Double trouble: aquatic invasive plants can promote mosquitoes

Schrama, M.J.J.; Chikodza, T.; Veldhuis, M.P.; Strange, E.F.

Citation

Schrama, M. J. J., Chikodza, T., Veldhuis, M. P., & Strange, E. F. (2025). Double trouble: aquatic invasive plants can promote mosquitoes. *Ecology Letters*, *28*(10). doi:10.1111/ele.70199

Ecology Letters

PERSPECTIVE OPEN ACCESS

Double Trouble: Aquatic Invasive Plants Can Promote Mosquitoes

Tressia Chikodza[1,2,3] | Ross N. Cuthbert[3,4] | Maarten Schrama[1] | Julie Coetzee[2,3,5] | Ryan Wasserman[3,5] | Michiel P. Veldhuis[1] | Emily F. Strange[1,2]

[1]Institute of Environmental Sciences, Leiden University, Leiden, the Netherlands | [2]Centre for Biological Control, Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa | [3]South African Institute for Aquatic Biodiversity, Makhanda, South Africa | [4]Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Belfast, UK | [5]Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa

Correspondence: Tressia Chikodza (chikodzat@cml.leidenuniv.nl)

Received: 20 June 2025 | **Revised:** 4 August 2025 | **Accepted:** 6 August 2025

Editor: Cleo Bertelsmeier

Funding: This work has been supported by the CML Impact Funds of Leiden University.

Keywords: aquatic invasive plants | biological invasions | disease vectors | mosquitoes | plant-insect interactions | public health

ABSTRACT

Human activities continue to facilitate biological invasions, profoundly impacting our environment and economy. Plants and insects constitute the majority of invasions to date, with facilitative links established between them, particularly in terrestrial habitats. These relationships remain understudied in aquatic environments, including potential associations between aquatic invasive plants and disease vectors such as mosquitoes. Here, we synthesise current knowledge on the co-occurrence of aquatic invasive plants and mosquitoes, identify key research gaps and present a conceptual framework underpinned by testable hypotheses on how aquatic invasive plants may influence immature and adult mosquito populations. We provide evidence suggesting that these plant-mosquito relationships could pose previously unrecognised risks and highlight priority areas for future research to better understand the potential public health implications of aquatic plant invasions. We call for targeted in situ and ex situ investigations to test the proposed hypotheses and increase our understanding of the interactions between aquatic invasive plants and mosquito population dynamics. Testing these hypotheses will inform adaptive, evidence-based management strategies to simultaneously control aquatic invasive species and vector mosquitoes.

1 | Introduction

Human activities are altering the environment at unprecedented rates through habitat destruction, climate change and pollution (Steffen et al. 2015; Edo et al. 2024; Damor 2024). Concurrent increases in globalisation accelerate introductions of non-native species beyond their natural geographical ranges, boosting numbers of biological invasions (Chapman et al. 2017; Hulme 2021; Schmidt et al. 2023). These are significant drivers of global biodiversity loss and have profound economic and social consequences (Malacrinò et al. 2020; Cuthbert et al. 2023; Carneiro et al. 2025). Plants and insects are the most numerous non-native taxa globally, with growing concerns around their influence on the environment (Van Kleunen et al. 2020; Kardol and De Long 2018; Seibold et al. 2019). While plant and insect invasions are often considered separately, strong macroecological links—for example, pollination, seed dispersal, herbivory and predation—have been made between plant and insect invasions (Bertelsmeier et al. 2024). The consequences of invasions from both of these taxa are particularly severe in freshwater

Ecology Letters, 2025; 28:e70199
https://doi.org/10.1111/ele.70199

BOX 1 | Parallel shifts in the global distribution of floating alien invasive plants and mosquitoes in recent decades.

An example of a rapidly spreading alien invasive aquatic plant is *Pistia stratiotes* (water lettuce), one of the worst aquatic invasive plants (Moore and Hill 2012). Originating from South America, it has spread across five continents where it is recorded as an invasive plant (Madeira et al. 2022). Like many aquatic invasive plants, water lettuce has high tolerance for aquatic pollution, reproduces vegetatively and produces massive numbers of seeds. Its large leaves and root structures make it a very good competitor in regions where native floating plant species are rare (Ismail et al. 2015; Xiong et al. 2023). These aquatic systems are also breeding habitats for mosquitoes. For example, *Aedes albopictus* is a prolific invader worldwide that has been introduced unintentionally with commodities—for example, tire or plant trades—or transport vectors, producing drought-resistant eggs that allow it to rapidly colonise aquatic environments, including container-based systems in urbanised environments (Asha and Aneesh 2014). Both species are highlighted here as they are globally widespread, well-documented and share parallel global expansions, illustrating potential associations. We note that these associations are illustrative and do not infer direct causation—overlaps could reflect environmental match, introduction pathways and human recording effort between these taxa.

ecosystems (Dudgeon et al. 2006; Gallardo et al. 2016), as they are greatly sensitive to environmental changes (Gallardo et al. 2016; Agha et al. 2020; Perrin et al. 2022; Carneiro et al. 2025).

Aquatic invasive plants (AIPs) and vector mosquitoes each pose significant ecological and public health risks (Charles and Dukes 2007; Ehrenfeld 2010; Lwande et al. 2020; Macêdo et al. 2024), are both strongly associated with (perturbed) aquatic environments, and are expanding their ranges globally (Box 1; Figure 1) (Porse et al. 2015; Lozano 2021). AIP distributions are commonly associated with eutrophication, travel, plant trade (as ornamentals/oxygenators) and warmer waters (Horan et al. 2002; Wu and Ding 2019). Likewise, distributions of known vector mosquito species are linked to water pollution and climate change, as well as unintentional introductions through trade (i.e., the used tire trade) (Sprenger and Reiter 1987; Lambin et al. 2010; Perrin et al. 2022). AIPs, particularly submerged and floating macrophytes, degrade ecological systems, affecting floral and faunal diversity, as well as social and economic activities (Hill 2003; McConnachie et al. 2003; Keller et al. 2018). Mosquitoes are primarily studied as vectors of pathogens that cause diseases in humans, livestock and wildlife, contributing significantly to global morbidity and mortality cases (Harbach and Besansky 2014; Cocke et al. 2022).

Strong links exist between plant and insect invasions, with non-native plants often preceding and promoting non-native insects,

