A Review of Climate Change and Mosquito Ecology in Constructed Wetlands: Implications for Urban Sustainability and Public Health

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Abstract. This study explores the ecology of mosquitoes within constructed wetlands, emphasizing the impact of climate change on their distribution and behaviour. Constructed wetlands are integral to green city initiatives, offering multiple benefits such as water purification, habitat provision, and climate resilience. However, these environments also serve as breeding grounds for mosquitoes, presenting challenges for public health. This paper reviews the ecology of mosquitoes in constructed wetlands, analyzing how climatic factors influence their populations and interactions within these systems. Rising global temperatures, which reached a record-high average of 1.45°C last year, are accelerating mosquito development. As temperatures continue to rise, the geographical distribution of mosquito species is shifting. or instance, Anopheles stephensi, a known malaria vector, has spread from its original habitats in Asia and the Middle East into parts of Africa. Additionally, Aedes aegypti's transmission potential is expected to increase, particularly in South Asia and sub-Saharan Africa, while Aedes albopictus is likely to experience a decline in transmission potential in tropical regions that are becoming too hot for its survival. These findings highlight the need for adaptive strategies in the planning and management of urban wetlands to mitigate public health risks while maintaining their ecological benefits amid ongoing climate change.

1 Introduction

Constructed wetlands are integral to sustainable urban development, providing multiple ecological services such as water purification, habitat creation, flood control, and enhancement of urban biodiversity [1]. These wetlands are designed to mimic the natural processes of wetland ecosystems offering critical benefits for environmental conservation and climate resilience in urban settings providing essential services such as water purification, flood control, and groundwater recharge [2]. By acting as natural filters, they remove pollutants from stormwater and wastewater, improving water quality and reducing the burden on traditional treatment facilities. In addition to these environmental benefits,

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constructed wetlands enhance biodiversity by providing habitats for diverse plant and animal species, thereby aiding in the preservation of local ecosystems.

However, the presence of standing water in constructed wetlands can also create an ideal breeding ground for mosquitoes, which can be a nuisance due to their persistent biting behaviour and public health problem [3]. Despite the growing relevance of this topic, a database search using Lens.org with the terms mosquito AND constructed wetlands AND climate change AND urban yielded only 109 scholarly works published between 1983 and 2024. This indicates that research in this specific area is still limited. Key gaps remain, particularly in understanding how climate change impacts mosquito ecology in urban wetlands. Future research should focus on understanding how climate-induced shifts in breeding behaviors and habitat suitability impact mosquito populations and their control in urban wetlands. This paper explores the complex ecology of mosquitoes within constructed wetlands, emphasizing the need for effective management strategies to mitigate these risks while enhancing the positive ecological outcomes.

2 Methods

To conduct this comprehensive review, a systematic search was performed across multiple databases, including PubMed, Web of Science, Google Scholar, and Scopus, covering publications between January 2010 and December 2023. The search strategy employed a combination of keywords such as “mosquito ecology,” “climate change and mosquitoes,” “constructed wetlands,” and “urban wetlands and mosquito control,” using Boolean operators (AND/OR) to refine the search. Studies were selected based on specific inclusion criteria: they had to focus on the ecological dynamics of mosquito species within constructed or natural wetlands, discuss the impact of climate change on mosquito population dynamics, distribution, or breeding patterns, and be peer-reviewed and published in English. Exclusion criteria were applied to filter out studies that did not focus on mosquito ecology or climate change impacts, were not published in peer-reviewed journals, or primarily addressed non-wetland environments or unrelated mosquito control methods. From an initial pool of 850 articles, 135 were shortlisted based on title and abstract screening, and after full-text evaluation, 65 articles were selected for inclusion in the review. These articles were critically analyzed for their relevance and contribution to the understanding of mosquito dynamics in relation to climate change and urban wetland management.

3 Global Public Health Impact of Mosquito-Borne Diseases

Mosquitoes are a major public health concern globally due to their ability to transmit diseases like malaria, dengue, Zika, and chikungunya. Different species of mosquitoes serve as vectors for various diseases, which are transmitted through the bite of infected mosquitoes. Mosquito-borne diseases are caused by viruses, bacteria, or parasites transmitted to humans through the bite of infected mosquitoes [4]. These diseases, particularly in developing countries with limited resources, contribute significantly to global morbidity and mortality, especially in tropical and subtropical regions.

Malaria, spread by *Anopheles* mosquitoes, remains the leading mosquito-borne disease, with 247 million cases and 619,000 deaths in 2021, primarily affecting young children in Africa [5]. Dengue, which has become endemic in more than 100 countries, is responsible for approximately 100 to 400 million infections each year [6]. Mosquitoes are the deadliest creatures, responsible for about one million deaths per year, far surpassing other animals like snakes, which cause around 100,000 deaths [7]. Table 1 provides a comprehensive list of common human pathogens transmitted by mosquitoes.

