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Urban-microclimate effect on vector mosquito abundance of tropical green roofs

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A B S T R A C T

Urbanization engenders habitats with distinctive and often adverse microclimates. Green spaces are actively incorporated in urban designs to make cities resilient against climate-change, disease spread and other environmental challenges. Adoption of green roof as an innovative urban green infrastructure has been hindered by the perceived disservice of attracting urban pests like mosquitoes. This study evaluated important microclimatic attributes that explain vector abundance differences between urban extensive green roofs and two control site types in humid-subtropical Hong Kong. Mosquito-trapping data were collected fortnightly for a year (March 2015 to 2016) from seven sites representing three experimental treatment groups: green roofs (GR), low-elevation blue-green spaces as positive controls (PC), and bare roofs as negative controls (NC). Concurrent ambient microclimate parameters were measured on site. Human-biting female mosquitoes of species known to transmit infectious diseases locally and globally constituted the vector abundance data. Generalized linear models evaluated the effects of site-specific microclimatic factors on abundance. Time-lagged microclimatic measurements were analyzed to reveal latent effects. The models consistently identified temperature and wind speed as significant factors. Wind speed accounted for differences in abundance across site types, while temperature exerted its effect on abundance chiefly through seasonal variation. Contrary to common preconception, urban green roofs had significantly lower vector abundance relative to controls. High wind exposure on elevated buildings, which acted as a deterrent of mosquito flight, was found to be the underlying microclimatic factor. Our findings could inform urban greening design and policy, as well as disease control and transmission risk assessment.

1. Introduction

1.1. The role of urban green infrastructure

Many cities around the world are increasing the supply of urban green spaces (UGS). The contribution of UGS to the physical and mental health of human inhabitants has been demonstrated by experimental, epidemiological, and questionnaire studies [54,61,92]. Green space can provide restorative ambience for stressed city-dwellers [32]. A comprehensive UGI system can mitigate the deleterious impacts of conventional built environment, rendering cities resilient against climate change [24,30,57,85]. By offsetting carbon emission, urban greening can help tackling anthropogenic climate change [16].

Urbanization incurs expansion and densification of developed areas. With limited land resources, UGS has to compete with other land uses in spatial planning [87]. Green roof, eco-roof, or vegetated roof, refers to landscaped rooftop of building structure [64,65]. By land consumption, green roof is versatile and frugal for not requiring additional footprint from compact cities. Akin to other UGIs, green roofs can provide multiple public and private services, including suppressing the urban heat island [42,86]; mitigating stormwater [6,20,105,106]; providing habitats for urban wildlife and enhancing biodiversity [9,59]; noise attenuation [95]; improving air quality [3,83]; prolonged service life of waterproofing membrane [15], instilling aesthetic and amenity values to neighborhoods [109]; and restoring viewer attention [48].

Positive values aside, green roof is thought to pose certain perceived risks, including the inadvertent establishment of favorable habitats for urban pests such as mosquitoes [13,31]. It is generally believed that vegetation harbors mosquitoes. Greening

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urban rooftops may increase disease transmission risk in regions with prevalent vector-borne infectious diseases. Yet, to the best of the authors' knowledge, no research has examined systematically whether green roof is indeed associated with such risks in the urban context. As long as this important knowledge gap remains unexplored, urban greening policies and efforts may be frustrated by enduring but probably unfounded misconception and uncertainty.

1.2. Mosquitoes as potential vectors of infectious diseases

Humans have long developed aversion and avoidance towards mosquitoes. Besides simple annoyance, mosquito bites can transmit some potentially life-threatening infectious diseases, such as dengue hemorrhagic fever, malaria, and West Nile virus [101]. In ecosystems, mosquitoes assume the roles of both prey and pollinator. The immature and mature stages of mosquitoes are important food sources of aquatic and terrestrial animals [26]. Adult mosquitoes rely on plant nectar and fruit juice for energy. For reproduction, female mosquitoes also require readily available protein from human and animal blood [79]. Owing to their broad-opportunistic blood-feeding propensity, infected females can carry and transmit disease-causing arboviruses, nematode worms, and parasitic protozoans [22,70]. The impact of vector-borne diseases on global health is tremendous, claiming more than one billion infection cases and one million related deaths every year worldwide [101].

