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Special Feature: Broadening perspectives

Urban mosquito distributions are modulated by socioeconomic status and environmental traits in the USA

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Abstract

The distribution of mosquitoes and associated vector diseases (e.g., West Nile, dengue, and Zika viruses) is likely to be a function of environmental conditions in the landscape. Urban environments are highly heterogeneous in the amount of vegetation, standing water, and concrete structures covering the land at a given time, each having the capacity to influence mosquito abundance and disease transmission. Previous research suggests that socioeconomic status is correlated with the ecology of the landscape, with lower-income neighborhoods generally having more concrete structures and standing water via residential abandonment, garbage dumps, and inadequate sewage. Whether these socioecological factors affect mosquito distributions across urban environments in the USA remains unclear. Here, we present a meta-analysis of 42 paired observations from 18 articles testing how socioeconomic status relates to the overall mosquito burden in urban landscapes in the USA. We also analyzed how socioecological covariates (e.g., abandoned buildings, vegetation, education, and garbage containers) varied across socioeconomic status in the same mosquito studies. The meta-analysis revealed that lower-income neighborhoods (regions with median household incomes <US$50,000 per household per year) are exposed to 63% greater mosquito densities and mosquito-borne illnesses compared with higher-income neighborhoods (≥US$50,000 per household per year). One common species of urban mosquito (*Aedes aegypti*) showed the strongest relationship with socioeconomic status, with *Ae. aegypti* being 126% higher in low-income than high-income neighborhoods. We also found that certain socioecological covariates correlated with median household income. Garbage, trash, and plastic containers were found to be 67% higher in low-income neighborhoods, whereas high-income neighborhoods tended to have higher levels of education. Together, these results indicate that socioecological factors can lead to disproportionate impacts of mosquitoes on humans in urban landscapes. Thus, concerted efforts to manage mosquito populations in low-income urban neighborhoods are required to reduce mosquito burden for the communities most vulnerable to human disease.

KEYWORDS
Aedes aegypti, *Aedes albopictus*, cities, environmental traits, mosquitoes, socioecological, socioeconomic status, urban, vector diseases

INTRODUCTION

A primary driver of global change is urban expansion resulting from human population growth, with projections indicating that 70% of the world's population will be living in cities by the year 2050 (Heilig, 2012; Huang et al., 2019). The ongoing growth across cities is unequal and often leads to increasing heterogeneity regarding the economic, racial, and social status of humans living in urban environments (Liu et al., 2007; Pickett et al., 1997). Factors such as structural racism and inequitable access to wealth, healthcare, and recreation via nature parks disproportionately affect minoritized and low-income communities (Des Roches et al., 2021; Schell et al., 2020). For example, historical redlining policies in Baltimore have relegated Black people to urban neighborhoods where pollution is widespread, outdoor recreation is limited, and flooding risk is high, with those effects still present today (Grove et al., 2018; Schell et al., 2020). In contrast, predominately White and affluent neighborhoods generally have more trees, green space, higher plant diversity, and less pollution, a phenomenon named the "luxury effect" (Chamberlain et al., 2020; Leong et al., 2018). Racial segregation and inequitable access to wealth, healthcare, and green spaces create high levels of landscape heterogeneity across cities, rendering cities highly complex human–natural systems with potential implications for public health (Des Roches et al., 2021).

The heterogeneity in cities resulting from social and economic inequalities can exacerbate the impacts of a major disease vector: mosquitoes (Diptera: Culicidae). Mosquitoes are a significant threat to humans, vectoring diseases that kill an estimated 780,000 people per year worldwide (WHO, 2014). Moreover, the mosquito burden—the harm mosquitoes inflict on humans through bites and vectored diseases—is projected to intensify as global change progresses, particularly in urban environments (Holeva-Eklund et al., 2021; Whiteman et al., 2020). In the USA, urban environments harbor invasive, medically important mosquitoes in the *Aedes* genus, which are competent disease vectors of chikungunya, dengue, yellow fever, and Zika (Goodman et al., 2018; Rose et al., 2020). Previous research has shown that the landscape heterogeneity in urban environments may cause mosquitoes to be unevenly distributed. For instance, mosquito hotspots can emerge in neighborhoods with abundant breeding habitats via plastic containers, high densities of human hosts, and low mosquito-mitigation efforts (Faraji et al., 2014; LaDeau et al., 2013); such conditions are often associated with low-income neighborhoods (Little et al., 2017).