Table 1 Common human pathogens that are transmitted

Pathogen	Mosquito Species	Ref.
Dengue Virus (DENV)	Aedes aegypti, Aedes albopictus	[8]
Chikungunya Virus (CHIKV)	Aedes aegypti, Aedes albopictus	[8]
Zika Virus (ZIKV)	Aedes aegypti, Aedes albopictus	[8]
Yellow Fever Virus (YFV)	Aedes aegypti, Aedes albopictus	[8]
West Nile Virus (WNV)	Culex pipiens, Culex tarsalis	[9,10]
Japanese Encephalitis Virus (JEV)	Culex tritaeniorhynchus	[11]
St. Louis Encephalitis (SLEV)	Culex pipiens, Culex quinquefasciatus	[10,12]
Plasmodium species (Malaria)	Anopheles gambiae, Anopheles stephensi, Anopheles funestus, Anopheles quadrimaculatus	[12,13]
Dirofilaria immitis (Heartworm)	Aedes species, Culex species, Anopheles species	[14–16]
Wuchereria bancrofti (Lymphatic Filariasis)	Anopheles species, Culex quinquefasciatus	[17]
Brugia malayi (Lymphatic Filariasis)	Anopheles species, Culex species, Aedes species	[17,18]

Some mosquitoes, such as those carrying West Nile or malaria, are dangerous, while others are simply "nuisance" mosquitoes that bite but don't spread disease [19]. The connection between mosquitoes and disease raises public health concerns around wetland conservation, despite wetlands providing essential ecological benefits. Addressing these concerns requires adaptive management and research to balance wetland benefits with the public health risks posed by mosquitoes.

4 Factors Influencing Mosquito Distribution in Constructed Wetlands

Mosquitoes are affected by many environmental factors, including temperature, water quality, predation, and the availability of suitable breeding sites. These physical, chemical, and biological components of the environment that affect the mosquito growth, development, and survival [20]. Understanding the ecological factors that affect mosquito populations in constructed wetlands is crucial for effective mosquito control and risk management [21].

4.1 Reproductive Behaviours

Mosquitoes exhibit various mating behaviours, from intricate courtship dances [22] to large aerial swarming [23]. These swarms' size, location, and circadian patterns vary significantly among species. For instance, Aedes aegypti gather in small swarms near human hosts, coinciding with peak blood-feeding times for females [24], while Anopheles freeborni, on the other hand, form large swarms numbering in the thousands at dusk above rice fields

[23]. Females are attracted to swarms, most likely by a combination of olfactory, audial, and visual cues [25]. Recent studies have shown that male mosquitoes are specifically attracted to human hosts, even though they do not feed on them, possibly to locate females seeking a blood meal [26]. For Aedes species, their mating behaviour typically occurs in small groups during daylight, male-dominated swarms near a blood-meal host [26]. Moreover, a separate study indicates that Ae. albopictus and Cx. quinquefasciatus exhibit distinct mating patterns, influenced by their core clock genes and pheromone-related genes within light-dark cycles. The findings reveal that Ae. albopictus had significantly higher mating rates during the daytime or subjective daytime compared to nighttime under various conditions (all $P < 0.01$). Conversely, Cx. quinquefasciatus showed notably higher mating rates at night than during daytime or subjective daytime across different conditions (all $P < 0.01$). Table 2 specify the typical mating behaviour based on the species. Cx. p. pipiens form molestus can mate without swarming, is classified as stenogamous (mating in confined spaces), and can produce its first batch of eggs without a blood meal. In contrast, Cx. p. pipiens form pipiens mates in open-area swarms, requires a blood meal for egg production, and undergoes reproductive diapause [27–29].

Physicochemical and biological characteristics of mosquito larval habitats play an important role in determining the choice of a breeding site by the females laying their eggs [30]. Key factors like water quality, presence of existing eggs, food availability, and surrounding vegetation play a crucial role in determining a suitable breeding site [31,32]. Mosquito larvae require a certain level of organic matter and nutrients for their development, and nutrient-rich water bodies such as those found in constructed wetlands can provide suitable conditions for mosquito breeding. In a study, mesocosms enriched with NH4-N demonstrated a substantial increase in the population of immature mosquitoes, primarily Culex tarsalis, compared to mesocosms that received ambient NH4-N levels below 0.3 mg/liter. [33].

Table 2 Mosquito species' egg-laying behaviour and favourable breeding conditions

Mosquito Species	Egg-Laying Behaviour	Favourable Breeding Conditions
Aedes aegypti	Lays eggs singly on water surfaces, often near human habitation	Standing water in open man-made containers, exposed to shaded areas, and commonly associated with activities such as gardening, household chores, water storage, or construction [34].
Aedes albopictus	Lays eggs in rafts on water surfaces, typically in natural and artificial containers that hold water	Various stagnant water sources such as tree holes, discarded tires, flowerpots, and other man-made containers that hold water [35]. Showed no preference for either the natural or artificial breeding sites[36]
Anopheles gambiae	Lays eggs singly on water surfaces, typically in sunlit areas	Open water surface, shallow, stagnant, such as temporary pools of water, marshes, and puddle with hydromorphic soil [37].
Anopheles arabiensis	Lays eggs singly on the surface of freshwater sources, typically in shaded areas	Water sources include rain pools, irrigation canals, neglected wells, artificial containers, and man-made ditches [38].
Culex pipiens	Lays eggs in rafts on water surfaces, usually in stagnant water	Freshwater habitats include vegetated ponds, rice fields, calm sections along riverbanks, flood-prone areas, puddles, ruts, artificial containers, and sometimes even water-filled

		tree holes, with a tolerance for low levels of salinity [39].
Culex molestus	Lays eggs in rafts on water surfaces, typically in underground or subterranean habitats	Subterranean environments consist of sewage and subway systems, flooded basements, pits, catch basins, and wastewater reservoirs [40].