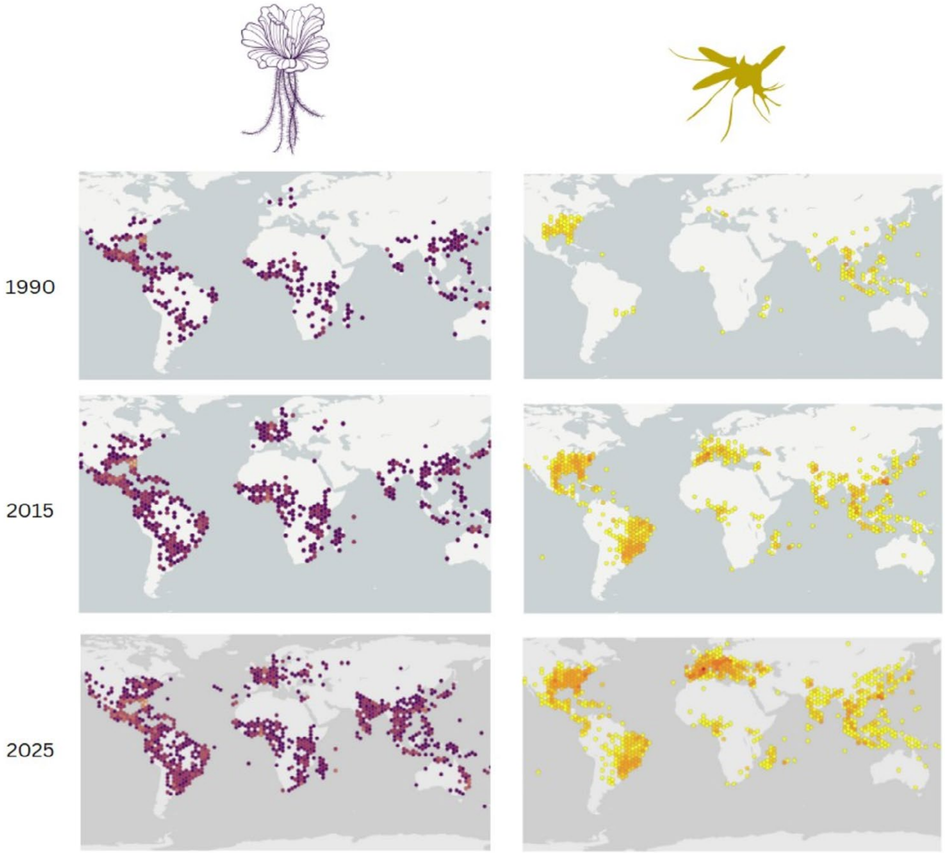

FIGURE 1 | Parallel shifts in the global distribution of aquatic invasive plants and mosquitoes in recent decades. These species depicted do not represent a causal link, but have been chosen to highlight similar shifts in global distributions across both taxa; *Pistia stratiotes* (left) and *Aedes albopictus* (right) (Occurrence Data 2025: GBIF.org accessed 30-05-2025).

resulting in distinct taxonomic waves at macroecological levels (Bonnamour et al. 2023; Bertelsmeier et al. 2024). As many insects feed on or are otherwise closely associated with plants, non-native plants provide habitats and resources that facilitate non-native insect establishment (Bertelsmeier et al. 2024). They also may be involved in the same pathways and occur as co-introductions. In particular, insect introductions frequently occur accidentally via the plant trade, resulting in regions with higher non-native plant richness often having higher non-native insect richness (Bonnamour et al. 2023). However, these associations could also reflect environmental filtering processes that affect both non-native plants and insects between the same origin and recipient regions. Therefore, their distributional overlaps may not necessarily indicate mutualistic interactions or co-introductions, but in part reflect similarities in environmental conditions or niches that promote invasion flows between regions (Liu et al. 2025). Moreover, plants and insects are among the most diverse taxonomic groups with an invasion history and would therefore be expected to each harbour large numbers of non-native species simply based on their highly biodiverse source pools (Briski et al. 2024). Nevertheless, given that both native and non-native plants are strong predictors of insect invasions more broadly (Liebhold et al. 2018), a similar pattern on the occurrence of AIPs and non-native mosquitoes can be expected, although this remains to be proven mechanistically at large scales.

The global distributions and impacts of these taxa are relatively well studied independently (Wilke et al. 2019), but we know little about the interactions between AIPs and mosquito populations. Their relationship is further complicated because mosquitoes display complex life history strategies—spanning both aquatic and terrestrial realms—making AIP-mosquito interactions both species and life stage dependent (Burkett-Cadena et al. 2013). These life history differences are also substantial among mosquito genera, for example, with some taxa producing desiccation-resistant eggs and others requiring aquatic habitats for direct oviposition. To better understand the potential risks associated with the co-occurrence of AIPs and mosquitoes, it is essential to investigate their context-specific interactions. Here, we present a novel framework, underpinned by key hypotheses, to uncover how AIPs may influence the proliferation of both immature and adult mosquito stages (Figure 2). We highlight priority areas for future research to enhance our understanding of the potential health impacts of aquatic invasive plants and provide evidence that interactions between these groups could lead to previously unidentified risks.

2 | Aquatic Invasive Plants Change Their Environment

AIPs are ecosystem engineers. They substantially impact the structure and functioning of the ecosystems they invade (Rilov et al. 2024), often in long-lasting and sometimes irreversible ways (Rai and Singh 2020; Rilov et al. 2024). The magnitude and nature of which depend on species-specific morphological, physiological and biochemical traits, and the characteristics of the recipient ecosystems (Coetzee et al. 2018). AIPs commonly dominate and structurally transform invaded systems through the formation of dense vegetative mats. The extent of their surface area cover changes water clarity, hydrology and trophic status and reduces light penetration, promoting algal photosynthetic activity, thereby limiting primary production and food resources for surrounding biota (Crooks 2002; Santos et al. 2011). The dense mats increase water stagnation (Merritt et al. 1992; Mack and Smith 2011), which modifies local conditions such as water temperature, physicochemistry and turbidity, affecting surrounding aquatic organisms (Urban et al. 2006; Vilas et al. 2017). The presence of AIP debris or inorganic material may increase the nitrogen (N) and phosphorus (P) content of the water, supporting the growth of other microorganisms (de Tezanos Pinto et al. 2007; Kipyab et al. 2015; Ugya et al. 2019). Biomass of AIPs also contributes to food sources for aquatic organisms, either directly through decaying organic matter or indirectly by supporting microbial communities that aquatic organisms, including mosquito larvae, feed on (Barber and Hayne 1925). AIPs can also create favourable microhabitats for aquatic insect communities whose composition is strongly influenced by biotic and abiotic cues in their environment (Beketov et al. 2014).

3 | Environmental Changes Affect Mosquitoes

Mosquito species respond in various ways to biotic and abiotic factors, including vegetation types, occurrence of predators and competitors, and aquatic physicochemical conditions (Rejmánková et al. 2013; Reinhold et al. 2018; Buxton et al. 2020). They breed in a wide range of environments, and the characteristics of suitable breeding sites vary strongly within and between species (Ammar et al. 2013; McCormack et al. 2019). Breeding water characteristics determine whether gravid female mosquitoes will select or avoid a site for oviposition and whether larvae successfully develop into adults (Reinhold et al. 2018). Environmental cues help to identify suitable habitats, such as the absence of predators, few competitors (Himeidan et al. 2013), and food availability for larvae (Albeny-Simoes et al. 2014; Boerlijst et al. 2023). However, responses are context-dependent, with effects of predators, conspecifics and other environmental conditions highly varied based on a spectrum of risk and reward (Vonesh and Blaustein 2010). Furthermore, the level of risk to mosquito progeny is affected by structural complexity, with aquatic plants known to mediate the interaction strength between mosquitoes and their natural enemies by increasing the availability of enemy-free space, depending on predation tactics (Cuthbert et al. 2019).

Breeding habitats among key vector mosquito genera are very diverse. For example, *Anopheles* mosquitoes, of which a subset are vectors of malaria parasites, commonly breed in naturally occurring freshwater habitats like pools, marshes, wetlands and ponds, where aquatic plants may be present (Wondwosen et al. 2017; McCormack et al. 2019). Conversely, *Aedes* mosquitoes such as *Aedes albopictus* and *Aedes aegypti*, key vectors for dengue and Zika viruses, are more strongly associated with artificial containers such as rain-filled tires or household containers (Ferdousi et al. 2015; McCormack et al. 2019), but also utilise phytotelmata (Johnson and Sukhdeo 2013). *Culex* species, which transmit arboviral and filarial pathogens to humans and animals, breed in a variety of habitats, both natural (e.g., river edges, rain pools, marshes) and artificial (e.g., cisterns and household containers) (Fakoorziba and Vijayan 2008; Djoufounna et al. 2022). In addition to these genus-dependent variations, there are also population-dependent differences in

