severe roach problem was a significant predictor of high exposures for all three pesticides (Table 4). These results were different from those for the organophosphate pesticides, likely related to the degree of current versus historical use. For the pyrethroids, the predictors seem more indicative both of current pesticide use and that a self-report encompasses differential sensitivity across individuals to roach infestation, which would not be captured in the pest consultant's assessment. For example, for cypermethrin, high-exposure households were those in which the residents perceived a severe roach problem but the pest consultant did not. Thus, determining factors that contribute to gaps in perception between residents and pest consultants as well as influences of perceptions on choices among pesticides would greatly inform our understanding of pesticide application patterns and subsequent high-exposure households.

An important issue to consider in interpreting our findings is whether the available covariates are interpretable and adequately capture the complex dynamics of pesticide use in public housing. Pesticides currently being used by this cohort include restricted use pesticides (RUPs), which could pose health risks to residents because of misuse. An example is cyfluthrin, the active ingredient in a product known as Tempo WP, which is a RUP in certain formulations. As mentioned above, the observed predictors of high concentrations of cyfluthrin included Hispanic ethnicity and living in the current apartment for more than 5 yr. This result is consistent with the information provided by families and general observations made in the field. According to field staff accounts, Hispanic families gained access to Tempo WP through a network of relatives and friends that also included purchases at local Latin American markets (bodegas). Longer-term residents would be expected to have stronger social networks that could facilitate access to Tempo WP. This pattern of access to restricted and illegal pesticides is also consistent with findings in other studies that have looked at pesticide use among inner-city residents.[17]

Additionally, on the basis of information received from the families, the product was purchased from bodegas without labeling instructions. Tempo WP in its powder form has some physical similarities with boric acid (a more benign product with an oral $LD_{50}$ value between 5280 and 5830 mg/kg in rats, compared with Tempo WP with an oral $LD_{50}$ value between 869 and 1271 mg/kg in rats).[18] Possibly because of this fact, in some households Tempo WP was applied as a powder rather than as a paste (at lesser concentrations) per labeling instructions. Thus, the misapplication of this product could result in higher cyfluthrin concentrations in the home, and could explain the highly skewed concentration data observed from the cumulative frequency distribution for the 42 households, which showed that cyfluthrin loadings of households in the >90th percentile exceeded the median value by over 2 orders of magnitude. It should also be noted that the Boston Housing Authority indicated that the pesticide products (pesticide gels) used by the current pest contracting services contained hydramethylnon as the active ingredient.

More generally, our CART results may indicate that many pest control practices are not readily predicted by publicly available information, with the possible exception of cyfluthrin, which has a well-identified ethnic predictor with a plausible causal interpretation in our cohort. This may be partly because, given our small sample size, we specified the maximum number of nodes for the model to limit overfitting and to help minimize models with illogical interpretations. Our small sample size also did not allow us to reasonably test the sensitivity of our findings to a range of appropriate thresholds to distinguish between high and low pesticide burdens. In addition, the changing sample size across analyses coupled with the small sample size led to some shifting in findings as Tier 2 data were added into the analysis; for example, high exposures to cypermethrin were predicted by having no work order requests in the Tier 1 analysis, but not in the Tier 1 and 2 analysis.

## CONCLUSIONS

Although the accuracy of CART may be sensitive to variable selection, these models are easily interpretable and better equipped to handle mixed data types, complex interactions between independent variables, and nonlinear cases than standard linear models.[19]

In our application of CART, this technique demonstrated reasonable sensitivity and specificity for models with more extensive covariate information and for selected current-use pesticides, but generally poor performance using only information available without a home visit, except for the case of cyfluthrin. Moreover, CART has many appealing risk management features, because outputs are readily interpretable to decision-makers considering pesticide mitigation strategies. It may be likely that some of our specific results do not generalize to other settings, given the unique social, physical, and demographic characteristics of the housing developments we studied. However, the results were generally physically interpretable, and our findings for pesticides such as cyfluthrin are likely robust across other urban settings with strong ethnically linked social networks that facilitate access to Tempo WP and other RUPs.

Our CART evaluation has also helped to inform current intervention strategies, including a pesticide buyback program in Boston public housing and outreach and education efforts directed at neighboring bodegas. Although these efforts were still in their infancy at the time this manuscript was prepared, they hold much promise to both safeguard and empower residents in these developments who are challenged by the practice of safe and effective pest control methods.

In conclusion, despite labeling requirements and other pesticide regulations, certain communities remain vulnerable to elevated exposures by reason of poverty, language, housing conditions, and health status (i.e., high asthma prevalence, which may lead to more aggressive actions against sources of allergens). Our CART analysis provides an approach to identify high-risk subpopulations within these vulnerable communities, informing the design of intervention strategies. The public health response to the problems identified in this study, namely promoting integrated pest management with peer education about pesticide toxicity, a pesticide buyback program, and an outreach program to bodegas on pesticide hazards, will help improve the health of residents in low-income, multifamily housing.

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