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Original Contribution

Linking Mosquito Infestation to Resident Socioeconomic Status, Knowledge, and Source Reduction Practices in Suburban Washington, DC

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Abstract: Eliminating water-holding containers where mosquitoes oviposit and develop (source reduction) can help manage urban disease-vector mosquitoes. Source reduction requires residents to be knowledgeable of effective practices and motivated to implement them. We tested relationships between demographics, resident knowledge, attitudes, and practices (KAP), and mosquito infestation by administering larval mosquito surveys and KAP questionnaires in Washington, DC. Respondents who reported practicing source reduction had lower numbers of pupae-positive containers and *Culex pipiens*-positive containers, but not *Aedes albopictus*-positive containers or water-holding containers, in their yards. When controlling for numbers of water-holding containers in statistical models, residents who reported source reduction had lower numbers of *A. albopictus*-positive containers in addition to numbers of pupae-positive containers and *C. pipiens*-positive containers. These results suggest that while active container reduction may be effective at reducing *C. pipiens* and overall pupal production, it may be offset by other resident activities that add containers to yards, and that source reduction that involves mosquito habitat management without outright container removal can also be effective at reducing *A. albopictus*. Source reduction was related to respondent knowledge of mosquitoes and, in particular, specific knowledge of mosquito development, which both varied with demographics alongside respondent motivation to control mosquitoes. Respondents from high socioeconomic status households reported greater knowledge but lower motivation than respondents from middle and low socioeconomic-status households. We conclude that mosquito-related education will help promote community-based container management as part of integrated mosquito management programs, particularly in middle and low socioeconomic status neighborhoods with lower knowledge and high motivation.

Key words: *Aedes albopictus*, *Culex pipiens*, Human–environment system, Integrated pest management, Socioeconomic, West Nile virus

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Introduction

Mosquito-borne diseases and pestiferous mosquito species are growing human health concerns in many urban areas worldwide. *A. albopictus*, the Asian tiger mosquito, and *C. pipiens*, the northern house mosquito, are among the most important disease-vector mosquito species in North America and elsewhere. *A. albopictus* invaded the continental United States in the mid-1980s, and has since spread rapidly throughout the southeastern part of the country (Sprenger and Wuithiranyagool 1986; Benedict et al. 2007). *A. albopictus* has become one of the most common human-biting urban mosquitoes in its new range (Barker et al. 2003; Braks et al. 2003), and is a capable vector for West Nile virus (WNv), La Crosse (LAC) encephalitis, and Eastern equine encephalitis (EEE) (Gerhardt et al. 2001; Turell et al. 2005; Leisnham and Juliano 2012), as well as chikungunya and dengue, which could invade from outside the country (Ibañez-Berñal et al. 1997; Gratz 2004). *C. pipiens* invaded North America over 200 years ago and is common in urban areas throughout the northern United States (Vinogradova 2000; Darsie and Ward 2004). Although not usually an aggressive human biter, laboratory, and field studies implicate *C. pipiens* as the principal WNv vector in the northern United States (Turell et al. 2005; Fonseca et al. 2004).

A. albopictus and *C. pipiens* are both refractory to conventional abatement in residential areas (Paupy et al. 2009). Adulticiding is costly and raises human health concerns. It is also largely ineffective against *A. albopictus* since the species is active during the daytime when spraying is rarely performed (Leisnham 2011). In urban areas, *A. albopictus* and *C. pipiens* mainly oviposit and develop in water-holding containers (e.g., bird baths, buckets, trash receptacles). While larvicides (e.g., *Bacillus thuringiensis* (*Bti*) or methoprene) can be applied to these habitats, most mosquito control agencies do not have the funding, personnel, or legal authority to access containers in private yards. Instead, the management of mosquito container habitats, or "source reduction", by residents can be a cost-effective means of controlling urban mosquitoes (Kay and Sinh Nam 2005), and is recommended by the World Health Organization for control of urban vector species worldwide (WHO 1997).

Effective management of *A. albopictus* and *C. pipiens* likely depends on the knowledge, attitudes and practices (KAP) of residents. Most studies investigating relationships between KAP and mosquito infestation have been conducted in developing countries where there are greater disease risks and where source reduction is a common mosquito control strategy (WHO 1997). Some studies have shown that education campaigns can be associated with increased household knowledge of mosquito-borne diseases and mosquito-prevention practices (Leontsini et al. 1993; Degallier et al. 2000; Winch et al. 2002; Sanchez et al. 2005), or decreased mosquito infestation (Lloyd et al. 1992; Leontsini et al. 1993; Espinoza-Gómez et al. 2002; Sanchez et al. 2005). Other studies, however, have shown that while education campaigns may promote greater mosquito-related knowledge, they do not lead to a reduction in mosquito populations (Rosenbaum et al. 1995; Degallier et al. 2000; Winch et al. 2002; Koenraadt et al. 2006). Relationships among household knowledge, source reduction, and mosquito populations are further complicated by differences among socioeconomic or demographic groups (van Benthem et al. 2002; Koenraadt et al. 2006; Sharma et al. 2007). Socioeconomic indicators have been associated with differing rates of source reduction, mosquito infestation, and disease incidence (e.g., Waterman et al. 1985; Hossain et al. 2000; Vinod Joshi et al. 2006; Hu et al. 2007; David et al. 2009). *A. albopictus* populations have been commonly associated with low socioeconomic levels (Chambers et al. 1986) but large populations can also be associated with higher-income areas (WHO 1986).

