


## Mosquito fauna of Cat Ba Island with a focus on breeding site characteristics in residential areas

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### Abstract

Mosquitoes are key vectors of numerous human diseases, yet their diversity and breeding ecology remain poorly understood in many tropical island ecosystems. This study provides the first comprehensive assessment of mosquito species composition and larval breeding site characteristics on Cat Ba Island, a UNESCO Biosphere Reserve in northeastern Vietnam. A total of 26 mosquito species belonging to six genera were recorded across four major habitat types: evergreen forest, mangrove, residential areas, and rice fields. *Culex* was the most diverse with 11 species, followed by *Aedes* (nine species) and *Anopheles* (three species). Species richness was highest in the evergreen forest with 18 species. The mangrove and residential areas were recorded ten and seven species, respectively, while rice fields had the lowest richness with five species recorded. Species overlap between habitats was limited, except for *Culex quinquefasciatus* Say, 1823, which occurred widely in all habitat types. Larval habitat analysis in residential areas revealed a strong association of vector species with artificial containers. *Aedes albopictus* (Skuse, 1894) was the dominant species, mainly found in plastic containers. Further, the invasion of *Aedes aegypti* (Linnaeus, 1762) in the island was clearly revealed. These findings underline the influence of human-modified habitats on mosquito distribution and emphasize the need for targeted source reduction strategies to manage vector populations in urban settings in tropical islands.

**Key words:** vector ecology, urbanization, tropical islands, *Aedes aegypti*, *Aedes albopictus*

### Introduction

Mosquitoes represent a critical component of ecological systems, fulfilling dual functions as key contributors to the food web and as vectors for a range of pathogenic diseases with significant public health challenges, including malaria, dengue fever, Zika virus, and chikungunya (Dhiman & Singh 2024; WHO 2020; Wilson et al. 2020). Most mosquito-borne diseases are reported in tropical regions (Hashimoto et al. 2017; Jupp 2005; Meyer Steiger et al. 2016). However, numerous cases have also been detected in temperate areas due to travel to endemic regions (Brown et al. 2011; Osman & Preet 2020). Therefore, reducing the risk of exposure to travelers has become an important aspect of mosquito vector management in such areas. Understanding vector species composition, distribution patterns, and breeding site characteristics is essential for developing effective and targeted mosquito control strategies (Wilson et al. 2020). Cat Ba Island, located in northern Vietnam, is called the pearl of the Gulf of Tonkin, so it has become a must-visit destination for tourists when visiting Vietnam. The island is renowned for its high biodiversity and unique combination of terrestrial and marine ecosystems (Cao & Nguyen 2018). The island attracts millions of visitors from worldwide annually and has experienced increasing levels of urbanization in recent decades. This combination of rapid anthropogenic development and habitat heterogeneity may create a diverse of potential mosquito habitats, from densely populated residential zones and agricultural fields to pristine mangrove forests and evergreen forests, these diverse environments may harbor distinct mosquito communities (Čabanová et al. 2018; Li et al. 2014; Ortiz Diana et al. 2022). Despite the

ecological importance of the island and the potential public health implications, there has been no prior comprehensive study documenting the mosquito fauna or their larval breeding site characteristics on Cat Ba Island. Furthermore, residential areas on Cat Ba Island are rapidly expanding to accommodate tourism-driven development, often without adequate environmental planning or vector control infrastructure. Dengue has been reported to Cat Ba Island since 2013 (Le et al. 2015); however, the distribution of mosquito vector species and their larval breeding sites are underexplored. Therefore, characterizing mosquito larval breeding sites in residential areas is crucial due to the high risk of vector-human contact in these environments.

In this study, we aim to (1) investigate the mosquito species composition across four major habitat types of land uses, including residential areas, rice fields, mangroves, and evergreen forests to understand how diverse land-use types influenced mosquito diversity in a tropical island. Further, we also focus on (2) identifying the types of containers used by mosquito larvae, quantifying larval densities, and documenting the associated species. This information is essential for informing targeted control strategies, such as eliminating or modifying the most productive breeding sites, and raising public awareness about household-level mosquito management. Our findings contribute essential baseline data for vector surveillance and public health planning in ecologically sensitive and rapidly developing islands in tropical regions.