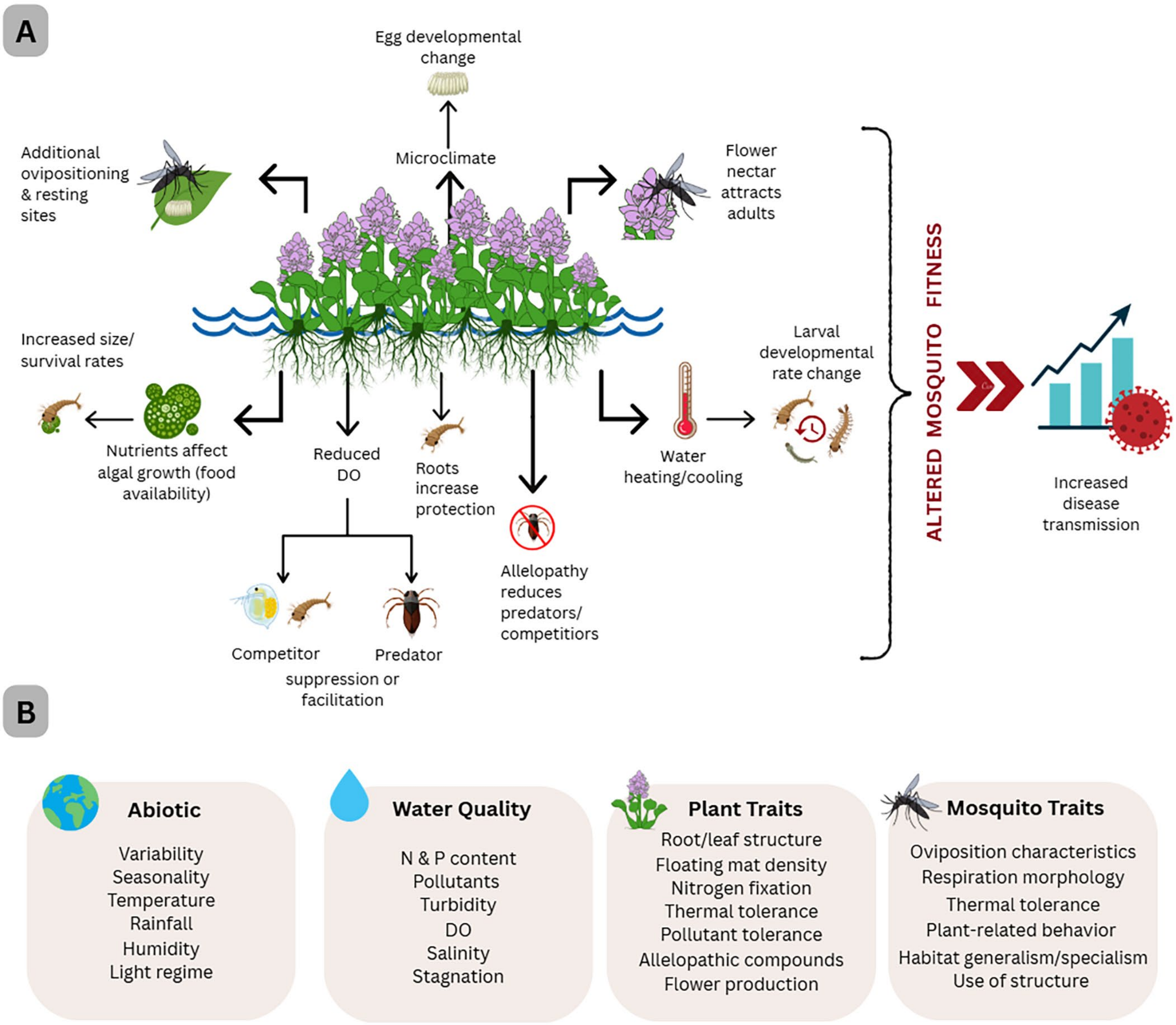

FIGURE 2 | Potential mechanisms for aquatic invasive plant effects on mosquito fitness. (A) Plant-mediated eco-evolutionary mechanisms—direct and indirect—can alter mosquito fitness, boosting potential for disease transmission. (B) The strength and direction of these mechanisms is dependent on environmental contexts and species traits. N, nitrogen; P, phosphorus; DO-dissolved oxygen.

habitat selection between invasive and native ranges (Cuthbert et al. 2023). For example, *Ae. albopictus* breeds in artificial containers in its invaded range, but historically exploited tree holes (Cuthbert et al. 2023); *Anopheles stephensi* has uniquely adapted to exploit urban containers in Africa, whereas other vectors exploit larger standing habitats, challenging malaria control efforts (Taylor et al. 2024). Many of these parameters affecting the quality of the breeding environment can be altered by human impacts on the environment (Boerlijst et al. 2023), but the role of AIPs within this is currently unknown.

4 | Evidence for Links Between AIPs and Mosquitoes

Understanding how AIPs influence the development and survival of vector species is crucial to predict and manage disease transmission (Figure 2). However, few studies explored the association between AIPs and disease vectors, with most research focusing on water-borne disease associations in Africa (Masifwa et al. 2001; Aloo et al. 2013). Mosquitoes are sporadically reported to be associated with AIP populations since the early 1900s, with contrasting conclusions (Stone et al. 2018; Honlah et al. 2019). The majority of these studies are observational and correlational, lacking scientific evidence for causation (Stone et al. 2018). Moreover, most approaches assess pairwise interactions between plants and mosquitoes, without considering wider cascading effects at community or ecosystem scales. Despite this, these studies provide a glimpse into the mechanisms through which AIPs may influence mosquitoes (Stone et al. 2018; Cuthbert et al. 2019; Portilla et al. 2021).

The structure of the aquatic plants provides habitat, such as water axils and leaf pockets, that can offer additional ovipositioning and resting sites, attracting mosquitoes (Stone et al. 2018). For example, *Pistia stratiotes* (water lettuce) is a preferred breeding habitat for vectors of rural filariasis and encephalomyelitis in many wetlands (Weldon and Blackburn 1967; Silver 2007). Ornamental bromeliads, though terrestrial, are important breeding habitats for a variety of mosquito taxa—including invasive *Ae. aegypti*—by retaining water in their leaf axils (Wilke et al. 2019). *Anopheles* mosquitoes breed in *P. crassipes* and duckweed (*Lemna minor* L. Lemnaceae) covered habitats in Lake Victoria (Kenyan shore), an area where malaria contributes to high child mortality (Minakawa et al. 2008). *Salvinia molesta* supported oviposition by *Culex annulirostris* (Webb et al. 2013). Similarly, the roots of *P. stratiotes* have been reported as a favourable breeding site for *Mansonia* species (Chandra et al. 2006). In contrast, the thick mats and the structure of floating AIPs physically block the water surface, preventing female mosquitoes from ovipositing. *Salvinia auriculata*, the eared water fern, inhibits mosquito breeding by preventing gravid females from accessing the water surface for egg-laying (Hobbs and Molina 1983).

Besides oviposition, AIPs can also affect egg and larval development. Some mosquito taxa (e.g., *Coquillettidia* spp.) require the presence of plants for immature development, given specially evolved adaptations that facilitate respiration directly through the root systems of floating aquatic plants, illustrating the strong co-evolutionary history between plants and mosquitoes. Increased water stagnation can also favour mosquito development (Bates et al. 1985; Mack and Smith 2011; Day 2016; Honlah et al. 2019; Segbefia et al. 2019). Yet, dense mats created by AIPs may be detrimental to larvae by impeding access to atmospheric air to breathe (Matheson 1930; Ta et al. 2017). Similarly, *P. crassipes* in California was reported to lower dissolved oxygen, creating conditions unfavourable for both mosquito breeding and development (Ta et al. 2017). Portilla et al. (2021) demonstrated this suppressive effect by comparing mosquito larval abundance across open water, water with floating *P. crassipes* and water with submerged *Egeria densa*. Open water had the highest number of mosquito larvae and competitors, while *E. densa* effectively reduced mosquito larvae without impacting predators or competitors.