1.3. Environmental factors of disease transmission

The epidemiology and transmission dynamics of mosquito-borne diseases are closely tied to some biotic and abiotic factors, including human, environmental, and biological drivers [46,70,74,97,100]. For example, the emergence and re-emergence of mosquito-borne diseases are commonly associated with land-use change and urbanization [25,70,100]. Human modification of the natural environment can create previously unavailable habitats for mosquitoes [37,62,84]. Human activities thus unintentionally introduce conditions that are conducive to disease transmission—intensification of ecologically disruptive development; rising human population; and spatial overlap between wildlife and human populations. Anthropophilic mosquitoes with special preference for human abode have adapted to thrive successfully in urban conditions, such as *Aedes albopictus* and *Aedes aegypti* [25,37,58,72,76,79].

Ambient environmental factors, particularly temperature and precipitation, play critical roles in pathogen and vector biology, ecology, and disease transmission [17,19,55,70,108,110]. The extrinsic incubation period (EIP), or the time between initial acquisition of an infectious agent by a mosquito vector and its subsequent ability to transmit the pathogen to other hosts, is one of the most vital parameters in determining infection risk and transmission intensity [46]. The EIP of many arboviruses and parasites is highly sensitive to temperature. These pathogens can undergo rapid development inside mosquitoes at optimal temperatures, thus shortening EIP and increasing the likelihood of disease transmission.

Temperature also influences all four stages of the mosquito life cycle. Mosquitoes are miniscule ectotherms—the duration of the developmental stages, emergence rate, survivorship, and adult behavior are all governed by ambient temperature [46,53]. Larval development rate is expedited at high temperatures [66]. Precipitation (and other sources of accumulated moisture) is also important since water bodies are required for the development of immature mosquitoes [34,55]. Several studies of ambient environmental factors and disease incidence have identified precipitation as an important determinant [8,18,82].

1.4. Study objectives

The urban built environment displays marked microclimate variations attributed by idiosyncratic physical features such as built materials, geometries, configurations. For example, solar and wind exposure of a street-level site are curtailed substantially by high-rise buildings in its vicinity [78]. A microclimate approach to study mosquito population can provide more relevant information since the scale is germane to mosquito biology [14,66,67,104]. Such improved understanding promotes better integration of environmental and biological information for disease risk projections in relation to land-use and climate changes.

Empirical mosquito microclimate studies have chiefly examined water body temperature and larval development rate [66]; indoor and outdoor temperature and parasite development rate [67]; water surface temperature, food quality, and larval development distribution and success [96]; environmental temperatures of urban transmission sites and extrinsic incubation period [14]; combined sewer water quality and temperature and immature mosquitoes population [52]. The effect of urban greenery on mosquito population vis-à-vis ambient microclimate parameters remains largely unexplored. This knowledge gap constitutes a major obstacle in implementing urban greening plans and policies.

The primary purpose of this empirical study is to investigate the relationship between urban green roof and vector mosquito population vis-à-vis microclimatic environmental conditions. We hypothesized vector abundance (VA) differ across experimental groups—green roof, bare roof (negative control), and low-elevation blue-green space (positive control). It is also hypothesized that such differences can be ascribed to important ambient microclimatic factors. Additionally, for an in-depth understanding, time-lagged microclimatic factors were analyzed to examine whether the effects are latent or proximate, that is, to identify the life cycle stage(s) (developmental or adult) through which the environmental factors act upon VA. We envisioned that our findings could offer insightful information regarding habitat suitability of vector mosquitoes in urban areas with particular relevance to urban greenery.

2. Materials and methods

2.1. Vector mosquito targets

The humid subtropical Hong Kong is home to a number of mosquito species, some of which have wide geographical spread. Local government surveys have registered at least 72 species, including the medically important genera of *Aedes*, *Anopheles*, and *Culex* [28]. *Aedes albopictus*, *Anopheles jeyporiensis*, *Anopheles minimus*, *Culex quinquefasciatus*, and *Culex tritaeniorhynchus* are among the 46 species that recurred frequently in surveys. In terms of statutorily notifiable mosquito-borne diseases, the most reported local cases in recent decades are dengue fever and Japanese encephalitis [28,53].

This investigation focuses on 11 local mosquito species that are implicated or capable of transmitting infectious diseases. They were selected based on government information (Table 1) [28], referred to hereinafter as “target species”. Five of the target species are considered as “medically important” by the local authority. Three target species are deemed as “global invasive species” by the Invasive Species Specialist Group (ISSG) of the World Conservation Union (IUCN) Species Survival Commission, given their extensive global distribution and impact on biological diversity and/or