

Opinion

Mosquito Adaptation to the Extreme Habitats of Urban Construction Sites

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The construction industry employs millions of workers in the USA. However, little is known about how environmental disturbances caused by the construction industry impacts vector mosquito ecology and behavior, and whether it is responsible for increasing the abundance of mosquitoes. There is a major scientific gap on how to assess the occupational exposure risk of mosquito biting and arbovirus transmission among outdoor worker populations who spend a disproportionate amount of time working outdoors. In our opinion, it is critical to address how construction workers and the surrounding communities may be geographically and seasonally exposed to vector mosquitoes. Research should identify modifiable worker- and organizational-level factors that improve worksite mosquito-control practices to give insights into future vector-control strategies in urban environments.

Urbanization and the Construction Industry

In the late 19th century humanity entered a new geological era known as the **Anthropocene** (see [Glossary](#)), defined by man's influence in modulating the environment on a level compared to that of the natural forces of planet Earth [1]. Human migration from rural areas to urban areas, and the construction of new dwellings, has been increasing since then and, as a consequence, **urbanization** processes have been intensified to accommodate new residents, urbanizing adjacent peri-urban areas, increasing urban verticalization, and population density [2–4].

Construction sites are an integral part of the urbanization process. They often lead to a significant disturbance in the environment, modifying land usage, increasing human presence, and generating significant amounts of waste, significantly affecting local fauna and flora [5]. The construction industry in the USA alone spent approximately US\$1.3 trillion in 2018, with more than 13 million new residential permits issued in the same period employing approximately 9.4 million workers on average [6]. However, very little is known to what extent the environmental disturbances caused by the construction industry impact the biodiversity and abundance of mosquito vector species.

Construction Sites Are Complex Environments

Construction sites, especially geographically large ones, are complex and dynamic. Several employers work on one site simultaneously, with a mix of contractors changing with the phases of the project [7,8]. Moreover, as the project develops, different building materials are brought to the worksite or, as the weather changes, the ambient conditions such as ventilation and temperature change too.

In 2016, the United States **Occupational Safety and Health Administration (OSHA)** issued empirical **mosquito control** guidelines considering the threat Zika virus poses for construction

Highlights

Recent studies have shown that the proliferation of vector mosquitoes is partially attributable to construction sites.

Very little is known about how environmental disturbances caused by construction sites impact vector mosquito ecology and behavior.

There is a significant scientific gap on how to assess the risk of mosquito biting and arbovirus transmission in construction sites.

In our opinion, it is critical to address how construction sites may be geographically and seasonally exposed to vector mosquitoes and their effect on the transmission of arboviruses in the surrounding communities and in the population as a whole.

Research should also identify modifiable worker- and organizational-level factors that improve mosquito-control practices to guide future vector-control strategies in urban environments.

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workersⁱⁱ. However, several features of construction sites (e.g., size, duration and phase, number and type of workers, presence and abundance of vector mosquito species) account for the effectiveness of vector-control guidelines in construction sites to effectively reduce the risk of **arbovirus** transmission.

Therefore, effective safety measures and guidelines must account for the complex worker-mosquito interaction in the highly heterogeneous job site environment, in which several variables account for the assessment of the multifactorial risk of workers being exposed to **vector mosquitoes**.

Indeed, the spread of mosquito-borne disease in the job-site environment represents a prototypical complex system, where the behaviors of human hosts and mosquito vectors mutually interplay and affect each other. This feedback cycle encompasses nonlinear dynamic aspects, emergent phenomena, and critical points that describe how each process affects the other both microscopically and macroscopically, in which a small change in a variable (e.g., mosquito abundance) can have a disproportionate effect on the risk of infection for workers.

Here, we hypothesize that features associated with the proliferation of vector mosquitoes in construction sites are likely to vary across space, such that high and low levels of vector mosquitoes are concentrated in specific geographic areas according to the size of the construction site, the number of workers present at the job site, the project duration and phase, each with unique biological, environmental, and physical features and respectively associated risks for the production of mosquitoes and the transmission of vector-borne diseases.

In perspective, a significant gap in the scientific literature includes worker- and organizational-level factors across the construction project life. The better understanding of these factors is needed for the development of more effective targeted evidence-based guidelines, tailor-made for construction workers, based on scientific evidence to support and potentially improve these guidelines aiming for the reduction of construction worker exposure to mosquito vectors of arboviruses.