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## Materials and methods

### Study area

Cat Ba Island located in northeastern Vietnam, characterized by numerous limestone islands and islets that are relicts of karstic limestone mountains submerged by the sea during the Holocene transgression 7000-8000 years ago (Cao & Nguyen 2018; Pham et al. 2014). In recent years, the archipelago has played a significant role in the socio-economic development of local provinces and is undergoing significant changes due to land planning initiatives (Nguyen et al. 2025). This not only leads to the disruption of the native habitat but also can enhance the risk of emerging transmission epidemics (Čabanová et al. 2018; Lee et al. 2020).

### Larval and adult collection

Both immature and adult mosquitoes were collected from 30 sites from 2023 to 2025 on Cat Ba Island, grouped into four different types of habitats including residential areas, rice fields, mangroves, and evergreen forests (Figure 1). In Cat Ba Island, the evergreen forest is a natural, undisturbed habitat characterized by dense canopy cover and year-round foliage. Mangroves are coastal wetland habitats characterized by brackish water, tidal influence, muddy substrate, and complex root systems provided by salt-tolerant mangrove vegetation. Residential areas are represented by a human-modified

habitat providing numerous artificial containers. And rice fields habitat is agricultural habitat dominated by seasonal rice cultivation and under periodic flooding and management practices, with shallow standing water during the cropping period and low vegetation diversity (Figure 1).

Mosquito larvae were collected from breeding sites such as artificial containers, ground pools, rock holes, and rice fields (Medlock et al. 2018). All water-holding containers were inspected for mosquito breeding, and a site was recorded as positive if any mosquito larvae or pupae were detected. Besides, adults were also collected using sweeping nets and aspirators. Further, we also aim to characterize the breeding sites in urban areas by documenting habitat types, species occurrence and abundance. Collected larvae were filtered through fine mesh to exclude excess water, and the sorted samples were preserved in 80% ethanol for later taxonomic identification. Adult mosquitoes were pinned immediately in the field to preserve their morphological characteristics for accurate subsequent identification. Mosquito samples were preserved either in dry (adults) or wet (larvae) in the laboratory of the Department of Applied Zoology, VNU University of Science, Hanoi. Mosquito collections were conducted without the need for special permits at most locations. However, access to private residences and island sites was granted only after obtaining consent from property owners and local authorities.