AIPs may also modify predator–prey dynamics in aquatic environments. Dense mats formed by AIPs may provide physical refuge for mosquito larvae, reducing predation risk from fish, dragonfly larvae and other aquatic predators (Buscemi 1958; Flores and Carlson 2006). *Anopheles* larvae prefer habitats with dense *Myriophyllum aquaticum* cover, due to increased refuge from predators and more abundant food resources (Orr and Resh 1992). Other studies suggest that AIPs can attract mosquito predators or promote competing species, which may in turn suppress mosquito populations (Yang et al. 2005; Flores and Carlson 2006; Weeks 2019). This could thus foster a trade-off between concurrent attraction and repellence effects between plants and predators.

While the direct mechanisms for mosquito colonisation responses to AIPs are poorly understood, they could result from a mixture of chemical and physical effects, or indirect effects through alterations of biotic communities that could in turn have attractant or repellent effects (Vonesh and Blaustein 2010). For some species, the release of natural compounds attracts mosquitoes; for example, root exudates from *P. crassipes* are reported to attract *Culex quinquefasciatus*, a vector of filariasis (Turnipseed et al. 2018). Other effects could be chemical, through influence on nutrients within waterbodies or through release of compounds associated with allelopathy and growth—phytochemicals released by *P. stratiotes* and *P. crassipes* potentially kill mosquito larvae (Ugya et al. 2019; Jayanthi et al. 2012; Ma et al. 2019). Flowering AIPs may attract nectar-seeking mosquitoes, as adult mosquitoes typically require one sugar meal per day (Lounibos et al. 1998). This could increase mosquito populations by providing both a stable sugar source and additional oviposition sites (Daehler 2001; Gardner 2016; Stone et al. 2018).

5 | Key Hypotheses

The existing literature suggests a multitude of complex interactions between AIPs and mosquitoes which are poorly understood. These pioneering studies have laid the groundwork for this relatively new area of integrative invasion and vector-borne disease science. We identified and prioritised the following knowledge gaps: (a) lack of scientific evidence to ensure causation; (b) limited understanding of the community and ecosystem-scale consequences of aquatic plant invasions on mosquitoes alongside indirect effects that may harbour ‘ecological surprises’; (c) lack of knowledge regarding context-dependent outcomes in relation to local environmental conditions (Portilla et al. 2021); (d) outcome-dependence on species traits for both AIPs and mosquito taxa; and (e) taxonomic and geographic biases that impede holistic understanding of global processes mediating plant-mosquito interactions (Stone et al. 2018).

To understand the underlying dynamics of the associations between AIPs and mosquitoes at population and community levels, we propose key testable hypotheses and specific predictions in relation to the various mechanisms through which aquatic invasive plants may influence mosquito populations (Table 1). Broadly, initial evidence for population-level mechanisms is supported by multiple studies across different contexts, including effects on microclimates, provision of resting or oviposition sites, nutritional resources and predator-free space. However, evidence for mechanisms remains largely weak or inconclusive, pointing towards context-dependency regarding species traits and/or environment. At the community level, evolutionary and trait-based associations between AIPs and mosquitoes are largely unexplored, lacking investigations to date.

Given that current evidence for the proposed hypotheses remains largely weak at both population and community levels (Table 1), it is particularly important that we anticipate ecological ‘surprises’ on interactive outcomes. These unanticipated outcomes occur where expected responses within natural systems deviate from observed outcomes (Doak et al. 2008; Lindenmayer et al. 2010; Filbee-Dexter et al. 2018). In the context of AIP–mosquito interactions, such ‘surprises’ may result from the ecological complexity inherent in context-dependent systems that mediate patterns of biological invasion, where interacting biotic and abiotic factors may alter interactions between both taxa. Surprises are expected to be especially pervasive given that AIPs could mediate both the population

TABLE 1 | Outline of key testable hypotheses underpinning the proposed framework, including initial evidence (where applicable). Hypotheses are organised by ecological level (population or community) mechanisms through which aquatic invasive plants may influence mosquitoes. For each mechanism, we outline a broad hypothesis with key testable predictions and the strength of currently available evidence. Evidence levels for each prediction are mentioned as follows: Strong = multiple studies support the prediction across different contexts; Mixed = conflicting results across studies; Weak = limited or indirect evidence; None = no empirical studies found to date.

Level	Mechanisms	Broad hypotheses	Prediction (s)	Existing evidence status and references
Population	Microclimate	AIPs alter microclimates which benefit mosquitoes	(i) AIP mats change temperature profile of water bodies which alter mosquito development (ii) AIP mats reduce dissolved oxygen which influences mosquito larvae survival	Weak (Portilla et al. 2021). Mixed (Matheson 1930; Ta et al. 2017; Portilla et al. 2021)
	Substrate	Increased AIP biomass raises substrate availability for mosquito activity	(i) AIPs create stagnant water conditions that favour adult mosquitoes by increasing resting sites near or on still waters (ii) AIPs create sheltered environments that encourage mosquito oviposition	Strong (Bates et al. 1985; Rajnikant et al. 1992; Mack and Smith 2011; Patel 2012; Stone et al. 2018; Honlah et al. 2019). Mixed (Matheson 1930; Weldon and Blackburn 1967; Hobbs and Molina 1983; Eid et al. 1992; Orr and Resh 1992; Chandra et al. 2006; Minakawa et al. 2008; Silver 2007; Webb et al. 2013)
	Food availability	AIPs provide food sources for adult mosquitoes and larvae	(i) Flowering AIPs attract nectar-seeking mosquitoes (ii) AIPs alter available organic matter in the water column as important food sources for larval development	Weak (Daehler 2001; Gardner 2016; Stone et al. 2018) Weak (Barber and Hayne 1925; Orr and Resh 1992)
	Chemical cues	AIPs release chemicals cues that influence mosquitoes	(i) Volatile compounds/extracts from AIPs attract mosquito activity stimulating ovipositioning (ii) Volatile compounds/extracts cause sub (lethal) effects on immature mosquito stages	Mixed (Turnipseed et al. 2018; Cuthbert et al. 2020) None
	Predation and competitors	AIPs alter the presence and efficiency of mosquito predators and competitors	(i) The structural complexity and shading of AIPs offer refuge from predators and competitors (ii) Predators and competitors have different sensitivities to allelopathic compounds released by AIPs (iii) Predators and competitors have different sensitivities to microclimatic changes	Mixed (Weed 1924; Matheson 1930; Wilson 1967; Yang et al. 2005; Flores and Carlson 2006; Weeks 2019; Portilla et al. 2021). None Weak (Portilla et al. 2021)

(Continues)

TABLE 1 | (Continued)

Level	Mechanisms	Broad hypotheses	Prediction (s)	Existing evidence status and references
Community	Generalism (plasticity)	Generalist mosquitoes are more likely to colonise waters with AIPs	(i) AIPs increase colonisation rates of mosquitoes with large habitat breadth or plasticity	None
	Relatedness	Mosquitoes are more likely to colonise AIPs that are phylogenetically or functionally similar to plant taxa in their native range	(i) Taxonomic or phylogenetic relatedness with native species mediates mosquito colonisation and growth towards AIPs (ii) Relatedness has tradeoffs with biotic resistance in mediating colonisation success outcomes for mosquitoes and IAPs	None
	Novelty	AIPs that are functionally distinct from native plant species are more likely to harbour impoverished or non-native mosquito communities	(i) Novel structural plant assemblages will alter mosquito communities most (ii) Native mosquitoes will be naive to chemical and physical cues from AIPs	None
	Enemy reduction	Newly identified AIPs are less effective in supporting natural enemy populations that regulate mosquito populations	(i) Natural enemies are more abundant in native compared to AIP communities given their evolutionary history	None
	Adaptation	Mosquitoes become more effective in exploiting IAP-related resources with increasing time since plant invasion	(i) The time since invasion by AIPs increases colonisation rates and recruitment success of mosquitoes due to reduced ecological novelty (ii) The influence of time since invasion on colonisation differs between mosquitoes and their natural enemies	None

dynamics of mosquitoes and their natural enemies in different ways over time, particularly given the complexity of the mosquito life history on land and in water. This requires understanding of factors such as ecological novelty, habitat association, phenology and trophic interaction strength across food web components. These factors could in turn mediate their competence to transmit pathogens. Furthermore, as ecosystems are increasingly exposed to anthropogenic pressures (Filbee-Dexter et al. 2017), and AIPs can affect microclimatic conditions, interactions between AIPs and mosquitoes, along with associated abiotic factors, may result in shifts of vector-borne disease risks in unpredictable ways. This suggests that it is crucial to employ flexible and adaptable vector management strategies to address unpredictable shifts in vector-borne disease risks, which may result from the presence of AIPs. Nevertheless, given the overall transformative role of AIPs in invaded systems, these invasions should be controlled wherever possible to reduce ecological harm and with biosecurity procedures strengthened to mitigate introduction and secondary spread. We thus call for increased mechanistic consideration of the role of AIPs in the management of mosquito-borne disease risk to better inform response planning.

