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Systematic review: The impact of socioeconomic factors on *Aedes aegypti* mosquito distribution in the mainland United States

Short Title: Review: Socioeconomic Factors and *Ae. aegypti*

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Abstract: *Aedes aegypti* mosquitoes are primary vectors of dengue, yellow fever, chikungunya and Zika viruses. *Ae. aegypti* is highly anthropophilic and relies nearly exclusively on human blood meals and habitats for reproduction. Socioeconomic factors may influence the spread of *Ae. aegypti* due to its close relationship with humans. This paper describes and summarizes the published literature on how socioeconomic variables influence the distribution of *Ae. aegypti* mosquitoes in the mainland United States. A comprehensive search of PubMed/Medline, Scopus, Web of Science, and EBSCO Academic Search Complete through June 12, 2019 was used to retrieve all articles published in English on the association of socioeconomic factors and the distribution of *Ae. aegypti* mosquitoes. Additionally, a hand search of mosquito control association websites was conducted in an attempt to identify relevant grey literature. Articles were screened for eligibility using the process described in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Initially, 3,493 articles were identified through the database searches and previously known literature. After checking for duplicates, 2,145 articles remained. 570 additional records were identified through the grey literature search for a total of 2,715 articles. These articles were screened for eligibility using their titles and abstracts, and 2,677 articles were excluded for not meeting the eligibility criteria. Finally, the full text for each of the remaining articles (n = 38) was read to determine eligibility. Through this screening process, 11 articles were identified for inclusion in this review. The findings for these 11 studies revealed inconsistent relationships between the studied socioeconomic factors and the distribution and abundance of *Ae. aegypti*. The findings of this review suggest a gap in the literature and understanding of the influence of anthropogenic factors on the

doi:10.20944/preprints201910.0190.v2

distribution of *Ae. aegypti* that could hinder efforts to implement effective public health prevention and control strategies should a disease outbreak occur.

Keywords: built environment; health equity; insect vectors; public health; social determinants of health

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1. Introduction

Although mosquito-borne diseases have recently drawn much attention as "emerging" diseases in the United States, they actually have a long history in the Americas. *Aedes aegypti* (L.) mosquitoes and the viruses transmitted by this vector originated in Africa and were introduced to what would become the United States via ships used in the slave trade around the 17th century [1,2]. Arboviruses such as yellow fever remained widespread in this country as recently as the 19th century; yellow fever caused over 100,000 deaths along the Mississippi River and eastern seaboard of the United States between the 18th and 19th centuries [2]. The decreased prevalence of mosquito-borne disease in the United States can mostly be attributed to improved socioeconomic factors (such as income and infrastructure) that protect against transmission of arboviruses to humans through the widespread use of window screens, the increased use of air conditioning, improved sanitation conditions, as well as the use of pesticides [2]. In addition, members of the Pan American Health Organization approved a resolution in 1947 with the intention of eradicating *Ae. aegypti* from the Americas by decreasing larval habitat and routinely applying insecticides to potential habitat [3].

During the 20th century, the Pan American Health Organization program aimed at mosquito eradication throughout the Americas was initially quite successful, and *Ae. aegypti* was declared eradicated from several Southern and Central American countries [3,4]. This attempt at eradication used insecticides and larval habitat reduction to reduce mosquito populations [4]. However, not all countries in the Americas participated equally in the efforts to eradicate *Ae. aegypti*. Most notably, the United States was slow to respond to requests that the country initiate a program aimed at eradicating *Ae. aegypti* and the eventual attempt to establish such a program

 doi:10.20944/preprints201910.0190.v2

lasted only a few years [4]. Additionally, financial support and resources for the program soon began to dwindle throughout the Americas, and *Ae. aegypti* developed resistance to some of the insecticides used in the program [3]. The program soon lapsed and beginning in the 1970s the mosquito populations that remained in the Americas began to regain and expand their previous geographic ranges which allowed *Ae. aegypti* to remain a threat to public health in the Americas [2,4]. The current spread of mosquitoes and mosquito-borne diseases to further regions causes concern for current and future outbreaks of mosquito-borne disease in areas that are not prepared to handle such a threat. Additionally, novel mosquito-borne diseases introduced to the United States from other areas of the world constitute a risk to public health.

The current distribution of *Ae. aegypti* throughout the world is more extensive than has ever been recorded [5]. In the last few decades *Ae. aegypti* has expanded its range in the United States, and this trend is predicted to continue in the coming decades [6]. *Ae. aegypti* live in warm environments, as their biological functions are hampered below a temperature of 14°C [7] and temperatures below 10°C are generally not survivable for adult or larval *Ae. aegypti* [8]. In nature, female *Ae. aegypti* live for approximately a month, although some have been recorded living up to 45 days [8]. *Ae. aegypti* have adapted to be able to thrive in environments altered and created by humans [9]. This mosquito primarily reproduces in human-made artificial containers and are able to thrive in urban environments where they face little to no threat from natural predators [9]. However, the invasive mosquito species *Ae. albopictus*, which was introduced to the United States in 1985, can impact *Ae. aegypti* populations through interspecies competition [10,11]. Although this review is not primarily focused on the interaction between these two species and instead attempts to characterize the impact of socioeconomic factors on the distribution of the mosquito vector *Ae. aegypti*, it is important to recognize that the presence of *Ae. albopictus* may be important to determining suitable habitat for *Ae. aegypti*.