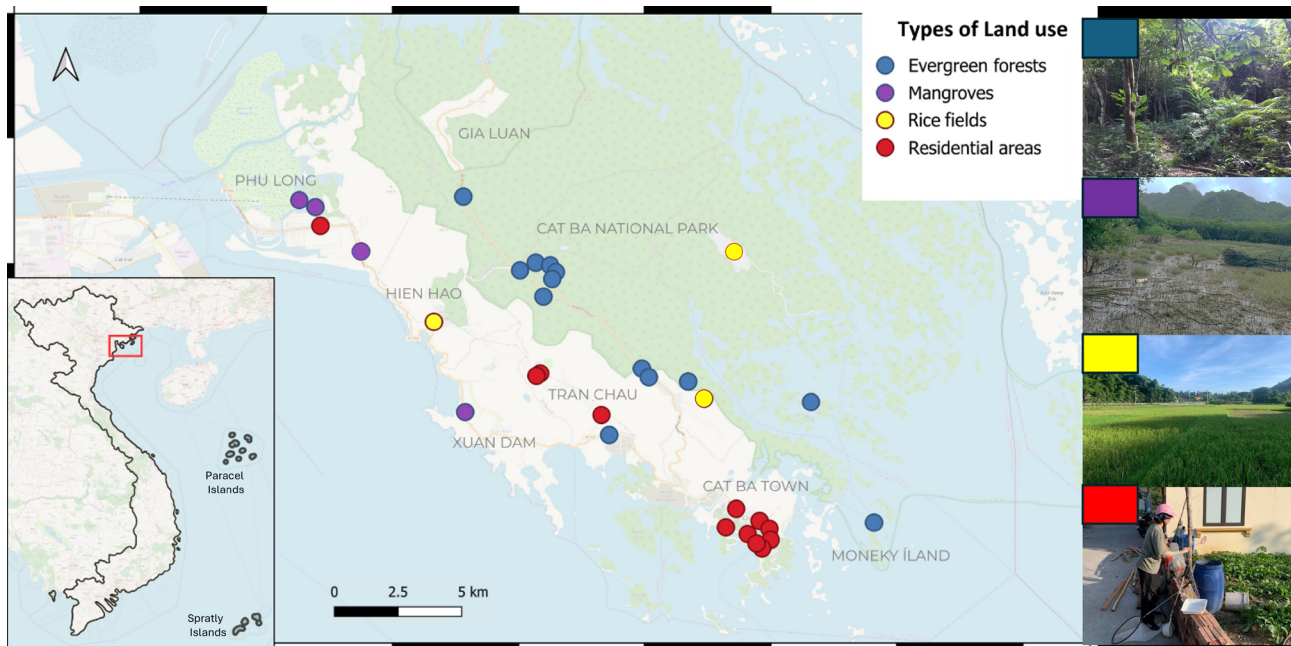


Figure 1. Map showing the distribution of mosquito sampling sites across four habitat types on Cat Ba Island, northern Vietnam. Colored dots represent different habitat types: evergreen forests (blue), mangroves (purple), rice fields (yellow), and residential areas (red). The inset map indicates the location of Cat Ba Island within Vietnam. Photographs on the right illustrate representative landscapes of each habitat type.

## Results

We recorded 26 species belonging to six genera of mosquitoes in Cat Ba Islands. Among them, *Culex* was the most diverse with 11 species, followed by *Aedes* with nine species, *Anopheles* with three species. The other genera (*Armigeres*, *Coquillettia*, *Toxorhynchites*) have only one species each (Figure 2).

Species richness was highest in the evergreen forest, with 18 out of 26 recorded species, including nine unique species for this habitat. The mangrove habitat contained ten species, of which four were exclusive. Residential areas harbored seven species, while the rice field had the lowest richness, with five species recorded (Figure 2). *Culex quinquefasciatus* Say, 1823 was the most common species occurred in all kinds of habitats. Four species were shared between the evergreen forest and residential area including *Armigeres subalbatus* (Coquillett, 1898), *Aedes albopictus* (Skuse, 1894), *Culex murrelli* Lien, 1968, and *Culex fuscocephala* Theobald, 1907. Three species were shared between the residential area and mangrove including *Anopheles barbumbrosus* Strickland & Chowdhury, 1927, *Aedes vexans* (Meigen, 1830), and *Culex mimulus* Edwards, 1915. Two species were shared between the rice field and mangrove including *Culex tritaeniorhynchus* Giles,

1901 and *Culex vishnui* Theobald, 1901. *Culex vishnui* was shared among the evergreen forest, rice field, and mangrove. *Culex sitiens* was found in both the rice field and the residential area.

We surveyed 194 water containers but 186 were recorded as positive breeding sites of mosquitoes, in which artificial-material containers accounted for largest proportion (91.9%) (Table 1). Among them, plastic containers were the most abundant with 75.8% were positive for mosquito larvae. A total of 1828 larvae were collected resulting in seven mosquito species for residential areas in Cat Ba Island (Figure 2). Among them, *Ae. albopictus* was the most dominant species, accounting for over half of all specimens (68.9%) and occurred in most of positive containers (66.1%), thriving nearly all types of available containers with highest productive in man-made containers (86.3%). *Aedes aegypti* (Linnaeus, 1762), the invasive species of Vietnam, occurred in residential areas and was strongly associated with artificial containers such as plastic and ceramic containers. *Culex* was only found in artificial containers, with *Cx. quinquefasciatus* being the most common species in the genus (Table 1).