Given the medical significance of mosquitoes and their potential disproportionate impacts across cities, a rich body of research has evaluated how socioecological factors impact mosquito burden in urban environments (reviewed in Holeva-Eklund et al., 2021; Sallam et al., 2017; Whiteman et al., 2020). However, the studies that investigated whether mosquitoes are simultaneously affected by ecological attributes and socioeconomic status (SES) have mixed results (Sallam et al., 2017; Whiteman et al., 2020). For example, several studies have reported higher mosquito densities in low SES neighborhoods in cities (Dowling, Armbruster, et al., 2013; LaDeau et al., 2013; Little et al., 2017; Lockaby et al., 2016), whereas other studies showed weak or no relationship between mosquito abundance and SES (Ferreira et al., 2007; Holeva-Eklund et al., 2021; Rochlin et al., 2011; Whiteman et al., 2020). Such inconclusive findings make it difficult to generalize mosquito burden across urban environments, limiting our ability to predict their impacts as urban expansion advances. Furthermore, while the previous reviews on mosquito impacts have been informative (e.g., Holeva-Eklund et al., 2021; Whiteman et al., 2020), narrative or systematic reviews can lack quantitative rigor, rendering their predictive power limited (Koricheva & Gurevitch, 2013). To address these deficiencies, we present a quantitative synthesis (i.e., a meta-analysis) that studies how mosquito distributions are modulated by SES and environmental traits in the USA that, to our knowledge, is the first meta-analysis to address this topic.

Furthermore, with respect to urban mosquitoes, the socioecological factors underpinning mosquito distributions are wide ranging and have not been addressed with a meta-analysis (Sallam et al., 2017). To provide a more synthetic understanding of the socioecological factors that relate to mosquito distributions in cities, we also conducted a meta-analysis on the social and environmental traits that might influence mosquito distributions in urban landscapes. Several studies have reported that low SES neighborhoods have high rates of mosquito-breeding habitats (LaDeau et al., 2013; Little et al., 2017), such as trash, garbage containers, and abandoned buildings, potentially causing a proliferation of mosquito populations. By contrast, high SES neighborhoods generally have higher access to green spaces, mosquito-mitigation efforts, education, and less garbage and abandoned buildings (Dowling, Armbruster, et al., 2013; Ferreira et al., 2007; Little et al., 2021), thereby limiting mosquito habitat. However, no meta-analysis has assessed how socioecological factors relate to SES and mosquito distributions in urban landscapes.

In the present study, we employ a meta-analysis to investigate how SES in urban environments in the USA correlates with mosquito burden (mosquito abundance and mosquito-vectored diseases). We addressed two questions: (1) What is the relationship between SES and mosquito burden in urban landscapes? and (2) How do socioecological factors (abandoned buildings, vegetation, education, and garbage containers) correlate with SES and mosquito burden? We hypothesize that if SES encourages uneven mosquito burden in urban environments, because they correlate with environmental conditions more suitable to mosquito populations, we expect a higher mosquito burden in low SES neighborhoods than in high SES neighborhoods. Furthermore, we suspect that low SES neighborhoods with elevated mosquito burden will have higher rates of garbage and abandoned buildings, whereas high SES neighborhoods will have increased levels of green spaces and education. The overall goal of this research is to understand how SES and ecological factors relate to mosquito populations across local and regional scales.

METHODS

Literature search and data extraction

To uncover the studies that evaluated how SES in urban environments correlated with mosquito densities and vector-disease transmission in humans, we conducted a literature search for primary articles in ISI Web of Science. We used the following string of search terms without any restriction on the year of publication (last accessed on 19 November 2022): (Socioeconomic OR socio economic OR socioeconomic OR socio ecological OR socio-ecological OR wealth OR income OR poverty) AND (urban* OR cit* OR town* OR population* OR densit* OR minorit* OR communit* OR neighborhood*) AND (vector* OR virus* OR West Nile OR Dengue OR chikungunya OR malaria OR Zika OR disease*) AND (Aedes aegypti OR Aedes albopictus OR Culex tarsalis OR Culex quinquefasciatus OR Anopheles freeborni OR Anopheles quadrimaculatus OR mosquito*) AND (United States OR USA* OR North America*). Our meta-analysis search protocol followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA; Moher et al., 2009; Figure 1). Our initial search resulted in 396 published articles.

During our initial search, we reviewed each article's title and abstract to discern its potential fit for inclusion in the meta-analysis; 335 articles were excluded after this stage. Next, we assessed each eligible article's reference list to uncover other potentially pertinent articles and contacted a handful of experts in the USA regarding available research articles; 22 additional articles were added to the list. At this stage, we evaluated each full-text article to determine its eligibility in the meta-analysis (65 additional articles were excluded at this stage). We used no unpublished datasets in this meta-analysis, resulting in 18 articles with 42 paired observations that met our full inclusion criteria. The studies spanned all regions of the USA, including the Northeast, South, Southwest, and Midwest. Although we acknowledge that we might not have collected every possible article on this topic, these search methods provided adequate coverage of the primary literature. Nevertheless, we recorded each article that emerged from the literature search and documented the number of studies excluded based on our inclusion criteria (full database provided at Zenodo: https://doi.org/10.5281/zenodo.7883752). Refer to Table 1 for details on the studies included in the meta-analysis.