Ae. aegypti mosquitoes have a very small range, and few stray further than about 100 meters from where they originated [12] unless the conditions of the immediate environment are unsuitable for reproduction in which case *Ae. aegypti* females have been observed to disperse up to 2.5 km from their origination point [13]. The tendency for these mosquitoes to remain in and seek out areas with well-suited habit indicates that small-scale, neighborhood level environmental factors, which are influenced by socioeconomic characteristics, likely have a considerable influence on the ability of *Ae. aegypti* to survive in specific areas.

The mosquito vector *Ae. aegypti* is highly anthropophilic and relies nearly exclusively on human blood meals and habitats for reproduction [5]. *Ae. aegypti* females feed preferentially on human blood, even if other potential hosts or sugar meals are available [14]. *Ae. aegypti* are generally most active during daytime hours which increases potential interactions between the mosquito vector and humans and in turn increases the potential for the spread of viruses by *Ae. aegypti* [8]. Dengue, yellow fever, and the newly emerged threats of chikungunya and Zika viruses are primarily transmitted in an urban cycle where the virus can be passed from human to mosquito to human [15]. The maintenance of an urban transmission cycles of these diseases requires the co-existence of *Ae. aegypti* mosquitoes [5,16,17] and humans [1] in the same geographic spaces. Travelers can potentially introduce diseases to the established but naïve *Ae. aegypti* populations at their travel destination in the United States because viruses can be passed from humans to *Ae. aegypti* [15]. The presence of this competent vector species has allowed for viruses such as dengue, Zika, and

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chikungunya viruses, to be introduced to and locally transmitted in the United States in the past [6]. Therefore, concern about these viruses becoming established in an urban transmission cycle the United States is warranted.

As globalization continues to bring our world closer together, it is increasingly important to monitor and prepare for the introduction of additional diseases spread by mosquitoes such as *Ae. aegypti* [2]. Given the generally small range of *Ae. aegypti*, those living or working in areas with suitable habitat for *Ae. aegypti* will be most likely to come in to contact with the mosquito vector and will therefore be at greatest risk of disease [12]. Developing a greater understanding of the populations and areas most at risk of infection by studying the relationship between *Ae. aegypti* and socioeconomic factors may allow for the improvement of existing methods to control mosquito populations and intervene in the life cycle of viruses that have the potential to be introduced to the United States. Certainly, organizations do currently exist to monitor and control mosquito populations throughout the United States and many states have comprehensive mosquito control and surveillance programs. This paper does not attempt to claim that mosquito control programs are nonexistent, but that they may benefit from an enhanced understanding of underlying relationships between socioeconomic factors and mosquito populations to efficiently allocate resources.

1.1. Arboviruses vectored by Aedes aegypti

Dengue has expanded its distribution throughout the world in the last few decades, and has been reported to have caused locally transmitted cases in the United States [18]. Over half of the world's population resides in areas that are at risk for outbreaks of dengue [19]. Importantly, the dengue virus has four subtypes, so individuals can be infected more than once and subsequent infections are potentially harsher and more life threatening [19]. Most dengue infections are generally mild, flulike, and self-limiting [19]. Although dengue is generally mild, infected patients can also present with the much more severe dengue hemorrhagic fever which was first reported in the Americas during an outbreak in Cuba in 1981 [20,21]. Due to the widespread occurrence of dengue, the disease has serious impacts both on health and on the global economy. It is estimated that dengue causes up to 100 million infections annually worldwide [17]. In 2013, over 13,000 people globally are estimated to have died from dengue, and the global cost of the disease was estimated to be between 8-9 billion USD [22].

Dengue likely circulated locally in Houston, Texas between 2003-2005, although routine dengue surveillance is not common in this area and dengue cases may be generally underreported [23]. Additionally, local transmission of dengue was reported in Key West, Florida in 2009 where, similar to Texas, dengue surveillance is not routine [24]. These outbreaks of dengue virus in Texas and Florida in the last 15 years have resulted in 25 cases and 90 cases of dengue infection, respectively [17,25]. A serosurvey conducted in 2004 in Brownsville, Texas found that 40% of residents had evidence of past infection of dengue [26], and during the 2009 dengue outbreak in Key West, Florida, a serosurvey revealed that 5% had evidence of dengue infection [24]. This evidence has raised concerns about the potential for dengue to establish itself in the United States.

Yellow fever infections and disease outbreaks typically occur in tropical areas of Africa and South America [27]. Despite the United States being outside of the commonly infected area, yellow fever virus caused an estimated 5,000 deaths in Philadelphia during the summer and fall of 1793 [28]. This is just one of many examples where the presence of a competent vector species combined with the importation of infected vectors or travelers has resulted in a devastating outbreak.

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Those who develop symptoms from infection with yellow fever virus experience fever, vomiting, kidney failure, hemorrhaging, and in 20-60% of cases, death [27]. A vaccine that effectively protects recipients from yellow fever has existed since the 1930s, but lack of vaccine coverage due to funding issues leading to a shortage of needed doses has allowed the disease to persist as a major threat to public health around the world [27,29].