6 | Concluding Remarks and Future Perspectives

Globalisation continues to promote the introduction of non-native species (Blackburn et al. 2011; Pyšek et al. 2020). Environmental changes create conditions that facilitate their establishment and invasion success (Hulme 2021). Although strategies to prevent invasions remain a high priority, not all invasions can be avoided (Early et al. 2016). Understanding the unforeseen and unintended consequences of biological invasions is therefore crucial to improve preparedness and promote proactive management actions, particularly along socio-economic dimensions including health.

We propose that AIPs can promote mosquitoes and synthesise potential mechanisms into a conceptual framework (Figure 2A). This framework portrays testable predictions (Table 1) on how these plants could boost mosquito numbers through providing predator-free space, food, substrate and improved microclimate. To move beyond observational studies, we call for in situ and *ex situ* experimental investigations to test these hypotheses and deepen our understanding of the interactions between AIPs and mosquito population dynamics. The strength and sign of these effects are likely to be context-dependent due to both biotic (e.g., community assembly, ecological novelty) and abiotic (e.g., climatic conditions, global change) factors. We identified key environmental variables and functional traits of both plants and mosquitoes (Figure 2B) that are expected to mediate these mechanistic pathways. This conceptual framework and associated context-dependencies assist in the design of future studies and could help to generalise their results pertaining to the potential connection between AIP and mosquitoes.

If future research confirms associations, the implications would necessitate a shift towards improved harmonisation between invasion ecology and medical entomology. As vector mosquitoes continue to present a significant global challenge to human health (Benedict et al. 2007; Agha et al. 2020; Cocke et al. 2022), such findings would underscore the urgency of managing aquatic invasions not only to protect ecosystems and biodiversity, but also to safeguard human health, particularly in regions endemic to high mosquito-borne disease burdens. Managing aquatic plant invasions would not only become an ecological priority but also a public health necessity. Testing these hypotheses would inform adaptive, evidence-based management strategies to control both aquatic invasive species and immature mosquitoes. We call on the scientific community to address this gap through targeted, interdisciplinary research—bridging invasion ecology and public health—to provide a comprehensive understanding of the cascading impacts of aquatic plant invasions.

Author Contributions

Tressia Chikodza led the writing of the manuscript. All authors contributed equally to conceptualisation, draft revisions and to the final manuscript.

Data Availability Statement

The authors have nothing to report.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ele.70199.

References

Agha, S. B., M. Alvarez, M. Becker, E. M. Fèvre, S. Junglen, and C. Borgemeister. 2020. "Invasive Alien Plants in Africa and the Potential Emergence of Mosquito-Borne Arboviral Diseases—A Review and Research Outlook." *Viruses* 13, no. 1: 32.

Albeny-Simoes, D., E. G. Murrell, S. L. Elliot, et al. 2014. "Attracted to the Enemy: *Aedes aegypti* Prefers Oviposition Sites With Predator-Killed Conspecifics." *Oecologia* 175: 481–492.

Aloo, P., W. Ojwang, R. Omondi, J. M. Njiru, and D. Oyugi. 2013. "A Review of the Impacts of Invasive Aquatic Weeds on the Biodiversity of Some Tropical Water Bodies With Special Reference to Lake Victoria (Kenya)." *Biodiversity Journal* 4, no. 4: 471–482.

Ammar, S. E., M. A. Kenawy, H. A. Abdel-Rahman, A. F. Ali, Y. M. Abdel-Hamid, and A. M. Gad. 2013. "Characterization of the Mosquito Breeding Habitats in Two Urban Localities of Cairo Governorate, Egypt." *Greener Journal of Biological Sciences* 3, no. 7: 268–275.

Asha, A. V., and E. M. Aneesh. 2014. "Diversity of Mosquito Species (Diptera: Culicidae) at Irinjalakuda, Thrissur With Special Reference to Their Breeding Habitats." *International Journal of Current Microbiology and Applied Sciences* 3, no. 2: 536–541.

Barber, M. A., and T. B. Hayne. 1925. "Water Hyacinth and Breeding of Anopheles." *Public Health Reports* 47, no. 40: 2555–2562.

Bates, A. L., E. R. Burns, and D. H. Webb. 1985. "Eurasian Watermilfoil (*Myriophyllum spicatum* L.) in the Tennessee-Valley: An Update on Biology and Control." *In Proceedings of the First International Symposium on Watermilfoil*: 23–24.

Beketov, M. A., Y. A. Yurchenko, O. E. Belevich, and M. Liess. 2014. "What Environmental Factors Are Important Determinants of Structure, Species Richness, and Abundance of Mosquito Assemblages?" *Journal of Medical Entomology* 47, no. 2: 129–139.

Benedict, M. Q., R. S. Levine, W. A. Hawley, and L. P. Lounibos. 2007. "Spread of the Tiger: Global Risk of Invasion by the Mosquito *Aedes albopictus*." *Vector-Borne and Zoonotic Diseases* 7, no. 1: 76–85.

Bertelsmeier, C., A. Bonnamour, E. G. Brockerhoff, et al. 2024. "Global Proliferation of Nonnative Plants Is a Major Driver of Insect Invasions." *Bioscience* 74, no. 11: 770–781.

Blackburn, T. M., P. Pyšek, S. Bacher, et al. 2011. "A Proposed Unified Framework for Biological Invasions." *Trends in Ecology & Evolution* 26, no. 7: 333–339.

Boerlijst, S. P., E. S. Johnston, A. Ummels, et al. 2023. "Biting the Hand That Feeds: Anthropogenic Drivers Interactively Make Mosquitoes Thrive." *Science of the Total Environment* 858: 159716.

Bonnamour, A., R. E. Blake, A. M. Liebhold, et al. 2023. "Historical Plant Introductions Predict Current Insect Invasions." *Proceedings of the National Academy of Sciences of the United States of America* 120, no. 24: e2221826120.

Briski, E., S. G. Kotronaki, R. N. Cuthbert, et al. 2024. "Does Non-Native Diversity Mirror Earth's Biodiversity?" *Global Ecology and Biogeography* 33, no. 1: 48–62.

Burkett-Cadena, N. D., C. J. McClure, L. K. Estep, and M. D. Eubanks. 2013. "Hosts or Habitats: What Drives the Spatial Distribution of Mosquitoes?" *Ecosphere* 4, no. 2: 1–16.

Buscemi, P. A. 1958. "Littoral Oxygen Depletion Produced by a Cover of *Elodea canadensis*." *Oikos* 9, no. Fasc. 2: 239–245.

Buxton, M., C. Nyamukondiwa, T. Dalu, R. N. Cuthbert, and R. J. Wasserman. 2020. "Implications of Increasing Temperature Stress for Predatory Biocontrol of Vector Mosquitoes." *Parasites & Vectors* 13: 1–11.