The meta-analysis was designed to evaluate peer-reviewed studies that compared mosquito densities or mosquito-borne diseases (i.e., infected mosquitoes and/or humans) in low and high SES urban neighborhoods in the USA (Table 1). The meta-analysis was also designed to compare how social–ecological factors were different according to SES using the mosquito studies in which covariates were measured. Here, we defined SES using the information provided in the original study. If the study did not define SES for the urban environments, we characterized low SES as households in neighborhoods making less than a median of US\$50,000 per year per household and high SES as neighborhoods making ≥US\$50,000 per year per household (inflation was accounted for in older studies), although almost all the eligible studies fell within these two SES categories. Finally, we only used articles in which the original study explicitly stated it investigated a city, metropolitan, and/or urban environment.

We focused the meta-analysis on the USA because it: (1) allows for a more objective comparison of low and high SES neighborhoods, given that categories of SES can vary widely across countries, and (2) makes it easier to identify the household income threshold where mosquito burden is altered. Each study had to compare mosquito burden in low versus high SES neighborhoods. Here, mosquito burden could be the number of mosquito larvae, adults, confirmed diagnosis of mosquito-borne illnesses (e.g., West Nile, dengue, and Zika viruses), and proportion of mosquito human bloodmeals in the population. The articles eligible for our meta-analysis required the following criteria:

1. A comparison between high and low SES urban neighborhoods. When multiple units of high and low

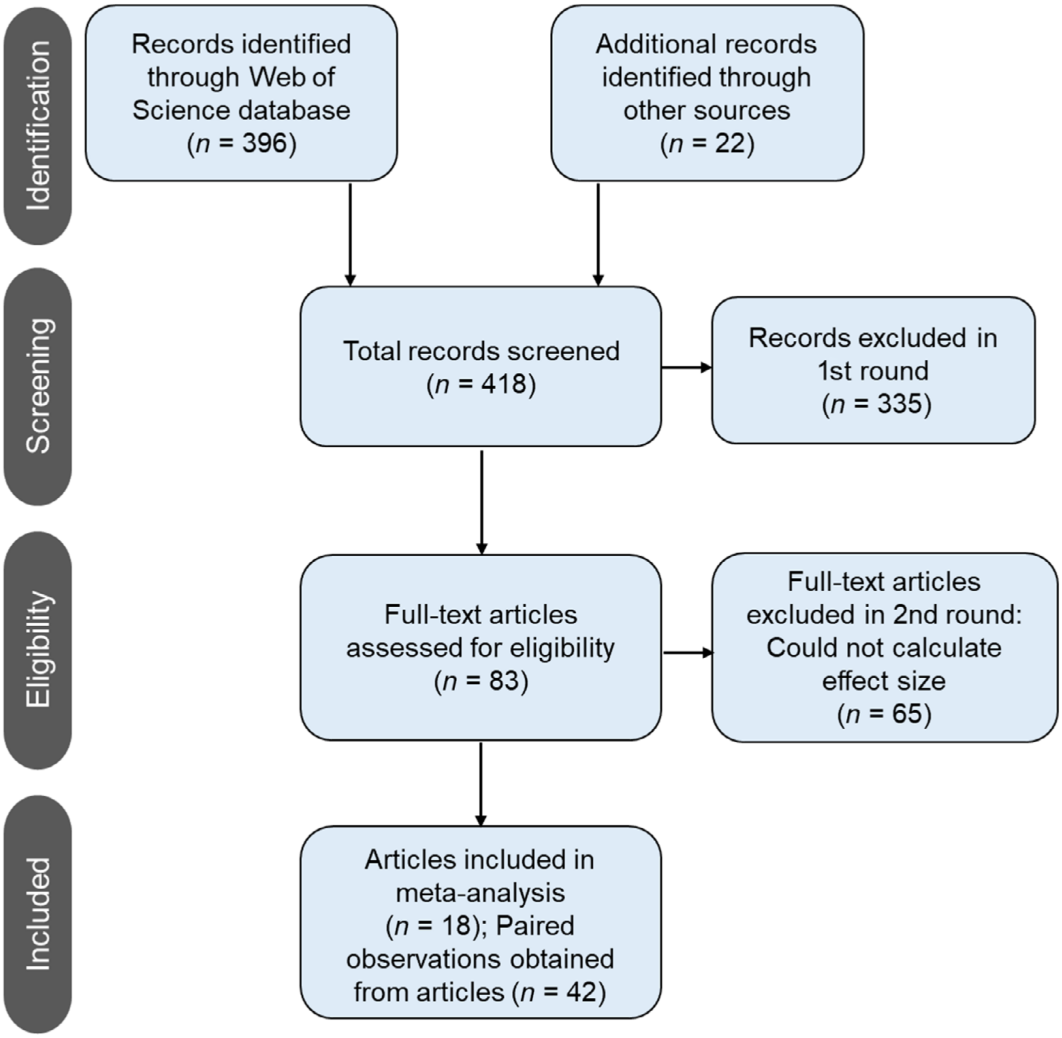

FIGURE 1 The modified PRISMA flow schematic (Moher et al., 2009). We recorded the number of articles screen during each step of the literature survey and meta-analysis.

SES neighborhoods were provided, we calculated a composite average of mosquito burden for each mosquito species across SES.

2. If a study provided multiple sample dates for mosquito burden, we only used the final period.
3. The studies had to include at least the mean and sample size for both high and low SES neighborhoods. For the studies that did not include an estimate of variance, we used a linear regression model using the studies with complete information to fill in missing variance values in the other articles (i.e., an imputation technique; Koricheva & Gurevitch, 2013). Our regression models proved to be a good predictor for the missing variance values (mosquito burden dataset: $R^2 = 0.70$, $p < 0.001$; covariate dataset: $R^2 = 0.95$, $p < 0.001$).
4. Each study needed to be an original research article. We did not include other meta-analyses, reviews, or modeling papers. Also, we only used one article if multiple publications used the same dataset.
5. For extracting information on social–ecological factors (abandoned buildings, vegetation, education, and garbage containers), we only used articles that included those covariates as a means to understand mosquito distributions.

Data points were obtained from the text, tables, supplemental materials, and figures. Data from the figures were extracted using ImageJ (Abràmoff et al., 2004), an image processing software.

Analysis

We used the log response ratio (LRR) (Hedges et al., 1999) effect size to measure the influence of SES on mosquito burden by calculating:

$$\mathrm{LRR} = \ln\left(\frac{X_l}{X_h}\right),$$

TABLE 1 The characteristics of the original studies included in the meta-analysis.

Study	City/state	SES low	SES high	Taxon	Development stage	Data type	Socioecological factors
(1) Becker et al., 2014	Baltimore, Maryland	NA	NA	*Culex* spp., *Ae. albopictus*	Adult	Abundance	Buildings, Containers
(2) Bodner et al., 2016	Washington, DC	<50 K	>50 K	*Ae. albopictus*, *Ae. japonicus*, *Culex* spp.	Pupae	Abundance	Education, Containers
(3) Chambers et al., 1986	East Baton Rouge, Louisiana	NA	NA	*Ae. aegypti*	Larvae	Frequency	Containers
(4) Crespo et al., 2021	Baton Rouge, Louisiana	<35 K	>65 K	*Culex* spp., *Ae. albopictus*	Adult	Abundance	Containers
(5) Crespo & Rogers, 2022	Baton Rouge, Louisiana	<30 K	>70 K	*Ae. aegypti*	Larvae	Abundance	Containers, Vegetation
(6) Donnelly et al., 2020	Los Angeles, California	42 K	75 K	*Ae. aegypti*	Adult	Abundance	Containers, Vegetation
(7) Dowling, Armbruster, et al., 2013	Los Angeles, California	<45 K	>90 K	*Ae. albopictus*	Adult	NA	Education
(8) Dowling, Ladeau, et al., 2013	Los Angeles, California	<45 K	>90 K	*Ae. albopictus*	Adult	NA	Containers
(9) Goodman et al., 2018	Baltimore, Maryland	<50 K	>50 K	*Ae. albopictus*	Adult	Blood meal frequency	NA
(10) Hopken et al., 2021	San Juan, Puerto Rico	<30 K	>65 K	*Culex* spp.	Adult	Abundance	Buildings, Containers, Education, Vegetation
(11) LaDeau et al., 2013	Washington, DC	<50 K	>50 K	Mosquitoes indistinguible	Pupae	Frequency	Containers
(12) Little et al., 2017	Baltimore, Maryland	<50 K	>50 K	*Ae. albopictus*	Larvae	Frequency	Buildings, Vegetation, Containers
(13) Little et al., 2022	High development regions in Pennsylvania	NA	NA	*Ae. albopictus*, *Ae. japonicus*	Adult	Abundance	NA
(14) Ruiz et al., 2007	Chicago, Illinois	<50 K	>50 K	Mosquitoes indistinguible	Adult	Frequency	NA
(15) Scavo et al., 2021	San Juan, Puerto Rico	<35 K	>50 K	Mosquitoes indistinguible	Adult	Diversity index	NA
(16) Shragai & Harrington, 2019	Southern New York	<50 K	>110 K	*Ae. albopictus*	Adult	Frequency	NA
(17) Unlu et al., 2011	Mercer, Monmouth County, New Jersey	<50 K	>50 K	*Ae. albopictus*	Adult	Abundance	NA
(18) Walker et al., 2018	Tucson, Arizona	<35 K	>50 K	*Ae. aegypti*	Larvae	Frequency	Containers