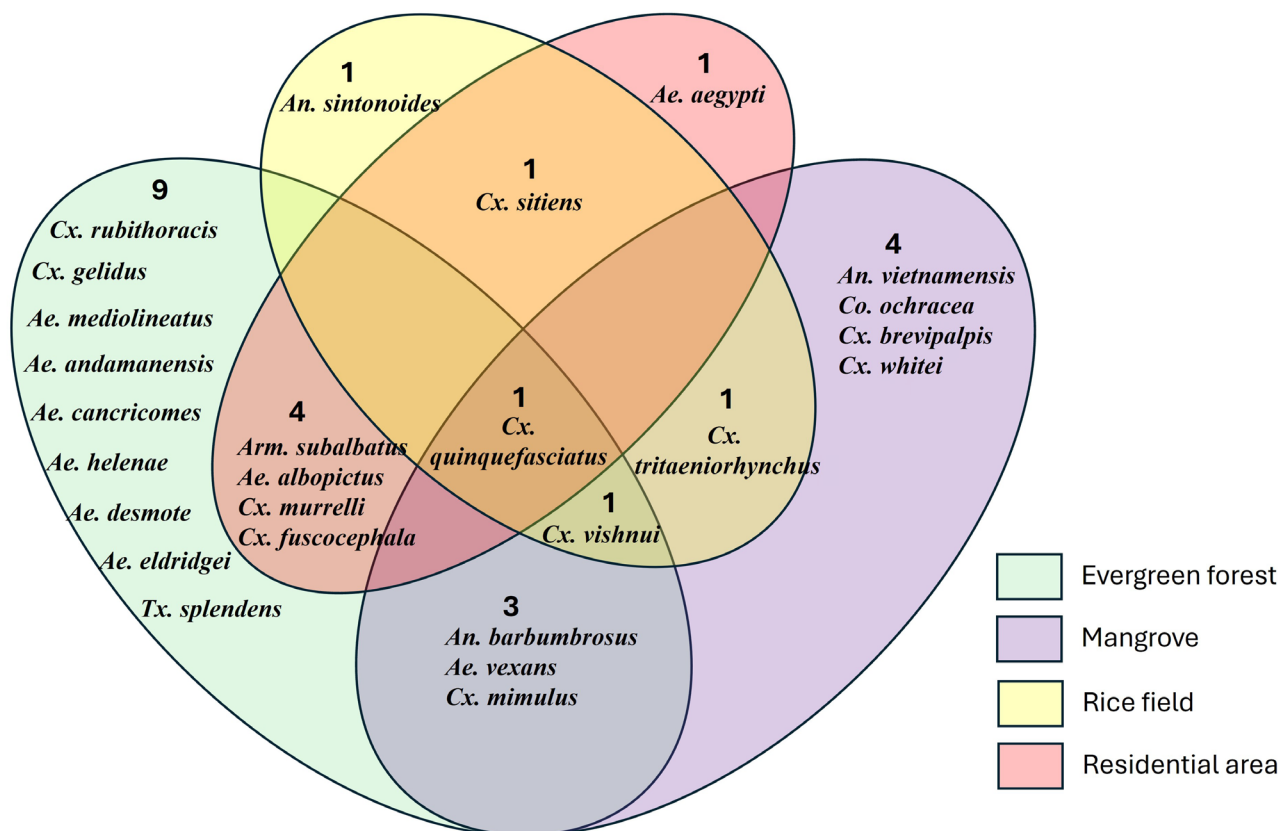


Figure 2. Venn diagram showing the distribution of mosquito species across four habitat types: evergreen forest (blue), rice field (yellow), residential area (red), and mangrove (purple). Numbers indicate the count of species in each intersection, and species names are listed within each section according to their presence in one or more habitats.

Table 1. Mosquito species and larval abundance in different types of artificial and natural breeding containers surveyed in residential areas of Cat Ba Island. Values represent the number of individuals, with the number of positive breeding sites shown in parentheses. - not computed.

Species	Type of containers										Total (N)
	Artificial material breeding sites				Natural material breeding sites						
	Plastic containers	Ceramic jar	Used tires	Cement tanks	Discarded glass containers	Discarded Styrofoam box	Tree holes	Leaf axils	Bamboo joints	Coconut shells	
<i>Armigeres subalbatus</i>	12 (2)	-	14 (2)	-	-	-	-	-	-	-	26 (4)
No. of individuals											
<i>Aedes albopictus</i>	1260 (123)	11 (4)	155 (5)	36 (4)	8 (2)	38 (7)	21 (4)	4 (2)	5 (3)	16 (6)	1554 (160)
<i>Aedes aegypti</i>	39 (7)	21 (2)	-	-	-	12 (1)	-	-	-	-	72 (10)
<i>Culex quinquefasciatus</i>	55 (3)	-	-	14 (1)	-	41 (1)	-	-	-	-	110 (5)
<i>Culex murrelli</i>	-	18 (1)	-	-	-	-	-	-	-	-	18 (1)
<i>Culex sitiens</i>	41 (5)	-	-	-	-	-	-	-	-	-	41 (5)
<i>Culex fuscocephala</i>	7 (1)	-	-	-	-	-	-	-	-	-	7 (1)
Total (N)	1414 (141)	50 (7)	169 (7)	50 (5)	8 (2)	91 (9)	21 (4)	4 (2)	5 (3)	16 (6)	1828 (186)

## Discussion

This study provides the first comprehensive assessment of mosquito species composition and breeding site characteristics on Cat Ba Island, a key conservation and tourism area in northern Vietnam. Habitat comparisons revealed low overlap in species composition, suggesting strong habitat-specificity of mosquitoes on the island. In residential areas, artificial containers were found more common than natural habitats, resulting in a higher species richness and abundance in these kinds of containers. Below, we discuss the variation in habitat distribution of mosquitoes in Cat Ba Island, along with the characteristics of breeding sites in residential areas, and the implication for mosquito control.

