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Bridging the gap: understanding arboviral vectors in the Caribbean

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Introduction

Vector-borne diseases in the Americas continue to gain attention due to the current dengue epidemic and increasing incidences of Oropouche virus in endemic and non-endemic areas (1, 2). Even though the region has long been a hotspot for well-studied viruses such as dengue, chikungunya, and Zika, we currently know very little about their vectors and other emerging/re-emerging viruses particularly in Caribbean.

Invasive species and understudied vectors

A recent study notes the identification of the invasive *Aedes vittatus* in Jamaica, where it was reported to display synanthropic characteristics (3). In the Americas, *Ae. vittatus* has previously been identified from the Dominican Republic (4) and Cuba (5–7). This mosquito has demonstrated great ecological plasticity, and its competency for multiple arboviruses has been established through laboratory experiments (8). Viral isolations have also occurred from field-caught specimens (8); however, its role in disease transmission throughout the region is currently unknown.

Undoubtedly, invasive *Aedes* species are of significant concern due to their production of desiccation-resistant eggs and the prevalence of arboviruses such as dengue within the Caribbean. Additionally, travel, migration, and trade are major factors (9) involved in facilitating vectors to spread regionally and adapt to new territories with favorable environmental conditions. The dispersal of these mosquitoes has been intimately linked to the used tire trade and air transportation (10), both of which thrive within the region. Unsurprisingly, *Aedes albopictus* is now ubiquitous throughout the Caribbean after first being reported from the Dominican Republic in 1993 (11). Of note, the lack of data from some regional countries does not indicate its absence. Interestingly, despite extensive surveillance efforts, there is no evidence of the established presence of *Ae. albopictus* in

Puerto Rico (12), thus supporting the need for more biogeographical studies throughout the region. Although considered an important vector for arboviruses such as chikungunya (13), *Ae. albopictus* remains understudied in the Caribbean, and its role in arboviral transmission has not been explored. With the lack of entomological surveillance systems in Caribbean territories, there exists no differentiation between the primary *Aedes* mosquito vector species, which may lead to underreporting (14, 15).

Additionally, the neglect of other medically important but "less significant" mosquito species, which may be competent for pathogens and other vectors, such as ticks and sandflies, may contribute to an increased public health risk. More work needs to be undertaken to elucidate the roles of these understudied vectors in the region. To compound matters, vectors may also exist in cryptic species groups (16, 17), adding to the uncertainty of possible spillover from sylvatic cycles to humans. Recently, a new *Haemagogus* mosquito species was identified in Trinidad using molecular analysis (18). Again, it is unknown what threat this new species may pose to public health because it is morphologically indistinguishable from *Hg. janthinomys*, the sylvatic vector for the yellow fever (19) and the emerging Mayaro virus (20), and was collected in close proximity to human settlements (21).

Surveillance and knowledge gaps

Renowned for its biodiversity, which includes a vast number of endemic species, the Caribbean was once a mecca for arbovirology and entomology research. The establishment of the Trinidad Regional Virus Laboratory on the island of Trinidad in 1952 resulted in the screening of over 1.5 million arthropods for viruses and the isolation of over 470 virus strains between 1953 and 1963 (22). Moreover, the extensive Mosquitoes of Middle America project from 1962 to 1976 examined the biodiversity of mosquitoes across much of the region and resulted in the publication of seminal entomological studies (23). The research capacity that was established during that period has since been lost, and the region has subsequently suffered from years of underinvestment in medical entomology. In many islands, baseline studies have not been conducted in decades, and taxonomic keys are grossly outdated. Furthermore, vector control programs remain underfunded, and many lack personnel with the skillset required to morphologically identify mosquito specimens and the facilities to conduct infectivity studies. Encouragingly, the rebuilding process has slowly begun with recent biological surveys from the Dutch Leeward Islands (24), Puerto Rico, and Vieques (12).