Construction Sites and the Proliferation of Vector Mosquitoes

Urbanization processes are often responsible for reducing the overall biodiversity of species [9], leading to a decrease in the richness of species and subsequent increase in the abundance of selected species capable of prospering in urban environments in a nonrandom process of biodiversity loss [10]. The mosquito vectors *Aedes aegypti* and *Culex quinquefasciatus* are among the species that are able to thrive in such urban habitats amongst the human population [11,12].

Ae. aegypti and *Cx. quinquefasciatus* are adapted to oviposit their eggs in artificial breeding habitats that are often widely available in construction sites, in which immature mosquitoes can develop without predators and blood feed on the exposed construction workers [13,14]. *Ae. aegypti* and *Cx. quinquefasciatus* are responsible for transmitting many arboviruses, such as dengue, chikungunya, yellow fever, and Zika viruses [15–19], and West Nile and Eastern Equine Encephalitis viruses [20,21] respectively.

Research done in Miami-Dade County, Florida, by Wilke *et al.* [14] found that immature and adult *Ae. aegypti* and *Cx. quinquefasciatus* were breeding in high numbers at construction sites in the accumulated stagnant water in elevator and stair shafts, Jersey plastic barriers, and on puddles on the floor (Figure 1A–C). Findings of this study provided information on how early-phase construction sites are often vulnerable to ambient elements and may collect rain and groundwater on the widely available artificial containers spread out throughout the area. These mosquito-

Glossary

Anthropocene: hypothetical geological age in which human activities have an influence equivalent to that of the forces of nature on the environment.

Arbovirus (arthropod-borne virus): an acronym used to refer to any viruses that are transmitted by arthropod vectors.

Construction site: a delimited area in which construction workers are working on the addition of a structure to real property in the form of residential or nonresidential buildings, infrastructure or industrial.

Mosquito control: public-health practice targeted to the management of mosquito populations aiming to reduce disease transmission and nuisance caused by their bites.

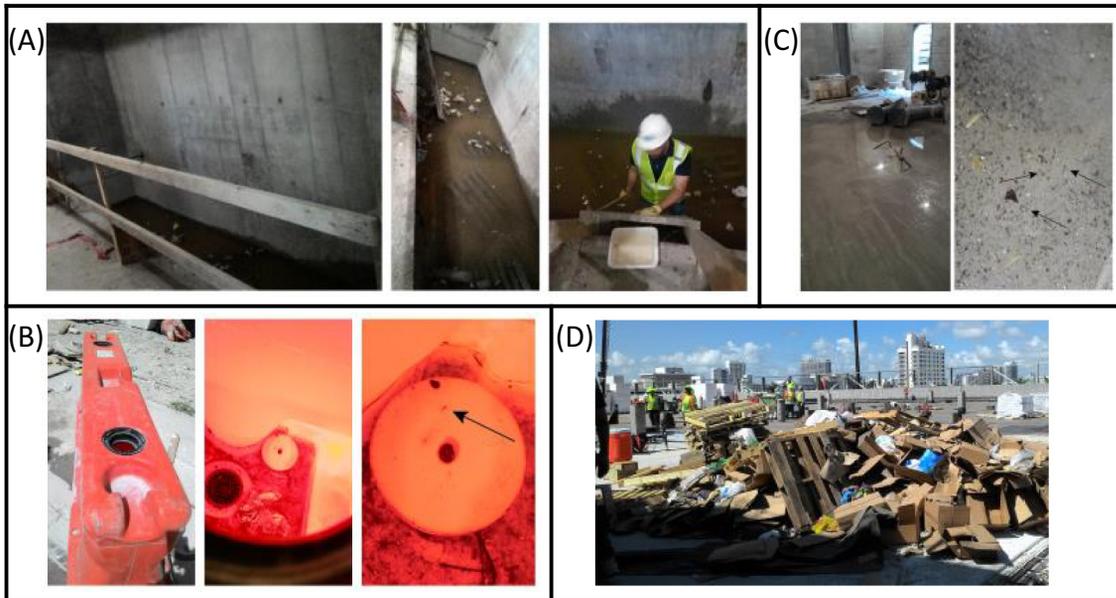
Occupational Safety and Health Administration (OSHA): an agency of the United States Department of Labor that aims to regulate work condition safety based on enforcement of laws, training outreach, education, and assistance.

Safety guidelines and best

practices: a group of recommended practices to increase workers' safety and to prevent injuries, illnesses, and deaths in the construction work site.