Chikungunya virus was first isolated in Tanzania in 1953 and is known to cause disease consisting of fever, rash, and debilitating joint pain [30]. Historically, chikungunya virus has caused sporadic cases of infection in Africa and Asia, but has recently caused large outbreaks in Southeast Asia from 2004-2005 and in the Caribbean in 2013 [31]. Chikungunya has developed as a potential global health threat in the past decade, as the disease has emerged rapidly in the Americas beginning with the Caribbean outbreak in 2013 [5,32]. At this point in time, the spread of chikungunya virus has been poorly recorded and is not well understood [30]. Although there is no evidence of local transmission of chikungunya in the United States, travelers with a viremic load capable of facilitating virus transmission have been identified returning to areas of the United States with established *Ae. aegypti* presence, raising the possibility that chikungunya could be introduced to *Ae. aegypti* populations in the United States [33]. Chikungunya virus is considered to be a potential public health threat should it emerge in the Americas, because the population has no current immunity to the disease [17].

Zika virus was first discovered in Uganda in 1947 during surveillance for yellow fever, and caused mild, sporadic illness in humans prior to the occurrence of unexpected large-scale Zika virus outbreaks beginning in the Pacific islands in 2007 [32,34]. The Zika outbreak in Brazil that began in 2015 introduced widespread

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concern that Zika infection was linked to severe neurological complications for infants infected during prenatal development [34]. Zika virus has been circulating autochthonously in Mexico since 2015 and is estimated to have caused over 270,000 human cases of Zika virus infection since that time [35,36]. Between 2015-2017, a large outbreak of Zika virus in the Americas resulted in over 3,000 cases of microcephaly associated with Zika infection and was estimated to cost between 7 to 18 billion USD during the outbreak alone [37,38]. In the United States in 2016, over 200 cases of locally-transmitted Zika were recorded in Florida and 6 locally-acquired cases of Zika were reported in Texas [39].

1.2. Framework of socioeconomic factors

Given the limited average dispersal of *Ae. aegypti*, [12], small-scale habitats and built environment characteristics are important for controlling the abundance of mosquito vectors in specific neighborhoods. *Ae. aegypti* have adapted to be able to thrive in environments altered and created by humans [9]. *Ae. aegypti* primarily reproduces in human-made artificial containers and are able to thrive in urban environments [9]. *Ae. aegypti* generally prefer humid environments, but anthropogenic modifications to the environment can create habitats that provide *Ae. aegypti* the ability to flourish even in areas where the natural climate would be inhospitable, such as Arizona [40]. The metropolitan area of Phoenix, Arizona is located in the arid climate of the Sonoran Desert of the southwestern United States [41]. Although the natural environment of Arizona is dry desert that would be inhospitable for *Ae. aegypti*, urban development in the Phoenix metropolitan area has created an “oasis” characterized by increased vegetation and shade trees, grassy lawns, and irrigated fields [41,42]. The abundance and diversity of vegetation as well as water usage is greater in residential areas with higher socioeconomic status in

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Phoenix [41,43]. Therefore, the potential available habitat for *Ae. aegypti*, which requires water to reproduce and has been associated with more abundant vegetation in a nearby similar desert climate [44], may be influenced by neighborhood socioeconomic factors in areas such as Arizona.

Socioeconomic status can impact a person's life and health in many ways and is often discussed as a part of a social determinants of health framework. Healthy People 2020 defines social determinants of health as, "conditions in the environments in which people are born, live, learn, work, play, worship, and age that affect a wide range of health, functioning, and quality-of-life outcomes and risks" [45]. As previously mentioned, the socioeconomic status of a neighborhood can influence the neighborhood design, infrastructure, and landscape, which in turn could potentially influence available mosquito habitat. For instance, green areas are found less often in economically disadvantaged areas of a city than in affluent areas which may influence the abundance of *Ae. aegypti* given that this mosquito has been found to be positively associated with vegetation [44,46]. Socioeconomic factors can also influence the way that people live their lives, such as how much time they spend outdoors. This is relevant to *Ae. aegypti* populations because these mosquitoes generally rely on human blood meals to be able to reproduce [5].

Socioeconomic factors may influence the spread of *Ae. aegypti* due to their reliance on human blood meals and their adaptation to the use of human-created habitat for reproduction. Surveillance efforts should continue to consider social determinants and local challenges to combatting mosquito-borne disease as part of comprehensive mosquito control programs [47] among the many other factors that influence mosquito populations and disease transmission. In order to implement prevention strategies and respond to future disease outbreaks, it is crucial to first

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understand the distribution of mosquito vectors [16,48]. Given that *Ae. aegypti* has extensive interaction with humans, understanding the distribution of *Ae. aegypti* could be enhanced by an understanding of how *Ae. aegypti* are affected by human socioeconomic factors.

Public health prevention and control efforts targeted toward areas at the greatest risk for disease transmission in the case that one of the aforementioned viruses enters the United States once again do currently exist. However, these programs may be enhanced through a deeper understanding of the influence of socioeconomic conditions on the *Ae. aegypti* distribution throughout the country. We focus solely on the mainland United States because socioeconomic conditions can vary widely around the world, and the results of a study with vastly different conditions in another country cannot be reliably extrapolated to conditions in the United States [17]. This paper summarizes the published literature on how socioeconomic variables influence the distribution of *Ae. aegypti* mosquitoes in the mainland United States and aims to answer the following question: how do socioeconomic factors impact the distribution of *Ae. aegypti*?