The Caribbean region has also become increasingly dependent on external studies that describe variable competencies of geographically distinct vector populations for arboviruses. Medically important arthropods that function in the transmission of Zika, chikungunya, dengue, Oropouche, and yellow fever viruses are well-studied during outbreaks in Africa and North and South America. In contrast, very few documented variations from Cuba (25), Martinique (26), and Puerto Rico (27) dictate our understanding of the local arboviral and vector landscape. Therefore, local studies that investigate vector competence are crucial for assessing the risks of arbovirus transmission and maintenance in nature. An in-depth understanding of the complex relationships between virus and its vector can lead to the development of robust mitigation strategies for vector and arboviral disease control. It is important to investigate the variation in *Aedes*, *Culex*, and *Anopheles* species vector competence using established field-collected mosquitoes across the Caribbean region, owing to the unique environmental pressures they withstand.

There is also a lack of knowledge on mosquito host preferences across the Caribbean, which may account for the unexplained variations in genetic plasticity and impact on arboviral transmission dynamics. It is evident that preferential feeding behavior may be a product of adaptive advantages determined by intrinsic and extrinsic factors (28). Additionally, patterns of host selection by mosquitoes have been described to be systematic in space and time. Hence, research efforts focused on mosquito host utilization for understanding olfactory and thermal cues are important (29). Though a recent study in the Dominican Republic (30) has begun to address these challenges, the need for more research in the wider region is essential.

Environmental changes and vector expansion

Global warming, urbanization, and deforestation have also led to the rapid expansion of habitats for medically important arboviral vectors and have contributed to the rapid spread of vector-borne diseases worldwide (31, 32). Furthermore, it is common knowledge that small island territories which dominate the Caribbean region are particularly vulnerable to the effects of climate change and urbanization (15, 33). Vector-borne disease incidences have been shown to increase with warmer temperatures, erratic rainfall, and expansion of breeding sites (34–36). This presents risk to densely populated geographic regions, particularly vulnerable communities, where the majority of infections take place.

There has been considerable debate as to whether climate change would pose a global risk on important arthropod-borne diseases that are transmitted by notorious mosquito vectors from infected to uninfected humans (29). Predictive models are being utilized in ongoing research studies worldwide to improve on precise climate models (35). In the Caribbean region, there is a paucity of long-term observational studies that monitor climate change effects. As such, in the first instance, model-based assessments are most likely to be challenged by words rather than tangible data. Added to that, the scarcity of systematically acquired field and/or laboratory-derived epidemiological data to account for arboviral spread presents entomological gaps. This hinders understanding the complexities of climate change in the Caribbean region and its influence on vector dynamics (15, 37).

Future directions

To enable improved early warnings and risk assessments, the integration of remote-sensing and Geographic Information System (GIS) methodologies to track environmental conditions that drive vector-borne disease risks, outbreaks, and transmission rates in real time should be sourced. These techniques should be woven into studies undertaken across Caribbean territories to enable the mapping of vector habitats, vector presence, species abundance and density, and spatial diffusion. In combination, these data would improve surveillance efforts to elucidate the root cause of the disease infection and its source.

These technologies can assist in building baseline data for understanding epidemiological public health risks based on age groups, gender, disease severity, and community structure. Additionally, the integration of sophisticated genomics and bioinformatics analysis tools would allow us to directly identify and track vectors and vector-borne pathogens to validate modeling efforts. The acquisition of robust baseline data for the Caribbean provides the framework for vector competence studies and the establishment of holistic reports on medically important vectors that are exposed to diseases. There is a need to review how climate may impact the most divergent of arthropod disease vector groups in the Caribbean. Local studies would allow us to evaluate mechanisms that implicate biological barriers that affect virus dissemination within vectors and subsequent presence in mosquito saliva, as a proxy of infectivity to host organisms. The generation of Caribbean vector transmission data is of major epidemiological significance as it allows for vector control teams across the Caribbean to utilize appropriate disease control methods. For instance, the screening of natural *Wolbachia*-infected mosquito populations (38) and the use of the sterile insect technique (SIT) against Aedes *aegypti* (39) as potential mosquito control strategies in Cuba.

Concluding remarks

It is imperative that we close the knowledge gap regarding the vectors and the infections they are associated with in order to influence strategic and preventative public health policies rather than reactive measures, which are frequently used throughout the Caribbean region. Stakeholders such as regional and international health organizations, government agencies, universities, and local communities should prioritize investments into entomological research-driven decision-making.

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