Fewer studies have examined links between resident knowledge of mosquitoes, source reduction practice, and mosquito infestation in developed countries. In North America, questionnaire results indicate high overall knowledge of WNv in urban populations, but not necessarily effective source reduction practice (Averett et al. 2005; Fox et al. 2006; Elliott et al. 2008; Grantham et al. 2009). Some studies have failed to detect reductions in mosquito-infested containers in residential neighborhoods after circulating black-and-white educational literature and other passive informational campaigns (Schreiber and Morris 1995; Bartlett-Healy et al. 2011). The only North American study that we are aware of to combine mosquito larval surveys with resident knowledge questionnaires found no association between knowledge or reported source reduction practice and numbers of mosquito-positive containers in residential yards (Tuiten et al. 2009). Moreover, as in developing countries, demographic variation can further complicate relationships among resident knowledge, practice, and mosquito infestation in developed countries. Lower rates of mosquito-related knowledge and source reduction have been observed among non-English speaking residents (Averett et al. 2005; Fox et al. 2006) and adult female *A. albopictus* have been positively associated with poverty levels (Unlu et al. 2011).

A better understanding of relationships between KAP and mosquito infestation along socioeconomic and other demographic gradients is needed to better predict mosquito infestation and inform community-based mosquito management. Because social and environmental context vary within urban areas and among regions, it is particularly important to test these relationships in North America where we have relatively little information on the social factors influencing resident-based source reduction. In this study, we conducted paired KAP questionnaires and mosquito surveys of households among socioeconomically diverse households in metropolitan Washington, DC.

Materials and Methods

Study Site

Five neighborhoods in Washington, D.C. (Deanwood, Georgetown, Petworth, Shepherd's Park, Trinidad) and one neighborhood in Montgomery Co., Maryland (Silver Spring) were selected to study. Neighborhoods were 186–414 ha and within 15 miles of each other. Data from the Potential Rating Index for Zipcode Markets (PRIZM) indicated that these neighborhoods provided a range of household socioeconomic and demographic conditions (Claritas 1999). We visited households in each neighborhood in summer (June–August) 2010, during the peak period of mosquito activity in the region (Leisnham, unpublished data). We visited each neighborhood twice during each of four 2-week sampling periods, and sampled at least five randomly selected households per visit during daylight hours (12:00 to 8:00 PM), to total at least 40 visited households per neighborhood. Apartment complexes and condominiums were not sampled. Households sampled on the sample collection date were located at least two city blocks from each other to insure spatial independence. If residents were not available at a preselected household, we proceeded to a neighboring house until sampling consent was granted.

KAP Questionnaires

One consenting adult (>18 years-old) completed a KAP questionnaire at each household. Demographic information was collected on respondent age, gender, and education, and household income, size (number of residents), and ownership status (rent, own). Questionnaire responses personally relevant to the individual respondent were assumed to be representative of the household.

Knowledge

Respondents were assigned an overall knowledge score based on their answers to three questions on mosquitoes. Question one asked what diseases are carried by local mosquitoes. Respondents who reported WNv or EEE scored 1 point. Other responses scored 0. No respondents reported LAC. Question two asked what animals are susceptible to locally transmitted mosquito-borne diseases. Respondents who reported WNv or EEE in question one, scored 1 point if they reported birds or horses. Other responses scored 0. For question three, respondents scored 1 point if they identified mosquito developmental sites as standing water, stagnant water, water, wet places, or damp or moist places. Other responses scored 0. Each respondent received a total score of 0–3 for overall index of knowledge.

Attitudes

Respondents were scored on their answers to four questions concerning their relationships with mosquitoes that likely affect their attitudes toward mosquitoes and motivation to undertake mosquito management. Question one required respondents to rate their concern of diseases transmitted by mosquitoes on a five-point scale. Because we deemed a high level of concern necessary to encourage prevention practices, respondents who rated their concern level as 4–5 scored 1 point for this question. Other responses scored 0. Question two asked how often respondents were bitten by mosquitoes. We considered residents who were often bothered by mosquitoes more likely to take preventive action, therefore respondents who reported that they were bothered daily or a few days a week by mosquitoes in the summer scored 1 point. Respondents reporting being bothered a few days a month or fewer scored 0. Question three asked if mosquitoes altered their behavior because of pestiferous mosquitoes. Those who reported altered their behavior scored 1 point. Respondents reporting no altered behavior scored 0. Question four asked who was most responsible for mosquito control. Respondents who identified residents as most responsible for mosquito control, or acknowledged a shared responsibility between control agencies and residents scored 1 point. Other responses scored 0. Respondents received a total score of 0–4 as an overall index of their motivation to control mosquitoes.