2. Materials and Methods

2.1. Search Strategy

A comprehensive search was developed to retrieve all published articles on the association of socioeconomic factors and the distribution of *Ae. aegypti* mosquitoes. The following search query was used: ("Aedes aegypti" OR "*Ae. aegypti*" OR "*Ae. aegypti*") AND (distribut* OR presence OR prevalence OR density OR geographic* OR habitat OR spatial OR abundance) AND (social OR equity OR justice OR economic OR socioeconomic OR social-ecological OR equality OR disparity OR disparities OR inequality OR inequalities OR environment OR landscape OR income OR neighborhood

OR community OR communities). Search results were limited to articles/reviews and publications written in English. Four electronic databases (PubMed/Medline, Scopus, Web of Science, and EBSCO Academic Search Complete) were searched using this query through June 12, 2019. Additionally, in an attempt to include grey literature published by mosquito control organizations, 24 mosquito control organizations located in the United States were identified using a popular search engine, and their websites were hand searched for articles, newsletters, or other publications that would be relevant to this review. This search was conducted by first identifying articles that named *Ae. aegypti* as the article's subject and then scanning the title or text of the article for references to the distribution of the mosquito or references to the consideration socioeconomic factors.

2.2. Article selection

Articles were screened for eligibility using the process described in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [49]. First, all articles discovered by searching the databases named above were downloaded and checked for duplicates using the Mendeley reference manager software (Mendeley Desktop, Version 1.19.4). After removing duplicates, the remaining articles were assessed for eligibility using their titles and abstracts. Articles that met the following criteria were considered relevant to this review: 1) published in English; 2) study specifically evaluated the distribution of *Ae. aegypti* mosquitoes, not a specific disease transmitted by *Ae. aegypti*; 3) study evaluated the influence of socioeconomic factors on the distribution of *Ae. aegypti*; 4) study took place in the mainland United States.

Relevant articles were then read in full to determine their eligibility for this review. Additional articles potentially relevant to this review were identified from the

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grey literature search, the bibliography of relevant studies, or previously known literature and were screened for eligibility in the same fashion. Articles eligible for this review were original peer-reviewed studies (i.e., not reviews, commentaries, editorials, abstracts, etc.) or publications of mosquito control organizations from the mainland United States that studied the impact of socioeconomic factors on the distribution of *Ae. aegypti* mosquitoes. See Figure 1 for a diagram of the selection process. Once the included articles were identified, each was read in full. The information relevant to location, date of study, survey methods, analysis methods, and socioeconomic factors were summarized for inclusion in this review. Main themes were then determined based on the compiled information.

Place Figure 1 about here

3. Results

Initially, 3,461 articles were identified through the database searches conducted, and an additional 32 articles were identified through bibliographies and previously known literature for a total of 3,493 articles. After removing duplicates, 2,145 articles remained. These articles were screened for eligibility for this review using their titles and abstracts, and 2,098 articles were excluded for not meeting the eligibility criteria noted above. Finally, the full text for each of the remaining articles (n = 38) was read to determine eligibility. Through this screening process, 11 articles were identified for inclusion in this review. See Figure 1.

The grey literature search resulted in 570 articles, publications, newsletters, or information from national meetings that directly mentioned *Ae. aegypti*. Of these, 6 were identified as potentially relevant to the review because the titles or articles contained some combination of the keywords used in the search process detailed in the methods relating to distribution and socioeconomic factors. These 6 articles were

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all identified through the Journal of the American Mosquito Control Association. The 6 identified articles were further reviewed, and 1 was found to be a duplicate to an already included article that was discovered through database searching, 2 were not research related to the mainland United States, and 3 did not actually address socioeconomic factors. Most publications from these organizations tended to address mosquito biology or the effectiveness of pesticides rather than the relationship between *Ae. aegypti* and socioeconomic factors. See Table 1 for a list of all mosquito control associations that were identified and searched.

Table 1. Mosquito and vector control associations with websites that were searched for grey literature.

Association	Type of Publication Searched	Years Available	Articles mentioning *Ae. aegypti* identified
American Mosquito Control Association	Journal of the American Mosquito Control Association (1985-2019), Mosquito News (1941-1984), Mosquito Systematics (1969-1994)	1941-2019	497
Alabama Vector Management Society	Meeting Agendas	2014-2019	2
Florida Mosquito Control Association	Best Management Practices (2012), Journal of the Florida Mosquito Control Association (2019), Wing Beats Magazine (1990-2019)	1990-2019	8
Georgia Mosquito Control Association	Publications of Interest linked on website, DIDEEBYCHA Newsletters	2010-2019	7
Illinois Mosquito and Vector Control Association	Newsletters	2001-2015	3

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Table 1 continued. Mosquito and vector control associations with websites that were searched for grey literature.