Carneiro, L., N. Miiller, J. G. Prestes, J. Vitule, and R. N. Cuthbert. 2025. "Impacts and Mechanisms of Biological Invasions in Global Protected Areas." *Biological Invasions* 27, no. 1: 1–16.

Chandra, G., A. Ghosh, D. Biswas, and S. N. Chatterjee. 2006. "Host Plant Preference of Mansonia Mosquitoes." *Journal of Aquatic Plant Management* 44, no. 2: 142–144.

Chapman, D., B. V. Purse, H. E. Roy, and J. M. Bullock. 2017. "Global Trade Networks Determine the Distribution of Invasive Non-Native Species." *Global Ecology and Biogeography* 26, no. 8: 907–917.

Charles, H., and J. S. Dukes. 2007. "Impacts of Invasive Species on Ecosystem Services." *Biological Invasions* 193: 217–237.

Cocke, T. E., E. A. Geest, and A. A. Shufran. 2022. "Learning About Mosquitoes, Diseases, and Vectors: A Classroom Activity." *Science Activities* 59, no. 3: 142–150.

Coetzee, J. A., M. P. Hill, A. Hussner, A. L. Nunes, and O. L. Weyl. 2018. "Freshwater Ecology and Conservation, Approaches and Techniques." In *Invasive Aquatic Species*, 338–358. Oxford University Press.

Crooks, J. A. 2002. "Characterizing Ecosystem-Level Consequences of Biological Invasions: The Role of Ecosystem Engineers." *Oikos* 97, no. 2: 153–166.

Cuthbert, R. N., T. Dalu, R. J. Wasserman, A. Callaghan, O. L. Weyl, and J. T. Dick. 2019. "Using Functional Responses to Quantify Notonectid Predatory Impacts Across Increasingly Complex Environments." *Acta Oecologica* 95: 116–119.

Cuthbert, R. N., F. Darriet, O. Chabrerie, et al. 2023. "Invasive Hematophagous Arthropods and Associated Diseases in a Changing World." *Parasites & Vectors* 16, no. 1: 291.

Cuthbert, R. N., G. Y. Vong, S. Paolacci, J. T. Dick, A. Callaghan, and N. E. Coughlan. 2020. "Aquatic Plant Extracts and Coverage Mediate Larval Mosquito Survivorship and Development." *Biological Control* 145: 104263.

Daehler, C. C. 2001. "Two Ways to Be an Invader, but One Is More Suitable for Ecology." *Bulletin of the Ecological Society of America* 82, no. 1: 101–102.

Damor, P. R. 2024. "Anthropocene: Human Activity Impact on the Climate and Environment." *Journal of Climate Change* 10, no. 1: 43–45.

Day, J. F. 2016. "Mosquito Oviposition Behavior and Vector Control." *Insects* 7, no. 4: 65.

de Tezanos Pinto, P., L. Allende, and I. O'Farrell. 2007. "Influence of Free-Floating Plants on the Structure of a Natural Phytoplankton Assemblage: An Experimental Approach." *Journal of Plankton Research* 29, no. 1: 47–56.

Djoufounna, J., M. P. A. Mayi, R. Bamou, et al. 2022. "Larval Habitats Characterization and Population Dynamics of Culex Mosquitoes in Two Localities of the Menoua Division, Dschang and Santchou, West Cameroon." *Journal of Basic and Applied Zoology* 83, no. 1: 30.

Doak, D. F., J. A. Estes, B. S. Halpern, et al. 2008. "Understanding and Predicting Ecological Dynamics: Are Major Surprises Inevitable." *Ecology* 4, no. 89: 952–961.

Dudgeon, D., A. H. Arthington, M. O. Gessner, et al. 2006. "Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges." *Biological Reviews* 81, no. 2: 163–182.

Early, R., B. A. Bradley, J. S. Dukes, et al. 2016. "Global Threats From Invasive Alien Species in the Twenty-First Century and National Response Capacities." *Nature Communications* 7, no. 1: 12485.

Edo, G. I., L. O. Itoje-akpokiniovo, P. Obasohan, et al. 2024. "Impact of Environmental Pollution from Human Activities on Water, Air Quality and Climate Change." *Ecological Frontiers* 5, no. 44: 874–889.

Ehrenfeld, J. G. 2010. "Ecosystem Consequences of Biological Invasions." *Annual Review of Ecology, Evolution, and Systematics* 41, no. 1: 59–80.

Eid, M. A. A., M. A. E. Kandil, E. B. Moursy, and G. E. M. Sayed. 1992. "Effect of the Duck-Weed, *Lemna minor* Vegetations on the Mosquito, *Culex pipiens* Pipiens." *International Journal of Tropical Insect Science* 13, no. 3: 357–361.

Fakoorziba, M. R., and A. Vijayan. 2008. "Breeding Habitats of Culex Tritaeniorhynchus (Diptera: Culicidae), A Japanese Encephalitis Vector, and Associated Mosquitoes in Mysore, India." *Journal of the Entomological Research Society* 10, no. 3: 1–9.

Ferdousi, F., S. Yoshimatsu, E. Ma, N. Sohel, and Y. Wagatsuma. 2015. "Identification of Essential Containers for Aedes Larval Breeding to Control Dengue in Dhaka, Bangladesh." *Tropical Medicine and Health* 43, no. 4: 253–264.

Filbee-Dexter, K., J. Pittman, H. A. Haig, S. M. Alexander, C. C. Symons, and M. J. Burke. 2017. "Ecological Surprise: Concept, Synthesis, and Social Dimensions." *Ecosphere* 12, no. 8: 1–12.

Filbee-Dexter, K., C. C. Symons, K. Jones, et al. 2018. "Quantifying Ecological and Social Drivers of Ecological Surprise." *Journal of Applied Ecology* 5, no. 55: 2135–2146.

Flores, D., and J. W. Carlson. 2006. "Biological Control of Giant Salvinia in East Texas Waterways and the Impact on Dissolved Oxygen Levels." *Aquatic Plant Management* 44: 115–121.

Gallardo, B., M. Clavero, M. I. Sánchez, and M. Vilà. 2016. "Global Ecological Impacts of Invasive Species in Aquatic Ecosystems." *Global Change Biology* 22, no. 1: 151–163.

Gardner, A. M. 2016. "Direct and Indirect Effects of Native and Invasive Plants on Mosquito Ecology (Doctoral Dissertation, University of Illinois at Urbana-Champaign)."

GBIF Secretariat. 2025. "Occurrence Data for *Pistia stratiotes* and *Aedes albopictus*." https://www.gbif.org/species/2870583. https://www.gbif.org/species/1651430.

Harbach, R. E., and N. J. Besansky. 2014. "Mosquitoes." *Current Biology* 24, no. 1: R14–R15.

Hill, M. P. 2003. "The Impact and Control of Alien Aquatic Vegetation in South African Aquatic Ecosystems." *African Journal of Aquatic Science* 28, no. 1: 19–24.

Himeidan, Y. E., E. A. Temu, E. A. El Rayah, S. Munga, and E. J. Kweka. 2013. "Chemical Cues for Malaria Vectors Oviposition Site Selection: Challenges and Opportunities." *Journal of Insects* 2013, no. 1: 685182.

Hobbs, J. H., and P. A. Molina. 1983. "The Influence of the Aquatic Fern *Salvinia Auriculata* on the Breeding of *Anopheles albimanus* in Coastal Guatemala." *Mosquito News* 43, no. 4: 256–459.

Honlah, E., A. Yao Segbefia, D. Odame Appiah, M. Mensah, and P. O. Atakora. 2019. "Effects of Water Hyacinth Invasion on the Health of the Communities, and the Education of Children Along River Tano and Abby-Tano Lagoon in Ghana." *Cogent Social Science* 5, no. 1: 1619652.