Practices

We asked respondents a yes/no question about whether they reduced mosquito populations in their yard. If residents reported that they reduced mosquitoes, we then asked residents what mosquito-reduction strategies they implemented and recorded whether or not they practiced source reduction since that is the focus of this study. Source reduction can include removing containers, emptying water-holding containers (but not removing them) and applying larvicides to containers (e.g., *Bti*, salt, oil). In this study, the majority of respondents that indicated that they practiced source reduction gave general or multiple responses indicating source reduction. Because it was difficult to determine the specific source reduction action that respondents practiced, we only recorded the practicing (or lack thereof) of source reduction.

Mosquito Surveys

At each household, we requested consent to survey the yard for all water-holding containers and larval mosquitoes. During each survey, we systematically searched for and enumerated all water-holding containers. For each container, we collected all larvae and pupae. For containers that could not be entirely inspected, we homogenized water by stirring before collecting a subsample of at least 0.5 L. For the vast majority of water-holding containers (88.7%, $n = 850$), we sampled at least 25% of their total water, thus we were confident of detecting mosquito infestation for the vast majority of containers. Collected mosquito larvae were preserved in ethanol and later identified. From each container, we randomly identified up to 50 third or fourth larvae to species using an established key (Darsie and Ward 2004). Up to 50 first or second instar larvae were identified to genus and their species was estimated based on co-occurring late-instar larvae. We did not determine the species identification for pupae because no rigorous pupal keys are available.

Data Analysis

We administered 250 total KAP questionnaires but not all questions were answered on each questionnaire. Questionnaires were complemented by mosquito surveys at 240 households.

Relationships between neighborhood, demographic factors, knowledge, attitudes, practices, and mosquito abundances were analyzed using regression models following a step-wise approach (SAS Institute Inc 2003) (Figure 1). Linear regressions (PROC GLM) were used to analyze effects of demographics [household income, education, age, gender, ownership (rent vs. own), household size (number of residents), and neighborhood] and collection date on overall knowledge and motivation. There is considerable literature on the treatment of ordinal and interval data, with strong arguments favoring the application of *F* tests to ordinal-scale data (e.g., Hatwell and Gatti 2001; Norman 2010). We took an operational theoretical approach wherein statistical techniques are considered independent of measurement scale and instead dependent on the distribution of the dependent variable (Gaito 1980; Knapp 1990). *F* tests are generally robust to departures of parametric assumptions (normality and homogeneity of variances) (Carifio and Perla 2008), especially when used on indices from summed binary items which then act like interval-scale data (Norman 2010). In our study, overall knowledge and motivation approximated parametric assumptions; thus we consider the use of *F* tests on such data appropriate. Effects of demographics, overall knowledge, and motivation were tested on resident-reported source reduction and numbers of water-holding containers, using logistic (PROC LOGISTIC; SAS Institute Inc 2003) and negative binomial (PROC GENMOD) regressions, respectively. In follow-up tests, we replaced overall knowledge with specific knowledge of mosquito development as independent and response variables to test relationships with knowledge likely to be particularly important for source

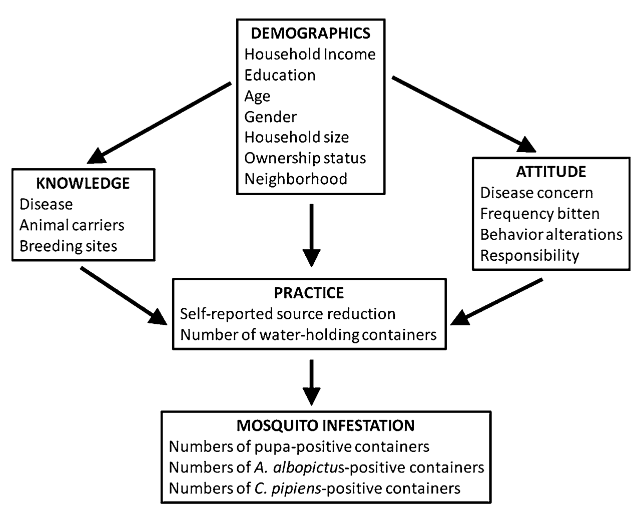

Figure 1. Diagram of relationships among demographics, knowledge, attitude, practices, and mosquito infestation.

reduction. Linear regressions was used to test effects of resident-reported source reduction and container number on household numbers of pupae-positive, *A. albopictus*-positive, and *C. pipiens*-positive containers, while controlling for collection date. Because the numbers of water-holding containers are only partly regulated by resident-based source reduction, we also tested effects of resident-reported source on numbers of mosquito indices while controlling for numbers of water-holding container in models.