Association	Type of Publication Searched	Years Available	Articles mentioning *Ae. aegypti* identified
Indiana Vector Control Association	No publications available on website	N/A	N/A
Louisiana Mosquito Control Association	Le Maringouin Newsletters	1987-2019	17
Michigan Mosquito Control Association	Skeeter Scanner Newsletters	2007-2018	23
Mid-Atlantic Mosquito Control Association	MAMCA Newsletters	2017-2019	5
Mississippi Mosquito and Vector Control Association	No publications available on website	N/A	N/A
Mosquito and Vector Control Association of California	Mosquito & Vector News (2019), Publications linked on website	2019	4
Nebraska Mosquito and Vector Control Association	Skeeter Newsletters	2008-2019	2
New Jersey Mosquito Control Association	NJMCA Newsletters	1989-2019	7
North Carolina Mosquito and Vector Control Association	The Biting Times Newsletters	2003-2019	3
North Central Mosquito Control Association	No publications available on website	N/A	N/A
Northeastern Mosquito Control Associations	News linked on website	N/A	0
Northwest Mosquito Vector and Control Association	Newsletters	2017-2019	1
Ohio Mosquito and Vector Control Association	No publications available on website	N/A	N/A
South Carolina Mosquito Control Association	The Landing Rate Count Newsletters	2012-2019	5
Tennessee Mosquito and Vector Control Association	Member Publications listed on website	2009-2016	0
Texas Mosquito Control Association	Newsletter archive "coming soon"	N/A	N/A

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Table 1 continued. Mosquito and vector control associations with websites that were searched for grey literature.

Association	Type of Publication Searched	Years Available	Articles mentioning *Ae. aegypti* identified
Utah Mosquito Abatement Association	Annual Proceedings of the UMAA	1948-2007	1
Virginia Mosquito Control Association	The Skeeter Newsletters	2017-2019	2
West Central Mosquito and Vector Control Association	No publications available on website	N/A	N/A

The included studies took place in Florida (n = 5), Texas (n = 3), Arizona (n = 2), or Louisiana (n = 1). The dates of the studies ranged from 1984 to 2018. Main themes that emerged from this summary were the inclusion of economic factors, housing and built environment factors, demographic factors, and/or interactions between these factors. See Table 2.

3.1. Economic factors

The earliest study that related *Ae. aegypti* presence to socioeconomic factors was conducted by Chambers et al. (1986); their results indicated that more containers holding water (potential *Ae. aegypti* habitat) were found in low-income areas as opposed to middle- or high-income and *Ae. aegypti* was only found independently of other mosquito species in low-and middle-income areas as opposed to high-income areas [50].

Most studies identified for this review only sampled *Ae. aegypti* outdoors. However, in one study conducted by Martin et al. (2019), *Ae. aegypti* were found to be more prevalent indoors in low-income communities compared to middle-income communities in South Texas. The abundance of indoor *Ae. aegypti* populations was not influenced by changes in seasonal temperatures as outdoor populations were [49]. No differences were observed for the outdoors abundance of *Ae. aegypti* depending on income; *Ae. aegypti* were found to be much more prevalent outdoors compared to indoors using ovitraps regardless of community income levels [49].

Income was studied in multiple publications with inconsistent results. In Tucson, Arizona, the presence of *Ae. aegypti* pupae was negatively correlated with household income [38]. In another study in Tucson, Arizona by Walker et al. (2011), *Ae. aegypti* larval abundance was found to be significantly negatively associated with income in a normal rain year but there was no significant association between larval abundance and income in a dry year [52]. A study conducted by Reiter et al. (2003) compared the abundance of *Ae. aegypti* in a city in Texas that straddles the United States—Mexico border and found that *Ae. aegypti* was more abundant in the Texas portion of the city where income was higher [54].

Models of *Ae. aegypti* distribution traditionally rely heavily on climatic variables, without taking into consideration the influence of human interactions; however, a study by Obenauer et al. (2017) found that adding a factor representing poverty to a species distribution model greatly improved its accuracy [55]. These findings indicate that poverty has a meaningful impact on the distribution of *Ae. aegypti* likely due to differences in available habitat based on socioeconomic factors.

3.2. Housing and built environment factors

Inconsistent results regarding the influence of land use were observed. A study conducted by Wilke et al. (2018) revealed that construction sites in urban areas of Florida are ideal habitat for *Ae. aegypti* reproduction. *Ae. aegypti* seem to be well suited to utilizing construction sites for reproduction, regardless of other socioeconomic characteristics of the surrounding area [9]. However, another Florida study found that *Ae. aegypti* were found to be more abundant in areas primarily used for residential purposes as opposed to areas used for commercial or industrial

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purposes in Tampa, Florida in 2006 [50]. No differences existed in the abundance of *Ae. aegypti* between cemeteries and the surrounding mixed urban environment [50].

Table 2. Summary of relevant information from identified articles studying the relationship between *Ae. aegypti* and socioeconomic factors.

Ref.	Location	Time Period	Study Design	Data Analysis	Socioeconomic Factors	Results
[9]	Miami-Dade County, Florida, USA	July–October 2017 and 2018	Adult survey using CO_2 traps and immature survey using collection of water existing naturally at 11 construction sites	Shannon and Simpson indices; Individual rarefaction curves; Data matrix plot	Presence of construction (indicator of expanding urbanization); sampling conducted across socioeconomically distinct locations; construction workers disproportionately exposed to *Ae. aegypti*	*Ae. aegypti* was most abundant mosquito species at construction sites. Construction sites represent ideal habitat for *Ae. aegypti* regardless of other socioeconomic factors
[51]	South Texas, USA	September 2016 – April 2018	CDC autocidal gravid ovitraps indoors and outdoors for 69 houses in 8 communities	Generalized Linear Mixed Model (GLMM)	Income	Low-income communities had higher abundance of *Ae. aegypti* indoors compared to middle-income communities
[52]	Tampa, Florida, USA	June and September 2006	Ovitraps and immature sampling at cemeteries and surrounding areas	Paired *t*-tests; nested ANOVAs	Built environment (cemetery, residential, commercial, industrial)	*Ae. aegypti* were more abundant in residential sites than in commercial or industrial sites; coexistence with *Ae. albopictus* occurs at residential sites; no differences existed in the abundance of *Ae. aegypti* between cemeteries and surrounding areas

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Table 2 continued. Summary of relevant information from identified articles studying the relationship between *Ae. aegypti* and socioeconomic factors.