As summarized in Table 2, Mosquitoes lay their eggs in standing water, such as puddles, ponds, and even containers that collect water. The eggs hatch into larvae, which feed on organic matter and microscopic organisms in the water. Then the larvae go through several developmental stages, called instars, before pupating and emerging as adult mosquitoes [41]. Adult mosquitoes primarily feed on nectar from flowers and other plants. However, female mosquitoes require a blood meal to produce eggs. Using their long, needle-like mouthparts, they pierce the skin of animals, including humans, to extract blood. During this process, they may transmit disease-causing pathogens from one host to another.

4.2 Temperature and global warming

Mosquitoes are ectothermic animals, meaning that their body temperature and activity are regulated by the temperature of their environment. Temperature is, therefore, one of the most important ecological factors affecting mosquito populations in constructed wetlands. Higher temperatures accelerate mosquito development and reproduction, leading to higher population growth rates [42]. Ae. aegypti exhibits developmental activity between temperatures of 16 °C (lower limit) and 34 °C (upper limit), with larvae becoming motionless and succumbing within a couple of days when exposed to lower temperatures such as 8 °C while the optimal development rate at 32 °C [42]. The findings on Aedes aegypti are comparable to those for Aedes albopictus. These mosquitoes become active when temperatures rise above 13°C, with their population gradually increasing as the temperature climbs. However, their population declines once temperatures exceed 36°C (upper limit) [43]. Meanwhile anopheles stephensi shows a wider thermal tolerance, with transmission of Plasmodium falciparum occurring between 15.3°C and 37.2°C impact [44]. Temperature impacts numerous aspects of mosquito biology, including egg-hatching rates, larval development time, and adult survival rates.

Recent studies underscore the impact of climate change on mosquito distribution and activity. For example, Anopheles stephensi, a primary malaria vector, has expanded from its traditional habitats in Asia and the Middle East to urban regions in Africa, driven largely by rising global temperatures[45]. This species has a broader thermal tolerance than other malaria vectors, enabling it to thrive in warmer climates, which extends its transmission season and increases public health risks. In addition, the transmission potential for *Aedes aegypti* is expected to increase as temperatures continue to rise, particularly in South Asia and sub-Saharan Africa, while Aedes albopictus may experience declines in regions where temperatures become too hot for its survival, as predicted by climate change models [46]. These findings highlight how temperature plays a pivotal role in the shifting dynamics of mosquito populations and their associated disease transmission risks.

Studies also show elevated temperatures nearing the upper survival limit for vectors and pathogens (approximately 35–37 °C) typically reduce transmission, while increased daily temperature variability near the lower survival limit tends to enhance transmission [47–49]. Table 3 summarize the optimal temperature for vector-borne disease transmission.

Table 3 Optimal thermal and limits across vector-borne disease transmission

Pathogen	Optimal transmission temperature
Dengue Virus (DENV)	Optimal at 29.1°C and no transmission occurs outside 17.8 and 34.6 °C [50]
Chikungunya Virus (CHIKV)	Optimal average at 27 °C, at which the viral load in the saliva of Ae. albopictus is the highest [51]
Zika Virus (ZIKV)	Optimal at 29°C with a thermal range of 22.7°C to 34.7°C [52]
Plasmodium species (Malaria)	Optimal at 25 °C with dramatic decreases of transmission at temperatures over 28 °C [53]
Dirofilaria immitis (Heartworm)	High infection and infective rates were registered at 15 to 21°C [15]
Wuchereria bancrofti & Brugia malayi (Lymphatic Filariasis)	Optimal temperature for the Microfilariae larval growth lies between 24-26°C and it will not be able to mature under 16°C [54]

5 Conclusion

Temperature is a critical factor in shaping mosquito behavior and the transmission of mosquito-borne diseases, with increasing evidence highlighting its impact. Climate change is extending the geographic range of diseases traditionally confined to tropical and subtropical regions, bringing them into temperate zones and contributing to their resurgence in areas where they had previously declined [54]. For instance, species like Anopheles stephensi and Aedes aegypti are expanding into new territories, driven by rising global temperatures. This highlights the need for ongoing research into how temperature influences mosquito ecology, particularly in constructed wetlands, where favorable breeding conditions could exacerbate public health risks. Understanding these dynamics is essential for developing adaptive strategies that balance urban sustainability with effective mosquito management and disease prevention.

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