For all analyses, factors with a screening significance of $P < 0.25$ in single-factor tests were included in multi-factor models with all estimable two-way interactions. Final multi-factor models were selected using backward selection. All two-way interactions were nonsignificant and eliminated. If there was no significant loss of fit, as evaluated by a partial F test or comparison of -2 log likelihoods, we continued to eliminate the next least significant variable until all non-significant variables were removed or until there was significant loss of model fit. Multi-colinearity was tested for all multi-factor tests by means of variance inflation characteristics (VIF), with a VIF above 5 for a variable indicating a problem (Kutner et al. 2004); however, none were evident. For linear and negative bionomial regressions we tested for significant differences among factor levels using pairwise contrasts (Scheiner and Gurevitch 2001), with sequential Bonferroni correction for all possible comparisons within each analysis. All tests used $\alpha = 0.05$ to determine statistical significance.

Results

Knowledge

Over 30% of respondents correctly identified WNv or EEE as local mosquito-transmitted diseases, while 16% of respondents incorrectly identified malaria (Table 1). The majority of respondents, 79%, correctly identified standing water, stagnant water, wet places, or water as mosquito development sites. Overall knowledge varied with income, education, and age in single-factor tests (Table 2). In multi-factor tests, overall knowledge varied with income ($F_{2,146} = 4.34$, $P = 0.0148$) and age ($F_{1,146} = 3.94$, $P = 0.0491$). Respondents from high-income households had greater knowledge than middle-income households and younger respondents had greater knowledge than older respondents (Figure 2). Specific knowledge of mosquito development varied by income, education, gender, and age in single-factor tests (Table 2). In multi-factor tests, specific knowledge varied with education ($\chi^2_1 = 10.91$, $P = 0.0010$), gender ($\chi^2_1 = 6.42$, $P = 0.0113$), and age ($\chi^2_1 = 7.76$, $P = 0.0053$), with male (odds ratio [OR] = 4.05), higher educated (college degree vs. no degree; OR = 6.64), and older (>46 vs. 18–45 years; OR = 4.90) residents more likely to have specific knowledge of mosquito development than female, lower educated (no degree), and younger residents (18–45-years old), respectively.

Table 1. Questionnaire Responses to Open-Ended Questions on Mosquito Knowledge

	Number of residents (%)
Diseases in region	
WNv	72 (28)
EEE	4 (2)
Malaria	40 (16)
Other	29 (12)
Do not know	105 (42)
Animal carriers	
Birds	35 (14)
Horses	2 (1)
Dogs/cats	72 (29)
All animals	23 (9)
Other	21 (8)
Do not know	97 (39)
Development site	
Standing water	198 (79)
Moist or damp places	8 (3)
Vegetation	13 (5)
Other	7 (3)
Do not know	24 (10)

Attitudes

Nearly half of all respondents (46%) reported great concern towards mosquito-transmitted disease, scoring 4 or 5 on the five-point scale (Table 3). A majority of respondents reported frequently being bothered by mosquitoes, with 47% reporting being bothered daily in the summer, and an additional 28% being bothered several days a week (Table 3). Sixty-one percent of respondents reported that mosquito biting influenced their behavior (Table 3), mostly forcing them not to spend time outside, take walks, or garden (not shown). Sixty-five percent of respondents thought that residents should be at least partially responsible for mosquito control, while 68% of respondents thought that public agencies or landlords were at least partially responsible for control (Table 3). Motivation

Table 2. Linear Model Results of Respondent Demographics on Overall Knowledge, Motivation, and Specific Knowledge of Mosquito Development

	Overall knowledge			Specific knowledge			Motivation		
Factor	*df*	*F* value	*P* value	*df*	X^2	*P* value	*df*	*F* value	*P* value
Income	2,149	4.24	0.0163	2	4.09	0.1291	2,149	5.10	0.0072
Education	3,200	5.09	0.0251	1	10.77	0.0010	3,200	3.30	0.0710
Gender	1,239	0.31	0.5755	1	8.93	0.0028	1,239	6.25	0.0131
Age	1,235	2.22	0.1380	1	7.21	0.0072	1,235	0.06	0.7993
Ownership	1,179	0.05	0.8184	1	1.58	0.2083	1,179	0.29	0.5925
Household size	1,143	2.23	0.1377	1	1.97	0.1595	1,143	0.79	0.4297
Neighborhood	5,244	4.65	0.0004	5	19.62	0.0014	5,244	2.95	0.0131
Date	1,248	0.25	0.6167	1	0.22	0.6439	1,248	14.73	0.0002

Factors with $P < 0.250$ were included in multi-factor models.

varied with income, gender, and marginally with education in single factor tests (Table 2). In multi-factor tests, motivation varied with income ($F_{2,146} = 5.24$, $P = 0.0063$), while gender remained in the final model and was marginally significant ($F_{1,146} = 3.74$, $P = 0.0550$). Respondents from low-income households showed higher motivation to control mosquitoes than respondents from high-income households (Figure 3).