Ref.	Location	Time Period	Study Design	Data Analysis	Socioeconomic Factors	Results
[40]	Tucson, Arizona, USA	August 2012	Outdoor larval habitat container survey of 355 houses in 20 neighborhoods; sampling of immature mosquitoes	Simple linear regression; multiple regression models; log-linear regression with Poisson distribution	Housing type, ownership status (own or rent), house age, household income, number of household residents, presence of children, use of landscaping services	Presence of *Ae. aegypti* pupae positively associated with home ownership and negatively associated with household income regardless of home ownership status
[53]	South Texas, USA	June – September 2010	Ovitraps at 21 sites in 4 cities	ANOVA; linear regression	Rural/suburban/urban gradient	Presence of *Ae. aegypti* was not influenced by rural/urban land use
[54]	Tucson, Arizona, USA	July – September 2003 and 2004	Outdoor ovitraps at 47 residential sites	Multiple regression; logistic regression	Population density, income, house age	Population density was not associated with *Ae. aegypti* abundance; income was negatively associated with *Ae. aegypti* abundance; house age was positively associated with *Ae. aegypti* abundance

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Table 2 continued. Summary of relevant information from identified articles studying the relationship between *Ae. aegypti* and socioeconomic factors.

Ref.	Location	Time Period	Study Design	Data Analysis	Socioeconomic Factors	Results
[55]	South Florida, USA	March 2002 – February 2003	Ovitraps at 45 sites throughout 3 counties	ANOVA; Kruskal-Wallis tests; multiple regression	Rural/suburban /urban gradient and industrial land use	*Ae. aegypti* abundance was positively associated with urban settings compared to rural settings
[56]	Laredo, Texas, USA and Nuevo Laredo, Taumalipas, Mexico	Summer 1999	Household *Ae. aegypti* habitat and larval survey of mosquito-infested containers as measured by the Breteau Index and the House Index	Univariate and multivariate analyses	Income, housing characteristics, number of household residents, housing density	*Ae. aegypti* were more abundant on the Texas side of the border where income is higher, housing density is lower, and number of household residents is lower compared to the Mexico side of the border
[57]	Southeastern USA	1960 – 2014	Use of existing database of *Ae. aegypti* occurrences	Maxent species distribution model	Poverty, population density	Adding poverty and population density factors greatly improves model accuracy
[58]	West Palm Beach and Boca Raton, Florida, USA	September – October 2001	360 ovitraps placed outdoors in varying residential areas	MANOVA and pairwise comparisons; maximum likelihood categorical analyses	Rural/suburban /urban gradient measured by population density, number of houses, level of sanitation, presence of non-human hosts	*Ae. aegypti* was most abundant in urban areas and co-occurred with *Ae. albopictus* in suburban areas

Table 2 continued. Summary of relevant information from identified articles studying the relationship between *Ae. aegypti* and socioeconomic factors.

Ref.	Location	Time Period	Study Design	Data Analysis	Socioeconomic Factors	Results
[50]	East Baton Rouge Parish, Louisiana, USA	May – August 1984	Container habitat and larval survey at 540 households	Split-split-split plot model; ANOVA; two-way contingency chi-square tests	Income	More wet containers (potential habitat) and were found in low-income areas; *Ae. aegypti* larvae were only found independently in low- and middle-income areas

Multiple studies evaluated the effects of urban and rural environments on the abundance of *Ae. aegypti*. In southeastern Florida, *Ae. aegypti* was more abundant in urban areas compared to suburban or rural areas and was found to co-occur with *Ae. albopictus* primarily in suburban areas [56]. A study in South Florida, USA found that *Ae. aegypti* abundance was positively associated with variables representing urban environments as opposed to variables representing rural environments in a regression analysis [53]. However, contrary to the Florida studies, a study in South Texas found that the abundance of *Ae. aegypti* was not influenced by whether ovitraps were placed in urban, suburban, or rural locations, although the presence of *Ae. albopictus* due to higher than usual rainfall during the summer of the study (2010) may have influenced the results [51].

The age of infrastructure was considered by two studies that were both conducted in Tucson, Arizona, an arid desert environment. A study by Walker et al. (2011) found that house age was positively associated with *Ae. aegypti* larval abundance in Tucson, Arizona potentially due to more mature vegetation and objects

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collected in the yards of older homes [52]. A later study in Tucson, Arizona found that house age was not significantly associated with the presence of *Ae. aegypti* larvae or pupae [38].

In one study comparing *Ae. aegypti* abundance in a Texas city on the United States—Mexico border, *Ae. aegypti* was more abundant in the Texas portion of the city where houses and buildings are more likely to be air-conditioned and have window screens, housing density is lower, and the number of residents living in each household is lower [54].