where X_l and X_h are the sample means of low and high SES neighborhoods, respectively. A positive LRR denotes that the mosquito burden or socioecological factor in low SES neighborhoods is higher, whereas a negative LRR means that high SES neighborhoods experienced a higher mosquito burden. The LRR variance was calculated as:

$$V = \left(\frac{S_l^2}{n_l X_l^2}\right) + \left(\frac{S_h^2}{n_h X_h^2}\right),$$

where S and n denote the standard deviation and sample size of replicates, respectively. The subscripts "l" and "h" refer to the low and high SES neighborhoods, respectively. LRR is a widely used effect size measure that allows comparisons of studies with different techniques and data types (Hedges et al., 1999; Lajeunesse, 2015).

We constructed a mixed effects model (MEM) with restricted maximum likelihood (REML) to evaluate differences in the effects of SES on mosquito burden and associated social–ecological factors. To evaluate how SES was related to mosquito burden, we first performed a MEM without any moderators to test the overall effects of SES on mosquito burden. Next, we used separate MEMs with mosquito taxa or social–ecological factors as moderators to assess their differences in LRR using weighted mean effect sizes (Borenstein et al., 2011). To ensure the best model fits, we tested each MEM with a (1) publication-level random effect as a nested factor to account for multiple effect sizes extracted from a given study, (2) publication-level random effect without a nested structure, and (3) no publication-level random effects. The best-fitting models were determined via corrected Akaike information criterion (AIC_c) scores and are presented below (alternative model fits are provided in Appendix S1: Tables S1 and S2). In the mixed effects models, the heterogeneity of effect sizes was calculated through the Q statistic, which was used to estimate the amount of heterogeneity attributed to unexplained variation due to unknown differences in environmental conditions across the studies (i.e., the weighted sums of squares tested against a χ^2 distribution; Hedges & Olkin, 2014). We considered mean effect sizes as statistically different if their 95% confidence intervals (CI) did not include zero (Borenstein et al., 2011). We used the *metafor* package in R version 4.0.3 (R Development Core Team, 2020) to conduct the meta-analysis.

Publication bias

Because studies with significant results are more likely to be published, the primary literature on a given subject can underrepresent studies reporting nonsignificant results, leading to publication bias (Jennions et al., 2013). To test if our results were affected by publication bias, we used two methods. First, we used Trim-and-Fill funnel plots (Duval & Tweedie, 2000), which are plots that illustrate effect sizes against sample sizes from individual studies. Trim-and-Fill plots from our data show symmetrical scatter plots across the 42 paired observations for mosquito burden and socioecological factors, indicating no evidence of publication bias (Appendix S1: Figures S1 and S2). Second, we calculated Rosenthal's fail-safe number (Orwin, 1983) for our random effects models. Rosenthal's fail-safe number is the number of missing case studies with nonsignificant results needed to nullify the combined effect size (Orwin, 1983). Our results also suggest no evidence of publication bias using Rosenthal's fail-safe number for mosquito burden (the number of studies needed to nullify the result is 208; $p < 0.001$) or socioecological factors (the number of studies needed to nullify the result is 47; $p = 0.002$; Appendix S1: Table S3).

RESULTS

Q1. Mosquito burden as a function of SES in urban landscapes

The MEM without moderators revealed that mosquito burden in low SES neighborhoods (regions with median household incomes <US$50,000 per household per year) was much higher than in high SES (≥US$50,000 per year) neighborhoods (MEM; log response ratio = 0.489, CI = [0.008, 0.968], $p = 0.046$; Figure 2). The best-fitting MEM with moderators revealed that one species of mosquito (*Ae. aegypti*) showed the strongest relationship with SES (MEM, $LRR_{Ae.\ aegypti} = 0.818$, CI = [0.112, 1.518], $p = 0.022$; Figure 2), indicating that *Ae. aegypti* is 126% higher in low SES than in high SES neighborhoods. The three paired observations that evaluated mosquito burden more broadly without identifying species also found more mosquitoes in low SES neighborhoods (MEM; log response ratio = 1.400, CI = [0.487, 2.307], $p = 0.002$; Figure 2).