Practice

Combined across all neighborhoods, 45% ($n = 206$) of respondents who identified water as a mosquito developmental site reported practicing source reduction. Resident-reported source reduction varied with overall knowledge, specific knowledge, age, ownership status, and neighborhood in single-factor tests (Table 4). In multi-factor models, source reduction varied with overall knowledge ($\chi^2_1 = 8.18$, $P = 0.0042$), specific knowledge of mosquito development ($\chi^2_5 = 4.44$, $P = 0.0035$), age ($\chi^2_1 = 14.93$, $P = 0.0001$), and neighborhood ($\chi^2_5 = 17.46$, $P = 0.0037$). Source reduction increased among respondents with higher overall knowledge (OR = 1.73) and was much more likely among residents with specific knowledge of mosquito development (OR = 4.03). Source reduction also was more likely undertaken by older residents (>46 vs. 18–45 years; OR = 3.75). No pairwise differences in source reduction were detected among individual neighborhoods after Bonferroni corrections ($P > 0.038$). Numbers of water-holding containers varied with overall knowledge, gender, education, and date in single-factor tests (Table 4). In

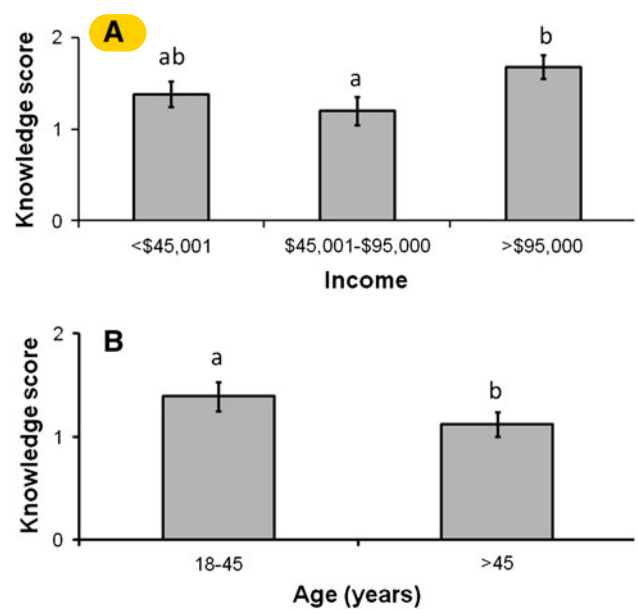

Figure 2. Mean (±1 SE) overall knowledge scores by **a** household income and **b** age. Different *letters* denote statistical significance among factor levels ($P < 0.05$).

multi-factor models, container numbers varied with education ($\chi^2_1 = 4.96$, $P = 0.0259$), with higher educated households having fewer containers (Figure 4), and collection date ($\chi^2_1 = 8.25$, $P = 0.0041$), with households sampled later in the summer having more containers (not shown). Age ($\chi^2_1 = 2.39$, $P = 0.0699$) and household size ($\chi^2_1 = 3.21$, $P = 0.0730$) remained in the final model and were marginally significant. Households with younger respondents and that had fewer members had lower container numbers (trends not shown). Container numbers did not vary between households where respondents

Table 3. Questionnaire Responses to Open-Ended Questions on Attitudes to Mosquitoes

	Number of residents (%)
How concerned about disease (n = 184)[a]	
0–3 Score	99 (54)
4–5 Score	85 (46)
How often bitten (n = 246)	
Everyday	118 (48)
Few days a week	70 (28)
Few days a month or fewer	58 (24)
Mosquitoes alter behavior (n = 247)	
Yes	150 (61)
No	97 (39)
Responsibility for control (n = 250)	
Residents	57 (23)
Public agency and/or landlord	66 (26)
Shared between resident and agency or landlord	104 (42)
No one	23 (9)

[a]Respondents scored concern of mosquito-transmitted diseases on a six-point scale, with *larger numbers* representing greater concern.

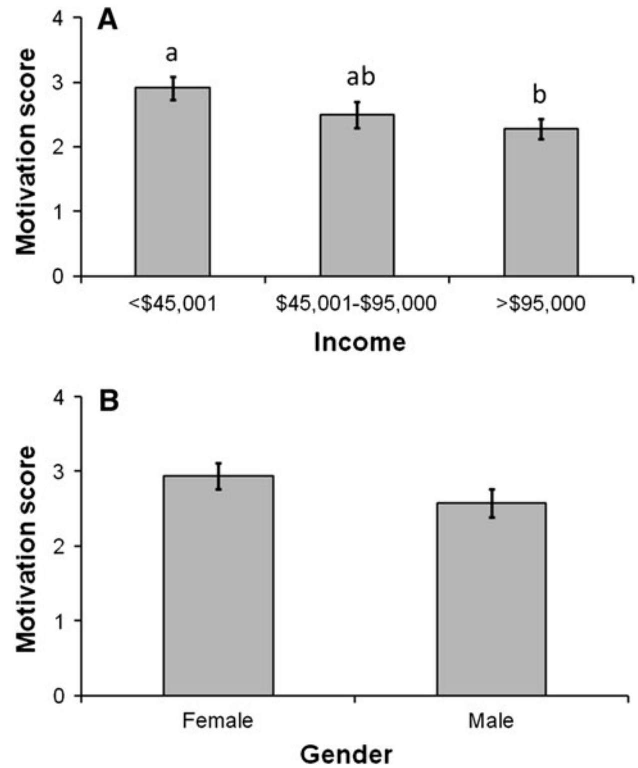

Figure 3. Mean (±1 SE) motivation by **a** household income and **b** gender. Different *letters* denote statistical significance among income levels ($P < 0.05$).

reported source reduction and those that did not (χ^2_1 = 0.11, P = 0.7392).