The evergreen forest harbored the highest mosquito diversity, with 18 species, including nine that were exclusive to this habitat. This highlights the importance of intact forest ecosystems for supporting native and potentially specialized mosquito fauna. The forest habitat likely provides a variety of natural breeding microhabitats such as tree holes, rock pools, and shaded puddles, along with stable humidity and minimal disturbance, creating favorable conditions for less urban-tolerant species (Wilke et al. 2021). However, several forest-associated mosquito species, such as *Ae. aegypti*, have successfully adapted to urban environments in response to land use changes (Wilke et al. 2021). Therefore, ongoing surveillance of mosquito adaptation in tropical forests may offer critical insights into emerging invasion patterns and the potential expansion of vector species into human-dominated areas. In contrast, rice fields showed the lowest species richness, likely due to their high exposure to agricultural disturbance, temporary water regimes, and limited vegetation diversity (Kaboré et al. 2023). The mangrove forest, while ecologically unique, supported

moderate diversity, likely influenced by tidal fluctuations, salinity gradients, and limited breeding niche availability (Kaboré et al. 2023).

Species overlap across habitats was limited, suggesting niche specialization or habitat filtering. Only a few species, such as *Cx. quinquefasciatus* and *Ae. albopictus*, were broadly distributed across multiple environments. Their wide ecological tolerance and ability to exploit both natural and artificial habitats may explain their presence across residential, forested, and agricultural areas (Anwar et al. 2015; Bradshaw et al. 2004). In contrast, the presence of unique species in evergreen and mangrove forests such as *Toxorhynchites splendens* (Wiedemann, 1819), reflects habitat-specific mosquito assemblages and emphasizes the need for multi-habitat sampling to understand mosquito diversity in island ecosystems.

In residential areas, artificial containers were the dominant larval habitats, with a high number of positive breeding sites and overall larval abundance. Among these, plastic containers such as water storage jars and discarded items were especially productive. *Aedes albopictus* was the most abundant species, accounting for over half of all larvae and found in nearly all container types. This species' dominance and container flexibility reinforces its role as a major urban vector, well-suited to human environments (Paupy et al. 2009). *Aedes aegypti*, although less common, showed a preference for specific artificial materials like plastic and ceramic, aligning with previous studies that document its breeding preferences in densely populated areas (Getachew et al. 2015). The presence of *Cx. quinquefasciatus* in a range of container types, including cement basins and plastic tanks, also reflects its adaptation to urban conditions and poor water management systems (Samson et al. 2015).

The dominance of vector species in artificial containers within residential areas has important implications for public health. Given that both *Ae. albopictus* and *Ae. aegypti* are competent vectors of dengue and other arboviruses (Gómez et al. 2022), their presence in common household containers raises concerns about potential disease outbreaks, especially in a tourism-intensive setting like Cat Ba. Control efforts should prioritize public education and source reduction strategies targeting the most productive container types. Simple interventions, such as covering water containers, removing unused items, and improving waste management, could significantly reduce breeding opportunities. In addition, the high container productivity highlights the need for integrating community engagement with routine surveillance to maintain sustainable vector control.

## Conclusion

This research highlights substantial changes in the mosquito species composition and abundance between distinct land-use categories on Cat Ba Island and highlights the implications of land-use change driven by urbanization and tourism development in terms of ecological importance. The evergreen forests possessed the greatest range of mosquito species, which underscore their value as biodiversity reservoirs, while in residential areas there existed a lower diversity yet higher abundance of disease vectors. These findings underscore the imperative of including vector surveillance within land-use planning and conservation management. Future research would be well-suited to explore seasonal patterns and vector competence to inform more efficaciously public health intervention and biodiversity conservation on rapidly changing tropical island ecosystems.

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