Overall, the *Ae. albopictus* and *Culex* spp. burden did not show a strong relationship between low versus high SES neighborhoods (MEM, $LRR_{Ae.\ albopictus} = -0.324$, CI = [−0.931, 0.283], $p < 0.295$; log response $ratio_{Culex} = -0.155$, CI = [−0.794, 0.486], $p = 0.636$; Figure 2), with both species abundance confidence intervals overlapping zero. The overall residual heterogeneity of effect sizes was large for the MEM ($Q_E = 62.48$, $df = 15$, $p < 0.001$), suggesting that important unmeasured factors contribute to the effects of SES on mosquito burden.

Q2. The relationship between mosquito socioecological factors and SES

When considering how the socioecological factors varied as a function of SES in studies investigating mosquito abundance in urban environments, we found that the abundance of containers in low SES neighborhoods was 67% higher (MEM; log response ratio = 0.510, CI = [0.141, 0.880], $p = 0.007$) than in high SES neighborhoods. In contrast, high SES neighborhoods generally had elevated levels of education compared with low SES neighborhoods (MEM; log response ratio = −1.232, CI = [−1.700, −0.766], $p < 0.001$). We did not find a large difference between the abundance of abandoned buildings and

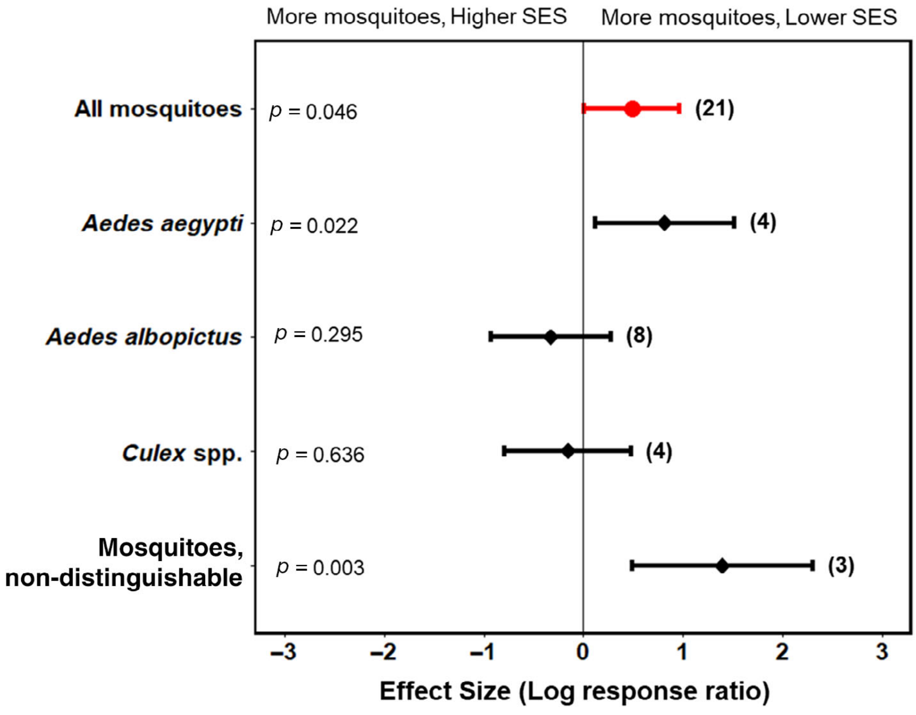

FIGURE 2 The relationship between socioeconomic status (SES) and mosquito burden using mean effect sizes (log response ratio [LRR]). Positive effect sizes indicate mosquito burden was greater in low SES neighborhoods, whereas negative effect sizes denote higher mosquito burden in high SES neighborhoods. Means of LRR are shown alongside 95% CI. The number provided in the parentheses are the number of paired observations analyzed for mosquito taxon. The results are from mixed effects models; mean effect sizes are statistically different if their 95% CI do not overlap zero. *Aedes japonicus* was excluded due to low sample size ($n < 3$).

vegetation as a function of SES (MEM, log response $\text{ratio}_{\text{Building}} = 0.028$, $\text{CI} = [-0.365, 0.421]$, $p = 0.889$; log response $\text{ratio}_{\text{Vegetation}} = -0.235$, $\text{CI} = [-0.612, 0.141]$, $p = 0.220$; Figure 3). Unmeasured factors were also important, with the model showing high overall residual heterogeneity of effect sizes ($Q_E = 422.43$, $df = 17$, $p < 0.001$).