Mosquito infestation

A total of 54% of households (n = 135/250) had a least one mosquito-positive container. We surveyed 850 total water-holding containers, 310 (36%) of which contained mosquitoes. *A. albopictus* and *C. pipiens* constituted 51.9% (10,744) and 38.4% (7,940) of all indentified larvae, respectively. Other species collected were *C. restuans*, *A. triseriatus*, *Toxorhynchites* sp., and *Orthopodomyia signifera*. Households with respondents who reported practicing source reduction and that had fewer water-holding containers had fewer pupae-positive and *C. pipiens*-positive containers (Table 5; Figure 5). Households with fewer water-holding containers also had fewer *A. albopictus*-positive containers, but resident-reported source reduction was not predictive of *A. albopictus* infestation (Table 5; Figure 5). Numbers of pupae-positive and *A. albopictus*-positive, but not *C. pipiens*-positive, containers increased with date (Table 5; trends not shown). Numbers of pupae-positive ($\chi^2_1 = 9.59$, $P = 0.0020$), *A. albopictus*-positive ($\chi^2_1 = 5.75$, $P = 0.0164$), and *C. pipiens*-positive ($\chi^2_1 = 4.99$, $P = 0.0254$) containers were lower in households when controlling for numbers of water-holding containers in the model.

Discussion

Previous studies have found inconsistent associations between source reduction practices and mosquito populations. Some studies have shown no observable relationships between resident-reported source reduction and mosquito populations (e.g., Tuiten et al. 2009; see "Introduction" for additional references). This study is consistent with other studies that have shown reductions in mosquito infestation with container management (e.g., Koenraadt et al. 2006; see "Introduction" for additional references), finding lower numbers of *C. pipiens*-positive and pupae-positive containers in yards of residents who reported practicing source reduction than in yards of residents who reported not practicing source reduction. This result provides evidence that resident-based source reduction may be effective at managing *C. pipiens* infestation and the production of total adult mosquitoes in a North American metropolitan area.

Table 4. Logistic and linear regression model results of respondent overall knowledge, specific knowledge of mosquito development, motivation, and demographics on source reduction practices and numbers of water-holding containers

	Resident-reported source reduction			Numbers of containers		
Factor	*df*	X^2	*P* value	*df*	*F* value	*P* value
Overall knowledge	1	9.97	0.0016	1	3.84	0.0500
Specific knowledge	1	14.80	0.0001	1	0.91	0.3409
Motivation	1	0.12	0.7333	1	3.61	0.0574
Income	2	3.64	0.1700	2	4.21	0.1217
Education	1	3.02	0.0824	1	4.30	0.0381
Gender	1	0.35	0.5517	1	3.90	0.0482
Age	1	8.65	0.0033	1	2.67	0.1024
Ownership status	1	6.76	0.0093	1	1.01	0.3148
Household size	1	0.84	0.3595	1	3.05	0.0807
Neighborhood	5	15.11	0.0099	5	7.64	0.1774
Date	1	0.82	0.3638	1	9.56	0.0020

Factors with $P < 0.250$ were included in multi-factor models.

Numbers of water-holding containers are usually considered a direct measure of available immature mosquito habitat and it was positively related to numbers of pupae-positive, *A. albopictus*-positive and *C. pipiens*-positive containers in this study. Water-holding containers can also be considered an independent measure of source reduction behavior (e.g., Bartlett-Healy et al. 2011), but were not lower in yards of residents who reported source reduction in the study here. One explanation for this result is that source reduction practices that do not consist of container removal are the predominant forms of resident-based container control. In addition to removing containers, source reduction can include emptying water-holding containers (but not removing them) and applying larvicides to containers (e.g., *Bti*, salt, oil). Overall, 56.6% ($n = 572/1011$) of water-holding containers in this study were moveable but functional (Dowling 2011), and thus may be regularly emptied or applied with larvicides (e.g., *Bti*, salt, oil) rather than removed by residents, after being filled with water. An additional 25.1% (254/1011) of containers were structural (and unmovable), and may have also had larvicides applied. Most notably, we found a reduction of pupae-positive, *A. albopictus*-positive, and *C. pipiens*-containers with resident-reported source reduction when we controlled for numbers of water-holding containers in statistical models, indicating that mosquito habitat management that does not remove container numbers is effective at reducing mosquito infestation and production. However, we cannot rule out the possibility