Urbanization: a set of processes by which towns and cities are formed, consisting of the conversion of rural areas into urban areas to accommodate the growth of the human population and human migration from rural areas to cities.

Vector mosquitoes: mosquito species capable of carrying and transmitting infectious pathogens such as viruses, parasites, or bacteria into another living organism.



Trends in Parasitology

Figure 1. The Risk of Mosquito Proliferation at Construction Sites. (A) Elevator shaft flooded with stagnated water in a construction site. From left to right: elevator shaft; stagnated water and accumulated trash inside elevator shaft; survey of immature mosquitoes breeding in the elevator shaft. (B) Jersey plastic barrier, filled with water, breeding vector mosquitoes. From left to right: Jersey plastic barrier; stagnated water inside Jersey plastic barrier; adult *Aedes aegypti* inside a Jersey plastic barrier. (C) Stagnant water on the construction site floor serving as breeding sites for *Ae. aegypti* mosquitoes. From left to right: shallow pool of stagnant water; *Ae. aegypti* larvae and pupae breeding in this habitat. (D) Accumulated trash in a construction site environment potentially creating breeding sites for vector mosquitoes.

breeding sites provide *Ae. aegypti* and *Cx. quinquefasciatus* with suitable conditions to freely reproduce and populate construction sites. The construction sites surveyed by Wilke *et al.* had a reduced species biodiversity, and even though 13 different mosquito species were collected in this study, *Ae. aegypti* and *Cx. quinquefasciatus* comprised 95% of all the 3351 mosquitoes collected and were the only species found in their immature form breeding inside construction sites. Such findings suggest that construction sites have highly favorable habitats for vector mosquitoes adapted to urban environments.

However, despite the size and world-wide importance of the construction industry, there is a lack of information globally on the relationship between construction sites and mosquito vectors. The role of construction sites in the proliferation of vector mosquitoes has been largely neglected and ignored and is for the most part unknown. There are only a few studies available on the subject, and many questions remain unanswered [22–26]. We still do not know the effect of construction sites on the epidemiology of vector-borne diseases. Moreover, longitudinal studies focusing on seasonal variation in the species composition of mosquito vectors, and their abundance according to fluctuations in weather conditions, the phase of construction, and specific physical features, are also lacking, substantiating the paucity of studies on this subject.

Construction Workers Are Exposed to Mosquito Vectors of Arboviruses

During the Zika virus outbreak in Miami-Dade County in 2016, construction workers from the Caribbean with asymptomatic infection inadvertently brought the Zika virus to Miami, and were subsequently bitten by *Ae. aegypti* mosquitoes breeding in high numbers at a construction site located in the city of Miami Beach, Florida, triggering a Zika virus outbreak [27,28]. Proactively, the Miami-Dade Mosquito Control Division issued a brochure alerting for the risk

of the proliferation of mosquitoes in construction sites (see Figure S1 in the supplemental information online).

Vector-borne diseases have considerable implications for construction worker safety due to the impairment these diseases may cause, comprising: severe joint pain, risks for conception and severe neurological diseases, such as Guillain–Barré syndrome, leading to worker absenteeism, long-term health consequences, and even death [16,29,30]. The arboviruses can be introduced into the construction job sites by workers who become infected during travel to other countries in regions where there is active transmission and then return to their job with asymptomatic infections (e.g., 80% of active Zika infections are inapparent) [31] and serve as reservoirs for the arboviruses.

Construction workers are available in large numbers and spend a disproportional amount of the workday outdoors being exposed to vector mosquitoes present in high numbers at the job site. Moreover, by neglecting existing **safety guidelines and best practices**, such as the removal of accumulated trash and stagnated water, construction companies are making available many potential breeding habitats for mosquito vector species (Figure 1D).

The development of effective safety guidelines to reduce the risk of subjecting construction workers to the presence of arbovirus mosquito vectors depends directly on reliable data on how construction site environments are driving the population dynamics of vector mosquitoes, and the interaction between mosquito and construction workers. It is of paramount importance to developing and put into action effective safety guidelines and best practices for the construction workers and construction firms taking into account how vector mosquitoes are currently exploring and thriving in habitats created by construction sites [32,33].