3.3. Demographic factors

A few publications in this review studied the influence of an urban environment compared to a rural environment on the abundance of *Ae. aegypti*, but only one study explicitly evaluated the effects of population density on *Ae. aegypti* abundance. Adding a variable representing population density to a species distribution model for *Ae. aegypti* resulted in a much better fit model of *Ae. aegypti* presence in the southeastern United States compared to a model that relied solely on climate data, reflecting the important interactions between the highly anthropophilic *Ae. aegypti* and humans that influence distribution [55].

The only other demographic factor considered was home ownership status. A study by Walker et al. (2018) found that the presence of *Ae. aegypti* pupae in the arid environment of Tucson, Arizona was significantly higher for homes occupied by the owner compared to rental homes [38].

3.4. Interactions between factors

Socioeconomic factors often do not exist independently and may interact to influence *Ae. aegypti* abundance. A study in Tucson, Arizona found the interaction between house age and income to be significant: *Ae. aegypti* larval abundance was

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higher in older low-income houses than in older high-income houses [52]. The interaction between population density and income was also significant in the study by Walker et al. (2011); this study found that *Ae. aegypti* larval abundance was higher in high-density, low-income areas as compared to high-density, high-income areas [52].

4. Discussion

The findings for these 11 studies revealed inconsistent relationships between the studied socioeconomic factors and the distribution and abundance of *Ae. aegypti*. Given that *Ae. aegypti* mosquitoes vector multiple significant viruses, are highly anthropophilic, and rely on interactions with human populations to reproduce [5], this area of study is extremely relevant to public health. The findings of this review suggest a gap in the literature which could potentially indicate a need for additional research or a need for better circulation of current findings regarding the influence of socioeconomic factors on the distribution of *Ae. aegypti* that could hinder efforts to implement the most effective public health prevention and control strategies should a disease outbreak occur.

Most studies in the United States are dependent on outdoor sampling, as indoor sampling is considered invasive. This could affect the results of these studies because *Ae. aegypti* have been known to rest and reproduce indoors [15] and areas of high income where houses may be more likely to have air conditioning, well-sealed doors and windows, and intact window screens may have higher populations of *Ae. aegypti* outdoors compared to low-income areas where mosquitoes can find habitat indoors. However, in the United States where the use of air-conditioning is widespread, *Ae. aegypti* that find their way indoors may not be able to successfully reproduce or transmit disease due to the lower temperatures and humidity [54] forcing these mosquito vectors to take blood meals outside.

The results of this review are of course limited by the methods adopted to complete the search of the literature. The search terms used in this review were designed to return comprehensive results, but there are likely studies that were missed in this search process. Additionally, a systematic review is naturally sensitive to publication bias, as only studies that were accepted by journals and published could have possibly been found through this search. It is possible that there exist many other studies with contradictory or null findings that were never accepted for publication and are therefore not included in this review. Additionally, many mosquito control organizations may already possess a deep understanding of the relationship between *Ae. aegypti* and socioeconomic factors that they use to implement effective mosquito control programs. Unfortunately, much of this knowledge is not published on platforms that are easily accessible. Therefore, despite extensive screening of the grey literature that was available on the websites of 24 mosquito control organizations in the United States, the results of this study may be lacking knowledge accrued by these organizations.

Overall, this review revealed a gap in available literature relating the *Ae. aegypti* population of the mainland United States to anthropogenic and socioeconomic factors. That only 11 articles were identified for this review reveals a need for additional published research into the human and built environment characteristics that contribute to ideal habitat for *Ae. aegypti* and therefore contribute to increased risk of disease transmission so that all involved in mosquito control and surveillance can access this information easily to benefit from this understanding. Additionally, these studies were mainly conducted in three states: Arizona, Florida, and Texas. Given that

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the survival of *Ae. aegypti* is tied to the local climate, more studies should be conducted in varying areas throughout the United States with an established presence of *Ae. aegypti*. The interaction between socioeconomic factors and the climate will likely vary for each local area. For example, in an arid, desert climate such as Arizona, areas of high socioeconomic status with greater use of water and more vegetation may create more suitable habitat for *Ae. aegypti* [39,41]. However, in environments with more regular precipitation such as Baltimore, Maryland, areas of low socioeconomic status with poor infrastructure are associated with greater abundance of *Ae. albopictus*, although more research is needed to determine if this relationship holds for *Ae. aegypti* [59]. As the mosquito vector *Ae. aegypti* re-emerges throughout the mainland United States and as diseases transmitted by the vector continue to remain a threat to public health, continuing to improve our understanding of *Ae. aegypti* distributions at a local level will allow public health efforts to continue to be targeted to the most at-risk or vulnerable areas and populations. Future studies should focus on including socioeconomic factors in the evaluation of *Ae. aegypti* distributions to gain a better understanding of the local neighborhood environments that support *Ae. aegypti* populations.

It is imperative that the distribution of *Ae. aegypti* be well understood prior to any potential major disease outbreaks. Understanding the habitat and areas where *Ae. aegypti* thrive will allow for a quicker, more targeted response to control the spread of disease should an outbreak occur. Targeted intervention will also help reduce the costs of any future outbreaks by targeting and therefore conserving prevention and treatment resources, limiting the number of people exposed to disease, and reducing the human cases observed. In order to prepare for potential future outbreaks, it is imperative that additional research be conducted in diverse cities throughout the

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United States to better understand the presence and distribution of *Ae. aegypti* as related to socioeconomic factors.