Horan, R. D., C. Perrings, F. Lupi, and E. H. Bulte. 2002. "Biological Pollution Prevention Strategies Under Ignorance: The Case of Invasive Species." *American Journal of Agricultural Economics* 84, no. 5: 1303–1310.

Hulme, P. E. 2021. "Unwelcome Exchange: International Trade as a Direct and Indirect Driver of Biological Invasions Worldwide." *One Earth* 4, no. 5: 666–679.

Ismail, Z., S. Z. Othman, K. H. Law, A. H. Sulaiman, and R. Hashim. 2015. "Comparative Performance of Water Hyacinth (*Eichhornia crassipes*) and Water Lettuce (Pista Stratiotes) in Preventing Nutrients Build-Up in Municipal Wastewater." *CLEAN-Soil, Air, Water* 43, no. 4: 521–531.

Jayanthi, P., P. Lalitha, and N. Aarthi. 2012. "Larvicidal and Pupicidal Activity of Extracts and Fractionates of *Eichhornia crassipes* (Mart.) Solms Against the Filarial Vector *Culex quinquefasciatus* Say." *Parasitology Research* 111: 2129–2135.

Johnson, B. J., and M. V. K. Sukhdeo. 2013. "Successional Mosquito Dynamics in Surrogate Treehole and Ground-Container Habitats in the Northeastern United States: Where Does *Aedes albopictus* Fit in?" *Journal of Vector Ecology* 38, no. 1: 168–174.

Kardol, P., and J. R. De Long. 2018. "How Anthropogenic Shifts in Plant Community Composition Alter Soil Food Webs." *F1000Research* 7: 4.

Keller, R. P., A. Masoodi, and R. T. Shackleton. 2018. "The Impact of Invasive Aquatic Plants on Ecosystem Services and Human Well-Being in Wular Lake, India." *Regional Environmental Change* 18, no. 3: 847–857.

Kipyab, P. C., B. M. Khaemba, J. M. Mwangangi, and C. M. Mbogo. 2015. "The Physicochemical and Environmental Factors Affecting the Distribution of *Anopheles merus* Along the Kenyan Coast." *Parasites & Vectors* 8: 1–8.

Lambin, E. F., A. Tran, S. O. Vanwambeke, C. Linard, and V. Soti. 2010. "Pathogenic Landscapes: Interactions Between Land, People, Disease Vectors, and Their Animal Hosts." *International Journal of Health Geographics* 9: 1–13.

Liebhold, A. M., T. Yamanaka, A. Roques, et al. 2018. "Plant Diversity Drives Global Patterns of Insect Invasions." *Scientific Reports* 1, no. 8: 12095.

Lindenmayer, D. B., G. E. Likens, C. J. Krebs, and R. Hobbs. 2010. "Improved Probability of Detection of Ecological "Surprises"." *Proceedings of the National Academy of Sciences* 51, no. 107: 21957–21962.

Liu, C., C. Bellard, and J. M. Jeschke. 2025. "Understanding Biological Invasions Through the Lens of Environmental Niches." *Trends in Ecology & Evolution* 40, no. 3: 385–394.

Lounibos, L. P., D. C. Lima, R. Lourenço-de-Oliveira, R. L. Escher, and N. Nishimura. 1998. "Egg Maturation in Neotropical Malaria Vectors: One Blood Meal Is Usually Enough." *Journal of Vector Ecology: Journal of the Society for Vector Ecology* 23, no. 2: 195–201.

Lozano, V. 2021. "Distribution of Five Aquatic Plants Native to South America and Invasive Elsewhere Under Current Climate." *Ecologies* 2, no. 1: 27–42.

Lwande, O. W., V. Obanda, A. Lindström, et al. 2020. "Globe-Trotting Aedes Aegypti and *Aedes albopictus*: Risk Factors for Arbovirus Pandemics." *Vector-Borne and Zoonotic Diseases* 20, no. 2: 71–81.

Ma, J., Y. A. Ugya, A. U. Isiyaku, X. Hua, and T. S. Imam. 2019. "Evaluation of *Pistia stratiotes* Fractions as Effective Larvicide Against Anopheles Mosquitoes." *Artificial Cells, Nanomedicine, and Biotechnology* 47, no. 1: 945–950.

Macêdo, R. L., P. J. Haubrock, G. Klippel, et al. 2024. "The Economic Costs of Invasive Aquatic Plants: A Global Perspective on Ecology and Management Gaps." *Science of the Total Environment* 908: 168217.

Mack, R., and M. Smith. 2011. "Invasive Plants as Catalysts for the Spread of Human Parasites." *NeoBiota* 9: 13–29.

Madeira, P. T., F. A. Dray Jr., and P. W. Tipping. 2022. "The Phytogeography and Genetic Diversity of the Weedy Hydrophyte, *Pistia stratiotes* L." *Biological Invasions* 24, no. 8: 2613–2634.

Malacrinò, A., V. A. Sadowski, T. K. Martin, et al. 2020. "Biological Invasions Alter Environmental Microbiomes: A Meta-Analysis." *PLoS One* 15, no. 10: e0240996.

Masifwa, W. F., T. Twongo, and P. Denny. 2001. "The Impact of Water Hyacinth, *Eichhornia crassipes* (Mart) Solms on the Abundance and Diversity of Aquatic Macroinvertebrates Along the Shores of Northern Lake Victoria, Uganda." *Hydrobiologia* 452: 79–88.

Matheson, R. 1930. "The Utilization of Aquatic Plants as Aids in Mosquito Control." *American Naturalist* 64: 56–86.

McConnachie, A. J., M. P. De Wit, M. P. Hill, and M. J. Byrne. 2003. "Economic Evaluation of the Successful Biological Control of *Azolla filiculoides* in South Africa." *Biological Control* 28, no. 1: 25–32.

McCormack, C. P., A. C. Ghani, and N. M. Ferguson. 2019. "Fine-Scale Modelling Finds That Breeding Site Fragmentation Can Reduce Mosquito Population Persistence." *Communications Biology* 2, no. 1: 273.

Merritt, R. W., R. H. Dadd, and E. D. Walker. 1992. "Feeding Behavior, Natural Food, and Nutritional Relationships of Larval Mosquitoes." *Annual Review of Entomology* 37, no. 1: 349–374.

Minakawa, N., G. Sonye, G. O. Dida, K. Futami, and S. Kaneko. 2008. "Recent Reduction in the Water Level of Lake Victoria Has Created More Habitats for Anopheles Funestus." *Malaria Journal* 7: 1–6.

Moore, G. R., and M. P. Hill. 2012. "A Quantitative Post-Release Evaluation of Biological Control of Water Lettuce, *Pistia stratiotes* L.(Araceae) by the Weevil Neohydronomus Affinis Hustache (Coleoptera: Curculionidae) at Cape Recife Nature Reserve, Eastern Cape Province, South Africa." *African Entomology* 20, no. 2: 380–385.

Orr, B. K., and V. H. Resh. 1992. "Influence of *Myriophyllum aquaticum* Cover on Anopheles Mosquito Abundance, Oviposition, and Larval Microhabitat." *Oecologia* 90: 474–482.

Patel, S. 2012. "Threats, Management and Envisaged Utilizations of Aquatic Weed *Eichhornia crassipes*: An Overview." *Reviews in Environmental Science and Bio/Technology* 11: 249–259.

Perrin, A., O. Glaizot, and P. Christe. 2022. "Worldwide Impacts of Landscape Anthropization on Mosquito Abundance and Diversity: A Meta-Analysis." *Global Change Biology* 28, no. 23: 6857–6871.

Porse, C. C., V. Kramer, M. H. Yoshimizu, et al. 2015. "Public Health Response to Aedes Aegypti and ae. Albopictus Mosquitoes Invading California, USA." *Emerging Infectious Diseases* 21, no. 10: 1827–1829.