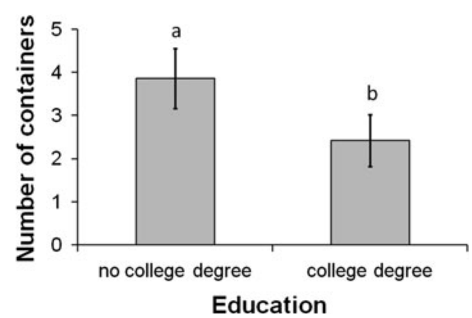

Figure 4. Household numbers of water-holding containers by respondent education (mean ± 1 SE). Different *letters* denote statistical significance between education levels ($P < 0.05$).

that resident-based container removal intended to reduce mosquito habitats is also offset by other household behaviors that add containers, such as watering lawns, gardening, or children's activities; thus resulting in no measurable reductions in total numbers of water-holding containers. Numbers of water-holding containers were marginally positively related to household size which may indicate container addition was related to increased human activity, especially if larger households tend to have children that play with toys that collect water outdoors.

There are several possible explanations for no observed association between resident-reported source reduction and numbers of *A. albopictus*-positive containers when we did not control for numbers of water-holding containers. Adult female *A. albopictus* often oviposit in small shaded containers that may be particularly ephemeral and cryptic,

Table 5. Negative binomial regression model results of source reduction practices on numbers of water-holding containers infested with pupae, *A. albopictus*, and *C. pipiens*; dfs = 1

	Pupae		*A. albopictus*		*C. pipiens*	
Factor	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
Resident-reported source reduction	5.35	0.0270	2.46	0.1165	5.04	0.0247
Number of containers	57.21	0.0001	67.78	<0.0001	13.21	0.0003
Date	0.28	0.8398	30.44	<0.0001	2.49	0.1143

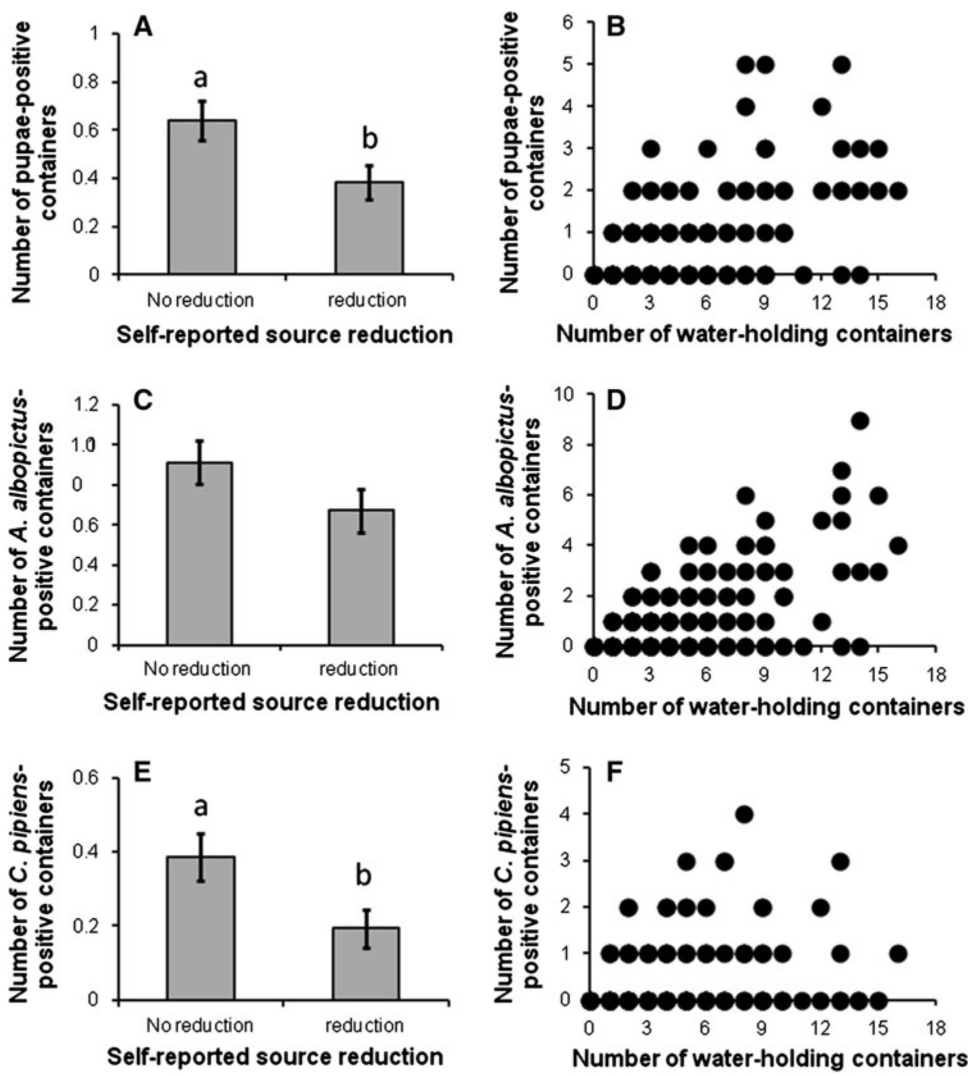

Fig. 5. Household numbers of pupae-positive (**a**, **b**), *A. albopictus*-positive (**c**, **d**), and *C. pipiens*-positive (**e**, **f**) containers by source reduction and numbers of water-holding containers (mean ± 1 SE). Different *letters* denote statistical significance between source reduction treatments ($P < 0.05$).