5. Conclusions

This systematic review revealed a lack of prior research regarding the connection between the distribution of *Ae. aegypti* mosquitoes and socioeconomic factors. Given that the life cycle of these mosquitoes is closely linked to human populations and behaviors, it is imperative that this connection is better understood. This mosquito vector transmits many diseases relevant to public health such as dengue, yellow fever, Zika, and chikungunya, and they are found throughout large portions of the United States. In the event that a disease is again introduced to the *Ae. aegypti* population in the United States, many people that live in areas where this mosquito is present could be at risk of contracting the disease. Preparation for a disease outbreak is essential and understanding the distribution of this disease vector is a crucial component to that preparation. More research is needed to better understand how the distribution of *Ae. aegypti* relates to socioeconomic factors in the United States.

Author Statement

Research Funding: This work has been supported by the following funds awarded to CMH: New Investigator Award from the Arizona Biomedical Research Center, start-up funds from the Arizona Technology Research and Initiative Fund, and a training grant to support WHE, from the Pacific Southwest Regional Center of Excellence for Vector-Borne Diseases funded by the U.S. Centers for Disease Control and Prevention (Cooperative Agreement 1U01CK000516).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Informed Consent: Informed consent is not applicable.

Ethical approval: The conducted research is not related to either human or animal use.

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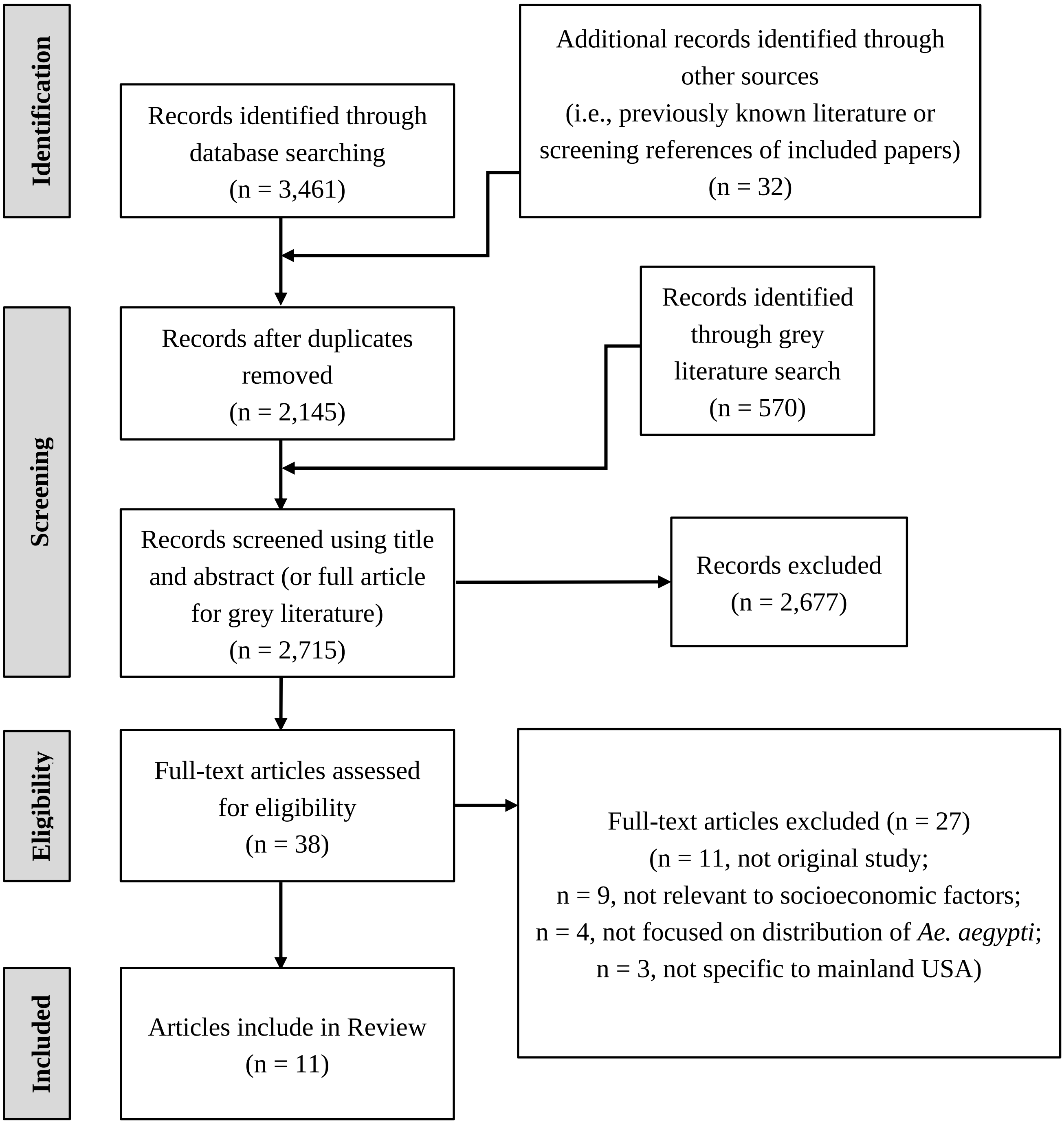

Fig 1. Systematic article selection process based on PRISMA guidelines.