Current Conceptual Framework for Construction Workers' Safety and Health

Several theoretical frameworks indicate that worker safety and health is the result of a complex interplay of factors involving the individual worker and the immediate work environment, as well as characteristics of the broader contexts in which both the worker and the construction work site are embedded [34,35]. Future studies should specify the causal pathways through which the worker- and organizational-level factors are intended to influence mosquito-control practices, acknowledging these multifaceted influences.

By illuminating these pathways, it becomes possible to design mosquito-control interventions that are meaningful and relevant for this construction worker audience because they attend to relevant work conditions, thereby potentially enhancing intervention efficacy.

We hypothesize that these workplace policies, programs, and practices will impact mosquito-control practices for several reasons. In addition, psychosocial factors, including supervisor and coworker support, have been shown to be associated with mosquito-control practices [36,37]. The physical work environment of the construction site may also provide opportunities for engaging in positive mosquito-control practices, for example, by the increased availability of mosquito repellent, surveillance/removal of standing-water sites, and application of larvicides to water sources [38].

Thus, in this model, workplace policies and practices are the primary engines which drive how work is organized. They are the upstream conditions that shape multiple downstream conditions [39]. In addition, for the individual worker, it would be desirable to build self-efficacy and skills for engaging in mosquito-control behavioral changes.

The arboviruses, such as Zika and chikungunya viruses, are of high concern because *Ae. aegypti* is highly anthropophilic and exhibits increased biting activity during the day when outdoor construction workers are most vulnerable [16,40,41]. It is currently unknown how worker health and safety at outdoor construction sites may be geographically and seasonally compromised by their exposure to the bites of mosquito vectors of arboviruses.

Unknown Epidemiological Importance of Construction Sites

Currently, risks to construction site workers are unknown because: (i) there is a lack of scientific information on how construction sites create favorable conditions for mosquitoes species; (ii) it is unknown to what extent mosquitoes are blood feeding on construction workers and ovipositing in breeding sites produced by construction sites; (iii) it is unknown how much construction workers are seasonally exposed to the bites of blood-feeding mosquitoes or how this risk varies across sites; (iv) the actual on-site health risks of workers exposed to mosquitoes remain uncharacterized; and (v) the possible effect of construction sites in shaping the epidemiology of arbovirus diseases at the population level is even more uncertain. However, as shown by the 2016 Zika outbreak in Miami-Dade County, we cannot exclude the possibility that construction sites may serve both as an amplifier of the transmission and as a trigger for population-wide epidemics [27,28].

The production of vector mosquitoes in construction sites is likely to vary across space, such that high and low levels of vector mosquitoes are concentrated in specific worksite areas according to the size of the construction site, duration and phase, number and type of workers, each with unique biological, environmental and physical features. Consequently, health and safety messages to construction workers provided by mosquito-control agencies, county officials, and federal agencies guiding worker protection are not solidly grounded on scientific evidence^{iii,iv}.

A Better Understanding of the Risk That Vector Mosquitoes Represent to Construction Workers Is Needed

Despite the risk that vector mosquitoes pose in the workplace to the construction workforce, little is known about what species of mosquito are present in construction sites, what features are driving their incidence and abundance, and the inherent risk that mosquito vectors of arboviruses represent to construction workers and the surrounding area. Additionally, there is a need to account for human behavior and best practices at the job site (worker- and organizational-levels) in order to evaluate the effectiveness and possible improvements of the current safety standards and guidelines employed in the construction workplace for the suppression of vector mosquito populations.

Furthermore, by developing data-driven predictive models for the complex worker–mosquito interaction in the construction site environment, it will be possible to understand transmission patterns of arboviruses in the construction site and surrounding communities, provide guidance to construction-site-specific mosquito-control strategies, which would otherwise be difficult to test without modeling, and to assess to what extent construction sites shape the epidemiology of arboviruses at the population level.

Concluding Remarks

More studies should be directed to address how individual construction workers and communities may be geographically and seasonally exposed to bites of vector mosquitoes (see Outstanding Questions). It is also essential to identify modifiable worker- and organizational-level factors that improve worksite mosquito-control practices to guide future mosquito-control strategies in urban environments (Box 1).

Outstanding Questions

What are the physical features in construction sites responsible for driving mosquito presence and abundance? What are the essential resources present in construction sites being used by mosquitoes for blood and sugar feeding? Are vector mosquitoes adapting to thrive in the extreme conditions of construction sites?

What is the impact of construction sites on the biodiversity of mosquito vector species? To what extent do construction sites promote biotic homogenization processes?