whereas *C. pipiens* often oviposit in larger open containers that are more persistent and obvious (Hawley 1988; Carrieri et al. 2003). If residents fail to locate more containers with *A. albopictus* than with *C. pipiens*, source reduction may be less effective at managing *A. albopictus* oviposition and adult *A. albopictus* production. *A. albopictus* is generally more efficient at transforming food into biomass and usually develops more rapidly than *C. pipiens* (Carrieri et al. 2003;

Costanzo et al. 2005) thus there may be considerable adult *A. albopictus* production from these small cryptic containers (Reiskind et al. 2009). A study in Puerto Rico reported that at households where residents had received source reduction education, immature mosquitoes were still found in "invisible" containers, presumably because these containers were too difficult for residents to locate after superficial inspection (Winch et al. 2002). In this study, residents who practiced source reduction often had containers hidden under porches, in shrubbery, or behind sheds, which may have been overlooked (Dowling, personal observation).

Previous studies have reported conflicting results regarding the effects of knowledge on mosquito prevention practices and mosquito infestation (e.g., Sanchez et al. 2005; Koenraadt et al. 2006; Tuiten et al. 2009; see "Introduction" for more references). In this study, resident-reported source reduction was related to overall knowledge of mosquitoes and, in particular, to specific knowledge of mosquito development, providing support for the potential effectiveness of education campaigns at fostering community-based mosquito management. Overall knowledge was higher in respondents from high-income households and specific mosquito development knowledge was greater in higher educated respondents, suggesting that mosquito-related education campaigns may see greater gains in mosquito-related knowledge when targeted at low and middle socioeconomic-status households.

This study also found that respondents from low-income households had greater motivation to control mosquitoes than respondents from high-income households, but that motivation was not related to source reduction practice or numbers of water-holding containers. These results suggest that mosquito-related knowledge, and in particular, specific knowledge of mosquito development may be a more limiting component inhibiting resident-based mosquito management than motivation and thus should be the focus of education campaigns. Both overall and specific mosquito-related knowledge, however, were also related to a number of other demographic variables in addition to income and education. For example, specific knowledge on mosquito ecology was higher in older respondents but overall knowledge, which was a cumulative score of knowledge on mosquito ecology, animal hosts, and disease, was higher in younger residents, presumably because of higher knowledge on animal hosts and disease. This finding may be the result of different experiences to mosquitoes and exposure to education messages by age group. Older residents may be more likely to garden or do yard work than younger residents, and thus be more familiar with mosquito larval habitats. In contrast, younger residents may be more exposed to media on the mosquito-related disease cycle. Complex relationships between demographic variables and knowledge, including that of age group with specific versus overall knowledge, may make it challenging for mosquito control agencies to target appropriate messages. Targeted mosquito education may be especially difficult if demographics vary within households (e.g., age, sex) or among households if they are spread throughout the urban landscape more widely than socioeconomic status (e.g., ownership status, household size), which is often spatially clustered.

There may be a number of explanations, some of which are likely related to knowledge, for why our index of motivation was not related to source reduction practice. Residents may not practice source reduction because they think other mosquito-prevention methods (e.g., adulticiding, trapping, or repellants) are more effective or easier to implement. In addition, residents may not realize they have standing water on their property (Grantham et al. 2009; Tuiten et al. 2009), or may think that habitats outside their yard produce most adult mosquitoes (McNaughton et al. 2010). Many residents in our study doubted that public agencies or residents could effectively control mosquitoes in Washington because much of the city was developed on wetlands which were perceived to produce abundant mosquito adults (Dowling, personal observation). Not surprisingly, we observed few wetlands and other ground pools in our study areas in metropolitan Washington, and while below ground storm water structures and ephemeral ground pools may be important habitat for some urban mosquitoes (e.g., Metzger 2004), container habitats are usually considered the most important habitat for *A. albopictus*, *C. pipiens*, and many other human-biting species in North America suburban areas (Vinogradova 2000; Costanzo et al. 2005).

Conclusion

This is the first study to investigate relationships between KAP and larval mosquitoes among socioeconomically diverse households in urban areas. We conclude that there is a clear link between socioeconomic status and demographics on mosquito-related knowledge, and that mosquito-related knowledge, and in particular, specific knowledge of mosquito development is related to source reduction practices and mosquito infestation. These findings support the use of education campaigns to foster community-based source education as part of area-wide integrated mosquito-management programs. If knowledge-based education campaigns are targeted at low-income households that tend to be motivated to control mosquitoes, there may be particularly substantial increases in source reduction practice and decreases in mosquito infestation and production.

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