Portilla, M. A., P. Moran, and S. P. Lawler. 2021. "Invasive Aquatic Weeds Influence Abundances of Larval Mosquitoes and Other Invertebrates." *Journal of Aquatic Plant Management* 59: 33–40.

Pyšek, P., P. E. Hulme, D. Simberloff, et al. 2020. "Scientists' Warning on Invasive Alien Species." *Biological Reviews* 95, no. 6: 1511–1534.

Rai, P. K., and J. S. Singh. 2020. "Invasive Alien Plant Species: Their Impact on Environment, Ecosystem Services and Human Health." *Ecological Indicators* 111: 106020.

Rajnikant, R., R. M. Bhatt, R. C. Sharma, D. K. Gupta, and A. S. Gautam. 1992. "Anopheline Breeding in Ponds of Central Gujarat With Reference to Water Hyacinth Infestation." *Indian Jounral of Malariology* 29, no. 1: 57–61.

Reinhold, J. M., C. R. Lazzari, and C. Lahondère. 2018. "Effects of the Environmental Temperature on Aedes Aegypti and *Aedes albopictus* Mosquitoes: A Review." *Insects* 9, no. 4: 158.

Rejmánková, E., J. Grieco, N. Achee, and D. R. Roberts. 2013. "Ecology of Larval Habitats." In *Anopheles Mosquitoes-New Insights Into Malaria Vectors*, 397–446. IntechOpen.

Rilov, G., J. Canning-Clode, and T. Guy-Haim. 2024. "Ecological Impacts of Invasive Ecosystem Engineers: A Global Perspective Across Terrestrial and Aquatic Systems." *Functional Ecology* 38, no. 1: 37–51.

Santos, M. J., L. W. Anderson, and S. L. Ustin. 2011. "Effects of Invasive Species on Plant Communities: An Example Using Submersed Aquatic Plants at the Regional Scale." *Biological Invasions* 13: 443–457.

Schmidt, R. J., M. R. King, M. F. Aronson, and L. Struwe. 2023. "Hidden Cargo: The Impact of Historical Shipping Trade on the Recent-Past and Contemporary Non-Native Flora of Northeastern United States." *American Journal of Botany* 110, no. 9: e16224.

Segbefia, A. Y., E. Honlah, and D. O. Appiah. 2019. "Effects of Water Hyacinth Invasion on Sustainability of Fishing Livelihoods Along the River Tano and Abby-Tano Lagoon, Ghana." *Cogent Food & Agriculture* 5, no. 1: 1654649.

Seibold, S., M. M. Gossner, N. K. Simons, et al. 2019. "Arthropod Decline in Grasslands and Forests Is Associated With Landscape-Level Drivers." *Nature* 574, no. 7780: 671–674.

Silver, J. B. 2007. *Mosquito Ecology: Field Sampling Methods*. Springer Science & Business Media.

Sprenger, P. R. D., and D. Reiter. 1987. "The Used Tire Trade: A Mechanism for the Worldwide Dispersal of Container Breeding Mosquitoes." *Journal of the American Mosquito Control Association* 3: 494.

Steffen, W., K. Richardson, J. Rockström, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347, no. 6223: 1259855.

Stone, C. M., A. B. Witt, G. C. Walsh, W. A. Foster, and S. T. Murphy. 2018. "Would the Control of Invasive Alien Plants Reduce Malaria Transmission? A Review." *Parasites & Vectors* 11: 1–18.

Ta, J., L. W. Anderson, M. A. Christman, et al. 2017. "Invasive Aquatic Vegetation Management in the Sacramento–San Joaquin River Delta: Status and Recommendations." *San Francisco Estuary and Watershed Science* 15, no. 4: 1–19.

Taylor, R., L. A. Messenger, T. A. Abeku, S. E. Clarke, R. S. Yadav, and J. Lines. 2024. "Invasive Anopheles Stephensi in Africa: Insights From Asia." *Trends in Parasitology* 40: 731–743.

Turnipseed, R. K., P. J. Moran, and S. A. Allan. 2018. "Behavioral Responses of Gravid *Culex quinquefasciatus*, Aedes Aegypti, and *Anopheles quadrimaculatus* Mosquitoes to Aquatic Macrophyte Volatiles." *Journal of Vector Ecology* 43, no. 2: 252–260.

Ugya, A. Y., T. S. Imam, and J. Ma. 2019. "Mini-Review on the Efficacy of Aquatic Macrophytes as Mosquito Larvicide." *Journal of Applied Botany and Food Quality* 92: 320–326.

Urban, R. A., J. E. Titus, and W. X. Zhu. 2006. "An Invasive Macrophyte Alters Sediment Chemistry due to Suppression of a Native Isoetid." *Oecologia* 148: 455–463.

Van Kleunen, M., X. Xu, Q. Yang, et al. 2020. "Economic Use of Plants Is Key to Their Naturalization Success." *Nature Communications* 11, no. 1: 3201.

Vilas, M. P., C. L. Marti, M. P. Adams, C. E. Oldham, and M. R. Hipsey. 2017. "Invasive Macrophytes Control the Spatial and Temporal Patterns of Temperature and Dissolved Oxygen in a Shallow Lake: A Proposed Feedback Mechanism of Macrophyte Loss." *Frontiers in Plant Science* 8: 2097.

Vonesh, J. R., and L. Blaustein. 2010. "Predator-Induced Shifts in Mosquito Oviposition Site Selection: A Meta-Analysis and Implications for Vector Control." *Israel Journal of Ecology & Evolution* 56, no. 3-4: 263–279.

Webb, C. E., A. Ironside, and S. Mansfield. 2013. "A Comparison of Oviposition Preference in the Presence of Three Aquatic Plants by the Mosquitoes' Culex Annulirostris' Skuse And'*culex quinquefasciatus*' Say (Culicidae: Diptera) in Laboratory Tests." *General and Applied Entomology: The Journal of the Entomological Society of New South Wales* 41: 21–26.

Weed, A. C. 1924. "Another Factor in Mosquito Control." *Ecology* 5, no. 1: 110–111.

Weeks, V. L. 2019. "Effects of the Invasive *Phragmites australis* on the Predation of Mosquitoes Through Changes in Habitat Complexity (Master's Thesis, University of Maryland, College Park)."

Weldon, L. W., and R. D. Blackburn. 1967. "Water Lettuce—Nature, Problem, and Control." *Weeds* 15, no. 1: 5–9.

Wilke, A. B., C. Chase, C. Vasquez, et al. 2019. "Urbanization Creates Diverse Aquatic Habitats for Immature Mosquitoes in Urban Areas." *Scientific Reports* 9, no. 1: 15335.

Wilson, F. 1967. "The Role of Aquatic Weeds in Mosquito Control." *Hyacinth Control Journal* 6, no. 1: 26–27.

Wondwosen, B., S. R. Hill, G. Birgersson, E. Seyoum, H. Tekie, and R. Ignell. 2017. "A (Maize) Ing Attraction: Gravid Anopheles Arabiensis Are Attracted and Oviposit in Response to Maize Pollen Odours." *Malaria Journal* 16: 1–9.

Wu, H., and J. Ding. 2019. "Global Change Sharpens the Double-Edged Sword Effect of Aquatic Alien Plants in China and Beyond." *Frontiers in Plant Science* 10: 787.

Xiong, W., Y. Zhang, D. Xie, et al. 2023. "Water Lettuce (*Pistia stratiotes* L.) (Araceae) in China: Distribution, Introduction Pathway, and Impacts." *BioInvasions Records* 12, no. 4: 1089–1097.

Yang, P. J., D. Manguchei, and C. Takekuma. 2005. "Impact of *Lemna minor* Linnaeus (1753) and *Azolla filiculoides* Lamarck (1783) on Mosquito Breeding in Kauai Taro Fields." *Pan-Pacific Entomologist* 81, no. 4: 159–163.