DISCUSSION

Because urban environments are highly heterogeneous, mosquito distributions and associated vector-borne diseases (e.g., West Nile, dengue, and Zika viruses) are likely to be affected by both social and ecological factors, with important implications for public health (Hernandez et al., 2019; Walker et al., 2018). We reveal through a meta-analysis of 18 studies from the USA that there is a consistent link between lower SES and higher mosquito burden in urban environments. In particular, the common urban mosquito *Ae. aegypti* was strongly associated with low SES compared with high SES neighborhoods. Furthermore, we found that socioecological covariates supported the findings of the meta-analysis, showing that traits typically associated with low SES neighborhoods (i.e., garbage containers and inadequate education) were higher in the areas with higher mosquito burden. To our knowledge, this is the first meta-analysis to demonstrate how mosquito distributions correlate with SES and environmental traits in urban landscapes.

Across a handful of metropolitan regions in the USA, we found that mosquito burden is much higher in low compared with higher SES neighborhoods, supporting our first hypothesis. Based on the meta-analysis of the socioecological factors, we also found partial support for our second hypothesis, with garbage/plastic containers being more abundant in low SES neighborhoods. As anthropophilic biting insects that can breed in a variety of artificial habitats (Faraji et al., 2014), mosquitoes such as *Ae. aegypti* can thrive in places where garbage, trash, and plastic containers are widespread. Artificial water-holding containers (e.g., old tires, buckets, disposable containers, etc.) can serve as breeding habitats for *Ae. aegypti* and other urban mosquitoes (Becker et al., 2014; LaDeau et al., 2013), thereby sustaining abundant populations despite the predominance of concrete structures in urban environments. The findings from our meta-analysis indicate that these containers provide favorable breeding conditions for mosquitoes in urban habitats, supporting the findings from previous studies (Dowling, Armbruster, et al., 2013; LaDeau et al., 2013; Little et al., 2017).

We also found that education levels were generally higher in high SES compared with low SES neighborhoods. Previous research has indicated a positive relationship between education level and antimosquito

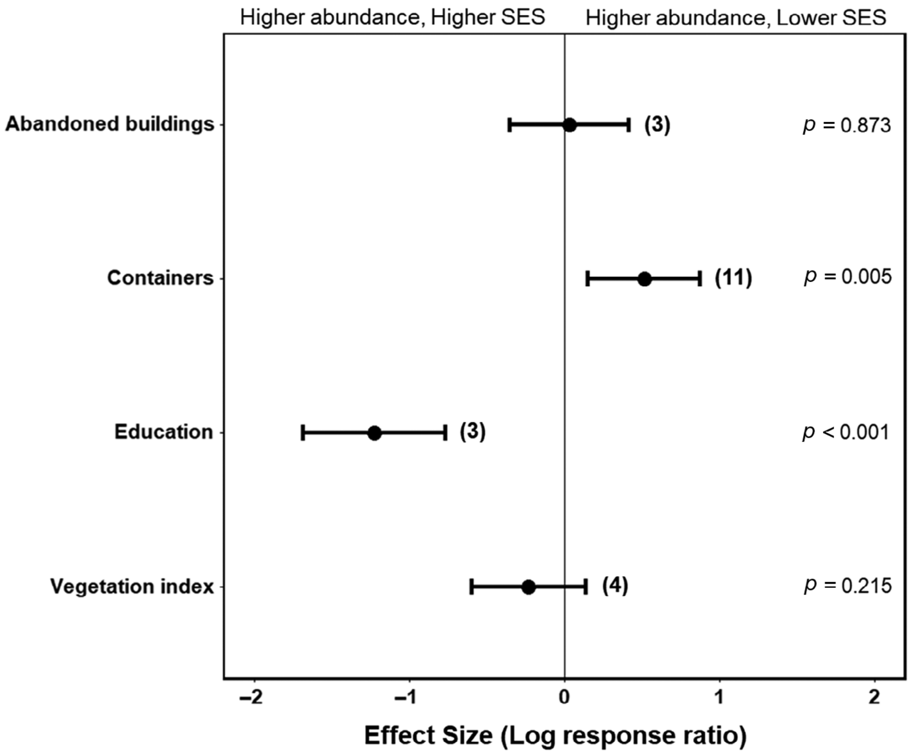

FIGURE 3 Socioecological factors as a function of socioeconomic status (SES) using mean effect sizes (log response ratio [LRR]). In this figure, positive effect sizes indicate the abundance of the socioecological factor was higher in low SES neighborhoods; negative effect sizes demonstrate higher abundance of the socioecological factor in high SES neighborhoods. As above, means of LRR are shown alongside 95% CI and the number indicated in the parentheses is the number of paired observations. The results are from mixed effects models; mean effect sizes are statistically different if their 95% CI do not overlap zero.