What human behaviors are associated with the proliferation of vector mosquitoes in construction sites? How much are construction workers seasonally exposed to vector mosquitoes in construction sites? What is the risk of arbovirus transmission on construction sites and surrounding communities?

What are the modifiable physical features in construction sites and human behavior that could reduce the proliferation of vector mosquitoes? How can we effectively control vector mosquitoes under different conditions and phases in construction sites? How is the interaction between mosquito and construction workers driving the population dynamics of vector mosquitoes and the transmission patterns of arboviruses?

Box 1. Research Framework for the Development and Improvement of Mosquito-Control Strategies in Construction Sites

1. Investigate the complex dynamics of mosquito–worker interaction in the highly heterogeneous environment of the construction site to assess how worker health and safety at construction job sites may be driven by their exposure to bites of mosquito vectors.
 - There is a dearth in knowledge about the interaction between mosquitoes and construction workers at construction sites.
 - It is unknown how construction sites are increasing the production of vector mosquitoes, and how much risk this scenario represents for the construction workforce and the community.
 - A key aspect of developing effective tailor-made guidelines for controlling arbovirus mosquito vectors on construction sites is the identification of specific species of mosquito present in the construction site workplace.
 - It also requires the identification of the mechanisms that vector mosquitoes are employing to thrive in construction sites. What is the potential risk of arbovirus transmission, given the complex scenario of construction environments?
2. Elucidate what species of vector mosquitoes are in contact with construction workers and what features commonly found in construction sites are driving their population dynamics and geographic distribution, rendering it possible to employ species-specific vector-control strategies for maximum efficacy for mosquito population suppression and control to lower the risks to construction workers and the surrounding community.
 - Determine the impact of worksite physical features (i.e., building materials, phases of the building project, workforce composition, job site sanitation) on mosquito ecology and human biting.
 - Determine the influence that worker behavior and practices (use of repellent, long sleeves, application of chlorine tablets to standing water) has on mosquito biting and mosquito population abundance.
3. Develop, calibrate, and validate predictive data-driven models of the complex construction worker–mosquito interaction in the job-site environment to evaluate the risk that vector mosquitoes pose to construction workers and the community.
 - Guide best practices in on-site mosquito-control operations to ensure a negligible risk of arbovirus transmission and, potentially, a mosquito-free work environment.
 - Develop more effective targeted safety measures and guidelines for reducing vector mosquitoes in the workplace and the risk of arbovirus transmission.
4. Guide and improve safety and mosquito-control guidelines for outdoor workers – based on scientific evidence for effective reduction of risk of vector-borne disease transmission and exposure to nuisance-biting mosquitoes.
 - Provide effective protection from vector-borne disease transmission in an effort that will reach millions of workers that are exposed to vector-mosquitoes on a daily basis during their working day.
 - Protect the general population from mosquito vectors of arboviruses, given that, during the Zika crisis that struck Miami-Dade County in 2016, many Zika cases were associated with transmission at the workplace.

Recent arbovirus outbreaks exposed the vulnerability of many countries to mosquito-borne pathogens transmitted by vector mosquitoes, including the USA, and many countries in Europe [18,27,41–43]. Future studies should focus on construction workers at high risk for exposure to mosquito biting and vector-borne disease, and modifiable work organization factors likely to be associated with these mosquito-transmission risks.

Studies should be conducted in collaboration with major construction firms and construction equipment vendors (i.e., safety barrier materials), which will support this research through in-kind contributions of project leadership time and by facilitating these organizational changes (i.e., mosquito-control practices). This process may be facilitated due their visibility and role in providing construction services. The major construction firms are key to set the pace of policy change for mosquito control among other employers, thereby maximizing the potential impact of research.

There is also a need to identify characteristics of the work organization, mosquito ecology, worker behavior, and aspects of the job-site environment that can be feasibly modified through changes in management and worker practices. Mosquito-control strategies should be based on both mosquito and human surveillance surveys across various construction phases and types of construction job sites with a random sample of construction workers and focus groups with construction firm leadership, management and entry-level construction workers.

Disclaimer Statement

The authors declare no competing interests.

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Supplemental Information

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Resources

ⁱwww.census.gov/topics/income-poverty/income.

ⁱⁱwww.osha.gov/laws-regs/regulations/standardnumber/1926

ⁱⁱⁱwww.osha.gov/Publications/OSHA3855.pdf

^{iv}www.cdc.gov/niosh/

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