practices, such as removing water-holding containers from yards, ultimately reducing mosquito infestations (Bodner et al., 2016; Rochlin et al., 2011). For example, residents with high levels of education in wealthier neighborhoods were more likely to remove water-holding containers from their yards, eliminating breeding habitats for mosquitoes (Dowling, Armbruster, et al., 2013). These differences in the behaviors of residents in high versus low SES neighborhoods could potentially explain why the mosquito burden is higher on average in wealthier neighborhoods. Furthermore, although we were unable to include this as a factor in our meta-analysis, another possibility for why high SES neighborhoods experience reduced mosquito burden is due to increased mosquito management efforts. Mosquito treatment and mitigation efforts are often concentrated in affluent neighborhoods (Biehler et al., 2019; Tedesco et al., 2010), consequentially limiting the mosquito burden experienced in high SES regions.

Despite the meta-analysis showing that the total mosquito burden is higher in low SES neighborhoods on average, we found that two common human-biting mosquitoes (e.g., *Ae. albopictus*, *Culex* spp.) in urban environments did not differentiate by household income. Several studies have implicated *Ae. albopictus* and *Culex* spp. to be urban mosquitoes with disproportionate effects in low SES neighborhoods (e.g., LaDeau et al., 2013; Little et al., 2021), but the findings across the literature are inconclusive and appear context-dependent. For example, several studies have found *Culex* mosquitoes were associated more with low SES neighborhoods (Chaves et al., 2011; Leisnham et al., 2014), whereas other studies have found no difference and even higher abundances in high SES neighborhoods (Dowling, Armbruster, et al., 2013; Goodman et al., 2018). One possible reason for the variation in results is that each species of urban mosquito utilizes urban landscapes differently or in ways that do not always differentiate along SES gradients. For instance, *Ae. albopictus* is a day hunter that appears more abundant in areas of high vegetation (Little et al., 2017), which from our meta-analysis does not clearly differ between low versus high SES neighborhoods.

Although our research indicates a clear relationship between mosquito burden and SES factors on average, our conclusions are somewhat different from recent systematic reviews that found no consistent relationship between SES and mosquito burden (i.e., Holeva-Eklund et al., 2021; Whiteman et al., 2020). For example, Holeva-Eklund et al. (2021) found that *Ae. aegypti* distributions vary inconsistently across SES in the mainland USA. There are several possible explanations for the contrasting results of our study with previous reviews. First, the explicit focus of our study was in urban environments, whereas the other studies considered SES across a broad spectrum, including rural, suburban, and urban environments. SES across these different gradients is likely to vary widely and therefore would not lead to consistent effects on mosquitoes. Second, although systematic reviews are useful for uncovering broadscale patterns within a given topic, the associated findings from recent reviews were not quantitative and cannot provide insights on the magnitude or variation of effects (Gurevitch et al., 2018; Koricheva & Gurevitch, 2013). The previous systematic reviews used either a narrative summary or vote-counting method to summarize the literature; both methods cannot test the strength of effects across studies (Koricheva & Gurevitch, 2013).

CONCLUSIONS

One of the unintended consequences of urban wealth disparities is that it creates environments that allow mosquito populations to proliferate among the economically disadvantaged (Harrigan et al., 2010). Our results highlight the finding that the mosquito burden is a complex issue in urban environments that must be understood through the dual prism of sociological and ecological factors, not just the latter. We reveal that the mosquito burden is concentrated among USA cities' low SES neighborhoods, suggesting regions most vulnerable to human disease due to inadequate resources and infrastructure are also the regions that experience higher exposure to mosquitoes and associated diseases. The consequences of income-associated mosquito burden are far reaching in urban environments (LaDeau et al., 2013; Little et al., 2017), considering that low SES neighborhoods in the USA are disproportionately minoritized populations (i.e., Black and Hispanic people). As urban expansion advances, the subsequent increased intensity and frequency of mosquito-borne diseases (Lockaby et al., 2016) will probably affect minorities disproportionately. Therefore, to mitigate mosquito impacts for the localities most vulnerable to disease and ensure environmental justice, equity, and inclusion, management efforts targeting mosquito populations in low SES urban neighborhoods that incorporate fine-scale socioecological data are required.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data and R scripts (McCary, 2023) supporting the results are archived at Zenodo at https://doi.org/10.5281/zenodo.7883752. Citations for the studies included in the meta-analysis are available in Table 1.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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